MW Electrolysis Scale Up

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DOE Electrolytic Hydrogen Production Workshop
27-28 February 2014
National Renewable Energy Laboratory
Golden, CO
Motivation – MW Electrolysis Markets

• Renewable energy storage
  – 10’s of GW’s of wind/solar energy capture
  – Power-to-gas

• Biogas market
  – Methanization

• Transportation market
  – H₂ infrastructure plans in US, Europe, Asia

• Multi-billion dollar opportunity in each

• MW-scale electrolysis needed
  – Targeting multi-MW product scale-up
## Scale-up/Cost Reduction Experience

<table>
<thead>
<tr>
<th>Product Type</th>
<th>HOGEN S-Series</th>
<th>HOGEN H-Series</th>
<th>HOGEN C-Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Launch</td>
<td>2000</td>
<td>2004</td>
<td>2011</td>
</tr>
<tr>
<td>Cells/stack</td>
<td>10-20</td>
<td>34</td>
<td>65</td>
</tr>
<tr>
<td>Stacks/system</td>
<td>1</td>
<td>1-3</td>
<td>1-3</td>
</tr>
<tr>
<td>H₂ Output (Nm³/hr)</td>
<td>1.05</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>$/kW vs. S-series</td>
<td>100%</td>
<td>43%</td>
<td>28%</td>
</tr>
</tbody>
</table>

**Input Power**

- 7kW
- 40 kW
- 175 kW

- Order-of-magnitude scale up resulted in greater than 70% cost reduction ($/kW basis)
Development Cost Curve

- Maintain trajectory to meet MW targets
- Initial projections validated with actual quotes

Source: IEA-HIA Task 33
MW Scale-up Needs: Overview

• Cost reduction areas defined for both stack and system
  – Over 50% decrease achievable
• Opportunities in material substitution, automation, and scale up
  – Collaborations established with key partners
• Roadmap developed for technology
  – Have shown cell scale feasibility
  – Need investment in manufacturing implementation:
    • Within company and also with rest of supply chain
• High capital intensity
  – Resources needed >50% of company annual revenues
Cell Stack Needs

- 50% reduction in bipolar assembly cost - funded
  - Reduction of materials & assembly process time
  - Still have issues finding US-based suppliers
- Electrolysis-specific MEA manufacturing development
  - No US-based 3rd party electrolysis MEA source
  - Process improvement pacing material advancements
- Online quality control measurements
- Increased yield from component suppliers

Manufacturing Scale-up Examples:

<table>
<thead>
<tr>
<th>Part</th>
<th>Current</th>
<th>End Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA</td>
<td>Manual CCM process</td>
<td>Roll-to-roll coating</td>
</tr>
<tr>
<td>Flow Field</td>
<td>Multi-piece manual assembly</td>
<td>Single piece high speed manufacture</td>
</tr>
<tr>
<td>Gaskets</td>
<td>Single piece die cut</td>
<td>Coll stamping</td>
</tr>
<tr>
<td>Quality control</td>
<td>Individual part measurement</td>
<td>In-line measurement</td>
</tr>
<tr>
<td>Bipolar assembly</td>
<td>Metal plate</td>
<td>Laminate or composite</td>
</tr>
</tbody>
</table>
System Needs

• Better utilization of off the shelf components (COTS)
  – Electronics and enclosures have high customization cost vs. standard
  – COTS components often do not meet all needs – adds expense to modify system to adapt
  – Standardization to drive volumes
• Investment in high speed tooling/molds
• Increased production volumes through strategic/subsidized deployment
• Investment in larger scale balance-of-plant
• Product design/sourcing for world-wide markets
• Optimization of grid and/or DC interface
Gaps and DOE Assistance

• Energy policy and outside investment are inter-related
  – Lack of long term commitments like in EU

• Government role/needs:
  – Pre-commercial market support of technology innovation and manufacturing
  – Benefits: high tech job creation and international competitiveness

• Critical tipping point for PEM electrolysis
  – Large markets are materializing
  – US holds leadership position but European developers have strong national investment
    • Research consortiums to technology demonstration projects
    • US companies unable to compete for EU funding directly