High Performance Fuel Cell and Electrolyzer Membrane Electrode Assemblies (MEAs) for Space Energy Storage Systems

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Presentation Outline

• Energy Storage: Regenerative Fuel Cell Systems
  – The Regenerative Fuel Cell Concept
  – Lunar Outpost Surfaces Systems
  – Key Performance Parameters
• NASA Fuel Cell Stack Development
• NASA Fuel Cell Membrane Electrode Assembly (MEA) Development
  – MEAs Fabricated for NFT Fuel Cell Systems
  – Vendor Tested MEAs
  – Advanced Electrode Structures
• NASA Electrolysis MEA Development
  – Catalysts Development
  – Electrolysis MEA Testing
• Fuel Cell Powered Mobility Systems
• Presentation Summary

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• The byproduct water recovered from the fuel cell reaction can be stored and electrochemically converted back into the required fuel cell reactants.
Conceptual Lunar Outpost Surface System


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## Key Performance Parameters, Energy Storage Project

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Performance Parameter</th>
<th>SOA (alkaline)</th>
<th>Current Value* (NFT PEM)</th>
<th>Threshold Value** (@ 3 kW)</th>
<th>Goal** (@ 3 kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altair:</td>
<td>System power density</td>
<td>49 W/kg</td>
<td>44 W/kg</td>
<td>88 W/kg</td>
<td>136 W/kg</td>
</tr>
<tr>
<td></td>
<td>RFC (without tanks)</td>
<td>n/a</td>
<td>n/a</td>
<td>25 W/kg</td>
<td>36 W/kg</td>
</tr>
<tr>
<td></td>
<td>Fuel Cell Stack power density</td>
<td>n/a</td>
<td>51 W/kg</td>
<td>107 W/kg</td>
<td>231 W/kg</td>
</tr>
<tr>
<td></td>
<td>Fuel Cell Balance-of-plant mass</td>
<td>n/a</td>
<td>2 kg</td>
<td>21 kg</td>
<td>9 kg</td>
</tr>
</tbody>
</table>

- Based on non-flow-through test hardware with 4-cells and heavy end plates, scaled to 3 kW.
- Threshold and Goal values based on full-scale (3 kW, 300 cm³) fuel cell and RFC technology.
- Includes high pressure penalty on electrolysis efficiency 2000 psi.

<table>
<thead>
<tr>
<th>System efficiency @ 200 mA/cm²</th>
<th>Fuel Cell</th>
<th>Parastatic penalty</th>
<th>Regenerative Fuel Cell***</th>
<th>Parastatic penalty</th>
<th>High Pressure penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>71%</td>
<td>8%</td>
<td>n/a</td>
<td>43%</td>
<td>20%</td>
</tr>
<tr>
<td>For Fuel Cell</td>
<td>64%</td>
<td>2%</td>
<td>n/a</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Individual cell voltage</td>
<td>0.90 V</td>
<td>2%</td>
<td>n/a</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>For Electrolysis</td>
<td>0.89 V</td>
<td></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual cell voltage</td>
<td>1.48</td>
<td></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For RFC (Round Trip)</td>
<td>60%</td>
<td></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Maintenance-free lifetime      | Maintenance-free operating life |
| Altair:                        | Fuel Cell MEA | 2500 hr | 220 hr |
| Surface:                       | Electrolysis MEA | n/a | n/a |
|                                | Fuel Cell System (for Altair) | 2500 hr | 220 hr |
|                                | Regenerative Fuel Cell System | n/a | n/a |


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NASA Fuel Cell Stack Development

Fuel Cell Technology Progression to Simpler Balance-of-Plant

M. A. Hoberecht, NASA PEMFC Development Background and History, {Presented at NUWC, Newport, RI, 2010

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Advanced MEAs for Non-Flow-Through (NFT) Fuel Cell Systems

• MEAs developed for NASA NFT Stacks tested in conventional fuel cell hardware
• MEA performance is a strong function of MEA thickness this is more pronounced in NFT hardware
• MEA Performance in NFT hardware, 0.88 Volts at 200 mA/cm², 30 PSIG Balanced Pressure Reactants

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Advanced NASA Fuel Cell MEA, Vendor Tested

- Membrane thickness crucial at high current densities, N115, 5 mil, N212, 2 mil
- MEA Performance, 0.92 V at 200 mA/cm², 80 °C

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RuO$_2$ deposition at the anode improves catalysts membrane interface can lower MEA high-frequency resistance (HFR) on the order of 1 mΩ with N212.

Deposition to be optimized, will increase cell voltages by 5 mV at 200 mA/cm$^2$ for MEAs fabricated with N212.
Oxygen Evolution: Doped Ruthenium Oxide Catalyst

- Heat-treatment required to activate the doped ruthenium catalyst
- Expected Reaction: $M + RuO_2 \rightarrow MO_x RuO_{(2-x)}$ ($x \approx 0.05$)
- Ir-black dominates the performance of non-heat treated Ir-black mixed with RuO$_2$
- The 9% iridium-doped ruthenium catalyst performed the best of all iridium-doped ruthenium oxide compositions fabricated
Electrolysis MEA Testing

- Advanced catalysts can meet the performance requirements of future NASA electrolysis systems
- MEA Performance, 1.42 V at 200 mA/cm², 70 °C
Hydrogen docking stations can provide a pathway for robotic vehicles to traverse several kilometers while operating on fuel cell power.
Presentation Summary

• Regenerative fuel cells provide a pathway to energy storage system development that are game changers for NASA missions
• The fuel cell/ electrolysis MEA performance requirements 0.92 V/ 1.44 V at 200 mA/cm² can be met
• Fuel Cell MEAs have been incorporated into advanced NFT stacks
• Electrolyzer stack development in progress
• Fuel Cell MEA performance is a strong function of membrane selection, membrane selection will be driven by durability requirements
• Electrolyzer MEA performance is catalysts driven, catalyst selection will be driven by durability requirements
• Round Trip Efficiency, based on a cell performance, is approximately 65%

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