Facilitated Direct Liquid Fuel Cells with High Temperature Membrane Electrode Assemblies

Emory S. De Castro
Advent Technologies, Inc.
June 8, 2015

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview - Program

Timeline
Project Start Date: June 1, 2015
Project End Date: May 31, 2017

Budget
Total Funding: $1,251,000
Advent Cost Share: $252,000 (20%)

Barriers (FCTO-MYRDDP, 2014)
A. Durability: new membrane approach
B. Cost: elimination of reformer. Lower PM
C. Performance: highly active anode catalyst

Partners
LANL (P. Zelenay): catalyst and testing
Objective: Demonstrate direct dimethyl ether (DME) oxidation at high temperature MEA significantly better than direct methanol fuel cells (DMFC)

Program Targets

<table>
<thead>
<tr>
<th>Key Performance Indicator</th>
<th>Current DMFC</th>
<th>Target Hi T Direct DME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power (&gt; )</td>
<td>0.180 W/cm²</td>
<td>0.270 W/cm²</td>
</tr>
<tr>
<td>Total precious metal loading</td>
<td>5 mg_{PGM}/cm²</td>
<td>3 mg_{PGM}/cm²</td>
</tr>
<tr>
<td>Degradation rate</td>
<td>19 µV/h at 0.2 A/cm²</td>
<td>10 µV/h at 0.2 A/cm²</td>
</tr>
<tr>
<td>Loss in start/stop cycling</td>
<td>1.5 mV/cycle; cycle</td>
<td>0.75 mV/cycle; cycle</td>
</tr>
<tr>
<td>Anode mass-specific activity</td>
<td>50 A/g measured at 0.5 V</td>
<td>75 A/g measured 0.5V</td>
</tr>
</tbody>
</table>

Benefit: carbon neutral auxiliary power for trucks and transport; extended run back up power
Approach - Overview

1. Benchmark
   - Run high temperature MEAs at LANL
   - Compare Pt anode w MeOH, EtOH, and DME at 160 °C – 180 °C
   - Use both PBI and TPS Hi T MEAs

2. GDE at 5 cm²
   - Make gas diffusion electrode (GDE) with LANL ternary anode catalyst, test DME
   - Compare to Pt:Ru with DME
   - Evaluate PBI and TPS DME cross-over and performance

3. Scale to 50 cm²
   - Optimize anode GDE for mass transport
   - Refine cathode, if needed
   - Adjust reaction conditions

6 mo.
6-12 mo.
Go/No Go
12-24 mo.
### Approach - Milestones

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Title</th>
<th>Type</th>
<th>No.</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benchmark</td>
<td>Milestone</td>
<td>1.1.1</td>
<td>LANL=Advent Hi-T test results</td>
<td>By 3&lt;sup&gt;rd&lt;/sup&gt; month</td>
</tr>
<tr>
<td>1</td>
<td>Benchmark</td>
<td>Milestone</td>
<td>1.3.1</td>
<td>Baseline power and degradation w DME and Pt anode</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; month</td>
</tr>
<tr>
<td>2</td>
<td>Catalyst / GDE @ 5 cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Milestone</td>
<td>2.1.1</td>
<td>DME anode mass specific current 1.5X over DMFC (75 A/g at 0.5V), unrestrained cathode</td>
<td>9&lt;sup&gt;th&lt;/sup&gt; month</td>
</tr>
<tr>
<td>2</td>
<td>Catalyst / GDE @ 5 cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Milestone</td>
<td>2.3.1</td>
<td>Select best of TPS or PBI systems</td>
<td>12&lt;sup&gt;th&lt;/sup&gt; month</td>
</tr>
<tr>
<td>2</td>
<td>Catalyst / GDE @ 5 cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Go/ No-Go</td>
<td>Sole Go/ No-Go</td>
<td>Anode specific mass activity ≥ 75A/g at 0.5V using unrestrained cathode and ≤ 4.5 mgPGM/cm&lt;sup&gt;2&lt;/sup&gt;, and optionally improved baseline KPIs (power, durability)</td>
<td>12&lt;sup&gt;th&lt;/sup&gt; month</td>
</tr>
</tbody>
</table>
### Approach – Milestones (continued)

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Title</th>
<th>Type</th>
<th>No.</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Scale to 50 cm²</td>
<td>Milestone</td>
<td>3.1.1</td>
<td>Mass-transport loss less than in DMFC anode (intermediate milestone)</td>
<td>By 15th month</td>
</tr>
<tr>
<td>3</td>
<td>Scale to 50 cm²</td>
<td>Milestone</td>
<td>3.1.2</td>
<td>Mass-transport loss 50% less than in DMFC anode (final milestone)</td>
<td>18th month</td>
</tr>
<tr>
<td>3</td>
<td>Scale to 50 cm²</td>
<td>Milestone</td>
<td>3.3.1</td>
<td>Cathode catalyst selected</td>
<td>21st month</td>
</tr>
<tr>
<td>3</td>
<td>Scale to 50 cm²</td>
<td>Milestone</td>
<td>3.3.2</td>
<td>DME Hi-T MEA &gt; DMFC (Max. power, PM, Degradation rate, loss with off/on, and anode mass specific activity)</td>
<td>24th month</td>
</tr>
</tbody>
</table>
Prior Accomplishments Leading to Concept

DME and methanol fuel cell performance comparison. Anode: 4.0 mg_{metal} cm^{-2} PtRuPd/C, HiSPEC® 12100, 40 sccm DME gas, 26 psig, 1.8 mL/min 0.5 M or 1.0 M MeOH, 0 psig; cathode: 2.0 mg cm^{-2} Pt/C HiSPEC® 9100, 100 sccm air, 20 psig; Membrane: Nafion® 212 (DME), Nafion® 115 (MeOH); cell: 80 °C.

Temperature dependence of DME fuel cell performance. Anode: 4.0 mg_{metal} cm^{-2}, PtRu/C (HiSPEC® 12100), 40 sccm DME (gas), 26 psig; cathode: 4.0 mg cm^{-2} Pt black, 500 sccm air, 20 psig; membrane: Nafion® 212; cell: 80 °C.

High DME activity with PtRuPd/c combined with temperature sensitivity
**Standard High Temperature MEA Performance**

**PBI**-based high-temperature MEA, cathode alloy, cathode average+/−3σ, T=160 °C pressure=1 bara, stoich: 1.2/2 H₂/air. Average and sigma derived from 360 single cell tests over several large scale production batches of gas diffusion electrode (Total PM = 1.78 mg/cm²)

**TPS**-based high-temperature MEA, same electrode system as on the left T=180 °C pressure=1 bara, stoich: 1.2/2 H₂/air.

Both PBI and TPS operate w/o additional water and tolerate 1-3% CO, a DME oxidation intermediate.
Collaborations: Anticipated

- Suppliers of non-precious metal cathode catalyst
  - Separate effort at LANL
  - Northeastern University (S. Mukergee)
  - Pajarito Powder

- Next generation PBI membranes
  - University of South Carolina (B. Benicewicz)

- Makers of reformed methanol systems using high T MEAs
  - UltraCell LLC
Advent will approach Hi T MEA customers that currently build systems based on reformed methanol.

Advantage will be reduction in system cost (no reformer) and simplicity.

UltraCell LLC can use 45 cm² scale in current systems.

SerEnergy (Denmark) has interest in auxiliary power for marine systems that use low emission, carbon neutral fuels.
  - Advent will need to scale to at least 165 cm².
  - SerEnergy has previously demonstrated battery range extenders for electric vehicles using reformed MeOH.
Overview – Wind to Wheels

Did you know?
DME has cetane number similar to diesel
Liquifies and can be handled like propane

DME is hydrogen carrier and stores renewable energy

DME for modified diesel and/or high
temperature Fuel Cell (this program)
Objective: Demonstrate direct DME oxidation with high temperature MEA and LANL catalyst significantly outperforming state-of-art DMFC

Relevance: DME is a carbon neutral hydrogen carrier that can be used both for internal combustion and cost effective auxiliary fuel cell power on transport vehicles

Approach: Incorporate new ternary anode catalyst in gas diffusion electrodes designed for high temperature MEAs. Evaluate with two different high temperature membranes (PBI and TPS). Optimize reaction conditions
THANK YOU

Please visit www.advent-energy.com for more information

LANL logo used with permission by LANL
Wind power picture on slide 11 used with permission by E.S. De Castro
Truck icon of slide 11 used under terms and conditions of www.freepik.com

Contacts: EmoryDeCastro@Advent-Energy.com
Zelenay@LANL.gov