Development of Polybenzimidazole-based High Temperature Membrane and Electrode Assemblies for Stationary and Automotive Applications

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Project ID #: FC8

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OVERVIEW

Timeline
- Project start date Aug 2003
- Project end date July 2006
- Percent complete 50%

Budget
- Total project funding $7.29 M
  - DOE share $ 5.84 M
  - Plug share $1.46 M
- Funding received in FY04 $1.50 M
- Funding for FY05 $2.05 M

Barriers
- O. Stack material and manufacturing cost
- P. Durability

Subcontractors
- Rensselaer Polytechnic Institute (RPI)
  - Polymer Science Laboratory
  - Fuel Cell Center (approval in progress)
- PEMEAS
- Albany Nano Tech
- Entegris
- University of South Carolina
OBJECTIVES

- To identify and demonstrate an MEA based on a high-temperature polybenzimidazole (PBI) membrane that can achieve the performance, durability and cost targets required for both stationary and automotive fuel cell applications (original)

- In August 2004, the Department of Energy modified the objective to focus only on stationary applications
APPROACH

- Membrane (Task 1-4)
  - Formulate and characterize polymers
  - Improve membrane mechanical stability
    - Scale up process and fabricate full size MEAs

- MEA (Task 5-8)
  - Conduct 50cm² screening tests at RPI
  - Conduct parametric tests to fully characterize MEA performance
    - Assemble and test a full size short stack

- Stack (Task 9-12)
  - Characterize acid absorbing materials
  - Optimize flow fields and sealing
  - Develop novel electrodes using nanotechnology
    - Cost assessment

✓ indicates in progress
TECHNICAL ACCOMPLISHMENTS
MEMBRANE (TASK 1)

- RPI created five membrane compositions (Type 1, 2, 3, 4 & 5)
- Down-selected to primary composition based on performance characteristics (Type 2)
- Focused polymer membrane effort on mechanical stability
  - Four reinforcing fillers scaled up and under evaluation at various loadings (Type 6, 7, 8 & 9)
- Developed techniques for uniformly dispersing fillers

Without filler

With filler
TECHNICAL ACCOMPLISHMENTS
50 CM² SCREENING (TASK 5)

- Membrane conductivity of filled and un-filled membranes is similar
- MEA performance with filled and unfilled membranes is similar
TECHNICAL ACCOMPLISHMENTS
MEMBRANE MECHANICAL PROPERTIES (TASK 2)

- Developed four mechanical test fixture to simulate fuel cell stack load conditions including temperature and humidity control
- Unexpectedly, the type 8 & 9 filled membranes showed a higher rate of stress relaxation than the unfilled membrane at 160°C, on different fixtures
- Further testing is underway to validate the effect with other fixtures
- Contact resistance needs to be investigated
- A mechanical model is under development at RPI to enable projection of 40,000 hour life
TECHNICAL ACCOMPLISHMENTS
ACID MANAGEMENT (TASK 9)

- Identified the factors that influence phosphoric acid loss:
  - Temperature
  - Reactant flow rates
  - Reactant water content

- Steady state phosphoric acid evaporation losses were studied on the types 1, 2, & 5 membrane and found to be less than theoretical.

- Acid loss remains unchanged during controlled startups and shutdowns.

*Overall acid loss rate: ca. 0.6 µg/m²s

Projected cell life is 40,000 hours measured loss rate
TECHNICAL ACCOMPLISHMENTS
ACID MANAGEMENT (TASK 9)

❖ **Acid loss occurs through**
  - Diffusion
  - Capillary transport
  - Compression
  - Evaporation

❖ **Acid Loss Calculation**
  - Measured rate 0.6 \( \mu \text{g} / \text{m}^2 \text{sec} \)
  - At 160\(^\circ\)C and reactant flows for 0.2 Amps/ \( \text{cm}^2 \)
  - A full size 5kw stack starts with 2100 g of acid
  - Acid loss per year 83 g
  - 4% loss/ year if running constant
  - Sufficient acid is available for 40,000 hours

❖ **Acid Management Requirements**
  - Must prevent contamination of other system components
  - Must have low service interval
  - Must have low service cost

❖ **Acid Management Solution**
  - Stack exhaust (anode and cathode) are passed through a pelletized bed
  - Sizing studies are underway to select best size.
  - University of South Carolina engaged to develop an acid transport model

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**Acid Acid Distribution With Small (S) and Large (L) Pellets**

- S-Standard
- L-Standard

**Axes:**
- X-axis: L (cm)
- Y-axis: Phos Acid Distribution
TECHNICAL ACCOMPLISHMENTS
PBI SPECIFIC FLOW FIELD DESIGN (TASK 10)

- Initiated work with Entegris for stack sealing technology development
- Modeled full size flow field to improve system efficiency
- Worked with National Renewable Energy Lab (NREL) on optimizing coolant flow

Flow field study
- 8 cathode / anode flow configuration modeled
- Co-flow vs. counter-flow and single vs. multi-pass high power vs. low power evaluated
- 2 configurations with the lowest variability and best mean performance will be built and tested to confirm model results
TECHNICAL ACCOMPLISHMENTS
ELECTRODE (TASK 11)

- Albany Nanotech subcontractor for nano-scale electrode development
- Investigated methods for measuring catalyst layer properties
  - Focus Ion Beam (FIB) used to look at pore structure and “connectedness” of pores below the electrode surface
- Investigating methods for creating low Pt loaded catalyst layers such as Pt sputter deposition
- RPI Fuel Cell Center added to program to explore alternate catalyst formulations to improve performance
### TECHNICAL TARGETS - STATIONARY

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<th>Characteristics</th>
<th>Units</th>
<th>Calendar Year</th>
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<td>Hydrogen Crossover</td>
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<td>Durability</td>
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<tr>
<td>Operating Pressure</td>
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- **Conductivity**: Meets DOE target at 160°C
- **Cross over**: Need to confirm with final membrane
- **Cost**: PEMEAS to provide cost estimate in 2006.
- **Temperature**: Routinely run at 180°C
- **Durability**: 14,000 hours demonstrated by PEMEAS in 50cm² testing
- **Survivability**: Data available from PEMEAS
RESPONSES TO REVIEWERS’ COMMENTS

- “Application to stationary is clear - not sure how this can be used in automotive, specifically… freeze and thaw cycle”
  - In August 2004, DOE modified program objective to focus on stationary applications
  - Limited freeze thaw data is available from PEMEAS

- “… PBI has serious acid retention and mechanical stability”, “… recommend speaking/working with a PAFC developer who can help with acid management, flow field design, cathode catalyst …”
  - Acid retention is not the issue, acid management is the issue- our solution is at this review. A PAFC consultant helped Plug Power and PEMEAS understand acid loss
  - Agree that mechanical stability is an issue and our focus has been around the membrane mechanical properties for the past 9 months

- “… an electrode structure that will allow performance greater than state of the art materials eg. Nafion”
  - We are adding a major program initiative to further address the electrode structure
  - Stack size is not critical for stationary applications, however cost is
  - PBI membranes are projected to be lower cost that Nafion event though the polar curve is lower
FUTURE WORK

Remainder 2005:
- Complete filled membrane characterization
- Select primary membrane for scale-up at RPI
- Build small scale prototypes and demonstrate stack sealing concept with Entegris
- Investigate failure modes associated with starts/stops and load cycling
- Test full-size flow field and quantify efficiency improvement
- ANT will build nano-scale electrodes for Plug Power test and quantify for Pt loading reduction & performance improvement

2006:
- Build and test a full size module with improved membrane, flow field and sealing concept
- PEMEAS will deliver price estimate for MEA
- Demonstrate 1,000 hours life with low degradation rate and project 40,000 hours life
PUBLICATIONS AND PRESENTATIONS

Publications (RPI-3)


Presentations/ Posters (RPI-20)

- NMR Studies of Mass Transport in High Acid Content Fuel Cell Membranes Based on PBI/Phosphoric Acid. 206th Electrochemical Society Meeting, 10/7/04.
HYDROGEN SAFETY

❖ The most significant hydrogen hazard associated with this project is:
   Hydrogen service to the lab space in order to perform the testing introduces hazards of pressurized gases, hydrogen leaks, which could serve as an ignitions source.

❖ Our approach to deal with this hazard is:
   • Annual safety training for every employee including hazard communication and general lab safety.
   • Lab design is expected to safe environment (100% outside ventilation, hydrogen sensors set at 18% and 25% LEL)
   • Safety reviews for all equipment prior to start-up
PLUG POWER.  PLUG WILL.