2007 DOE HYDROGEN PROGRAM REVIEW

DEVELOPMENT OF POLYBENZIMIDAZOLE-BASED HIGH TEMPERATURE MEMBRANE AND ELECTRODE ASSEMBLIES FOR STATIONARY APPLICATIONS

Clean, Reliable On-site Energy

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Project ID: FC8

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OVERVIEW

Timeline

- Project start date Aug 2003
- Scheduled end date July 2006
- Extended to FY07 due to funding cuts in 06

Budget

- Total project funding $7.29M
  - DOE share $ 5.84M
  - Plug share $1.46M
- Funding received in FY04 $1.50M
- Funding received in FY05 $2.05M
- Funding for FY06 $0.94M
- Funding for FY07 $0.4M

Barriers

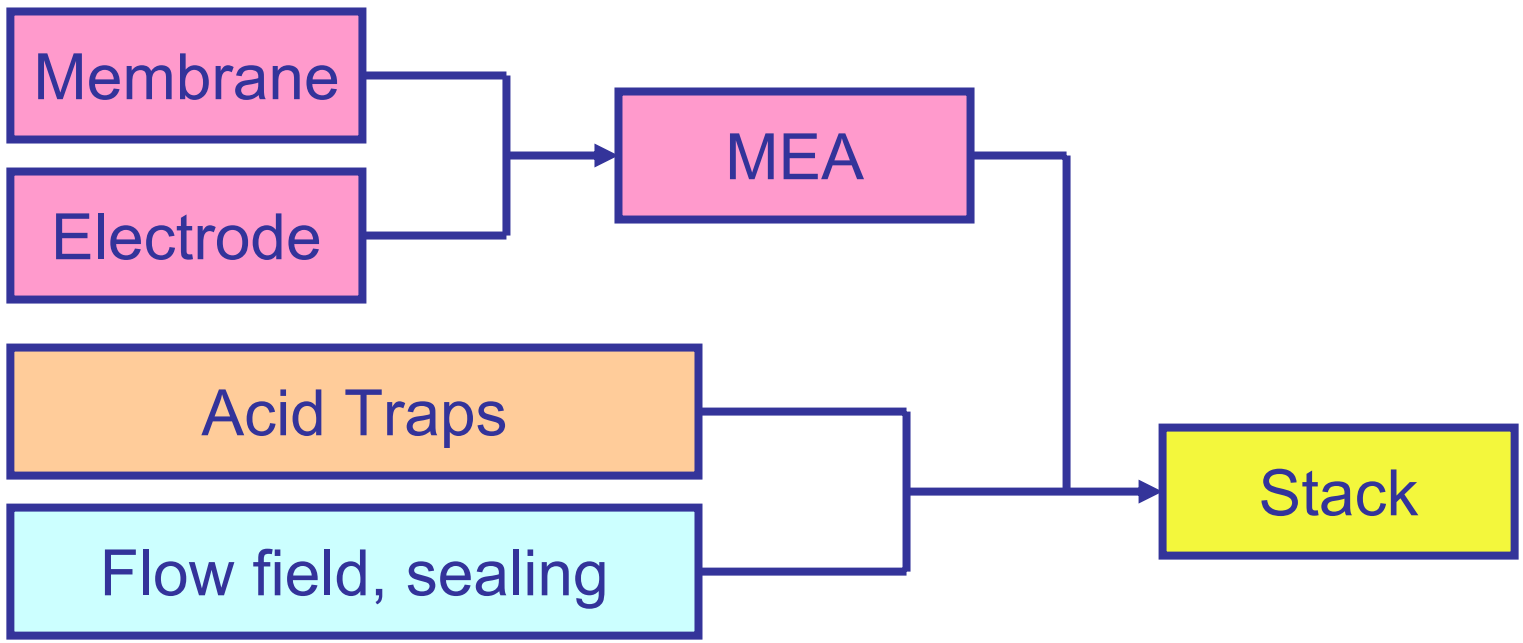
- O. Stack material and manufacturing cost
- P. Durability

Subcontractors

- Rensselaer Polytechnic Institute (RPI)
  - Polymer Science Laboratory
  - Fuel Cell Center
- PEMEAS; now BASF Fuel Cell
- 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 stationary fuel cell applications



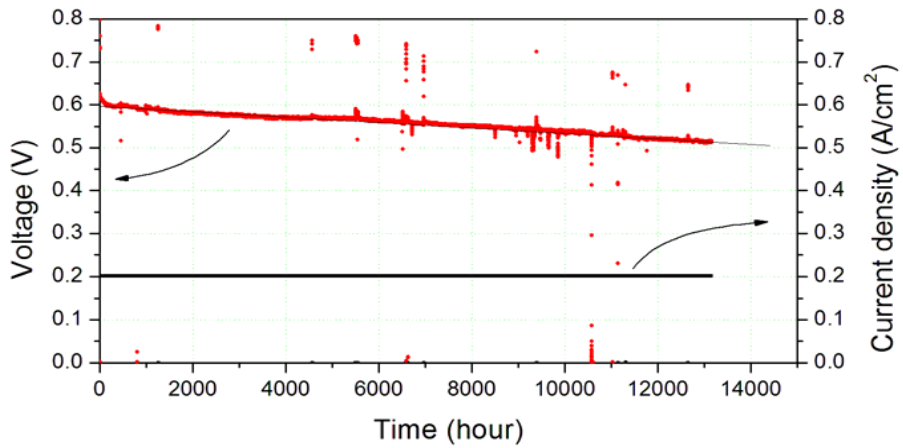
APPROACH

- Membrane (Task 1-4) *95% complete*
  - ✓ Formulate and characterize polymers
  - ✓ Improve membrane mechanical stability
  - ✓ Scale up process and fabricate full size MEAs
- MEA (Task 5-8) *90% complete*
  - ✓ Conduct 50cm^2 screening tests at RPI
  - ✓ Conduct parametric tests to fully characterize MEA performance
  - ✓ Assemble and test a full size short stack
- Stack (Task 9-12) *90% complete*
  - ✓ Characterize acid absorbing materials
  - ✓ Optimize flow fields and sealing
  - ✓ Develop novel electrodes using nanotechnology
  - ✓ Cost assessment

✓ Progress made

TECHNICAL ACCOMPLISHMENTS MEMBRANE (TASK 2)

- MEA Degradation Analysis
  - Summary of Improved MEA Performance to Date:
    - RPI and BASF have demonstrated on 50cm^2 cells:
      - < 10 µV/hr, H_2/air, dry, steady state, 20,000 and 14,000 hrs
      - 6,000 hrs load cycling (projected 14,000 hr life)
      - 110 Start-up/shut down cycles



TECHNICAL ACCOMPLISHMENTS MEMBRANE (TASK 2)

- MEA Degradation Analysis Continued
  - Plug Power Summary:
    - RPI and BASF trends were confirmed, especially, no difference in decay rates between dynamic load and static load operations
    - However, all cells tested at Plug Power showed much higher decay rates (average 3X, up to 10X) than those reported by RPI and BASF
    - Major effort last year in determining and eliminating differences

TECHNICAL ACCOMPLISHMENTS MEMBRANE (TASK 2)

Temperature	Cell number	Decay rate (μV/hr)
180 C	3059	32
180 C	3061	26
180 C	3067	31
180 C	3064	25
160 C	3179	23
180 C	3186	30
160 C	3187	25

Sources of difference discovered, lab to lab correlation achieved. Required mindset change from Nafion® to PBI!

TECHNICAL ACCOMPLISHMENTS MEMBRANE (TASK 2)

- Intrinsic reasons for MEA performance decay:
  - Catalyst sintering and dissolution
  - Catalyst support corrosion
    - Including carbon in the micro-porous layers
  - Acid loss/redistribution
    - Acid loss from MEAs high but to outside cell low
    - A large portion of acid moves to plates from MEAs
  - Membrane thinning/creeping
    - Expect worsened by acid loss from MEAs

All above failure modes are accelerated at 180 °C vs. 160 °C

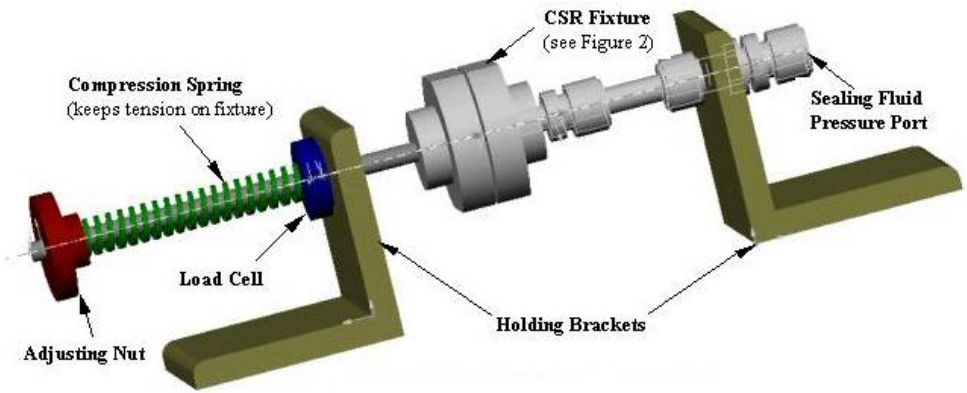
TECHNICAL ACCOMPLISHMENTS MEMBRANE (TASK 2)

- MEA Robustness Improvements
  - Change to graphitic carbon catalyst-support and micro-porous layer
  - Use Pt alloys as catalyst
  - Increase PBI content and reduce low MW PBI
- Cell/stack Optimization
  - Flow-fields and manifolds for PBI properties
  - Plates
    - Oxidative stability and porosity of non-graphitic materials
    - MEA/plate compression tolerance optimization
    - Improve sealing/bonding to prevent edge failure and cooler bowing
    - Pre-condition stack components to reduce acid loss from MEAs
- Optimization of fuel cell operation

TECHNICAL ACCOMPLISHMENTS
STACK DESIGN (TASK 10)

- Brainstormed plate bonding and sealing concepts
  - Evaluated conductive and non-conductive materials
  - 11 bonded samples exposed to phosphoric acid and coolant at 180ºC - 6 failed
  - Lap shear tests and sealing pressure tests performed - 2 survived
  - Large scale bond line optimization in progress with MEAs
- 2 patents filed regarding aspects of the bond and seal concept
- Big cost saving potential by eliminating gaskets, assembly time, end hardware

CSR holding fixture



Sealing Pressure Tester

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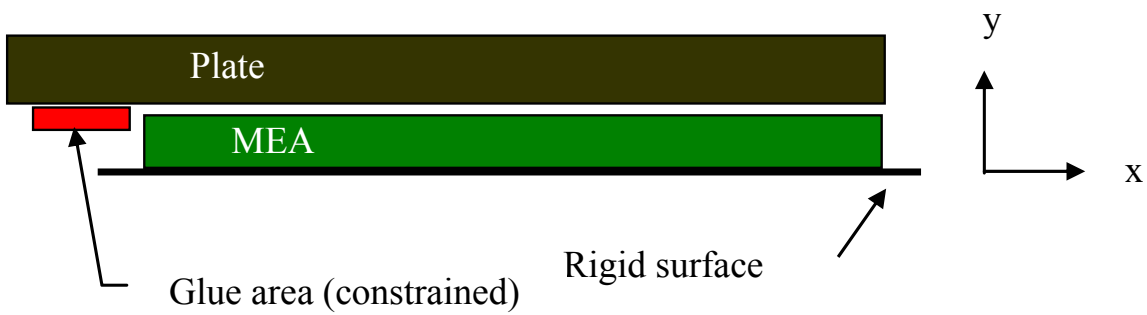
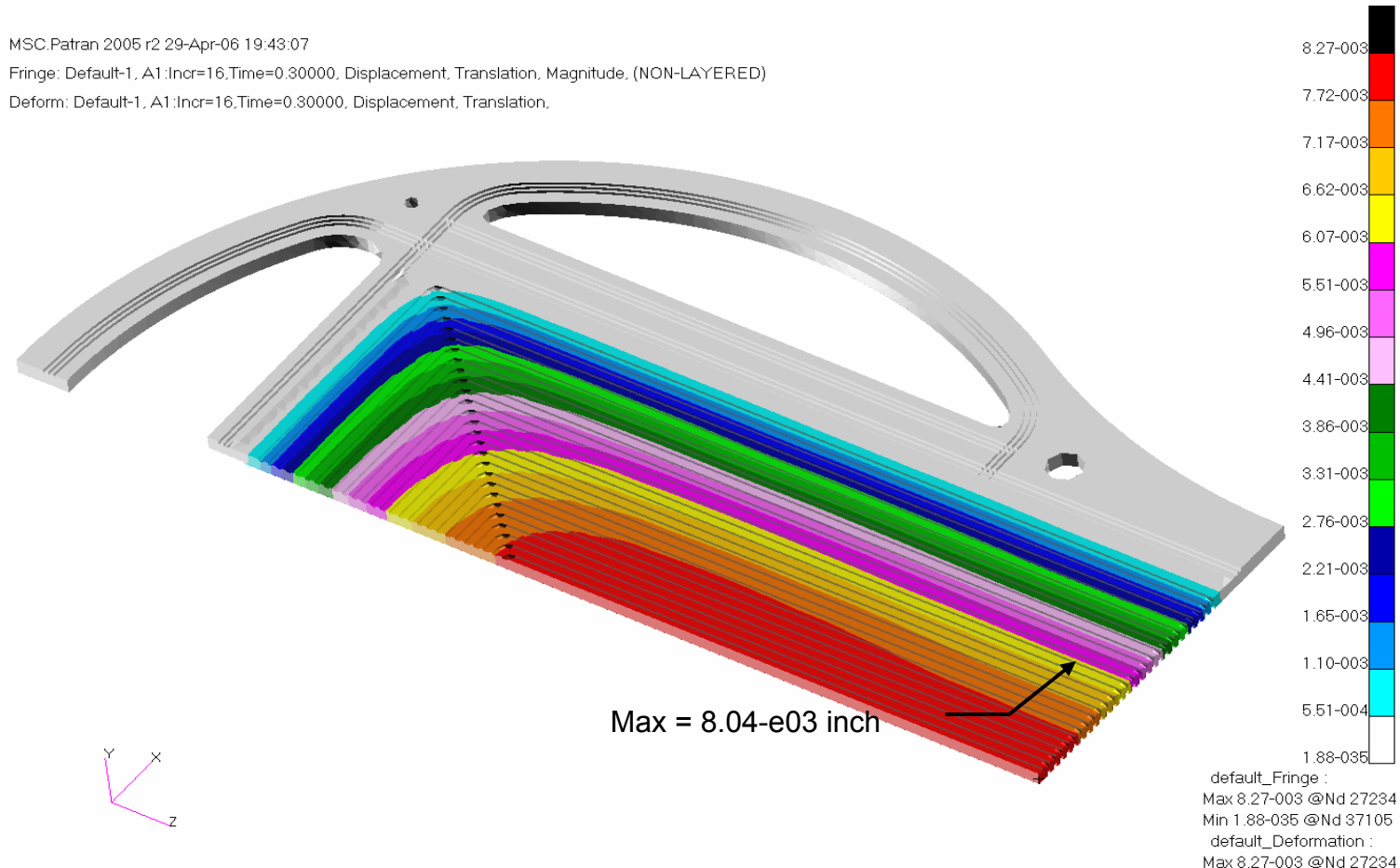


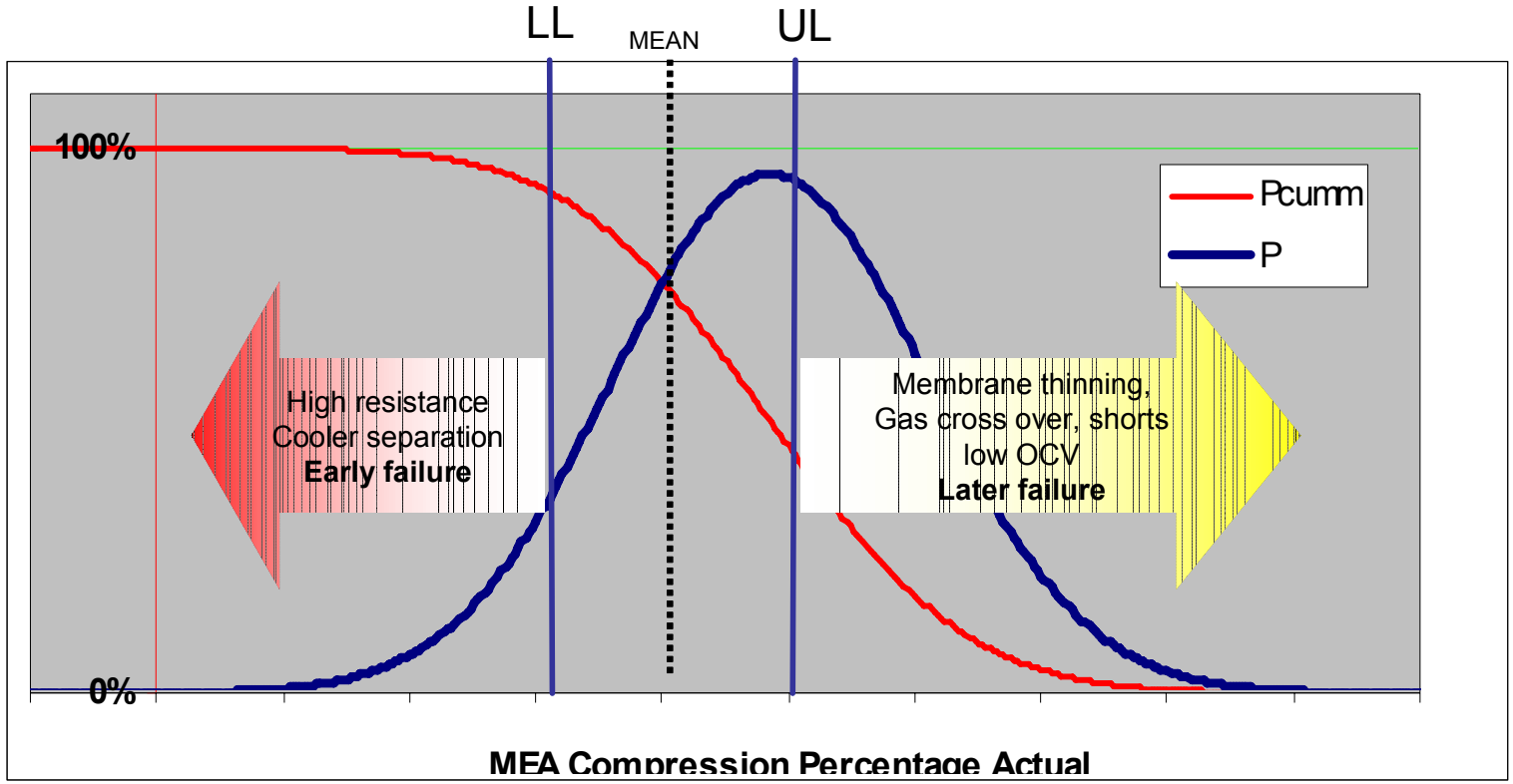
Entegris FEA Model of Bond and Seal

TECHNICAL ACCOMPLISHMENTS
STACK DESIGN (TASK 10)

- Plate displacement calculations

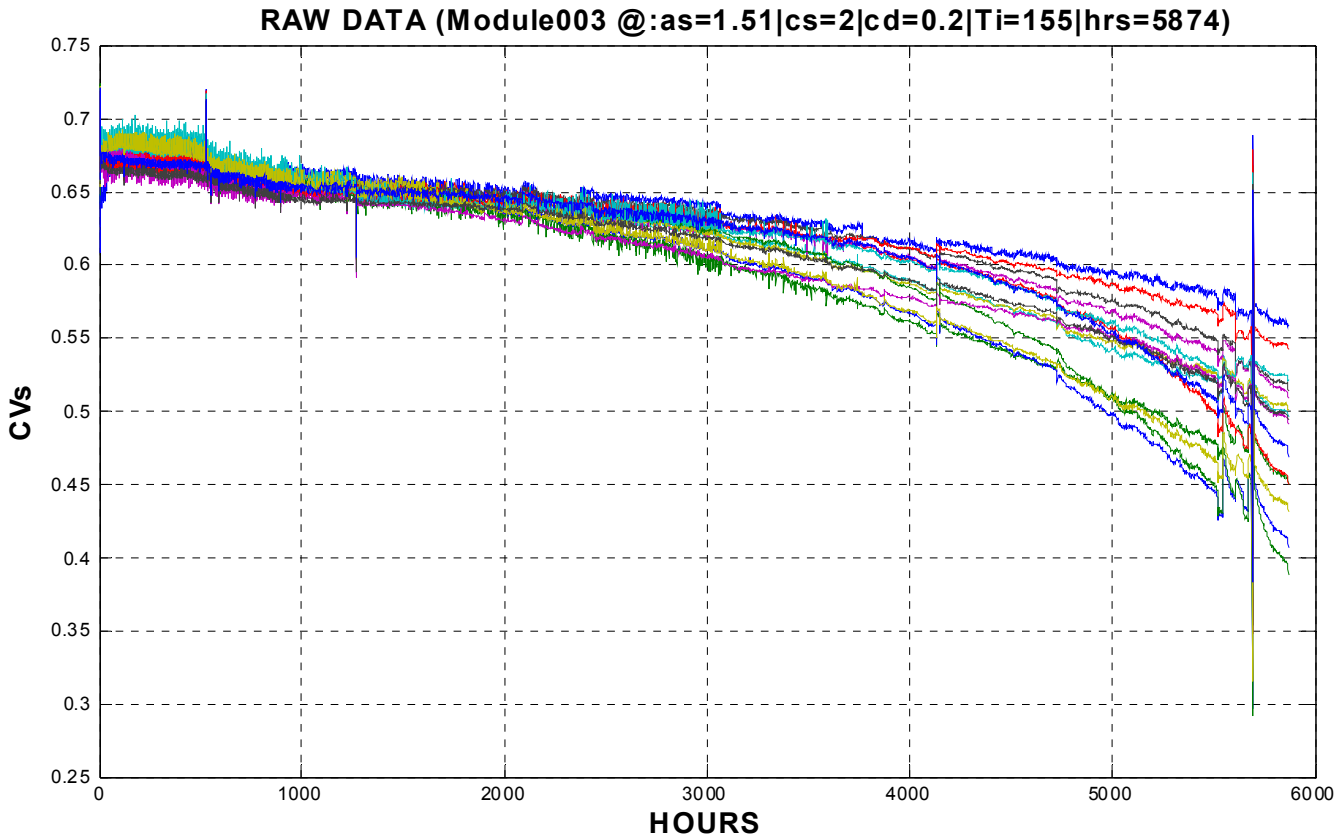


TECHNICAL ACCOMPLISHMENTS
STACK DESIGN (TASK 10)



- Pocket depth tolerances for full sized MEAs and plates have higher mean and wider variation
- Shifting the mean without minimizing the variation puts more cells at risk for early failure modes

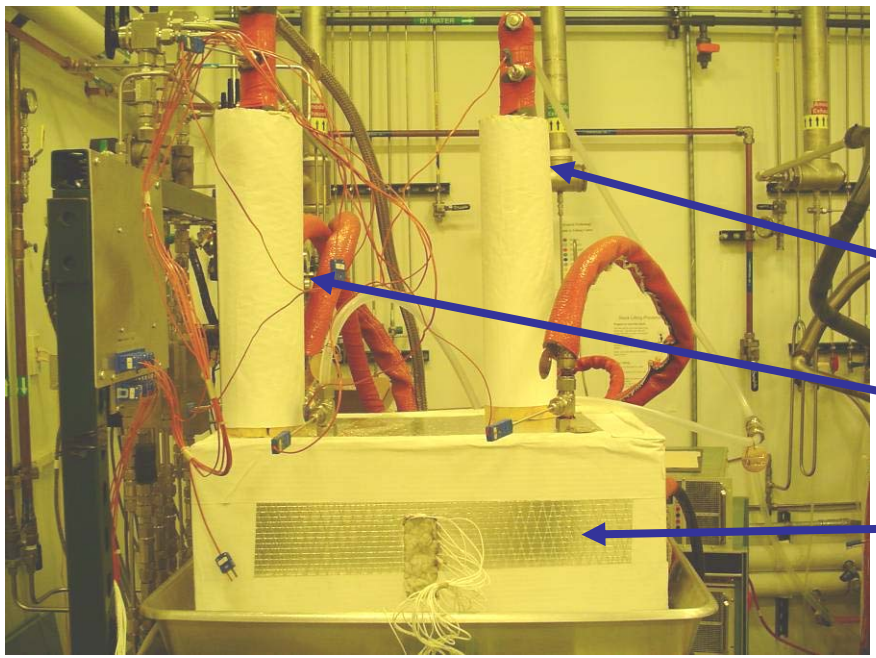
TECHNICAL ACCOMPLISHMENTS
STACK DESIGN (TASK 10)



16-cell module, 7200 hrs. < 10 to 60 µV/hr degradation

TECHNICAL ACCOMPLISHMENTS
ACID MANAGEMENT (TASK 9)

- Acid loss mechanisms defined, loss rates characterized and controllable
- 8,000 hours of acid trap testing completed on full size Type 2 MEAs



Phos acid is trapped preventing contamination of the rest of the system

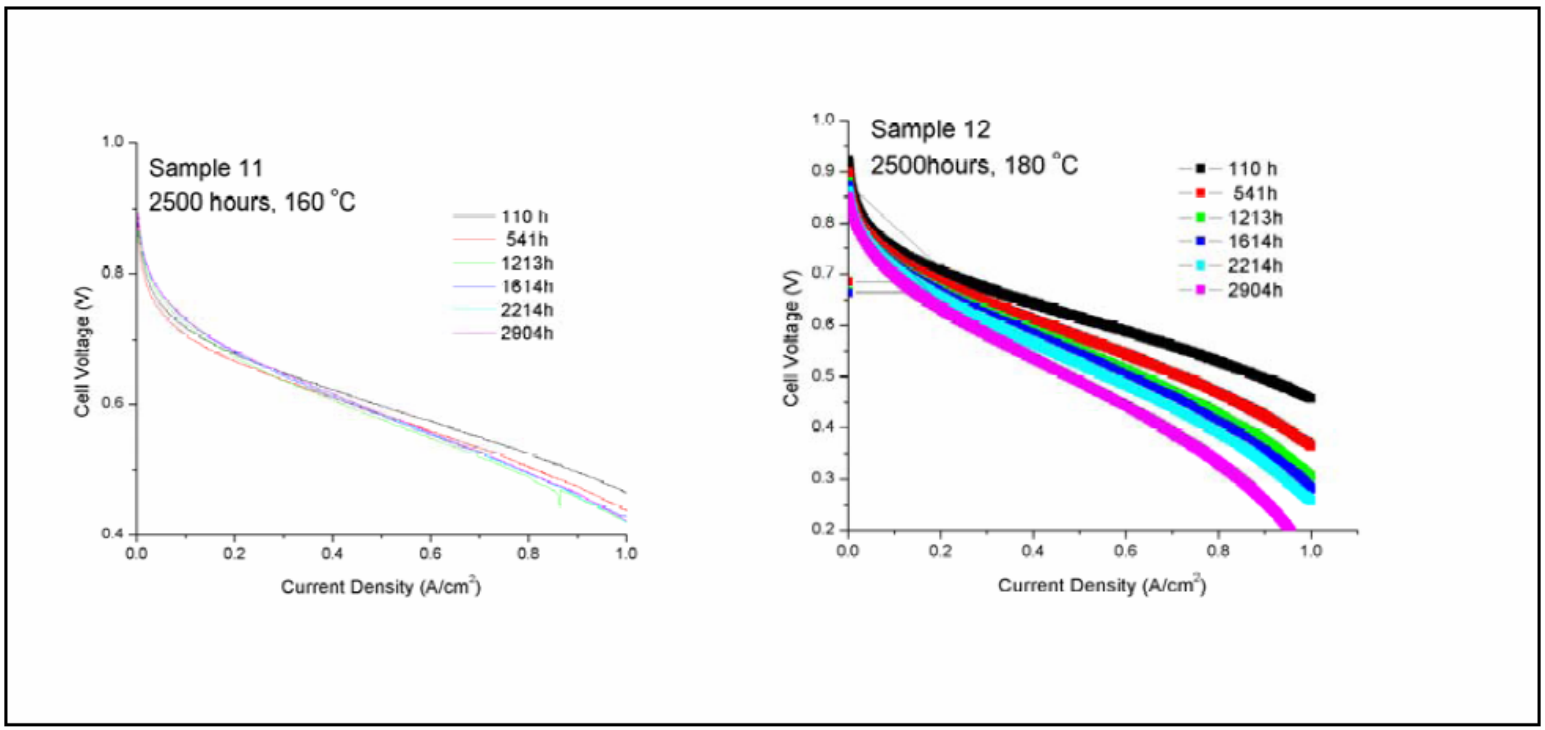
Cathode Acid Trap

Anode Acid Trap

16 cells 440 cm^2 module

TECHNICAL ACCOMPLISHMENTS
ACID MANAGEMENT (TASK 9)

- Polarization curves taken at 160 °C (left) and 180 °C (right) during 2500 hour operation. Polarization curves were taken at constant flow conditions, 1.2/2.0 stoic for hydrogen and air set at 1 A/cm2.



TECHNICAL TARGETS- STATIONARY

Characteristic	Units	Calendar Year			
		2004 Status	2005 Status	2006 Outlook	2010 Target
Membrane conductivity, operating temperature	Ohm-cm^2	0.10	0.10	0.10	0.10
Oxygen crossover	mA/cm^2	5	5	5	2
Hydrogen crossover	mA/cm^2	5	5	5	2
Cost	$/ kW		50	50	5
Operating temperature	^{o}C	160	160	160	170
Durability	Hours	5,000	>15,000	>15,000	40,000
Survivability	^{o}C	-20	-30	-30	-40

- **Conductivity:** Meets DOE target at 160^{o}C
- **Cross over:** Need to confirm with final membrane
- **Cost:** BASF and Entegris cost estimates delayed due to funding cuts on FY 06.
- **Temperature:** Routinely run at 180^{o}C
- **Durability:** 20,000 hours demonstrated by BASF in 50cm^2 testing, 13,000 hours demonstrated by RPI at 120^{o}C
- **Survivability:** Data available from BASF

FUTURE WORK

Remainder of 2007:

- Scale-up membrane & procure MEAS from BASF utilizing their latest electrode.
- Test a full size module with improved membrane, flow field and sealing concept.
- Build full size prototypes and demonstrate stack sealing concept with Entegris.
- Complete long term acid trap testing.
- BASF, Plug Power and Entegris will deliver price estimate for MEA and stack.
- Demonstrate 1,000 hours life with low degradation rate and project 40,000 hours life
- Complete program.

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