



2007 DOE HYDROGEN PROGRAM REVIEW

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

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16 May 2007

Clean, Reliable On-site Energy

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

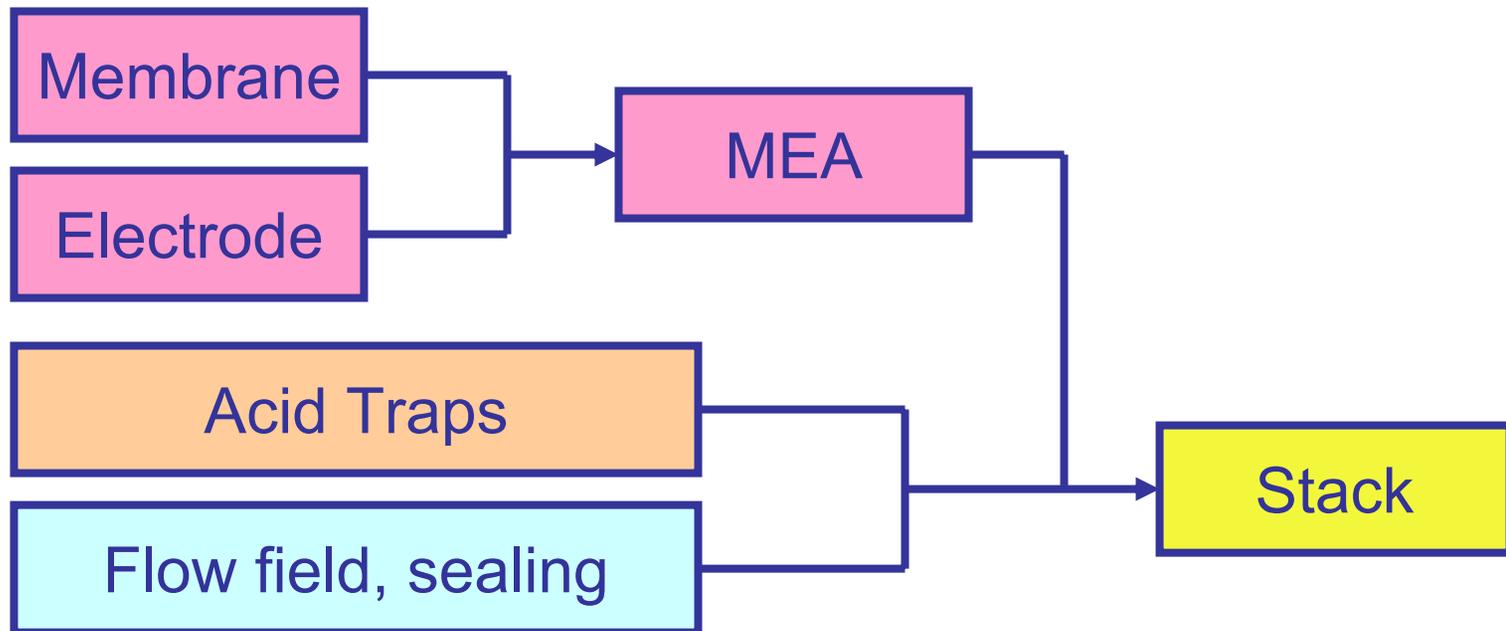
- ❖ O. Stack material and manufacturing cost
- ❖ P. Durability

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 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) *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 50cm² cells:

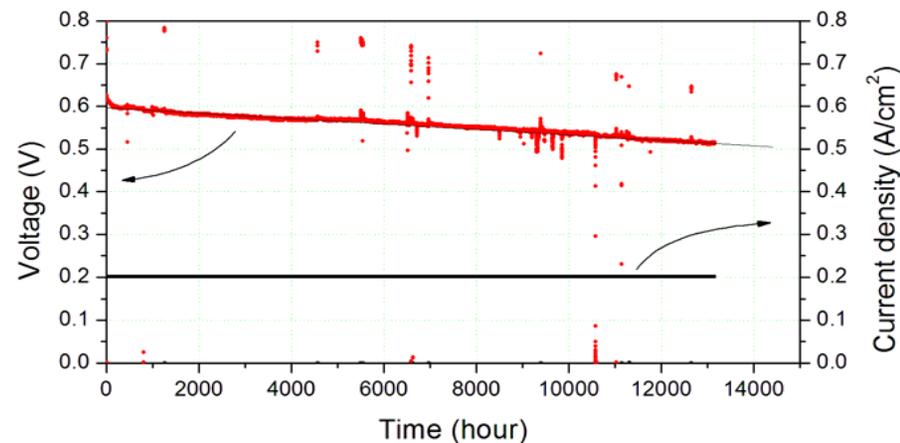
- ❖ < 10 $\mu\text{V/hr}$, H₂/air, dry, steady state, 20,000 and 14,000 hrs

- ❖ 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 ($\mu\text{V/hr}$)
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)

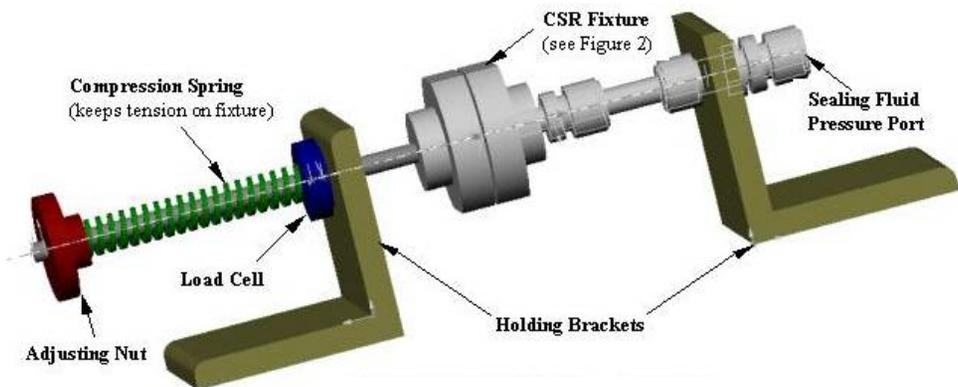
- ❖ MEA Robustness Improvements
 - Change to graphitic carbon catalyst-support and micro-porous layer
 - Use Pt alloys as catalyst
 - Increase PBI content and reduce low MW PBI
- ❖ Cell/stack Optimization
 - Flow-fields and manifolds for PBI properties
 - Plates
 - Oxidative stability and porosity of 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 180°C - 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



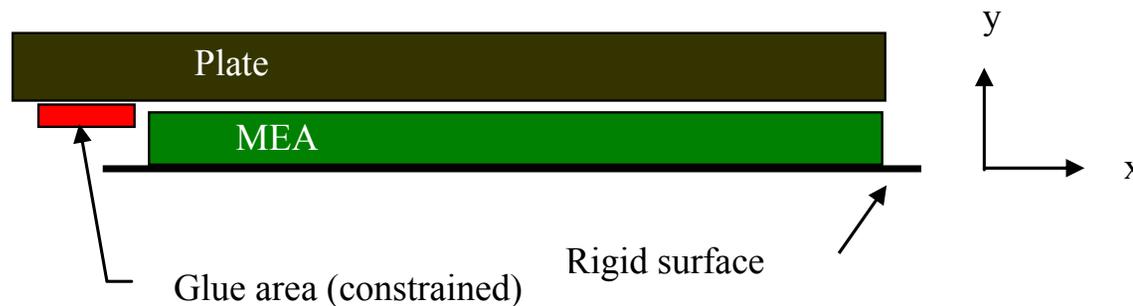
CSR holding fixture



Sealing Pressure Tester

TECHNICAL ACCOMPLISHMENTS STACK DESIGN (TASK 10)

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Entegris FEA Model of Bond and Seal

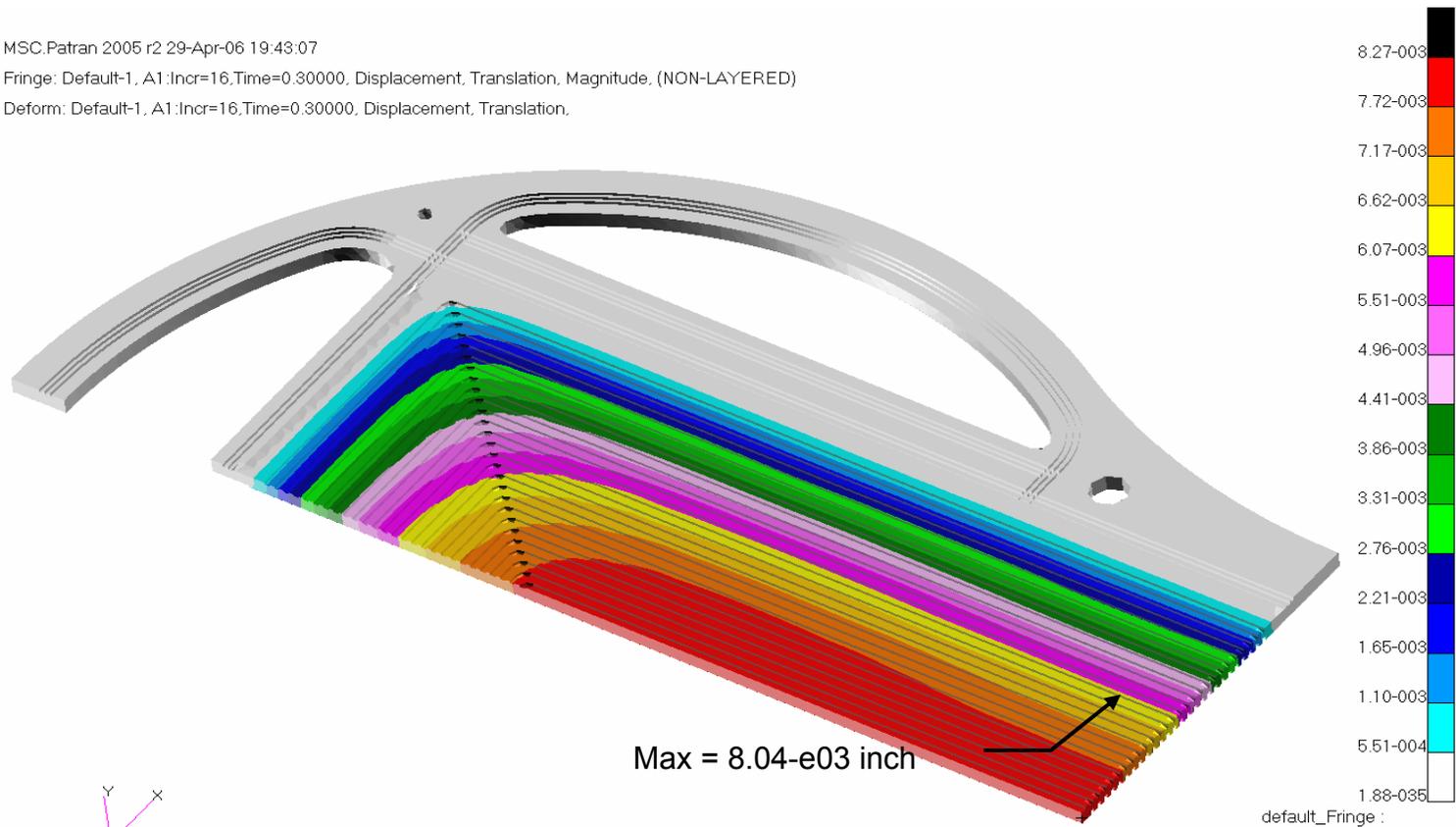
TECHNICAL ACCOMPLISHMENTS STACK DESIGN (TASK 10)

❖ Plate displacement calculations

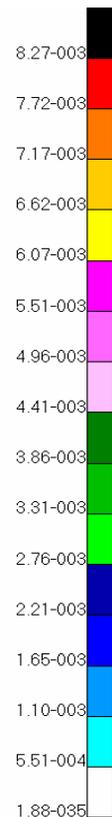
MSC.Patran 2005 r2 29-Apr-06 19:43:07

Fringe: Default-1, A1:Incr=16,Time=0.30000, Displacement, Translation, Magnitude, (NON-LAYERED)

Deform: Default-1, A1:Incr=16,Time=0.30000, Displacement, Translation,



Max = 8.04-e03 inch



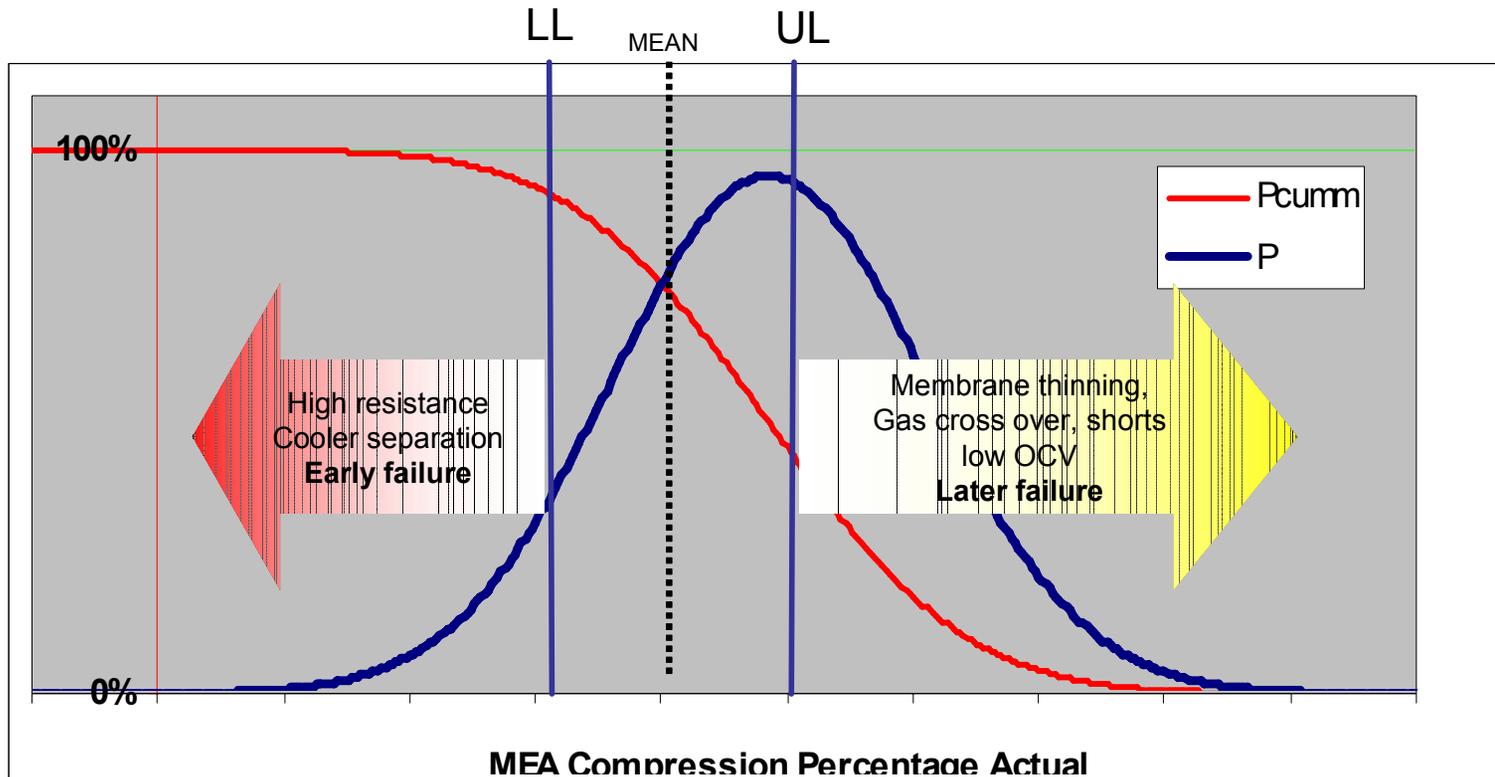
default_Fringe :
Max 8.27-003 @Nd 27234
Min 1.88-035 @Nd 37105

default_Deformation :
Max 8.27-003 @Nd 27234



TECHNICAL ACCOMPLISHMENTS

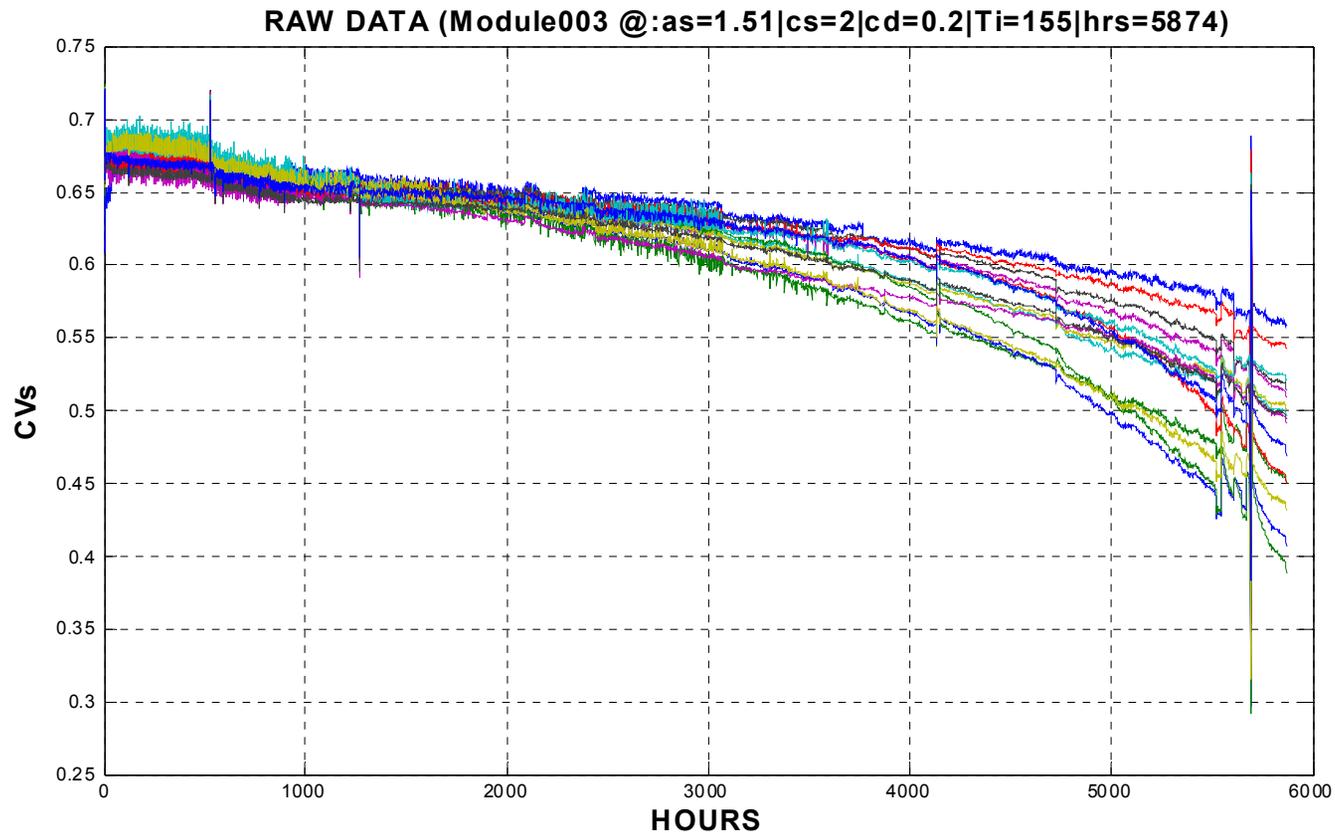
STACK DESIGN (TASK 10)



- ❖ 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)

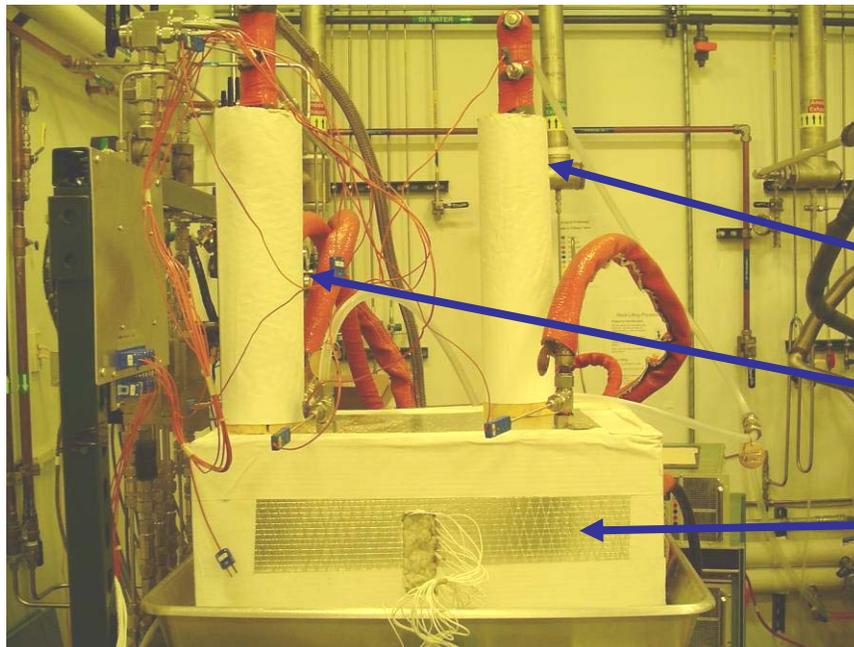


16-cell module, 7200 hrs. < 10 to 60 $\mu\text{V/hr}$ degradation

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

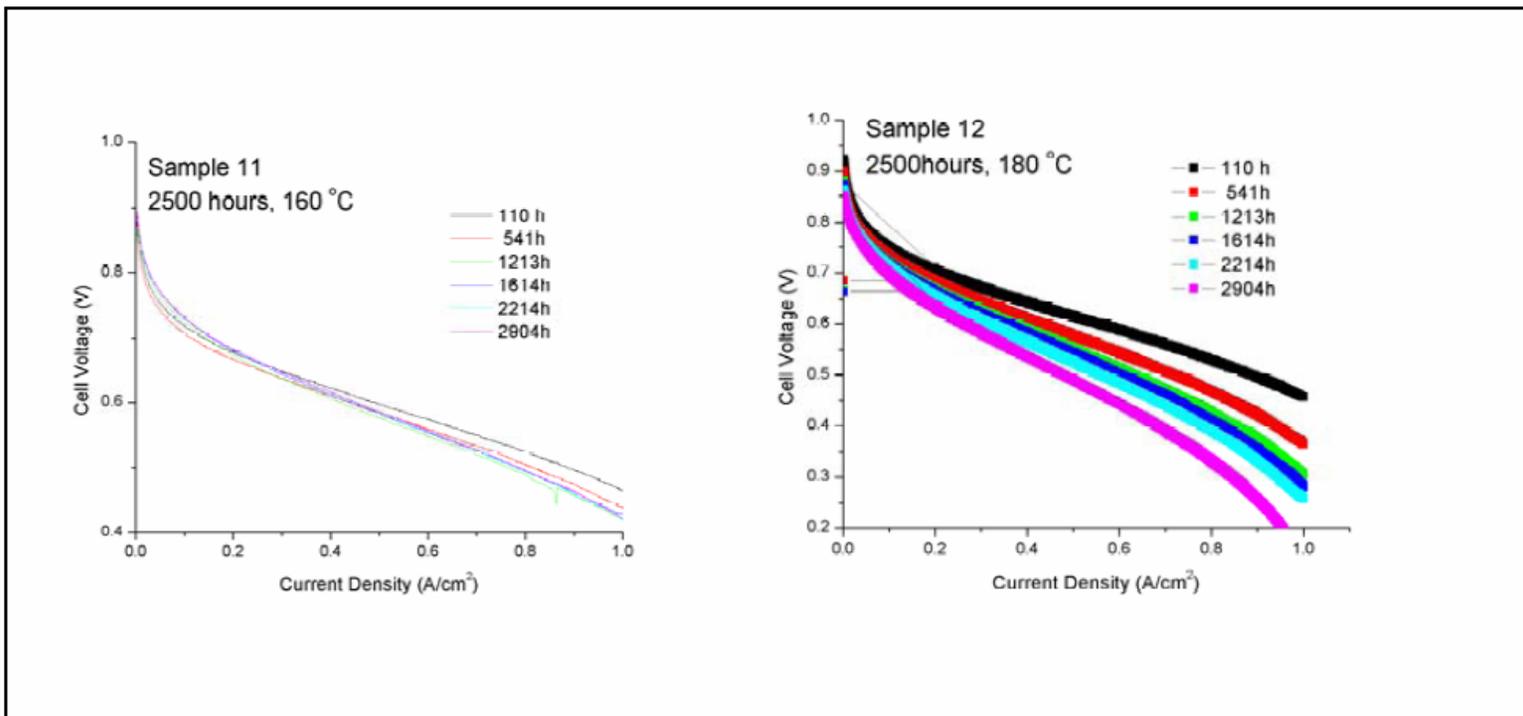
Anode Acid Trap

16 cells 440 cm² 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	°C	160	160	160	170
Durability	Hours	5,000	>15,000	>15,000	40,000
Survivability	°C	-20	-30	-30	-40

- **Conductivity:** Meets DOE target at 160°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°C
- **Durability:** 20,000 hours demonstrated by BASF in 50cm² testing, 13,000 hours demonstrated by RPI at 120°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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