Accelerated Testing Validation

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Los Alamos National Laboratory
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FC016

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Project Overview

Timeline

- Project Start Date
  - **August 2009**
- Project Duration
  - **4 Years (End: Sept '13)**
- ≈ 90% complete

Budget

- Total project funding
  - 4 Years : $4,159,790
  - DOE Cost : $4,000,000
  - Cost Share : $159,790
- Funding for FY12/FY13

LANL	$ 397k, 750k
+ Partners (Industry)	
Other National Labs	$ 300k, 250k
FY12/FY13 Total	$ 697k,1000k

Barriers

Fuel cells: 2011 Technical Plan

A. Durability

Automotive

5,000 hours (10% degradation)

Stationary

2017 : 40,000 hours (20% degradation)

2020 : 60,000 hours (20% degradation)

Bus

1016 : 18,000 hours

Accelerated testing protocols need to be developed to enable projection of durability and to allow for timely iterations and improvements in the technology.

Partners

- Ballard Power (System Integrator)
- Ion Power (Materials Supplier)
- ORNL (Metal Bipolar Plates)
- LBNL (Modeling)

Objectives/Barriers - Relevance

The objectives of this project are 3-fold

1. Correlation of the component lifetimes measured in an AST to real-world behavior of that component.
2. Validation of existing ASTs for Catalyst layers and Membranes
3. Development of new ASTs for GDLs, bipolar plates and interfaces

Technical Targets

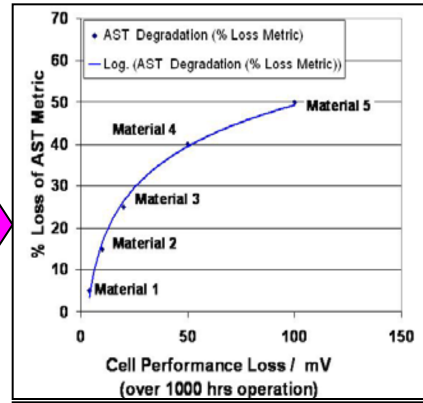
Automotive : Durability with cycling: 5,000 hours (2010/2015): 2005 Status (2000 hours for stack and 1000 hours for system)
Stationary : Durability: 40,000 hours (2011): 2005 Status = 20,000 hours
Bus Data : 18,000 hours (2016); 25,000 hours (ultimate); Status = 12,000 hours.

Importance of Accelerated Stress Test (AST)

- Allows faster evaluation of new materials and provides a standardized test to benchmark existing materials
- Accelerates development to meet cost and durability targets
- Different ASTs are available (DOE-FCTT, USFCC and JARI)
  - Lack of correlation to “Real World” Data
  - No tests available for GDLs and other cell components
  - Value of combined vs individual tests

Approach

Materials
- BPS provides materials used in Bus Stack
- W. L. Gore provides commercial MEAs
- Ion Power provides custom MEAs
- SGL carbon provides commercial GDL materials
- ORNL provides metal bipolar plates



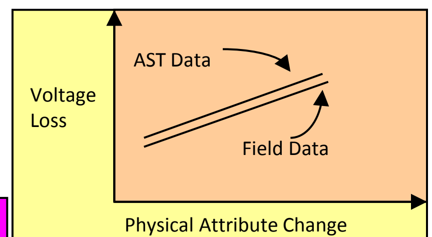
LANL performs DOE-FCTT ASTs
Develops GDL, bipolar plate ASTs

Characterization
Fuel Cell Performance
VIR, Impedance, HelOx, Modeling
Catalyst
- ECSA, Mass activity, particle size, layer thickness, composition, loading

Membrane
Cross-over, shorting resistance, HFR, thickness
GDL
- Impedance, Hydrophobicity

BPS Bus Fleet Data
- Voltage degradation distribution data from P5 fleet & HD6 Module
- Cell Data (36 Cells)
- MEA Characterization (108 MEAs)

LANL Drive Cycle Testing
- Automotive drive cycle testing
- RH, Temp, Pressure effects



Statistical Correlation
- Relate field and AST data to physical attribute change
- Good correlation if AST slope similar to “Real World Data” slope

Goals
- Recommend improved catalyst and membrane ASTs that correlate to real world data
- Recommend ASTs for GDL and bipolar plate materials
- Co-ordinate efforts with FCHEA and USDOE-FCTT

Approach - Milestones

Begin	M1	M2	M3/M4	M5/M6	M7	M8	M9/M10	End
08/09	12/11	03/12	04/12	12/12	04/13	06/13	09/13	09/13

Milestones

M1: Complete failure analysis of LANL AST samples (Complete 12/2011)

M2: Developed improved multi-model and multi-variable fitting algorithm. (Complete 03/2013)

M3: Complete failure analysis of Ballard samples (Complete 04/2012)

M4: Complete AST testing on a high SA and a low SA carbon (Complete 04/2012)

M5: Delivery of AST, field, and virgin membranes to LBNL for testing. (Complete 12/2012)

M6: Complete failure analysis of LANL AST samples including 3 different catalyst layers on DuPont XL membranes. (Complete 12/2012)

M7: Deliver a total of 50 MEAs customized for 2 different MEA types (standard, FCT, 50 cm^2 and 50 cm^2 for GM/RIT hardware) (Complete 04/2013)

M8: Complete drive cycle testing on 3 different membranes and 3 different catalyst layers (33% complete)

M9: Propose validated GDL, membrane and start/stop ASTs (80% complete)

M10 : Final Statistical correlation of AST and Bus data to material property and AST lifetimes to drive cycle of materials with varying lifetimes

Materials Used

- Gore™ MEAs (AST: 2010 AMR, F/A: 2011 AMR)
  - Gore™ Primea® MESGA MEA A510.1/M720.18/C510.2
  - Gore™ Primea® MESGA MEA A510.2/M720.18/C510.4
  - Gore™ Primea® MESGA MEA A510.1/M710.18/C510.2

M710 : Discontinued product. Lower chemical and mechanical durability sample

- Ballard P5 and HD6 MEAs (AST: 2011 AMR, F/A: 2012 AMR)
- Ion Power MEAs (AST, F/A: 2012 AMR)
  - DuPont XL membranes
  - Tanaka Catalysts
    - TEC10E50E, TEC10E40E, TEC10E20E (High Surface area carbon 50 wt%, 40 wt% and 20 wt% Pt)
    - TEC10V40E, TEC10V20E (Vulcan carbon 40 wt%, 20 wt% Pt)
    - TEC10E40EA Low Surface area carbon 40 wt% Pt

M720 : technology circa 2005. Higher chemical and mechanical durability sample

- GDL
  - SGL 24BC (5% PTFE-substrate/23% PTFE MPL)
  - Varying PTFE content and substrate porosity

F/A = Failure Analysis

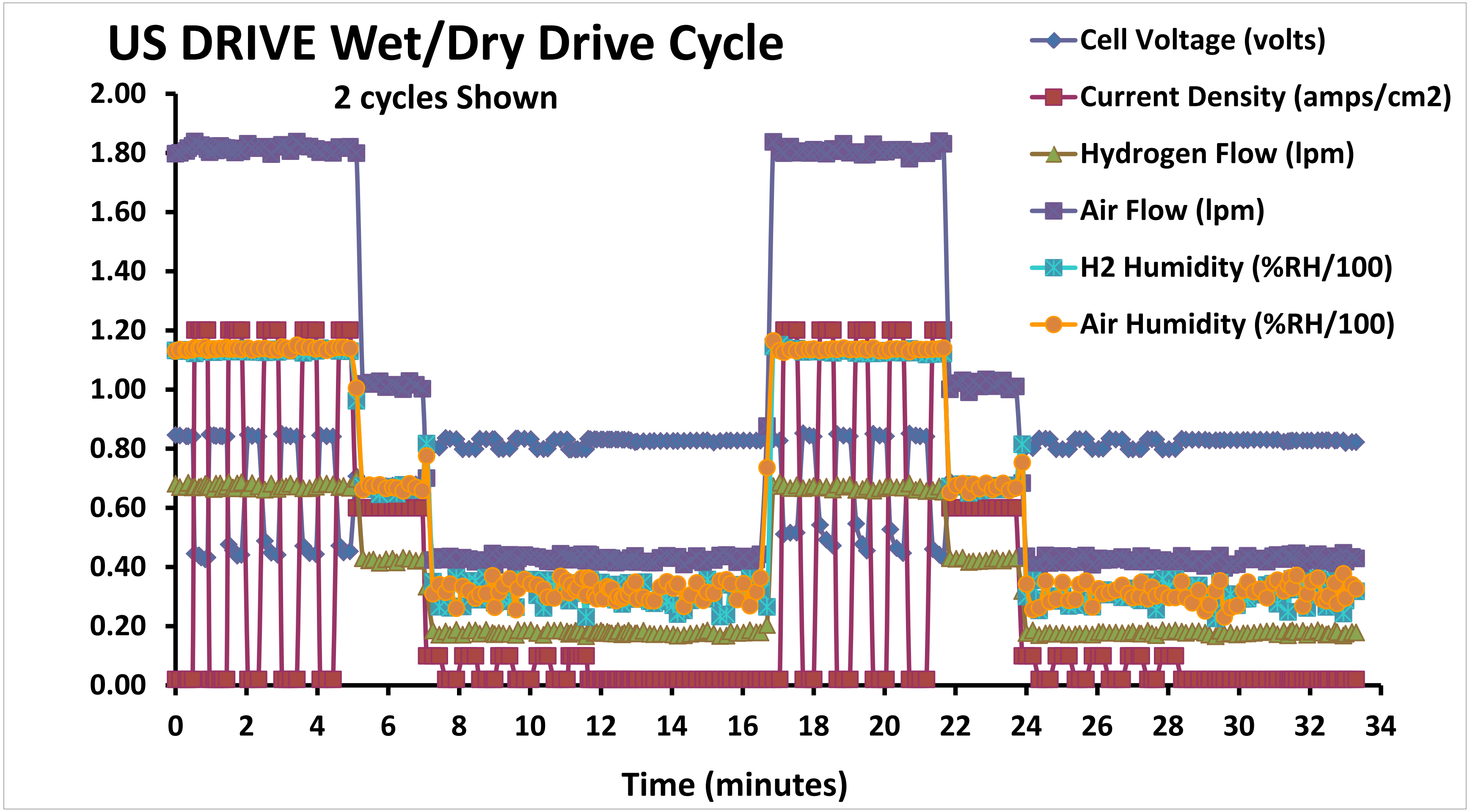
- Bipolar plates
  - G35 and Ni50Cr: Corrosion testing (coupons) and fuel cell testing (plate)
  - No degradation observed in short term testing in MEA (awaiting input from other LANL durability project)

Field Data

- History of P5 Stacks are as follows:
  - PE4 with 2,769 hours of operation
  - PE22 with 3,360 hours of operation
  - PE24 with 2,597 hours of operation
  - All 3 buses operated in Hamburg for their life
  - Data over a sample stretch of 1-2 hours were analyzed to define performance degradation
  - 8-10 time periods per stack were analyzed to ensure enough points to develop a good average performance degradation rate
- HD6 Stack is designated as follows:
  - SN5096 with 6,842 hours of operation
  - Stack was system tested in lab under Orange County Transit Authority (OCTA) cycle
  - Due to pull outs of MEAs from stack will have failure analysis (FA) data at ~2,400 hours, 4,300 hours and 6,842 hours

Presented in 2011/2012 AMR

Drive Cycle Testing



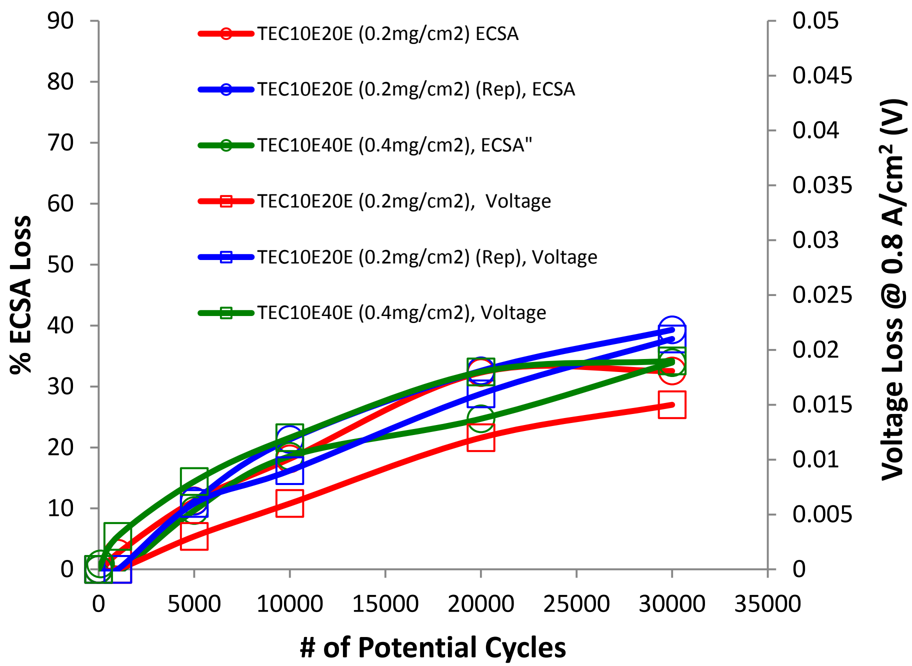
Use 100% H_2 instead of 80% H_2

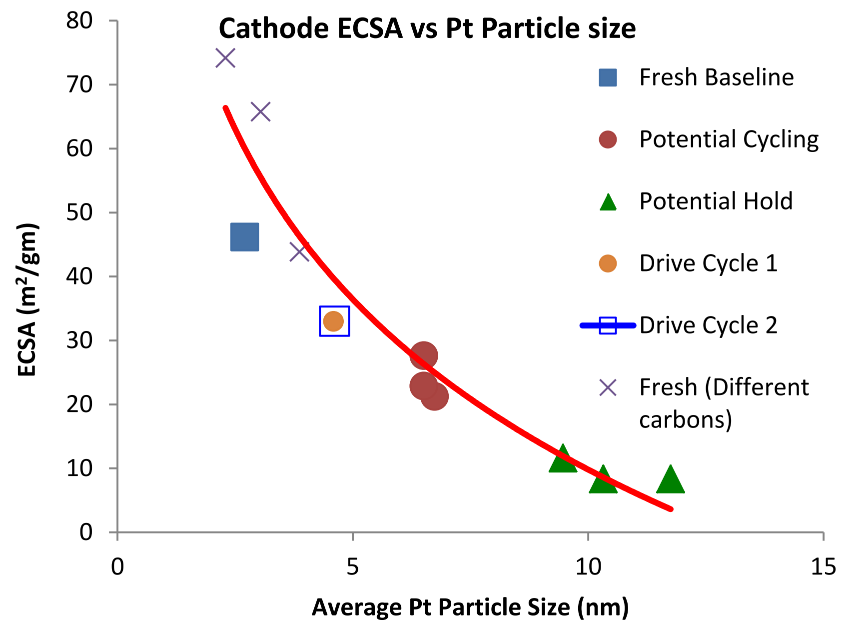
Only one station capable of RH control (bottle = 90°C, adjust dry and wet flows)

Also performing cycles at the high RH conditions (Wet Cycling)

Potential Cycling AST

Accomplishments /Progress





- Pt particle size growth observed in both TEM and XRD
- Correlates with decreasing ECSA
  - Observed in both electro-catalyst (potential cycling) and carbon corrosion (high potential hold) AST
- Mass activity, voltage loss, and increased impedance in kinetic region observed
- 40% ECSA loss corresponds to approx. 20 mV voltage loss

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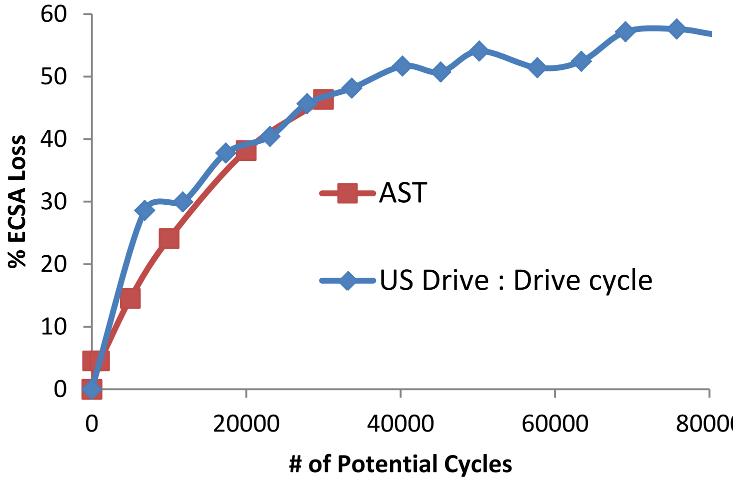
Correlation of AST and Drive Cycle

- 30,000 cycles ≈ 2000 hours of bus operation (Both P5 and HD6)
- 30,000 cycles ≈ 850 hours of US DRIVE Drive-Cycle
- 30,000 cycles ≈ 500 hours of wet drive cycle
- 5000 hours ≈ 175,000 cycles
- Need > 30,000 cycles for 5000 hour automotive durability



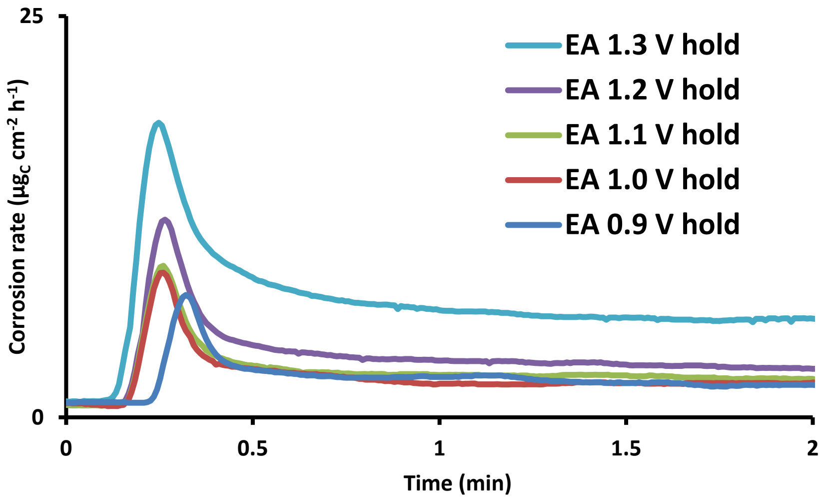
- Pt particle size increase.
  - Consistent with potential cycling AST
  - Larger Pt growth in drive cycle samples than AST samples

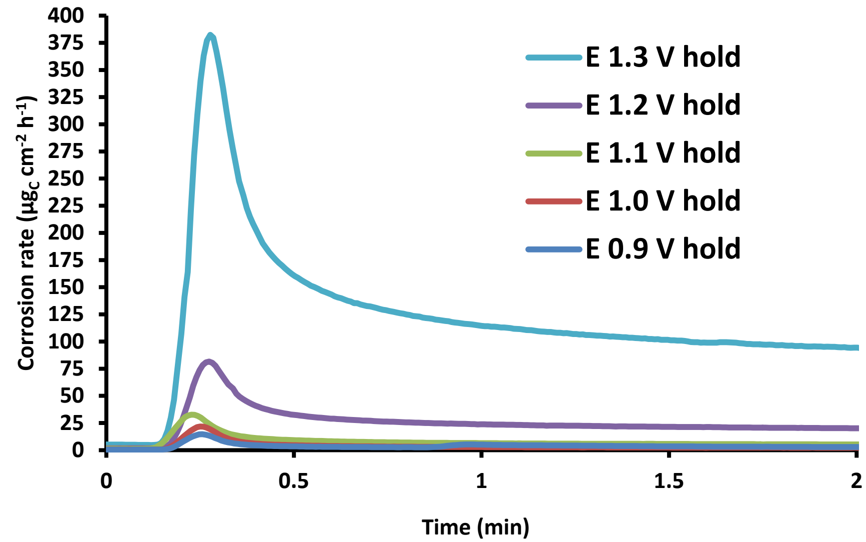
    6.5 nm after 30,000 cycles
    9.5 nm to 11.5nm after 1.2 V AST
    9.4 nm after 2000+ hours wet/dry cycle
    7.5 nm after 1200 hours wet cycle
    5.6 nm after 300 hours wet cycle

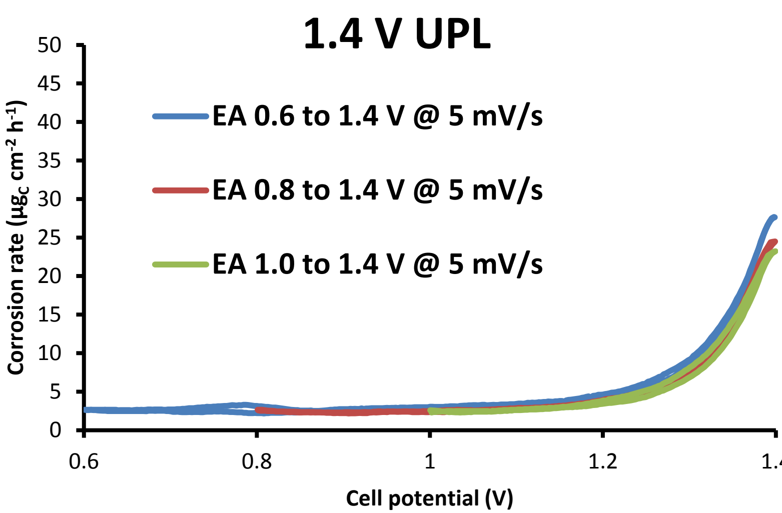
Catalyst	AST 30000 Cycles	Drive Cycle 30000 cycles
C510.2	53.80%	53.7%, 54.3%
C510.4	46.3%, 46.8%	46.60%

Carbon corrosion at low potentials

Accomplishments /Progress







Significant carbon corrosion observed @ 0.9 V for high surface area carbon

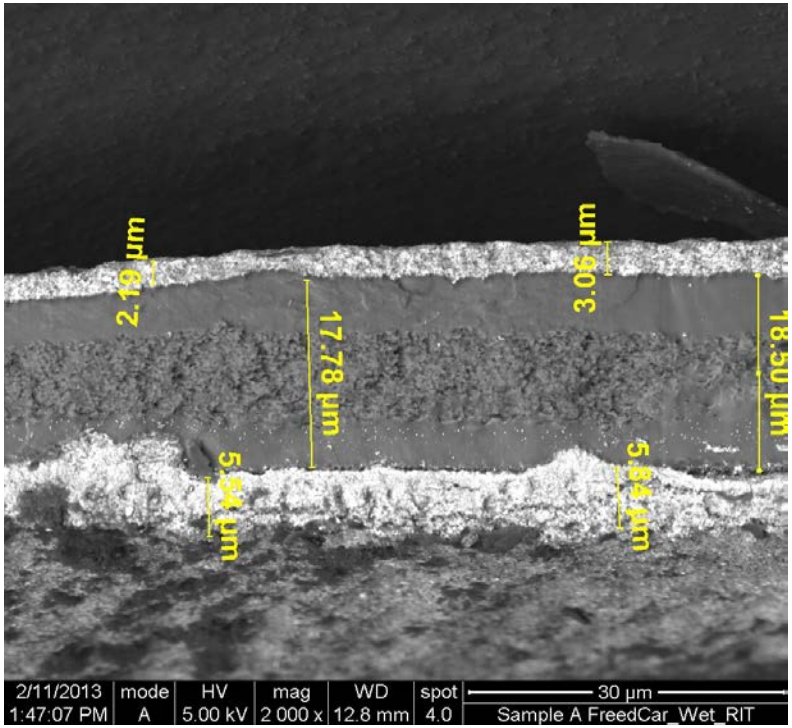
Corrosion can be significantly accelerated using higher upper potentials and cycling instead of holds

FCTT adopting 1 – 1.5 V cycling

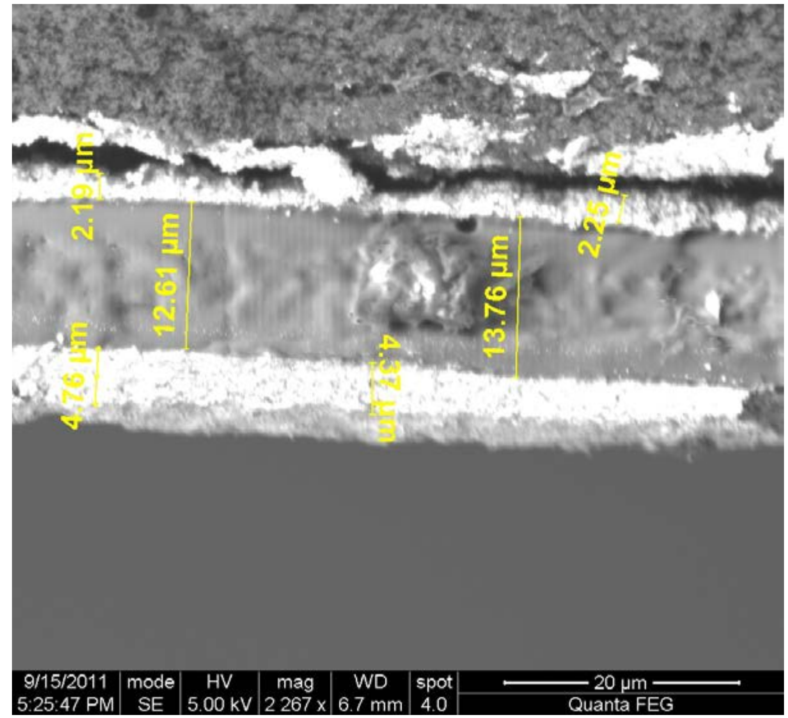
Drive Cycle: Catalyst degradation (HSAC)

HSAC : High surface area carbon

860 hrs wet drive cycle



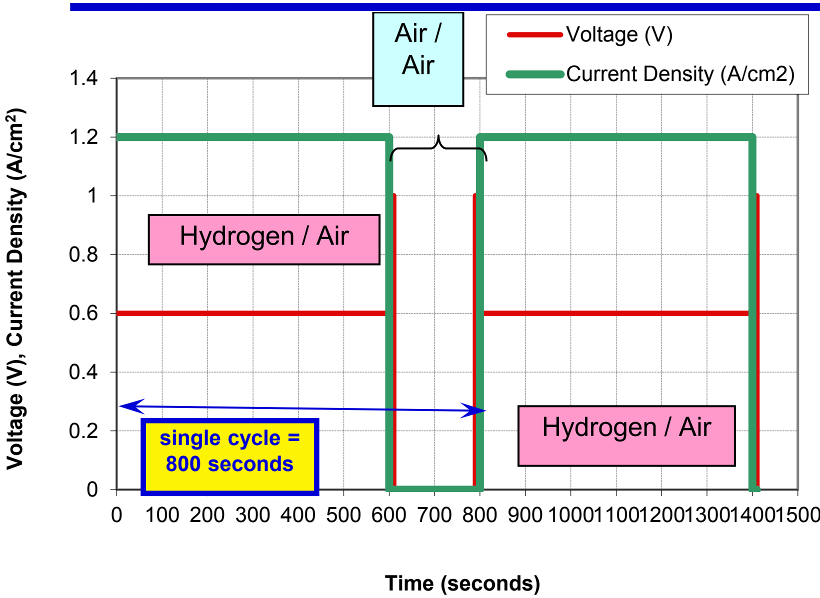
1224 hrs wet drive cycle

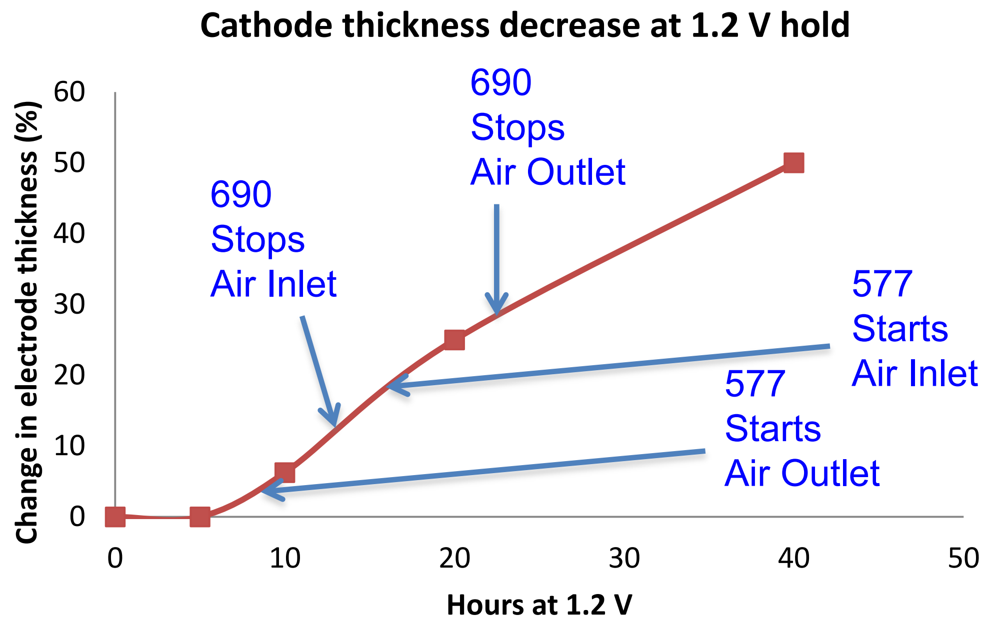


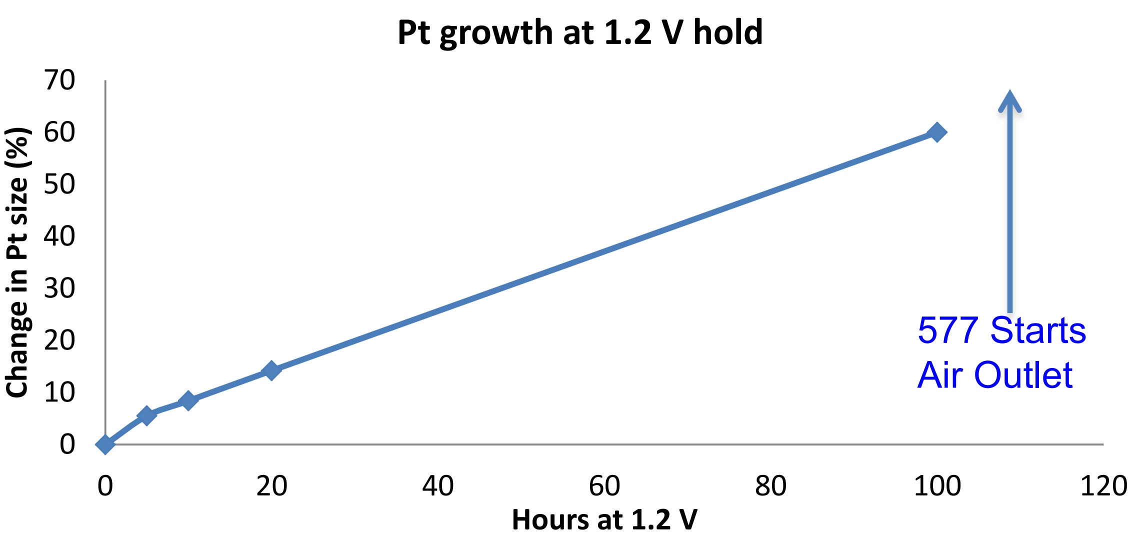
Pt band observed on cathode side of MEA. Band clearly visible after 2000 hours with high (0.4 mg.Pt/cm^2) loaded catalyst

860 hours results in 10% thinning of catalyst layer, 1200 hours results in 25 % thinning and 2000+ hours in 50% thinning

Carbon Corrosion : Correlations

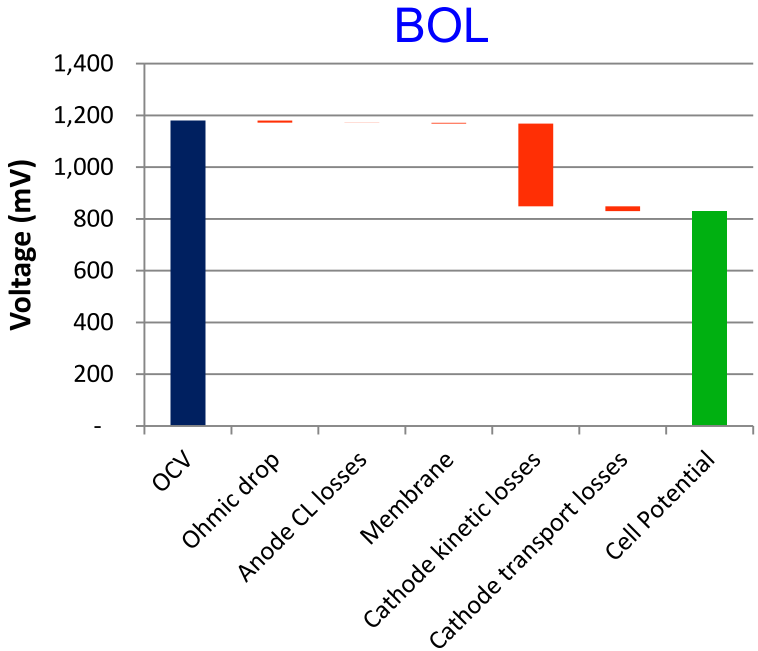


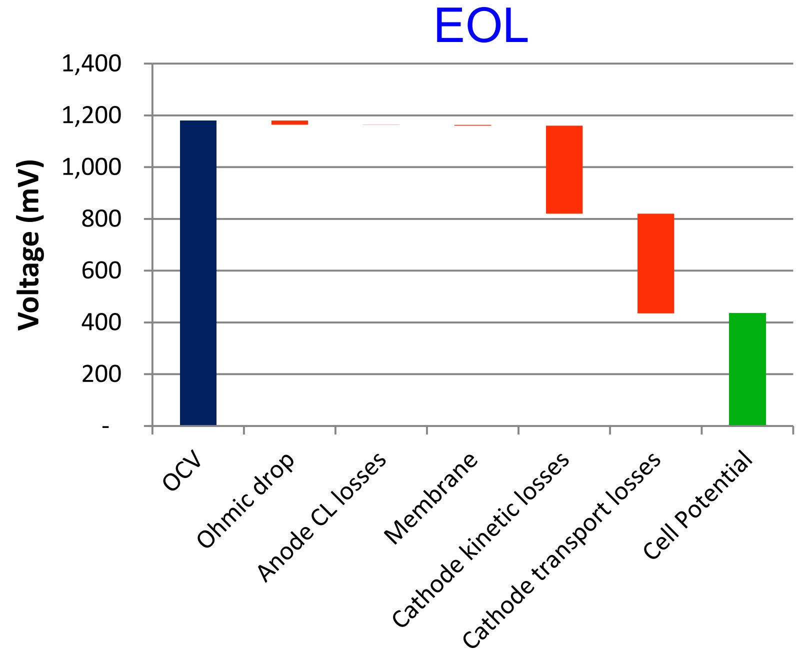


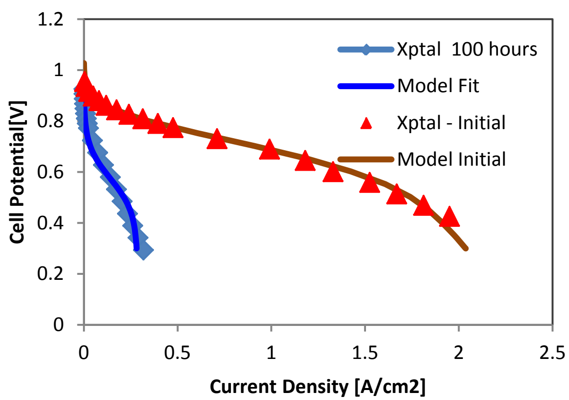


- Large spatial variations in corrosion due to start/stop
- Longer times at air/air potential results in greater corrosion
- Pt particle size growth much larger during start/stop tests.

Voltage loss Breakdown Analysis

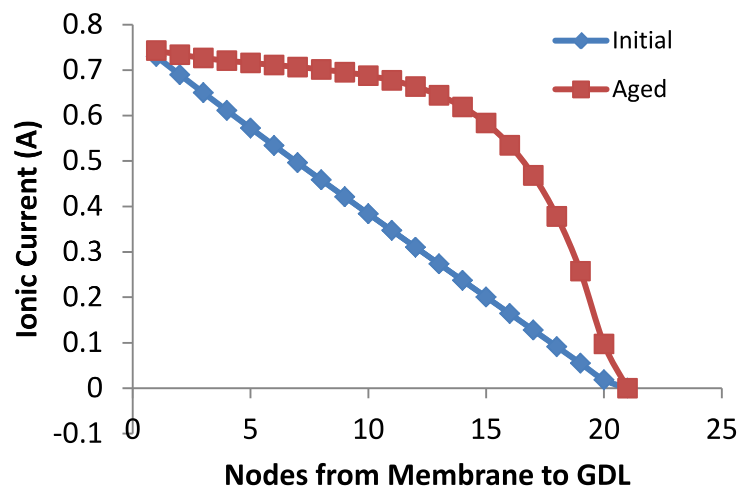






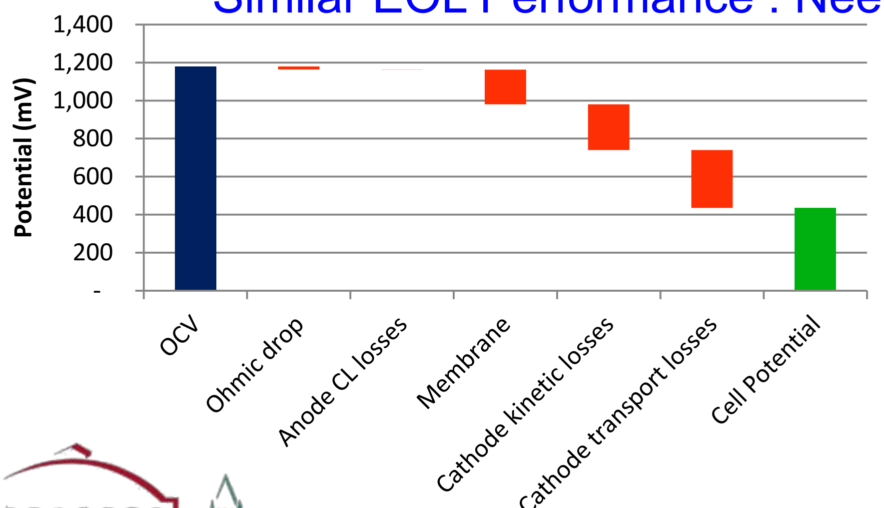
- LBNL modeling used for VLB
- Catalyst coarsening causes slight increase in cathode kinetic loses
- Little Ohmic changes
- Major loss is cathode transport losses consistent with collapse of cathode structure
- Will be compared with drive cycle testing using multiple catalyst layers to get statistical correlations

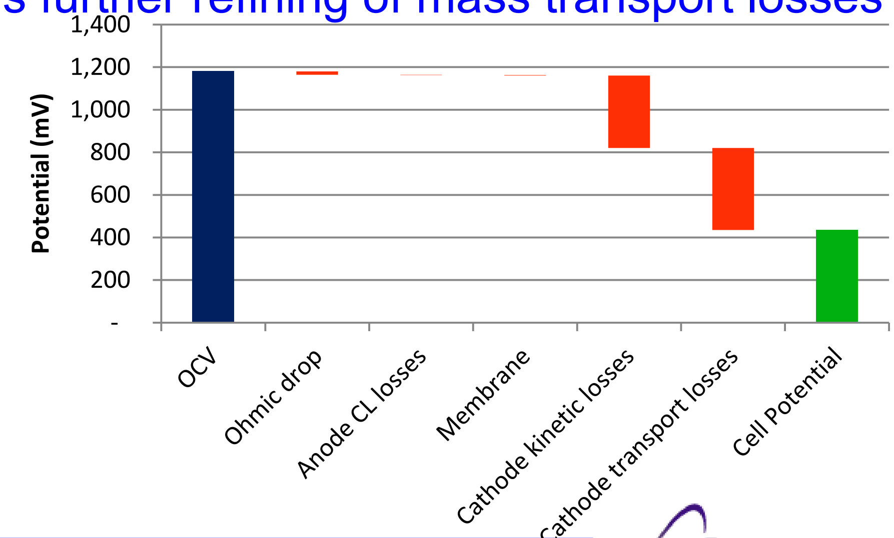
Voltage loss Breakdown Analysis



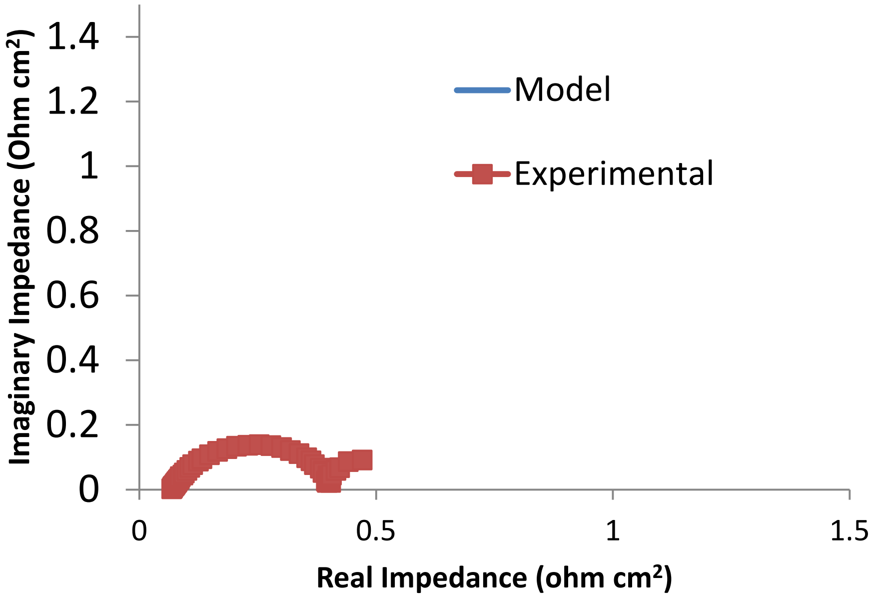
- Similar performance could be achieved for different distribution of resistance
- Manual supervision is required to allot appropriate weight to the various resistances
- Reaction distributions in the catalyst layers need adjustment
- Mass transport losses in ionomer, catalyst layer pores, GDL

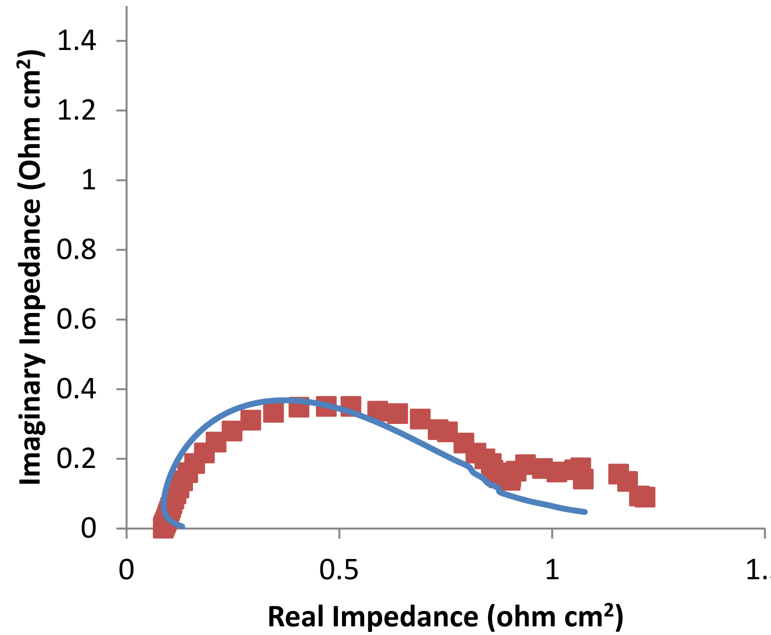
Similar EOL Performance : Needs further refining of mass transport losses





Voltage loss Breakdown Analysis

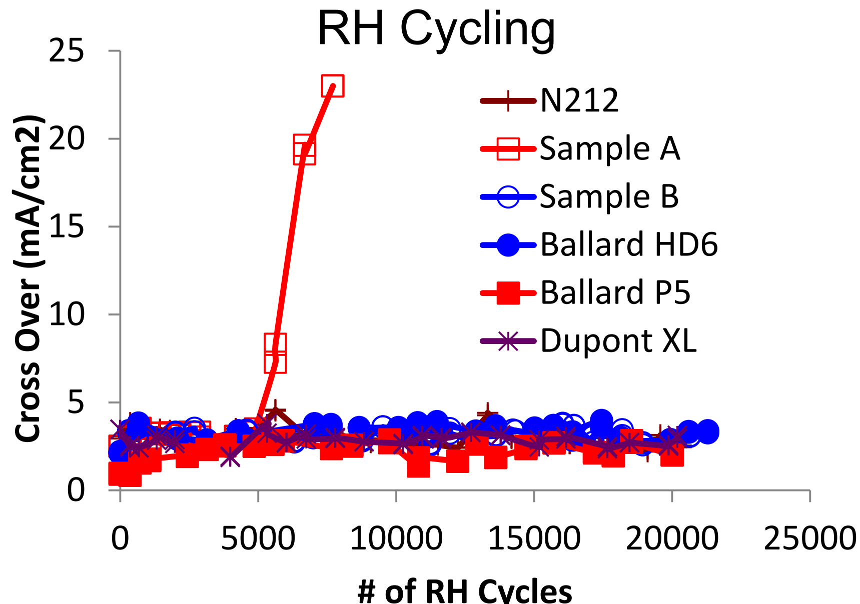


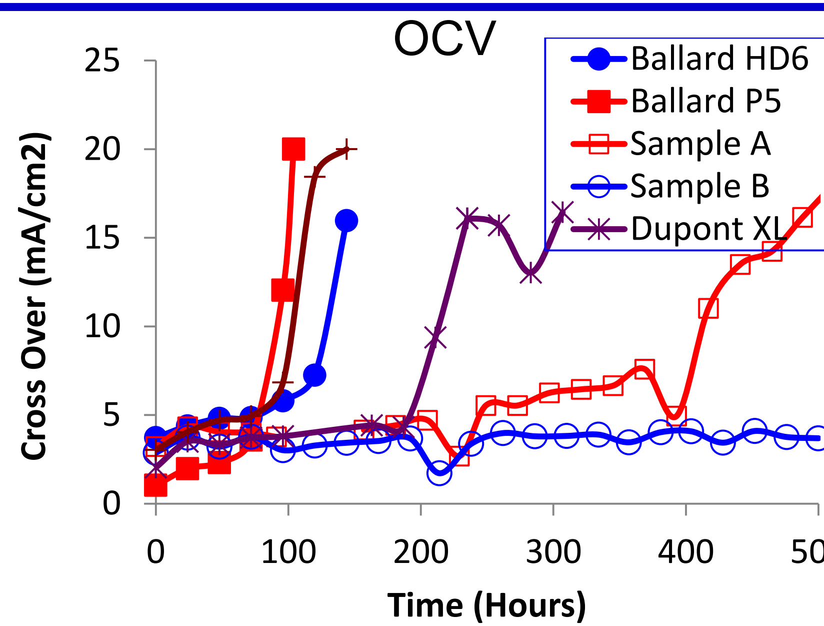


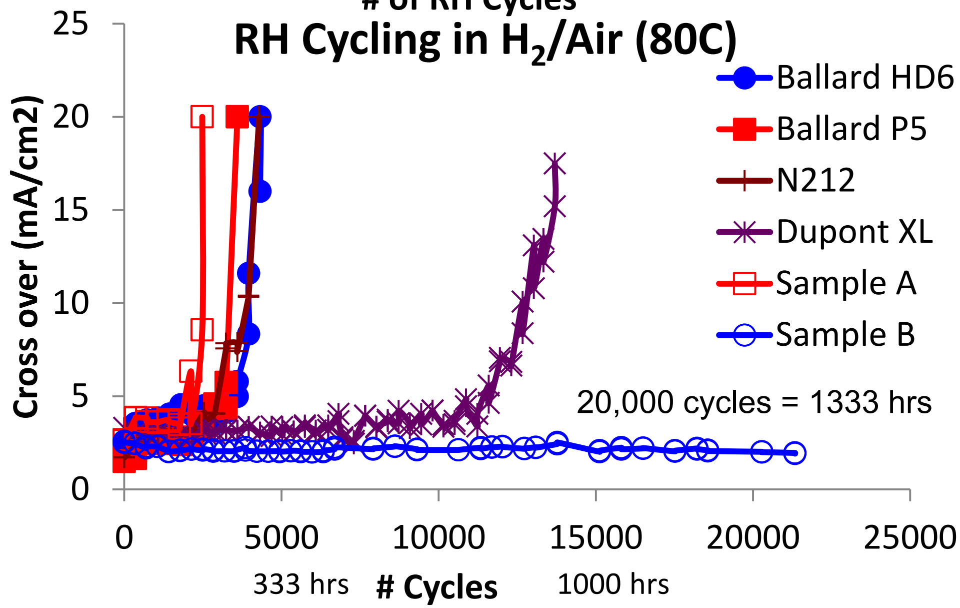
- Good agreement in the kinetic region
- The second capacitance loop is associated with channel effects
- Modeling impedance gives an accurate determination of individual resistance
- Simultaneous fitting of Air and HelOx data at different current densities

Membrane ASTs

Accomplishments /Progress

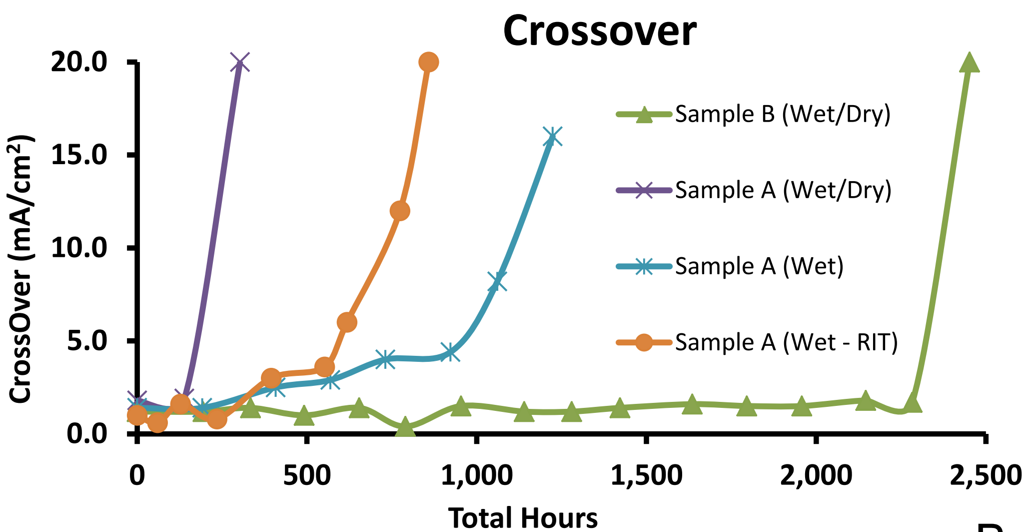






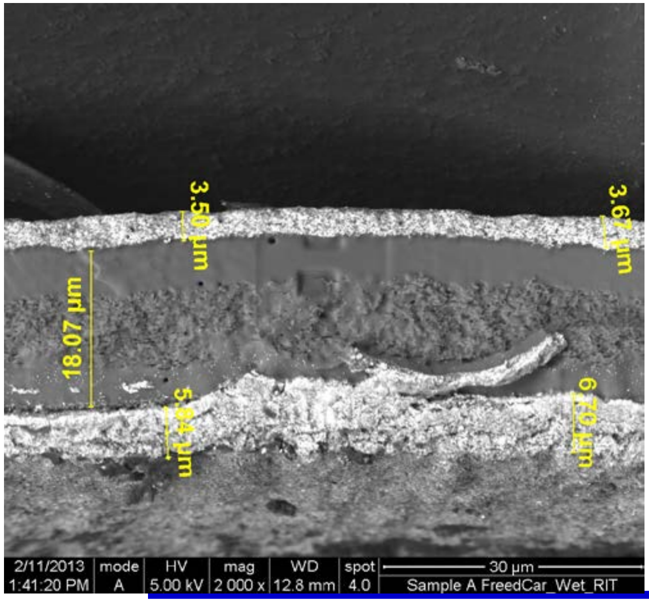
- RH cycling test does not have ability to distinguish between most PFSA membranes
- OCV testing too severe for bus applications
- Combined mechanical/chemical AST has ability to distinguish between MEAs, needs further acceleration.

Drive Cycle: Membrane failure modes

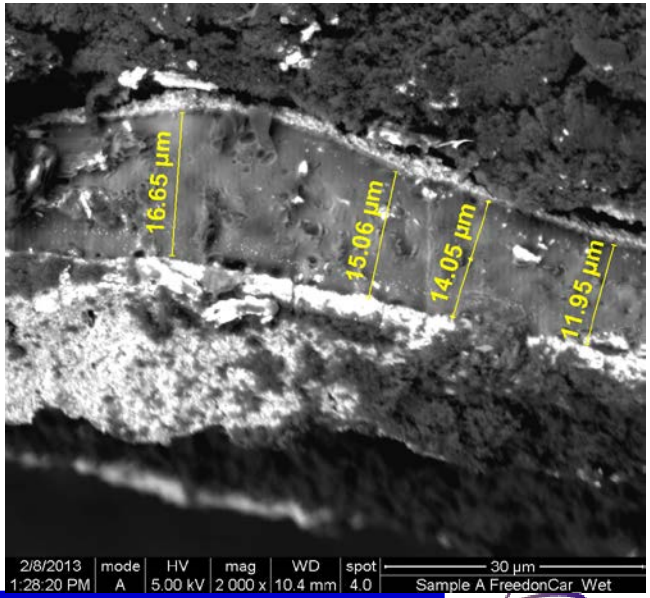


- Both Wet/Dry and Wet cycles result in crossover increases and membrane failure
  - Little thinning observed in membrane (< 10% to none)
  - Consistent with field data from buses
  - Not compatible with OCV AST.

Baseline: 850+ hours wet cycling

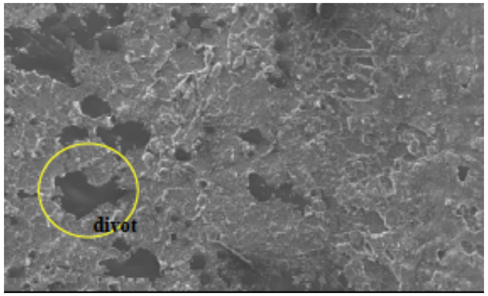


Baseline: 1200+ hours wet cycling

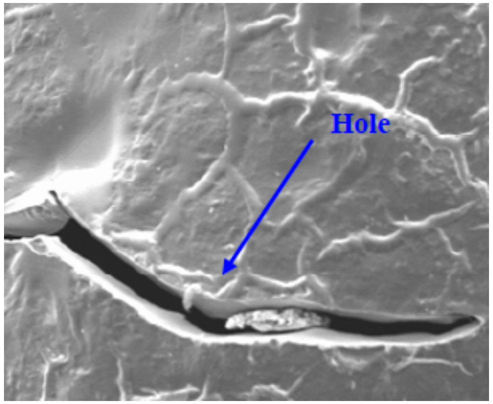


AST/Field correlation - Membrane

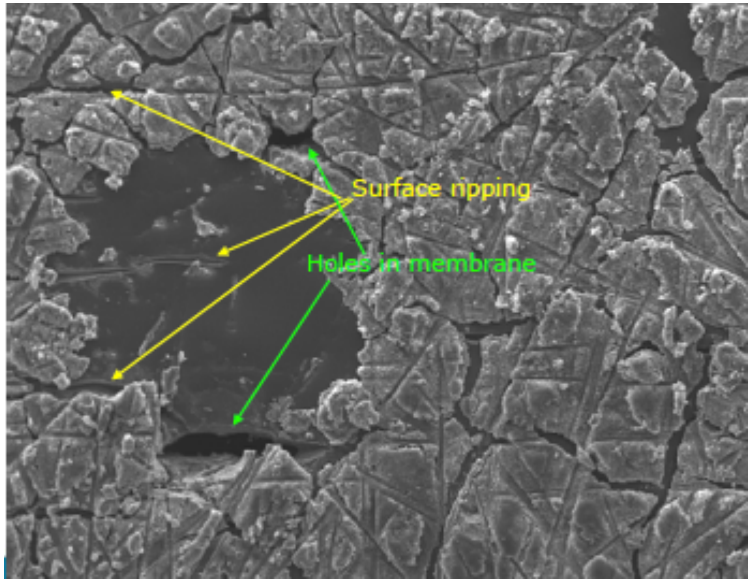
HD6 Field Sample

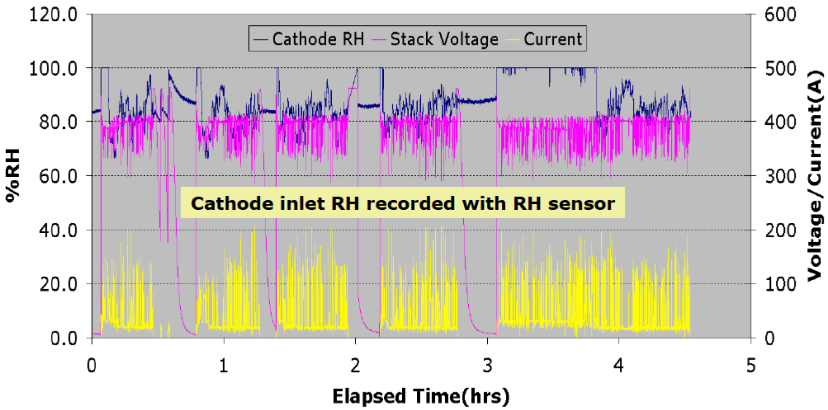


P5 Field Sample



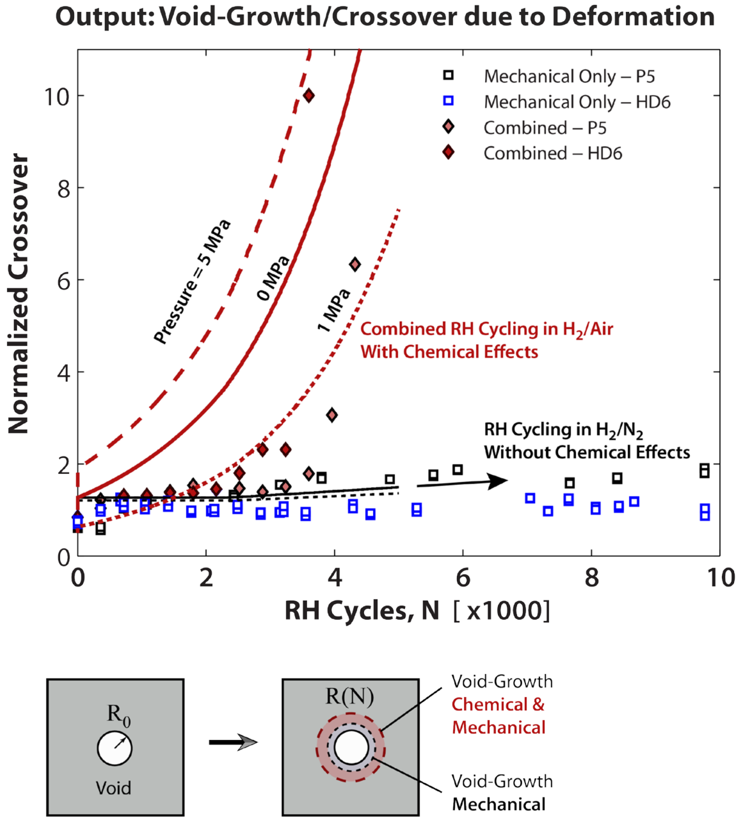
P5 sample after H_2/Air RH cycling AST





- RH cycling data being analyzed
- Membrane failure time decreases with increased time > 0.8 V
- Membrane failure time increases with increasing inlet RH

Membrane Degradation

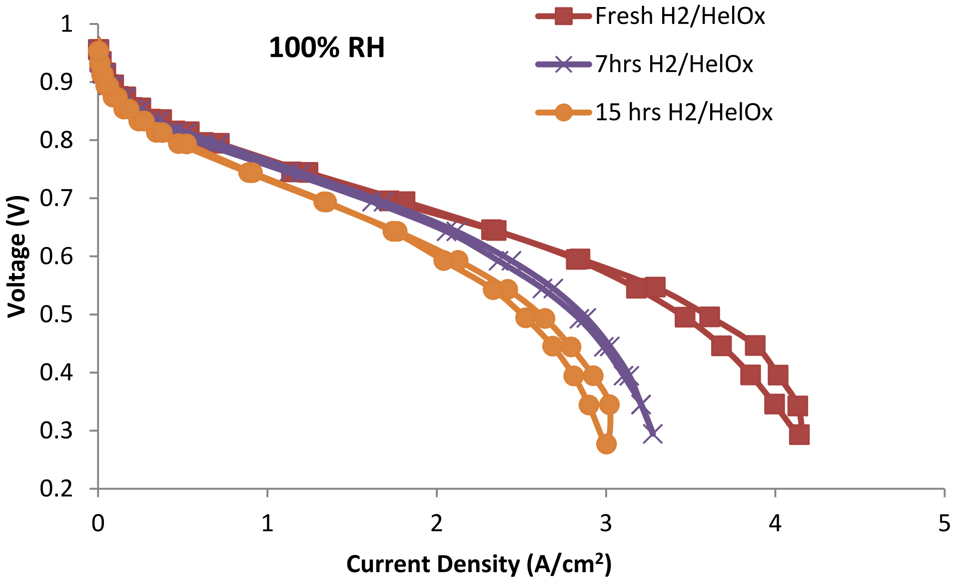


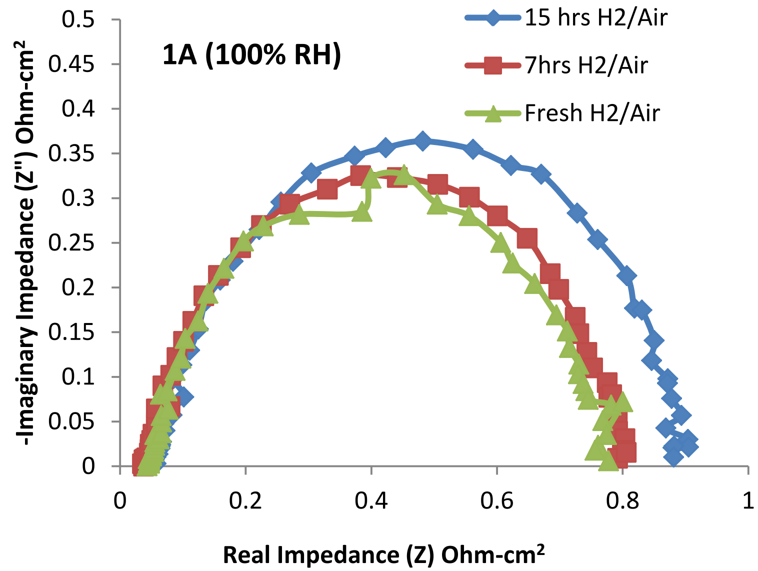
	vs. Field	
	Dry	**Liquid**
RH Cycling **Mechanical**	Different	**Similar**
Chemical AST	**Similar**	More Severe
RHC @ OCV **Mechanical / Chemical**	**Similar**	**Similar**

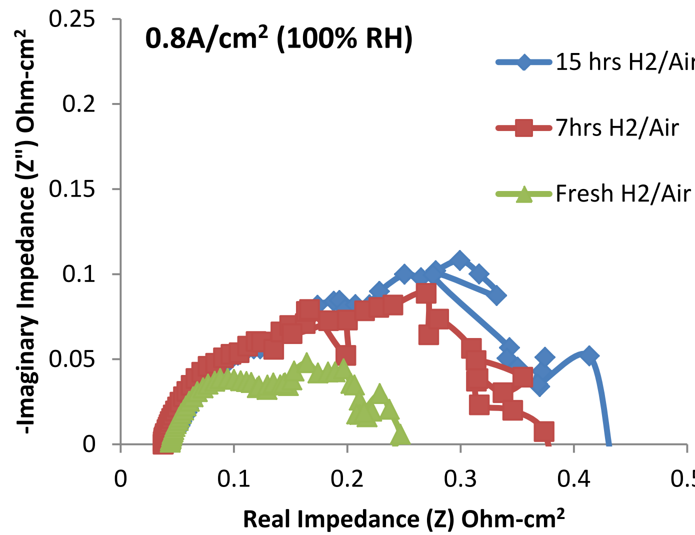
SAXS reveals similar membrane degradation in field samples as those aged under the combined mechanical/chemical cycle.

The OCV aging is too severe and the RH cycling is too benign.

Develop GDL AST







Collaborative development with UTC to examine observed field GDL degradation

GDLs aged at 95°C in 30% H_2O_2

(Original procedure from Decode project, Peter Wilde: SGL Carbon)

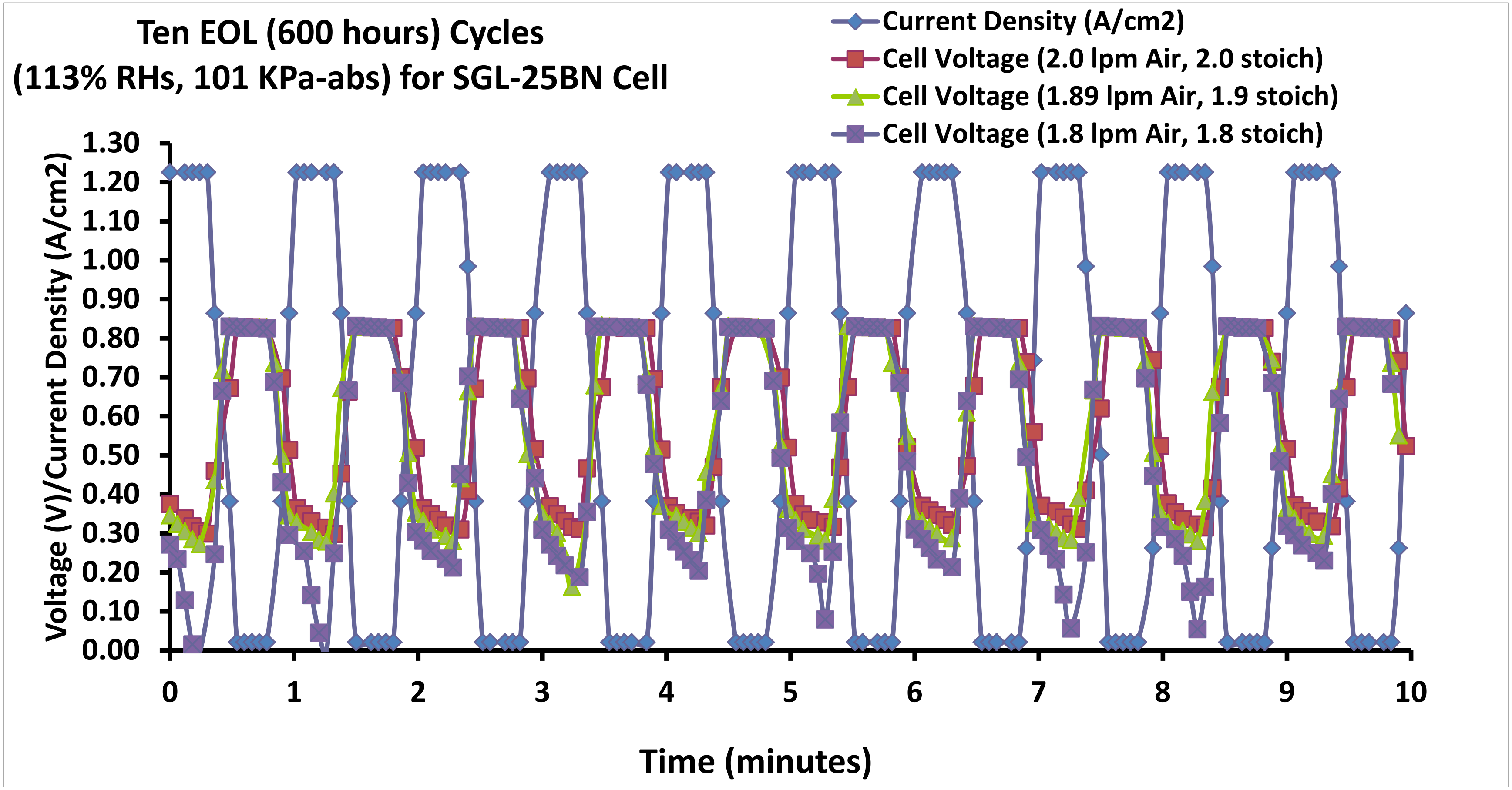
Simulates loss of hydrophobicity

Substrate pore volume increases

Low current/ low RH performance similar

Degradation in high current/high RH performance

Drive Cycle: GDL Failure mode



- Mass transport issues. Catalyst layer/GDL flooding
- Slightly higher flow rates can easily restore performance to almost BOL levels

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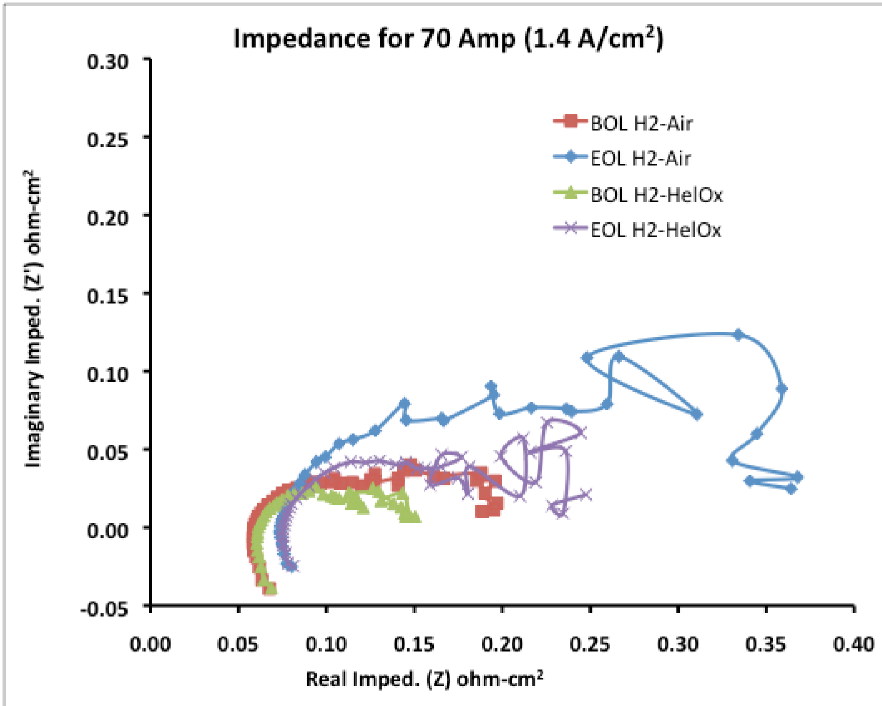
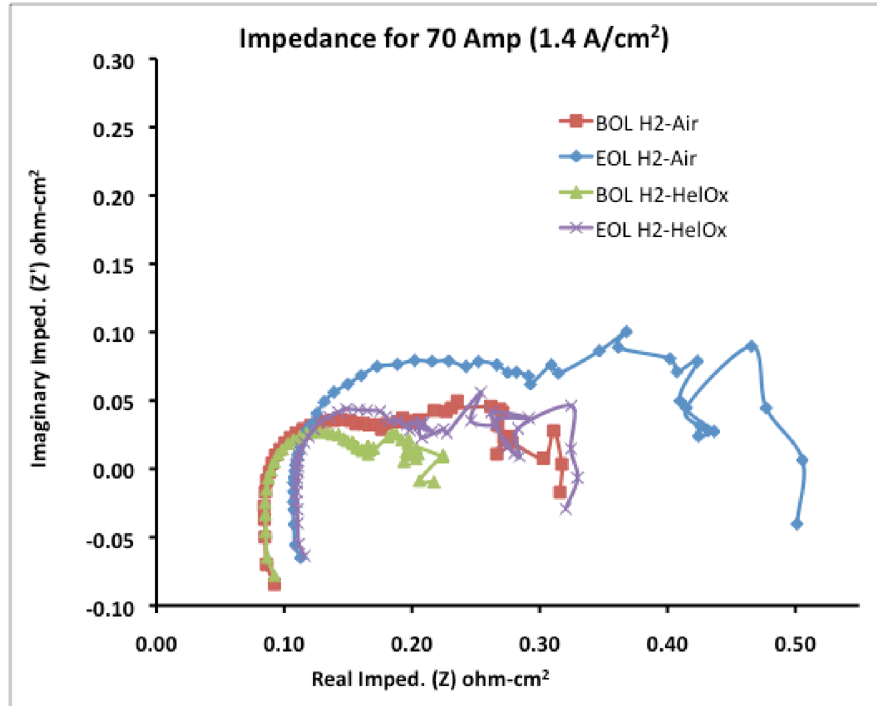
Mass transport losses : HSAC

HSAC : High surface area carbon

3040 hours of drive cycle



1224 hours of wet drive cycle

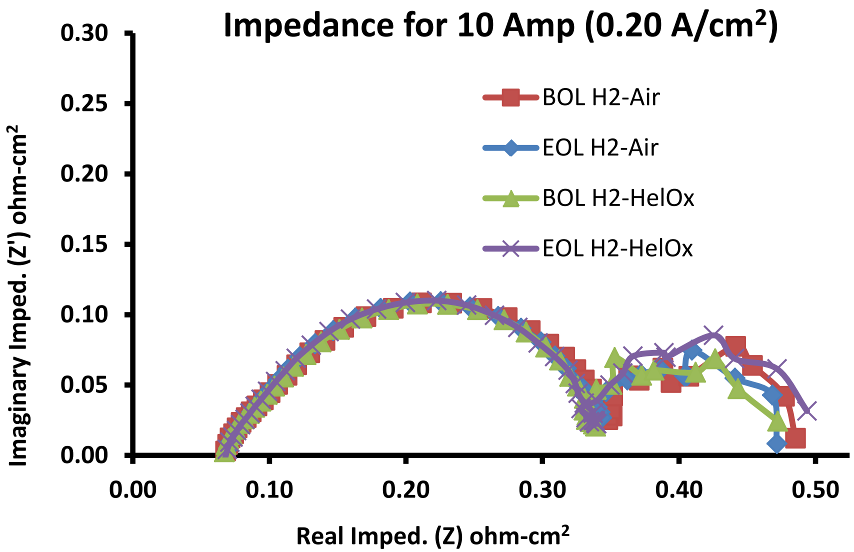


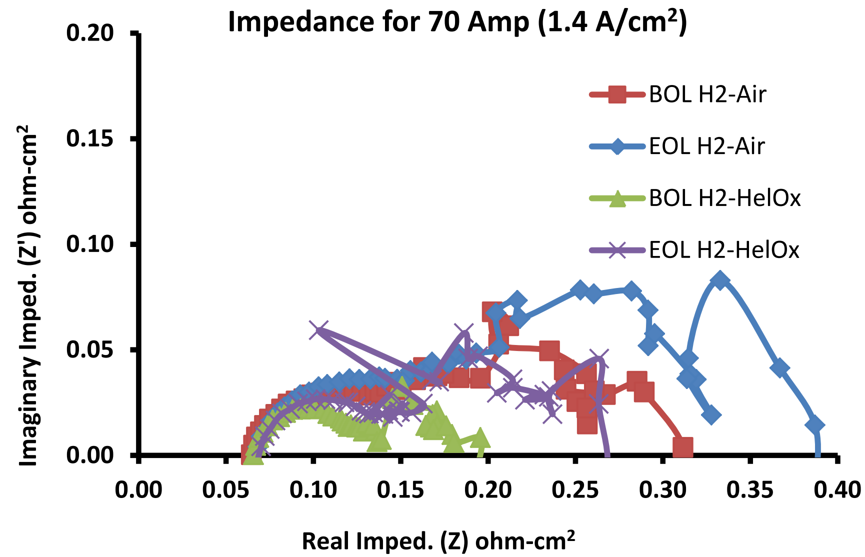
Significant increase in mass transport losses

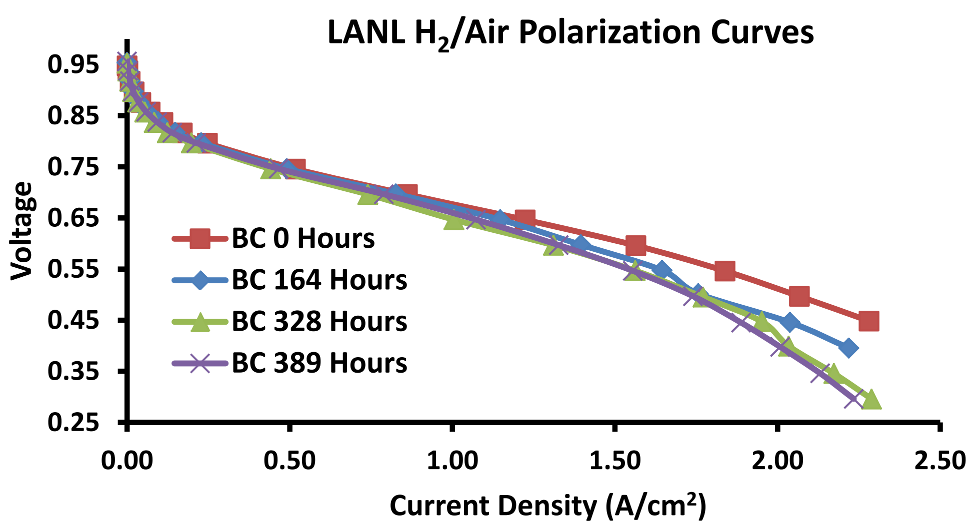
GDL degradation?
Difficult to de-couple catalyst layer effects

Mass transport losses : LSAC

LSAC : Low surface area carbon (Graphitized)







- Mass transport losses : Stopped Wet Drive cycle testing @ 382 hours. (Cannot sustain high currents, Cell Reversal)
- Little thinning observed.
- 30-35% ECSA loss with 80% increase in Pt particle size

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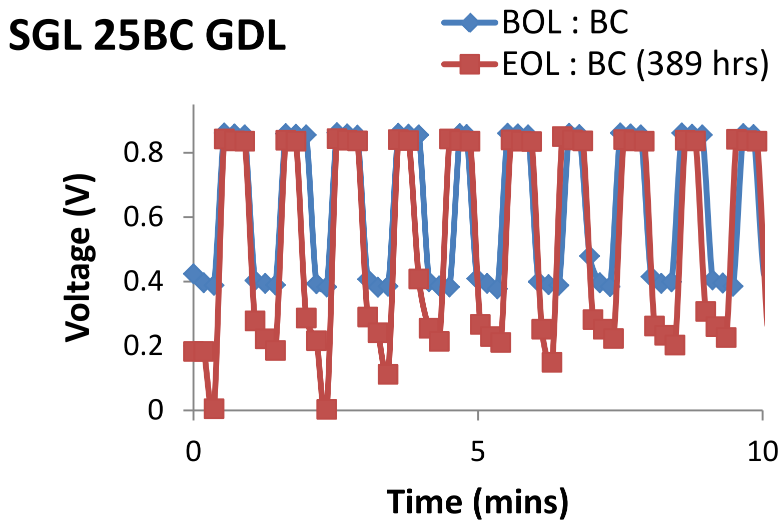
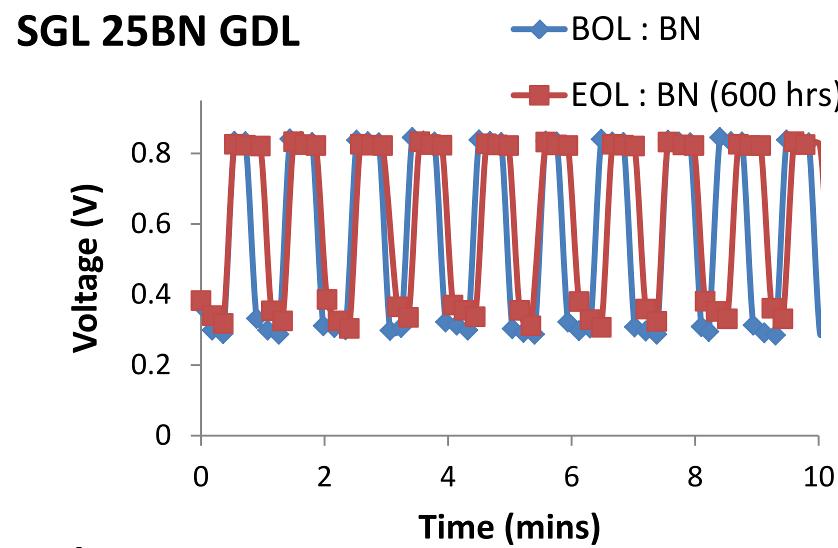
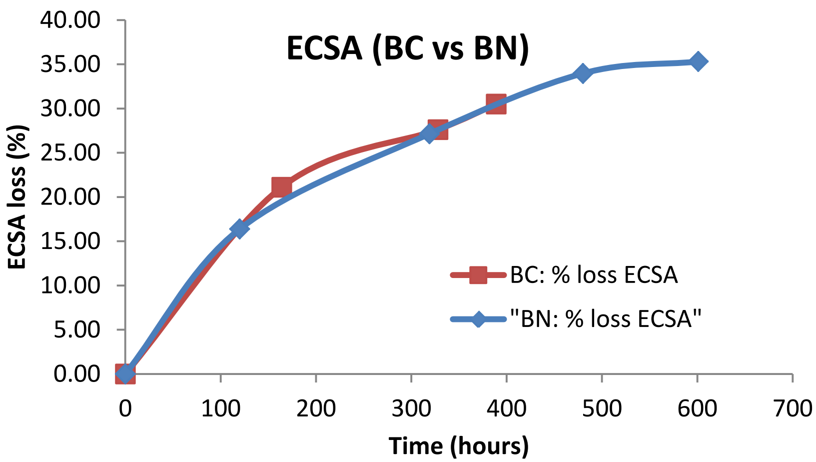
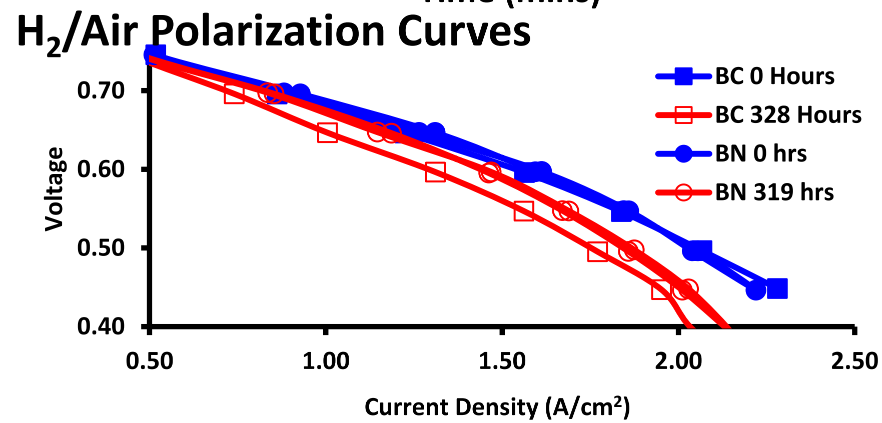
Drive Cycle Testing: Varying GDLs

Accomplishments /Progress









Same MEA: Similar Catalyst Degradation and ECSA loss

XPS confirms increase in C_xO_y peaks in aged GDLs (AST, Drive cycle, ex situ aged)

Collaborations

LANL (**Rangachary Mukundan, Rodney Borup, John Davey, David Langlois, Dennis Torraco, Roger Lujan, Dusan Spernjak, Joe Fairweather and Fernando Garzon)**

• Co-ordinate project; Perform all ASTs and Drive cycle testing; Materials Analysis of BOL and EOL materials

Ballard Power Systems (Paul Beattie, Greg James, Dana Ayota)

• Analyze Bus Data; Deliver BOL MEAs used in Buses; Analysis of MEAs

LBNL (Adam Weber, Siva Balasubramanian, Wonseok Yoon)

• Detailed Voltage loss break-down; Statistical correlation of materials properties to lifetimes and AST metric loss of materials with differing durabilities

Ion Power (Steve Grot)

Deliver MEAs with varying durability

ORNL (Mike Brady, Karren More)

Deliver metal bipolar plates/TEM

W. L. Gore and Associates Inc., and SGL Carbon (materials suppliers)

Durability working group (Start/Stop protocol)

Nancy University (Start/Stop segmented cell testing)

Olivier Lottin (PI)

Summary/Future Work - I

- Initial AST (electrocatalyst, catalyst support, membrane chemical and mechanical) performed
  - Baseline materials from W.L. Gore, P5 and HD6 and Ion Power MEAs with three different catalyst supports
  - Failure analysis from all ASTs
- Bus Data analysis completed on P5 and HD6 bus stacks
  - Data on number of RH cycles and potential cycles from the buses are being analyzed
- Automotive drive cycle (FCTT) testing in progress on GM-RIT and quad-serpentine hardware
  - Baseline materials completed
  - Ion Power materials initiated.
  - GDL degradation issues have been addressed (need to be quantified)
  - Start/Stop will not be incorporated in drive cycle. The Durability Working Group protocol for start/stop is being studied separately.

Summary/Future Work - II

- Start/Stops performed at Nancy University
  - Large spatial variations make average correlations difficult
  - Extremes will be studied
- Voltage loss break down modeling being refined
  - Down the channel effects being added to simultaneously fit impedance data
  - Models to be refined for better fit at > 1 A/cm^2 (GDL transport)
- NEW ASTs
  - GDL AST proposed. Surface oxidation of carbon observed in all samples. Degradation mechanism similar in drive cycle, AST and ex situ samples
  - Membrane mechanical/chemical AST found to reliably simulate field and drive cycle failure modes
  - 1 to 1.5 V carbon corrosion AST to be evaluated
- Compile all data in a Web site in addition to publications

Acknowledgements

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(DOE – EERE – Fuel Cell Technologies – Technology Development Manager)
Dimitrios Papageorgopoulos

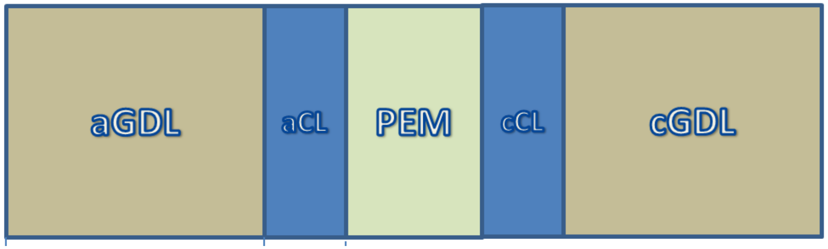
Fuel Cell Tech Team (Craig Gittleman, Jim Waldecker and Balsu Lakshmanan) for guidance on ASTs

W. L. Gore and Associates (MEAs)

SGL Carbon (GDLs)

Technical Backup Slides

1-D simplified model



- The model is 1-D, steady state
- Add in transient terms to do impedance

$$x_i = \bar{x}_i + \mathrm{Re}\{\tilde{x}_i \exp(j\omega t)\}$$

Steady-state solution Complex function

$$Z = \frac{\tilde{V}}{\tilde{i}}$$

- Model is updated and leveraged from work in other LBNL projects
- Fitting parameters depend on AST, but are typically effective transport coefficients, surface area (if not measured), *etc.*

- Catalyst layer
  - Agglomerate model using Pt-oxide coverage terms and ionomer film

    Yoon and Weber JES **158**, B1007
  - Gas transport mainly by Knudsen diffusion
- Diffusion media
  - Stefan-Maxwell diffusion
  - Liquid water with Darcy's law
  - Use capillary pressure and contact-angle distribution model

    Weber JPS 195, 5292
    - This is being reevaluated
- Membrane
  - LBNL chemical-potential approach

Weber and Newman, in *Device and Materials Modeling in PEM Fuel Cells*, Paddison and Promislow, Eds., Springer, 157-198 (2009).

1-D simplified model

Inputs

- Operating/test conditions
- Cyclic voltammetry (active area)
- Electrochemical impedance
- Polarization curve

Model

- 1-D simple model
- Modify to calculate/fit EIS profiles and polarization curves using physical equations
- Fit parameters to data

Outputs

- VLB
- Sensitivity to model fit parameters
- Look for controlling dimensionless groups

$$
\begin{vmatrix}
1 & 0 & 0 & 0 \\
\dfrac{\partial f_2}{\partial i_f} & -1 & \dfrac{\partial f_2}{\partial c_i} & \dfrac{\partial f_2}{\partial \gamma_k} \\
\dfrac{\partial f_3}{\partial i_f} & \dfrac{\partial f_3}{\partial V} & -1 & \dfrac{\partial f_3}{\partial \gamma_k} \\
\dfrac{\partial f_4}{\partial i_f} & \dfrac{\partial f_4}{\partial V} & \dfrac{\partial f_4}{\partial c_i} & -1
\end{vmatrix}
\bullet
\begin{vmatrix} \tilde{i}_f \\ \tilde{V} \\ \tilde{c}_i \\ \tilde{\gamma}_k \end{vmatrix}
=
\begin{vmatrix} \tilde{i}_f \\ 0 \\ 0 \\ 0 \end{vmatrix}
$$

$$\tilde{x}_i = \tilde{x}_i^{\mathrm{Re}} + j.\tilde{x}_i^{\mathrm{Im}}$$

$$
\begin{vmatrix} J^{\mathrm{Re}} & -J^{\mathrm{Im}} \\ J^{\mathrm{Im}} & J^{\mathrm{Re}} \end{vmatrix}
\bullet
\begin{vmatrix} \tilde{x}_i^{\mathrm{Re}} \\ \tilde{x}_i^{\mathrm{Im}} \end{vmatrix}
=
\begin{vmatrix} G^{\mathrm{Re}} \\ G^{\mathrm{Im}} \end{vmatrix}
$$

- Jacobian matrix from the steady state model is used to estimate the impedance in the frequency domain

Tech Team Protocol (Pt Catalyst)

Table 1
Electrocatalyst Cycle and Metrics
Table revised March 2, 2010

Cycle	Triangle sweep cycle: 50 mV/s between 0.6 V and 1.0 V. Single cell 25-50 cm^2	
Number	30,000 cycles	
Cycle time	16 s	
Temperature	80°C	
Relative Humidity	Anode/Cathode 100/100%	
Fuel/Oxidant	Hydrogen/N_2 (H_2 at 200 sccm and N_2 at 75 sccm for a 50 cm^2 cell	
Pressure	Atmospheric pressure	
Metric	**Frequency**	**Target**
Catalytic Mass Activity*	At Beginning and End of Test minimum	$\leq$40% loss of initial catalytic activity
Polarization curve from 0 to $\geq$1.5 A/cm^2**	After 0, 1k, 5k, 10k, and 30k cycles	$\leq$30 mV loss at 0.8 A/cm^2
ECSA/Cyclic Voltammetry***	After 10, 100, 1k, 3k, 10k, 20k and 30k cycles	$\leq$40% loss of initial area

* Mass activity in A/mg @ 150 kPa abs backpressure at 857 mV iR-corrected on 6% H_2 (bal N_2)/O_2 {or equivalent thermodynamic potential}, 100%RH, 80°C normalized to initial mass of catalyst and measured before and after test.

** Polarization curve per Fuel Cell Tech Team Polarization Protocol in Table 5.

*** Sweep from 0.05 to 0.6V at 20mV/s, 80°C, 100% RH.

Tech Team Protocol (Catalyst Support)

Table 2
Catalyst Support Cycle and Metrics
Table revised March 2, 2010

Cycle	Hold at 1.2 V for 24 h; run polarization curve and ECSA; repeat for total 400 h. Single cell 25-50 cm^2	
Total time	Continuous operation for 400 h	
Diagnostic frequency	24 h	
Temperature	80°C	
Relative Humidity	Anode/Cathode 100/100%	
Fuel/Oxidant	Hydrogen/Nitrogen	
Pressure	150 kPa absolute	
Metric	**Frequency**	**Target**
Catalytic Activity*	Every 24 h	$\leq$40% loss of initial catalytic activity
Polarization curve from 0 to $\geq$1.5 A/cm^2**	Every 24 h	$\leq$30 mV loss at 1.5 A/cm^2 or rated power
ECSA/Cyclic Voltammetry***	Every 24 h	$\leq$40% loss of initial area

* Mass activity in A/mg @ 150 kPa abs backpressure at 857 mV iR-corrected on 6% H_2 (bal N_2)/O_2 {or equivalent thermodynamic potential}, 100%RH, 80°C normalized to initial mass of catalyst and measured before and after test.
** Polarization curve per Fuel Cell Tech Team Polarization Protocol in Table 5
*** Sweep from 0.05 to 0.6V at 20mV/s, 80°C, 100% RH.

Tech Team Protocol (Membrane/Chemical)

Table 3 MEA Chemical Stability and Metrics Table revised December 10, 2009		
Test Condition	**Steady state OCV, single cell 25-50 cm^2**	
Total time	500 h	
Temperature	90°C	
Relative Humidity	Anode/Cathode 30/30%	
Fuel/Oxidant	Hydrogen/Air at stoics of 10/10 at 0.2 A/cm^2 equivalent flow	
Pressure, inlet kPa abs (bara)	Anode 150 (1.5), Cathode 150 (1.5)	
Metric	**Frequency**	**Target**
F^- release or equivalent for non-fluorine membranes	At least every 24 h	No target – for monitoring
Hydrogen Crossover (mA/cm^2)*	Every 24 h	$\leq$2 mA/cm^2
OCV	Continuous	$\leq$20% loss in OCV
High-frequency resistance	Every 24 h at 0.2 A/cm^2	No target – for monitoring
Shorting resistance**	Every 24 h	>1,000 ohm cm^2

* Crossover current per USFCC "Single Cell Test Protocol" Section A3-2, electrochemical hydrogen crossover method.

** Measured at 0.5V applied potential, 80°C and 100% RH N_2/N_2. Compression to 20% strain on the GDL.

Los Alamos

Tech Team Protocol (Membrane/Mechanical)

Table 4 **Membrane Mechanical Cycle and Metrics** **(Test using a MEA)** **Table revised December 10, 2009**		
Cycle	**0% RH (2 min) to 90°C dewpoint (2 min), single cell 25-50 cm^2**	
Total time	Until crossover >2 mA/cm^2 or 20,000 cycles	
Temperature	80°C	
Relative Humidity	Cycle from 0% RH (2 min) to 90°C dewpoint (2 min)	
Fuel/Oxidant	Air/Air at 2 SLPM on both sides	
Pressure	Ambient or no back-pressure	
Metric	**Frequency**	**Target**
Crossover*	Every 24 h	$\leq$2 mA/cm^2
Shorting resistance**	Every 24 h	>1,000 ohm cm^2

* Crossover current per USFCC "Single Cell Test Protocol" Section A3-2, electrochemical hydrogen crossover method.

** Measured at 0.5 V applied potential, 80°C and 100% RH N_2/N_2. Compression to 20% strain on the GDL.