# 2011 DOE Hydrogen Program Annual Merit Review

## *SPIRE*

*Sustained Power Intensity with Reduced Electrocatalyst*

(aka: Durability of Low Pt Fuel Cells Operating at High Power Density)

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Presenter: Olga Polevaya (PM)

Nuvera Fuel Cells

5/11/2011

FC014

# Overview

## Timeline

- Kick-Off: December, 2009
- Nuvera and DOE agreed on extending to 4-year program ending 09/30/2013
- 25% Complete (03/11/2011)

## Barriers

- Barriers addressed
  - Stack Durability with Cycling: **target: 5000hrs (2015)**
  - Stack Cost: **target: $15/kW (2015)**

## Budget

- $5.642M Total Project
  - $3.875M DOE Share
  - $1.767M Contractor Share
  - $975,000 National Labs
- $1.162M received through FY10
- $0.915M planned for FY11

## Partners

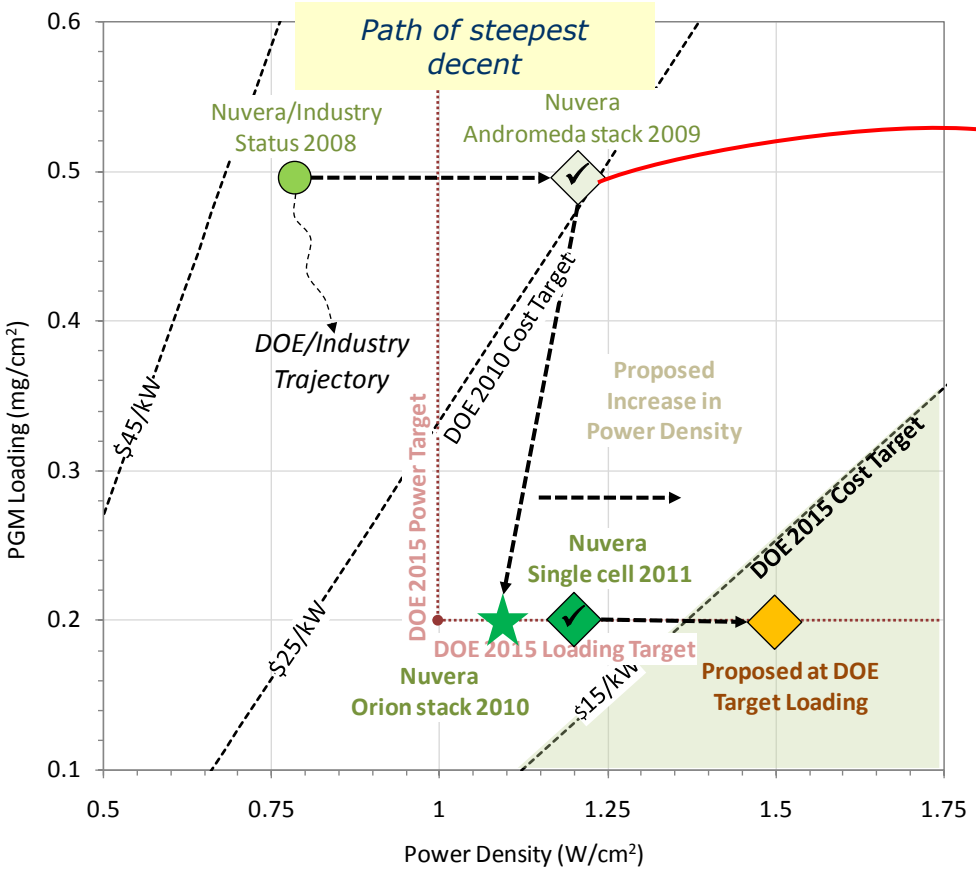
NUVERA FUEL CELLS

Argonne NATIONAL LABORATORY

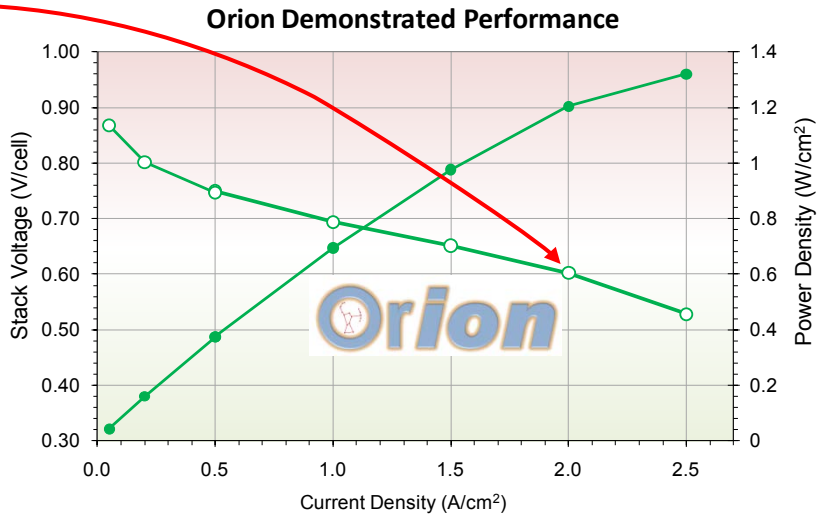
Los Alamos NATIONAL LABORATORY

# Relevance: Objective and Deliverables

**The technical objective is to identify and model PEMFC durability factors associated with low-Pt MEAs operating at high(>1W/cm²) power density.**




*Capable stack architecture*

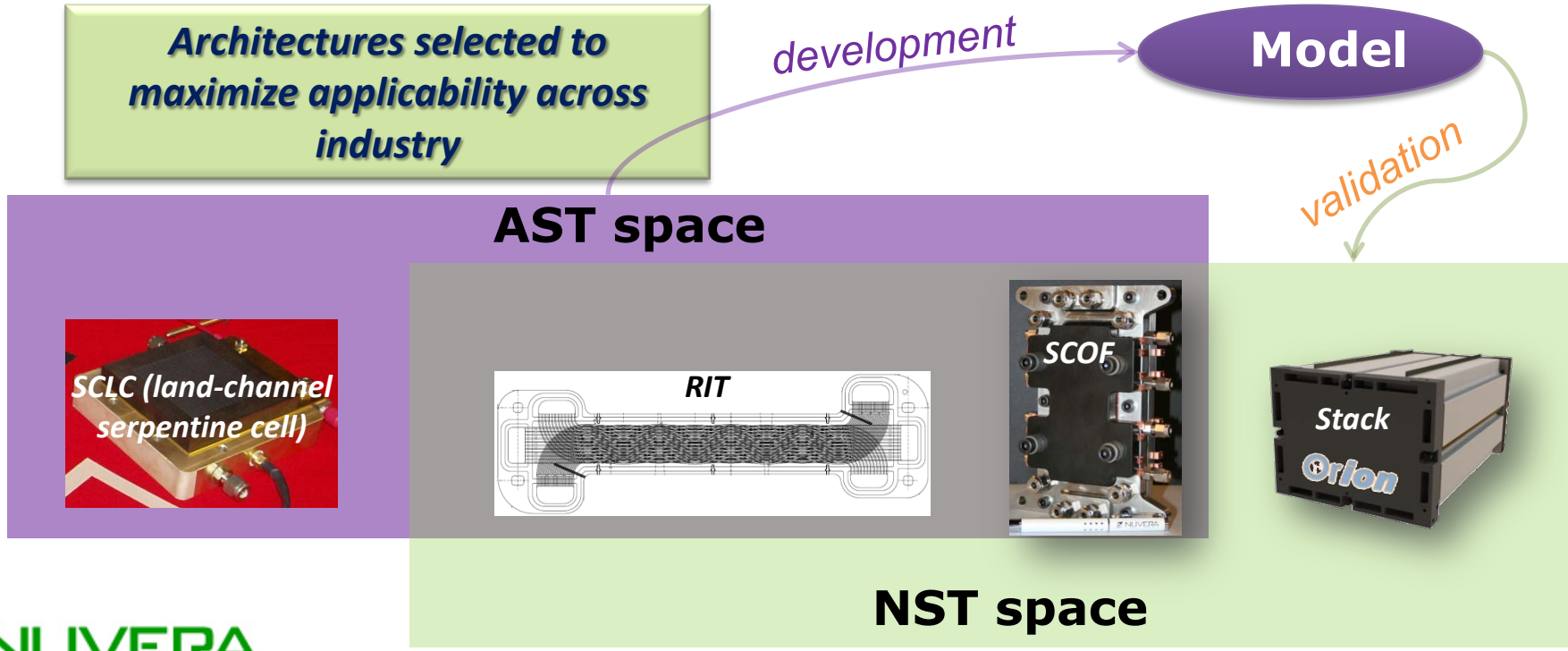



*Iso-cost curves fit to 2008 DTI results for 500k vehicles per year with 2015 technology.*

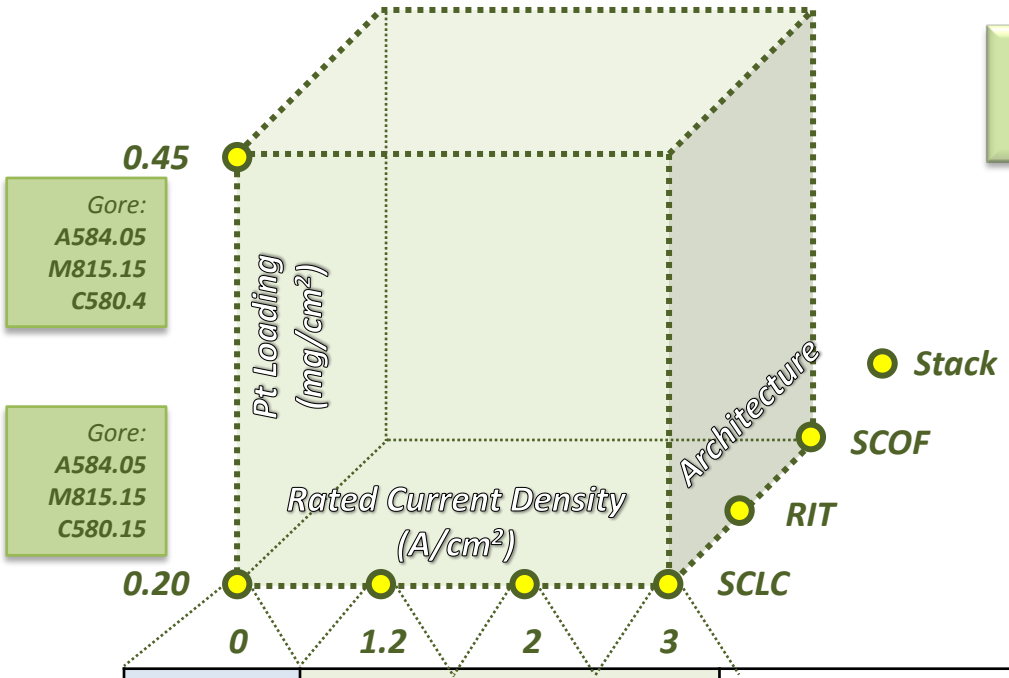
**The key deliverable of this program is a durability model experimentally validated over a range of stack technologies operating at high power**

# Approach

- SPIRE program balances modeling and experimentation.
  - Performance decay model is being developed based on ASTs across selected 50-cm$^2$ cell architectures.
  - Relevance of ASTs (component stressors) to NSTs (New Stress tests in fuel cell power mode) is studied in new high power density SCOF (Single Cell with Open Flowfield) cell.
  - Full-area stack testing used to validate the model results throughout NSTs.



# Technical Approach-Experimental Design

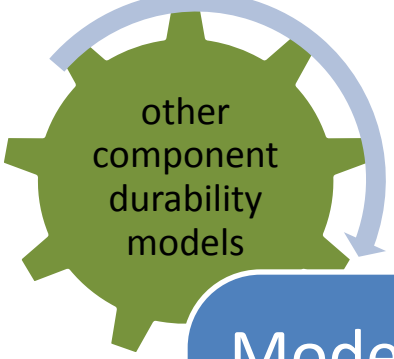



**9 ASTs and 22 NSTs are planned**
**~25% complete**

| AST | NST | | | Purpose |
|---|---|---|---|---|
| B1 | | N1A-2 | | Benchmarking electrode stability to potential cycles with and without current *B1* potential limits equivalent to N1A-2* |
| B1* | | | | |
| B4 | | N1B-2 | | Membrane mechanical stability with and without current |
| component_durability_may_2010.pdf | N2A-1 | N2A-2 | N2A-3 | FCTT combined load & humidity over range of RCD/ICD |
| | | N3A-2 | N3A-3 | Combined city/highway drive cycle over range of RCD/ICD |

| Test ID | Protocol ID | Architecture ID | Material ID | Test Location | Test status |
|---|---|---|---|---|---|
| TID-1 | B1 | SCLC | A | LANL | Completed |
| TID-2 | B1 | SCOF | A | LANL | In progress |
| TID-3 | B1 | SCLC | B | LANL | Completed |
| TID-4 | B4 | SCLC | A | LANL | Completed |
| TID-5 | B4 | SCOF | A | LANL | Not started |
| TID-6 | B4 | RIT | A | LANL | Not started |
| TID-7 | B1* | SCOF | A | LANL | Not started |
| TID-8 | B1* | SCLC | B | LANL | Completed |
| TID-9 | B1* | SCOF | B | LANL | Not started |
| TID-10 | N1A-2 | SCOF | A | Nuvera | In progress |
| TID-11 | N1A-2 | SCOF | B | Nuvera | In progress |
| TID-12 | N1A-2 | RIT | A | LANL | Not started |
| TID-13 | N1B-2 | SCOF | A | Nuvera | Not started |
| TID-14 | N1B-2 | SCOF | B | Nuvera | Not started |
| TID-15 | N1B-2 | RIT | A | LANL | Not started |
| TID-16 | N2A-1 | SCOF | A | LANL | Not started |
| TID-17 | N2A-1 | RIT | A | LANL | Not started |
| TID-18 | N2A-2 | SCOF | A | Nuvera | Not started |
| TID-19 | N2A-2 | SCOF | A | LANL | Not started |
| TID-20 | N2A-2 | Stack | A | Nuvera | Not started |
| TID-21 | N2A-3 | SCOF | A | Nuvera | Not started |
| TID-22 | N2A-1 | SCOF | B | LANL | Not started |
| TID-23 | N2A-1 | RIT | B | LANL | Not started |
| TID-24 | N2A-2 | SCOF | B | Nuvera | Not started |
| TID-25 | N2A-2 | SCOF | B | LANL | Not started |
| TID-26 | N2A-3 | SCOF | B | Nuvera | Not started |
| TID-27 | N3A-2 | Stack | A | Nuvera | Completed |
| TID-28 | N3A-2 | Stack | B | Nuvera | In progress |
| TID-29 | N3A-3 | Stack | A | Nuvera | Not started |
| TID-30 | N3A-3 | Stack | B | Nuvera | Not started |
| TID-31 | N2A-2 | Stack | B | Nuvera | Not started |

# Modeling Approach– Durability Model Framework




Model outputs: ECSA, PSD (particle size distribution), η (overpotentials), V(time, A/cm²)

Inputs
- Cell Architecture
- Use cycles
- ECP BOL

Validation on NST

Pt Electrode stability Model

Pt Ion Transport Model

AST B1 inputs

Pt Aqueous Kinetics

Oxide coverage

Pt ⇔ PtOx

Dissolution-Redeposition

Pt ⇔ $Pt^{2+}$

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- Pt wire
- Pt/C –Etek 0.5mg/cm²
- Pt/C – Gore C580.15

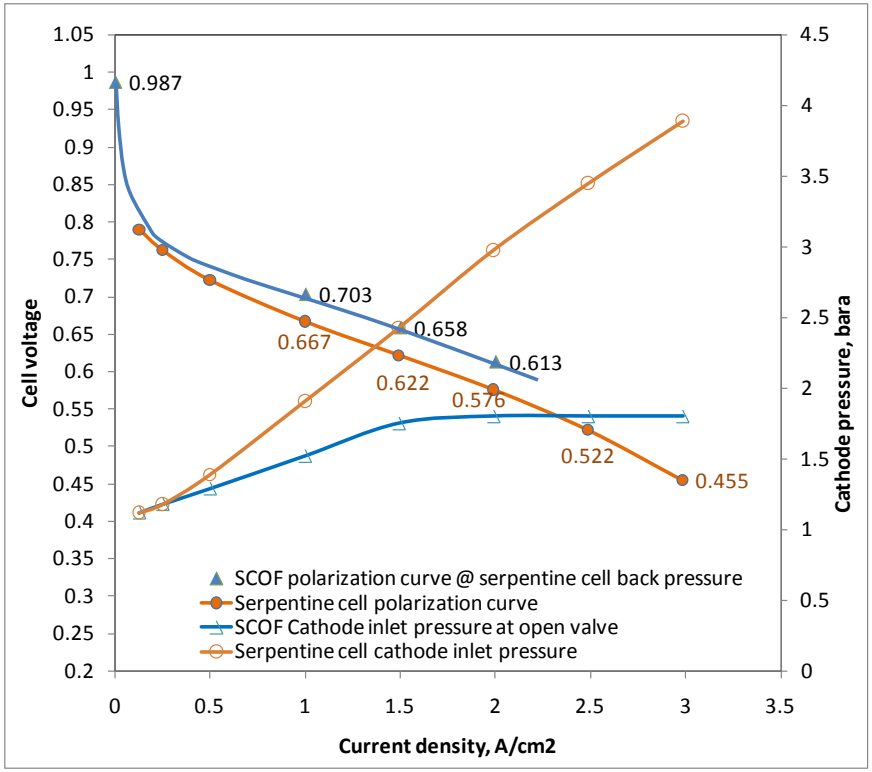
**Spire activities are synchronized with other DOE durability programs to avoid duplication of effort**

# Technical Progress – Milestones

| Milestone | Due date | Status |
|---|---|---|
| **1. Model Block diagram published.** | **FY2010, Q3** | **Complete** |
| **2. SCOF hardware validated and delivered to LANL.** | **FY2011, Q1** | **Complete** |
| 3. Comparative data for SCLC and SCOF on AST protocol is published | FY2011, Q3 | In progress |
| **GNG decision: Demonstrate durability results (voltage decay, diagnostic and post-test measures) in SCOF are consistent with full-area short stack testing using baseline operating conditions and materials.** | **FY2011, Q4** | **Moved to FY2012, Q1 with new 4-year plan** |
| 4. Model correlations to full-area test results published. | FY2012, Q1 | Moved to FY2012, Q4 with new 4-year plan |
| 5. Validated model and data set published and available to industry | FY2012, Q4 | Moved to FY2013, Q3 with new 4-year plan |

# Technical Progress – Single Cell

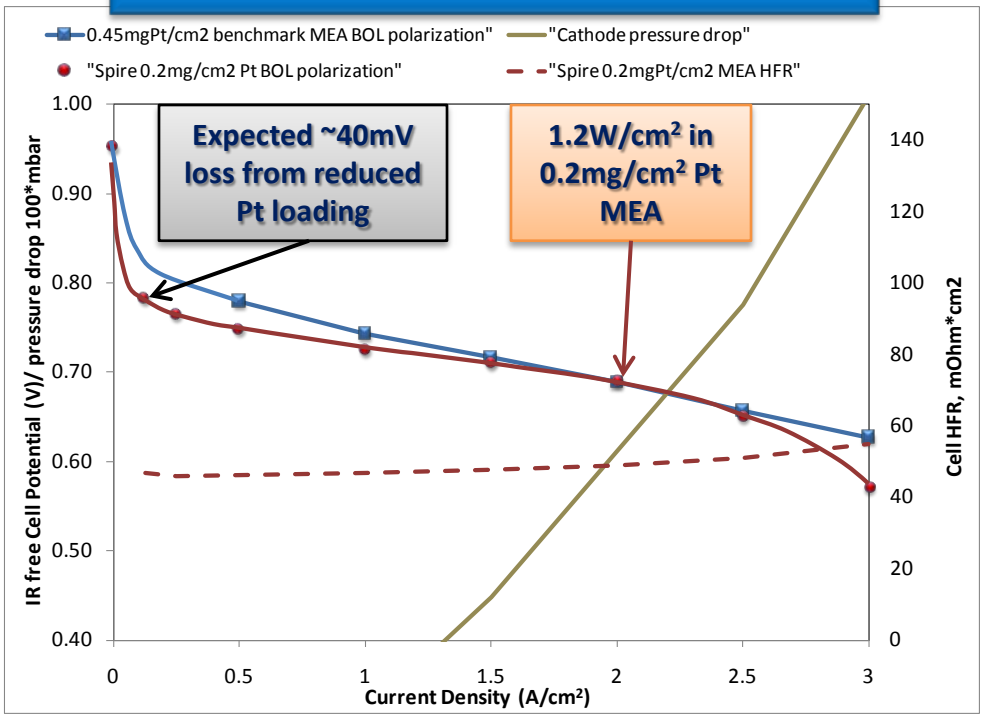
## SCOF vs. Serpentine Cell, High Pressure





*Open flowfield single cell showed benefits both at elevated and lowered cathode pressures*

## Dry cathode, Low Pressure Operation 1.8bara inlet




**SCOF hardware is delivered to LANL for validation in ASTs and NSTs.**

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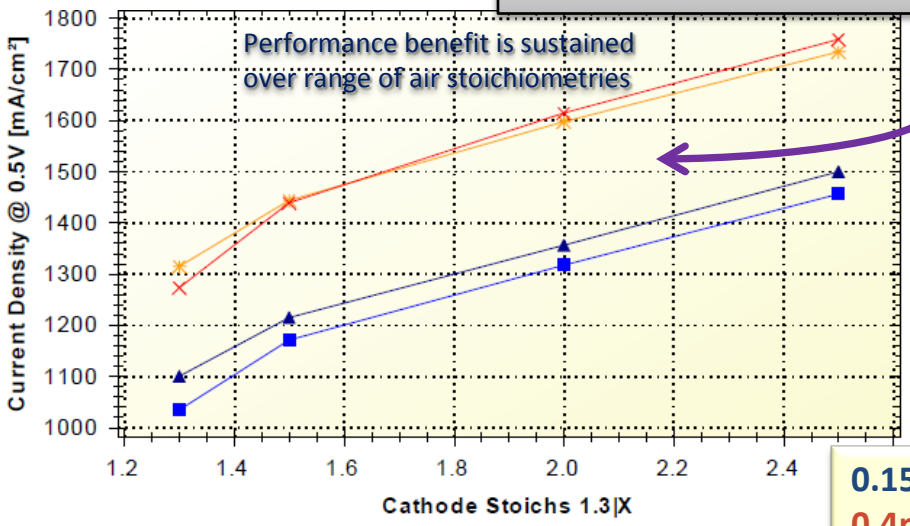
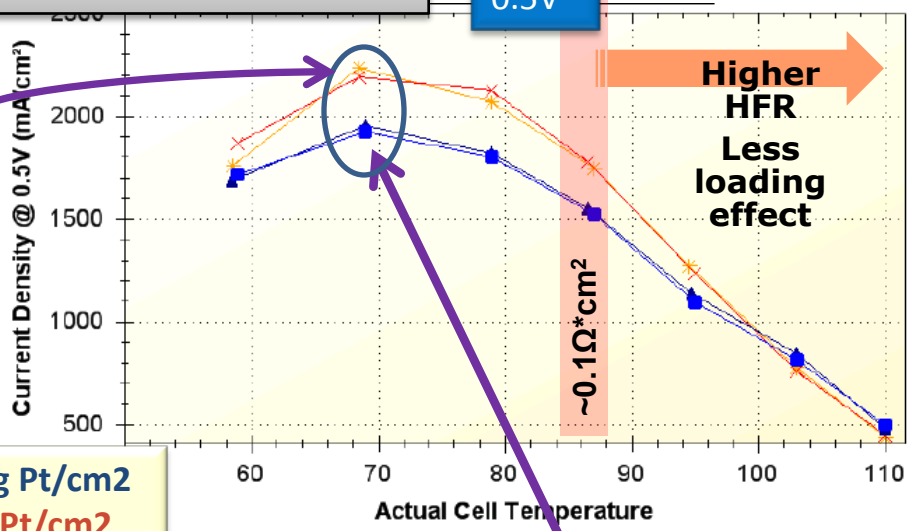
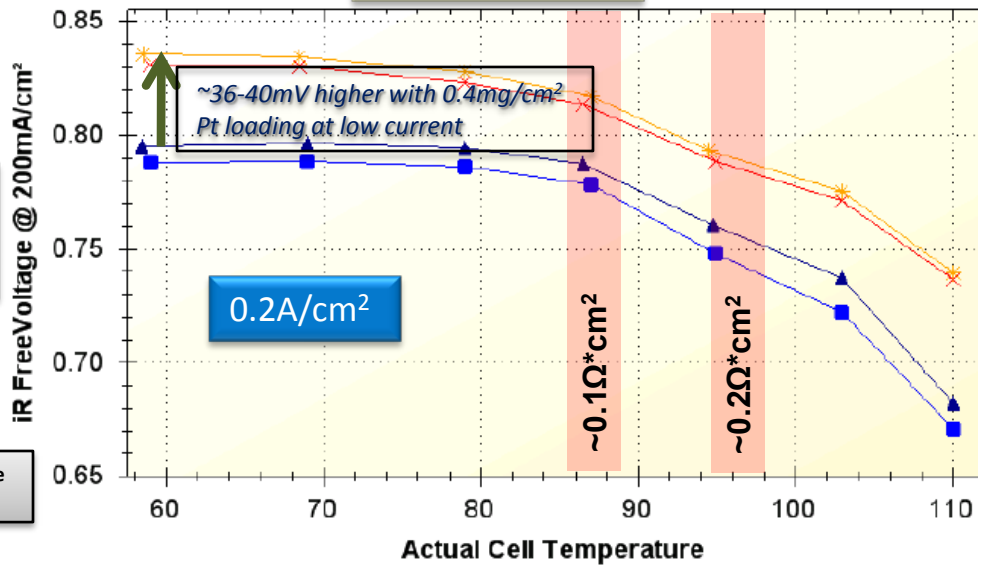
# Technical Progress
# Reduced Pt Loaded Cathode MEA – BOL

Sensitivity Data from Gore QA6 Quality Protocol



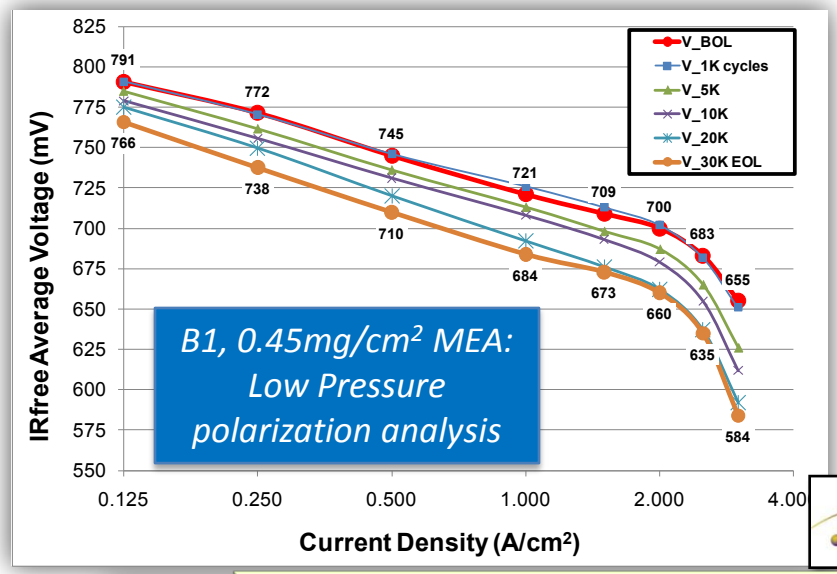

0.15mg Pt/cm2
0.4mg Pt/cm2

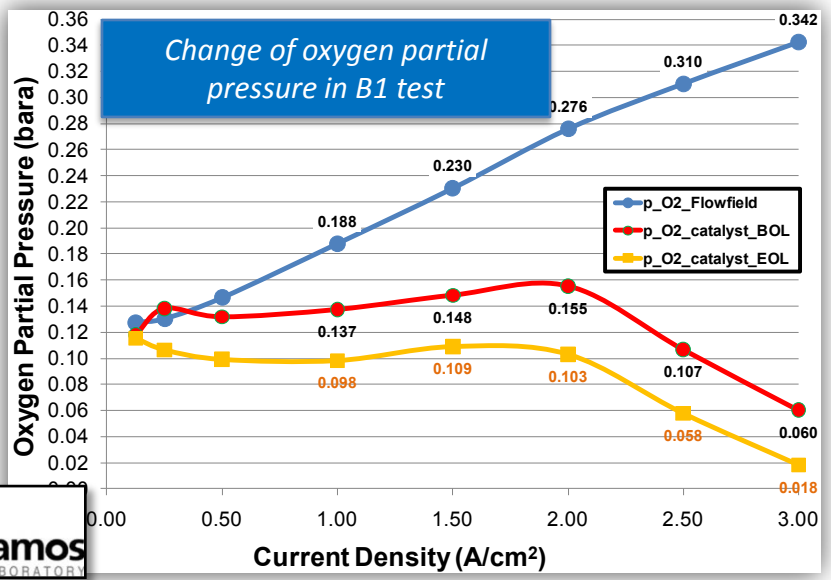



**Confirmed in LANL and Gore cells**

**RCD limited to <= 2A/cm² due to serpentine cell architecture.**

# Technical Progress – ASTs

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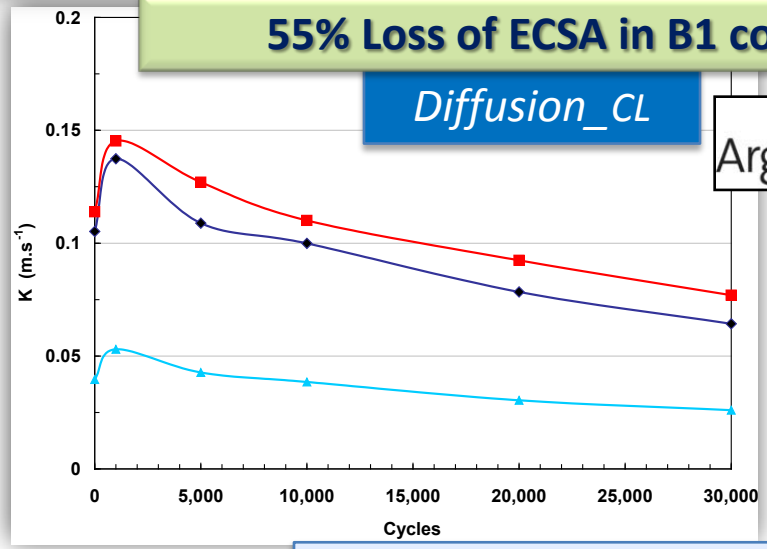
**55% Loss of ECSA in B1 consistent in CV and V-I curve analysis**

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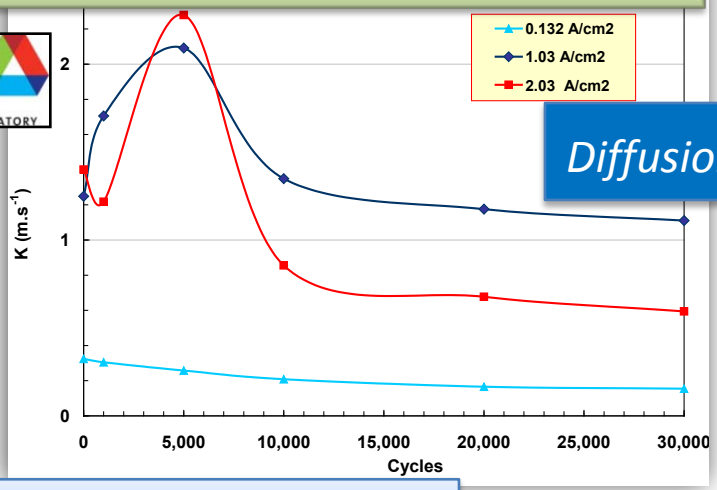
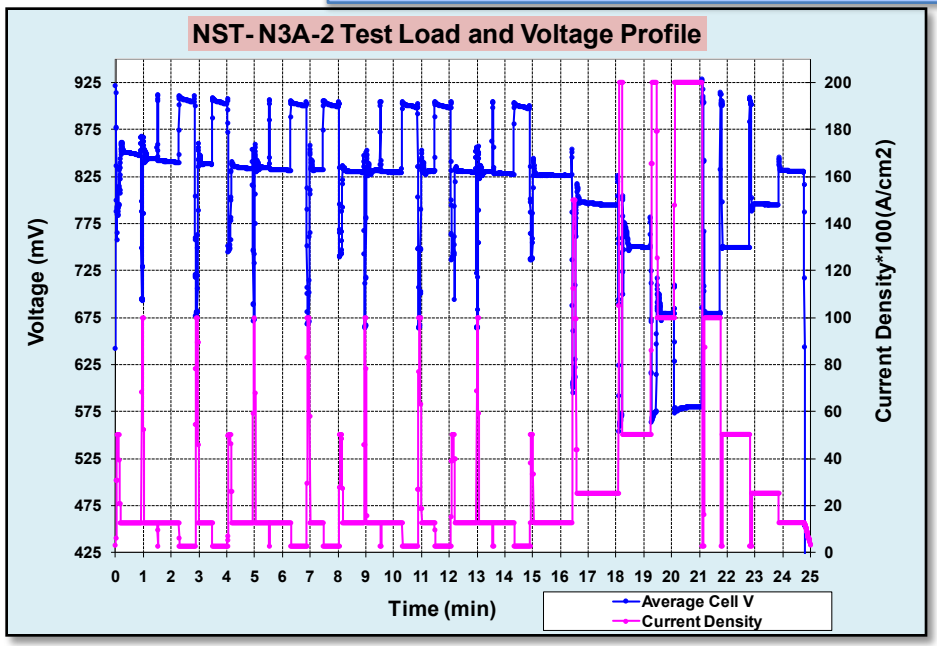


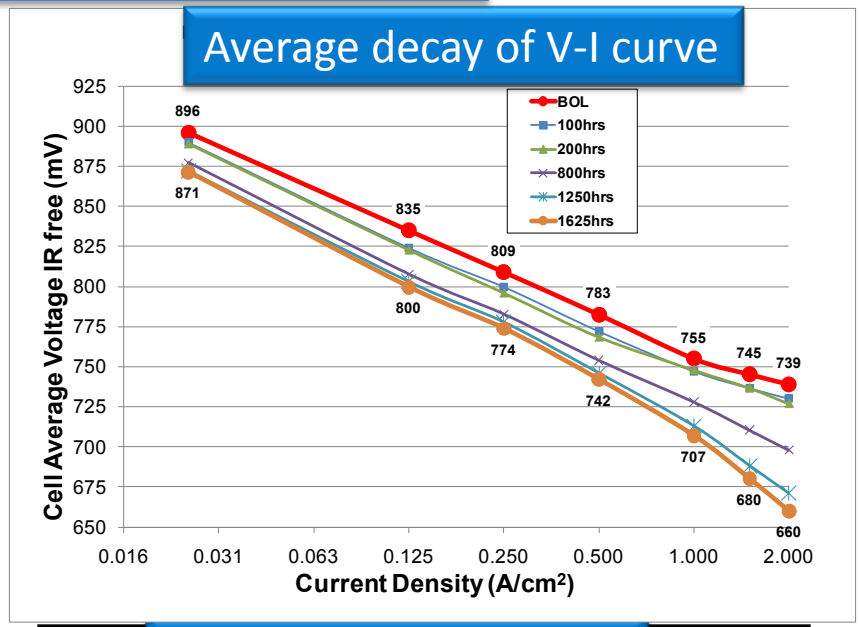

**Oxygen mass transfer decreased in both catalyst and GDL by 30K cycles**

# Technical progress - Stack durability

## NST-N3A-2 cycles to 2A/cm² Rated Current Density.

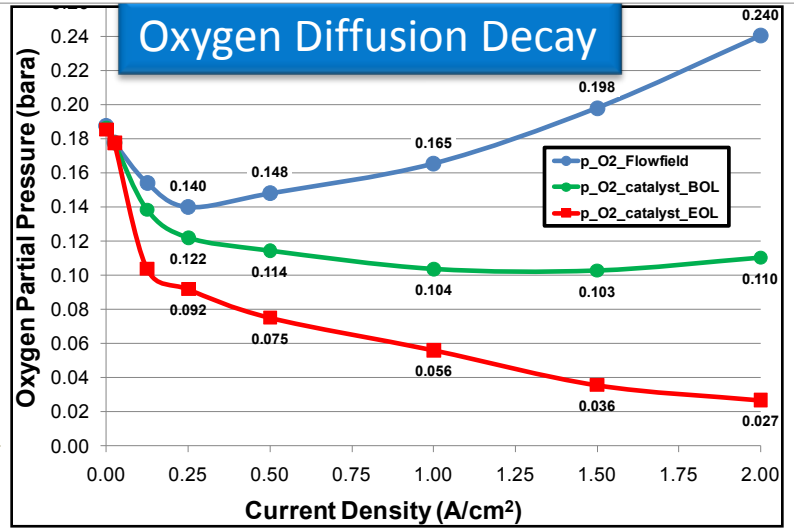
**8-cell stack , 360-cm² cell, 0.45mg/cm² total Pt loading**




- **Cathode ECSA loss 46-48% is consistent by CV and $V_{IR\_free}$ analysis**
- **Diffusion increase by 75% loss of $Po_2$ at reaction sites by V-I analysis.**

$$\Delta\eta_{MT} \propto \ln \frac{P_{O2,cat}^{BOL}}{P_{O2,cat}^{EOL}}$$



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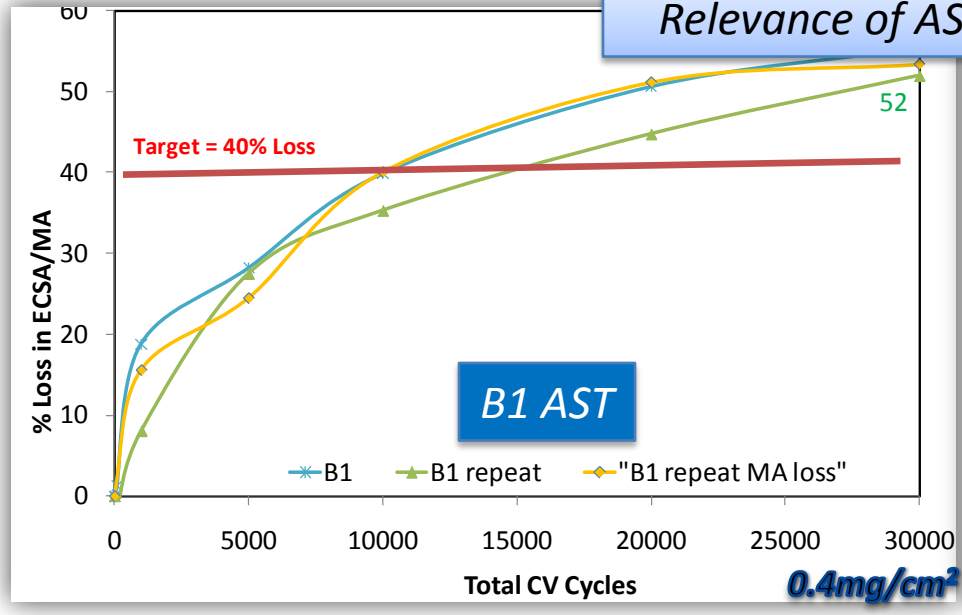
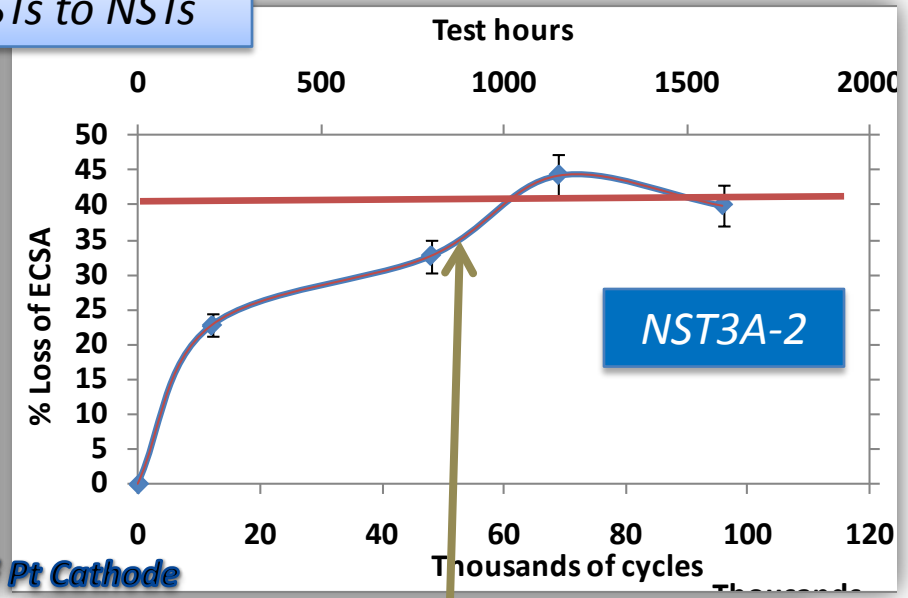
# Technical Progress: Catalyst stability

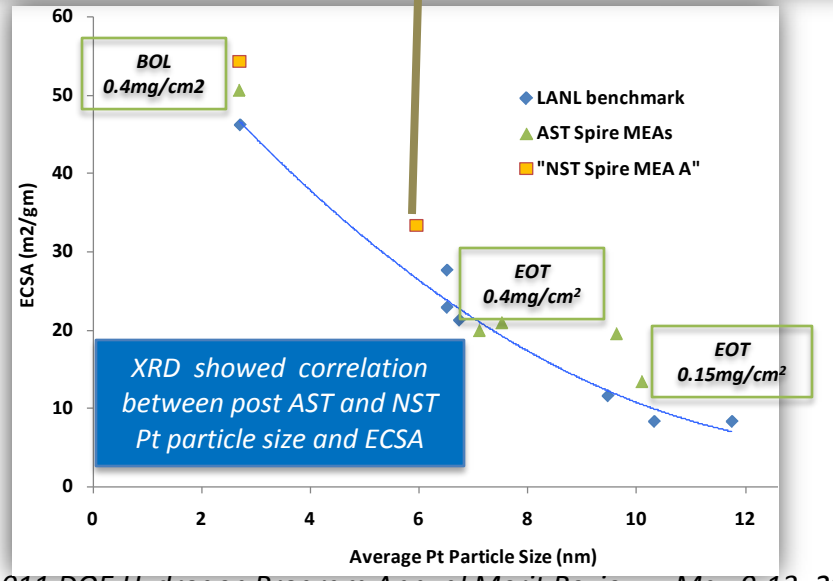
## Relevance of ASTs to NSTs



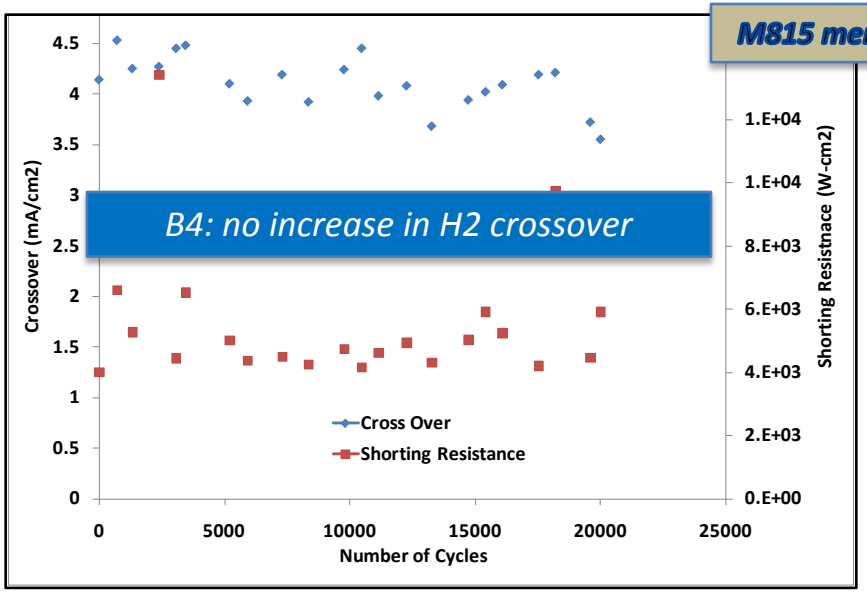

**0.4mg/cm² Pt Cathode**

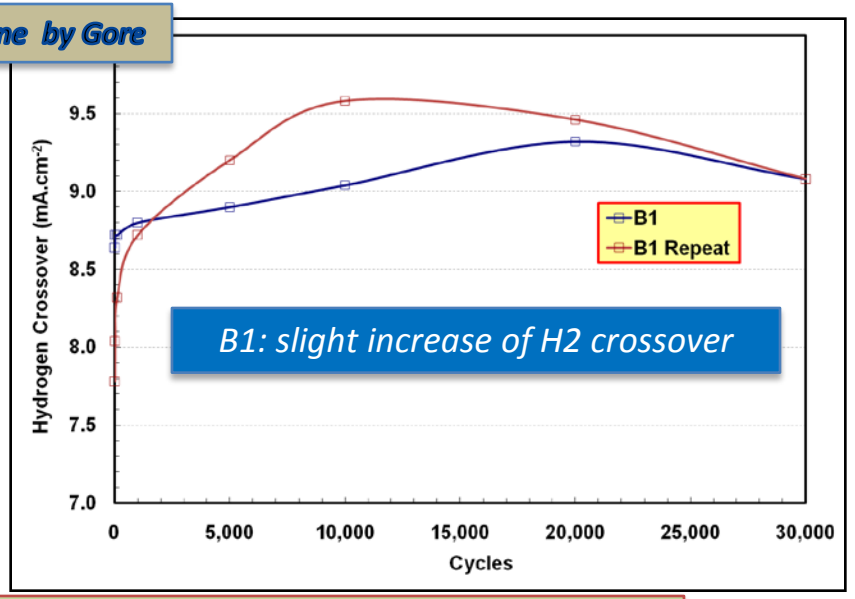
**B1 AST accelerates ECSA loss by 5-6 times versus NST3A-2**



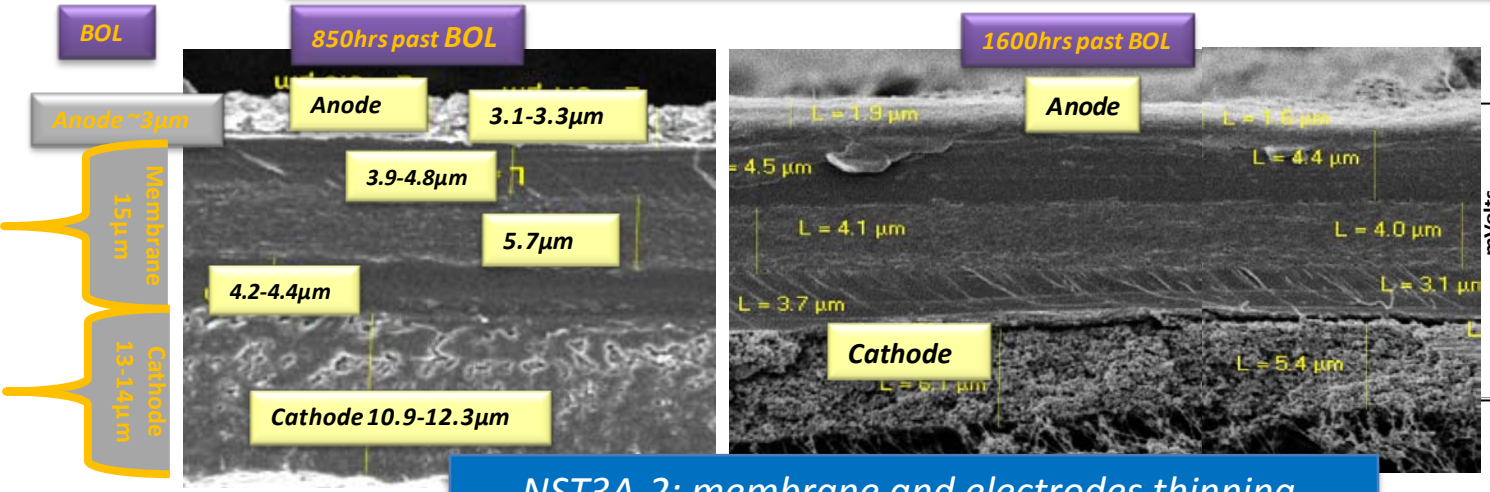
# Technical Progress – Membrane stability

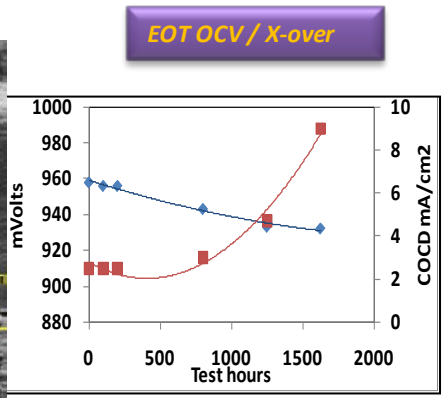
**M815 membrane by Gore**




**B4 results had no correlation with NST3A-2**




*NST3A-2: membrane and electrodes thinning, loss of OCV, increased crossover*

# Collaborations

- Nuvera Fuel Cells (Industry) – prime contractor
  - Program management,
  - SCOF Development, validation and high power NSTs,
  - Stack NSTs.
- Los Alamos National Lab (Federal)– subcontractor
  - Single cell AST/NST testing,
  - Post-test characterization.
- Argonne National Lab (Federal) – subcontractor
  - Developer of Platinum stability and fuel cell durability model.
  - Lead data analysis and post-processing for LANL and Nuvera.
- Durability Work Group – Borup/Myers lead
- W.L. Gore & Associates (Industry) – lead MEA developer

# Proposed Future Work

## FY2011

- Publish Comparative data for SCLC and SCOF on AST protocols – Milestone #3.
- Accumulate sufficient NST data sets (SCOF versus stack) in approaching GNG decision.

## FY2012

- Continue NST campaign

  (SCOF, RIT – LANL, full-area cells - Nuvera).
- ANL to reconstruct model polarization curves using inputs from ASTs and initiate validation of model results on NST data sets.
- ANL to conduct model sensitivity tests.

# Summary

**Relevance:** SPIRE addresses two of the most critical targets in the hydrogen program – cost and durability.

**Approach:** Combined experimental and modeling campaign to elucidate durability-critical factors at low Pt loading and high current density.

**Technical Accomplishments and Progress:**

Good progress in ASTs and NSTs for catalyst aging. Performance in SCOF demonstrated at 1.2W/cm$^2$ at 0.2mg/cm$^2$ Pt loading.

**Technology collaborations:**

Spire activities are synchronized to other durability projects through the Durability Work Group.

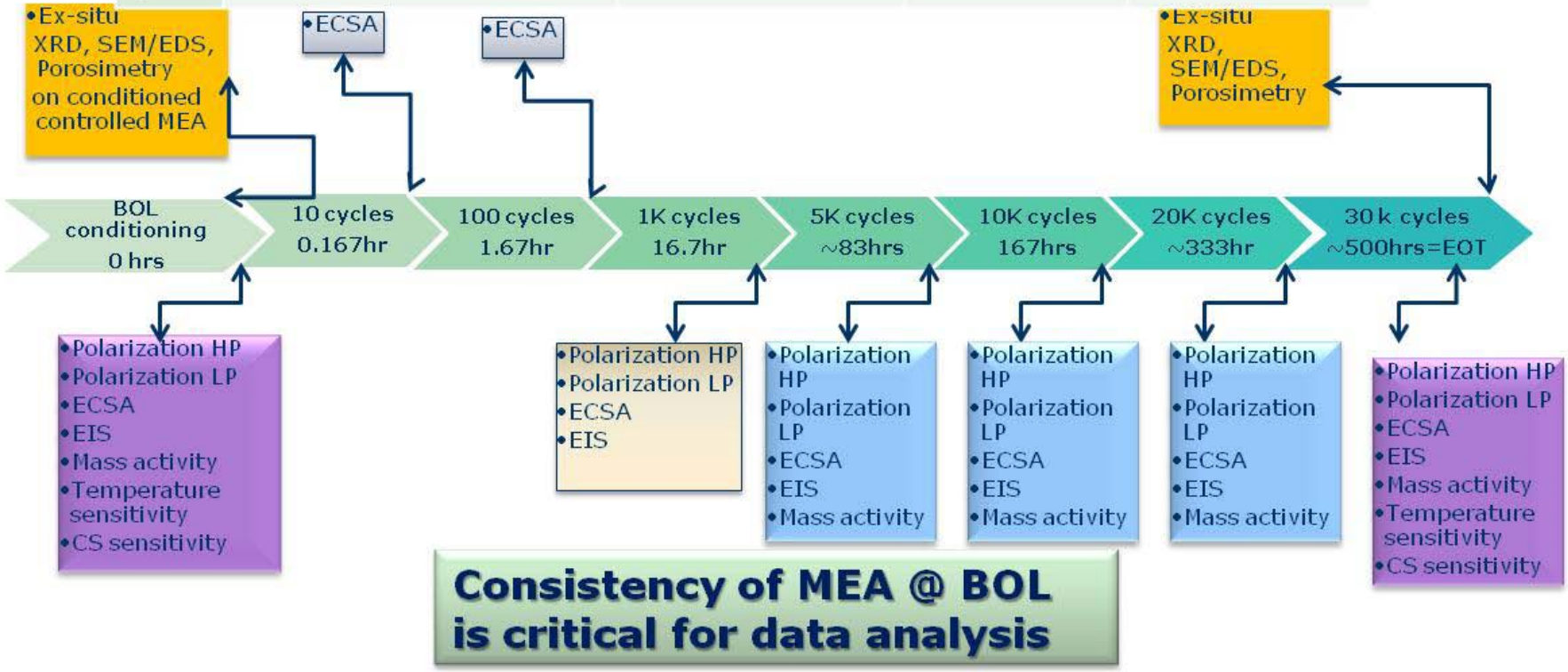
**Proposed Future Work:**

Remaining tests with different cell architectures and reduced Pt loading are critical to elucidate the effects of load cycles in stressing MEA degradation.

# Technical Back-Up Slides

# Technical Approach – AST B1 timeline

| TID | Protocol ID | Architecture ID | Material ID | Location |
|---|---|---|---|---|
| 1 | B1: 30sec potential cycle 0.6-1.0Volt, Cell @80C Anode/Cathode 100% RH $H_2/N_2$, 150kPa | SCLC 50cm2 | A | LANL |
| 2 | | SCOF 50cm2 | A | LANL |
| 3 | | SCLC 50cm2 | B | LANL |
| 7 | B1*:30sec , potential cycle 0.582 -0.883Volt, Cell @80C Anode/Cathode 100% RH $H_2/N_2$, 150kPa | SCOF 50cm2 | A | LANL |
| 8 | | SCLC 50cm2 | B | LANL |
| 9 | | SCOF 50cm2 | B | LANL |



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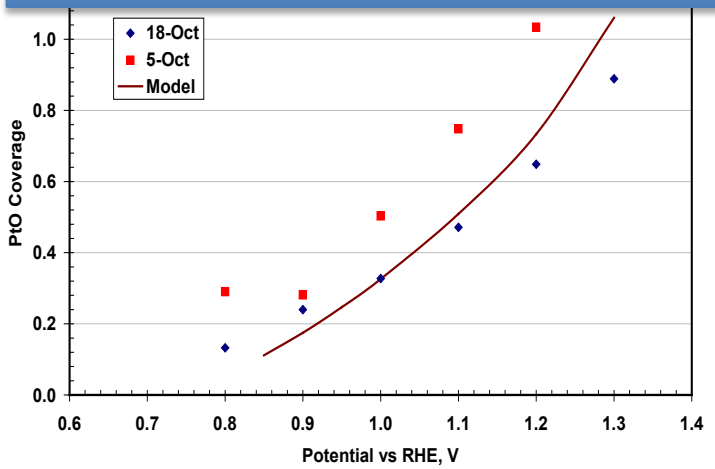
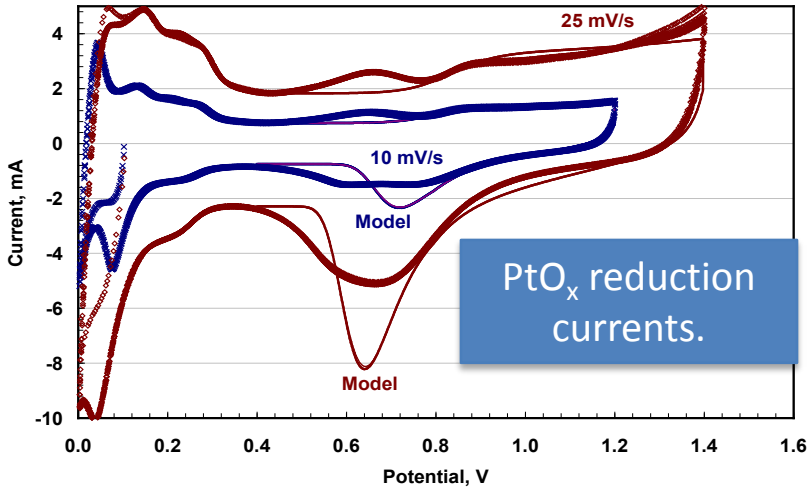
# Technical Progress – Modeling Pt dissolution

Potential dependence of equilibrium O/Pt.

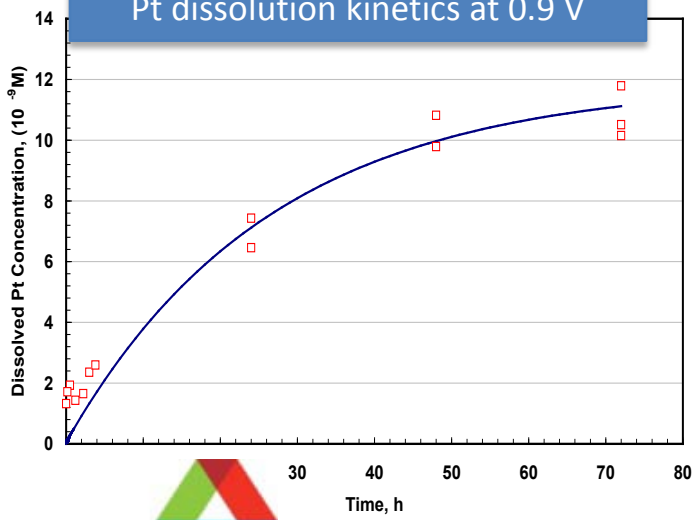


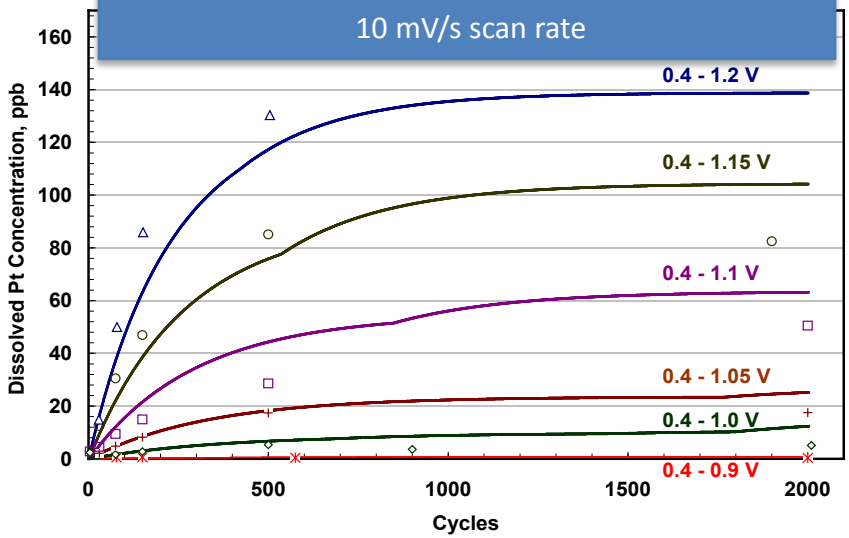

$PtO_x$ reduction currents.

**Ground work for Pt stability model in aqueous media is complete**

Pt dissolution kinetics at 0.9 V

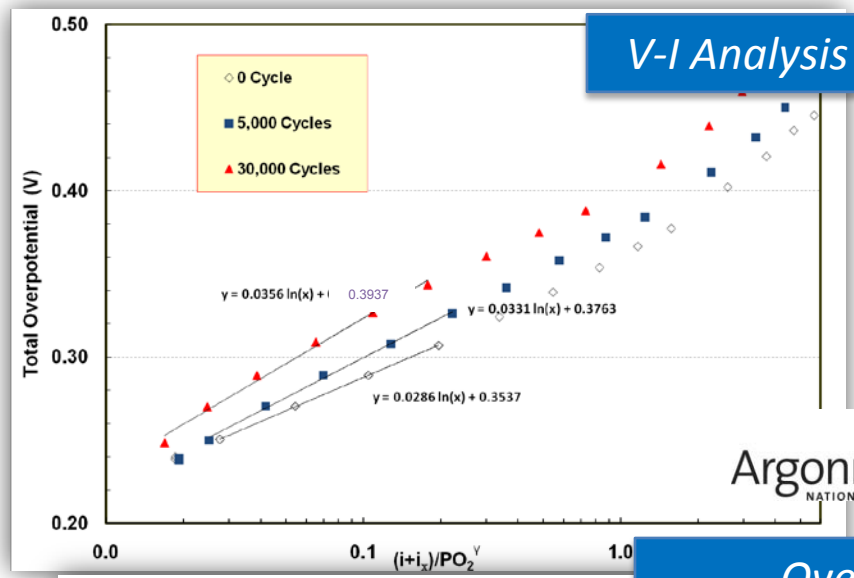



Pt dissolution with triangular wave cycles, 10 mV/s scan rate

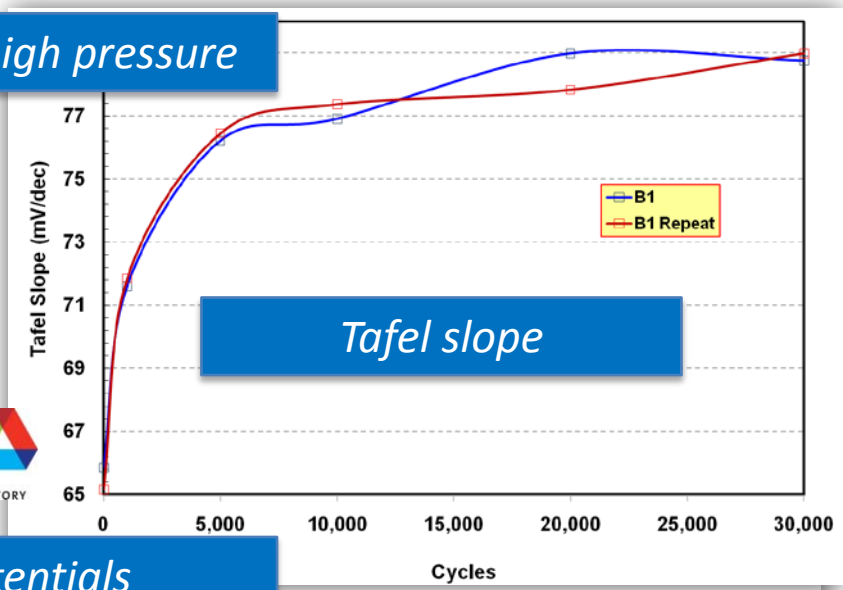


# Technical Progress – AST B1 Data Analysis

## V-I Analysis at high pressure




## Tafel slope

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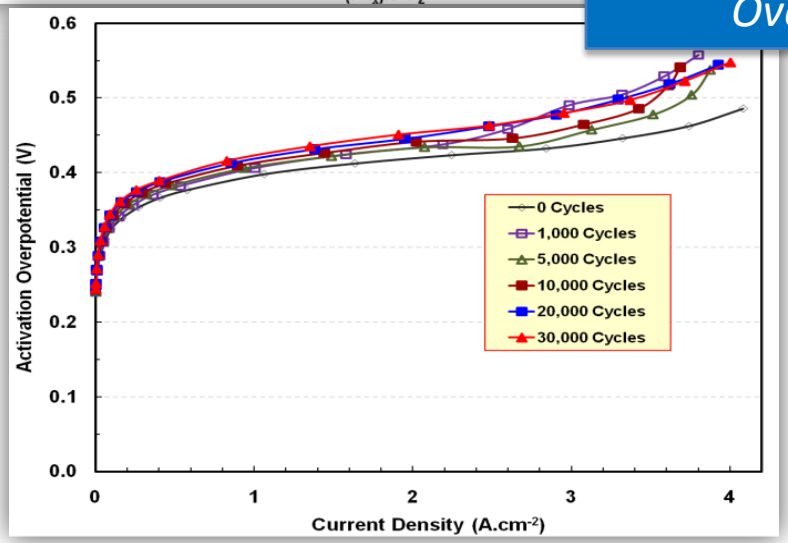
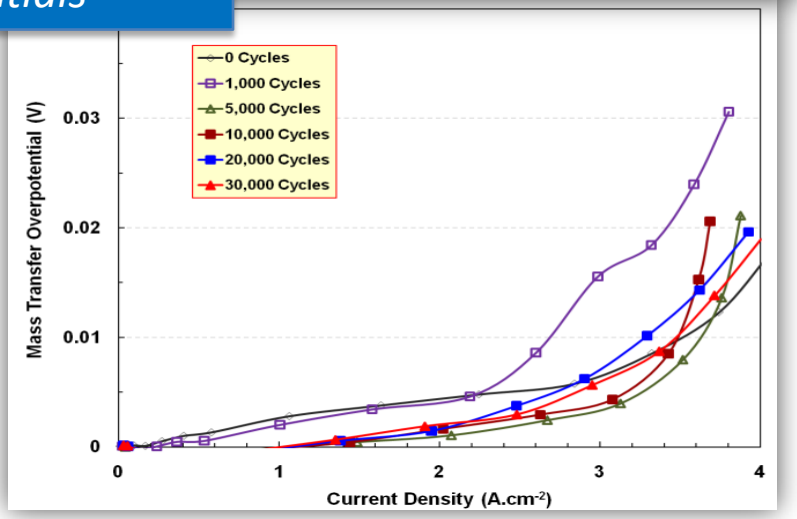
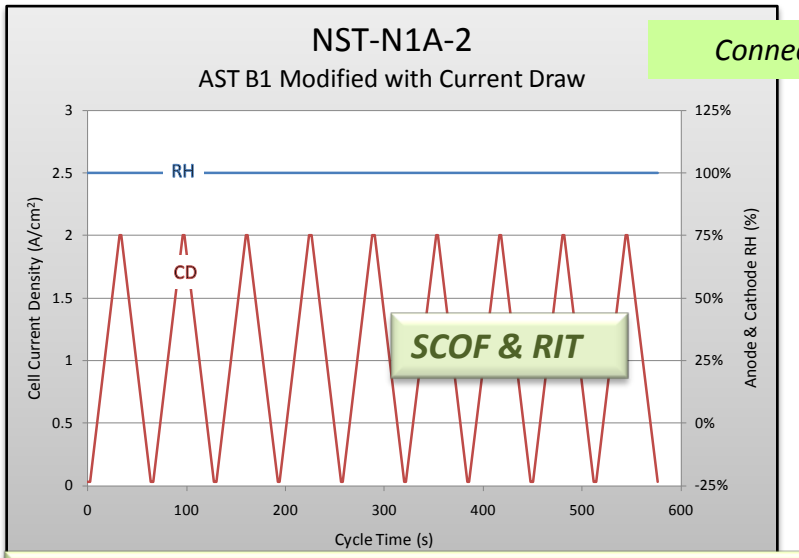
## Overpotentials



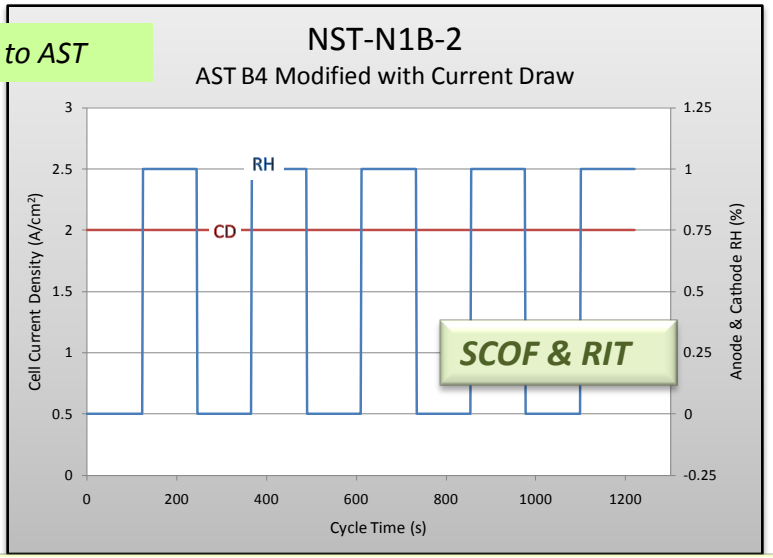




**Activation and Mass Transfer overpotentials increase with time**

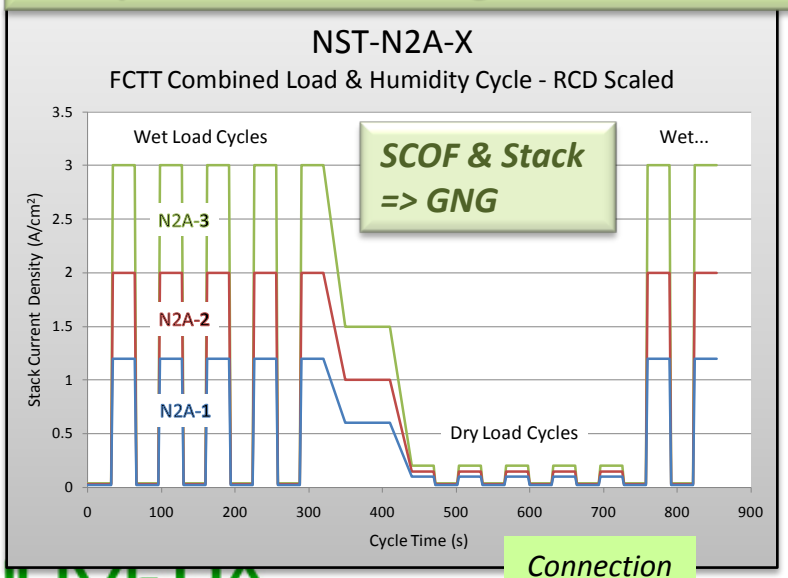
# NST load and humidity profiles

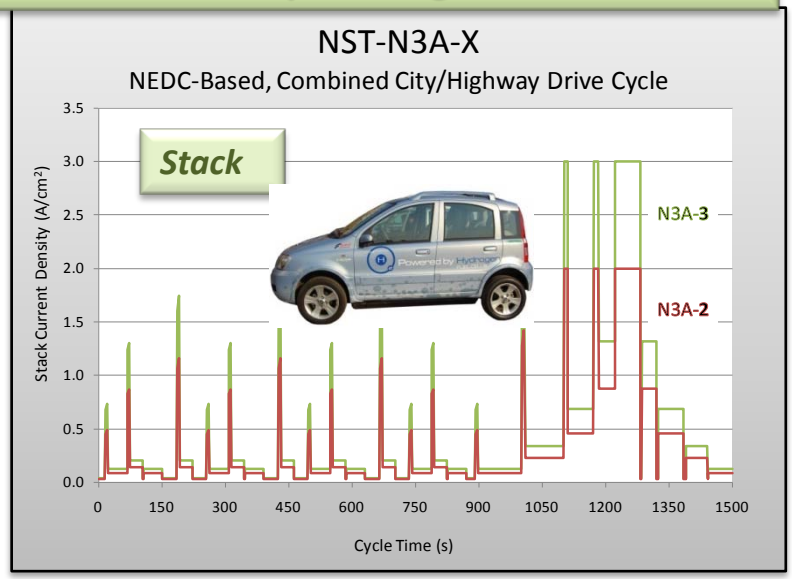



*Connection to AST*



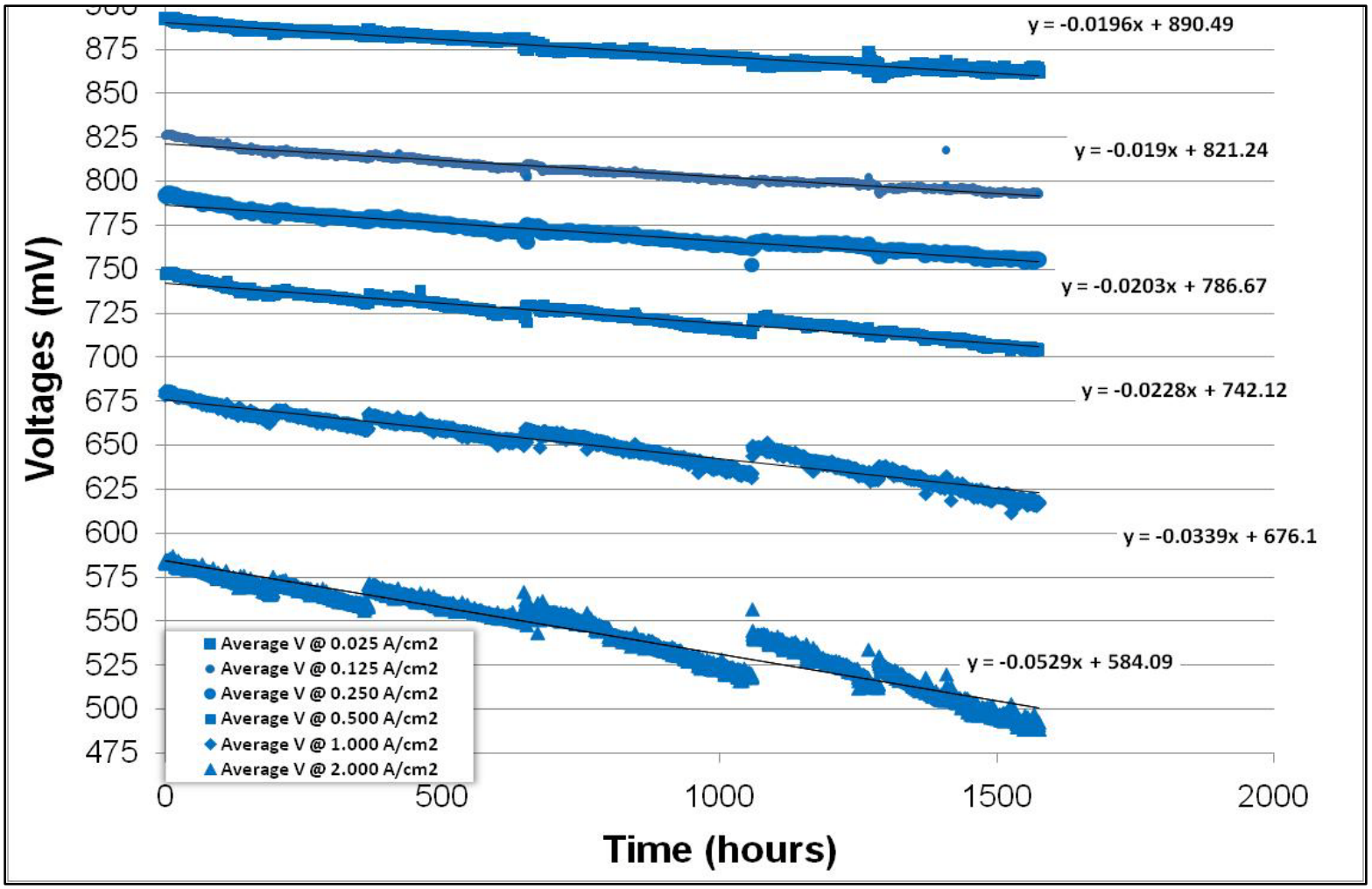

**NST protocols are designed to stress ECP under fuel cell operating conditions**




*Connection to industry*

# Technical Progress – stack NST3A-2




**Decay values were consistent in three full-area (250-360cm²) cell tests**