

Improved Accelerated Stress Tests (ASTs) Based on Real World FCV Data

June 8th, 2010

Tom Madden

UTC Power Corporation



This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project ID: FC015

Overview

Timeline

- Start Date: **Dec 2009**
- Finish Date: **May 2012** (expected)
- Status: 20% Complete

Budget

- Total funding \$3,847,218
- Cost share 20%
- Spend on-plan

GFY '09	\$478,609
GFY '10	\$1,187,500
GFY '11	\$1,312,754
GFY '12	\$868,355

Barriers

(2007 RD&D for auto FC)

- >5,000hr stack durability (with cycling)
 - Include all materials (e.g. membrane, seals)
 - UTC bus fleet target >15,000hr stack life
 - <10% Performance decay
 - Start-stop / transient operation
- ↓
- ASTs used to avoid costly durability testing

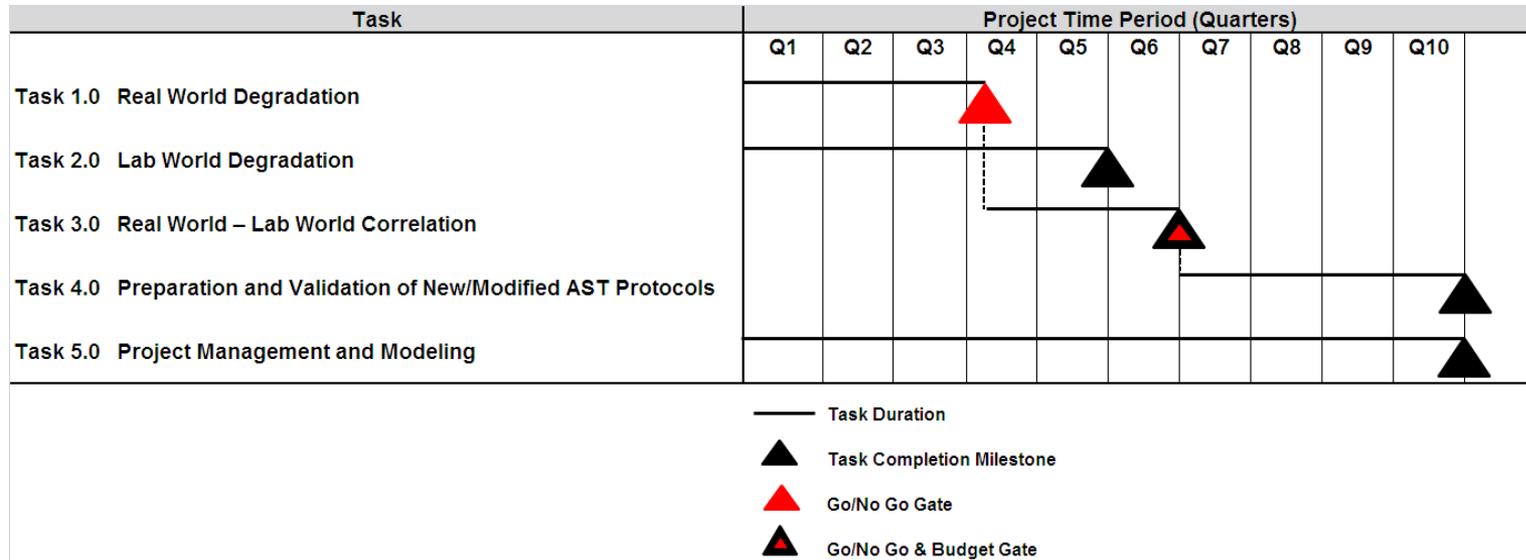
Partners



Relevance

Program Objectives	Current Gaps	2009-2010 Objectives
Comparison of conditions & materials in bus field operation vs. DOE ASTs	DOE ASTs not calibrated with real world degradation	<p>Task 1 - Analyze performance data and characterize degraded materials from 2850hr stacks in bus service</p> <p>Task 2 - Analyze data and degraded materials run in DOE ASTs (same as in bus stacks)</p>
Develop acceleration factors for DOE AST mechanisms → recommend modifications	DOE ASTs may over- or under-accelerate mechanisms → inadequate material selections	<p>Task 3 - Correlate results for all current DOE ASTs:</p> <ol style="list-style-type: none"> 1) PGM decay 2) Carbon corrosion 3) Membrane mechanical 4) Membrane chemical
Identify life-limiting mechanisms not addressed by DOE AST's → recommend new AST's	DOE ASTs do not encompass all mechanisms that drive FCV stack lifetime	None for 2009-2010

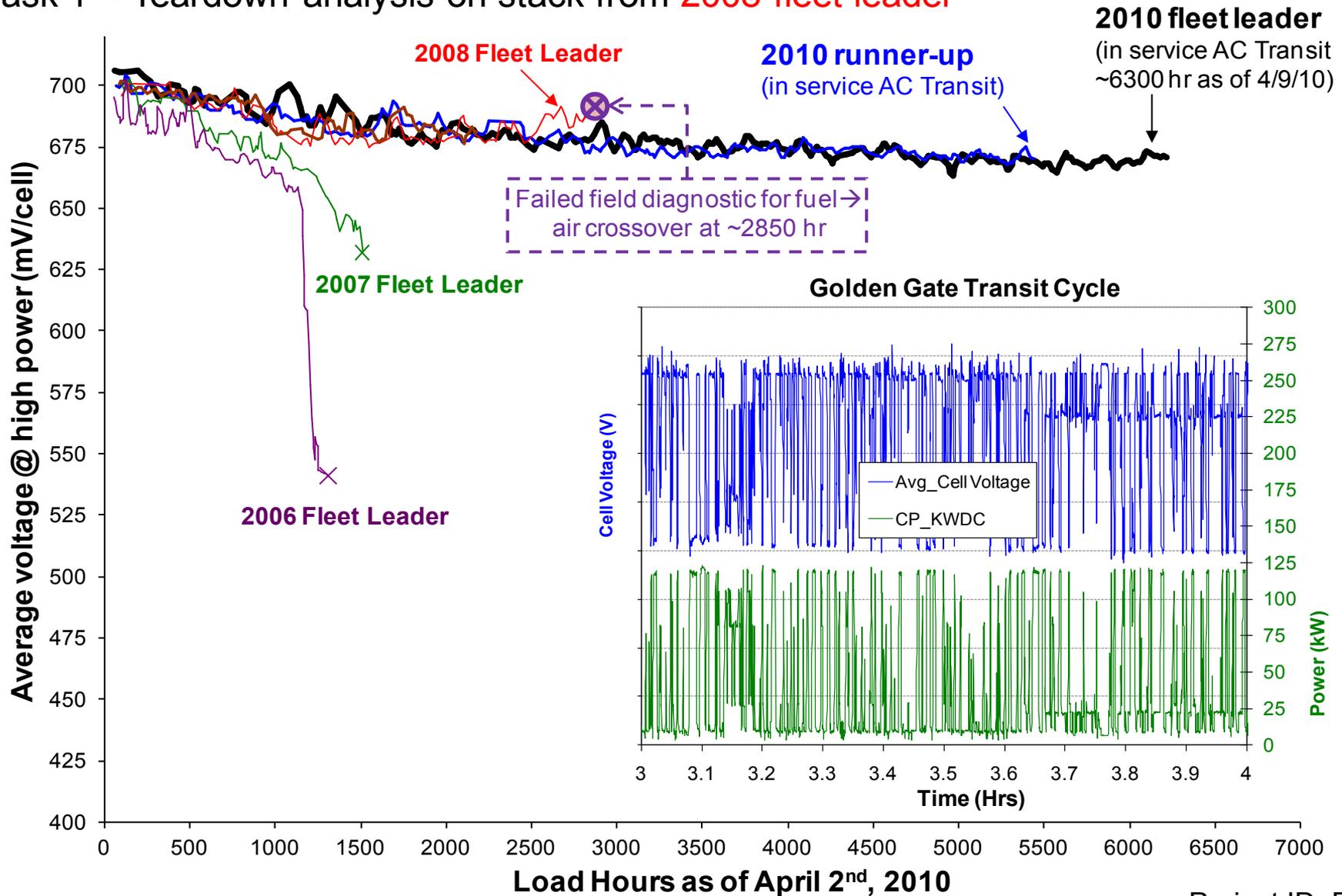
Approach



Task	Progress	Status
1.0 - Real world degradation	<ul style="list-style-type: none"> Completed bus operating cycle analysis Completed characterization of field-operated bus stack (2850hr) for PGM decay mechanism 	50% complete
2.0 - Lab world degradation	<ul style="list-style-type: none"> Completed PGM decay AST on the same materials as the bus stack (LANL) Initiated 2 other ASTs (LANL) as of 4/9/2010 	25% complete
Go / No-go Gate #1	<ul style="list-style-type: none"> Correlate all observed degradation to field operating conditions 	Expected completion – July 2010

Technical Progress – Real World Stack Degradation

Task 1 - Teardown analysis on stack from **2008 fleet leader**



Technical Progress – Task 1 Real World Summary

PGM decay (yellow cells) reported in this presentation

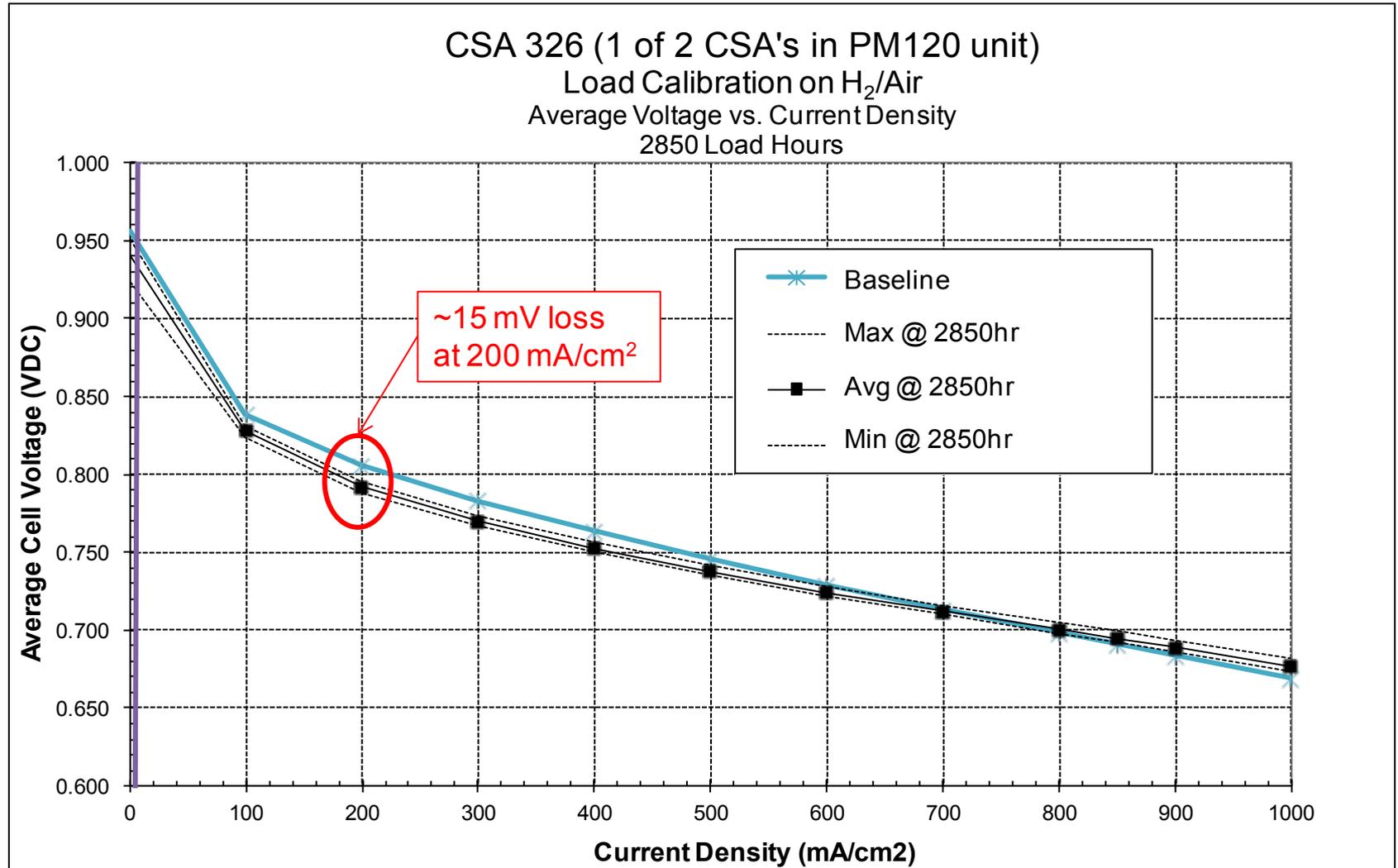
Decay Mechanism	Real world cycle	Materials	Real world diagnostics	Real world teardown
PGM decay	- H ₂ /Air - 63 C, 100%RH >100 cycle/ hr - V(idle) to V(full power)	- Anode / cathode: 0.4 mg Pt/cm ² ea. - non-alloy	- Voltage loss @ 0.2 A/cm ²	- XRD - TEM - ECA
Carbon Corrosion	TBR	TBR	TBR	TBR
Membrane Mechanical	TBR	TBR	TBR	TBR
Membrane Chemical	TBR	TBR	TBR	TBR

Root cause of stack failure at 2850 hrs (membrane failure)

TBR – to be reported

Technical Progress – Real World Stack Diagnostics

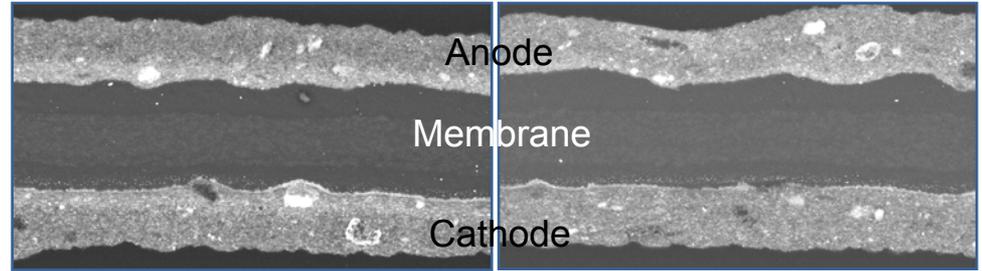
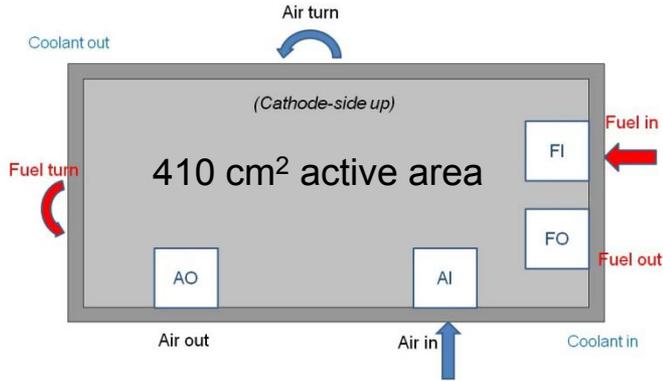
Analysis of performance loss in field-operated stack @ 2850hr on test stand



Technical Progress – Real World Stack Teardown

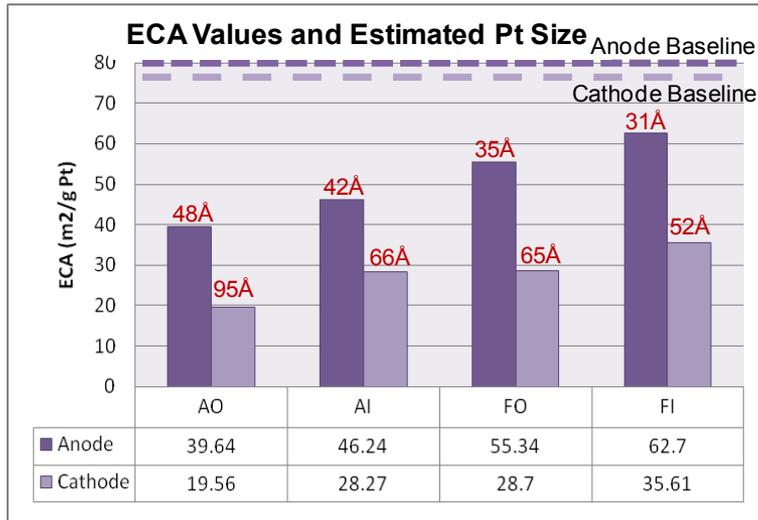
ECA & XRD Baseline vs. 2850 hr

- 50%-75% Cathode ECA loss
- Less ECA loss on anode

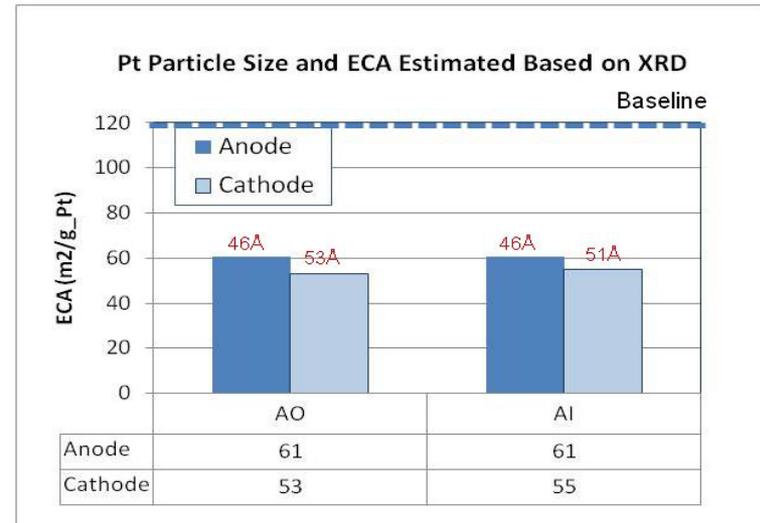


AO AI
BSE images obtained from air outlet (AO) & air inlet (AI) areas

Cell planform and areas analyzed: AI, AO, FI, FO
SEM, ECA (ex-situ) and XRD performed at each location



ECA measurements performed on subscale sections at indicated locations (calculated particle size shown in red)

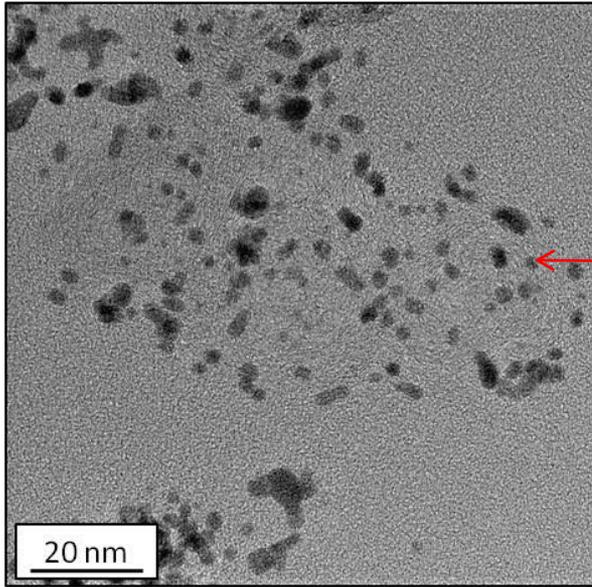


Avg. XRD particle size measurements (ECA calculated) at AO and AI

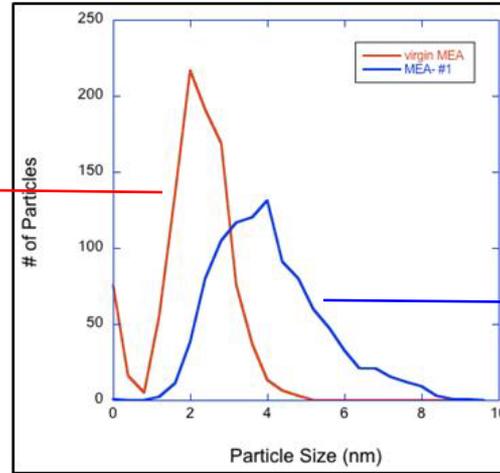
Technical Progress – Real World Stack Teardown

TEM Baseline vs. 2850 hr

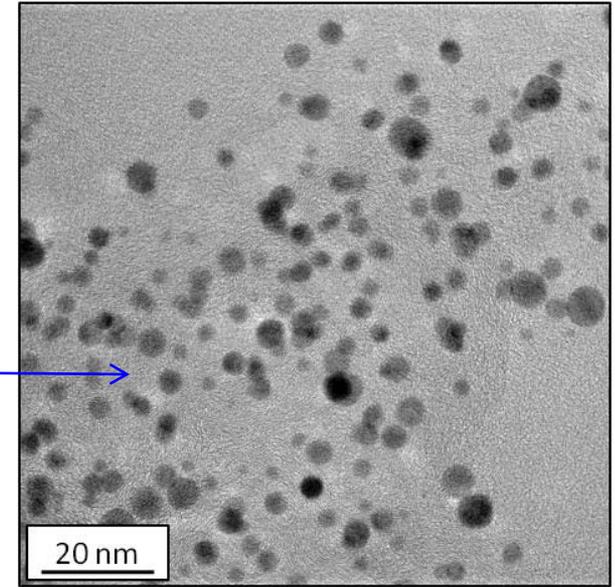
TEM results consistent with ECA & XRD analyses



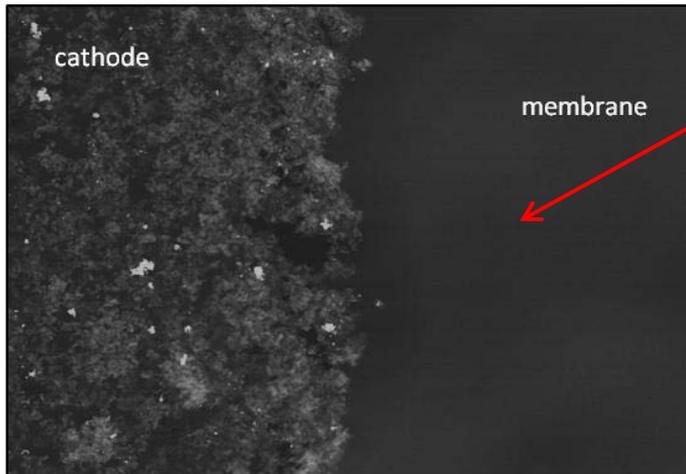
Baseline



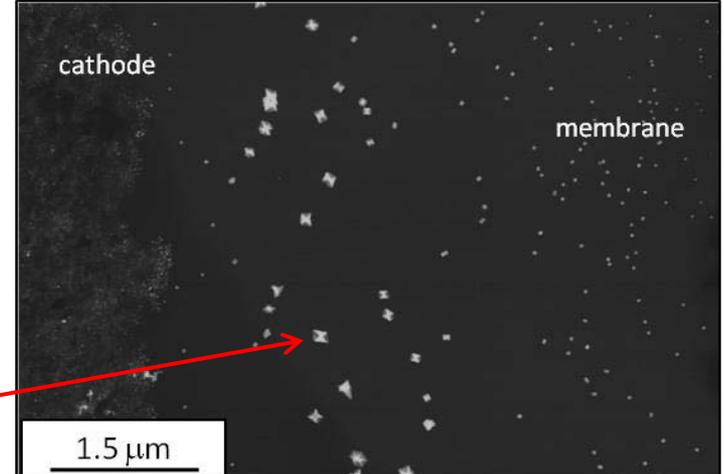
Baseline cathode = ~2nm
2850 hr cathode = ~4nm



Air Inlet - 2850 hr



No Pt observed in membrane of virgin MEA



Pt precipitation in cathode membrane

UTC Power used Gore® PRIMEA® catalyst-coated membranes. GORE, PRIMEA and designs are trademarks of W. L. Gore & Associates, Inc.

This work is funded under DOE Project # DE-EE0000468

Project ID: FC015

Technical Progress – Task 2 DOE ASTs Summary

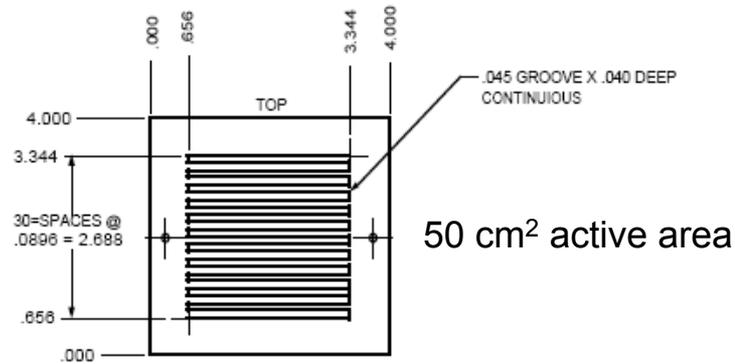
PGM decay (yellow cells) reported in this presentation

Decay Mechanism	Real world cycle	Real world diagnostics	Real world teardown	Lab AST cycle	Lab-world diagnostics	Lab-world teardown
PGM decay	- H ₂ /Air - 63 C - 100%RH > 100 cycle / h - V(idle) to V(full power)	- Voltage loss @ 0.2 A/cm ²	- XRD - TEM - ECA	- H ₂ /N ₂ - 80 C - 100%RH - 30,000 cycle 0.6-1.0V	- Voltage loss @ 0.2 A/cm ² - ECA/mass activity loss (0.9 V)	- XRD - TEM
Carbon Corrosion	TBR	TBR	TBR	- H ₂ / N ₂ - 1.2 V hold	TBR	TBR
Membrane Mechanical	TBR	TBR	TBR	- air / air - RH cycling	TBR	TBR
Membrane Chemical	TBR	TBR	TBR	- H ₂ / air - OCV hold	TBR	TBR

TBR – to be reported

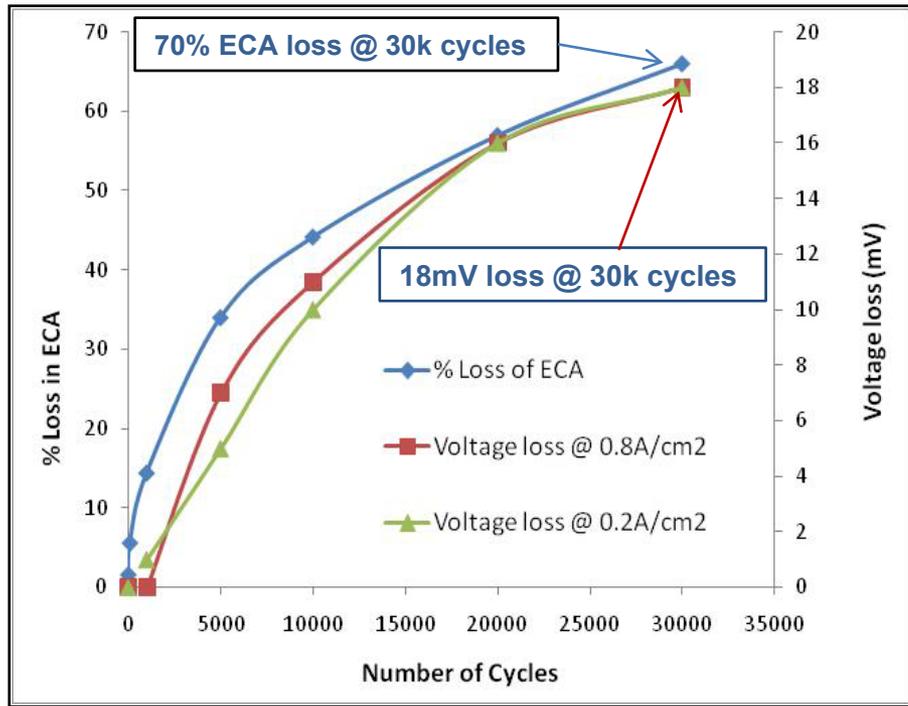
Technical Progress – DOE AST Degradation/Diagnostics

Summary of PGM decay results

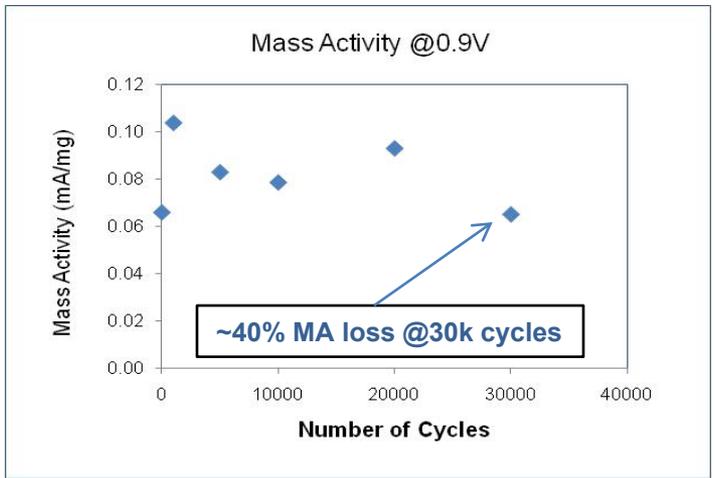


DOE AST#1 – PGM decay

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
%RH	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



Observed @ 30k cycles	DOE Target @ 30k cycles
~70% ECA loss	≤40% loss of initial area
~18 mV loss @ 0.8 A/cm ²	≤30 mV loss at 0.8 A/cm ²
~40% loss of activity	≤40% loss of activity



Summary

Task Summary

- Completed real world bus drive cycle analysis & performance diagnostics (Task 1)
 - Completed real world bus PGM decay characterization (Task 1)
 - Completed laboratory PGM decay AST testing and diagnostics (Task 2)
-

Conclusions

- Small but measurable performance decay in field operated unit at 2850 hrs
- Catalyst decay AST leads to ~18mV voltage loss (@0.2A/cm²) which is in agreement with that observed in 2850hr bus stacks (~15mV)
- ECA loss measurements consistent with TEM and XRD analyses

Future Work

- Complete characterization of real world degraded materials for remaining decay mechanisms (Task 1)
 - Carbon corrosion
 - Membrane mechanical
 - Membrane chemical
 - Other mechanisms (TBR)
- Complete laboratory DOE AST tests, diagnostics, and teardown for all four decay mechanisms (Task 2)
- Determine acceleration factors and mechanistic gaps (Task 3)
- Complete implementation of Accelerated Life Test
 - Complete protocol “baselining”
 - Teardown analysis to confirm failure modes seen in 2008 fleet leader

Future Work – Accelerated Life Test

Accelerated life test

Background

- In-field validation time-consuming : 1 yr operating time → ~3 mos. load time
- Develop a system-based test protocol that accelerates all relevant decay mechanisms in bus stacks

Benefits

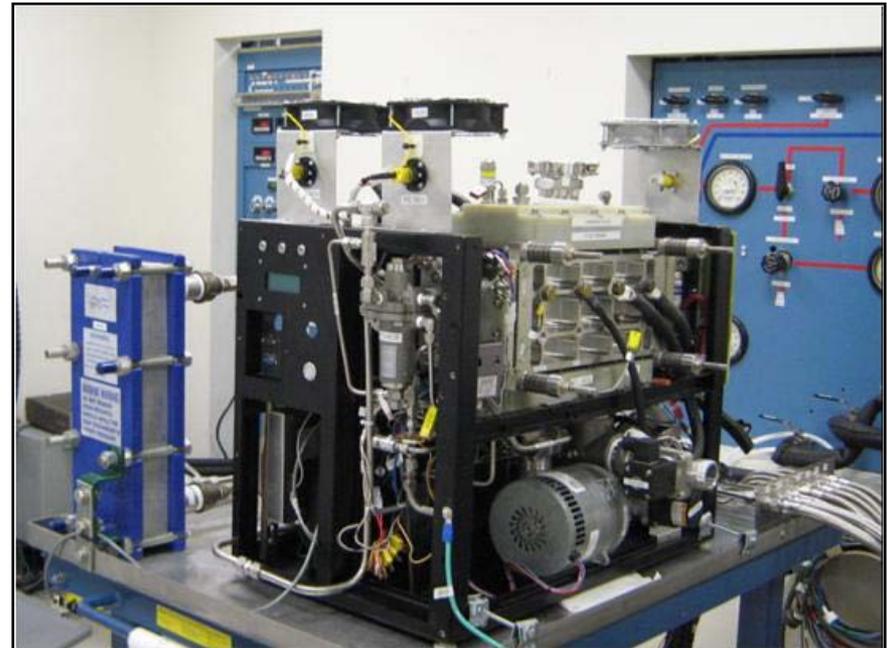
- Provides simulated “real world” test articles at 1000’s of calendar hours while awaiting field failures (2+ yrs)
- Facilitates interactions between different mechanisms typically not addressed in targeted mechanism-based ASTs
- Expedites stack material qualifications to 15 kWhr UTC fleet requirement using an accelerated bus protocol

Features

- Modular 5 kW unit (20-cell short stack)
- Equivalent system to bus
- Built-in reactant, coolant, and ventilation control systems
- Built in fuel cell controller, power distribution system

Status

- Installed on test stand – anticipating 4/15 start



Collaborations



UTC Power

A United Technologies Company

Tom Madden, T.T. Aindow, Andrew Alarcon



**United Technologies
Research Center**

Dave Condit, Mike Perry, Mallika Gummalla



Rangachary Mukundan, Rod Borup



OAK RIDGE NATIONAL LABORATORY

Managed by UT-Battelle for the Department of Energy

Karren More, Kelly Perry



NREL

National Renewable Energy Laboratory

Innovation for Our Energy Future

Project ID: FC015



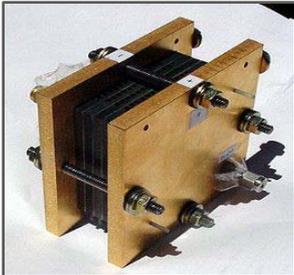
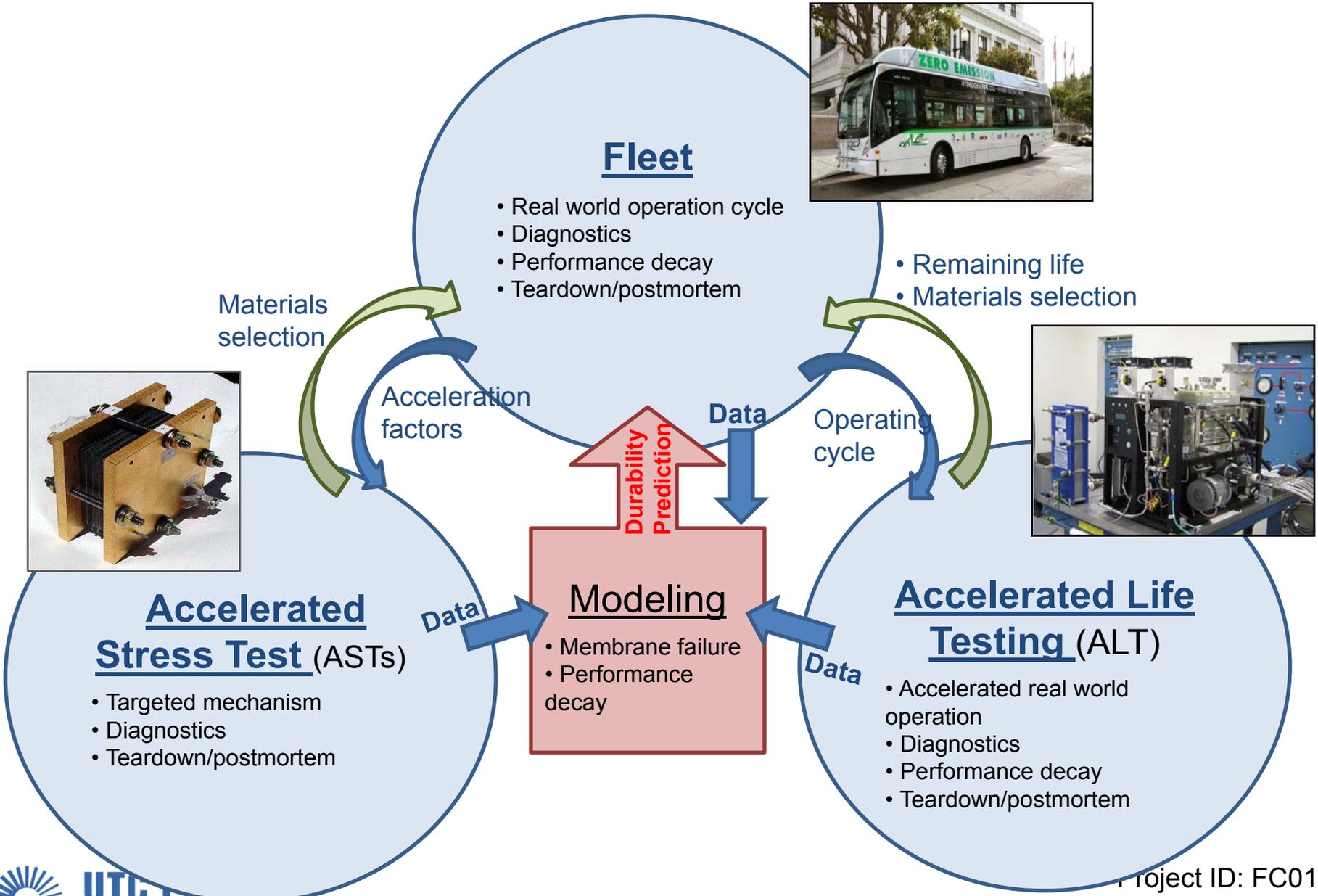
UTC Power

A United Technologies Company

This work is funded under DOE Project # DE-EE0000468

Questions?

UTC Fleet Durability Strategy



Fleet Hybrid Integration & Test Lab at UTRC

Fuel Cell Hybrid Vehicle (FCHV) integration testing

- Drive-cycle operation
- Power management software / hardware verification
- Comparison with actual fleet data

Full Scale Fleet Hybrid Integration and Test Facility

