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

June 8th, 2010

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UTC Power Corporation

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Project ID: FC015

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This work is funded under DOE Project # DE-EE0000468

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

United Technologies Research Center

Los Alamos NATIONAL LABORATORY EST. 1943

OAK RIDGE NATIONAL LABORATORY
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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	**Task 1** - Analyze performance data and characterize degraded materials from 2850hr stacks in bus service **Task 2** - Analyze data and degraded materials run in DOE ASTs (same as in bus stacks)
Develop acceleration factors for DOE AST mechanisms → recommend modifications	DOE ASTs may over- or under-accelerate mechanisms → inadequate material selections	**Task 3** - Correlate results for all current DOE ASTs: 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

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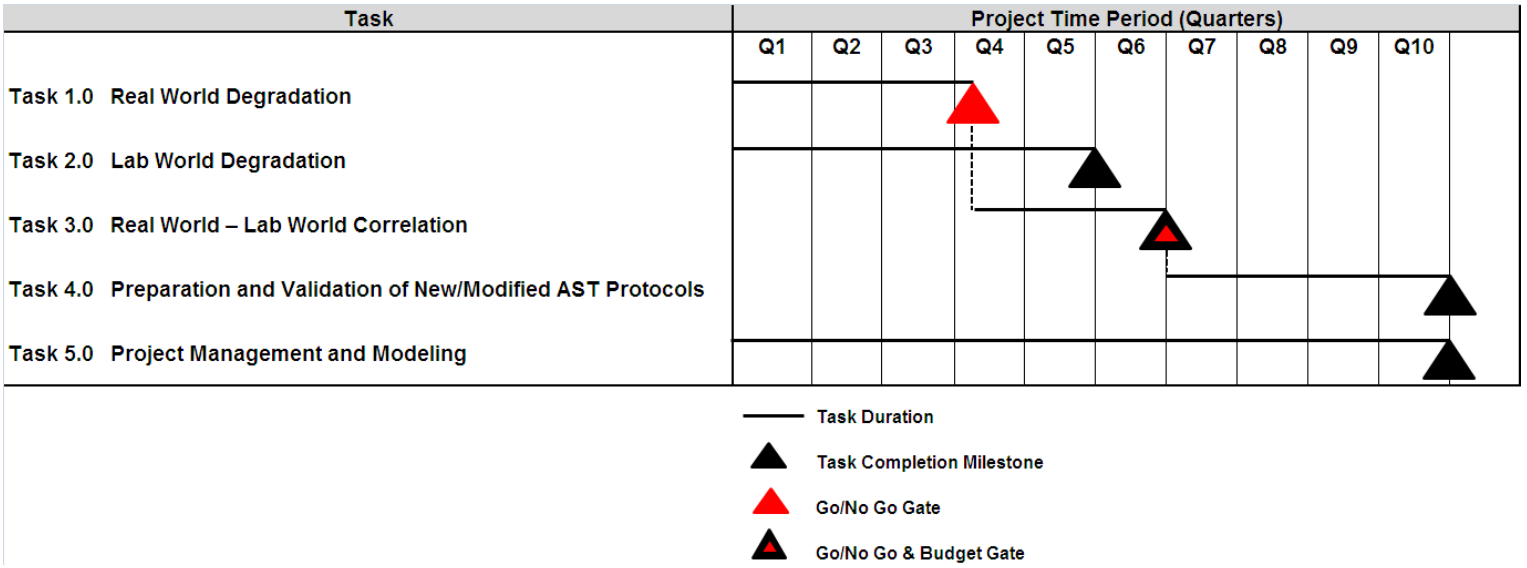
Approach



Task	Progress	Status
1.0 - Real world degradation	• Completed bus operating cycle analysis • Completed characterization of field-operated bus stack (2850hr) for PGM decay mechanism	50% complete
2.0 - Lab world degradation	• 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	• Correlate all observed degradation to field operating conditions	Expected completion – July 2010

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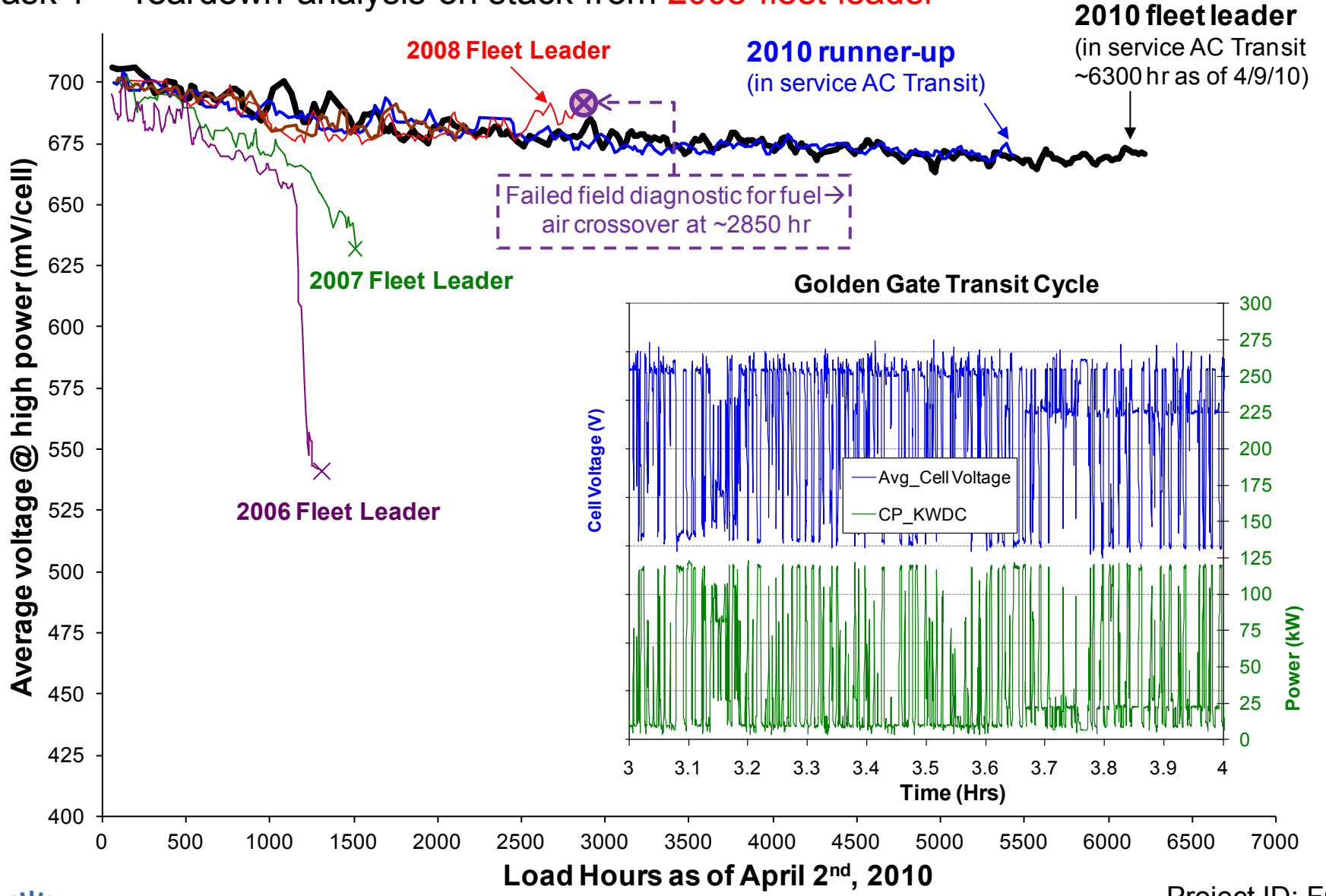
Technical Progress – Real World Stack Degradation

Task 1 - Teardown analysis on stack from 2008 fleet leader



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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

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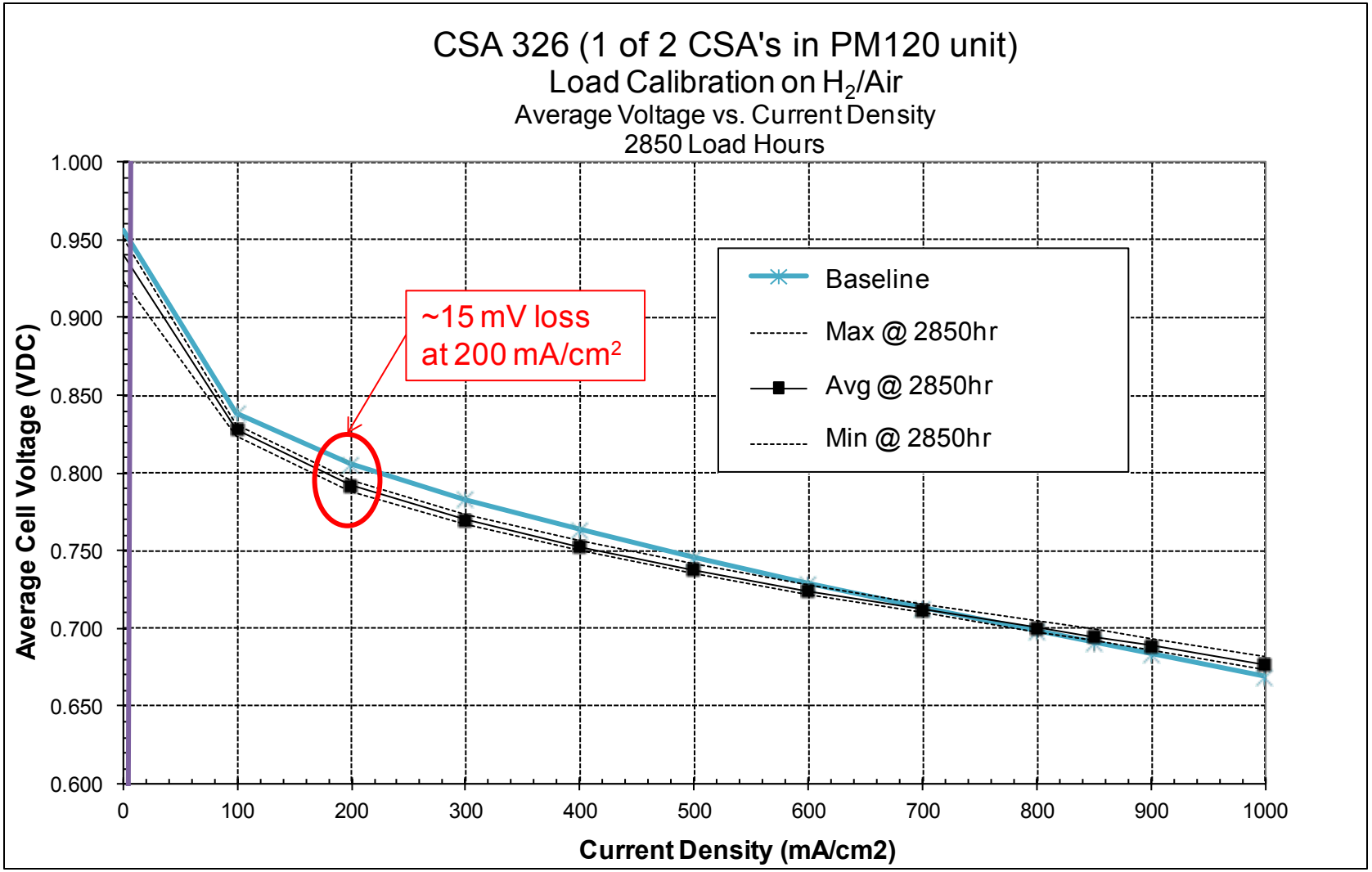
Technical Progress – Real World Stack Diagnostics

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



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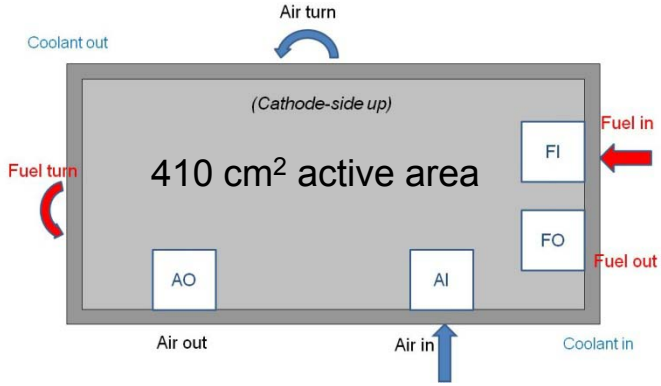
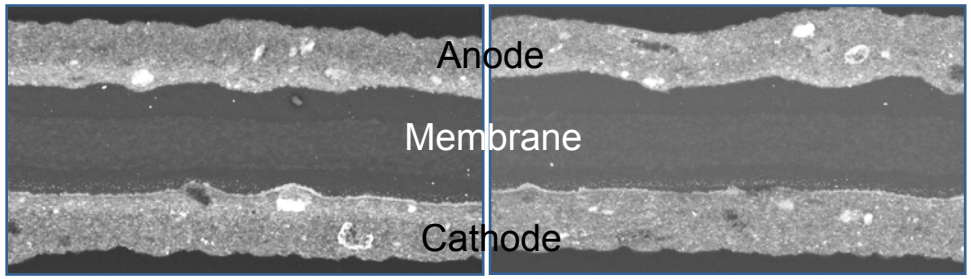
Technical Progress – Real World Stack Teardown

ECA & XRD Baseline vs. 2850 hr



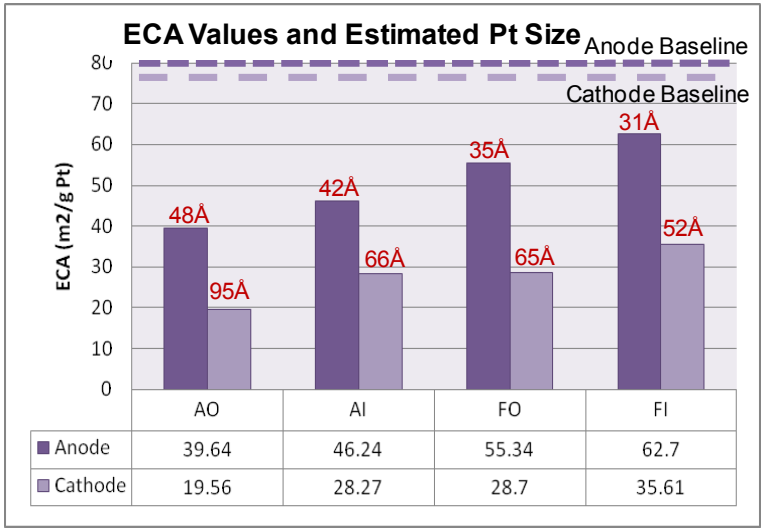
Cell planform and areas analyzed: AI, AO, FI, FO
SEM, ECA (ex-situ) and XRD performed at each location

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

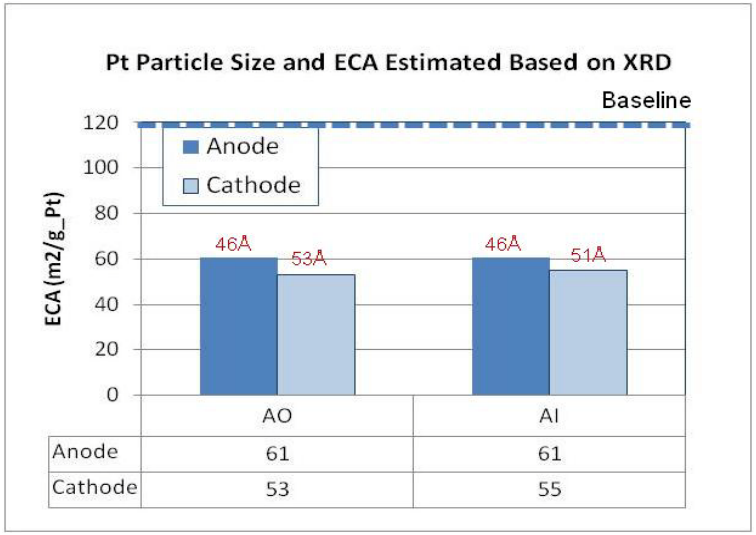


AO AI

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



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

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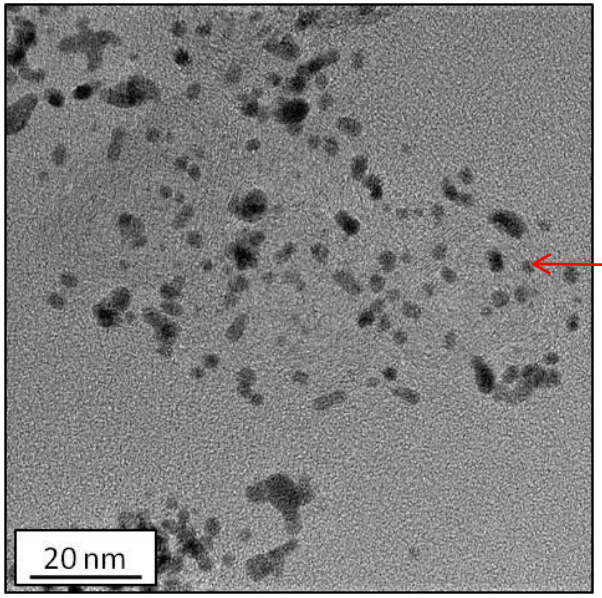
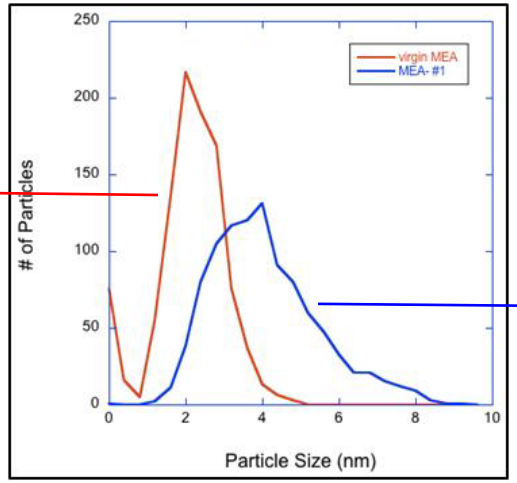
Technical Progress – Real World Stack Teardown

TEM Baseline vs. 2850 hr

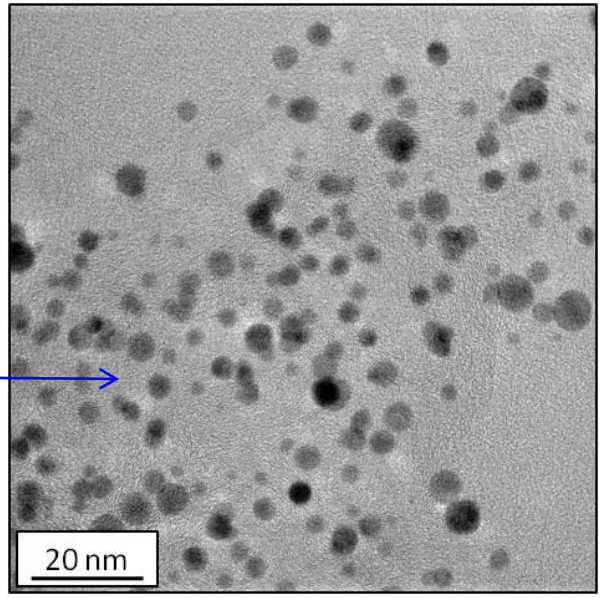
TEM results consistent with ECA & XRD analyses



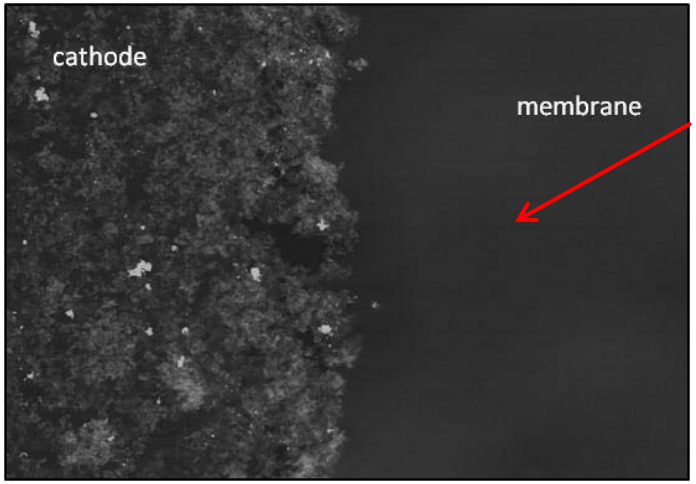
Baseline



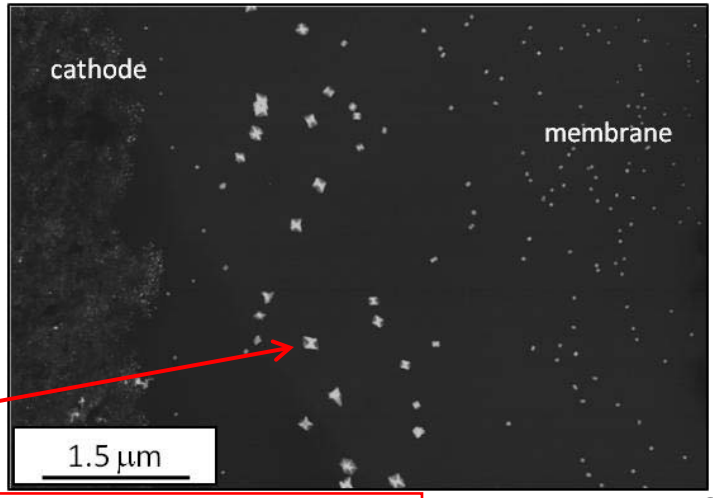
Baseline cathode = ~2nm
2850 hr cathode = ~4nm



Air Inlet - 2850 hr



No Pt observed in membrane of virgin MEA



Pt precipitation in cathode membrane

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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

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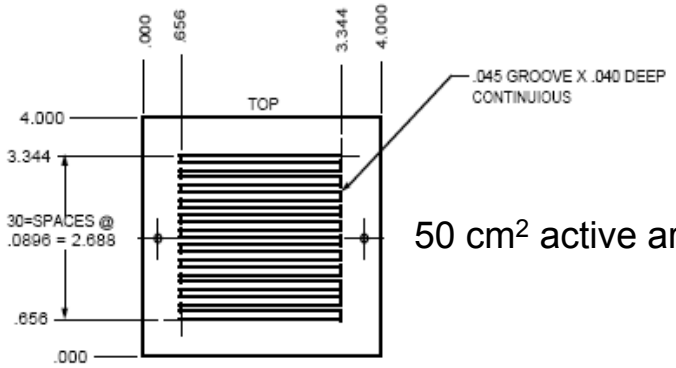
Technical Progress – DOE AST Degradation/Diagnostics

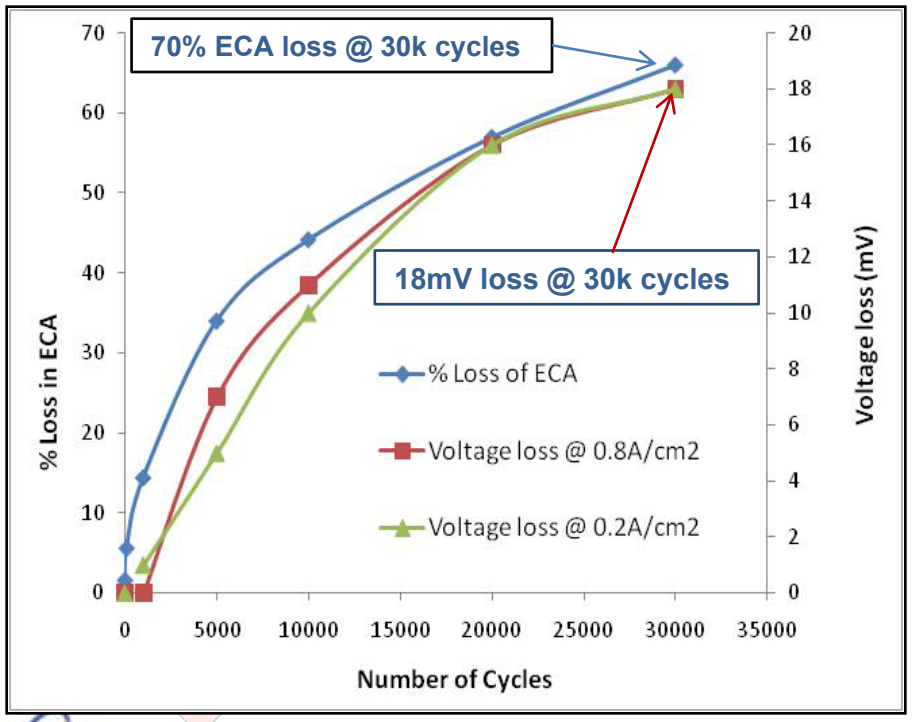
Summary of PGM decay results



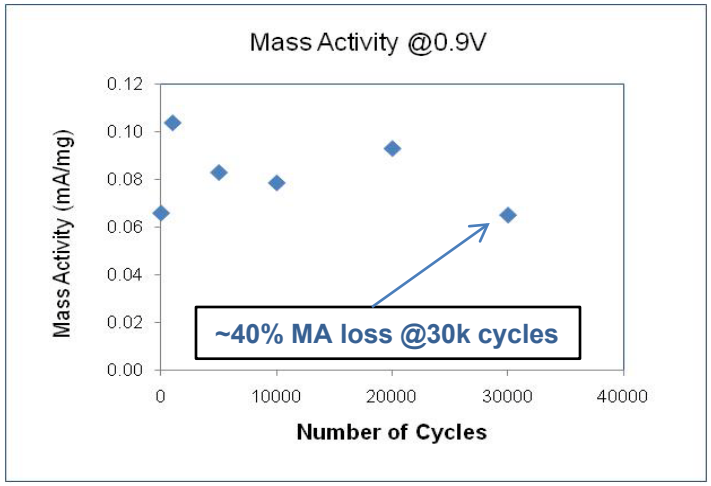
50 cm^2 active area

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	80ºC
%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



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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

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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

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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 kHr 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

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Collaborations

UTC Power
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United Technologies Research Center

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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

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Questions?

UTC Fleet Durability Strategy

Fleet

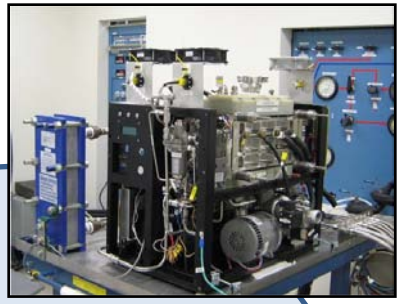
- Real world operation cycle
- Diagnostics
- Performance decay
- Teardown/postmortem

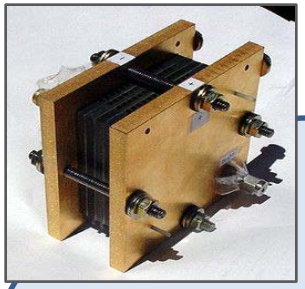
Materials selection

Acceleration factors

- Remaining life
- Materials selection

Operating cycle





Data

Durability Prediction

Modeling

- Membrane failure
- Performance decay

Data

Data

Accelerated Stress Test (ASTs)

- Targeted mechanism
- Diagnostics
- Teardown/postmortem

Accelerated Life Testing (ALT)

- Accelerated real world operation
- Diagnostics
- Performance decay
- Teardown/postmortem

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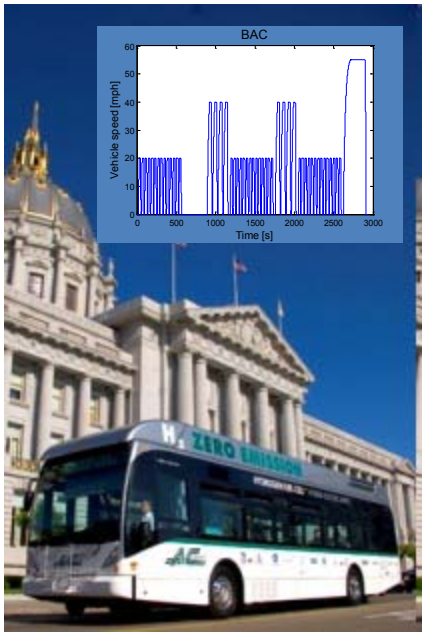
Fleet Hybrid Integration & Test Lab at UTRC

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