V.E.6 Improved Accelerated Stress Tests Based on Fuel Cell Vehicle Data

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Fiscal Year (FY) 2011 Objectives

- Correlate real-world operating conditions to cell degradation.
- Correlate existing DOE accelerated stress tests (ASTs) to degradation.
- Assess degradation modes between real-world operating conditions and existing DOE ASTs.
- Recommend modified ASTs that more accurately gauge in situ component behavior.
- Identify life-limiting mechanisms not addressed by current DOE ASTs and recommend new ASTs.

Technical Barriers

- > 5,000 hours stack durability (including cycling and all materials, e.g. membrane, seals).
- < 10% overall performance decay (including start/stop and transient operation).
- Current DOE ASTs not calibrated with real-world degradation.

FY 2011 Accomplishments

- Fleet performance and operating cycle analyses complete.
- Correlation of platinum decay in real-world operation and lab AST complete.
- Lab ASTs for platinum degradation complete.
- Lab ASTs for carbon support corrosion complete.
- Lab ASTs for membrane mechanical degradation complete.
- Lab ASTs for membrane chemical degradation complete.
- Accelerated life test (ALT) complete.

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Approach

UTC will lead a top-tier team of industry and national laboratory participants to update and improve DOE's ASTs for hydrogen fuel cells. This in-depth investigation will focus on critical fuel cell components (e.g. membrane electrode assemblies [MEAs]) whose durability represents barriers for widespread commercialization of hydrogen fuel cell technology. UTC has access to MEA materials that have accrued significant load time under real-world conditions in PureMotion® 120 power plants used in transit buses. These materials are referred to as end-of-life (EOL) components in the rest of this document. Advanced characterization techniques are used to evaluate degradation mode progress using these critical cell components extracted from both bus power plants and corresponding materials tested using the DOE ASTs. These techniques will also be applied to samples at beginning of life (BOL) to serve as a baseline. These comparisons will advise the progress of the various failure modes that these critical components are subjected to, such as membrane degradation, catalyst support corrosion, platinum group metal dissolution, and others. Gaps in the existing ASTs to predict the degradation observed in the field in terms of these modes will be outlined. Using these gaps, new ASTs will be recommended and tested to better reflect the degradation modes seen in field operation. Also, BOL components will be degraded in a test vehicle at UTC designed to accelerate the bus field operation.

Results

Task 1 - Fleet Data Analysis

Fleet data analysis has been completed and has been reported previously.

Task 2 - Lab-World Degradation

UTC has facilitated the development of a test vehicle for accelerated evaluation of stack components under this project. The main motivation for this exercise results from the relatively slow rate of load-hour accrual for buses in the field. Because UTC Power is currently targeting >18,000 hours stack durability for bus fleet applications, a more rapid test vehicle is necessary to increase product maturity on new stack configurations. The test vehicle for accelerated stack component evaluation is termed the ALT. This small power plant has the identical piping and instrumentation configuration as the bus power plant, but operates on a 5-kW short stack. The key operating modes of the bus that have been linked to stack component degradation have been reflected in the protocol. The implementation of the ALT vehicle has been complete. Testing of the unit has been completed. The results are described in the following paragraphs.

Figure 1 shows the UTC bus fleet durability data. The 2006 fleet leader failed after 1,000 hours due to carbon corrosion of the cathode gas diffusion layer (GDL). A carbon corrosion AST was developed to evaluate resistance of cathode GDLs to oxidizing conditions. The protocol for this AST is summarized in Table 1. The acceleration factor for the GDL corrosion based on this test was approximately 10X of the fleet data. Using the AST for carbon corrosion, a new cathode GDL was implemented into the 2008 fleet leader. As shown in Figure 2, the new GDL showed at least a 5X improvement in durability over the 2006 fleet leader GDL at 0.55 V. This enabled the fleet durability to increase from 1,000-1,500 hours to 2,800 hours, at which point the 2008 fleet leader failed due to membrane failure. The failure was caused by mechanical fatigue due to hydration strain cycling at the air inlet. A membrane AST protocol, shown in Table 2, was developed to evaluate membrane resistance to hydration strain cycling. Scanning electron microscope images, shown in Figure 3, of the MEA returned from the field and the MEA tested using the lab AST protocol show that the failure mode was consistent. Figure 4 shows the open circuit voltage (OCV) pressure response with time as a function of temperature, load profile, and membrane type. The MEA in the 2011 fleet leader shows a >16X improvement in lifetime over the 2008 fleet leader MEA in the membrane AST protocol. As shown in

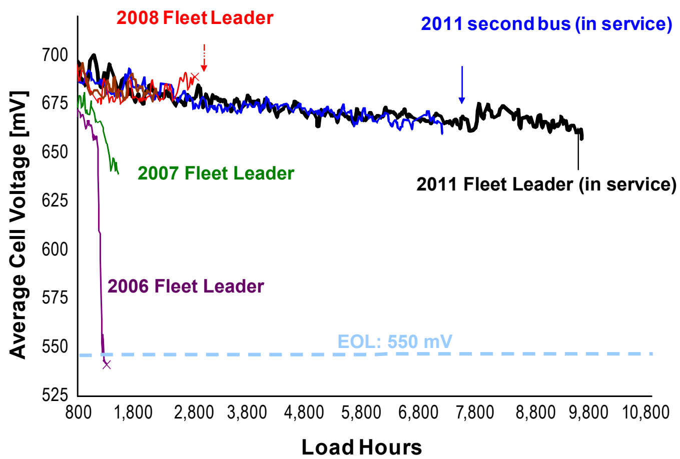

FIGURE 1. UTC Fleet Durability Data

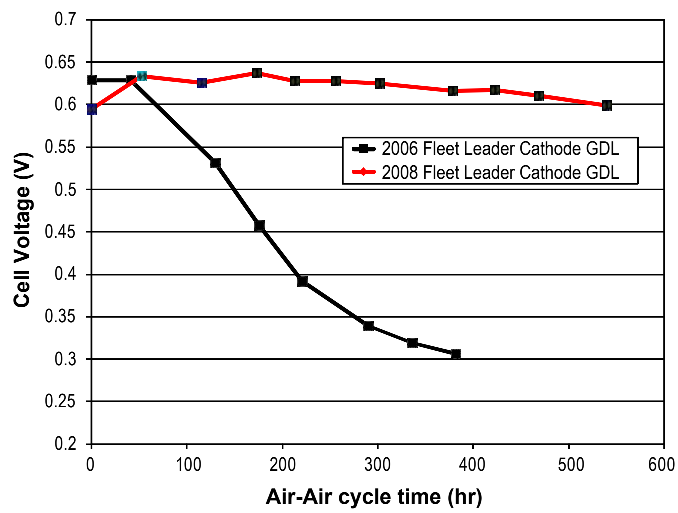

FIGURE 2. Effect of Cathode GDL on Performance Decay in Carbon Corrosion AST

TABLE 1. AST Protocol for Air-Air Cycling Test

Coolant inlet temperature (°C)	**65°C**		
Percent Relative Humidity	**100**		
Cell Current	**0 Amps**		
Reactant flow cycle	**Time**	**Anode Reactant**	**Cathode Reactant**
	5 minutes	H_2	H_2
	5 minutes	N_2	N_2
	1 hour	Air	Air
	5 minutes	N_2	N_2
Applied external resistance	<0.2 mOhm (to avoid potential difference between anode and cathode)		

TABLE 2. AST Protocol for High Temperature Flow/Load Cycling Test

Coolant inlet temperature (°C)	80°C	
Percent Relative Humidity	100	
Anode reactants	Hydrogen, 80% utilization (SR = 1.25)	
Cathode reactants	Air, 60% utilization (SR = 1.66)	
Load cycle	**Time**	**Current density**
	20 sec	10
	15 sec	800 or 1,500 mA/cm^2
OCV Pressure Response	Measure cell voltage difference at open circuit when the anode to cathode cross-pressure is changed from 0 kPa to 15 kPa	

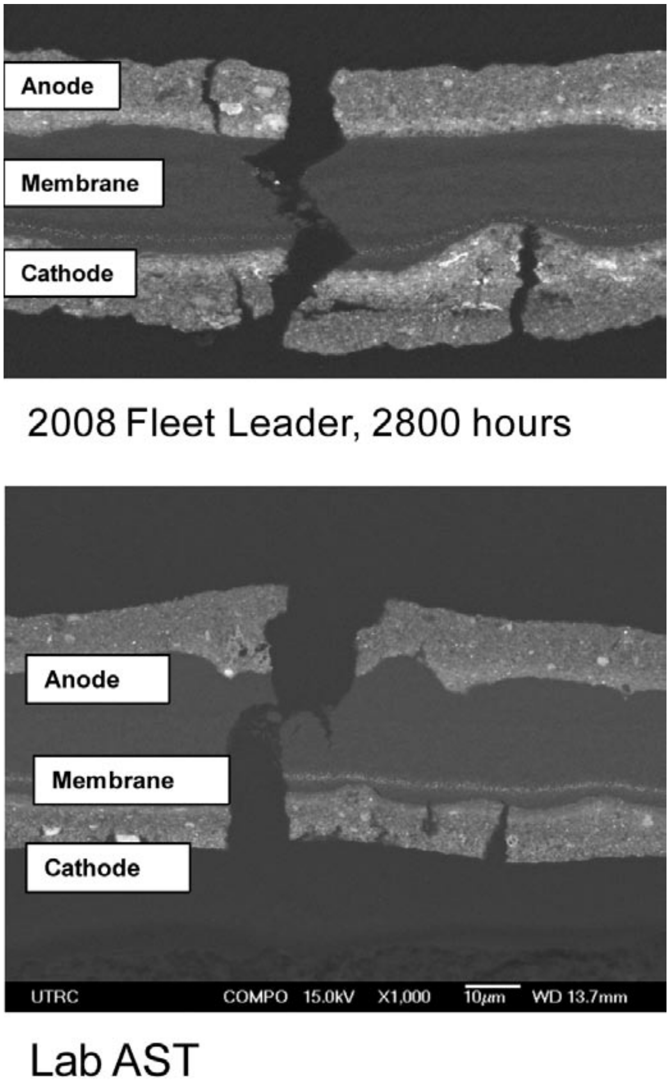

FIGURE 3. Comparison of Microscopy Results for MEAs Run in the Field and in Lab ASTs

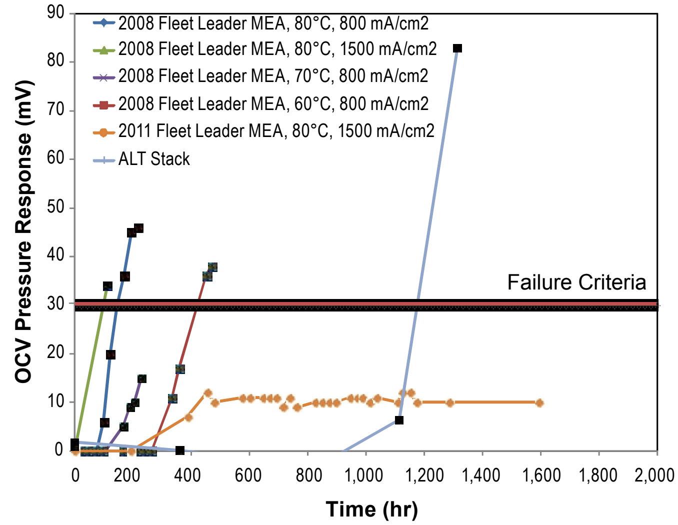

FIGURE 4. Summary of Open Circuit Voltage (OCV) Pressure Response for Single-Cell And Short Stack Membrane AST

Figure 1, implementation of this MEA in the field resulted in an increase in field durability from 2,800 hours to over 9,600 hours, or 3.4 times higher. Based on the acceleration factor measured in the lab AST, the MEA in the 2011 fleet leader is projected to last over 40,000 hours, if mechanical fatigue is still the controlling failure mode.

The effect of temperature and current density was also investigated. As shown in Figure 4, increasing the temperature from 60°C to 80°C decreased the lifetime by a factor of 4. Increasing the current density from 800 to 1,500 mA/cm^2 decreased the lifetime by about 20%. The ALT rig ran at 70°C, with a load cycling profile that mimics the fleet cycle. The ALT failed at 1,400 hours whereas the single cell, running at the same temperature, failed at 250 hours. The ALT cycle is much faster than the single-cell AST protocol. The membrane stress is lower in the ALT cycle because the rapid cycling does not allow the membrane water content to reach equilibrium. This is also apparent between the single cell run at 60ºC and the field unit, which also runs at 60ºC. The field unit lasted 2,800 hours, or seven times longer than the single cell, which only lasted 400 hours. These results indicate that the load cycle profile is as important to membrane durability, if not more, as the operating temperature. Table 3 summarizes the membrane AST results and membrane lifetime predictions.

TABLE 3. Summary of Membrane AST Data and Membrane Life Predictions

Membrane	Cyclic Protocol	Temperature	Estimated Time to Failure (hr)	Actual Time to Failure (hr)
2008 Fleet leader	Membrane AST	60°C	Not Applicable	425
2008 Fleet leader	Membrane AST	70°C	Not Applicable	~250
2008 Fleet leader	Membrane AST	80°C	Not Applicable	120
2011 Fleet leader	Membrane AST	80°C	Not Applicable	>1,600
2008 Fleet leader	Field (ALT)	70°C	Not Applicable	1,400
2008 Fleet leader	Field	60°C	2,975	2,800
2011 Fleet leader	Field	60°C	45,000	>9,500 (still running)

Conclusions and Future Directions

- Fleet/Real-World: UTC fleet performance and operating cycle analyses have been completed and reported. Teardown analyses of the real-world degraded components have been completed and reported.
- Lab-World: ASTs for platinum group metal decay, carbon support corrosion, membrane mechanical decay, and membrane chemical decay have been completed. Teardown analyses of the lab-world degraded components have been completed and reported.
- ALT: Testing has been completed.
- Next Step: Correlate real-world degradation to lab tested degradation for carbon corrosion of GDLs. Develop ex situ aging method for GDLs to isolate GDL oxidation effects from catalyst layer oxidation effects.

FY 2011 Publications/Presentations

1. "Improved AST's based on FCV data" presentation to Freedom CAR & Fuel Partnership, Fuel Cell Tech Team Review January 13, 2010.

2. "Improved AST's based on FCV data" presentation to DOE Annual Merit Review meeting June 8, 2010.

3. "Improved AST's based on FCV data" presentation to DOE Annual Merit Review meeting May 12, 2011.

4. "GDL Degradation in PEFC", ECS Transactions - Las Vegas, NV Volume 33, Polymer Electrolyte Fuel Cells 10, from the Las Vegas, NV meeting, October 30, 2010.

5. "Use of Mechanical Tests to Predict PEMFC Membrane Durability under Humidity Cycling", Journal of Power Sources, 196 (2011) 3851–3854.