V.H.3 Durability of Low Platinum Fuel Cells Operating at High Power Density

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- Los Alamos National Laboratory (LANL), Los Alamos, NM
- Argonne National Laboratory (ANL), Argonne, IL

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Objectives

- The objective of this project is to study and identify strategies to assure durability of fuel cells designed to meet DOE 2015 cost targets.
- Develop a practical understanding of the degradation mechanisms impacting durability of fuel cells with low platinum loading (≤0.2 mg/cm^2) operating at high power density (≥1.0 W/cm^2)
- Develop approaches for improving the durability of low-loaded, high-power stack designs.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability

(B) Cost

Technical Targets

TABLE 1. Progress towards Meeting Technical Targets for Transportation Fuel Cell Stacks Operating on Direct Hydrogen for the Transportation Applications

Characteristics	Units	2010/2015 Stack Targets	Nuvera 2010 Status
Cost	\$/kWe	25/15	~22 estimated[1]
Durability with cycling	Hours	5,000	9,000 hrs[2] 2,000 hrs in automotive cycle conditions[3]
Performance at rated power	mW/cm^2	1,000	1,200[4]

[1] Cost assessment of Nuvera's architecture by Directed Technologies, Inc. based on their DOE-sponsored Design for Manufacturing and Assembly model [1] and comparing the results to an updated "Industry" estimate. 0.60 V/cell @2.0 A/cm^2 were obtained at 0.5 mg/cm^2 platinum loading on Orion stack by Nuvera.
[2] Demonstrated under power profile specific-to-fork truck applications in material handling market at total platinum loading of 0.5 mg/cm^2.
[3] Demonstrated in 360-cm^2 stack by Nuvera in New European Driving Cycle power profile at platinum loading of 0.50 mg/cm^2.
[4] Demonstrated in 250 cm^2 stack by Nuvera - 0.60 V/cell @ 2.0 A/cm^2.

Accomplishments

- Nuvera completed system analysis specific to high-power operation and its impact on the process conditions throughout the active area of the fuel cell stack. The results informed the experimental design for the combined test cycles, or new stress tests (NSTs), based on rated current density (RCD) of 1, 2 and 3 A/cm^2 and respective constant power turn down.
- New single-cell, open flowfield hardware capable of high RCD was developed and validated over the planned range of experimental operating conditions.
- Catalyst-coated membranes (CCMs) with two levels of platinum loadings (0.45 and 0.2 mg/cm^2) were selected and the higher loaded material was procured and characterized at the beginning of life (BOL) in Nuvera 360-cm^2 cells and LANL 50-cm^2 hardware throughout the range of operating conditions. The CCM proved promising to allow increased operating temperature with sub-saturated inlet gasses at appropriate gas stoichiometries as targeted by the automotive system map presented by ANL [2]. An accelerated stress test (AST) campaign on the selected material set has started at LANL.
- ANL performance model was calibrated for the open flowfield, and the resulting modeling polarization curves matched Nuvera experimental BOL data, completing the ground work for further development of the durability model.

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Introduction

Understanding and improving the durability of cost-competitive fuel cell stacks is imperative to successful deployment of the technology. Stacks will need to operate well beyond today's state-of-the-art rated power density with very low platinum loading in order to achieve the cost targets set forth by DOE ($15/kW) and ultimately be competitive with incumbent technologies. Little-to-no study of durability factors has been carried out in this area of design and operation. The industry today is focusing mostly on reduced platinum loading as it heads for the DOE target point of 0.2 mg/cm^2 platinum and 1.0 W/cm^2 power density. As demonstrated through DOE-sponsored cost modeling, this point falls short of the corresponding $15/kW stack cost target for 2015.

Approach

Nuvera proposes an accelerated cost-reduction path focused on substantially increasing power density to address non-platinum group metal material costs as well as platinum. Understanding the largely unstudied factors affecting stack durability under these high power conditions is the focus of the present project. Of specific interest is the impact of combining low platinum loading with high power density operation, as this offers the best chance of achieving long-term cost targets. The team effort will be divided into two activities: modeling and experiments.

Results

Development efforts were focused on the detailed design, procurement and validation of single cell with open flowfield (SCOF) hardware. Nuvera's patent pending design, shown in Figure 1, allows operation at high current density, flexible selection of the flowfield design, simulation of stack-level temperature gradients as well as an isothermal profile, control and uniformity of compression over the active area apart from sealing, and current distribution measurement.

Material sets A and B were selected for the project in standard and custom platinum loadings with advice from leading CCM developer W.L. Gore. Anode electrode 584.05 loaded at 0.05 mg/cm^2, membrane M815 at 15 microns thickness, and cathode electrode C580.4 loaded at 0.4 mgPt/cm^2 comprise the benchmark CCM A. Custom cathode electrode C580.15 is being procured by W.L.Gore for the CCM B, preserving the same anode electrode structure and membrane as in CCM A and resulting in total platinum loading of 0.2 mg/cm^2 in material set B. All cells are assembled with gas diffusion media produced by W.L. Gore.

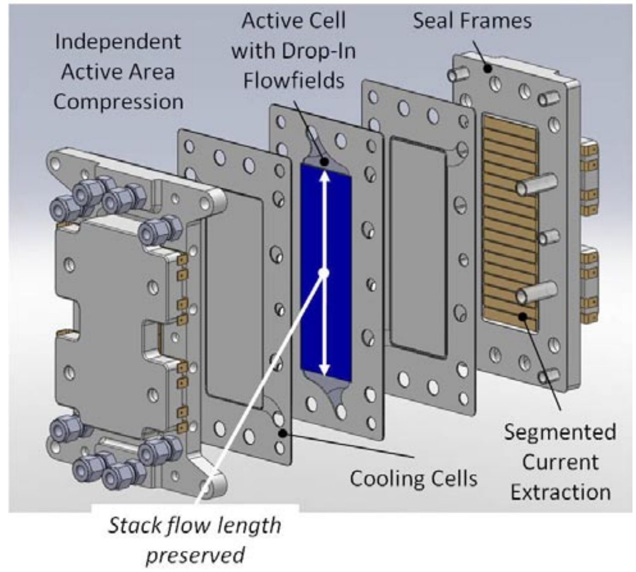


FIGURE 1. Single Cell with Open Flowfield

Material set A was received in 50-cm^2 format for the ASTs and in 360-cm^2 format for the NSTs and characterized for the BOL polarization curve, sensitivities to relative humidity, temperature, and cathode stoichiometry. Data obtained both at Nuvera and Gore demonstrated capabilities of M815 to increase the window of operating temperatures using sub-saturated inputs to the cell provided specific stack operating conditions are maintained. Electrochemical impedance spectroscopy and other diagnostic data obtained on material A both at LANL and Nuvera showed expected cell low initial resistivity and other metrics to be monitored in the test campaign.

In the experimental campaign we focused only on those ASTs which provide direct input to the durability model and can be compared to the fuel cell tests under load protocols (NSTs). ASTs will focus on the electrocatalyst stability at cycling potential defined in B1 protocol by the DOE. Additional AST B1* will be conducted with a lower range of cycling potential than B1 to correspond to the cell voltage achieved in Nuvera large-area cell at 2.0 A/cm^2. We will also focus on the membrane mechanical stability defined in the B4 protocol by the DOE.

The NST protocols focused on the combined power cycles at the different current densities were proposed, discussed and agreed among Nuvera, LANL and ANL. Three groups of NSTs are defined as following: **N1** is the group of sensitivity tests aimed at evaluating the addition of electrical current on the ASTs, **N2** is a group of combined humidity and load cycles derived from the protocol recommended by the Fuel Cell Technical Team (FCTT), and **N3** is a group of combined city/highway drive cycles accounting for system conditions and implications.

The test plan is designed along three parameter vectors: total Pt loading, current density and the flowfield architecture (graphite single cell with land and channel, SCOF and stack). The latter parameter doesn't represent a quantified metric, however, is chosen to maximize applicability of the test results across the industry. The schematics of the experimental design space is shown in Figure 2.

N3A-X protocols were evaluated in Nuvera 360-cm^2 cell stacks for performance and stability over several hundred hours. On-going N3A-2 durability test on material set A in an eight-cell stack is currently passing 600 hours with the cell voltage decay stabilizing below 10 µV/hr/cell at 1 and 2 A/cm^2 current density, shown in Figure 3.

A two-dimensional fuel cell performance model was established at ANL and initial assessment against

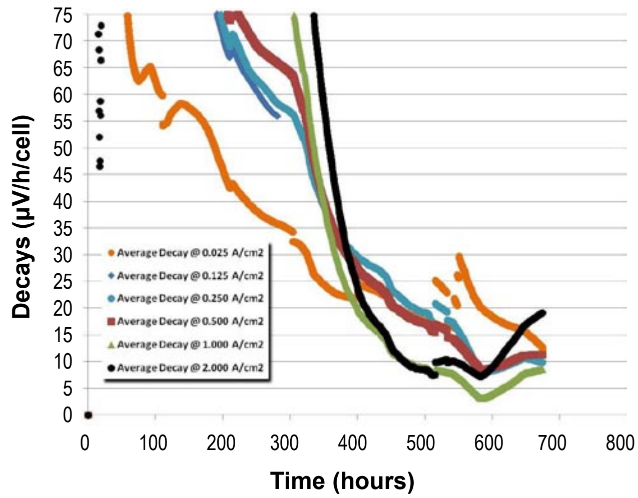
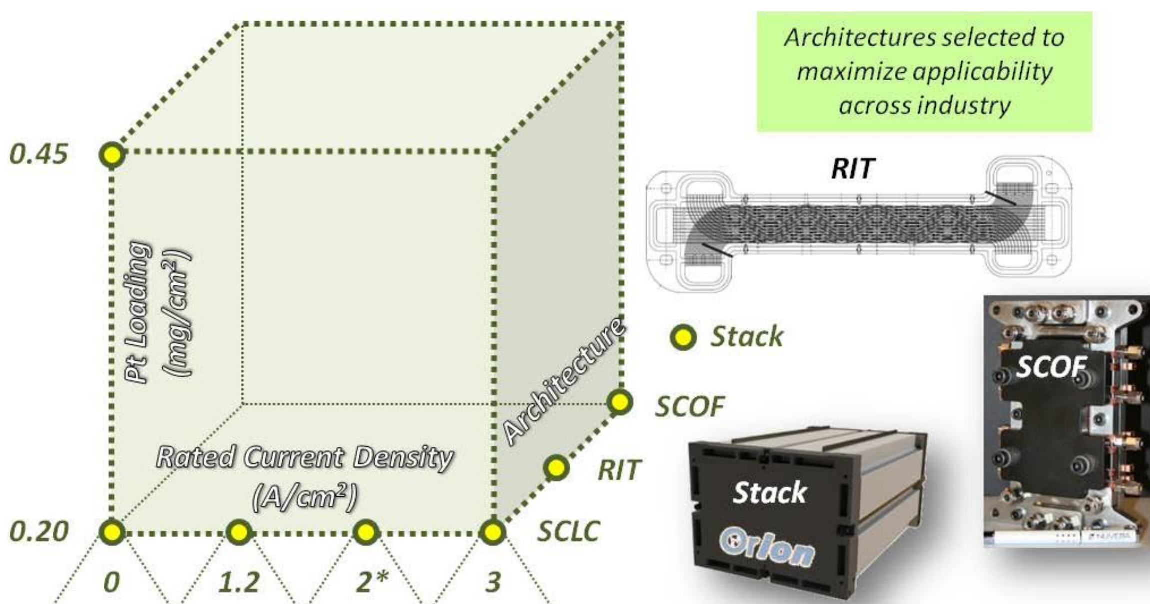


FIGURE 3. N3A-2 Test Progress



AST	NST			Purpose
B1		N1A-2		Benchmarking+Electrocatalyst cycle stability with and without current
B1*				*B1* potential limits equivalent to N1A-2*
B4		N1B-2		Membrane mechanical stability with and without current
	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

** mid-current point added based on FCTT recommendations*

FIGURE 2. Experimental Design Space

the BOL data was completed. The model accounts for: a) a seven-layer cell architecture, including both anode and cathode flowfields, gas diffusion and catalyst layers; b) temperature, current, potential, relative humidity, and species distribution; and c) anode/cathode counter-flow, cathode/coolant co-flow. Modeling results were calibrated with the polarization curves from 360- and 250-cm^2 area cell stacks.

Polarization curves resulting from modeling effort are plotted in Figure 4 overlaying experimental data at BOL on 360-cm^2 area cells with 18-micron membrane and 0.5 mg/cm^2 total Pt loading electrodes, representing Nuvera's internal benchmark MEAs.

Conclusions and Future Directions

The work completed in the first nine months of the project has concluded the preparatory phase of the experimental and modeling scope. All partners agreed to the detailed experimental test plan of ASTs and NSTs going forward. Preliminary qualification of CCM A in

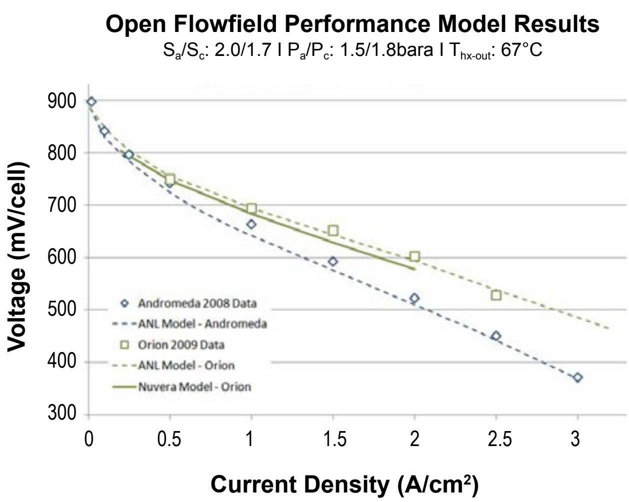


FIGURE 4. Performance Model Results

Nuvera 360-cm^2 area stacks proved the feasibility of using this material set for the project and helped establish essential aging parameters towards understanding degradation mechanisms and durability model development. In the next period work will focus on:

- Delivery to and validation of SCOF at LANL.
- Completing ASTs on CCMs A and B and analysis of test results by the partners.
- Analysis of the ANL model's sensitivities to metrics recorded in the ASTs.
- Beginning the NST campaign on SCOF both at LANL and Nuvera.
- Continuing the NST campaign in the large-format cells in short stacks and benchmarking the results between SCOF and large area cells.
- Publishing the degradation model framework and further model validation.

Special Recognitions & Awards/Patents Issued

1. B.S.Lunt Variable load fuel cell. Patent pending Application #61319522, 03/31/2010.

FY 2010 Publications/Presentations

1. J. Cross –FCTT SPIRE Project Review, January 13, 2010, Southfield, MI.

2. B. Lunt -High Power Density Test Fixture, Small Fuel Cells Conference, April 13, 2010, Cambridge, MA.

3. S. Blanchet, SPIRE, 2010 DOE Annual Merit Review, Washington, D.C., June 8, 2010.

References

1. B.James et al, Mass Production Cost Estimation for Direct H2 PEM Fuel Cell Systems for Automotive Applications, March 26, 2009.

2. R.K. Ahluwalia et al, Fuel Cell System Analysis. DOE Hydrogen Annual Merit Review 2010, Washington, D.C.