V.F.6 Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks

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Subcontractors:
- Johnson Matthey Fuel Cell Ltd., London, United Kingdom
- Lawrence Berkeley National Laboratory, Berkeley, CA
- Pennsylvania State University, State College, PA
- University of Tennessee at Knoxville, Knoxville, TN

Project Start Date: September 1, 2009
Project End Date: August 31, 2012

Fiscal Year (FY) 2011 Objectives

- Develop and publish a predictive transport model that enables efficiency maximization at conditions that meet DOE cost targets.
- Demonstrate stable and repeatable high performance on a full-format fuel cell stack, namely 7.5 W/mg-Pt.
- Optimize the efficiency (electric potential at rated current) of a stack technology that meets DOE cost targets.

Technical Barriers

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

(B) Cost

(C) Performance

(E) System Thermal and Water Management

Technical Targets

This project is primarily focused on reducing stack cost and improving efficiency by modeling and optimizing transport properties of the membrane electrode assembly (MEA). Stack cost is reduced through a combination of increased power density and decreased noble metal content. The performance target of 7.5 W/mg-Pt @ 500 mV was selected, based on cost modeling results, as the performance required to achieve the 2015 DOE cost target of \$15/kW$_e$. Efficiency (electric potential at rated current) of the stack technology will be optimized with the ultimate goal of approaching the 2015 DOE efficiency targets:

- Stack efficiency @ rated power: 55%
- Stack efficiency @ 25% of rated: 65%

FY 2011 Accomplishments

- A new gradient preserving single-cell fixture capable of high power density operation was delivered to University of Tennessee, Knoxville (UTK)/Penn State University (PSU), and Johnson Matthey Fuel Cells (JM).
- Single-cell testing was conducted on two flowfield architectures, and the results suggest that the performance advantage of open flowfield is the result of improved oxygen diffusion to the cathode reaction sites.
- A two-dimension (2D)+1 mathematical model capable of predicting high current density operation in different architectures was developed and refined, and the accuracy of the model was partially validated with experimental testing.
- MEAs with low Pt loading electrodes, thin membranes, and low equivalent weight (EW) ionomer in the electrodes were developed and optimized for performance at ultra-high current densities.
- The Go/No-Go milestone was satisfied by demonstrating >1 W/cm^2 @ 0.2 mg-Pt/cm^2 on a full-format stack.

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Introduction

Hydrogen fuel cells are recognized as one of the most viable solutions for mobility in the 21st century; however, there are technical challenges that must be addressed before the technology can become available for mass production. One of the most demanding aspects is the costs of presentday fuel cells which are prohibitively high for the majority of envisioned markets. The fuel cell community recognizes two major drivers to an effective cost reduction: (1) decreasing the noble metals content, and (2) increasing the power density in order to reduce the number of cells needed to achieve a specified power level. Nuvera's technology exhibits great promise for increasing power density on account of its proven ability to operate stably at high current densities (>1.5 A/cm^2). However doing so compromises efficiency, increases the heat rejection duty, and is thus more demanding on the cooling system. These competing aspects are being assessed in order to identify the proper trade offs, and ensure the modeling and experimental activities of the AURORA Program respect system-level constraints for automotive applications. This project will develop a predictive transport model to identify and help us reduce losses and increase efficiency for high current density operation.

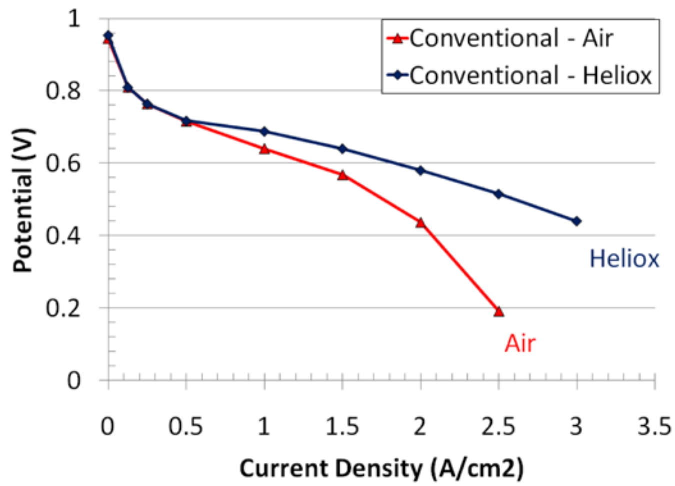
Approach

Nuvera structured the activities in the scope of the project to orbit around a focal point consisting of the fuel cell predictive model. Cost and system analyses were performed in order to define the boundaries of the design space that the model should represent. This analytical work will inform the experimental tests on a new single cell fixture to illuminate the physics and the parameters composing the backbone of the fuel cell model. The predictions generated by the model drive both the process of optimization of the fuel cell operating conditions and the material development. The combined results of these two activities are verified on single cell fixtures as well as on full active area hardware, and the experimental data obtained is used to validate and calibrate the model through multiple iterations.

Results

In FY 2011 Nuvera delivered a new gradient preserving single-cell open flowfield (SCOF) cell to partners UTK/PSU and JM. A new single-cell test station was also received and commissioned to facilitate SCOF testing at Nuvera. A number of test station issues were resolved with hardware upgrades, and the test station is now fully verified, and SCOF testing has begun.

UTK/PSU tested both a conventional land/channel cell and the Nuvera SCOF cell in order to compare the two architectures. The results highlight a significant advantage of the SCOF cell to operate at ultra-high current densities without suffering from diminishing return of power density. As shown in Figures 1 and 2, the conventional land/channel cell exhibits significantly lower performance with air than with heliox while the Nuvera SCOF cell exhibits almost the same performance with both oxidants. The SCOF cell operating with air also exhibited similar performance to the conventional land/channel cell operating with heliox. These results suggest that the performance advantage of the SCOF is the result of improved oxygen diffusion to the cathode reaction sites.



Tcell= 60°C, An 50% RH, Ca 0% RH, Press ~1.1 to 1.8 bara
MEA: Gore 5730, 0.15 mg Pt/cm^2 An, 0.4 mg Pt/cm^2 Ca - GDL: SGL 25BC

RH - relative humidity; GDL - gas diffusion layer

FIGURE 1. Air vs. Heliox Performance Comparison of Conventional Land/Channel Architecture

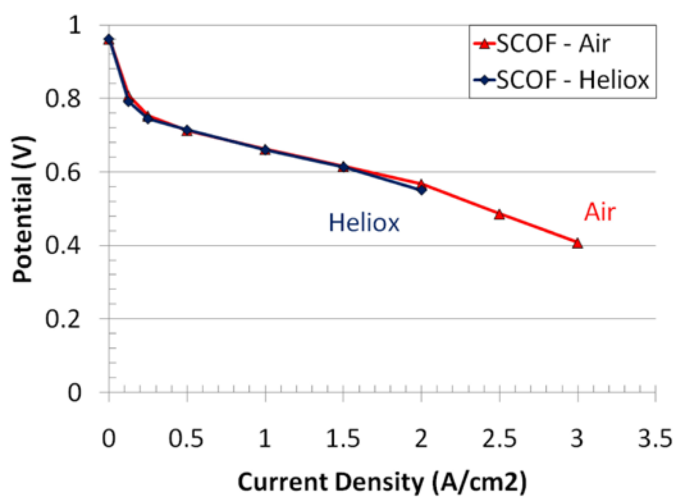


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FIGURE 2. Air vs. Heliox Performance Comparison of SCOF Cell With Open Architecture

UTK/PSU also developed and refined a 2D+1 mathematical model capable of predicting high current density operation for different flowfield architectures. The physics and electrochemistry of a previously implemented 2D model was used to create a new 2D+1 "AURORA model" capable of simulating both the conventional land/channel and Nuvera open flowfield architectures. Significant additional physics were added to the model formulation in order to more accurately predict water, gas, and heat transport, and an advanced agglomerate electrode model from Lawrence Berkeley National Laboratory (LBNL) was integrated into the model in order to provide a more accurate account for cathode kinetic loss. The accuracy of this model has been partially validated with simultaneous in situ experimental testing in terms of performance, high frequency resistance (HFR) and net water drag coefficient. The predictions from the 2D+1 model are compared with experimental results in Figure 3 in terms of performance and HFR with close agreement. Consistent with experimental results, the computational model predicts that the HFR increases with current density, which signifies the onset of the possible membrane dry-out in the ultra-high current density regime. The experimental and modeling investigation found that for the open flow field architecture, gas phase mass transport is not the limiting factor even in the ultra-high current regime.

JM developed low Pt loading MEAs optimized for performance at ultra-high current densities. JM produced and tested a number of MEA design iterations in order to develop an MEA with low Pt loading electrodes, a thin low resistivity membrane, and low EW ionomer in the electrodes. First, a low loading (0.2 mg/cm^2) electrode design was optimized with a thin membrane to achieve a performance improvement of 50 mV @ 2 A/cm^2 over the baseline which had higher Pt loadings (0.5 mg/cm^2) and a thicker membrane. This optimized MEA was produced and delivered to Nuvera for testing. The performance of the MEA was then improved even more by using a low EW ionomer (between 750 and 850) in the electrode. Initial versions of the MEA with low EW ionomer exhibited performance lower than expected as a result of significant electrode flooding. The electrode was then optimized for water management, and the final version was able to achieve a performance improvement of 40 mV @ 2 A/cm^2 in the JM single cell. This new MEA design was also produced and delivered to Nuvera for testing. Development work has started for anode electrodes with very low Pt loading (0.02 mg/cm^2). Initial results show promise at low current densities, however water management has been an issue at high current densities thus far.

Nuvera tested various developmental MEAs from JM on full format automotive stacks. Figure 4 shows performance of two optimized MEA designs, MEA 23 (blue) has a thin membrane with high Pt loadings (0.5 mg/cm^2), and MEA 25 (red) has the same thin membrane with low Pt loadings (0.2 mg/cm^2). As expected, the low Pt loading MEA exhibits lower performance in the low current density Tafel region (30 mV lower @ 0.2 A/cm^2) due to lower electrochemical surface area; however, the ohmic losses of this MEA are lower and the performance approaches that of the high loading MEA at high current density (2 A/cm^2). The high performance demonstrated by the low loading MEA of 0.548 V @ 2 A/cm^2 exceeded the 1 W @ 0.2 mg-Pt/cm^2 target and satisfied the Go/No-Go milestone for the project.

Conclusions and Future Directions

Nuvera has demonstrated high performance (5.57 W/mg-Pt), satisfying the Go/No-Go milestone, and Nuvera will continue evaluating JM development materials with the goal of demonstrating stable and repeatable high power performance of 7.5 W/mg-Pt on a full format fuel cell stack.

JM has achieved significant Pt reduction and performance improvements at high current density and will continue executing the materials development plan investigating reduced loading anode electrodes, graded Pt cathode electrodes, and novel MEA architectures.

UTK/PSU has developed, refined, and partially validated a predictive 2D+1 mathematical model using feedback from simultaneous in situ experimental testing. UTK/PSU will continue tuning and validating the model, in

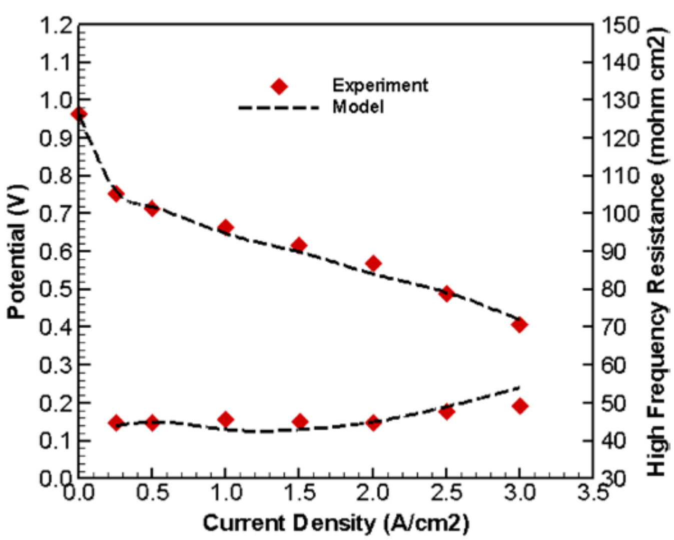

FIGURE 3. Comparison of Voltage and HFR between Experiment and Model

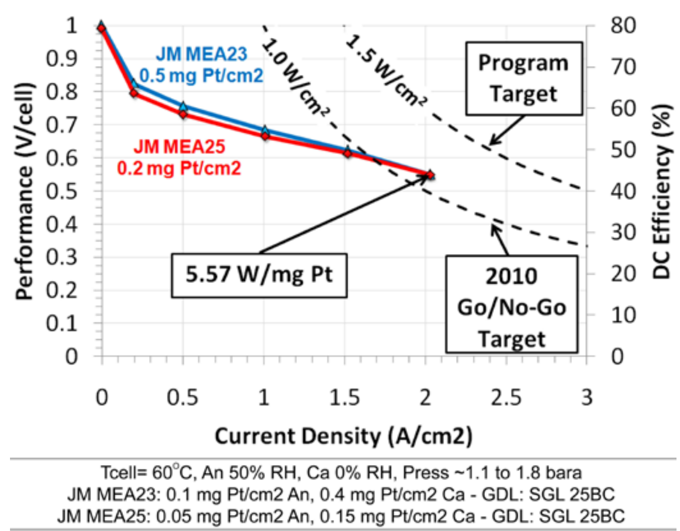

FIGURE 4. Performance Curves of Standard and Low Loading JM MEAs with Thin Membranes

terms of performance, HFR, and net water drag coefficient, with the goal of publishing a fully validated predictive model at the end of the project.

FY 2011 Publications/Presentations

1. May 2011 – Washington, D.C. - 2011 DOE Hydrogen Program Merit Review (FC028).

2. June 2011 – Detroit, MI - FreedomCar Review.