V.F.4 Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks

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Contract Number: DE-EE0000472

Subcontractors:
- Johnson Matthey Fuel Cell Ltd., UK
- Lawrence Berkeley Laboratory, Berkeley, CA
- Pennsylvania State University, State College, PA

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

Fiscal Year (FY) 2012 Objectives

- Develop and validate 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

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 DOE efficiency target for stack efficiency at 25% rated power of 65% and a project target of 55% efficiency at rated power.

FY 2012 Accomplishments

- Achieved the technical target for the project by demonstrating stable and repeatable performance above 7.5 W/mg-Pt @ 500 mV on a full-format stack.
- Developed and tested several MEAs optimized for ultra-high current densities with Pt loadings <0.2 mg-Pt/cm^2.
- Tuned and validated a two-dimensional plus one mathematical model, capable of predicting ultra-high current density operation in different architectures, under a wide range of conditions.
- Demonstrated stable performance at high temperatures (90°C), with both single cells and full-format automotive stacks.

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 cost of present-day fuel cells which is 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 tradeoffs, and ensure the modeling and experimental activities of the Area Use and Reactant Optimized at Rated Amperage 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 2012 Johnson Matthey Fuel Cells (JM) continued to develop and deliver MEAs optimized for performance at ultra-high current densities. Following the MEA development roadmap established at the beginning of the project JM continued working to reduce the MEA ionic resistivity. Two MEA designs were developed and delivered with a new low resistivity membrane (MEM3). Significant performance and durability improvements were demonstrated for this new membrane at JM on a cell with a channel/land architecture, however when Nuvera tested the MEAs there was no performance improvement measured. The improved performance measured by JM is now believed to be specific to the conditions and architecture tested, and do not translate to the open flowfield architecture and Nuvera automotive conditions.

As part of the MEA development roadmap JM also continued working to reduce Pt loading of the electrodes. While the original development plan for the project specified average total Pt loadings between 0.2 and 0.5 mg/cm^2, JM and Nuvera agreed that decreasing the Pt loading even further was the best option to maximize the specific power and reach the technical target for the project (7.5 W/mg-Pt @ 500 mV). Several MEAs were developed and delivered with reduced Pt loading of both anode and cathode electrodes. These MEAs were evaluated by Nuvera, and the results of the best performing MEA (#29) are reported here. As shown in Figure 1 MEA #29, with an average total Pt loading of 0.131 mg/cm^2, was tested in a 4-cell, full-format automotive stack. The results at 2 A/cm^2 (yellow) demonstrate a cell potential of 552 mV and specific power of 8.43 W/mg Pt, exceeding the specific power target for the program by almost 1 W/mg Pt and the voltage target by over 50 mV! A second stack was built with the same MEA which also exceeded the project targets and demonstrated stability during a 100-hour stability test, thus satisfying the technical target requirement to demonstrate stable and repeatable performance of the MEA.

In order to address concerns about the heat rejection capability of the stack Nuvera conducted a temperature sensitivity study on a 64-cell full-format automotive stack. As shown in Figure 2 four sets of conditions were tested, two with no cathode humidification and two with a membrane humidifier connected to the cathode side of the stack. For each condition the coolant temperature was increased until performance became unstable. As shown with the dark blue line, humidifying the cathode and reducing cathode stoichiometry allowed the stack to achieve stable performance above 90°C. This elevated temperature will significantly improve the heat rejection capability of an automotive style system.

The University of Tennessee, Knoxville (UTK) completed extensive validation of the predictive transport model across a wide range of test conditions and operating temperatures up to 90°C. Model predictions were compared

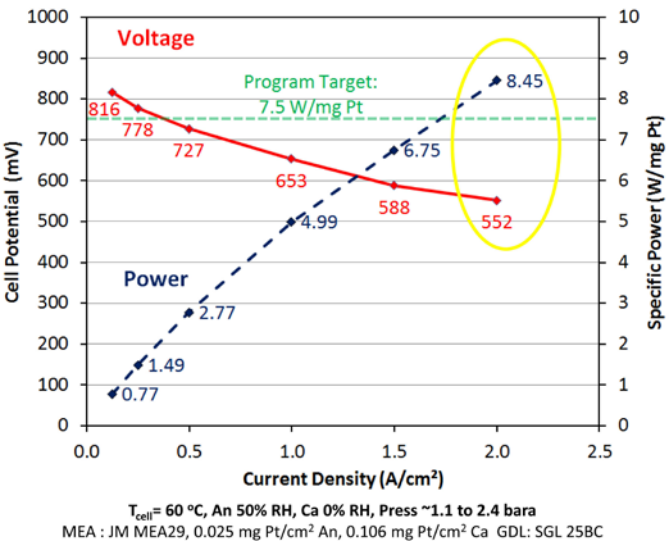

FIGURE 1. Polarization Curve for JM MEA#29

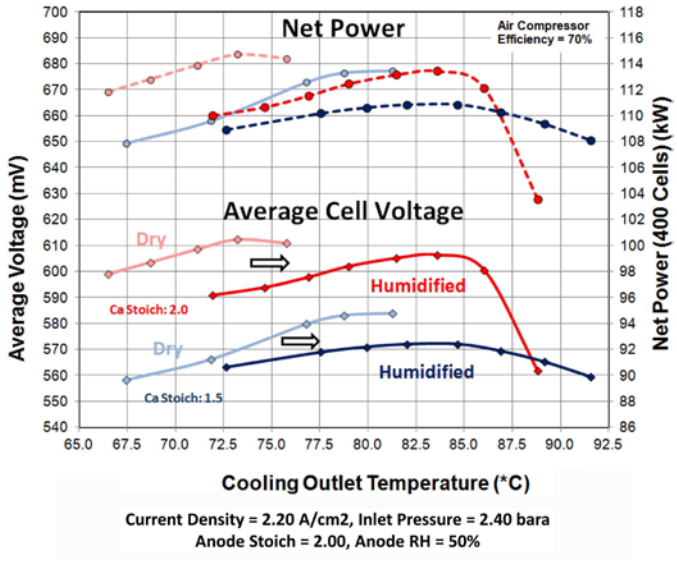

FIGURE 2. Temperature Sensitivity Test for a 64-Cell Full-Format Orion Stack

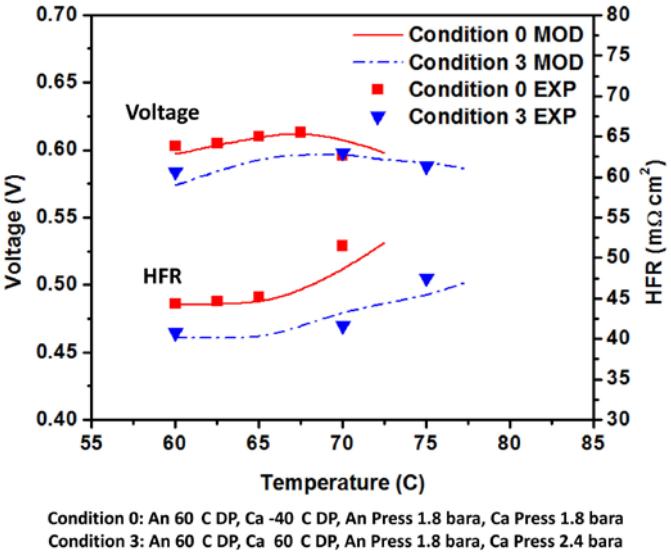

FIGURE 3. Predictive Model Validation Study for Voltage and HFR

with experimental results in terms of cell voltage, high frequency resistance (HFR), and net water drag across a wide range of operating conditions. As an example of the model validation conducted in this project, Figures 3 and 4 show a temperature sensitivity study for two conditions with varied reactant humidification and pressure. Condition 0 (red) has a cathode inlet dewpoint of -40°C at 1.8 bara, and condition 3 (blue) has a cathode inlet dewpoint of 60°C at 2.4 bara. Figure 3 shows close agreement between modeling predictions and experimental results for cell voltage and HFR, specifically trends and inflection points measured experimentally are predicted well with the model. Figure 4 again shows close agreement between the model and data in

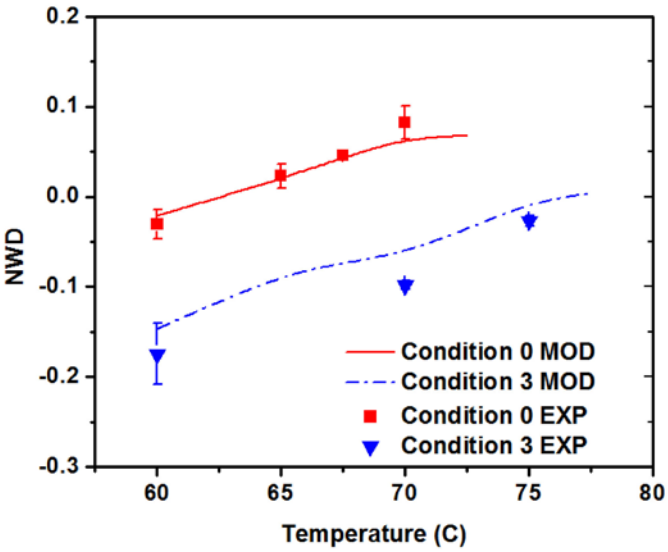

FIGURE 4. Predictive Model Validation Study for Net Water Drag

terms of net water drag throughout the temperature range studied. The model validation studies conducted by UTK provide a high level of confidence that the model is valid through a wide range of reactant and cell conditions.

Conclusions and Future Directions

- Finish model validation studies
- Publish the predictive model in format agreed to by the DOE

FY 2012 Publications/Presentations

1. Dross, R. 2012. "Ultra-High Power Density Fuel Cell Stacks Enabling Commercialization Through Cost Reduction". Plenary Talk presented at the Electrochemical Energy Storage and Conversion Forum, Knoxville, Tennessee.

2. Dross, R. 2012. "Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks" Paper presented at the DOE Hydrogen Program Annual Merit Review, Washington, D.C.

3. Dross, R. 2012. "Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks" Presented at the Fuel Cell Tech Team Review, Detroit, Michigan.

4. Mench, M.M. 2011. "Characterization of Heat & Water Transport in Gas Diffusion Layers and Associated Interfaces". Plenary Talk presented at the Fall meeting of the Electrochemical Society, Boston, Massachusetts.

5. Srouji, A., and M. M. Mench. 2011. "A Comparison of Open Flow Field and Conventional PEFC Architecture Limitations at Ultra-High Current Density". Paper #292 presented at the Spring meeting of the Electrochemical Society, Montreal, Quebec.

6. Srouji, A., L. Zheng, R. Dross, A. Turhan, and M.M. Mench. 2012. "Performance and Mass Transport in Open Metallic Element Architecture Fuel Cells at Ultra-high Current Density." Journal of Power Sources. doi:10.1016/j.jpowsour.2012.06.075.

7. Zheng, L., A. Srouji, F. Gambini, and M.M. Mench. 2011. "Exploration of Ultra-High Current Operation in PEFC Using a Validated Model." In Electrochemical Society Transactions, 41(1):229–240. Boston, Massachusetts.

8. Zheng, L., A. Srouji, F. Gambini, and M.M. Mench. 2011. "Exploration of Ultra-High Current Operation in PEFC Using a Validated Model". Paper #1032 presented at the Fall meeting of the Electrochemical Society, Boston, Massachusetts.

9. Zheng, L., A. Srouji, A. Turhan, and M.M. Mench. 2012. "Computational Exploration of Ultra-high Current PEFC Operation with Porous Flow Field." Journal of the Electrochemical Society 159 (7): D1–D11.