

## 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. (JM), England
- Lawrence Berkeley National Laboratory, Berkeley, CA
- Pennsylvania State University, State College, PA

Project Start Date: September 1, 2009

Project End Date: November 30, 2012

### Overall Objectives

- Optimize the efficiency (electric potential at rated current) of a stack technology that meets DOE cost targets.
- Develop and publish a validated 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.

### Fiscal Year (FY) 2013 Objectives

- Validate the predictive transport model with varied operating conditions, membrane electrode assembly (MEA) Pt loadings, and flowfield architectures.

- Publish the predictive model in format agreed to by the DOE.

### Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell Technologies Office 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 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 at 500 mV was selected based on cost modeling results, as the performance required to achieve the 2015 DOE cost target of \$15/kW<sub>e</sub>. Efficiency (electric potential at rated current) of the stack technology will be optimized with the ultimate goal of approaching the 2015 DOE efficiency targets (as defined in the 2007 DOE Multi-Year Research, Development, and Demonstration Plan):

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

### FY 2013 Accomplishments

- Exceeded the technical target for the project by 66% demonstrating performance of 12.5 W/mg-Pt at 500 mV on a full format stack.
- Optimized the efficiency of the stack, demonstrating over 50% stack efficiency (635 mV) at a specific power of 7.9 W/mg Pt.
- Validated the predictive transport model with varied operating conditions, MEA Pt loadings, and flowfield architectures.
- Published the predictive model as an executable file at <http://ecpower.utk.edu>.



## INTRODUCTION

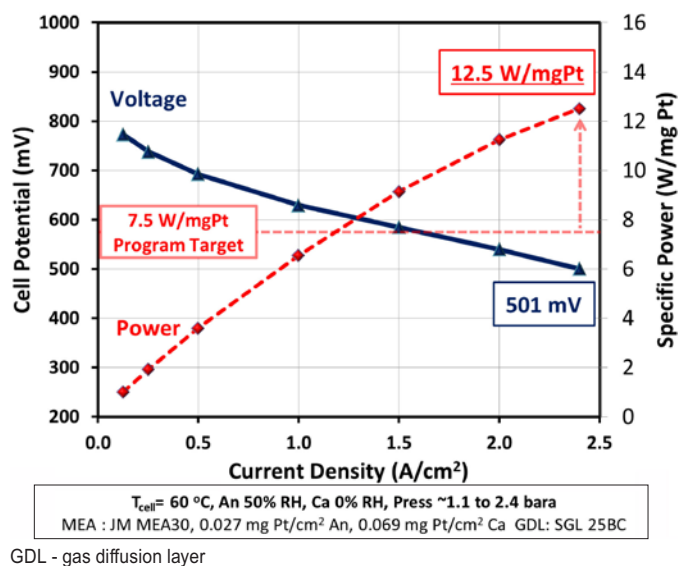
Hydrogen fuel cells are recognized as one of the most viable solutions for mobility in the 21<sup>st</sup> century; however, there are technical challenges that must be addressed before the technology can become available for mass production. One of the most demanding aspects is the costs of present-day 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 ( $>1.5 \text{ A/cm}^2$ ). 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 AURORA Program with respect to 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.

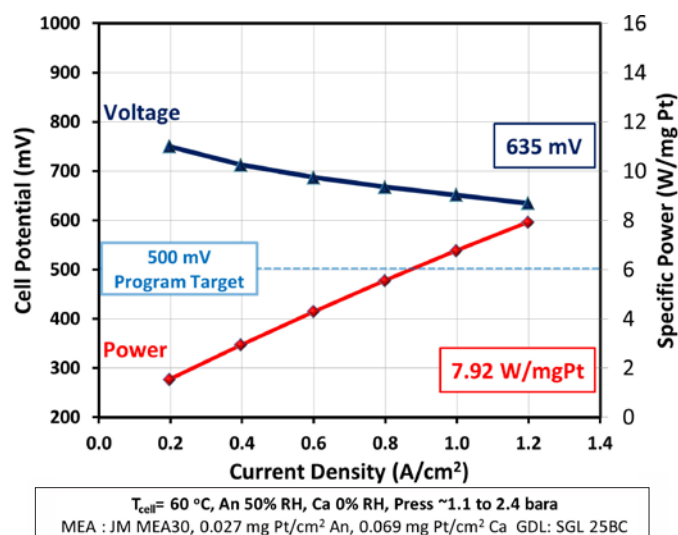
## RESULTS

In FY 2013 Nuvera completed the evaluation of low Pt loaded MEAs from JM with the goal of demonstrating even higher performance in terms of specific power and efficiency. As shown in Figure 1, Nuvera tested a JM MEA 30 with a total Pt loading of  $0.096 \text{ mg Pt/cm}^2$  in a 4-cell full-format stack. This stack demonstrated a significant improvement in specific power reaching  $12.5 \text{ W/mg Pt}$  at  $501 \text{ mV}$  and  $2.4 \text{ A/cm}^2$  thus exceeding the project target by  $5 \text{ W/mg Pt}$ ! The polarization curve was also optimized for efficiency and, as shown in Figure 2, the stack achieved an average voltage



GDL - gas diffusion layer

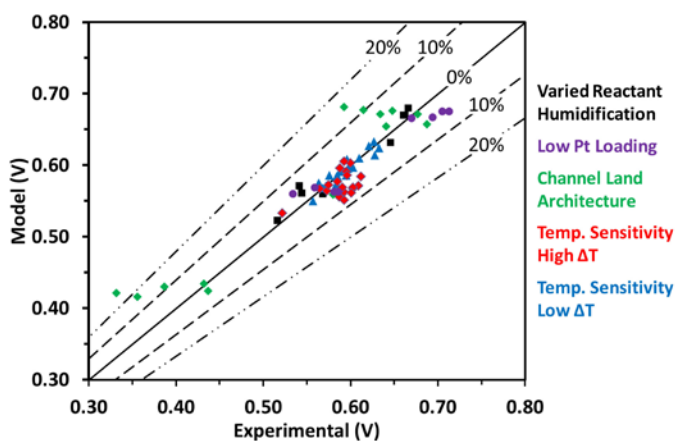
**FIGURE 1.** Polarization Curve for JM MEA#30 – Optimized for Maximum Specific Power



**FIGURE 2.** Polarization Curve for JM MEA#30 – Optimized for Maximum Efficiency

of  $635 \text{ mV}$  at  $7.92 \text{ W/mg Pt}$  and  $1.2 \text{ A/cm}^2$  thus exceeding the efficiency target for the project by  $135 \text{ mV}$ .

The University of Tennessee, Knoxville team completed an extensive validation test matrix of the predictive transport model. The model was validated under a wide range of conditions including current densities of  $1$  and  $2 \text{ A/cm}^2$ , coolant inlet temperatures from  $60^\circ\text{C}$  to  $90^\circ\text{C}$ , low and high coolant flowrates, reactant humidification from  $0$  to  $100\%$ , reactant pressures of  $1.8$  and  $2.4 \text{ bara}$ , and cathode reactants of air and heliox. Two different architectures (channel/land and open-flowfield) and two different MEA designs (total Pt loadings of  $0.55$  and  $0.20 \text{ mg Pt/cm}^2$ ) were also



**FIGURE 3.** Predictive Model Validation Summary for Performance

used to validate the model. For each of these conditions cell performance, high frequency resistance and net water drag were measured on a 50-cm<sup>2</sup> cell and compared with model predictions. In Figure 3 the voltage obtained experimentally is plotted vs. the model prediction for each of the 67 different conditions validated. Ninety-eight percent of the points were within  $\pm 20\%$  error and 92% of the points were within  $\pm 10\%$  error. The model validation studies conducted by the University of Tennessee, Knoxville provide a high level of confidence that the model is valid through a wide range of reactant and cell conditions.

## CONCLUSIONS AND FUTURE DIRECTIONS

The project has ended, successfully meeting all objectives and technical targets.

## FY 2013 PUBLICATIONS/PRESENTATIONS

1. Srouji A.K., Zheng L.J., Dross R., Turhan A., Mench M.M., "Oxygen transport in PEFC with ultra-low loading electrodes," in preparation.
2. Srouji A.K., Zheng L.J., Dross, R., Turhan A., Mench M.M., "Water management in PEFC with porous metallic flow field at ultra-high current density," *Journal of Power Sources*, in press.

3. Zheng L.J., Srouji A.K., Dross, R., Turhan A., Mench M.M., "Computational engineering of porous flow field PEFCs to enable high temperature high power density operation," *Journal of the Electrochemical Society*, **160**, F119 (2013).
4. (Invited) M.M. Mench, "Progress in Ultra-High Current Fuel Cell Designs and Emerging Research Challenges in Polymer Electrolyte Fuel Cells," *University of Toronto Mechanical and Industrial Engineering Distinguished Seminar Series*, University of Toronto, March 9, 2012.
5. (Invited) M.M. Mench, "Progress in Ultra-High Current Fuel Cell Designs in Polymer Electrolyte Fuel Cells and Pathway to Greatly Enhanced Power Density in All-Vanadium Flow Batteries," *University of Padova, Italy*, June 12, 2012.
6. (Keynote Speaker), Mench, M. M., "Pathways to Achieve Ultra-High Power, Low Cost Polymer Electrolyte Fuel Cells Through Heat and Water Management," *The International Workshop on Fuel Cell and Hydrogen Energy*, KAIST University, Republic of Korea, on February 16<sup>th</sup>, 2012.
7. (Keynote Speaker), Mench, M. M., "Progress and Emerging Research Challenges in Polymer Electrolyte Fuel Cells," *HYFUSEN2 Conference*, Mar del Plata Argentina, June 6–11, 2011.
8. Srouji A.K., Zheng L.J., Turhan A., Mench M.M., "Eliminating the Channel/Land Paradigm: Ultra-high Current Density Operation of PEFC with Open Metallic Element Flow Field," *1<sup>st</sup> International Educational Forum on Environment and Energy Science*, Kona, Hawaii Dec. 2012.
9. (poster) Zheng L.J., Srouji A.K., Mench M.M., "Combined Study of Porous-Flow-Field PEFC Under Ultra-High Current Density Operation," *Gordon Research Conference Fuel Cells*, Smithfield, Aug. 2012.
10. Srouji A.K., Zheng L.J., Mench M.M., "Study of Water Transport in a PEFC with an Open Metallic Element Flow Field at Ultra-High Current Density," *22<sup>nd</sup> ECS Meeting*, Seattle, May 2012.