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

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Subcontractors:
- Johnson Matthey Fuel Cell Ltd. (JM), Swindon, UK
- Lawrence Berkeley National Laboratory (LBNL), Berkeley, California
- Pennsylvania State University (PSU), State College, Pennsylvania

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Project End Date: September 30, 2012

Objectives

The objective of this project is to optimize the efficiency (electric potential at rated current) of a stack technology that meets DOE cost targets – the specific technical goal is to demonstrate stable and repeatable high performance on a full-format fuel cell stack, namely 7.5 W/mg-Pt. As cost reduction is of central importance in commercialization, the objective of this project addresses all applications.

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

The key deliverable of this project is a performance model validated over a range of stack architectures operating at high power. Validation will be performed using a new, gradient-preserving test fixture that will enable high power density operation. The test campaign will consider: loadings from 0.5 mg/cm^2 to less than 0.2 mg/cm^2, current densities from 1.0 to 3.0 A/cm^2, and two flowfield architectures (land-channel and open). Results from these parametric studies will be used to inform and calibrate an electrode sub-model and a thermo-fluidic transport model. The integrated models will be used to investigate design and process aspects limiting performance. Throughout this project cell element designs will be refined and operating protocols will be adjusted accordingly. The operating map of the most promising architecture will be optimized in full-format testing. As mentioned earlier the experimental target consists of running a fuel cell stack at 7.5 W/mgPt and achieving a performance greater than 0.6 V at a power density greater than 1 W/cm^2.

Accomplishments

- System and cost analyses were conducted in collaboration with external partners. Data collected confirmed the value of studying high power density operation and increasing efficiency.
- Results collected on existing single cell hardware confirmed the need for an optimized fixture for this project.
- Initial tests on full active area hardware (Andromeda™) demonstrated 2.2 W/mgPt using a membrane electrode assembly (MEA) with 0.3 mgPt/cm^2 loading.
- A roadmap was defined by JM to describe the necessary steps of material development that are needed to achieve the goal of the project
- A fuel cell performance model was built by PSU to represent both the channel/land and the open flowfield architectures.

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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 cost of present-day fuel cells which are prohibitively high for the majority of envisioned markets. The fuel cell community recognizes two major drivers to effective cost reduction: (1) decreasing the noble metal 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 because it entails an increase of 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-off, and ensure the modeling and experimental activities of the AURORA Program with respect to system-level constraints for automotive applications.

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 are being 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 will drive both the process of optimization of the fuel cell operating conditions and the material development. The combined results of these two activities will be verified on single-cell fixtures as well as on full active area hardware, and the experimental data obtained will be used to validate and calibrate the model through multiple iterations.

Results

In Fiscal Year (FY) 2010 Nuvera worked with Directed Technologies, Inc. (DTI) to understand the impact of high power density on stack cost. The analysis was performed while minimizing the discrepancies between the most promising technical solutions identified respectively by DTI and Nuvera. This allowed for full leverage of DTI assumptions and experience in the cost analysis field. The results of this activity are shown in Figure 1 where the stack efficiency is benchmarked against the stack cost for different fuel cells characterized by increased level of performances. The advantage of high power density is clear. Depending on the achievable performance and the acceptable efficiency, this advantage translates into saving between \$300 and \$840/vehicle (with respect to DTI case). On the other hand Nuvera used a detailed vehicle model to predict heat rejection and radiator size for a spectrum of driving conditions and car types. This analysis showed the heat management is particularly challenging for large-size fuel cells vehicles (like sport utility vehicles) at any power density while it becomes a milder issue for small to medium-size cars.

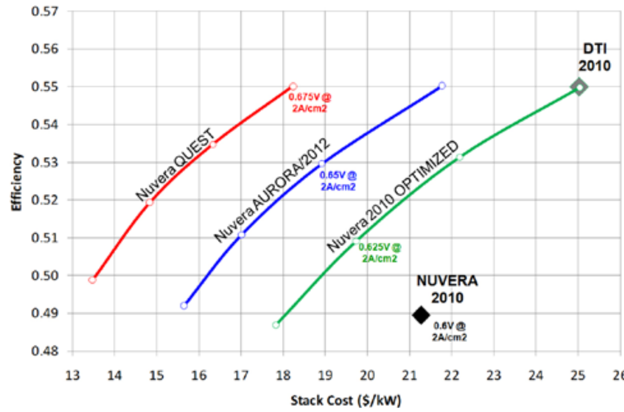

FIGURE 1. Nuvera – DTI Cost Analysis Showing Tradeoff of Cost and Efficiency

PSU ran preliminary tests on existing single-cell fixtures consisting of a parallel channel/land flowfield with an active area of 14.6 cm^2 and 25 cm^2. In both cases, the polarization curves collected show the inability of the hardware to reach very high current densities. As shown in Figure 2, the mass transfer limitation for the 14.6 cm^2 cell becomes evident beyond 1 A/cm^2. In order to explore a broader range of current densities, Nuvera will provide PSU with a new fixture, that is equipped with Nuvera's open flowfield and enables such characterization. A prototype of the fixture is represented in Figure 2.

Nuvera and JM performed a first test on a full active area, and 8-cell Andromeda stack with low loading MEAs (0.3 mgPt/cm^2). This test represented the first attempt at running with Pt content below 0.5 mgPt/cm^2 and neither the stack architecture nor the materials used were optimized for the purpose. The performance recorded was quite low (0.33 V @ 2 A/cm^2) but it was stable at all the current densities and the stack was capable of reaching 2.2 W/mgPt that is far from meeting the target but confirmed the feasibility of operating low loading materials at high current densities.

Based on the targets for this project JM crafted a roadmap to delineate the actions needed to achieve the project performance goals. This roadmap will be refined as more information becomes available through the model predictions, but for the time being it is

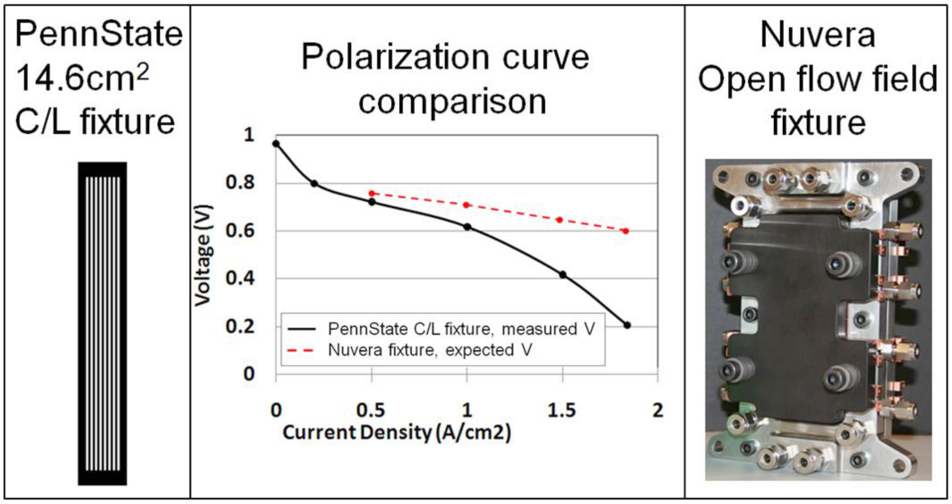

FIGURE 2. PSU Single-Cell Fixture Showing Mass Transfer Limitation over 1 A/cm^2 and Nuvera new Single-Cell Prototype

articulated into two major areas of research: (1) JM will develop a membrane optimized in terms of thickness and equivalent weight (to help lower the resistivity of the membrane and accordingly boost the performance in the ohmic region), and (2) JM will tune the catalyst layer to perform with a Pt loading approaching 0.2 mgPt/cm^2. Tuning will involve several steps including reducing Pt content of the existing catalyst structures, developing new catalyst structure that will enable lower loading, and using a gradient of Pt over the layer surface to optimize the local use.

PSU and Nuvera selected a model approach suitable to represent both channel/land and open flowfield stack architectures. In order to minimize the computational effort a two-dimensional (2-D)+1 geometry was preferred to a three-dimensional (3-D) one. The fuel cell is ideally divided in N control volumes in the Y direction (see Figure 3). The Y direction parameters (such as temperature, pressure, etc.) do not vary inside the control volume therefore each volume can be treated as a surface that can be represented by a 2-D model. This model is built with a fine mesh that is capable of properly capturing the phenomena in the XZ plane for the specific control volume. However, species concentrations and temperature are allowed to vary in Y direction along different control volumes (based on the equations describing mass conservation and heat transfer). Therefore each 2-D model simulating the corresponding control volume (or better surface) is inferred by the respective discrete variations along Y and is then solved for in the XZ plane.

PSU started the construction of the model ("Aurora model") developing the convergence algorithm, implementing the equations that describe the variations

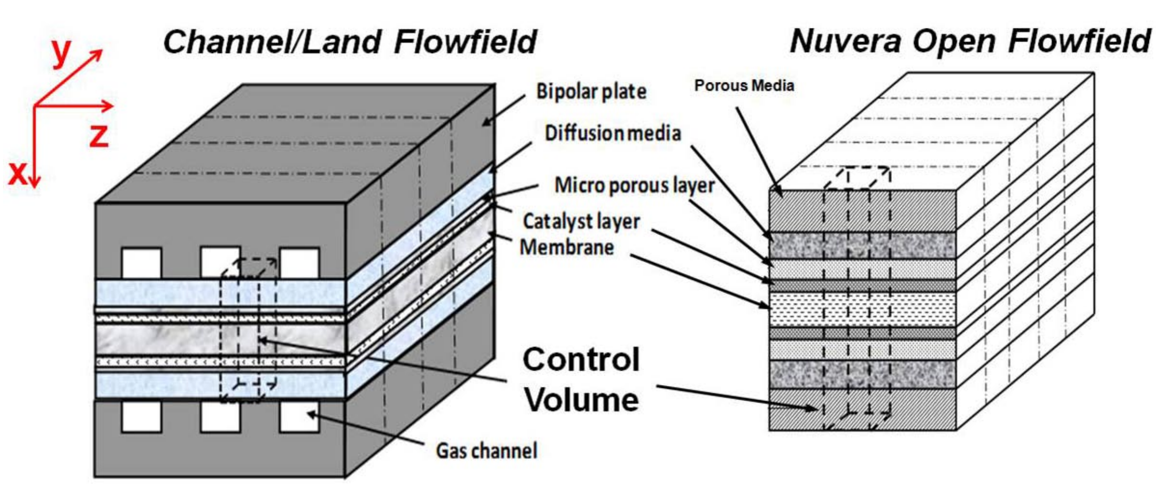

FIGURE 3. Graphic Representation of Aurora Model Approach

in the Y direction, and using their pre-existing 2-D model ("PSU model") as a first representation of the XZ plane. The Aurora model was adjusted to simulate Nuvera's open flowfield and the predictions generated were compared to those corresponding with the Nuvera internal model. This benchmark offered a first level of confidence in the approach and it will also be pursued in the next phase of development when PSU integrates the LBNL membrane and catalyst sub-models into the Aurora model.

Conclusions and Future Directions

Nuvera will deliver the new single-cell fixture to PSU in order to start exploring the design space and to provide feedback to the model predictions. At the same time Nuvera will use the fixture internally to test new components with specific focus to high current density operation.

JM will pursue their material development roadmap and in 2010 the first generation of low-resistivity, low-Pt loading MEAs (0.2 $mgPt/cm^2$) will be available for testing in both single-cell fixtures and full active area hardware.

LBNL will build the first version of the membrane and electrode sub-model while incorporating parameters to be provided by JM. The sub-model will then be embedded into the Aurora model and the predictions will be verified and tuned through the comparison of the Nuvera internal model and the experimental results collected.

FY 2010 Publications/Presentations

1. May 2010 - Detroit, MI - FreedomCar Review.
2. June 2010 - Crystal City, VA - 2010 DOE Hydrogen Program Merit Review (FC028).