V.K.1 Light-Weight, Low-Cost PEM Fuel Cell Stacks

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Objectives

- Demonstrate edge-collected stack design capable of >1 kW/kg (system level).
- Develop low-cost, injection molded stack components.
- Verify stack performance under adiabatic conditions.
- Develop direct humidification scheme based on printed 2-dimensional (2-D) microfluidics.
- Develop optimized printable current collectors for edge collection.
- Accelerate stack development by incorporation of multiple cell level sensors within the stack coupled with computational fluid dynamics modeling.

Technical Barriers

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

(B) Cost

(C) Performance

Technical Targets

TABLE 1. Relevant Technical Targets for Fuel Cell Stacks and Systems Operating on Direct Hydrogen

Metric	Units	2010 target	Status*
System Specific Power	W/kg	650	1,050
Stack Efficiency at Rated Power	%	55	40
Stack Cost	$/kW$_e$	25	Not Determined

*Estimated from results of single cell testing, when combined with the weight of the molded cell component.

Accomplishments

- Fuel cell results in single cell hardware, combined with the weight of the first generation of molded components are consistent with a stack power density greater than 1 kW/kg. However, adhesion and long-term stability of the printed current collector remain issues.
- We have incorporated temperature and humidity sensors within our single-cell edge collected hardware and have demonstrated that these results are in good agreement with our 2-D water transport model.

Introduction

The benefits and limitations associated with conventional bipolar stack construction are well known. The primary benefit of bipolar construction is that it allows for low internal resistance due to the maximum conducting area between cells. It also leads to dense, highly compact stacks. However, despite considerable effort the bipolar plate still represents a daunting fabrication challenge. As a result, bipolar plates represent a sizable fraction of the weight and cost of the stack. Furthermore, they are inactive components that do not contribute directly to energy conversion. Bipolar construction has a negative impact on stack operation as well, including water management issues related to water retention in the stack (especially critical during freeze/thaw cycling), relatively high pressure drop and a large number of seals that must be maintained.

In response to these issues, a light-weight, low-cost proton exchange membrane (PEM) stack design is being developed that is responsive to DOE performance and

cost goals and that is substantially simpler in design and construction than conventional bipolar stacks. This design is based on edge collection of current and eliminates the need for bipolar plates.

Approach

The edge-collected design being pursued uses gas diffusion layers/current collectors that are fabricated by a printing process that provides intimate contact between the various components, eliminating the need for compressive forces currently used to ensure low-resistance contacts. As a result, numerous components of conventional stacks including bipolar plates, tie-rods and individual cell-level seals are eliminated, greatly reducing the parts count, weight, and assembly complexity. Low-cost, light-weight housings will be fabricated by injection molding to enclose the fuel cell components and to provide reactant manifolding. Adiabatic operation with very low pressure drop will allow for extremely low parasitic power losses due to the elimination of the compressor and substantially simpler humidification requirements. Printed microfluidic pathways (essentially 2-D wicks for introducing water directly into the stack) will be an essential element in achieving adiabatic operation. Figure 1 shows the conceptual design of a 27-cell stack (ca. 150 W), which consists of four molded plates, and three sheets of catalyst-coated membrane (CCM). The dimensions of this sub-stack are 22 cm x 15.5 cm x 1.8 cm.

Results

Our progress this year has been slowed as a result of two significant issues. The first of these is related to adhesion of the printed current collector/gas diffusion layer (GDL). Our preferred formulation for this layer, which yields our best fuel cell performance, was shown to have poor adhesion under repetitive wet/dry cycling at 60°C. Loss of adhesion was typically observed in ≈30 cycles, far too few to be acceptable. As a result, a large portion of our effort has been spent on evaluating alternative formulations for this critical component, as we attempted to find an acceptable balance between adhesion, electrical conductivity and porosity. We have demonstrated a formulation (formulation 'B') with excellent conductivity and adhesion under wet/dry cycling, but with a lower than acceptable porosity. This lack of porosity is manifested in a fairly low limiting current, on the order of 200-300 mA/cm^2, as shown in Figure 2. Various attempts to improve the limiting current, while maintaining the required level of conductivity have not been successful.

The second major issue we have been addressing is the performance of the commercial CCM material that has been our starting point for fuel cell production. In a presentation at the FreedomCar Tech Team Review in late September 2008, we presented a number of significant issues with this material. These issues included relatively poor fuel cell performance, characterized by low open circuit potentials (ca. 0.8 V), excessive hydrogen crossover (10-20 mA/cm^2), low power density, and a significant frequency of electrically shorted cells after fabrication. We have also presented results from testing in conventional fuel cell hardware, for the same CCM material, showing similar deficiencies. These results showed that to a significant extent, the poor fuel cell performance could be traced to the performance of the commercial CCM material. Since this was an unexpected result, samples of this material were sent to Los Alamos National Laboratory (Drs. R. Borup and T. Rockward) in October 2008 for evaluation at the recommendation of the Tech Team. Their preliminary results received in mid-November are in good agreement with our own. Further testing in our labs showed that the electrical shorts observed are present in the as-received CCM material, although it is

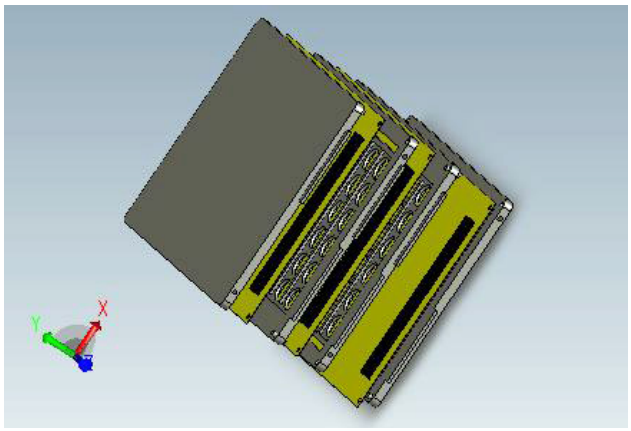

FIGURE 1. Exploded View of a 27-Cell Short Stack, Consisting of 3–9 Cell Sub-Stacks

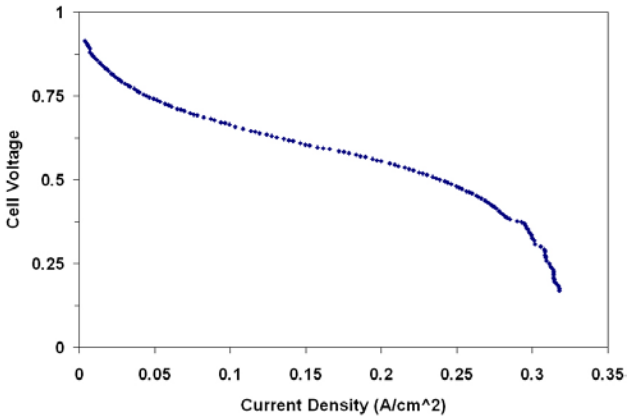

FIGURE 2. H_2/Ar Polarization Curve For In-House Fabricated CCM with Printed Current Collector (temperature = 60°C, dry air, humidified hydrogen)

likely that our current collector fabrication exacerbated these inherent faults. As it is clear that this material will not be suitable for this project, we are currently scaling-up our in-house fabrication of the CCM. Our goal will be to produce CCM material that is more suitable for this project, which, by the nature of the edge-collected assembly used, is aimed at relatively low current density (ca. 0.4 A/cm^2) and high efficiency ($V_{cell} > 0.7$ V) operation. The fuel cell performance shown in Figure 2 was obtained with our in-house fabricated CCM, which has an acceptable open circuit potential (≈0.94 V), and acceptable hydrogen crossover (≈1 mA/cm^2).

We have also continued our efforts to incorporate sensors within our edge-collected fuel cell hardware and to demonstrate that our water transport model correctly predicts local relative humidities within the cell for a variety of conditions (for example, open-circuit vs. hydrogen pump vs. fuel cell operation, and conventional reactant humidification vs. humidification via the microfluidic pathways). While these experiments are still in progress, the results to date show good agreement between the model and the laboratory results.

Conclusions and Future Directions

- **Current Collector Formulation/Fabrication**: It is clear that we need to consider substantially different approaches to fabricating a current collector/GDL that achieves all of our targets for conductivity, porosity and adhesion simultaneously. A breakthough in this area is necessary to achieve a viable result. Electrospraying of this layer is one such possibility.
- **Water Transport Modelling/Measurement**: We will continue our efforts in this area in order to demonstrate the advantages that we believe will result from the edge-collected design with adiabatic operation and humidification via microfluidic pathways.

Publications/Presentations

1. A presentation was made for the FreedomCar Tech Team Review on September 24th, 2008.