

Title: AIR-BREATHING FUEL CELL STACKS FOR PORTABLE POWER APPLICATIONS

RECEIVED  
OCT 11 1996  
OSTI

Author(s): M. S. Wilson, D. DeCaro, J. K. Neutzler, C. Zawodzinski, S. Gottesfeld

Submitted to: Fuel Cell Seminar, Kissimmee, Fl., November 1996

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**Los Alamos**  
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

**DISCLAIMER**

**Portions of this document may be illegible  
in electronic image products. Images are  
produced from the best available original  
document.**

## AIR-BREATHING FUEL CELL STACKS FOR PORTABLE POWER APPLICATIONS

M. S. Wilson, D. DeCaro, J. K. Neutzler, C. Zawodzinski and S. Gottesfeld  
Electronic and Electrochemical Materials and Devices Research Group, MS D429,  
Los Alamos National Laboratory, Los Alamos New Mexico 87545

### Introduction

Increasing attention is being directed towards polymer electrolyte fuel cells as battery replacements because of their potentially superior energy densities and the possibility of "mechanical" refueling. On the low end of the power requirement scale (ca. 10 W), fuel cells can compete with primary and secondary batteries only if the fuel cell systems are simple, inexpensive, and reliable. Considerations of cost and simplicity (and minimal parasitic power) discourage the use of conventional performance enhancing subsystems (e.g., humidification, cooling, or forced-reactant flow). Thus, we are developing a stack design that is inherently self-regulating to allow effective operation without the benefit of such auxiliary components [1-3]. As such, the air cathode does not use forced flow to replenish the depleted oxygen. Instead, the oxygen in the air must diffuse into the stack from the periphery of the unit cells. For this reason the stack is described as "air-breathing." This configuration limits the ability of water to escape which prevents the polymer electrolyte membranes from drying out, even at relatively high continuous operation temperatures (+60°C). This results in stacks with reliable and stable performance.

This air-breathing configuration assumes a unique stack geometry that utilizes circular flow-field plates with an annular hydrogen feed manifold and the single tie-bolt extending up through the central axis of the stack. With this geometry, the hydrogen supply to the unit cells is radially outward, and the air supply is from the periphery inward. This configuration has several advantages. The entire periphery is free to air access and allows greater heat conduction to enhance cooling. Furthermore, all of the components in the stack (e.g., the flow-fields, seals and membrane/electrode assemblies), are radially symmetrical, so part fabrication is simple and the entire system is potentially low-cost. Lastly, this configuration is compact and lightweight.

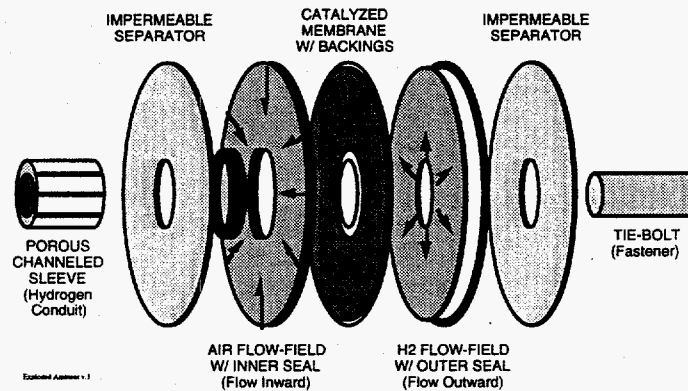


Figure 1. Schematic of the components in a unit cell of the air-breather fuel cell stack.

### Air-Breather Stack

Figure 1 depicts the key components of a unit cell for an air-breather stack. Most stacks are 2" (5.1 cm) in diameter with cell active areas of about 13 cm<sup>2</sup>, although 1.5" (3.8 cm) diameter stacks with 6 cm<sup>2</sup> active area cells have also been investigated. End-plates (not shown in the figure) compress the collection of unit cells together with the use of a tie-bolt projecting up through the middle. Around the tie-bolt is a porous, channeled sleeve that provides alignment for the unit cell components and a conduit for the hydrogen to reach the inner edge of the hydrogen flow-fields. Hydrogen feed is dead-ended, although provision is made for an initial purge. The reactant flow-fields are typically reinforced carbon paper (e.g. Spectracarb, from Spectracorp,

Lawrence, MA). Seals are located at the inner edge of the air flow-field and the outer edge of the hydrogen flow-field. The flow-fields bracket the membrane/electrode assembly (MEA), which consists of a catalyzed polymer electrolyte membrane sandwiched between two gas diffusion backings from E-TEK (Framingham, MA). Stainless steel foil separators, that are typically 0.010" (0.25 mm) thick, prevent the reactants in the back-to-back flow-fields from mixing. In multi-cell stacks, the odd separators are of a larger diameter to provide cooling fins, which gives the stack the appearance of a finned tube.

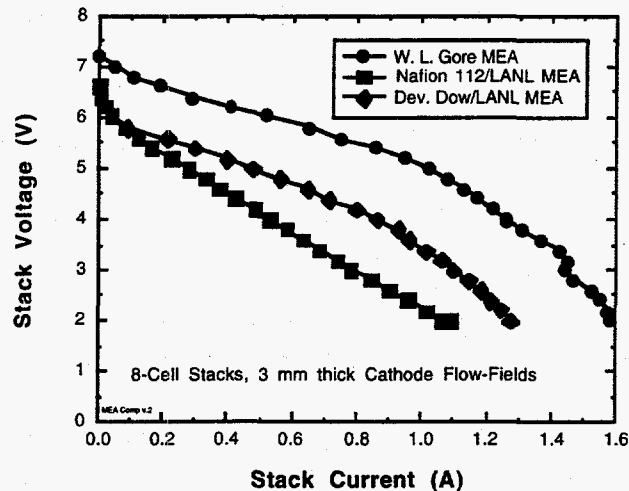


Figure 2. Polarization curves of 8-cell air-breather stacks using a series of different MEAs.

### Results

A series of 13 cm<sup>2</sup> active area, 8-cell stacks using the 2" (5 cm) diameter elements and 2.5" (6.4 cm) diameter cooling fins/separators every two cells were assembled and tested using various combinations of flow-fields, MEAs and backings at ambient pressures of 0.75 atm (the laboratory is at an altitude of 7,200 ft or 2,200 m). Not surprisingly, cell performance is substantially affected by the thickness of the cathode flow-field because oxygen must diffuse in from the periphery through this structure. However, while the performance of a single cell air-breather increases with flow-field thickness, more modest thicknesses provide the best performances in multi-cell stacks. Since under continuous operation a multi-cell stack naturally runs warmer than a single cell (ca. 60°C vs. ca. 30°C), too thick of a flow-field allows the cell to dry out excessively. Modeling suggests that the cells suffer once the water partial pressure throughout the flow-field drops below the saturated vapor pressure [3]. A cathode flow-field thickness of about 3 mm is optimal for continuous operation with the 2" diameter 8-cell stacks.

Figure 2 depicts polarization curves for a series of continuously operating 8-cell stacks using different MEAs, one a W. L. Gore catalyzed composite membrane product [4], and the other two MEAs are commercially supplied membranes catalyzed by a process developed at Los Alamos (LANL) [5]. It is readily evident that the W. L. Gore MEA enjoys more than a 100 mV advantage over the other two MEAs, most likely due to an electrode kinetic advantage realized by attaining a higher water content in the catalyst layer. Since the LANL catalyzed process "toughens" the ionomer in the catalyst layer such that it can withstand the rigors of high current density operation, it apparently does not adsorb an appreciable amount of water under the air-breather conditions. Not only is the W. L. Gore MEA quite thin (ca. 20 μm), but it also appears to accommodate substantially more water in the catalyst layer, the combination of which results in improved hydration and performance under these conditions.

Another key component is the gas diffusion backing. 8-cell stacks were operated with and without E-TEK backings and with and without a Teflon treatment. The cells using the backings were clearly superior, as flooding was apparent in the cells with the MEA directly against the carbon paper. The need for a "microporous" backing structure to control flooding has been previously observed in high performance cells [5].

Figure 3 depicts the voltage output of an 8-cell air-breathing stack operating on a portable metal hydride canister at a constant current of 1 A. After coming up quickly, the fluctuations about 5 V are quite small for the first 5 - 6 hours, at which point the hydrogen becomes depleted and some of the cells become starved for hydrogen.

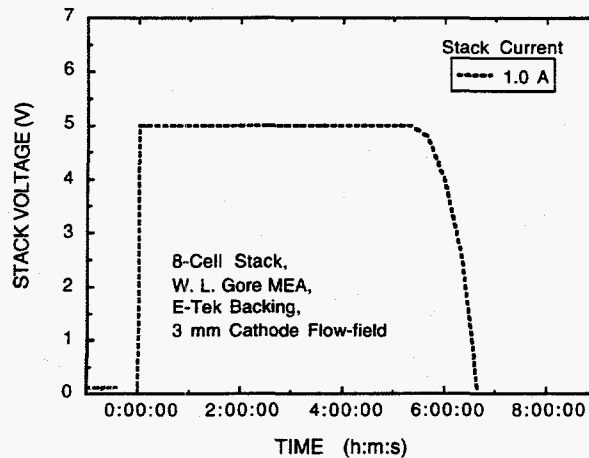


Figure 3. Voltage response (at 1 A) of an 8-cell stack fueled by a portable metal hydride cylinder.

A number of cells have operated for over a thousand hours. Barring seal failures or similar events, performance losses are minimal. Long shut-down periods usually have no effect except on the rapidity of start-up. Upon disassembly, separators made of 304 SS foil typically exhibit some corrosion. The features on the anode sides appear to be a deposit and the cathode sides are pit corroded. The use of 316 SS foils improves the situation, but some effects are still noticeable.

#### System Energy Densities

At this point, the specific powers we obtain for a roughly 6 to 7 W, 10-cell stack are in the neighborhood of 40 W/kg. In combination with the commercial portable metal hydride supply canisters that we currently use (that are about 0.5 wt% hydrogen), a system specific energy of about 60 Wh/kg is obtained for a 10 W system (Figure 4). If the gravimetric density of the hydride storage would be increased to 1.5 wt% hydrogen (which is within the realm of room temperature metal hydrides), then about 150 Wh/kg could be obtained for a 10 W, 10 hour system. From this point on, increased fuel capacity provides even higher specific energies, which increases the appeal of a system that can use multiple, replaceable fuel canisters. In contrast, the specific energies of conventional batteries are tied to the design, not the total energy capacity, and the best rechargeable batteries (Li-ion) are currently limited to about 110 Wh/kg. As suggested in Figure 4, increases in hydrogen storage density significantly increase the specific energies. Higher levels, such as the 4 wt% hydrogen density depicted in the figure, are easily attainable with chemical hydrides, although the challenge in this case is to develop systems that are low-cost, relatively

benign, and viable for consumer applications. However, if such hydrogen storage systems can be realized, the portable fuel cell will become a formidable competitor for many applications.

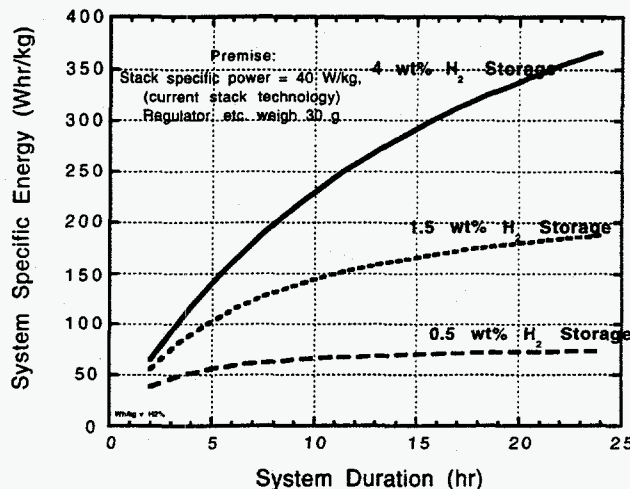


Figure 4. Effect of hydrogen storage density on the specific energy of a 10 W fuel cell system.

### Applications

For the immediate future, the use of portable fuel cells will probably be limited to niche applications for technically proficient users (e.g., industry, military, hobbyists, etc.). As such, we have demonstrated the air-breather fuel cells in several different radio-control model cars. The hydrogen storage and "transparent" consumer interface challenges will need to be resolved for truly huge markets such as communications or portable computers. In anticipation, we routinely demonstrate an Apple Powerbook 180 laptop operating on two 10-cell stacks with hydrogen supplied from interchangeable portable cylinders. No cooling fan or auxiliary electronics (e.g. a DC to DC converter) are necessary. Thus, this system (the two 10-cell stacks, a pressure regulator, and a metal hydride canister) could conceivably fit into a roughly 2.5"x2.5"x12" (5x5x30 cm) enclosure. Appropriate modifications of the metal hydride alloy may possibly even eliminate the need for the pressure regulator. Either way, a very simple, potentially low-cost, high energy-density fuel cell system is achieved.

### References

1. M. S. Wilson, "Annular Feed Air Breathing Fuel Cell Stack," U. S. Patent No. 5,514,486.
2. M. S. Wilson and J. K. Neutzler, "Annular Feed Air Breathing Fuel Cell Stack," Pat. Pend.
3. J. K. Neutzler, "Development of a Portable, Passive, Air-Breathing, Polymer Electrolyte Fuel Cell Stack," M. S. Thesis, Arizona State University, May 1995.
4. J. A. Kolde, B. Bahar, M. S. Wilson, T. A. Zawodzinski and S. Gottesfeld, "Advanced Composite Polymer Electrolyte Fuel Cell Membranes," in Proton Conducting Membrane Fuel Cells I, Edited by S. Gottesfeld, G. Halpert and A. Landgrebe, The Electrochemical Society Proceedings Series, Vol. 95-23, pp. 193-201, 1995.
5. M. S. Wilson, J. Valerio and S. Gottesfeld, "Low Platinum Loading Electrodes for Polymer Electrolyte Fuel Cells Fabricated Using Thermoplastic Ionomers," *Electrochim. Acta*, Vol. 40, p. 355, 1995.

### DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.