V.I.4 Direct Methanol Fuel Cell Power Supply for All-Day True Wireless Mobile Computing

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Objectives

- To build a complete direct methanol fuel cell (DMFC) laptop power supply with a significant advantage over lithium ion batteries.
- To fully integrate this power supply into a laptop computer.
- To deploy a radically different design approach that will enable significant gains in the energy density compared with available designs.
- PolyFuel's long term intention is to license any arising fuel cell system intellectual property to manufacturers while manufacturing and selling the polymer membrane required for the devices.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability
(B) Cost
(C) Performance
(D) Water Transport with the Stack
(G) Startup and Shutdown Time and Energy/Transient Operation

Technical Targets

This project involves taking a system-scale approach to the design and integration of a DMFC power supply into a laptop computer. A new design approach involving recycling water internally to the fuel cell stack enables the use of pure methanol and a dramatically simplified balance-of-plant (BOP). The gains from these technological improvements enable a substantial increase in the overall system energy density. The numbers in the table below are based on PolyFuel's system design with a net output power of 15 Watts and a run time of 10 hours from a single fuel cartridge.

TABLE 1. Progress Against Technical Targets for Consumer Electronics

Technical Targets: Consumer Electronics (sub-Watt to 50-Watt)				
Characteristic	**Units**	**PolyFuel 2008 Status**	**2006 Target**	**2010 Target**
Specific Power	W/kg	35	30	100
Power Density	W/L	48	30	100
Energy Density	Wh/L	325 (one cartridge) 435 (two cartridges)	500	1,000
Lifetime	Hours	1,000	1,000	5,000

Accomplishments

- PolyFuel has developed a novel membrane electrode assembly (MEA) structure with a new cathode gas diffusion layer (GDL) and novel membrane that enables the transport of water from the cathode directly to the anode within the fuel cell. The mechanism used to move water from the cathode to the anode does not increase the rate of methanol crossover in the cell.
- PolyFuel has demonstrated 1,000 hours of operation using a fuel cell design that transports enough water from the anode to the cathode to enable the use of pure alcohol as a fuel.
- PolyFuel has developed a miniature recirculation pump for dilute alcohol solutions that is twice the efficiency and one quarter the size of any pump available today. The pump is 7 cc in size, delivers 40 cc/min at 10 kPa and uses only 1 Watt of power.

- PolyFuel has operated a complete DMFC system that has very low BOP parasitic loads. Including the direct current converter to deliver power to the laptop computer, only 4 Watts of parasitic power is required to deliver 15 Watts to the user. This means the fuel cell stack is sized to deliver only 19 Watts of gross power.
- PolyFuel has demonstrated the operation of a complete DMFC system fully integrated with a laptop computer. The integrated system uses a battery for start-up and for peaking loads and the control circuits recharge the battery during periods of excess fuel cell power.

Introduction

Mobile electronic devices require increased run time and operational flexibility to realize the full benefits of true wireless operation. This project has been a three-year effort to design, develop, fabricate, and validate a DMFC power system sufficient to meet the key performance targets for a notebook computer and to provide all day wireless computing. Over the course of the project, PolyFuel developed novel membrane and MEA technologies to create a high performance MEA structure with internally recycled cathode water. This new MEA has been combined with miniature balance-of-plant components in a high-performance system design. This system has been integrated with a commercial laptop computer and emphasizes a simplified design approach with a reduction in components compared to other systems of similar power.

Approach

Conventional DMFCs typically have complex structures to capture one-third of the water produced on the cathode and recycle it to the anode where it is consumed. PolyFuel started this project with an overall system concept that focused on passive recovery of this water within the fuel cell itself without having to rely on either bulky water recovery components such as heat exchangers and condensers or lower energy density cartridge approaches with water/fuel mixtures. The basic concept is to dramatically reduce the BOP components and eliminate their parasitic losses from the system and utilize pure methanol fuel cartridges. The recycling of water within the cell enables the elimination of the oxidant compressor and allows the use of a single fan to provide oxidant and cool the fuel cell stack directly. Other BOP components that could not be eliminated were aggressively targeted for size and power consumption reductions.

Results

The PolyFuel laptop power supply system consists of the fuel cell stack, a combined oxidant/coolant subsystem, a recirculated fuel subsystem with an integrated CO_2 separator, and a controls and power conditioning subsystem. The combined oxidant/coolant subsystem is a very low profile fan that blows air at near ambient pressure through the fuel cell cathode passages. The dilute fuel subsystem recirculates low concentration (0.6 to 1.2 Molar) methanol fuel to the fuel cell stack anode passages. A piezoelectric pump delivers pure methanol into this loop as fuel is consumed. As the stack operates, the waste CO_2 generated in the anode reaction is vented through a CO_2 separator. The controls subsystem monitors several sensors and measures currents, voltages, methanol concentration, and various temperatures in the system. The power conversion circuit converts the wide voltage output of the fuel cell stack into suitable voltages to interface with the laptop power input. The power conversion circuit has a built in variable current limit and operates at an efficiency of about 97%. A basic system schematic is shown in Figure 1 showing all of the major components.

The key element in the system, however, is the fuel cell stack. PolyFuel has developed a novel MEA that is capable of recycling water from the cathode to the anode with performance sufficient to meet the power density targets of the project. The high level performance requirements for the MEA are given below:

- Power Density 58 to 60 mW/cm^2
- Fuel Cell Current Density 150 mA/cm^2
- Fuel Cell Temperature 50°C

In addition to these performance numbers, targets were placed on the cathode GDL to ensure the water recovery goal was met. These are given below:

- Water Escape Fraction 0.66
- Minimum Liquid Water Pressure 140 kPa
- GDL Water Transport $K_{H2O} = 1.5$ mm/s

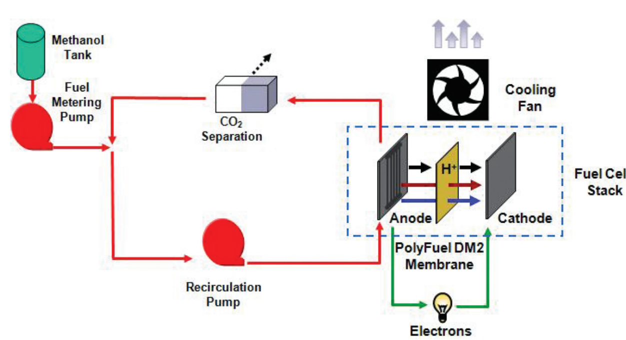

FIGURE 1. System Schematic for Passive Water Recovery

To develop the cathode GDL, a structure with several layers was devised. The gas diffusion barrier controls the rate of vapor water egress from the overall structure while the liquid barrier layer ensures that all liquid water on the cathode is held within the MEA. A water distribution layer distributes water evenly across the MEA surface. A sketch showing how these layers are arranged is shown in Figure 2.

Several single cells meeting these requirements have been produced and have been operated with an acceptable degradation rate over the course of 1,000 hours of testing. During these life tests, the water recovery rate was demonstrated to be very stable. See Figure 3 for a typical polarization curve. The target operating point is highlighted in the graph.

The cells were integrated into a highly compact stack design with an absolute minimum amount of volume used for the compression system to hold the stack together. A simple leaf spring with set of five composite strings holds the stack together. Initial stack performance is about 20% below the expected level based on the initial single-cell tests. In spite of the lower than anticipated stack performance, integration with the other components has been completed and entire units

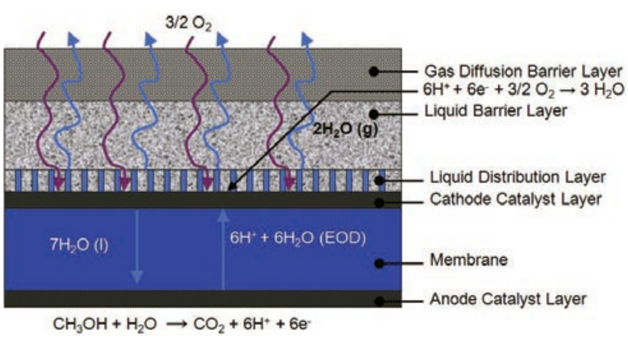

FIGURE 2. Sketch of the Layered MEA Structure for Achieving Passive Water Recovery

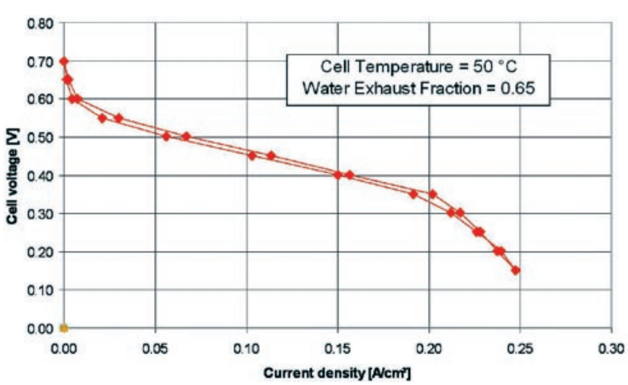

FIGURE 3. Polarization Curve of a Cell Operated with Passive Water Recovery at 50°C

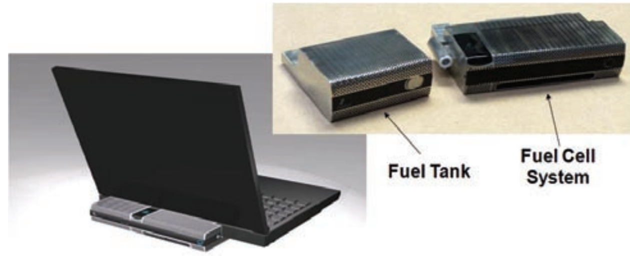

FIGURE 4. Photo of Fully Integrated DMFC Power Supply for a Laptop Computer

produced. Work is on-going to resolve this difference in performance. A photo of a complete unit is shown in Figure 4.

Two complete units have been built and operated with positive results in the test laboratory environment. The methanol concentration control, the temperature control, and the fuel cell output control have all been thoroughly tested and work to their specifications. Both units have been integrated with laptop computers and are able to power the laptops for several hours at a time with low rates of degradation as long as the units are operated regularly. During lengthy off periods, initial results suggest that the fuel cell performance degrades more quickly than expected.

Conclusions and Future Directions

Below is a summary of the major conclusions of the work conducted thus far this year:

- Complete DMFC systems that are fully integrated into laptop computers have been operated on pure methanol for several hours. It is PolyFuel's belief that this project represents state-of-the-art technology and surpasses the energy density of any other DMFC system of this power level publicly shown to date.
- Cells with sufficient power density to meet the 325 Wh/L energy density target and adequate water recovery have been demonstrated, but the power output of scaled-up stacks has fallen about 20% short of expectations.
- A full stack has been operated for over 1,000 hours with acceptable levels of degradation.
- Complete systems show low levels of degradation while operating, but have shown unexpectedly high levels of degradation while off.

Below is a summary of future work slated to be conducted over the coming year:

- Resolution of the performance gap between initial single-cell results and the lower performance seen in the first produced stacks.

- Developing a more thorough understanding of the degradation during the off state as well as taking measures to counteract the losses.
- Multiple durability tests of complete systems to ascertain the mean time between failure of overall units and identify further potential failure modes.
- Based on all identified failure modes, conduct further enhancements to the robustness of the unit.

Special Recognitions & Awards/Patents Issued

1. Anisotropic Gas Diffusion Layer and Vapor Phase Fuel Cells (US Provisional) Filed 5/5/2006, Application Number: 60/798,723.

2. Vapor Phase Fuel Cells (US Provisional) Filed 10/11/2006, Application Number: 60/851,182.

3. Gas Phase Fuel Cells (US Utility Application based on some of the inventions contained in 60/798,723 and 60/851,182) Filed 5/5/2007, Application Number: 11/745,341.

4. Passive Recovery of Liquid Water Produced by Fuel Cells (US Provisional) Filed 11/7/2006, Application Number: 60/864,767.

5. Passive Recovery of Liquid Water Produced by Fuel Cells (US Provisional) Filed 9/4/2007, Application Number: 60/969,890.

6. Passive Recovery of Liquid Water Produced by Fuel Cells (US Utility based on some of the inventions contained in 60/864,767 and 60/969,890) Filed 11/6/2007, Application Number: 11/936,048.