VII.K Auxiliary/Portable Power

VII.K.1 Direct Methanol Fuel Cell Prototype Demonstration for Consumer Electronics Applications

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Methanol Foundation, Arlington, VA

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Objectives

- Develop an early pathway for the large-scale public introduction to fuel cell benefits.
- Create manufacturing infrastructure for high-volume fuel cell fabrication, benefiting both methanol and hydrogen fuel cell technologies.
- Validate a complete fuel cell system for consumer electronic applications.
- Demonstrate 1000 hours of continual operation.
- Demonstrate overall energy density equal to or better than 800 Wh/liter.
- Develop fuel cell arrays with power densities of 100 – 200 W/liter.
- Implement manufacturing pathways to achieve $20 per unit (at high volume).
- Accelerate codes and standards activities, leading to regulations that allow shipping and use of methanol and hydrogen in airline passenger cabins.
- Prepare three successive generations of benchmark prototypes to evaluate system integration issues.

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:

- A. Durability
- B. Cost
- C. Electrode Performance
- D. Thermal, Air and Water Management
- F. Fuel Cell System Integration

Technical Targets

Target metrics for the sub-Watt to 50-W fuel cell system category are shown in Table 1. Some of the targets are a stretch for the sub-Watt systems. These, the smallest of systems, will not have the power density or cost of a 25-W system. On the other hand, market studies show that the sub-Watt systems in handheld devices can have performance metrics that are lower, and costs that are higher, than the current DOE targets for this category, and still enter high-volume markets. The actual performance, either achieved or expected for 2005, is shown in Table 1. This project and subsequent product programs are on track to achieve all the metrics needed to make a direct methanol fuel cell (DMFC) for handheld electronics a commercial success, helping to clear the path for similar hydrogen fuel cell powered device introduction.

Table 1. Comparison of Actual Performance in 2005 to DOE Sub-Watt to 50-Watt Targets

Parameter	Units	DOE Target		Actual 2005
		Metric	Year	
Specific Power	W/kg	30*	2006	> 3*
Power Density	W/L	30*	2006	> 3*
Energy Density	Wh/L	500	2006	> 200
Cost	$/W	5	2006	**
Lifetime	Hours	1000	2006	> 500

* - Metric for sub-Watt category should be 10 W/kg
** - Early prototype costs are not applicable

Approach

- Develop system design that reduces complexity, size and number of components.
- Use non-dilute methanol fuel to maximize energy density.
- Passively manage the fuel and water to optimize power, efficiency and size.
- Apply high-volume manufacturing technology to array fabrication.
- Work with original equipment manufacturers (OEMs) to develop product introduction strategy, getting them familiar with fuel cell characteristics and advantages.
- Pursue early product codes and standards to smooth the introduction of fuel cell technology to regulatory bodies, and remove any product introduction roadblocks.
- Develop supply chain, teaching suppliers about fuel cell technology as appropriate.

Accomplishments

- Produced an array with energy density of 90 W/L using early mass manufacturing processes.
- Developed micro-pumps, with volumes under 1 cm^3, capable of resisting the typical degrading effects of neat methanol on most plastics.
- Designed and tested 3 options for thermal control.
- Developed a simple, space-efficient insulation package that requires minimal system volume.
- Demonstrated passive fuel and water management in a system breadboard with component and fuel volume less than 120 cc.
- Prepared a codes and standards roadmap that removes all regulatory barriers to large-scale introduction of direct methanol fuel cells for consumer electronics applications by 2007.
- Reached approval for an International Electrotechnical Commission (IEC) standard that includes both the DMFC and hydrogen fuel cell systems. This was driven primarily by the DMFC interests at MTI, Methanol Foundation, Duracell, BIC and DuPont.

Future Directions

- Continue to upgrade the array design and fabrication process to reduce size, optimize performance and reduce cost.
- Investigate manufacturing options and continue to develop infrastructure for both methanol and hydrogen.
- Advance micro-fluidics to further reduce component size and optimize performance.
- Compare and down-select thermal control options to provide a low-cost, small-volume subsystem.
- Optimize passive hydration state control.
- Miniaturize electronic components and investigate application-specific integrated circuit (ASIC) options.
- Optimize low-voltage boost converter.
- Complete international standard for consumer use of small fuel cells and attendant fuel – both methanol and hydrogen.

Introduction

Direct methanol fuel cell (DMFC) technology is well suited for portable power applications in consumer electronics such as cell phones, personal digital assistants (PDAs) and laptops. It uses a liquid methanol fuel directly, instead of hydrogen, so that issues associated with converting the liquid fuel to hydrogen and then managing the hydrogen gas are avoided. This, along with the lower costs associated with the smaller platform, allows the DMFC technology to proceed at a faster development pace than the related hydrogen fuel cell technology. An early introduction of fuel cells into the consumer environment will help facilitate the development of the necessary manufacturing base for all fuel cell technologies to follow, and it will broaden public understanding of the fuel cell merits.

This project is focused on the development of the technology elements and manufacturing base such that low-cost fuel cell products can be introduced on an accelerated timeline. While early products have been introduced, the actual manufacturing costs are much too high to ever enter even into niche consumer products. The fuel cell array, which contains many of the same components as a hydrogen fuel cell, must undergo two orders of magnitude cost reduction. Such components as the membrane, catalyst, diffusion layers, current collectors and humidification membranes must be developed for mass production. This project is working with a broad range of suppliers to develop low-cost components to meet performance specifications. These components are then integrated with balance-of-plant components to produce prototypes to evaluate system integration and to develop OEM interest in the technology. One vision of an

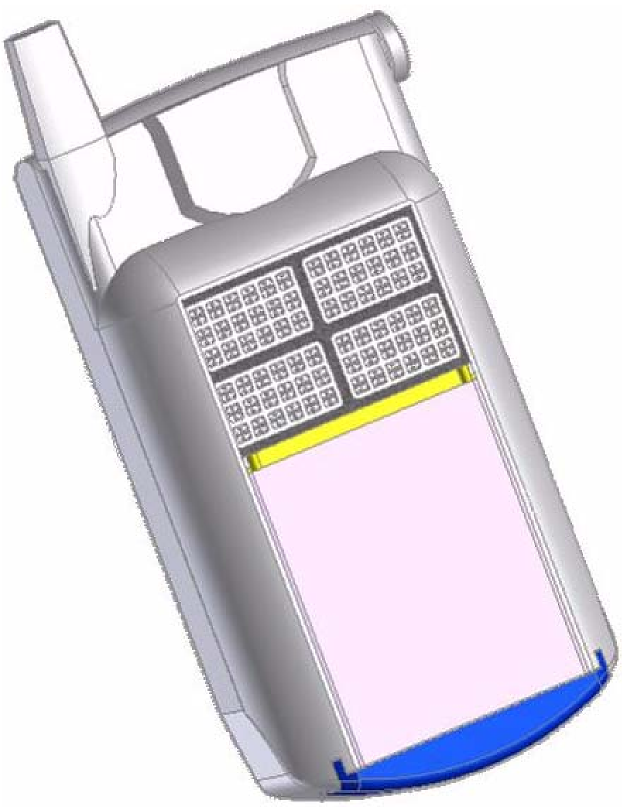

Figure 1. Fuel Cell Powered Handheld Electronics Concept

integrated fuel cell is shown in Figure 1. This has a small planar fuel cell, with cathodes facing outward, a hybridizing battery and a removable methanol cartridge. The fuel cell provides the average load and the small (smaller than what is typically in a cell phone) battery provides the peak loads.

Approach

In order to create a compelling justification to ramp up industrial capability to support DMFCs, and in turn hydrogen fuel cells, end-to-end systems need to be developed. This includes the fuel cells, balance of plant and fuel. All system elements are therefore addressed in this project, as well as the codes and standards that must be developed. All barriers need to be knocked down to get to a market of sufficient volume that attendant infrastructure will benefit the DOE Hydrogen Program.

Of special interest is the design and manufacturing of the arrays. This project is working with a broad spectrum of well-known manufacturers to develop fuel cell components and materials. Drawing on teams from DuPont, Flextronics, Donaldson, Tessy Plastics and a number of gas diffusion layer/membrane electrode assembly (GDL/MEA) suppliers, a fuel cell array is going through design and fabrication trials to evaluate promising low-cost manufacturing approaches. Key issues associated with the performance and cost trade-offs in a high-volume manufacturing process, all critical to very similar components in the hydrogen fuel cell, are being addressed.

Figure 2. Rugged Fuel Cell Array and Fuel Cell Powered Device Demonstrator

Results

A rugged fuel cell array, shown in Figure 2, has been developed for the sub-Watt handheld systems. It is shown here in front of a smart phone that has an embedded fuel cell system for demonstration to OEMs. This simple monolithic array uses lead-frames to capture the MEA and GDLs and hold them in place while molding a frame around the working components. Improvements were made to the molding process and components such that the last

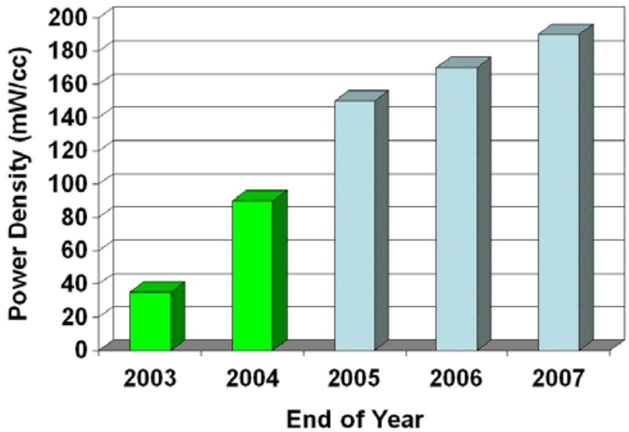

Figure 3. Array Power Density Growth; Actual and Planned

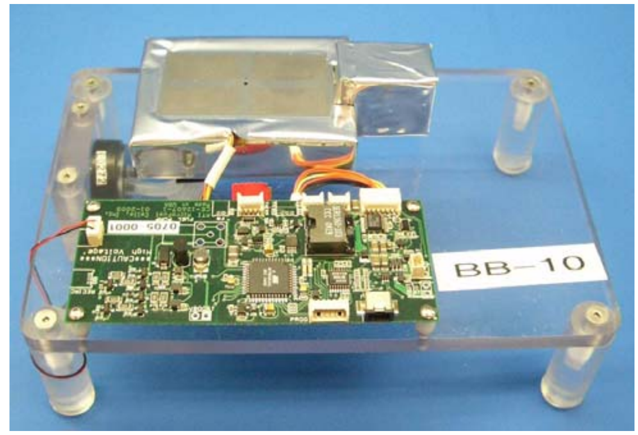

Figure 4. Breadboard Test Hardware – Cartridge not Shown

generation of molded cell in 2004 had twice the energy density as in the previous year. Figure 3 illustrates the two years of historical progress and projects the anticipated progress through the next couple years. Molding of a more compact array for 2005 has started, and trial runs have been made. Performance still varies widely as the component tolerances and mold process variables are aligned and optimized.

Advanced manufacturing strategies are under development. One approach to a high-volume manufacturing system is to roll process all components. Catalyst-coated membranes (CCMs), GDLs and current collectors are all fed to the assembly process – in this case the mold – from continuous rolls of components produced in an earlier step. This approach will significantly reduce the labor involved in handling individual components and lead to significant cost reductions. Many of these very same techniques could be carried over to hydrogen fuel cell stack production.

System breadboards, with the components shown in Figure 4, were assembled and tested this period. Details of the thermal control system and cartridge are not shown for proprietary reasons. Ten units were evaluated to provide a reasonable statistical performance benchmark. One unit tested was a prototype fuel cartridge developed by a Fortune 500 company. The best performance achieved to date was 220 mW and 600 Wh/L of fuel. The total component volume of a 20-Wh system was 120 cc, including fuel. Given the component volume in early 2005, this performance level results in 170 Wh/L at the system level (including the fuel cartridge). System performance is expected to reach higher levels (>200 Wh/L) as array performance increases during the remainder of the year. It is expected to approach the 500 Wh/L target sometime in 2006.

A number of thermal control, insulation and fuel control options were evaluated. Passive and active thermal control prototypes were assembled and tested, some having a potential cost of pennies per system. Fuel feed components were also miniaturized and tested. These components will be further optimized and integrated to reduce system size.

There is a substantial body of regulations that govern the use and transport of flammable materials. In order to get fuels and fuel cells of any kind delivered to the point of use or carried in commercial transport such as automobiles and airplanes, a large investment is needed to develop the codes and standards for fuel cells and the attendant fuels. This project has concentrated in this past year on the international regulations for fuel transport and fuel cell use in airline passenger cabins. Teams from MTI and the Methanol Foundation have been deeply involved in wide-ranging tasks with multiple international bodies, as shown in Figure 5, driving the standards forward. Many milestones in the process have been achieved toward acceptance of fuel cells in airline passenger cabins. In the process, a number of white papers and presentations have

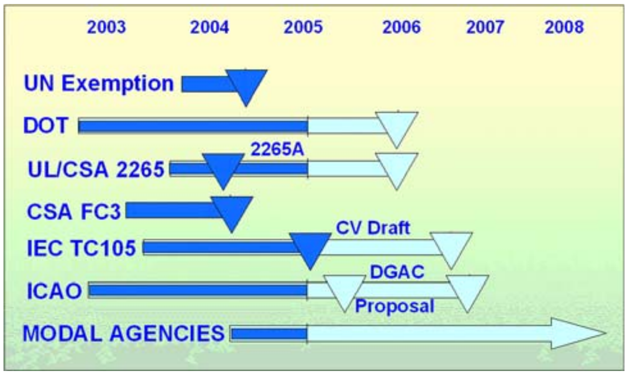

Figure 5. Codes and Standards Activities and Timeline

been prepared for the Department of Transportation (DOT) and the Federal Aviation Administration to allow them to become familiar with the fuels and fuel cell technology and address their safety concerns (see Ref. 1-2). As shown in Figure 5, all key initiatives are on schedule. This process has carried the sub-50-W hydrogen fuel cells forward as well. The DMFC forward involvement will potentially trim 2 years from the deployment of hydrogen fuel cells in this environment, if the hydrogen annex to this standard is accepted during the international vetting process this year.

Conclusions

- Project performance metrics are on target, with small exceptions made for the sub-Watt end of this DOE system category.
- Commercial introduction of fuel cells through the DMFC in handheld consumer electronics is on track.
- Regulatory work for DMFCs is also benefiting hydrogen fuel cells for the same power space.
- Manufacturing development is building infrastructure capabilities that will benefit subsequent hydrogen fuel cell products.

FY 2005 Publications/Presentations

1. "DMFCs Power Up for Portable Devices," The Fuel Cell Review, 1(2), 25, 2004.
2. "Direct Methanol Fuel Cell Technology and Product for Fuel Cell Applications," ECS, Fall, 2004.
3. JA Paterson, "Methanol Fuel Cell Fact Sheet," MTI MicroFuel Cell, December, 2004, http://www.usfcc.com/usfcc/methanol/Methanol_Micro_FC_Fact_Sheet_2004.pdf
4. "First DMFC Power Source Integrated into a Hand Held Electronic Device," Proceedings of the 22nd International Battery Seminar, Fort Lauderdale, Florida, March 2005.
5. "First DMFC Power Source Integrated into a Hand Held Electronic Device," Proceedings of Small Fuel Cells 2005, Washington, DC, April 2005.
6. "Fuel Cell/Battery Hybrid Systems for Portable Power Applications," Proceeding of 22nd International Seminar on Polymer Batteries and Fuel Cells, Las Vegas, Nevada, June 2005.

References

1. JA Paterson, "Methanol Fuel Cell Fact Sheet," MTI MicroFuel Cell, December, 2004, http://www.usfcc.com/usfcc/methanol/Methanol_Micro_FC_Fact_Sheet_2004.pdf
2. "Current Codes and Standards Work," USFCC Website, http://www.usfcc.com/usfcc/methanol/currentwork.html#S