V.J.5 Direct Methanol Fuel Cell Prototype Demonstration for Consumer Electronics Applications

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Objectives

- Develop an early pathway for the large-scale public introduction to fuel cell benefits.
- Demonstrate 1,000 hours of continual operation at a system level.
- Demonstrate overall energy density equal to or better than 600 Wh/L.
- Accelerate codes and standards activities that allow shipping and use of methanol and their cartridges in airline passenger cabins.
- Develop straight-forward refueling with 100% methanol, possible while source is on.
- Prepare three successive generations of benchmark prototypes (P1, P2, P3) to evaluate system integration issues and validate performance and life.

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) Performance

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 not applicable to the sub-Watt systems. These systems will not have the power and energy density or cost of a larger system in this category. The metrics defining a market introduction point for sub-Watt systems can be obtained from analysis of the power source currently used for the targeted application. Commercially available rechargeable Li-Ion battery-based power packs are used to charge handheld electronic devices on the road. The emergence of these products signals a market need and an entry point for handheld fuel cells. These power packs have an energy density of about 100–150 Wh/liter with a fully charged battery. This energy is even lower if one takes into consideration the volume of the wall charger. Fuel cell products under development for this market need only to be significantly better than these battery-based chargers to be successful. 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. Progress toward Meeting Technical Targets for sub-Watt to 50 Watt Category

Characteristic	Units	DOE 2006/2010 Targets	2008 MTI Status
Specific Power	W/kg	100	NA
Power Density	W/L	100	NA
Energy Density	Wh/L	1,000	600*
Cost	$/W	3	NA
Lifetime	Hours	5,000	>1,000**

*Projection based on using a large cartridge/tank with average performance from 18 DOE systems tested in Q4 2009
**Testing completed on P2 prototypes in 2007/2008
NA - not available

Approach

- Develop system designs that reduce complexity, size, and number of components.
- Use 100% methanol fuel (undiluted) to maximize energy density.
- Passively manage water to optimize power, efficiency, and size.
- Work with original equipment manufacturers to develop product introduction strategy, getting them familiar with fuel cell characteristics and advantages.
- Accelerate codes, standards, and regulations to allow shipping and airline passenger cabin usage.
- Develop supply chain, teaching fuel cell technology to suppliers as appropriate.

Accomplishments

- Achieved 1,000-hour target of system operation on multiple units completing this key project objective.
- Built and tested 18 P3 integrated prototypes demonstrating performance, life, orientation independence, and 0-40 degrees Celsius temperature latitude.
- Membrane electrode assembly (MEA) power and life achieving product requirements. Achieved over 6,000 hours of operation with less than 30% degradation.

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Introduction

DMFC technology and MTI's passive Mobion® implementation is well-suited for handheld portable power applications in consumer electronics such as cell phones, cameras, smart phones, personal digital assistants, and game systems. 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 assist the development of the necessary manufacturing base for all fuel cell technologies to follow and will gain a broader public understanding of the fuel cell merits.

Approach

The overall technical approach MTI has used from the beginning of this project has been to reduce the number of components needed in a typical DMFC system. MTI focused on reducing the complexity of the anode loop and water recovery from the cathode stream. These two systems are interrelated because of water management. MTI's fuel cell is designed in such a way that there is a net water transport from cathode to anode through the membrane. This is a passive process that requires no energy. This results in a simplified DMFC system as shown in Figure 1.

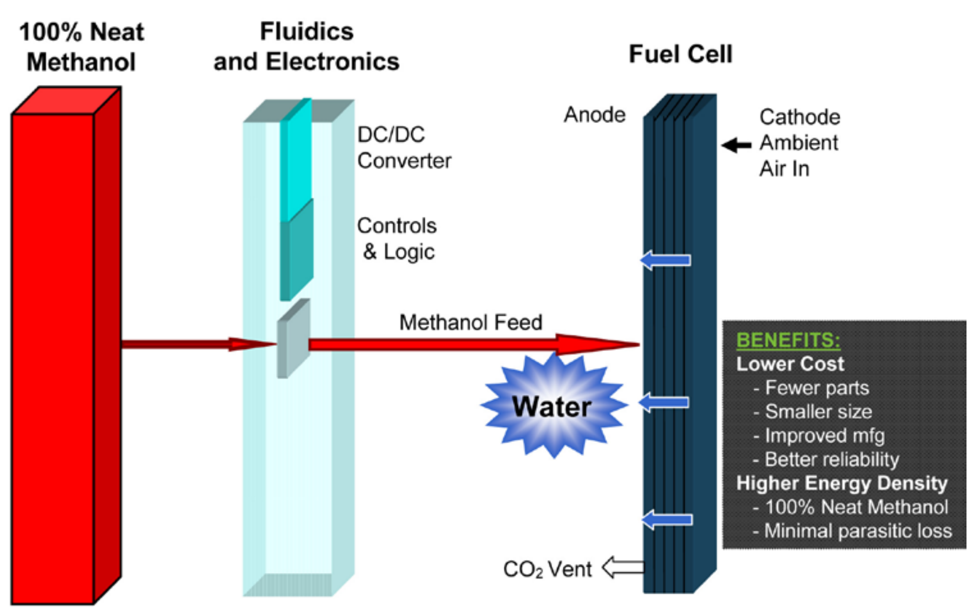

FIGURE 1. MTI Simplified DMFC System

FIGURE 2. P3 DMFC Prototype System with Removable Methanol Cartridge

Results

The work completed under this project has significantly increased the understanding of how DMFCs can be deployed successfully to power consumer electronic devices. The prototype testing has demonstrated the benefits a direct methanol fuel cell system has over batteries typically used for powering consumer electronic devices. The universal charger developed in-part by this project is an early pathway for the large scale public introduction to fuel cell benefits.

Three generations of prototypes have been developed and tested for performance, robustness and life. The technologies researched and utilized in the fuel cell stack and related subsystems for these prototypes are leveraged from advances in other industries such as hydrogen fueled PEM fuel cell industry. The work under this project advanced the state-of-the-art of direct methanol fuel cells. The system developed by MTI Micro Fuel Cells aided by this project differs significantly from conventional DMFC designs and offers compelling advantages in the areas of performance, life, size, and simplicity.

The project has progressed as planned resulting in the completion of the scope of work and available funding in December 2008. All 18 of the final P3 prototype (see Figure 2) builds have been tested and the results showed significant improvements over P2 prototypes in build yield, initial performance, and durability. The systems have demonstrated robust operation when tested at various orientations, temperatures, and humidity levels.

Durability testing has progressed significantly over the course of the project. MEA, engine, and system level steady-state testing has demonstrated degradation rates acceptable for initial product introduction. Over 5,000 hours of test duration have been achieved at both the MEA and breadboard system level. Figure 3 shows

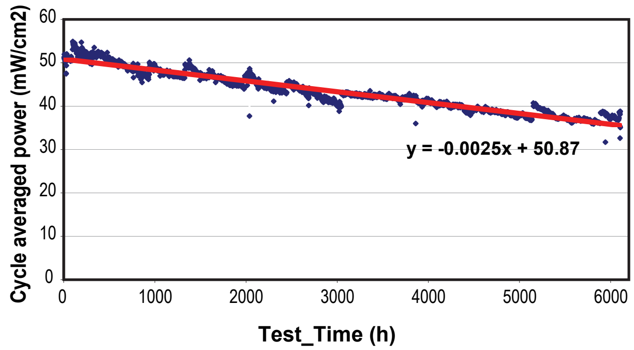

FIGURE 3. MEA Life Test Demonstrating over 6,000 hours of Operation with less than 30% Decay

an MEA life test demonstrating over 6,000 hours of operation with less than 30% decay.

P3 level prototype life testing on engines showed degradation rates comparable to carefully constructed lab fixtures. This was a major improvement over the P2 and P1 engine designs, which exhibited substantial reductions in life and performance between the lab cell and the actual engine.

Over the course of the work on the P3 technology set, a platform approach was taken to the system design. By working in this direction, a number of product iterations with substantial market potential were identified. Although the main effort has been the development of a prototype charger for consumer electronic devices, multiple other product concepts were developed during the project showing the wide variety of potential applications.

Cartridge size is the major factor driving energy density of the platform. By changing the size of the fuel cartridge, the same fundamental platform design can be used with minimal changes to meet the requirements of the various markets. A small cartridge is best for the applications where the consumer carries the device on his/her body, such as an external charger for portable electronics. A large cartridge is best for applications where reducing service (fuel refills) is important. This large cartridge design is capable of long run applications, like unattended ground sensors which are currently powered by lead acid batteries. These two applications bound the extremes of the cartridge size with many other applications falling in between these bounds. Based on the 18 DOE unit's average baseline performance the energy density is projected to exceed 600 Wh/L when using the large cartridge capable of 2,000 hours of run time. The same platform equipped with a single small cartridge, can easily fit in your pocket, which makes it easy to carry, but also results in lower energy density.

There is a substantial body of regulations that govern the use and transport of hazardous materials. This project has concentrated on the international

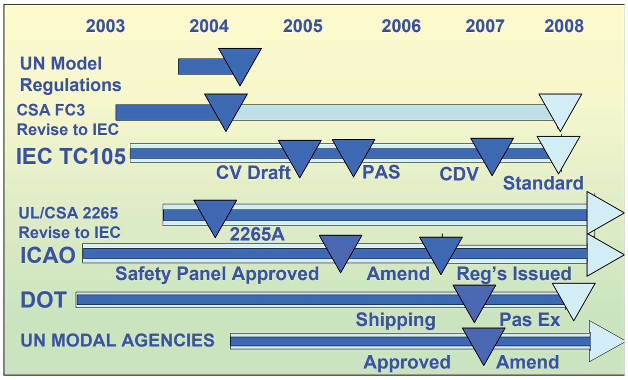

FIGURE 4. Codes and Standards Activities and Timeline

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 4, driving the standards forward. Many milestones have been achieved toward acceptance of fuel cells in airline passenger cabins. In the process, a number of white papers and presentations have been prepared for U.S. Department of Transportation and Federal Aviation Administration to allow them to become familiar with the fuels and fuel cell technologies and to address their safety concerns.

Removable cartridges containing 100% methanol have been produced and have demonstrated hot swap capability on the P3 system prototype. MTI/Methanol Foundation team led efforts on life-cycle issues for methanol fuel cartridges. Meetings were held with officials from the New York State Department of Environmental Conservation in 2007 and again in late 2008 to demonstrate actual working prototypes and discuss proper "end of life" options for fuel cell cartridges and fuel cell systems.

Conclusions and Future Directions

- Achieved over 1,000 hours of runtime on multiple prototype systems and demonstrated over 5,000 hours on a P3 breadboard system.
- Tested 18 fully integrated P3 prototypes demonstrating performance, life, orientation independence, and temperature latitude.
- Removable cartridges containing 100% methanol have been tested with the P3 prototype and have demonstrated the capability of refueling while the power source remains on.
- Achieved over 6,000 hours of MEA operation with less than 30% degradation.
- No future work under this project. The project's scope-of-work and available funding was completed in December 2008.

FY 2009 Publications/Presentations

1. Prueitt, J., Qi, Z., Lu, G., Liu, W., and Carlstrom, C., 2009, "Performance and Durability of Direct Oxidation Fuel Cells Fed with Neat Methanol," Small Fuel Cells Conference, May 7–8, Orlando, FL.

2. Minas, C., 2008, "Structural and Thermal Design Challenges of Portable Microfuel Cell Systems," IMEC2008-69270, ASME Congress, Nov 2–6, Boston, MA.

3. Qi, Z., Prueitt, J., Lu, G., and Carlstrom, C., 2008, "Fuel Cell Battery Hybrid Systems," Lithium Battery & Fuel Cell Hybrid Systems Conference, December 10, Las Vegas, NV.