V.I.2 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.
- Create manufacturing infrastructure for high-volume, low-cost fuel cell fabrication, benefiting both methanol and hydrogen fuel cell technologies.
- 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.
- 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 smallest of systems will not have the power density or cost of a larger system in this category. The power and energy density, and cost targets are especially “not applicable” (NA) for the sub-Watt category. 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	2007 MTI Status
Specific Power	W/kg	30/100	NA
Power Density	W/L	30/100	NA
Energy Density	Wh/L	500/1,000	415*
Cost	$/W	5/3	NA
Lifetime	Hours	1,000/5,000	>1,000**

* Testing on P2 units with several refills of small internal tank
** Testing completed on P2 prototypes in 2007/2008

Approach

- Develop system designs that reduce 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.

- 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 P2 units completing this key project objective.
- Built and tested 11 P2 integrated prototypes demonstrating performance, life, and temperature latitude.
- Membrane electrode assembly (MEA) power and life achieving product requirements. Less than 15% degradation demonstrated in over 2,700 hours of operation. Test is still running as of July 11, 2008.
- Demonstrated P2 injection molded array with high yield and performance of 50 mW/cm^2 and a fuel energy density of 1.4 Wh/cc. Initial testing of the P3 arrays shows performance exceeding these levels.

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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

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, shown in Figure 1, which contains many of the same components as a hydrogen fuel cell, must go through a manufacturing volume ramp-up and attendant cost reduction. Such components as the membrane, catalyst, diffusion layers, current collectors, and humidification hardware 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. Each design-build-test cycle yields further performance improvements and cost reductions necessary to get into an early market.

FIGURE 1. P2 Fuel Cell Array

Results

The project has achieved several milestones over the year and has made significant progress in all areas. Eleven complete P2 prototype systems have been built and tested (Figure 2). These systems have been tested for performance, temperature latitude, and life. Multiple systems have been tested for over 1,000 hours exceeding the associated program milestone.

The P2 systems mentioned above contain MTI's P2 injection molded array which has also progressed substantially over the year. The injection molded process for the cell as well as the components within the cell have improved resulting in a very reliable manufacturing process.

MEAs of many configurations from several suppliers were tested and their impact on initial performance and life were assessed. Several diagnostic techniques were employed to quantify performance and decay of the anode, cathode, and membrane separately. Major advances in reducing MEA degradation have been achieved by changing components and operating conditions. With these changes many cells demonstrated very low degradation rates. A lab cell has achieved over 2,700 hours of steady-state operation with less than 15% degradation. The design and analysis of the reduced height P3 array was completed in early 2008. This new design reduces the array assembly height by over

FIGURE 2. 2007 P2 Prototype

30% compared to P2 assembly while also improving thermal gradients and other performance related aspects of the design. One study conducted in 2007 that contributed to reducing array assembly height was a cell compression study. This study revealed that the MEA compression could be reduced to more than half of its original design value, without any change in cell performance. This enabled structural designs previously not possible. The structural analysis was iterative with design changes being made to reduce stress or limit deflections. Adequate pressure needed to be maintained on all sealing surfaces and the variability in MEA load was kept to a minimum. Thermal modeling was used to verify that an even temperature was maintained across the MEA surface for a wide range of ambient conditions and heat rejection levels. To minimize array assembly volume, all structural and thermal component thicknesses were minimized based on allowable stress and deflection and temperature uniformity requirements.

The results of the P3 array testing are very promising. In fact, the cell performance was very close to ideal lab cell performance. In previous cell designs there was a significant fall-off in performance between an ideal lab cell and a fully integrated array. Since the ideal lab cell has no size or cost restrictions, it has ideal compression and temperature control. Also, other parameters are closely controlled and monitored in the lab cell. This new design appears to have achieved a near optimum balance between the system level compromises and the maximum performance capability of the cell.

The P3 array subsystem and system design eliminated most of the drop in performance seen at the system level in previous designs. Thermal and fluidic improvements make the P3 array subsystem more robust against conditions that would previously hinder performance. Initial work on the control algorithms for the P3 system has also been initiated with positive results to date.

A new clean-room environment was completed and is now being used for all assembly operations. The last 10 systems delivered were built in this area and showed no signs of failure due to contamination (either chemical or particulate). The clean room consists of a general work area controlled to class 10k standards with specific build stations controlled to class 100 standards.

Several of our assembly stations are now instrumented with computer interfaces that reduce the amount of operator input. All of the subsystems are now being assembled by technicians with little to no engineering input. This, along with a handful of design changes, has improved yields on several of our subsystems by 20-50 percentage points putting us well within an acceptable yield for this generation of prototypes.

The system energy density, shown in Figure 3, is a critical metric for this project and is one of the measures in the mix for product success. The DOE roadmap target (for the sub-Watt to 50 W category) provides a goal line for this project, although it is not as applicable to the 1-W system as it is to the 50-W system. The system's ability to beat the battery it would replace in handheld devices is also a good measure of platform development success. The battery capability, shown in Figure 3, is based on our evaluation of current and reasonable improvements in lithium ion batteries. Any platform that can be turned into a viable product will likely need to be better than the battery capability.

In addition, we have surveyed some battery power packs now entering the consumer market. These rechargeable lithium 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. Our benchmarking of these power packs shows that they fall far short of the lithium ion battery capabilities. Current energy density with a fully charged battery is about 100 – 150 Wh/liter. It is even lower if the wall charger is assumed to be part of the system volume. Fuel cell products under development for this market need to be significantly better than these battery-based chargers to find an eager consumer.

The progression of the prototype developed in this project is also shown in Figure 3. This progression started with the breadboard demonstration in May 2005. There was an intermediate proof-of-concept prototypes built and tested during the DOE funding gap. This has been plotted in Figure 3 as reference information. Note that this prototype was about equal to the battery capability. The P2 and P3 target energy density were prepared assuming multiple cartridges, taking into account the additional volume added for each cartridge. This represents how the user of a fuel cell system in a handheld device will view it. Each refill must be better than a battery, and after a few refills, the entire system with those refills must be better than the technology it replaces. These targets get the methanol fuel cell

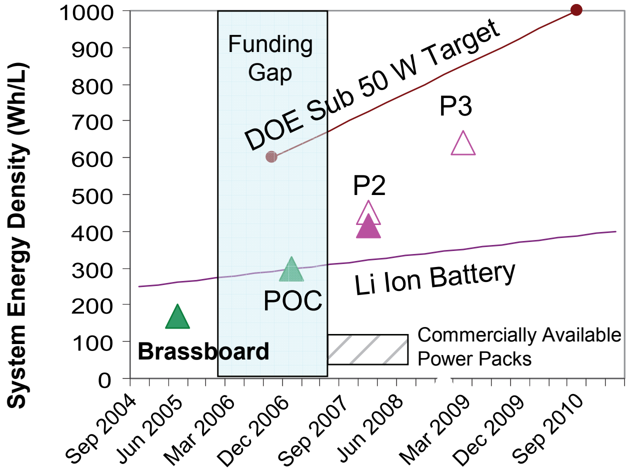

FIGURE 3. Prototype System Energy Density

technology clearly superior to the basic rechargeable battery as well as the available power packs.

There is a substantial body of regulations that govern the use and transport of hazardous materials. In order to get fuels and fuel cells of any kind delivered to 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 the past two years 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 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 the U.S. Department of Transportation and the Federal Aviation Administration to allow them to become familiar with the fuels and fuel cell technologies and to address their safety concerns. MTI and the Methanol Foundation also continued efforts on life-cycle issues for methanol fuel cartridges. Following up on a 2007 meeting with officials from the New York State Department of Environmental Conservation, information on proper "end-of-life" options for fuel cell cartridges and fuel cell systems was provided.

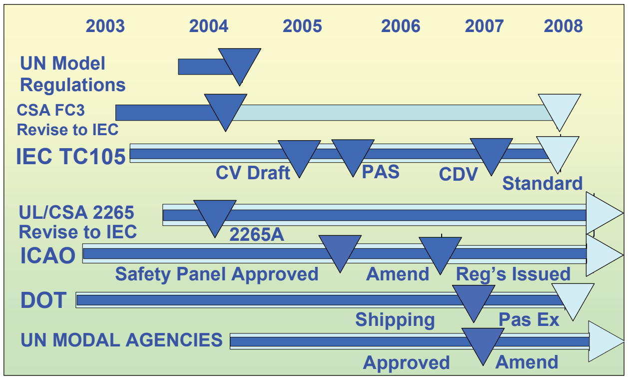

FIGURE 4. Codes and Standards Timeline

Conclusions and Future Directions

- Many of the projects milestones have been completed and the project is on track to complete the remaining milestones by December 2008.
- Achieved over 1,000 hours of runtime on multiple P2 prototype systems.
- Tested 11 fully integrated P2 prototypes demonstrating performance, life and temperature latitude.
- Achieved over 2,700 hours of MEA operation with less than 15% degradation.
- Future direction will be to complete next generation array design and assemble into P3 final system prototypes for testing:
  - Power and efficiency
  - Life (steady state and with start/stop cycles)
  - Temperature latitude

FY 2008 Publications/Presentations

1. Gottesfeld, S., and Minas, C., 2008, "Optimization Of Direct Methanol Fuel Cell Systems and their Mode of Operation," Micro-Mini Fuel Cells-Fundamentals and Applications, S.Kakac, L. Vasiliev, A. Pramuanjaroenkij (Eds.), Springer Verlag.

2. Minas, C. and Gottesfeld S., 2007, "Micro Fuel Cells: From System Level Considerations to Electrocatalysis," FC Expo, Tokyo, Japan.

3. Minas, C., 2007, "Spring Loaded Fuel Cell System," ANSYS Regional Conference, May 14-16, Philadelphia, PA.