

ADVANCES IN DIRECT METHANOL FUEL CELLS FOR MOBILE AND PORTABLE APPLICATIONS

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Introduction

The emerging need for portable sources that can provide long operating times and freedom from electrical re-charging is currently urging further development of direct methanol fuel cells. While advanced lithium-ion batteries are capable of at best 150 Wh/kg and require to be electrically recharged, fuel cells based on high energy liquid fuels such as methanol can potentially provide the energy content that exceeds the current battery technologies by 10 times with the possibility of instantaneous recharge by change of a fuel cartridge. Typical power levels considered for mobile and portable systems range from 100 mW – 1kilowatt and the approximate size and mass constraints for several candidate applications are shown in Table 1.

Table 1. Power source requirements for various mobile and portable applications

Application	Power Requirement, Watts	W/liter	W/kg
Cellular phone battery charger	0.1	2	1
Portable Phones/Personal Wireless devices	2-5	>20	>10
Laptop computer, Soldier-Portable Power Source	15-25	>35	>15
Multipurpose Emergency Power Source, Field Battery Chargers	50-100	>20	>10
Mobile Rovers	200-400	>130	>40
Medical Mobility and life support	300-500	>30	>30
Back up power supplies at cell phone towers	500-1000	>5	>15

According to Table 1, cellular phone chargers are the least demanding of all applications while power systems for mobile rovers present the most significant challenges. In addition to satisfying these principal electrical demands, the product design will also have to meet other requirements associated with fuel handling, product disposal and operation in extreme environments. While the DMFC is a candidate for all the applications in Table 1, only in some applications can all the requirements be readily addressed by state-of-art technology. In other cases, two to three times improvement in technology characteristics would be needed to optimally satisfy all the requirements. State-of-art and recent technological advances are now discussed.

Bipolar Stack and Balance of Plant Status

With a single cell operating at 0.45V at 150 mA/cm² and with state-of-art bipolar plate stack technology, the power density under realistic system operating conditions (55°-60°C, ambient pressure air operation) is approximately 55 W/kg. While it is not unusual to find higher power densities reported for DMFC stacks, it is important to qualify the stack properties under operating conditions that are consistent with the realization of overall thermal balance and water balance for the system. Such a qualification usually results in reduced values of specific power.

Bipolar stack designs have been developed jointly by the Jet Propulsion Laboratory and Giner Inc. under DARPA funded programs. A five-cell (80 cm² active area) stack (about 20 W output) and a 68-cell stack (1.4 kW output) have been studied under system operating conditions. In the 20-Watt stack, air was supplied from a plenum and flows through wide channels perpendicular to the flow of methanol solution. The pressure drop on the cathode side was less than 0.2 cm of water. When operated at 55°C on ambient pressure air, at airflow rates of about 1.7 times the stoichiometric requirement, the water and thermal balance requirements of a system are met. The 1.4 kW stack was internally manifolded, and operated at ambient pressures at about 2 times the stoichiometric air flow rate.

For handheld applications such as mobile phones, because of user comfort requirements the preferred operating temperature for the stack is close to ambient temperature, and typically not more than 35°C. At these low operating temperatures, the specific power of conventional bipolar plate stack designs reduces to about 20 W/kg.

The balance- of- plant for DMFC systems consists of the heat exchangers, pumps, sensors, gas-liquid separator, methanol concentration sensor, control electronics and the power management sub-system. Since concentration of methanol in the fuel circulation loop influences the power density, crossover rate and efficiency, the Jet Propulsion Laboratory has developed a methanol concentration sensor that has been operated for extended periods as part of an automated feedback and control system [1]. A balance-of-plant design by the Jet Propulsion Laboratory that allows system operation with instant start-up to full power between 15°C and 42°C and employing off-the-shelf components is estimated to be about 5 kg for a 150-Watt system. This translates to about 30 Watts of power generation supported by every kilogram of balance-of-plant.

Given the technology characteristics of 50W/kg for the stack and 30 W/kg for the balance-of-plant, at a 100 Watt power source that weighs 5 kg can be realized. The overall power density of conventionally-built DMFC systems could therefore aim at being 20 W/kg. The balance of plant for a typical DMFC system is expected to take up 15% of the power generated by the stack. Given the operating point of 0.45-0.5V /cell and a fuel efficiency of 85%, this translates to an overall system efficiency of about 26-29%. A 2-Watt portable phone power system that weighs 100g should also be realizable. However, the internal stack temperatures of 55°C, and temperature of air exhaust could be challenges to product design. To operate at lower stack operating temperatures lightweight stack designs would be essential. Also, miniature fluid handling systems would be necessary to attain the balance-of- plant characteristics required for handheld compact systems. An advanced 100 Watt hydrogen-air fuel cell power system developed by Ball

Aerospace Corporation has a specific power of 27 W/kg. When a portable power source with a capability of 5000 Wh is considered, such a hydrogen-air system would have a total weight (system and pressurized hydrogen fuel at 3000 psig included) of 10 kg. The direct methanol fuel cell system with the same capacity and operating at a system efficiency of 20% would weigh about 9.1 kg. While more efficient hydrogen storage options are being pursued, it is clear that at the current state of technology, direct methanol fuel cell systems with comparable energy and power densities to the hydrogen-air systems, can be realized when fuel supply is considered part of the power source package.

Advances in Lightweight Stack Technology:

With the value for specific power for the bipolar stack being 20W/kg at 35°C, realizing a cellular phone power source places a tremendous demand in the reduction of the weight of the balance-of-plant unless the specific power of the stack can be raised substantially. This situation has prompted the development of lightweight stack designs. The weight of the biplates and endplates is usually 80-90% of the stack mass in conventional stacks. Biplates are crucial in

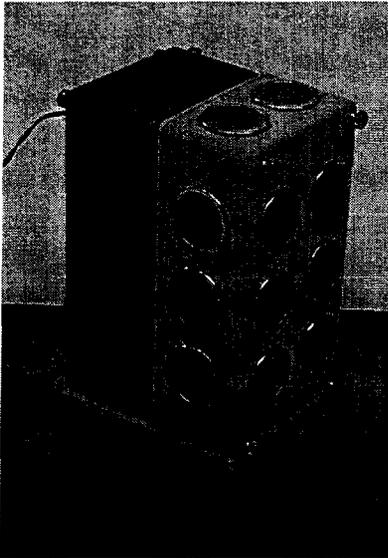


Figure 1. 5- Watt DMFC Unit with monopolar stack

minimizing voltage losses when operating at high stack currents. However, when the actual currents flowing through the stack are small, higher cell impedance configurations may be acceptable. This would be an attractive trade-off especially if significant weight reduction can be accomplished with an acceptable value of stack impedance. Such a compromise is readily achieved in monopolar configurations where the current is collected along the edges, or in the plane of the electrodes and bipolar plates are eliminated [2]. Challenges of designing monopolar stacks rest in minimizing orientation insensitivity, water removal and achieving good sealing. Such monopolar

stacks that provide 50 Watts/kg operating at 35°C have been developed at the Jet Propulsion Laboratory. In March 2002, under

funding from TechSys Inc, JPL demonstrated a 5-Watt direct methanol fuel cell system that uses a lightweight monopolar stack, shown in Figure 1. The unit is approximately 15 cm x 10 cm x 7.5 cm and is capable of powering several cell phones and is operated on dilute 1.5 M methanol. The cell power densities as high as 35 mW/cm² was demonstrated at 30°C operating on ambient pressure airflow supported by natural convection. When operated at 60°C, the stack is expected to have a specific power of 120 W/kg, demonstrating that weight reductions can be realized by adopting a monopolar stack design. The monopolar design may be applied to power levels as high as 50 Watts in a single stack configuration. In a modular configuration where several such individual stacks are used, much higher wattage levels can be realized.

Demonstration of a 1 kW system:

JPL and Giner Inc., under funding from SCAQMD and CARB have integrated a 1kW DMFC unit and demonstrated system operation. The stack fabricated by

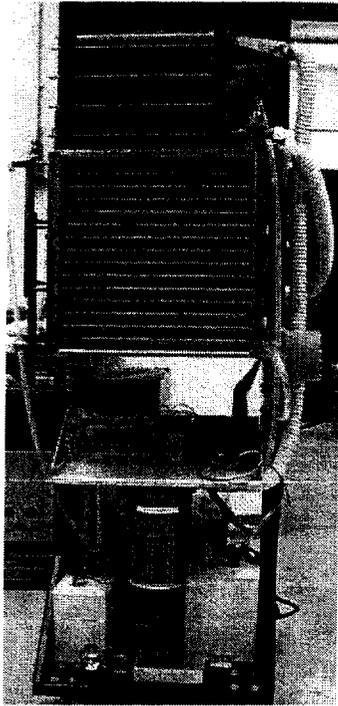


Figure 2. 1 kW DMFC Demonstration Unit

Giner Inc., to meet JPL's requirements[3], consists of 68 cells (electrode active area of 400 cm^2). A continuous output of 1.4 kW was realized at 60°C from this stack operating on unpressurized air, which translates to specific power of 42 W/kg. The system incorporates an advanced lightweight "polycapillary matrix" condenser fabricated by MER Corporation, in addition to automated concentration control. The current unit has been mounted on a six-foot rack for test purposes. A packaged version of this unit is anticipated to be about half the size seen in Figure 2. This demonstration establishes the feasibility of DMFC technology for applications such as in cellular phone towers and back up generators.

Membrane and Catalyst Layers

As a collaborative effort between the University of Southern California, Giner Inc., and JPL with funding from DARPA, an advanced membrane based on polystyrene sulfonic acid has been successfully demonstrated in a five-cell stack with an electrode active area of 80 cm^2 . The membrane exhibits a crossover rate of 25% of that of Nafion 117 with similar electrical performance. Recent advances in sputter deposition of catalyst layers at JPL have allowed the attainment of catalyst utilization of 800-1000 mW/mg. At this level of catalyst utilization, platinum-ruthenium loadings of 0.5 mg/cm^2 are conceivable without substantial loss in performance. Further improvements in catalyst activity and utilization can be achieved by development of porous three-dimensional structures by various modifications to the sputtering technique.

References:

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2. S. R. Narayanan, T. I. Valdez and F. Clara, *Proceedings of the Direct Methanol Fuel Cell Symposium*(Editors, S.R. Narayanan, S. Gottesfeld and T. Zawodzinski), Electrochemical Society Proceedings, PV 2001-4, p.254 .
3. A. Kindler, T. I. Valdez, C. Cropley, S. Stone and E. Veksler, *Proceedings of the Direct Methanol Fuel Cell Symposium* (Editors, S.R. Narayanan, S. Gottesfeld and T. Zawodzinski), Electrochemical Society Proceedings, PV 2001-4, p.231.

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