Functional Differences Between Micro Fuel Cells and Battery Packs Integrated in Portable Electronic Products

By

UL 2265 - Working Group 15

Jerry Hallmark (Motorola) – Chair
Elizabeth Bostic (US Army), Thomas Burke (UL),
Harry Jones (UL), Kurt Kelty (Panasonic),
Bill Lowe (CSA International), Steve Wicelinski (Gillette)

August 4, 2004

Introduction

As power demands continue to increase for portable electronic devices, it is likely that conventional primary (non-rechargeable) and secondary (rechargeable) batteries may not be able to meet these increased power demands. Fuel Cells are one of the promising technologies that could address these needs. There are a range of fuel cell technologies and potential applications, and the term "Micro Fuel Cell" (MFC) refers to small fuel cells that are designed to power portable electronics equipment, and in many cases can be integrated into the electronic device itself.

It is expected that micro fuel cells systems can provide more operating time for these devices before requiring a recharge or refuel. This is due to the high amount of energy that can be stored in fuels such as methanol, hydrogen, etc. This chemical energy stored in the fuel is converted into electric power in the fuel cell. The total energy is usually referred to in units of Watt-hours (Wh), calculated as power in watts times operating time of system (hours). It is expected that fuel cells will provide higher total energy for a given size or weight than batteries, calculated as Watt-hours per liter (Wh/l) or Watt-hours per kilogram (Wh/kg). A second advantage of fuel cells is that once the fuel is consumed, the fuel cartridge can be replaced and the system continues to provide power. A user does not have to plug a battery charger into an AC power (wall) outlet and allow several hours to recharge the battery. In fact, a fuel cell will continue to supply power indefinitely as long as fuel and air are supplied.

Micro Fuel Cell Fundamentals

Fuel cells are electrochemical devices that convert chemical energy into electrical energy. By combining oxygen with a hydrogen-containing fuel, fuel cells are capable of generating electrical power (See Figure 1 – Direct Methanol Fuel Cell). Several fuels are being investigated as possible candidates, such as hydrogen, alcohols (methanol, ethanol), chemical hydrides (sodium borohydride), and hydrocarbon. These fuels will be utilized in equipment designs that include proton exchange membrane (PEM) stacks and direct methanol fuel cell (DMFC) stacks.

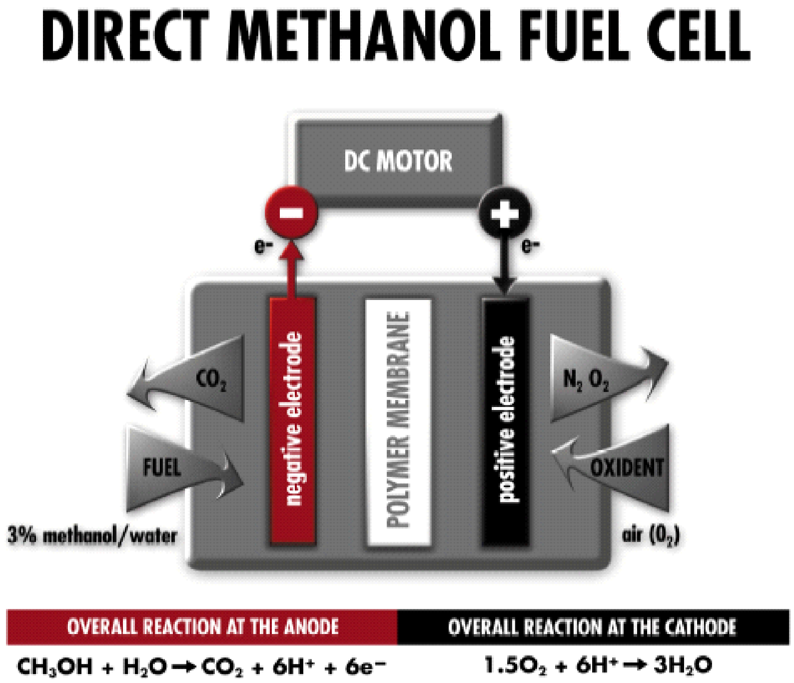

Figure 1 – Basic Direct Methanol Fuel Cell Operation
(Source: Methanol Institute)

While fuel cells are similar to batteries in some ways, there are some key differences. In a fuel cell, the active materials are supplied from an external source when power is desired. In this manner, it differs from a battery where the active materials are stored inside the battery. The electrode materials of a fuel cell are inert (provide catalytic sites for the active materials to react) and are typically not consumed like the electrodes in a battery. Fuel cells offer cord-free operation and instant recharge, whereas a battery must be replaced (disposed of) or recharged when its active materials are consumed.

As micro fuel cell technology progresses toward commercialization, there are some hurdles that must be overcome. One of those hurdles is the lack of high pulse power capability required during start-up by today's high-tech electronic devices, such as laptop computers and PDA's. Current design strategies to overcome this obstacle involve the use of hybrid systems, which, in addition to a MFC, incorporate a rechargeable battery into the system circuitry. In this manner, the battery can supply the initial high power demands of start-up, and at switchover, the fuel cell can provide extended steady state runtime.

Fuel Cell construction

The heart of a fuel cell system is the fuel cell stack. The key component is the Membrane Electrode Assembly (MEA) made up of a proton conducting membrane with catalyzed electrodes and gas diffusion backings on either side (anode and cathode) – Fig. 2. The fuel cell stack consists of a number of MEAs sandwiched between current collectors (typically graphite) that contain flow fields to direct the flow of fuel and oxygen across the MEA.

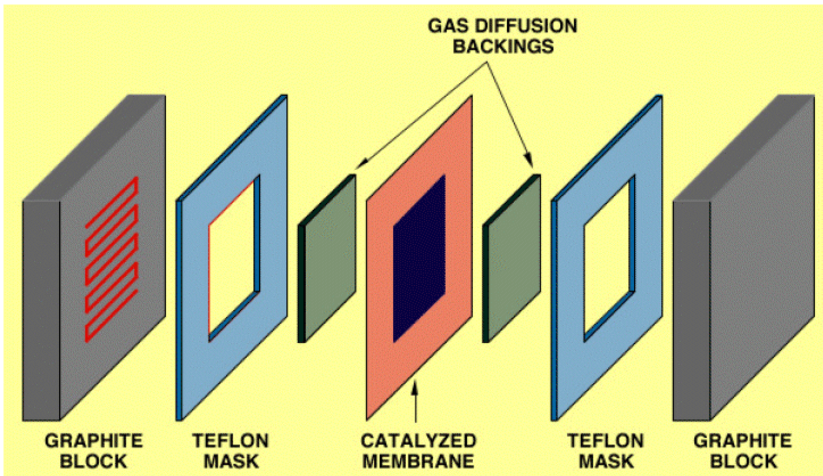

Figure 2 – Construction of Fuel Cell Stack
(Source: Fuel Cell Handbook – 6th Edition, US Dept. of Energy)

The fuel cell system also contains other components such as fuel storage, fuel and air supply to stack and electronics for system control & power conditioning. In some systems, the fuel is "processed" prior to introduction to the fuel cell. This fuel processing can range from simple mixing of fuel with water (dilution) to a chemical reaction (reforming) of the fuel to form hydrogen that is then fed to the fuel cell.

For fuel storage, it is anticipated that replaceable fuel cartridges will be used initially. These would be "plugged into" the MFC and replaced when empty. These cartridges would likely be designed in a few standard sizes/configurations and would be widely available for a variety of sources, similar to ink jet printer cartridges.

Targeted applications

MFCs are targeted to replace or charge Li-ion batteries in portable applications such as laptop computers, cell phones, PDA's and military devices.

A recent portable fuel cell market study projected that almost 22% of all hand held electronic devices with rechargeable power packs could be powered by MFCs by 2011. Various OEMs have announced commercialization plans for laptops powered by MFCs in 2005. Significant military applications of MFC are projected as soon as 2006.

Applications: battery packs vs. MFCs

In applications where large or repetitive bursts of power outside the capability of fuel cells are required, it is advisable for designers to focus on batteries or a hybrid system. When operation is required outside the rated range of ambient temperatures of a fuel cell, batteries may serve a more dominant power-source role for the application. For example, in sub-freezing environments where the efficiency of aqueous based fuel cell systems drastically reduced, batteries would be the preferred source of power. In cases where cord-free operation is not critical or the user is not in need of an "instant recharge", batteries can be considered or used to compliment the fuel cell.

Initially, when MFCs are incorporated into portable consumer applications, OEM's may be hesitant to introduce a product based on an unproven technology. They may also hesitate due to the lack of availability of fuel cartridges. As a result, the initial MFCs will probably be designed to be interchangeable with a battery pack in the same form factor. Once the initial market is established, it is expected that OEMs will design their products around either a MFC or a battery. The advantage to designing the device around a MFC is that some of the components of the MFC can be designed into the device rather than leaving them in the MFC. This can reduce size and cost. Furthermore, customized designs of the MFC and device can enable more efficient cooling, exposure to air source, etc.

When MFCs are introduced into military applications or industrial applications, they are expected to be designed directly into the device without consideration to battery interchangeability. In these particular cases, test marketing is not as important and the user will mostly likely be a captive user in which case replacement cartridges would be readily available.

Operational/functional differences with a battery pack versus MFC

MFC have the advantage of being able to provide consumers with convenient, on-demand power anytime, anywhere, without the need to ever plug the device into an AC power (wall) outlet. Furthermore, MFCs have the potential to provide longer run-times for portable consumer electronics currently powered by batteries. MFCs can be instantly 'recharged' by simply replacing or refilling the fuel cartridge, unlike a battery powered device which needs time and an AC power outlet. Once these refueling cartridges become readily available, consumers will be able to purchase replacement cartridges at convenient locations, allowing users to extend their runtime on demand.

If the MFC is designed to replace a Li-ion battery pack, then the use of the MFC should be similar to a Li-ion battery. The major difference is that users will need to purchase replacement fuel cartridges instead of recharging their battery from a power outlet.

If the MFC is designed to charge the battery, then the MFC will replace the charger. This will enable users to charge anywhere, anytime without a power outlet. Consumers would again need to purchase replacement cartridges. Users would need to understand that the charge time may increase due to the smaller charging current.

Potential performance issues when using micro-fuel cells

Several issues must be considered when operating a fuel cell in an electronic system. First is the supply of fuel and oxygen (air) to the fuel cell. The system designer must provide means for fuel supply (fuel cartridge and periodic replacement, or fuel reservoir with periodic refilling) and oxidant supply (generally forced air from fan or pump). In addition, a means should be provided to determine the amount of fuel remaining and estimated time before replacement/refilling (fuel gauge). The designer must also accommodate the exhaust requirements of the fuel cell, mainly the air exhaust that will likely be above ambient temperature and will contain some amount of water vapor. Micro fuel cell systems will be designed such that the exhaust will not contain any appreciable levels of unconsumed fuel or other potentially flammable or toxic materials.

A second set of design issues involve the potential heat and noise/vibration generated by the fuel cell system. Since all fuel cell systems are less than 100% efficient in converting chemical (fuel) energy into electricity, the fuel cell will generate excess heat that must be removed from the system. This can be partially accomplished by the oxidant/air supply and exhaust, but additional heat sinks/spreaders and cooling may be needed. Many of the fuel cell systems being considered are active systems that use pumps/fans to move fuel and air into and out of the fuel cell stack. These will generate some level of noise and possible vibration in the fuel cell system.

Designers and users will also need to consider possible forced discharge/short circuit of the fuel cell power source. Fuel cells generally will not be able to source very high peak currents that batteries can, but precautions must be taken to limit the current drawn from the fuel cell. Many fuel cells systems will include such short circuit protection. A simple solution is to stop the flow of fuel and/or oxidant to the fuel cell, which will stop the generation of electrical power and effectively shutdown the fuel cell. In addition, other electronic means may be used to disconnect the fuel cell from an excessive load or short circuit condition.

Note also that since an air supply is generally required for operating and cooling the fuel cell, air inlet/outlets and fans/air pumps must not be blocked during operation of the fuel cell. This could cause a shutdown of the fuel cell due to loss of oxidant and/or overheating.

Safety and Regulatory implications

Although fuel cell technology has been around for over 100 years, MFCs have emerged only in the past few years. As with any new technology, there are new potential safety implications and risks. Standards must be developed for construction and performance. The most basic issue concerns the fuel for the fuel cell. The fuels most commonly being considered for fuel cells include hydrogen, alcohols (methanol, ethanol), and chemical hydrides ($NaBH_4$, etc.). These are considered to be hazardous materials and include various potential hazards such as flammability, toxicity, corrosivity. These materials must be properly handled by the user and transported. The standards will address the potential fuel leakage during cartridge connection, disconnection, and normal operation. These hazards are not unique to fuel cells and had to be addressed for batteries as well (NiCd, Li-Ion, etc.). Beyond the fuel itself, fuel cell systems must be designed in accordance with accepted practices for portable electronics, IT equipment, power supplies/chargers, etc.

Micro fuel cell standards are being developed in the United States by Underwriters Laboratories Inc. (through its ANSI/UL 2265 standards technical panel) and internationally by IEC TC105 (through its WGs 8,9,10). The first version of these standards are planned to be completed within the next year and would allow for testing and certification of micro fuel cell systems.

Due to the potential hazards with fuel cells, regulations for their use, transportation, and disposal/recycling must be developed. Work has already begun with the US Dept. of Transportation's Office of Hazardous Materials Safety. DOT generated a draft regulation in conjunction with the US Fuel Cell Council and it was recently submitted to the United Nation's Committee of Experts on the Transport of Dangerous Goods. If this draft regulation is accepted by UN, it would pave the way for regulations for fuel cells and fuel cartridges to be brought on-board public transportation (airplanes, trains, rail, etc.).

The industry expects that MFCs will be developed with electrical output capabilities of 60 VDC or less and 240 VA or less. Early developments indicate electrical ratings to be less than 20 VDC and less than 50 VA.

Markings/instructions for end products with MFCs

While many of the markings and instructions for fuel cells are similar to those of batteries, there are some differences. In addition to the appropriate instructions for the fuel cell, detailed and explicit safety information will need to be provided for the fuel cartridge. As appropriate, information on oxygen depletion in closed spaces should also be provided. In some cases, it may be necessary to provide instructions dealing with the avoidance of unintended exposure to fuel after disconnection of a cartridge. As applicable, safety instructions dealing with flammable or combustible fuels should also be provided. Lastly, for pressurized fuel cartridges a caution may need to be added that the cartridge contains flammable gas under pressure.

Military Perspective

The limiting factor in the effectiveness of a dismounted soldier is the ability of that soldier to carry energy. For a more effective soldier, the military needs a high energy density power source that is lightweight. MFCs are being examined to meet the demands of the dismounted soldier. Current military efforts focus on three power applications for fuel cell technology including soldier and sensor power (<100W), stand-alone battery charging (100W-500W) and auxiliary power units (500W-10kW). These target areas represent the most practical near term applications where fuel cell technology could transition into battlefield environments.

MFCs fall in the soldier and sensor power range and have numerous near term applications. Today's military operates at a level where others cannot in a large part due to the significant tactical advantage state of the art power technologies provide. However the issue of powering these technologies has been something the military has struggled with. Soldiers are overloaded with night vision devices, laser target designators, range finders, global positioning systems and many other electronic devices that provide our troops tactical and strategic advantages over their enemy. The power demand of these devices continues to climb which leads to soldiers overloaded with cumbersome and heavy batteries. The future force concepts seek to create a lightweight, overwhelmingly lethal, fully integrated individual combat system, including weapon, head-to-toe individual protection, netted communications, soldier worn power sources, and enhanced human performance providing unsurpassed individual & squad lethality, survivability, communications, and responsiveness.

MFCs that fall in the soldier and sensor power ranges are being investigated to meet the ever-growing power demands of these electronic devices. One potential scenario would be for the soldier to carry one fuel cell and several charges of fuel that allow him to be fully operational with all these electronic devices for as long as 72 hours, and to meet this power demand with a weight burden less than that of current military batteries. In the sensor power applications, fuel cells could be used to power remote sensors in areas that are not readily accessible. This may involve dropping the unit from a plane into an area of surveillance, being able to control the unit from a satellite location, and the transmission of data. The military has focused on direct methanol fuel cells (DMFC) as the principal near-term technology solution for soldier and sensor power for several reasons. While there are many fuel cell technologies that utilize compressed hydrogen, this type of technology is not currently feasible in a battlefield environment. DMFCs use methanol to directly and efficiently provide power without a reforming process. The high energy density, quick start capability, and technology maturity of DMFCs make this technology an attractive choice for low power scenarios. Additionally, methanol can be prepackaged making the logistics of deploying this technology safer and easier.

However, fuel cells are only a small part of the power solution. Future power sources will most likely be a hybrid of many power technologies in order to provide the greatest benefit and to compensate for the large gamut of military operating conditions and tactical capabilities. Fuel cells are not viewed as a replacement for current military batteries and in many situations batteries are still consistently the best available power source for the soldier. The functions of the soldier's power source are far and wide. Durability and reliability are two major issues that micro fuel cells will need to overcome. Under military specifications potential operating scenarios fuel cells must be able to effectively operate from -50F to +145F. Additionally it is necessary for the soldier's power source to be able to operate under 1 meter of water for 30 minutes. This poses a significant problem to fuel cell technologies because of the required air intake. The military envisions a single power source that is small, lightweight, and high in energy for soldier power. This would not necessarily have to be a fuel cell and would most likely be a combination of several power technologies with the ability to toggle each power technology on and off depending on the power demand and operating conditions with no change in available power. Ideally this device would be in a configuration where all necessary electronic equipment that the soldier would need to operate could be run simultaneously off of a single power source box containing whatever power technologies were necessary.

The military focus is not on one specific technology moving forward, but to move in the direction of providing the soldier the best power source when it is needed. Limiting the operational capabilities of the soldier is not an option. Degradation in performance on the battlefield is unacceptable. Clearly for some scenarios, batteries continue to be the best power option. Recent military test and evaluation of several DMFC's from across the globe have shown that for missions less than 24 hours batteries continue to be the best available power source in terms of weight and available energy, but at the mission length increases fuel cell technology becomes more attractive in specific scenarios. Reduction in size and weight of the fuel cell stack and balance of plant components is an obstacle that will need to be overcome in order to compete with battery technology. For fuel cells to be integrated into the military they will need to come in a ruggedized pack with all necessary connections for currently fielded equipment.