LA-UR-01-4380

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Title: FUEL CELL SYSTEMS FOR PERSONAL AND PORTABLE POWER APPLICATIONS

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Submitted to: Symposium 2001: Highlighting Student and Postdoctoral Research

FUEL CELL SYSTEMS FOR PERSONAL AND PORTABLE POWER APPLICATIONS

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ABSTRACT

Fuel cells are devices that electrochemically convert fuel, usually hydrogen gas, to directly produce electricity. Fuel cells were initially developed for use in the space program to provide electricity and drinking water for astronauts. Fuel cells are under development for use in the automobile industry to power cars and buses with the advantage of lower emissions and higher efficiency than internal combustion engines. Fuel cells also have great potential to be used in portable consumer products like cellular phones and laptop computers, as well as military applications. In fact, any products that use batteries can be powered by fuel cells.

In this project, we examine fuel cell system trade-offs between fuel cell type and energy storage/hydrogen production for portable power generation. The types of fuel cells being examined include stored hydrogen PEM (polymer electrolyte), direct methanol fuel cells (DMFC) and indirect methanol fuel cells, where methanol is reformed producing hydrogen. These fuel cells systems can operate at or near ambient conditions, which make them potentially optimal for use in manned personal power applications. The expected power production for these systems is in the range of milliwatts to 500 watts of electrical power for either personal or soldier field use. The fuel cell system trade-offs examine hydrogen storage by metal hydrides, carbon nanotubes, and compressed hydrogen tanks. We examine the weights each system, volume, fuel storage, system costs, system peripherals, power output, and fuel cell feasibility in portable devices.

INTRODUCTION

Fuel Cells are electrochemical devices that produce electricity from a fuel (usually hydrogen gas) and oxygen. Electricity is produced electrochemically, similar to an ordinary battery; no combustion is involved. In a typical fuel cell two electrodes, an anode and a cathode, are separated by an electrolyte. One or more fuel can be combined, like batteries, into groups what are called stacks, to obtain a usable voltage and power output. Batteries are similar to fuel cells in that they both convert chemical energy into electricity very efficient and they both require very little maintenance because neither have any moving parts.

Fuel cells are being developed to run cars and other forms of transportation because they are much more efficient in converting fuel to power and produce virtually no air pollution in comparison to the standard internal combustion engine. Fuel cells can also be used in portable electronic devices such as cellular phone and laptop computers, as well as portable military applications.

Three types of fuel cells investigated in this project:

- Hydrogen gas polymer electrolyte membrane (PEM) fuel cells
- Direct methanol fuel cells (DMFC)
- Indirect methanol fuel cells

The purpose of this project is to examine the trade-offs of incorporating the above fuel cell systems in portable power applications. These trade-offs include a comparison of weight, volume, fuel storage, fuel availability, costs, system peripherals, and power output in the above fuel cells systems.

BACKGROUND

A fuel cell system normally consists of a fuel cell stack. The fuel cell stack is a combination of individual fuel cells combined to achieve a required voltage. The maximum voltage of an individual fuel cell is about 0.7 V. An individual fuel cell consists of a polymer electrolyte membrane (usually Nafion™), electrodes (platinum on carbon), porous carbon backing layers, and flow fields/current collectors, all of which are indicated in figure 2. The fuel cell system also includes fuel a section for fuel production (if needed) and a section for fuel storage.

Hydrogen gas PEM fuel cells produce electricity directly from hydrogen gas and oxygen. The fuel cell produces electricity, water and heat using hydrogen gas. These fuel cells are about 60% efficient in converting chemical energy to electrical energy. A single hydrogen gas fuel cell can operate at only 0.7 Volts (or about 60 % of the maximum electrical potential which is about 1.23 Volts). Theses fuel cells normally operate between 70-80 °C.

Fuel storage in a hydrogen gas PEM can occur in a variety of methods. The methods considered in this project include direct hydrogen storage in high pressure gas cylinders, direct hydrogen storage in carbon nanotubes, and chemical storage in metal hydrides. $FeTiH_{1.9}$ [1] is a metal hydride that has been studied and is used in this project. A hydrogen weight percentage of 4.2 wt %[2] for carbon nanotubes is used for this project.

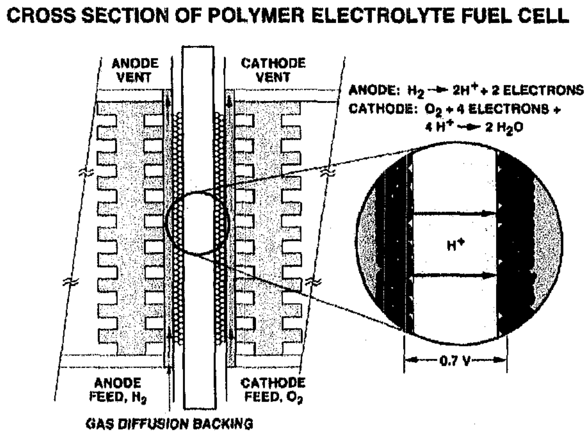

Figure 1. Hydrogen gas fuel cell schematic[3]

Direct methanol fuel cells use the same principles as the hydrogen gas PEM, with the exception that it directly uses methanol as a fuel instead of hydrogen. DMFCs are fuel cells that produce electricity directly from methanol and oxygen. The DMFC normally operates between 70-90 ° C is about 40% efficient. Methanol fuel can be stored in storage tanks for the DMFC and the indirect methanol fuel.

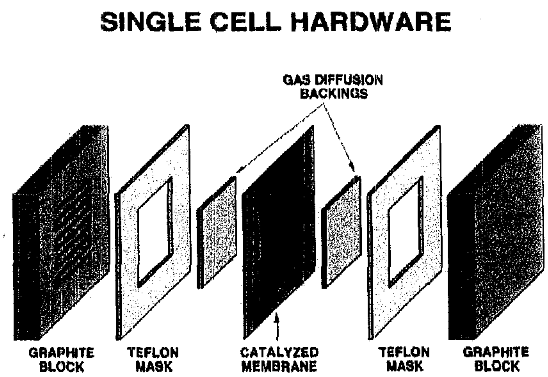

Figure 2. The components of a single PEMFC[4]

The indirect methanol fuel cells involve internal reforming of methanol fuel using steam to produce hydrogen gas, as well as other products, through a process called "steam reforming". Hydrogen gas is not directly supplied in the indirect methanol fuel cell; instead, it is produced through a series of reforming and purification reactions to make hydrogen gas and remove carbon monoxide that is produced within the fuel cell.

Besides the internal reforming of methanol, this type of fuel cell operates using the same principles as the direct hydrogen PEMFC. The efficiency of this fuel cell can be about the same as a hydrogen gas PEM fuel cell.

ANALYSIS

1) Examine and calculate volumes, weights, and costs of each fuel cell based on industry, commercial, and estimated values at energy capacities at 30, 60, 90, 120 Watt-hours

2) Compare the above values to conventional cellular phone batteries:
   a) Lithium ion battery (Nokia model BLS-4): 13.5 watt-hour capacity, volume and mass unknown, approximately $71.00
   b) Lithium ion battery (Sony model UR-S4Li): 9.7 watt-hour capacity, 25.99 cm^3, 92 grams, approximately $90.00
   c) Nickel metal hydride battery (Sony model S333): 8.6 watt-hour capacity, 85.8 cm^3, 110 grams, approximately: $75.00

RESULTS

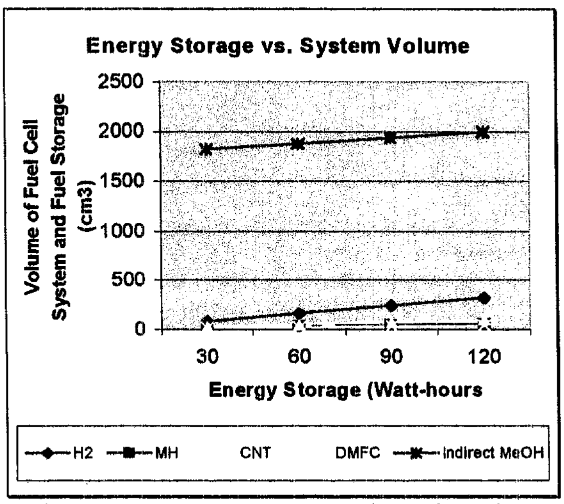

Figure 3. Energy storage plotted against the volumes of each fuel cell system.

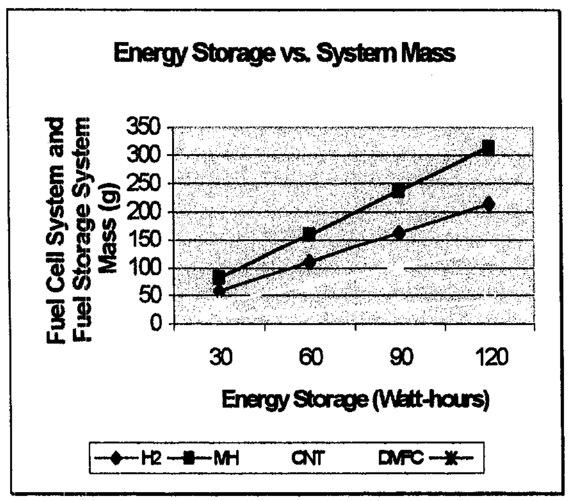

Figure 4. Energy storage plotted against the weights of each fuel cell system.

The storage weight for the indirect methanol fuel cell system was between 223.2 kg and 239.8 kg. These values are not on the above graph in figure 4 because they were much higher than the weights for the other fuel cell systems.

The calculated fuel cell costs for energy capacities between 30 and 120 Watt-hours are as follows:

- DMFC system - $134.90-$196.40
- Hydrogen PEM system using compressed hydrogen - $101.70-$120.50
- Hydrogen PEM system using a metal hydride - $2.9-$11.3 thousand
- Hydrogen PEM system using carbon nanotoubes - $193.2-$772.5 thousand
- Indirect Methanol fuel cell system - $223.2-$239.8 thousand

CONCLUSION

DMFC is the most cost effective fuel cell it also has a low weight and volume which gives it the greatest potential among the other fuel cell systems to be used in cellular phones, and other similar portable consumer products and military applications. PEM fuel cells using compressed hydrogen fuel storage has potential to be used in cellular phones based cost and weight, but will not likely be a likely candidate because they require large volumes and has many safety issues associated with handling high pressure containers.

Fuel cells using MH or CNT to store hydrogen gas appear to be cost ineffective to the average consumer. They are also closer in price, weight, and volume to the conventional cellular phone batteries examined in the project.

The indirect methanol fuel cell system appears to be bulky and complex. It would also be cost prohibitive to the average consumer. It also has a high weight and volume, which would be impractical to use for cellular phones. The indirect methanol fuel cell may be more applicable to power larger devices, such as portable power, as well as military use.

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2. Bruce Lin. Princeton University, Princeton, New Jersey. Conceptual Design and Modeling of a Fuel Cell Scooter for Urban Asia, p. 138, November 1999. Estimates for $FeTiH_{1.9}$ from table 3.7.

3. Shimshon Gottesfeld. Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico. *The Polymer Electrolyte Fuel Cell: Materials Issues in a Hydrogen Fueled Power Source*. Figure 1.

4. Shimshon Gottesfeld. Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico. *The Polymer Electrolyte Fuel Cell: Materials Issues in a Hydrogen Fueled Power Source.* Figure 2