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Portable fuel cell power generator

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Abstract

The proliferation of electronic equipment in the market-place is driving the growth of portable power generators. The ability to store a sufficient amount of energy is the key issue for applications requiring high power levels or extended operation. The source of this energy, measured in watt-hours, can be either batteries or fuel for energy conversion systems. This paper compares energy storage methods and shows that fuel cell systems are well suited for portable power applications due to their use of high energy density storage capabilities.

Keywords: Fuel cells; Polymer electrolyte membrane; Applications/portable power

1. Introduction

Due to the limited energy storage capability of battery technologies, weight becomes a key limiting factor. Table 1 shows typical values of energy storage densities of various battery technologies.

For most applications which require either high power or high energy storage, or both, the convention today is internal combustion (IC) generator systems which typically use hydrocarbons as fuel. Such fuels offer high energy storage capability but require energy conversion into electrical power. For comparison purposes, Table 2 shows the energy storage density of some hydrocarbon fuels (using an optimistic 25% LHV energy conversion efficiency). It is obvious that such fuels represent nearly two orders of magnitude increase in energy storage density over the most advanced battery technologies.

In spite of the tremendous energy storage advantage of hydrocarbon fuels, such systems must also account for the weight penalty of the energy conversion system — the IC generator. These systems are commonplace for power requirements above 1 kW, but few examples exist for lower power, portable, systems.

Fuel cell technology represents a new approach to addressing the needs of the portable power market. The fuel cell is inherently an energy conversion device, combining fuel and air directly into electricity. One important advantage is that it can be sized to meet the power and energy requirements of the specific application.

Table 1
Energy density of various battery technologies

Technology	Energy density ($Wh\ kg^{-1}$)
Primary batteries	
Alkaline–manganese dioxide	130
Lithium/sulfur dioxide	170
Rechargeable (secondary) batteries	
Lead–acid	35–40
Nickel/cadmium	40–50
Nickel/metal hydride	60–80
Lithium-ion	110–125

Table 2
Energy storage density of hydrocarbon fuels

Fuel	Energy density ($MJ\ kg^{-1}$, LHV)	($Wh\ kg^{-1}$, 25% η_{LHV})
Diesel	42.5	2900
Propane	46.4	3200
Liquid natural gas	49.0	3375
Methanol	20	1375

Fuel cells have been identified as the energy conversion method for the future. Ballard has been active in the development and commercialization of polymer electrolyte membrane (PEM) fuel cell technology for both the utility and transportation markets. Recently, Ballard has developed low power fuel cell systems which have attracted significant interest.

Ballard has recently developed a version of its technology which is targeted to the portable market. This system uses near ambient pressure air and hydrogen as the reactants,

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Table 3
Refillable fuel storage options for pure hydrogen

Fuel storage method	Hydrogen (wt.%)	Wh kg^{-1}	Comments
Metal hydride	1.0–2.0 [1]	80–370	15–40% reduction in energy storage density for packaging rechargeable 100–10000 times
High pressure gas cylinders	4–5	740–930	significant weight penalty for low energy storage tanks

thereby simplifying the system dramatically over compressed reactant gas systems. Through this simplification, the weight of the fuel cell system becomes small or even insignificant compared to the energy storage component.

2. Fuel storage for PEM fuel cells

PEM fuel cells can operate on different fuels. The simplest and most elegant is pure hydrogen. Options for pure hydrogen storage are shown in Table 3. Cryogenic systems may contain up to 30 wt.% hydrogen but are typically sized to match consumption with boil-off rate. Chemical hydrides, primary sources of hydrogen, are under development for specialized applications. Some of these are capable of hydrogen storage with an energy density similar to that of some liquid hydrocarbon fuels.

To evaluate how effectively hydrogen is converted into electrical power, one must know the cell voltage of the fuel cell and the system parasitic losses. The following formula can be used to calculate the energy storage density of a fuel based upon its initial hydrogen content:

$$\text{Fuel consumption} = \frac{3.767 \times 10^{-2}}{V_\eta} \frac{\text{kg H}_2}{\text{kW h}}$$

where V is the cell voltage and η is the efficiency of the supporting system. Table 4 provides a view of energy storage density based upon net hydrogen storage density of the fuel source, assuming no system parasitic loads ($\eta = 100\%$). In Ballard's portable fuel cell system, these parasitic loads are typically less than 5%, hence $\eta > 95\%$. Energy storage densities of battery, internal combustion generator and fuel cell are compared in Fig. 1.

Table 4
Energy density based upon fuel cell voltage and wt.% hydrogen storage fuel source

Hydrogen (wt.%)	0.7 V/cell	0.6 V/cell
0.5	93	80
0.75	139	119
1.0	186	159
1.25	232	199
1.5	279	239
1.75	325	279
2.0	372	319
3.0	557	478
4.0	743	637
5.0	929	796
10.0	1858	1593
15.0	2787	2389

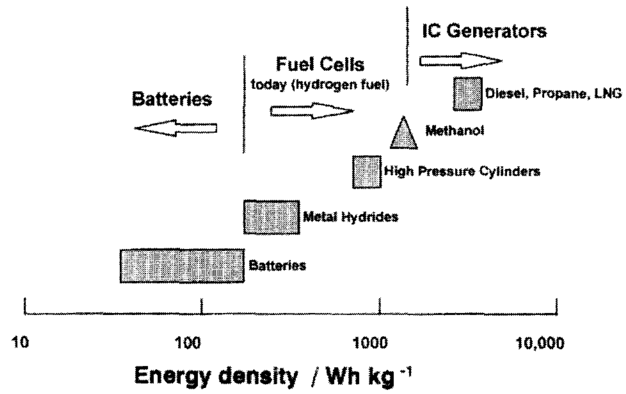

Fig. 1. Comparison of energy storage densities.

Liquid hydocarbon fuels offer high energy storage but require processing to convert into a hydrogen-containing gas stream. At present, liquid fuel processors are under development.

Johnson Matthey has recently unveiled a Hot-Spot™ partial oxidation reactor for methanol fuel conversion, weighing 200 g and producing an equivalent 250 W of hydrogen gas flow. Matsushita Electric Works has also announced a small butane reformer which is capable of a 300 W hydrogen gas flow. Both systems produce a reformed gas stream which must be further processed to reduce carbon monoxide levels before the fuel can be safely fed to a fuel cell.

3. Fuel cell systems

PEM fuel cell technology has attained a high level of interest recently as a high power density source for a variety of applications. Prototype PEM fuel cell vehicles have been unveiled by both Daimler Benz and Toyota over the past 3 years. This technology has been touted as the future replacement for existing car engines. Ballard has released information pertaining to one of its motive stack designs, which has a power density of 700 W kg^{-1} and 1000 W liter at typical motive operating conditions.

There is no 'ideal' fuel cell design. Fuel cells must be designed to meet the system requirements of the end products. For example, high power density and low cost can only be achieved with fuel cell systems which operate at high current density (e.g. for motive applications). Conversely, high efficiency is achieved at higher individual cell voltage, which results from lower current density and thus higher unit cost

Table 5
Portable fuel cell power generators

System	Size (mm)	Weight (kg)	Continuous power (W)	Energy (kWh)
Fuel cell and chemical hydride	304×203×457	13.6	100 at 12 or 24 V	13
Fuel cell and high pressure gas	304×203×457	12.2	100 at 12 or 24 V	5
Fuel cell and metal hydride	229×203×457	12.7	100 at 12 or 24 V	1.3

(e.g. for utility applications). The performance of PEM technology is related to the concentration of the reactant gases: the higher the pressure, the higher the cell voltage at a given current density. Hence, system design engineers focus on methods to compress the reactant gases without incurring significant parasitic power losses. This provides benefit for power density, efficiency and cost reduction. Portable, low power systems, on the other hand, focus on system weight. Ballard has found that lower power fuel cell systems can be achieved in simple, lightweight designs provided the reactant gases are at near ambient pressure.

Fuel efficiency of fuel cells is dependent upon both cell voltage and system parasitic loads. One component of the parasitic loss is the utilization of the fuel. Ideally, all hydrogen is electrochemically reacted to produce power. However, this is rarely the case — impurities exist in either the original fuel source or from diffusion through the polymer electrolyte membrane from the oxidant side (such as nitrogen from an air stream). These impurities do not electrochemically react and, in a closed loop or dead-ended system, will accumulate over time within the anode, reducing the available hydrogen and negatively impacting fuel cell performance. A method used by Ballard to maximize fuel utilization in a portable power system supplies the fuel to the individual cells in series, such that impurities accumulate in the last cell in the series. The voltage of this cell will provide information as to the concentration level of the impurities and can be used as the control signal to open a valve and purge this last cell. Ballard has observed a fuel utilization rate of 99.875% for an ambient air fuel cell stack operating at typical conditions using this technique. Fuel utilization will depend upon current density (higher utilization at higher current density), and membrane-electrode design. Fuel manifold arrangements can be configured in a variety of ways to achieve the design principle of impurity accumulation. This approach, which has been previously employed in other fuel cell systems, provides a simple technique to maximize fuel utilization and is especially relevant to portable PEM fuel cell systems.

Recently, there has been increased interest in ambient pressure fuel cell systems. These systems use near ambient pressure air as the source of oxidant, typically supplied by a small fan or air pump, and use substantially pure hydrogen as the fuel source. The advantage of such a system design is simplicity; there are far fewer components and moving parts than in pressurized designs. While the benefit of increased concentration is negated, the simplicity and low parasitic power requirements of the supporting system are of benefit. This system design is the most appropriate for lower power, portable applications.

Ballard has been working in the area of ambient fuel cell systems, collaborating with Ball Aerospace and Hydrogen Consultants Inc. A 100 W system was produced for the US Department of Defense (DOD) (Fig. 2). It used ambient pressure air as the oxidant and coolant, supplied to the fuel cell stack by two small fans, and hydrogen as the fuel. Fuel is supplied from either a metal hydride, a compressed gas cylinder, or, still in development, a chemical hydride source, supplying 1.3, 5 or 13 kWh of energy to the 100 W fuel cell system. System characteristics are listed in Table 5.

Ballard has also developed its own ambient air fuel cell demonstrator. Using the same cell technology as the DOD

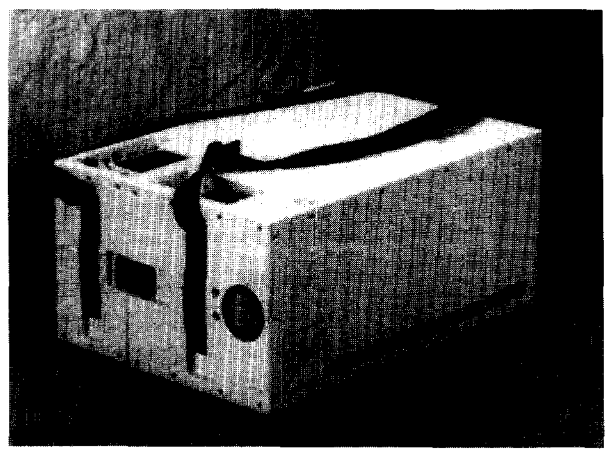

Fig. 2. Portable fuel cell power generator with high pressure gas fuel module.

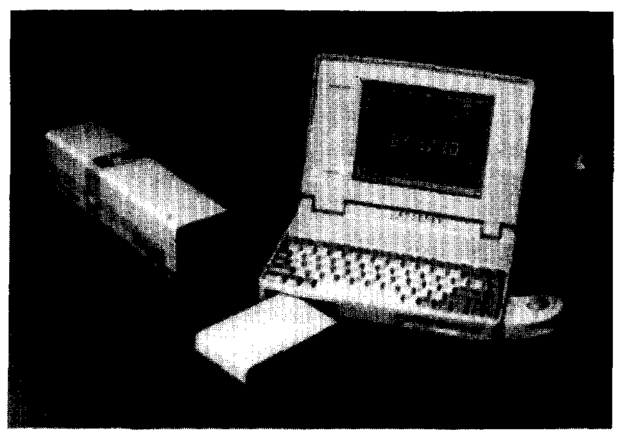

Fig. 3. Ballard portable power generator with 250 Wh energy module attached.

Table 6
Specifications for the Ballard portable power generator

System component	Size (mm)	Weight (kg)	Continuous power (W)	Energy (Wh)
Power section	85 × 85 × 235	1.7	25 at 12 V	
Energy section/250 Wh	85 × 85 × 120	1.6		250
Energy section/500 Wh	85 × 85 × 200	2.8		500
Energy section/1000 Wh	85 × 85 × 365	5.0		1000

unit, a 25 W system was constructed. It featured an interchangeable bayonet mount metal hydride–hydrogen fuel canister which contained either 250, 500 or 1000 Wh of fuel. Metal hydride canisters were supplied by Hydrogen Consultants, Inc. This unit is shown in Fig. 3 with the 250 Wh energy module attached. Specifications for the unit are listed in Table 6.

4. Conclusions

Ballard's portable fuel cell systems offer substantial weight advantages for high energy, lower power applications. Fuel cells can be combined with various fuel storage methods, depending upon energy requirements: metal hydrides for low energy, high pressure cylinders for medium energy and, in the future, liquid fuel-processing systems for high energy storage applications.

References

[1] Toyota, *Press Release*, Oct. 1996