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Fuel cells for portable applications

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Abstract

The prospect of small fuel cells replacing batteries in portable equipment is considered in terms of their prospective energy density, technological feasibility, safety and cost. Fuel cells seem to be best suited to applications where significantly more energy storage is required than at present in portable devices (>20 Wh). Energy requirements (Wh) are likely to increase with the introduction of broadband mobile computing, and fuel cells with lightweight fuel supplies could dramatically increase the amount of energy available in the same volume. However, in contrast to batteries, since the energy source and the energy converter are separated, a fuel cell system adds complexity and associated safety and reliability issues will need to be carefully assessed for portable applications. However, the prospective commercial market for high energy density power sources is attractive enough to support significant development and accelerate the introduction of small fuel cells since battery technology is unlikely to be able to meet the growing energy demands of a mobile workforce. © 2002 Published by Elsevier Science B.V.

Keywords: Energy density; System; Safety; Cost; Li-ion

1. Introduction

Interest in using fuel cells to power portable equipment for commercial applications is relatively recent [1,2] This is perhaps partly due to the success of Li based batteries in powering laptop computers, mobile phones and the like. The requirement for higher energy density, higher specific energy or longer operational time between recharges was generally well served by the Li-ion battery and nickel-based batteries especially those based on metal hydrides. Safety and environmental factors were key considerations in addition to the high energy density of these batteries.

There is now growing pressure on battery manufacturers to increase further the energy density for the next generation of portable electronic equipment, which will require much higher energy densities, if the equipment is to be conveniently portable. This is not just due to marketing and product differentiation, it is a technological requirement for high bandwidth applications, which demand much more power. The situation becomes critical as mobile phones and laptop computers merge to provide users with broadband wireless and multifunctional portable computing capability. Unfortunately, battery technology is unlikely to keep pace with these growing power demands and laptop equipment manufacturers are already being faced with introducing various power-down options to save battery energy. In the future, this will severely limit the practical capability of the planned broadband computing devices. Projections for the size and growth rate of these new product markets are impressive. Up to a 40% per annum potential growth rate and an annual market size for the power source alone in excess of $10 billion, is inspiring some researchers and developers of fuel cells to address the issues of scale-down of their technology, which has generally and for some time now, been targeting vehicles and distributed power applications.

2. Energy density

Fig. 1 shows the theoretical energy densities of the energy storing components of several batteries and fuel cells [3]. It is immediately apparent that there is a large jump in energy density for air-cathode fuel cells using hydrogen, hydrocarbon and metal as fuels. Although metal/air systems have impressive high energy densities, widespread market acceptance has suffered maybe because of their lack of convenient rechargeability, which is a prerequisite for portable applications. It is unlikely that there will be a comparable rechargeable battery couple that could compete with fuel cells in specific energy terms.

2.1. Packaging and efficiency

Energy packaging in practical devices, reduces the available energy content of batteries to about 25% of their

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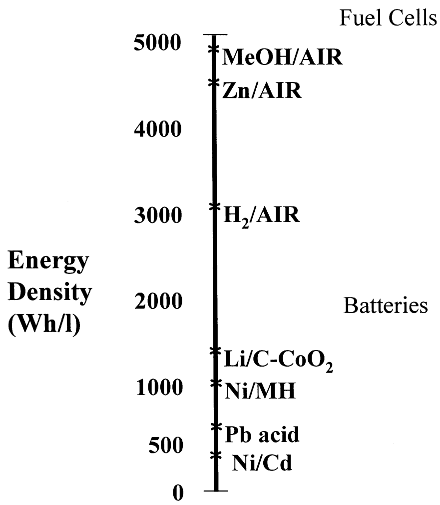

Fig. 1. Theoretical energy densities.

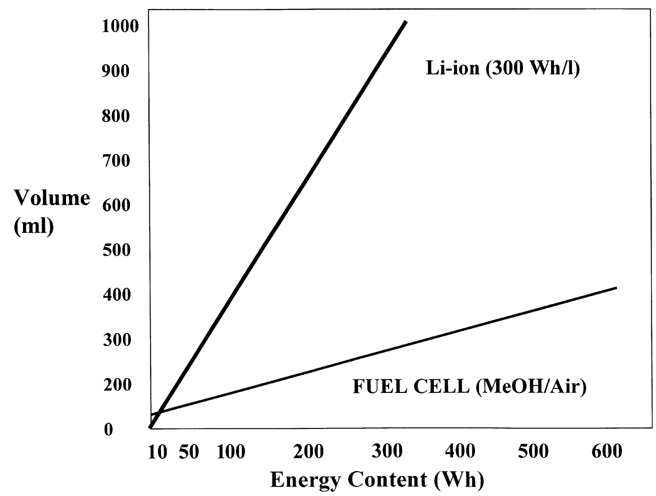

Fig. 2. Practical system volumes.

theoretical value, although the efficiency of energy conversion is quite high (above 80%). The reverse could be said to be true for fuel cells—conversion efficiency limits the practical energy density of a notional fuel cell device. However, despite much lower energy-conversion efficiencies in the range 25–35% fuel cells still offer an overall advantage over batteries in energy density terms. This advantage becomes even greater when larger amounts of energy are required as envisaged for the new potable electronic applications. Fig. 2 demonstrates this relative advantage as the energy content increases with reference to the popular Li-ion battery. For relatively low total energy levels, a battery may be better when the volume of the fuel cell is comparable to, or larger than, its portable fuel supply. For instance a 10 W fuel cell with a 200 W/l specific power density, has a volume of 50 cm^3 without any fuel and with 20 Wh or less of fuel it would not be as energy dense as a battery.

The comparison improves for fuel cells when one considers the complete system requirements for both approaches.

2.2. System level comparisons

A direct comparison of material energy densities used in fuel cells and batteries ignores the contributions to weight and volume that their support systems need. This is especially important in mobile or portable applications where the weight and volume of the peripheral equipment must be included. Battery chargers can contribute as much weight and volume as the battery itself, while fuel cells eliminate this component. Fig. 3 shows some comparisons based on replacement of a standard Li-ion battery and its

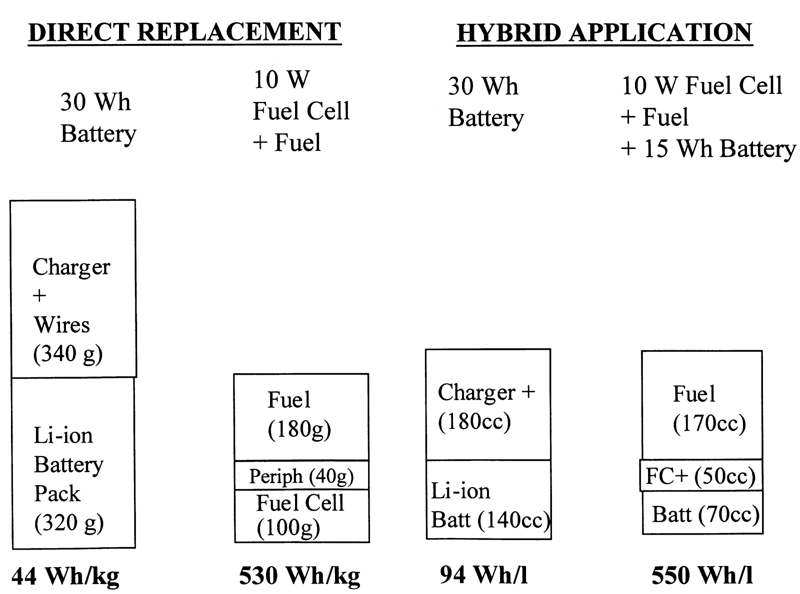

Fig. 3. System energy density comparisons for a 10 W laptop computer. Assumptions: Battery 10.8 V, 2.8 Ah Li-ion; Fuel cell 10 W, 100 W/kg, 200 W/l, 25% effic. MeOH/Water.

recharger entirely with a fuel cell or with a fuel-cell/battery hybrid, where the fuel cell acts as the battery recharger. Considerable savings in weight and volume result in huge gains in system energy density, well beyond those based on the energy content of the materials themselves. For the hybrid system, there is an improvement of roughly 6-fold over the all battery powered computer. A hybrid system would provide the wide dynamic power range that users expect from a battery. For equipment that requires a steadier power level, with perhaps only brief power surges, the battery could be entirely replaced by a fuel cell for dramatic 12-fold improvement in gravimetric energy density.

3. Cost

Cost is a major factor and will become critical as widespread commercial use of the new broadband devices occurs. There is presently a severe basic cost penalty associated with the use of large batteries, to gain a higher energy content, in particular the popular Li-ion battery. This is due to the relatively higher cost of the basic battery materials compared with the cost of the fuel for a fuel cell. Again, for small amounts of energy storage, this cost is a comparatively small component of the total cost, but for energy contents above say, 50 Wh, the energy storing material cost becomes predominant. Fig. 4 illustrates the relative cost of a battery and a fuel cell for a 100 Wh energy supply. The assumption is that a small fuel cell can be built for $5/W (this is based on the $ 100 cost for a 20 W, 60 Wh battery). The conclusion is that a fuel cell could be significantly cheaper than the battery. Basic research in fuel cell materials technology, should yield further reductions in the per watt cost.

From the perspective of the vehicle application of fuel cells, $ 5/W seems at first sight excessive. But of course the unit size for vehicles is much larger and has to compete on a cost basis with the internal combustion engine plus its exhaust cleanup. Table 1 shows what is termed "allowable cost" which is based on the competitive technology to be displaced or complemented. On this basis, for portable devices, batteries are relatively expensive and so offer an opportunity to fuel cell developers wanting to enter the commercial marketplace.

Table 1
Allowable costs compared with other fuel cell applications[a]

Application	Cost tolerance
Automotive(50 kW)	Low: 5 cents/W
Portable equipment (up to 40 W)	High: $3–5/W

[a] Assumptions: Automotive $ 50/kW for internal combustion engine; 20 W Li-ion battery for a laptop computer $ 100/60 Wh.

4. Convenience & safety

In considering the replacement of the incumbent battery technology by fuel cells, customer convenience and safety must be paramount. The convenience and perceived safety of a sealed rechargeable power source, like a battery, is obvious. But even the displacement of the Ni/Cd battery by the sealed rechargeable Li battery in mobile phones, was slowed by early safety issues related to several major technological differences from conventional aqueous-based batteries, which caused severe overheating problems. For fuel cells, ambient temperature air-breathing operation is essential in most consumer applications despite diminished power density under these operating conditions. This is not a problem in a hybrid configuration (Fig. 3) in which a small battery with high power density could complement a low power density fuel cell. Concerns over the method of storage and delivery of hydrogen will need to be addressed in conjunction with the safe distribution and transportation of refueling supplies. For hydrocarbon fuel cells, e.g. methanol/air this may be less of an issue but the technical limitations of the materials (both the catalysts and the membranes) may reduce the practical advantages in terms of performance and cost over batteries. All air-based fuel cells generate water, which must be managed in a user-sensitive manner. The major advantages for fuel cells with regard to convenience, are of course the rapid and less frequent rechargeability.

Recycling of fuel cells is not expected to be a major consideration from either a cost or environmental perspective. This is because of the inherent longevity of fuel cell

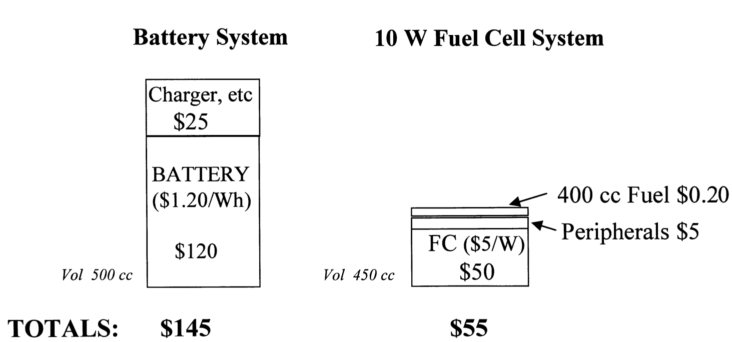

Fig. 4. Estimated cost of providing 100 Wh by fuel cell and battery.

catalysts which have achieved over 200,000 h of operation in space applications.

5. Technical feasibility

Fuel cell development has benefited from the focus on larger power applications such as automotive to the extent that the specific costs of the various components has been dramatically reduced. This will generally benefit technical progress in making cost-effective small fuel cells, but the per unit cost of miniaturization of subsystems is, as yet, unknown. Scale-down of what is after all, an energy-converting *system* consisting of a fuel cell plus a fuel supply, rather than a ‘‘simple’’ energy-storing electrode couple, is not technologically trivial. Unlike a battery, subsystems will be involved in the supply of both fuel and air and the removal of product water and carbon dioxide in the case of hydrocarbon fuels. Miniature electromechanical delivery and control systems will add complexity, which may affect the reliability and the life of the entire fuel cell system. These concerns will be additional to the usual list of electrochemical and materials degradation factors which reduce the longevity of batteries but fortunately are less troublesome in some fuel cells. Also, and fortunately, since the main competition, again, is the battery power source, with its comparatively lower energy content, the ‘‘allowable’’ cost of a small fuel cell in the commercial marketplace may exceed $ 5/W even in mass applications. This may support the use of far more sophisticated and reliable miniaturized-engineering solutions.

In summary, while it is not yet possible to pick winners from the competing technologies, the opportunity in terms of market size and growth rate for small fuel cells is commercially compelling. Several companies have recognized this and are already building development and engineering programs to address the technical issues [2] The various difficulties of developing small portable fuel cells; cost, safety and technological feasibility, are overshadowed by the growing portable power needs of the mobile workforce and the major industries that now support them.

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