Future power sources for mobile communications

by K. Green and J. C. Wilson

As the encroachment of portable electronics into everyday life continues, the demand for improved power sources is continuing to increase. New technologies such as nickel metal hydride and lithium ion batteries have largely replaced nickel cadmium systems because of their superior performance. The paper reviews the very recent developments in battery technology and looks ahead to the future of portable power sources. In doing so it aims to advise the reader on the possible future technologies that they may one day be using.

1 Introduction

A previous review[1] of new battery technology introduced the three main rechargeable batteries for portable electronics, of which one, the nickel-cadmium battery, has become virtually unknown in mobile communications, especially in the Far East. The two most common batteries are lithium ion and nickel metal hydride.

Lithium ion is the preferred chemistry, having a superior specific energy to nickel metal hydride. Lithium polymer, a development of lithium technology, promises to further improve on these values. The chemistry of lithium ion batteries, which Sony was the first to market, is now established[2]. Lithium moves from one electrode to the other and back again, depending on whether the battery is being charged or discharged. Essential points of development involve better materials (storing more lithium per gram, especially in the cathode) and better engineered products (with less void space and lighter packaging). The improvements in the specific energy of the lithium ion battery since 1990 and possible improvements beyond 2000/2001 are shown in Fig. 1. Within the next few years the improvements will diminish and will plateau with time as limits on the cell chemistry are approached[3].

New technologies must be developed to meet likely future consumer requirements, but most manufacturers have been concentrating on joining the lithium ion and lithium polymer battery markets[4].

Glossary

Energy density	The amount of energy stored per unit volume, Wh/l[3]
Energy efficiency	The percentage fraction of energy in the output to that of the input
Specific energy	The energy per unit weight of a battery, Wh/kg
Specific power	The power output per unit weight of a battery, W/kg
Self discharge	The fraction of charge lost per month

2 Fuel cells

One possible option for solving the performance shortfall is fuel cell technology. The fuel cell was originally invented by Sir William Grove over 150 years ago, and it is still being developed. With the potential perceived benefits in terms of environmental protection and energy storage it is now being actively pursued and developed for both military and consumer portable electronics and electric vehicles. Fuel cells differ from batteries in that the energy is stored away from the energy conversion device, rather like an internal combustion engine and its petrol tank. Fuel cells also need oxygen to complete the chemical reaction.

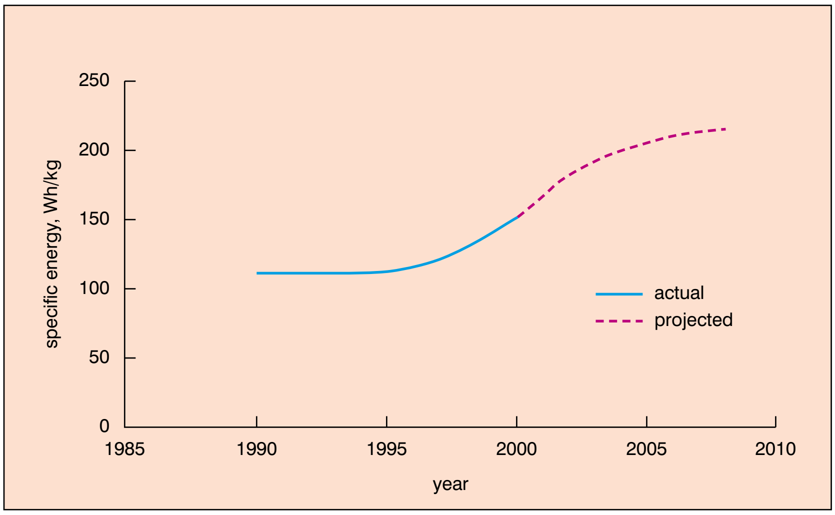

Fig. 1 Progress in lithium ion technology

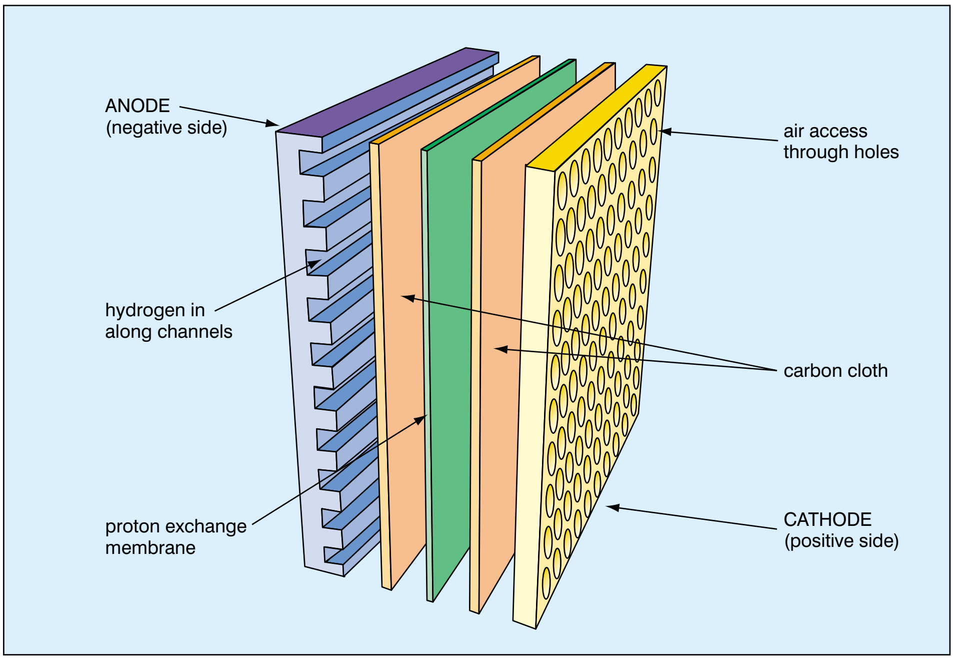

Fig. 2 Schematic diagram of air-breathing fuel cell

Oxygen can either be stored in cylinders or harvested from the atmosphere to reduce weight. The product from the reaction is water vapour. Obviously the need for oxygen and the exhalation of water can present serious operational issues. For instance, what happens when a mobile phone is kept is someone's pocket for extended periods of time? Is there sufficient air access and does the pocket become damp from the expelled water?

The active centre of a fuel cell is its ion permeable membrane[5]. One of the most common types is a polymer electrolyte membrane (PEM) that can conduct protons, Fig. 2. While operating, hydrogen at the anode is converted to protons, which pass through the membrane and react with oxygen to give water, often the only chemical product of a fuel cell. The process of chemical conversion occurs upon carbon catalysts that are loaded with minute amounts of platinum catalyst, often only milligrams per square centimetre. The electrochemical reaction releases heat and electrical energy, which can be used to power electrical devices. The power generated is DC, just as in a battery. The voltage from a single cell is typically between half and one volt, Fig. 3, so that several cells must be stacked together to obtain a practical potential. Whilst the PEM fuel cell is the most common room temperature system, other fuel cell chemistries are also known. Two of the most developed alternative systems are the solid oxide fuel cell, which operates at temperatures around 800–1000°C, and the alkaline fuel cell, which has been used by NASA in the space program, but these are not very suitable for man-portable applications.

A direct comparison between a battery and a fuel cell system, Table 1, is difficult because the energy density of a fuel cell system depends upon the method used to store the fuel. For this reason fuel cell performances are usually given in terms of their power density. The problem for any battery or fuel cell is that, no matter how great the figures in the table appear, as soon as equipment manufacturers package the cells then the energy density of the system drops dramatically. An example is the lithium ion battery pack (Fig. 4) for a laptop computer. Despite the high energy figures for a single lithium ion cell, when the cells are assembled into a pack, the energy density is significantly less than that of the original cells.

Fuel cells are also being developed by Defence Evaluation and Research Agency (DERA) with the objective of replacing even the most advanced battery technology with a lighter weight alternative. Fuel cell stacks require that compression is maintained to ensure that electrical contact resistances are minimised. This is usually done with relatively bulky end plates that increase the system weight. Among the designs that DERA is developing is a new tubular design that obviates the need for the end plates, see Fig. 5. The fuel source can be stored within the tubular stack, so that the internal volume of the stack is

Table 1: Comparison of available batteries (AA size) and future technologies

Battery	Nominal voltage, V	Rated capacity, mAh	Weight, g	Dimensions $d \times h$, mm	Energy density, Wh/l[3]	Specific energy, Wh/kg
Nickel cadmium	1·2	620	21	$14{\cdot}5 \times 50$	90	35
Nickel metal hydride	1·2	1100	26	$14{\cdot}5 \times 50{\cdot}5$	158	53
Lithium ion	3·7	830	25	$17 \times 49{\cdot}5$	270	123
Fuel cell	**Nominal voltage, V**	**Operating temperature, °C**	**Current density, mA/cm^2**	**Specific power, W/kg**	**Development stage**	
Hydrogen/air PEMFC	0·6	30–100	300–750	200	Advanced prototypes undergoing testing, 2 years from commercial?	
Direct methanol	0·4	100	300	~50	Advanced prototypes underoing testing, 5 years from commercial?	

fully utilised. Using a tubular design means that steel foils, which also act as current collectors, can maintain even compression in a cell. Cells may be linked together to form a fuel cell stack of the required voltage. Other technologies that DERA is developing and evaluating include novel electrode materials, such as Supagraf™ and titanium, which are being investigated in a collaboration with Advanced Power Sources Ltd., a spin-off company from Loughborough University. APS is developing its own technology and designs, and these too are being evaluated by DERA. Although better electrode materials are required to reduce cost, weight and size, fuel cells suitable for powering mobile phones have been demonstrated.

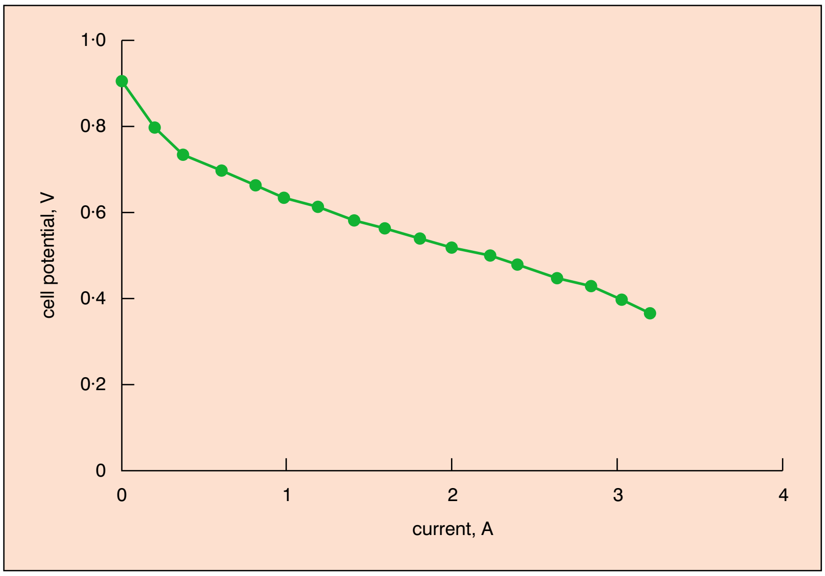

Fig. 3 Polarisation curve for single fuel cell

A number of other companies are developing fuel cells, including H-Power Inc.[6] and DAIS-Analytic Power[7], both based in the USA. It is now possible to buy stacks, and they have been used commercially to power road traffic warning signs.

Although fuel cells are being developed they have yet to be proven by a large-scale commercialisation of the technology. Several large multinationals have pooled resources to develop this technology for the electric vehicle market, but there exist several more hurdles to be overcome before the introduction of this technology.

Hydrogen storage

One of the critical enabling technologies for the successful commercialisation of fuel cells is hydrogen storage. Commercial, practical and viable hydrogen storage methods for portable communications are still very much in the development phase. The most common form of storage is in compressed gas cylinders, but the associated equipment and safety implications probably make this an unrealistic option for the mass consumer market. This is why a lot of companies are looking at alternative methods of storing hydrogen fuel. Although several methods of hydrogen storage are known, e.g. compressed gas cylinders and metal hydrides, as well as liquid fuels such as methanol (discussed below), many researchers would like to improve on the current technology. An increase in the amount of hydrogen stored from its present 1–3 wt %* (186–558 Wh/kg)† to around 20–30 wt % (3·3–5·6 kWh/kg) would enable smaller, lighter fuel cell systems for mobile phones and laptops.

*The weight of hydrogen stored to the weight of the storage medium expressed as a percentage.
†Each hydrogen atom is assumed to provide one electron of charge at 0·7 V.

One of the most promising proposals was published in the late 1990s by Terry Baker and Nellie Rodriguez of Northeastern University, Boston USA. Their group disclosed details of hydrogen storage in carbon nanofibres at up to 50 wt %, at room temperature. Although this technology has not been independently verified, several other groups have reported significant amounts of hydrogen storage in carbons. If proved it would revolutionise fuel cell technology: 50 wt % is equivalent to 9000 Wh/kg at 0·7 V operating potential, compared to a rechargeable battery's 150 Wh/kg.[8] This would enable a fuel cell system, using carbon nanofibres to store the hydrogen fuel, to outlast even the best batteries. The exact performance benefits will clearly depend upon the whole system, so developing a lightweight fuel cell as well as a lightweight energy store is extremely desirable.

Direct methanol fuel cells

One of the most practical fuels is methanol, a liquid.

Fig. 4 Li-ion battery pack

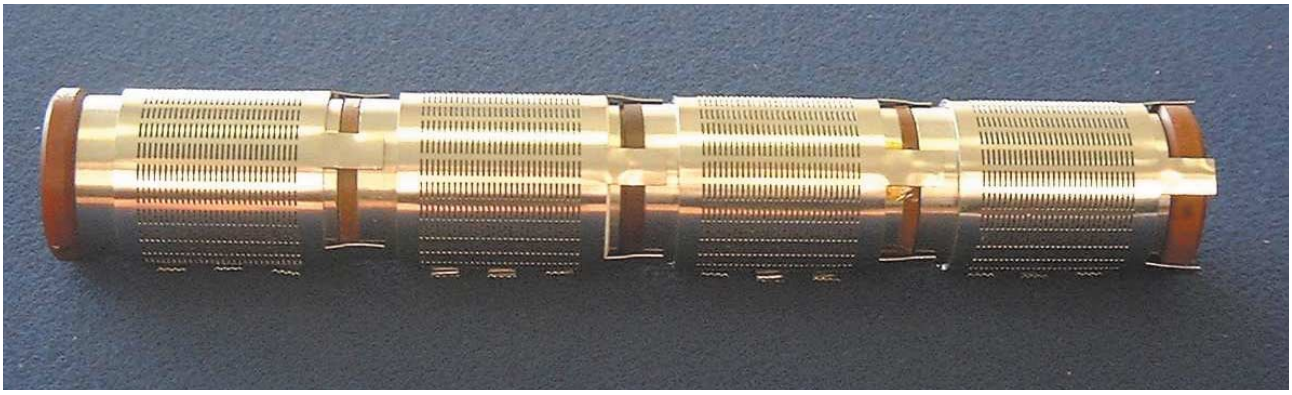

Fig. 5 Tubular fuel cell stack, 160 x 22 mm

Methanol can not only be chemically converted to a hydrogen rich fuel, but can also be used as a fuel. Direct methanol fuel cells (DMFCs), as they are known, are viewed by many as a practical solution to the problems of fuel transport and storage. Not only can methanol be easily transported, it also allows the fuel cell to be refilled conveniently. Methanol is used as a diluted solution. Refuelling simply involves the addition of pure methanol to the solution.

The DMFC uses a PEM type electrolyte, but the development of direct methanol fuel cells is further behind that of the PEM fuel cell, and the time-scale of the commercialisation of DMFCs reflects this. The polymer is coated with a platinum–ruthenium catalyst layer that, ideally, directly oxidises the methanol to create electricity. The chemistry within the cell is not efficient at present, and there are losses caused by contamination of the cathode by methanol crossing the polymer membrane from the fuel side to the oxygen side.

However, recently Motorola announced that it is pursuing this technology for future applications such as mobile phones. DMFCs will also allow the relatively easier introduction of fuel cells to the electric vehicle market. NASA's Jet Propulsion Laboratory (JPL) is one of the leaders in this technology, and Ballard, the main developer of fuel cells for electric vehicles, purchased its technology in 1999 with the aim of exploiting it commercially.

Direct methanol fuel cells for the most part operate at 80°C or above, which means that energy must be expended to maintain this temperature. The power densities for DMFCs are a factor of ten below that of current PEM fuel cells, as a result of the poor chemistry and parasitic power losses. However, if these problems were thought to be insurmountable, then the DMFC would not be receiving the attention that it is presently attracting. The perceived advantage of the DMFC lies in the fuel: methanol requires only lightweight containment and possesses a relatively high energy density. Motorola recently publicised its desire to commercialise a DMFC within a few years[9]. The distribution and transportation of methanol would be achieved by selling capsules of methanol to recharge the fuel cell. DERA is investigating and developing improved membranes for DMFCs in collaboration with other groups.

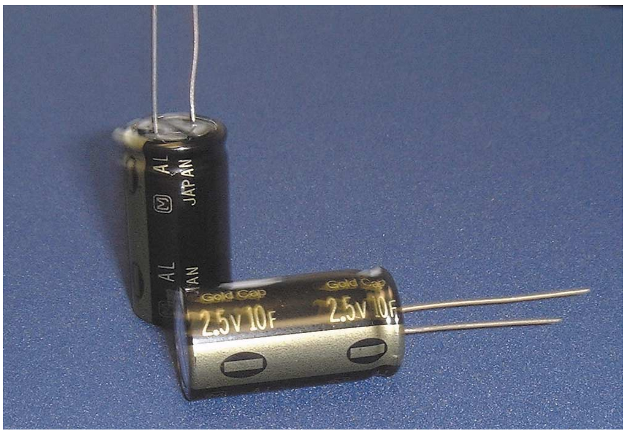

Fig. 6 2·5 V 10 F EDLCs

Some of the most promising technologies are being developed by NovArs and Manhattan Scientific[10,11]. NovArs has developed a hydrogen fuelled cell that has a specific power of over 200 W/kg for a complete system, compared with ~100 W/kg for a lithium ion laptop battery pack. Manhattan Scientific is developing a methanol-powered fuel cell, called a micro fuel cell, specifically aimed at mobile telephones. The fuel cell electrodes can be mass produced by lithography and then simply folded together. Instead of having a battery that lasts for a few days on standby, the developers claim that the fuel cell could power the phone for weeks. The fuel is a water–methanol mix, and the system is recharged by replacing the fuel store, rather like changing an ink cartridge. It is hoped to have these cells on the market by the end of 2001. NovArs has recently sold its intellectual property rights to Manhattan Scientific, and the company is continuing to develop both systems.

3 Electrochemical double layer capacitors

Electrochemical double layer capacitors (EDLCs), Fig. 6, sometimes called supercapacitors by chemists, are another energy storage device, though in view of their very poor energy density they might better be termed power storage devices. EDLCs have superior energy density compared to the capacitors that most electronics engineers are familiar with. This is because their method of energy storage is different. The energy is stored electrochemically and, although no reactions take place, ions are trapped at the surface of high-surface-area carbon electrodes. Lack of chemical reactions probably accounts for their prolonged cycle life—100 000 cycles or more, 100 times that of the best batteries. The power density of EDLCs is higher than that of most batteries, though high power lead acid batteries offer a similar level of performance.

There is of course a trade-off to balance these benefits and this is observed in the energy density, which makes even the lead acid battery seem like a high-energy storage device. EDLCs are therefore probably best used in conjunction with other power sources, such as batteries or fuel cells, in a hybrid system, in which EDLCs provide the power to meet transient surges in the electrical load. In such a system, the overall size is smaller than would be required if a battery were to meet the load by itself. EDLCs can be used for a number of applications, such as communications, to provide power for burst transmission and as emergency power backup to protect memory. They are available from electrical stockists. Larger versions could be used in electric vehicles for load levelling

The search for higher energy densities in EDLCs has focused on materials research. Improvements in the carbon electrodes and other chemical components are continuing to raise the energy density, though it is unlikely that is will achieve even the relatively modest levels of lead acid batteries. The energy stored is typically in the range of 1–10 Wh/kg, but the specific peak power can be as high as 4 kW/kg.

4 Conclusions

Research into improvements in batteries, fuel cells and electrochemical double layer capacitors is continuing to improve the available selection of power sources. Compared to the developments in electronics the process of miniaturisation is painstakingly slow. However, portable electronics do depend almost entirely on batteries at present, and perhaps may one day depend on fuel cells. Therefore, developments in portable power sources cannot be underestimated. Battery and fuel cell development owes a lot to the improvements in mobile communications. Conversely, power source development has aided the deployment of portable consumer electronics. However, consumer demand is for longer operating times, decreased weight and increased cycle life. This is sufficient commercial reason for the world-wide research that is going on.

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Kevin Green completed his BSc and PhD degrees in physical chemistry at Nottingham University. After working for Ultralife Batteries Ltd., where he developed lithium polymer batteries, he joined Defence Evaluation and Research Agency in 1995. Since then he has worked on a number of battery and fuel cell projects, including small ambient air-breathing fuel cells, such as those used in portable communications. He has also developed novel electrolytes for electrochemical double layer capacitors and has published a number of papers and patents in these areas.

Address: Power Sources Group, Environmental Sciences, DERA Haslar, Gosport, Hants., PO12 2AG, UK.
E-mail: KJGREEN@dera.gov.uk

Jim Wilson gained a first degree in chemistry and in 1990 a PhD degree from the University of Edinburgh for research on interfaces between electronic and ionic conductors. He subsequently joined the Admiralty Research Establishment (now DERA) at Holton Heath and has since worked on many electrochemistry based projects in the field of both chemical sensors and novel materials for batteries. He is presently seconded from DERA to the Ministry of Defence in London.

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