A Review of Power Sources for Mobile Applications

The development of mobile devices is being fuelled by changes in mobile communications services and technologies – such as third-generation handsets – and by consumers' increasingly mobile lifestyles and work patterns. However, current and next-generation mobile devices – such as handsets that offer video on demand, Internet access and always-on connectivity, digital cameras and personal audio players – are pushing existing battery technology to its limits.

Nevertheless, battery technology is currently meeting consumer demand for convenience through an average annual increase in battery performance of 10%. But with battery technology and chemistry nearing its limits, it is expected that incremental improvements in battery performance will not keep pace with tomorrow's power-hungry mobile devices.

This report explores battery technology and chemistry as they stand, and speculates on the alternatives to batteries that are emerging to fulfil the demands of 21st-century electronics.

Peter McLeod

Pera Knowledge

PRIME Faraday Partnership

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Wolfson School of Mechanical and Manufacturing Engineering
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Comments on this publication are welcomed. Please send them to
<feedback@primetechnologywatch.org.uk

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1.0 Introduction

The growth in the popularity of mobile electronics is one of the major developments of the last few decades. Advances in electronics, audio, video and communications technologies are delivering an ever increasing array of mobile or ‘in-built’ electronic systems offering consumers access to a range of services and features anywhere at any time. The operation of these devices is placing an increasing strain on their energy sources, predominantly electric batteries, and the inconvenience of recharging and juggling multiple batteries is an area of concern for consumers and manufacturers.

The main aim of this report is to provide an understanding of the principal energy sources that find application for powering today’s portable equipment, and identify the challenges that lie ahead for the next generation of power-hungry mobile devices. It must be made clear that current battery technology has been utilised successfully to deliver the energy required by today’s mobile devices. However, as these devices demand more power, battery technology becomes unwieldy, in terms of the size, weight and cost required to deliver the power required.

This report aims to address the requirements for today’s major consumer products and devices such as hand-held computer games, portable power tools, cameras and video cameras, mobile phones, laptop computers, as well as tomorrow’s generations of personal digital assistants (PDAs) and universal voice/video communication handsets, all of which are set to enjoy strong market growth. The growing acceptance and use of these mobile devices, each requiring a mobile energy supply, is the market driver for mobile power-source development.

The functionality of many of these devices is likely to become increasingly complex in response to consumer demand and a need to differentiate products within a sophisticated marketplace. The mobile phone, for example, has reached a point where demand is significantly driven by fashion and image, so increased functionality is now a major competitive factor. This is likely to explode when third-generation (3G) phones are launched and access to Internet, new services, less intermittent use, flat complex screens and other enhanced electronic components become standard expectations. These advances in functionality and basic capability will impact significantly on power consumption and demand improved power-source performance.

Manufacturers can currently improve battery lifetimes but have to sacrifice size, cost, environmental friendliness or performance in the process. Also, with the exploding demand for portable products, manufacturers race to offer lighter models than their competitors can offer. The weights of such components as microprocessors, memories, and displays have decreased, leaving batteries as their Achilles heel. Today's batteries may account for as much as 30% of the weight of a notebook computer and 50% of a cellular phone, making them the single biggest impediment to further weight reduction.

Given the status of today’s mobile device technology, consumers seem prepared to accept existing battery lifetimes of a few days and comparatively lengthy charging times, but it is accepted that the market is becoming less tolerant of such factors as lifestyles change, and future devices will be more demanding of power, thereby reducing battery performance margins and making users less tolerant.

Consumer product manufacturers are aware of these trends and alongside electronic component and circuit developers they are working to optimise circuit architectures and components in order to reduce consumption and develop miniature energy sources that are more effective than the current storage batteries.

This report principally discusses the existing technology used to provide energy to mobile devices, concentrating on rechargeable batteries as the main outlet. It also outlines and considers other mobile power-source developments that have the potential over the medium to long term to supplement or replace battery technology, such as micro-fuel cells, mechanical devices and power-storage components.

2.0 Market Growth in Portable Electronics

The market for portable power sources is driven by consumer demand for portable electronic devices. With the mobile phone leading the trend, there is significant demand for hand-held computers and notebook computers, which, having started life in the business world, are increasingly finding resonance with a wider range of consumers as the functionality of such devices increases and prices fall.

The innovation in portable electronics owes a lot to the efforts of Japanese companies in forging ahead with the miniaturisation of popular consumer goods such as cameras, CD players and radios. As such, the market for portable power sources is also based mainly in the Asia Pacific region and increasingly in the US. Significantly, there are well over 100 firms that manufacture portable power sources in the US alone.

Given the global nature of consumer electronics there is a large degree of consolidation within the various markets and many of the corporate leaders within the US and Japan are also global players. However, given the importance of portable power sources, both Japanese and US firms have been successful in protecting their domestic markets for primary and secondary batteries from foreign competitors.

With regards to the structure of the industry there is a major barrier to entry which comes from the incumbent economies of scale and the technological capabilities of the main corporate players, who currently enjoy control over distribution channels and high brand-name recognition. As a result, new market entrants often with innovative concepts are discouraged or find difficulty integrating with the existing supply chains, limiting them to niche markets where technological requirements are extremely high (such as fuel cells and lithium polymer batteries) or where opportunities are insufficient to attract the interest of the major players (e.g., zinc-carbon and zinc-chloride primary batteries). Also evident is the willingness of the larger market players to acquire and buy-out up-and-coming companies that are developing potentially disruptive power-source technologies.

Furthermore, in the US the major companies do not appear to participate extensively in multiple segments of the power-source business, sticking with the battery format with which they are most familiar. This is not the case in the Asia Pacific region, where a greater degree of innovation and industry interchange is evident. Japanese battery producers, for example, compete in both the dry cell (primary) and rechargeable (secondary) market sectors.

2.1 Market Drivers

Personal electronic devices have enjoyed strong market growth and represent the market drivers for the development of portable power sources. It would be impractical to list all of the devices that find applications within today's burgeoning consumer electronics markets. However, devices that typify the portable/mobile market are highlighted in Table 1.

With regards to existing mobile electronics, such as the mobile phone or the mobile cassette player, many analysts feel that the years of super-high growth rates have now passed as the market reaches saturation and there is a large installed base of existing products. Many of these devices are now considered lifestyle products or fashion accessories, and the type, size, and functionality now say more about a person than just owning one.

Table 1 Portable electronic devices

Portable Electronics Devices		
Low Power Devices	**Entertainment**	**Portable Power Tools**
Hearing aids	Portable DVD players	Drills
Remote controls	Video cameras	Jig saw
Car fobs	Digital cameras	Planes
Torches	MP3 players	Screwdrivers
Personal alarms	Minidisc players	Nail guns
Electric shavers	Walkmans	**Computing**
Communications	Radios	Hand-held computer games
Pagers	Miniature TVs	Personal digital assistants
Mobile phones		Laptop computers
Universal handsets		

Consequently, manufacturers are under increasing pressure to differentiate their products from those of their competitors by being innovative and deriving maximum performance from all product subsystems. Increasingly, hand-held and portable electronics are incorporating a number of new features as manufacturers try to distinguish their products in the marketplace, and keep pace with the demands of a more sophisticated consumer market. By way of example, mobile phones are moving from simple black-and-white screens to full colour. Also the convergence of devices is evident, such as the integration into phones of wireless Internet browsers, address book, calendar, FM radio and MP3 music player features.

The implications of this explosion of functionality within many mobile devices is clear. In the short term they will consume more energy and power. User surveys have shown that one of the biggest inconvenience factors when using mobile devices is the need to change or recharge batteries and the problems that occur when you are caught short. Manufacturers are seeking to address these issues by adopting circuitry that consumes less power and by integrating all the functions that they can onto silicon and single-chip architectures. For example the internal components of a pocket computer, personal digital assistant or mobile phone are being built in increasingly fine-line circuitry, and use low-voltage CMOS technologies amongst others, all of which allows very high levels of integrated functionality with relatively small energy requirements.

It is recognised that today's portable electronic devices are increasingly being limited by power-source performance. Currently battery technology is proving the limiting factor for a number of high-profile consumer electronics, such as mobile phones. These devices, incorporating large batteries, are relatively heavy goods and have limited operational performance. So manufactures are exploring all options that will allow them to tackle these issues and improve product performance.

2.2 Consumer Electronics Markets

Portable battery-powered electronic devices account for over 50% of the manufacturing output of the electronics industry.[1] As more and more miniature devices flood the market place, this figure will no doubt grow. Consensus forecasts of all major subsectors within the market for portable electronic products point to consistent increases in demand over the next five years. As these sectors represent the drivers for mobile power sources, an indication of the behaviour and current status of the leading portable equipment markets is necessary to appreciate the significant potential for power-source usage. A number of the major equipment sectors are explored in brief below.

2.2.1 Mobile Phones

Despite a large installed base, mobile-phone shipments are expected to increase steadily through 2005. These will entail a similar rising profile in power-source requirements over the same period, and as 3G wireless applications drive devices to higher levels of functionality and sophistication, the demands on power sources will increase – demands for improved performance and reduced size and weight. By 2005, according to a recent market forecast, Cahners In-Stat expect the number of mobile phones shipped worldwide to reach about 800 million units, double the number shipped in 2000.

The mobile-phone sector is one of the most demanding areas of power-source applications. Within the sector leading manufactures such as Ericsson and Nokia are constantly seeking to innovate their products and provide users with engaging functionality. Current battery technology enables phones to operate in call mode for a few hours, with standby time measured in days. They and other manufactures are engaged in a number of alliances to develop future forms of power source that will enable them to improve upon these limits and build even greater, and more power-hungry, features into their products.

2.2.2 Personal Computers (PCs)

Whoever coined the term *personal computer* can be credited with impressive foresight. Having originally evolved from room-sized systems to the sleek desktop products that we know and occasionally love today, the personal computer is set for a further revolution. The reduction in size of computing electronics and memory technologies is fostering the development of the truly *personal* computer, one that is as mobile as the user and which is capable of accessing a wide range of services from any location. The growth in laptop and notebook computers is a sign of the latent demand for truly mobile computing. One growth area within this sector is the PDA (personal digital assistant), which is very much seen as the convergence of mobile phone and computing technologies.

Overall, the growth in popularity and use of the Internet has fuelled an increase in demand for computer hardware. In the case of laptop and notebook PCs the implication of increased unit shipments is an increase in demand for mobile power supplies and emergency back-up power supplies for their deskbound cousins. Market analysts Ovum have estimated that global demand for net-enabled mobile phones and PDA devices increased by 364% between 1999 and 2000.

Following 11 September 2001, some analysts, such as Semico Research Corporation, downgraded their forecasts for the mobile PC industry. Hand-held computers are forecast to triple over the next four years, but with a declining growth rate through 2004. However, many have suggested that the strong sense of national unity and patriotism displayed by the US since the attacks may have a positive impact on the world computer industry. According to Cahners In-Stat Group, companies determined to pursue business as usual could be stirred from their market-watching doldrums. ‘Dollars and technology may flow if this corporate unity can bring a new business focus, a shift psychologically,’ it said.[2] After a flat 2001, with worldwide shipments of 129 million desktop and notebook PCs, In-Stat predicted a cumulative growth rate of 8.6% to lift shipments to 195 million by 2005.

Notebook computers will continue to get smaller and more powerful, making them even more attractive to consumers. This trend will also be seen in the segment of personal digital assistants, though that should also lead to an increase in unit sales. Hand-held shipments are expected to triple, from 15.5 million in 2001 to 44.3 million in 2005, according to Semico. The market is growing at a far faster pace than desktop or notebook computers, and over the next few years, PDAs will get faster and provide greater data-processing capabilities.

2.2.3 MP3 AND PORTABLE DIGITAL AUDIO PLAYERS

Electronic Business recently reported on how compressed digital music files (MP3) have revolutionised the corporate music industry. ‘Suddenly with a potential huge market for individual digital music tracks and the devices to play them, the recording industry found itself out of tune and behind the beat,’ it said. The industry seems to have devoted more time to taking legal action against music pirates than finding a way to deliver affordable access to legal content over the Internet.[3] Ironically, the publicity surrounding high-profile court action has helped to spread awareness and drive demand for MP3 players.

Analysts at IDC are expecting the market for compressed digital audio players of all kinds to increase dramatically from $5.4 million in 2001 to an estimated £25.8 million in 2005. Similarly, analysts at Cahners In-Stat Group forecast that the market for portable digital music players alone will grow to more than 10 million units and to just under $2 billion in sales by 2005. Such growth will drive the need for power supplies, and as the technology increases in sophistication, again the demands on power sources will increase.

At present the main stumbling block for the MP3 market is the lack of content available from record companies. Until the content issue is resolved, consumer electronics firms, audio chipmakers, memory producers and power-source manufacturers must be patient.

2.2.4 UNCONSCIOUS NETWORKING

‘Unconscious networking’ is a new term that has been adopted to cover the forthcoming generation of mobile communications devices. These items of equipment will be designed to give the user *always-on* connectivity to a wide range of services. This unconscious connectivity is something that other technologists are seeking to emulate, none more so than the developers of wireless personal area networks (PANs), such as Bluetooth, which are designed to connect the user to a whole range of previously un-networked devices.

Electronic Business published an article recently stating that the trend towards wireless connectivity will pick up steam as new standards take hold over the next few years.

> *Most of the action in the mobile data business will be in Europe and Asia. Because spectrum has yet to be allocated for third generation (3G) wireless in the United States and because there's little pent-up demand – domestic 3G applications aren't likely to take off much before 2005.*[4]

Bluetooth products have made little impact on the market to date mainly due to concerns over security and potential interference and over cost. However, a survey by In-Stat found that PANs are gaining acceptance and expects shipments of Bluetooth-enabled products to soar from less than half a million units in 2000 to 955 million units by 2005.

Finance, insurance, real estate and healthcare likely will be among the other early adopters. Products likely to feature Bluetooth include PCs, printers, headsets, MP3 players, mobile phones and video cameras, as well as a range of currently unconnected devices such as cars and various domestic appliances.

The demands of such connectivity will be for mobile power sources capable of complete integration into a wide range of products which will last for the whole of the product's life. They also must be capable of handling long standby times and delivering short intensive bursts of power, as well as handling a constant energy drain.

3.0 Battery Technology

The battery is effectively an electric cell that produces electricity from a chemical reaction. A cell consists of a negative electrode; an electrolyte, which conducts ions; a separator; an ion conductor; and a positive electrode. The electrolyte may be aqueous (containing water) or non-aqueous, in liquid, paste, or solid form. When the cell is connected to an external load, or device to be powered, the negative electrode supplies a current of electrons that flow through the load and are accepted by the positive electrode. When the external load is removed the reaction ceases. Non-rechargeable batteries are referred to as 'primary' batteries as they are the primary source of electricity, are not meant to be recharged and have a definite use life after which they are discarded. A primary battery is one that can convert its chemicals into electricity only once. Rechargeable batteries are sometimes called 'secondary' batteries because their power is derived from a secondary source, usually the mains. A secondary battery has electrodes that can be reconstituted by passing electricity back through it; also called a storage or rechargeable battery, it can be re-used many times.

3.1 Battery Types

There are many different types of batteries designed to meet the demands of individual appliances and their applications. A number of the major battery types, denoted by their electrochemical systems, can be found on the website of the British Battery Manufacturers Association (http://www.bbma.co.uk). The voltage of a given battery depends on the number of single cells connected in series and on their electrochemical system. The capacity of a battery is determined by the amount of chemical energy stored inside its housing.

3.2 Battery Sizes

Batteries standardised by the International Electrotechnical Commission (IEC) have an internationally valid designation. As use is voluntary, the designation will not necessarily appear on every battery, but the manufacturer's designation and the battery voltage are always printed on the housing.

Many obsolete designations have been retained due to their popularity. No longer officially valid, for example, the American National Standards Institute (ANSI) designations are still used to denote battery sizes. The original designation AA, for instance, was formerly used for an R6-sized zinc-carbon battery, using natural manganese dioxide. Today 'AA' is frequently used as a size designation, irrespective of the electrochemical system. See Table 2.

Table 2 Commonly used battery sizes

American number	International standard number
D	R20
C	R14
AA	R6
9V	6F22
AAA	R03

3.3 Smart Batteries

Many batteries are getting smarter.[5] By using bits of intelligence or software, new battery technologies can communicate with their device and power down when certain functions are not being used. The technology not only conserves power but also works to prevent battery overheating, a serious issue in late 2000 with Dell's Latitude and Inspiron notebook computers, which had to be recalled. According to the Dell recall notice, these batteries could 'short circuit, even when the battery is not in use, potentially causing them to become very hot, release smoke and possibly catch fire.'

Global rechargeable-battery-sales market-research firm Darnell.com Inc. has stated that the market for smart battery technology has been growing at a rate of 22%. Major drivers for smart battery technology are demand for the power-management needs of notebook computers, the emergence of dual-battery notebooks, docking stations that include charging bays, and flexible battery form factors to fit the requirements of thinner, more compact notebooks.

Beyond notebook computers, smart batteries are being used for camcorders and cellular telephones. Keith Nowak, media relations manager and former battery product manager at Nokia, has said that most Nokia phones come equipped with robust power management software to communicate with the battery and charger to know if it should be powering full speed or slow down to a trickle. Nowak has said that Nokia is working very closely with its battery suppliers to ensure the right battery technology will be available for its new products.

3.4 Battery Market Overview

3.4.1 Primary Batteries

According to Freedonia Group [6] three companies dominate the primary battery segment of the portable power-supplies industry in the US, namely:

- Duracell
- Energizer Holdings
- Rayovac

A small number of other producers hold positions in niche markets based on specific battery chemistries, and electronics manufacturers based in Japan have also gained share in the US market through exports and direct investment in local production facilities.

3.4.2 Secondary Batteries

To a greater extent than the primary battery segment, Japanese manufacturers dominate the market for rechargeable batteries for portable devices. Four Japanese electronics-based conglomerates accounted for over 50% of demand in 2000. They were:

- Matsushita Electric Industrial
- Sanyo Electric
- Toshiba
- Sony

Maxell (a subsidiary of Hitachi) is another important Japanese supplier of non-lead-acid secondary batteries. The US is gaining ground on Asian producers. Moltech entered this market segment in late 1999 through the acquisition of Energizer's rechargeable battery unit. Development work is going on in the field of lithium polymer rechargeable batteries at Motorola. However it is likely that this segment will also be dominated by the Asian companies, which presently control most lithium-ion battery output.

Worldwide sales of rechargeable batteries total approximately $5.5 billion. The top Japanese suppliers held about 80% of the market in 2000, but new market entrants from countries in Asia are making significant inroads. Examples of new global entrants include Chinese battery producers BYD Battery Co. Ltd, Taijin Lantian High-Tech Power Sources Joint-Stock Co. Ltd and the two Korean battery manufacturers, LG Electronics Inc. and Samsung Electronics Co. Ltd

Lithium-polymer battery sales are still a very small percentage of the total lithium-ion market, due primarily to cost. Battery market analysts EBN have reported a price premium of about 10% on lithium-polymer batteries, which are primarily used in mobile phones. They comment that adoption of lithium-polymer batteries will depend upon the willingness of users to pay premiums for the small size of the technology, as there are no additional performance benefits. Although prices of lithium-polymer battery cells have dropped, so has the price of lithium-ion cells. 'Depending on the type and size of the lithium battery, prices have eroded 20% to 50% this year. As a result, battery manufacturers have started to shift production to lower-cost regions such as China,' EBN has said.

Prices are also reported to have dropped for NiCd and NiMH chemistries by about 10% to 20% in 2001. Although the market for NiMH battery cells is shrinking, they are still used in lower-cost phones, whilst NiCd batteries dominate market share for power tool applications.

3.5 Battery Selection

Rarely does any single battery system meet all the requirements for any given application. When faced with such a wide range of commercial portable power systems in a variety of models, it is difficult to reduce the selection process to an exact science. Battery performance is affected by a number of factors including temperature, current drain, peak power demand and service schedules. As a result, the selection process will normally require a compromise between battery requirements and battery-system characteristics.

As the power source for portable applications is an integral part of the electrical system, it should be considered as early as possible in the design process. As a guideline, there are four steps that should be followed:

1. Determine the battery requirements, including:
   - Physical – size and weight limitations, shape, shock and vibration resistance, operating position, acceleration, high-altitude use;
   - Electrical – voltage, current drain (initial and operating), constant or interrupted demand, discharge schedule;
   - Environmental – storage and operating temperatures, moisture and humidity factors;

- Special considerations – cost, replace or recharge, service life, shelf life, operating schedule, activation, type of terminals, and end-point voltage (if equipment will not operate below a certain critical voltage).

2. Establish the relative importance of requirements, determining those that are mandatory and those that are desirable. List the requirements in order of importance.
3. Compare the characteristics of each battery system with the battery requirements. For each requirement list those systems that make the grade.
4. Determine any necessary compromises. The selected system must meet the mandatory requirements. Trade off on the desirable requirements, beginning with those of least importance.

Proper battery system design focused on the demands of use will lead to the establishment of:

- an automatically activated primary
- a manually activated primary
- a rechargeable secondary

When designing for any of the above battery systems, there are a number of considerations for each.

- Automatically activated primary
  - Method of activation – mechanical or electrical
  - Activation time required to distribute electrolyte
  - Wet stand time after activation prior to application of load
  - Orientation during activation
  - Orientation during operation
  - Temperature in storage prior to use
- Manually activated primary
  - Soak time after activation prior to use
  - Cycle life (if any) – number of charge/discharge cycles
  - Wet shelf life – wet stand time after activation
  - Temperature in storage prior to use
- Rechargeable secondary
  - Cycle life
  - Wet shelf life
  - Capacity as a function of cycling – capacity at first cycle compared with capacity at last cycle.
  - Charge retention – ability to stand in a charged condition
  - Method of recharging
  - Maintenance

Further information on guidelines for battery selection may be found in the *Battery Reference Book*[7] or by consultation with a battery specialist.

3.6 Applicable Battery Chemistry

The majority of mobile phones are currently equipped with nickel-metal-hydride (NiMH) or lithium-ion batteries. NiMH is a well-established technology that offers more than twice the volumetric energy density (energy stored within a given volume) of cheaper nickel-cadmium (NiCd) batteries. Lithium-ion batteries offer still higher energy density, using a newer technology that became commercially viable in 1991. These batteries are becoming standard on most high-end mobile phones and are taking over the market from NiMH.

The main thrust of current electrochemical research and development is the search for new compounds that can be used as the electrodes and electrolyte. A good example of this quest for new materials is the discovery that the malleability of a lithium battery can be improved by replacing the liquid electrolyte with a polymer gel. As a result, the latest rechargeable lithium-ion polymer batteries can be fabricated in different shapes and sizes without the risk of seepage of reactive and hazardous lithium components.

3.6.1 LITHIUM BATTERIES

According to BCC[8] most lithium batteries are manufactured in the Far East, resulting in a preponderance of lithium-material companies within the region, but a number of companies in the US are beginning to produce lithium batteries. This shift from Far East to US sources is expected to accelerate as the value of the lithium battery market grows, and will see material sources develop within the US market. The market is expected to increase significantly over the period, which will afford opportunities to companies involved in related material industries.

3.7 Rechargeable Batteries

The global market for rechargeable batteries for mobile IT and telecommunications devices alone generated revenues of $2.78 billion in 2000 and is projected to surge to $4.68 billion by 2007 in an new analysis by Frost & Sullivan.[9] As demand for such consumer products continues, the market for rechargeable batteries is likely to remain strong and viable.

The report states that the industry is anticipating Li-ion polymers to emerge as the key driver for market revenues worldwide. Currently, the largest applications for Li-ion polymer batteries are cellular telephones and PDAs. Li-ion polymers are expected to experience high growth rates as electronic manufacturers incorporate these batteries into various devices other than IT and telecommunications products.

3.8 Performance Comparison of Rechargeable Battery Chemistries

The most common types of rechargeable battery available are nickel cadmium (NiCd), nickel-metal hydride (NiMH), lead acid, lithium ion (Li-ion), lithium ion polymer (Li-ion polymer) and reusable alkaline.

Nickel cadmium is a matured product within the battery marketplace. It is well understood and serves as the benchmark for other battery products but it does contain toxic metals which make it environmentally harmful. Table 3 provides a comparison of the above battery types in terms of energy density, cycle life, exercise requirements and cost. The figures are based on average ratings of commercially available batteries at the time of publication. Exotic batteries with above average ratings are not included.

Table 3 Characteristics of rechargeable battery systems

	NiCd	NiMH	Lead acid	Li-ion	Li-ion polymer	Reusable alkaline
Gravimetric energy density (Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal resistance (includes peripheral circuits) (mW)	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500	50[3] (to 50%)
Fast charge time	1h typical	2-4h	8-16h	2-4h	2-4h	2-3h
Overcharge tolerance	moderate	low	high	very low	low	moderate
Self-discharge/month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell voltage (nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load current - peak - best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating temperature (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.	not req.
Typical Battery cost (US$) (reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per cycle (US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10–0.50
In commercial use since	1950	1990	1970	1991	1999	1992
The figures are based on average ratings of batteries available commercially at the time of publication; experimental batteries with above average ratings are not included.						

1. Internal resistance of a battery pack varies with cell rating, type of protection circuit and number of cells. Protection circuit of Li-ion and Li-polymer adds about 100mW.
2. Cycle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may reduce the cycle life by a factor of three.
3. Cycle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.
4. The discharge is highest immediately after charge, then tapers off. The NiCd capacity decreases 10% in the first 24h, then declines to about 10% every 30 days thereafter. Self-discharge increases with higher temperature.
5. Internal protection circuits typically consume 3% of the stored energy per month.
6. 1.25V is the open cell voltage. 1.2V is the commonly used value. There is no difference between the cells; it is simply a method of rating.
7. Capable of high current pulses.
8. Applies to discharge only; charge temperature range is more confined.
9. Maintenance may be in the form of ‘equalizing’ or ‘topping’ charge.
10. Cost of battery for commercially available portable devices.
11. Derived from the battery price divided by cycle life. Does not include the cost of electricity and chargers.

Source: Buchmann, *Batteries in a Portable World*[10]

3.8.1 Nickel Cadmium

Nickel Cadmium rechargeable batteries have a long life and high discharge rate. They have the advantage of being cheap, but they do contain toxic metals. Their main uses are in two-way radios, biomedical equipment, professional video cameras and power tools. Over 50% of all rechargeable batteries for portable equipment are NiCd. However, the introduction of batteries with higher energy densities and less toxic metals is causing a switch from NiCd.

Table 4 Advantages and disadvantages of NiCd rechargeable batteries

Advantages	Disadvantages
Quick charge time	Comparatively low energy density to newer systems
High number of charge cycles	High level of self-discharge
Long shelf life	Cell plates crystallise if not used
Available in a range of sizes and performance options	Environmentally unfriendly due to presence of toxic metals
Good load performance	
Resilient	
Cheap	

Source: Buchmann, *Batteries in a Portable World*[10]

3.8.2 Nickel-Metal Hydride

Nickel-metal hydride batteries have a higher energy density than NiCd but a reduced cycle life. They tend to be used in mobile phones and laptop computers. The success of the NiMH has been driven by its high energy density and the use of environmentally friendly metals. NiMH offers up to 40% higher energy density compared to NiCd. In some parts of the globe, buyers are encouraged to use NiMH rather than NiCd batteries due to environmental concerns about disposal of spent batteries.

Table 5 Advantages and disadvantages of NiMH rechargeable batteries

Advantages	Disadvantages
30-40% higher capacity than NiCd	Limited service life, with deep cycles reducing life to as few as 200 cycles
Transportation is not subject to regulatory control	Limited discharge current
Environmentally friendly	High self discharge – about 50% higher than NiCd
Less prone to crystals forming on cell plates when not used than NiCd	Storage at high temperatures results in degradation
	High self discharge – approximately 50% higher than NiCd

Source: Buchmann, *Batteries in a Portable World*[10]

3.8.3 Lead Acid

Lead acid was the first rechargeable battery for commercial use. Lead acid rechargeable batteries are economical for larger power applications where weight is of little concern. There are two variants of the lead acid battery: sealed lead acid (SLA), typically used for portable applications, and valve-regulated lead acid (ARLA), typically used for stationary applications. Lead acid batteries are often used in back-up and emergency power applications such as hospital equipment, wheelchairs, emergency lighting and UPS systems.

Table 6 Advantages and disadvantages of lead acid rechargeable batteries

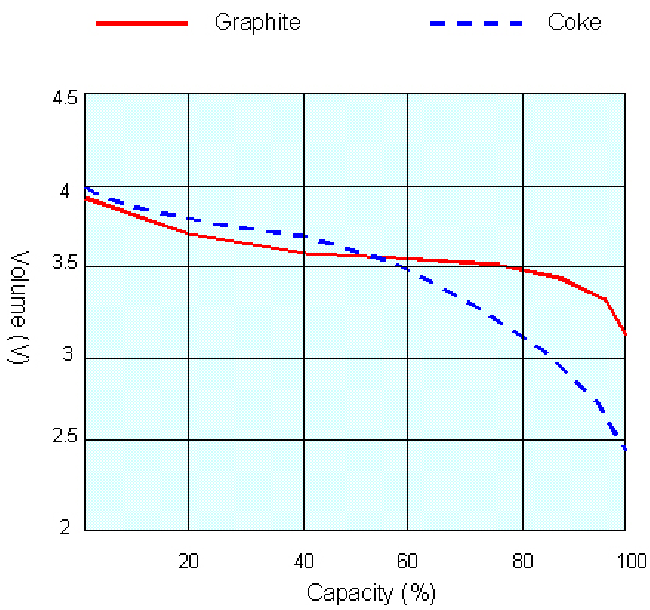
Advantages	Disadvantages
Reliable and well understood technology	Cannot be stored in a discharged condition
Capable of high discharge rates	Electrolyte and lead content is environmentally unfriendly
Low need for maintenance	Low energy density
Simple and inexpensive to make	Only allows limited full discharge cycles
Low level of self-discharge	Transport restrictions on flooded lead acid

Source: Buchmann, *Batteries in a Portable World*[10]

3.8.4 Lithium Ion

Lithium ion batteries are lightweight, and so suitable for use in notebook computers and cellular phones. Their principal shortcoming is their relatively high price. The first lithium ion (Li-ion) for commercial use was released in 1991 by the Sony Corporation. The energy density of the Li-ion is typically twice that of the standard NiCd. There are several Li-ion battery types, each with its own characteristics. The original Li-ion from Sony used coke as the negative electrode. However, since 1997 Sony has shifted to graphite, along with many other manufacturers, which provides a flatter discharge voltage curve as detailed in Figure 1.

Figure 1 Lithium-ion electrode discharge characteristics



Source: Buchmann, *Batteries in a Portable World*[10]

The positive electrodes used in lithium-ion batteries are typically constructed of cobalt or manganese (spinel). With cobalt, the battery has a higher energy density than with manganese, and a longer a life expectancy of 300 cycles. It works well over a wide temperature range but is best suited to operation at elevated temperatures, whereas manganese suffers capacity loss at temperatures in excess of 40^{o}C and becomes less durable. Manganese is also thought to have a shorter life expectancy, but does offer cost advantages over cobalt, as the raw material is 30% cheaper. Although cobalt has been in use longer, manganese is safer and more forgiving of abused.

Table 7 Advantages and disadvantages of Li-ion rechargeable batteries

Advantages	Disadvantages
High energy density	Protection circuit is required which limits voltage
Self discharge is relatively low	Subject to ageing
No periodic discharge is required resulting in low maintenance requirements	Transportation regulations apply when shipped in larger quantities
	Expensive – approximately 40% more than NiCd to manufacture

Source: Buchmann, *Batteries in a Portable World*[10]

3.8.5 LITHIUM ION POLYMER

Lithium Ion Polymer rechargeable batteries are a lower cost version of the Li-ion, and are appropriate for use in mobile phones. The Li-polymer differentiates itself from other battery systems in the type of electrolyte used. The original 1970s design uses a dry solid polymer electrolyte only, which resembles a plastic-like film that does not conduct electricity but allows an exchange of ions. The Li-polymer battery consists of a gelled electrolyte that allows the battery to be formed into convenient shapes. Most of the commercial Li-polymer batteries used today for mobile phones are a hybrid and contain gelled electrolyte. The gelled electrolyte provides enhanced ion conductivity. Overall, with a gelled electrolyte added the characteristics and performance of Li-ion and Li-ion polymer are very similar.

Table 8 Advantages and disadvantages of Li-ion polymer rechargeable batteries

Advantages	Disadvantages
Very low profile	Expensive to manufacture
Light weight	Lower energy density than Li-ion
Improved resistance to overcharge – higher safety level	Lower cycle count than Li-ion
Potential for lower cost once mass produced	
Cell formats are flexible	
Easier and simpler packaging	

Source: Buchmann, *Batteries in a Portable World*[10]

3.8.6 REUSABLE ALKALINE

Reusable alkaline have a limited life cycle, but are used in portable entertainment devices and torches. The reusable alkaline is designed for repeated recharge, but it does lose charge acceptance with each recharge. The longevity of the reusable alkaline is a direct function of the depth of discharge; the deeper the discharge, the fewer cycles the battery can endure. The reusable alkaline is inexpensive but the cost per cycle is high when compared to the nickel-based rechargeable batteries. For many applications it is still economical when compared to non-reusable alkaline batteries. The standard (non-rechargeable) alkaline offers maximum energy density whereas the reusable alkaline provides the benefit of allowing some recharging. The compromise of the reusable alkaline is loss of charge acceptance after the first recharge.

Table 9 Advantages and disadvantages of reusable alkaline rechargeable batteries

Advantages	Disadvantages
More economical than primary batteries	Light-duty applications only, due to limited current handling
Low self discharge	Limited life cycle
Environmentally friendly	
No maintenance required	
Inexpensive	

Source: Buchmann, *Batteries in a Portable World*[10]

3.9 Other Battery Developments

There are continuous developments in battery technology with regards to both chemistries and packaging. The following are examples of some of the latest developments.

3.9.1 Film Batteries

The area of battery design is one of intense research and there is evidence of emerging battery forms and chemistries that promise, if adopted, to bring significant functionality and performance benefits to battery products. Battery formats are undergoing a revolution. Lithium-polymer batteries offer the promise of energy source that can be shaped to fit behind a PC screen and make use of any available space within an end product. Film-battery technology is allowing the production of energy cells in a flat and flexible form. One manufacturer refers to the battery it produces in this way as a film battery because they are reminiscent of film frames. Film battery cells could soon be as thin as 0.2 millimetres. They can be manufactured in long, continuous strips, which reduce production costs. Both NiCd and NiMH cells can also be produced using the film format.

3.9.2 Lithium-Polymer Developments

Lithium-ion polymer batteries represent the current state-of-the-art with regards to rechargeable batteries. Many independent, innovative companies are currently undertaking research aimed at improving the performance capabilities of this particular battery electrochemistry. US companies Lithium Technology and Moltech are developing lithium-based batteries which use an alternative to the conventional homogeneous gel. Lithium Technology has developed a fibrous web substrate to create a composite battery structure with reduced manufacturing costs. Although the company is focused on developing larger batteries (laptop computers are the smallest devices that it has targeted so far), the technology could be modified for use in smaller communications applications. Similarly, Zinc Matrix Power of the US has replaced lithium with silver and zinc in its silver polymer battery released in June 2001.

Handset-battery makers may dispense with toxic lithium ions in favour of highly mobile positive hydrogen ions (protons). NEC have unveiled the world's first proton-polymer battery. The Japanese company is now producing proton-polymer batteries as small as a credit card, which suggests that the technology may be appropriate for mobile communications technology.

3.9.3 METAL-AIR BATTERIES

A generation of metal-fuelled batteries that sit between fuel cell and conventional battery technology is emerging. Fuelled by particulate metals, such as zinc, iron or aluminium, these batteries offer greater energy density than current technology. For example, zinc-air batteries are under development which use oxygen from the atmosphere as the negative electrode reactant. Holes in the battery casing allow air to react with a powered zinc positive electrode through a highly conductive potassium-hydroxide electrolyte. Zinc-air batteries can be stored almost indefinitely, providing they do not come into contact with air. This means that they have a much longer shelf life than standard batteries.

eVionyx Inc. is developing a new zinc-based battery called the Revolutionary Power Cell (RPC). To use zinc as a fuel (aluminium, magnesium and other metals can also be used), abundant zinc ore is converted to low-cost zinc metal. Within the RPC, energy is extracted from the zinc as it is electrochemically converted to zinc oxide. The battery can work in four modes: disposable, refuelable, rechargeable, and RefRec (refuelable and rechargeable). AER Energy in the US has also developed a zinc-air prototype battery for use in Nokia's 5100, 6100 and 7100 mobile phones. The battery is said to enable the phones to be used up to four times longer in talk mode. The company has also patented an air-distribution system which should increase battery lifetime by controlling the rate at which air reaches the active area of the battery.

In further developments, Power Paper in Israel[11] have recently commercialised a paper-thin battery using layers of zinc and magnesium dioxide as the electrodes. The first products of this technology – novelty wrapping paper capable of displaying images or playing selected audio clips – are already on the market. Disposable mobile phones and electronic medical tags are among some of the many other applications proposed in the not-too-distant future.

Further in the future, a new generation of micron-sized devices and machines, termed MEMS (micro-electromechanical systems), are expected to spur further developments in battery miniaturisation.[12] US Nanocorp is developing, but has not yet commercialised, microscopic batteries fabricated on silicon wafers. These microbatteries are typically the size of a pinhead but can be as small as the breadth of a human hair. Since the cell is on a wafer, the weight and bulk of connections, wiring and so forth is eliminated, thereby increasing the effective energy density.

3.10 Battery Legislation and Standards

The EU's Battery Directive stipulates minimum standards for the production, marking, recycling and disposal of batteries, similar type power supplies and appliances containing batteries, in the EU and European Economic Area, with particular attention to heavy-metal content. The main aim of UK and European legislation pertaining to batteries is not to improve their performance, but to ensure that the product chemistries are safe and do minimum environmental damage, through recycling and careful disposal. Batteries sold in the British market must meet the required dimensional and other requirements of the relevant British and international standards. The main standard for batteries is BS397 (International harmonised standard IEC86).

The main requirements of the UK/EC battery legislation include:

- taking appropriate steps to ensure that spent NiCd batteries are collected separately with a view to recovery or disposal – gradual reduction, in household waste;
- ensuring that NiCd batteries and, where appropriate, appliances into which they are incorporated, are marked in the appropriate manner. The marking must include indications as to separate collection, where appropriate, and recycling of heavy-metal content.
- requiring that NiCd batteries cannot be incorporated into appliances unless they can be readily removed, when spent, by the consumer.

As Table 10 highlights, primary batteries in the UK are covered by the five-part BS EN 60086 series.

Table 10 Primary battery standards

Primary battery standards	
Standard	**Basic overview**
BS EN 60086-1	Specifies nomenclature, dimensions, polarity, terminals, test conditions, marking and service output requirements for batteries and primary cells based on any electrochemical system.
BS EN 60086-2	Must be read in conjunction with part 1 and provides information on the sizes and tolerances each battery should meet.
BS EN 60086-3	Describes the dimensions, designation and requirements for primary watch batteries, including a menu of test methods.
BS EN 60086-4	Gives performance requirements for primary lithium batteries to assure their safe operation under normal use and foreseeable misuse and abuse.
BS EN 60086-5	Sets out the performance and safety requirements for batteries with an aqueous electrolyte.

BS EN 60086-1 also sets out some general service-output requirements for batteries. However, the batteries of different manufacturers have differing performance characteristics. Each manufacturer will produce a datasheet detailing the performance of its battery. These are available from the battery supplier once the required battery performance has been identified. Under the battery directive, if a manufacturer uses batteries or accumulators, instructions will have to be provided on how the spent batteries and accumulators are to be disposed. Further, in several countries, disposal is a manufacturer's obligation, and it will be necessary to participate in a disposal system. Finally, products will have to be so constructed that batteries can be removed for disposal separate from the product itself. This applies to all products.

Links to the relevant sections of the HMSO website concerning regulations (in these cases, statutory instruments) on batteries are listed below:

- SI 2001 No.2551 The Batteries and Accumulators (Containing Dangerous Substances) (Amendment) Regulations 2001
- SI 2000 No.3097 The Batteries and Accumulators (Containing Dangerous Substances) (Amendment) Regulations 2000
- SI 1994 No.232 The Batteries and Accumulators (Containing Dangerous Substances) Regulations 1994

3.10.1 BATTERY RECYCLING

There are currently no NiCd recycling facilities in the UK. Significant quantities of them are accumulated before it is cost effective to arrange shipment for recycling overseas. Collected nickel cadmium batteries are categorised as special waste and must be managed by a certified waste handler. In order to encourage recycling and the establishment of further collection schemes, the storage of up to 5 tonnes of waste NiCds is proposed. Storage of waste which is destined for recovery is permitted in a secure place on any premises provided certain conditions are satisfied. The European Commission is proposing to revise the battery directive to require the collection and recycling of all portable batteries. The European Portable Battery Association (EPBA) supports this initiative in principle. The EPBA has developed technology to recycle general-purpose batteries in the metals industry.

3.10.2 CE MARKING

There are currently no CE-marking regulatory directives that apply to batteries. Such regulations currently cover the final application devices.

4.0 Fuel Cells

Miniaturised fuel cells represent one of the most viable alternatives to conventional battery chemistries. Hype does surround the technology and its application but given the interest among battery manufactures, fuel cells have the potential for commercialisation in perhaps two to four years and are likely to have a significant impact on the mobile power-source sector.

4.1 Fuel Cell Construction

A fuel cell is an electrochemical energy-conversion device very much like a battery that can be recharged. Instead of recharging using electricity, a basic fuel cell uses hydrogen and oxygen. The operation of a fuel cell is, in principle, similar to that of a battery, but with a performance potential for energy storage and power delivery that far exceeds even the most currently sophisticated Li-polymer battery chemistries many times over. A basic fuel cell consists of an electrolyte sandwiched between an anode and cathode. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat.

Whilst a basic fuel cell uses oxygen and hydrogen to produce electricity, the oxygen required comes from pumped air. Unfortunately, an abundant supply of hydrogen is not so readily available, and hydrogen has limitations that make it impractical for use in most applications. Hydrogen is difficult to store and distribute, so it would be much more convenient to develop cells that use fuels that are more readily available and present fewer technical challenges. Some of the more promising fuels are natural gas, propane and methanol which present fewer distribution problems. Also of interest are some metal fuels, such as zinc and aluminium, which may be used in particulate form to generate energy when exposed to air. Given their relatively clean output, fuel cells are poised to become a leading energy source in the 21st century.

4.2 Fuel Cell Chemistries and Applications

There are many different types of fuel cells, using a wide variety of cell chemistries. The cells themselves are typically classed by the type of electrolyte they use. Basic types include phosphoric acid, proton-exchange membrane, molten carbonate, solid oxide, alkaline, direct methanol fuel cells and regenerative fuel cells. The proton-exchange-membrane fuel cell (PEMFC) is one of the most promising, with others, such as phosphoric acid fuel cells already commercially in use all over the world in hospitals, nursing homes, hotels, office buildings, schools and utility power plants.

Fuel cells also possess a wide variability in their potential applications, with proposed applications ranging from portable tools to power generation. The majority of fuel cells currently available are for stationary power applications, typically serving industrial or energy dependant facilities such as hospitals. In this role they offer the potential to reduce facility energy service costs by 20% to 40% over conventional energy services, but there are also residential and transportation applications being developed for commercial use.

One major area of fuel-cell development is the automotive sector, where research is being carried out into using the technology in next-generation hybrid petrol-electric and fully electric vehicles. Many of the worlds major auto makers are now working to commercialise a fuel-cell car. An article in *Fuel Cell Today* reported that, with the exception of Isuzu, all of Japan’s car manufacturers currently have active fuel-cell vehicle programmes.[13] At present there are as many fuel-cell vehicle prototypes coming out of Japan as the rest of the world put together, and Japanese corporations are investing many millions (if not billions) of pounds into fuel-cell vehicle research and development.

With the full backing of the government, the development of fuel-cell vehicles has excelled in Japan. The Ministry of Economy, Trade and Industry (METI) is already working to establish standards for the industry and NEDO (Japan's New Energy and Industrial Technology Development Organisation) has run a fuel-cell vehicle programme since 1998. In August 2001 it was reported that METI plans to create a fuel-cell vehicle market of 50,000 units by 2010.

4.3 Micro Fuel Cells

An exciting area of research is in fuel cells to power portable applications. The increasing power and battery-life requirements of portable equipment mean that new breakthroughs have to be made in the performance of miniature energy sources. The fuel cell, which separates the energy storage and power conversion functions, is an attractive solution. Micro fuel cells, once they become available to the commercial market, could enable consumers to talk continuously for up to a month on a mobile phone without recharging. Fuel cells have the potential to change the telecommuting world radically, powering laptops and palm pilots hours longer than batteries. Other applications for micro fuel cells include pagers, video recorders, portable power tools, and low-power remote devices such as hearing aids, smoke detectors, burglar alarms, remote controls and car fobs.

Whilst these capabilities remain largely unproven and based on laboratory research, they are rapidly approaching commercialisation. One miniature fuel cell, a device that uses liquid methanol (wood alcohol), was announced in February 2002 by Motorola Laboratories and the US Los Alamos National Laboratory.[14] The biggest benefit is going to be an operating life ten times longer than today's batteries, according to Bill Ooms, director of Motorola's Material, Device, and Energy Research. The cells are intended for use as a primary source and are not rechargeable. The cells will be inexpensive enough to be disposed of after use. 'Our intention is to have the price of a fuel cell be the same or less than the cost of a rechargeable battery. This is in the early stages. We envision it being available in the three- to five-year time frame,' Ooms said.

Casio Computer Co. has developed a small, long-life fuel cell for mobile-information terminals such as notebook computers, which it aims to commercialise in 2004. The company has reduced the size of a device inside the fuel cell that extracts hydrogen from methanol, and has developed technology to replace from 300 to 1,000 parts with a single chip. The new fuel cell is said to last four times as long as the current mainstream rechargeable batteries and will enable use of a notebook computer for 20 hours, up from the five hours offered by lithium-ion batteries.

Leading the competition, Toshiba Corp., NEC and Hitachi Ltd. are also accelerating development of fuel cells as their main focus for next-generation batteries. For example, NEC are working on a fuel-cell technology that uses tiny carbon tubes (nanotubes) as electrodes for the chemical reaction between hydrogen and oxygen. The company claims that the fuel cell has ten times the energy density of lithium-ion batteries and could be used to power mobile phones.

Fuel-cell innovation is being driven not just by leading research institutes and established consumer-product manufacturers but also by many small and medium sized companies. These companies have established programmes for the development of miniature fuel cells, finessing the technology into a reliable, powerful and safe resource.[15] In this crowded arena Medis Technologies Inc. have said they are working on a cartridge that can be refuelled with a patented liquid-fuel composition instead of methanol, which is toxic and flammable. It also does not require a proton-exchange membrane. This would eliminate a development problem for fuel cells: water, generated as part of the reaction product, diffuses through the membrane, leading to unwanted water on one side of the fuel cell. Medis says it plans to demonstrate a prototype in 2004.

Manhattan Scientifics is developing a ‘power holster’, a portable charger system for battery-powered mobile phones. The essence of what Manhattan Scientifics has developed is a way to produce fuel cells in a flat printed form. Likewise, Ballard Power Systems plans to make portable fuel cell system for laptop computers, as does Samsung's Advanced Institute of Technology (SAIT), which has developed a prototype claimed to have powered a notebook computer for more than six hours without recharging.

Fuel cells are expected to make mobile equipment much easier to use because of their long life and help facilitate development of mobile equipment that consumes a large amount of power. The environmentally friendly power sources are expected to account for 10% of batteries used in mobile equipment by 2010.[16]

4.4 Market Overview

There are a number of market reports that examine the potential for fuel cells and speculate on their further development and adoption. Significantly, all reports indicate a great potential for fuel-cell technology and highlight strong expectations of growth in future years. Market analysts The Freedonia Group predicted in a report published in May 2003 that the world commercial market for fuel-cell products and services will reach $2.4 billion in 2007.[17] In another report, published in February 2004, the same company has forecast U.S. demand for fuel-cell products and services – including revenues associated with prototyping and test marketing activities, as well as actual product sales – of $1.1 billion in 2008.[18] In 2003, the US Fuel Cell Council reported US sales of fuel cell products, parts and services for those organizations that participated in a survey of its members of $151 million and $167 million for 2001 and 2002 respectively.

A report published in 2003 by Allied Business Intelligence (ABI) estimated that although world sales in 2004 would probably be nominal, the market could grow to $35 by 2013.[19] Daniel Benjamin, the report’s author commented, ‘In the long term, fuel cells will provide a clean and renewable source of energy, but for product launches within the next few years, cost and technical issues will pose significant barriers for consumers.’ He said early fuel-cell consumer applications are likely to cluster in stationary power generation and portable electronics. But he warned of the possibility that despite a higher cost, their performance may not equal that of the power systems they replace at first.

4.5 Micro Fuel Cell Selection

Ultimately, there are three main technical hurdles to be overcome in realising micro fuel cells for miniature electronic devices, namely cell power management, miniaturisation and safety. The power demands of portable devices on the energy source are different in their standby and various operating modes. Management of fuel flow rates, which vary accordingly, may come up against problems of inertia and of availability of the micro components allowing the necessary dynamic fuel supply of the cell core.

A cell producing power virtually continuously would require storage of the electrical energy supplied and consequently the use of a buffer element to regulate the necessary instantaneous electrical power to the portable device. This is technically challenging and is still the more likely solution given current technology levels. Many major fuel-cell developers are also involved in the manufacture and development of batteries. Any commercial solutions that combine the two, with a rechargeable battery used as a buffer energy store, would no doubt find favour in the market.

Managing the required electrochemical reaction on the small scale of micro fuel cells is a challenge. In the considerably larger traditional fuel cells, it is comparatively simple for oxygen and fuel to be supplied at the core to provide hydrogen in order to produce water, but to reproduce this at a micro level for portable devices is more difficult. This may prove to be the most difficult challenge faced by developers.

A third problem concerns the storage and supply of fuel in a safe form within a compact space, one that meets the requirements of the cell’s life span. The original fuel-cell material, hydrogen, presents many safety and distribution problems. Cells will have to be designed to minimise the risk of the end user’s coming into contact with fuel.

Micro fuel cells will be selected on the basis of a balancing of user demands, competitive factors, fuel-cell performance versus battery performance and, of course, economics. Current micro-cell technology is in its near-commercial phase and there are existing mass applications that could benefit significantly from the technology. For manufacturers to adopt such a step change in their selection of energy sources will demand the reliable manufacture of fuel cells on a scale not yet seen. The issue of form factor will also be pressing as consumer-goods manufacturers will not be easily persuaded to step away from existing power formats such as the AAA battery form without a convincing and proven improvement in performance and value to the device user. For many electronics manufacturers a fuel-cell technology that does not cause significant disruption to their existing product designs, in terms of battery space, storage requirements, or pass-through user-maintenance needs, is the ideal solution. It is evident that many current developments in micro fuel cell technology are aimed at replicating cells in the battery formats that manufacturers are used to.

4.6 Performance Comparison of Micro Fuel Cells

A good deal of hype surrounds the performance capabilities and potential of the wide array of fuel-cell technologies. According to many market reports, for example one from Allied Business Intelligence, fuel cells may be able to provide up to 10 times the peak power of conventional batteries and they may allow up to 30 days of standby time for mobile phones – five times the amount of time typically provided by batteries. These figures are impressive and commercial testing has been undertaken on a number of cell chemistries and designs which validate the improved capabilities of fuel cells over battery technology. The eVionyx AAA fuel cell, a near-market hybrid of fuel cell and battery technology, has demonstrated a more modest improvement when used as the power supply for a Palm Pilot. The fuel cell lasted around twice as long as batteries widely available on the high street today.

Manhattan Scientifics published the results of performance-comparison tests they conducted in 1999. The prototype methanol fuel cell they had developed performed three times as well as the best alternative, the Li-ion battery, which displayed an energy-per-unit-mass consumption of 100 compared to 300 for the fuel cell.

4.7 Codes and Standards for Fuel Cells

There is a range of requirements for fuel cells as well as a number of established national and international bodies which, as well as overseeing fuel-cell development, are equally keen to set standards and guidelines for their construction and operation. Such standards are viewed as vital in enabling the technology to move from research into industrial commercialisation.

4.7.1 UK Developments

Currently, the legislation and codes covering fuel cells are a mix of other regulations not specific to fuel cells, from electrical regulations to health-and-safety regulations. As this is a comparatively new technology, no firm regulations have yet been introduced. The energy review published in February 2002 by the Cabinet Office's Performance and Innovation Unit (now called the Strategy Unit) advised British policy-makers to expand the role of renewable energy sources while keeping open nuclear and clean-coal options.[20] The review did not consider fuel cells in great detail but it is still hoped that it will bring a welcome boost to an area that has received limited support in the past. Mark Cropper commented in *Fuel Cell Today*, 'A number of proposals it makes could favour the adoption of fuel cells. Most importantly, it calls for a substantial increase in investment in wind farms and energy efficient combined heat and power systems, which could include fuel cells.' [21]

4.7.2 Institute of Electrical and Electronics Engineers

The IEEE is a non-profit, technical professional association of more than 375,000 individual members in 150 countries. Through its members, the IEEE is a leading authority in technical areas ranging from computer engineering, biomedical technology and telecommunications, to electric power, aerospace and consumer electronics.

Within the IEEE is the Standards Coordinating Committee 21 (SCC21) concerned with fuel cells, photovoltaics, dispersed generation, and energy storage. SCC21 oversees the development of standards in these areas and coordinates efforts in these fields among the various IEEE Societies and other affected organisations to ensure that all standards are consistent and properly reflect the views of all applicable disciplines. For more information on SCC21 see http://grouper.ieee.org/groups/scc21

The IEEE has developed a number of recommended industry practice documents, including:

- IEEE P937, Draft Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems
- IEEE P1013, Draft Recommended Practice for Sizing Lead-Acid Batteries for Photovaltaic (PV) Systems
- IEEE P1547, Draft Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE P1589, Draft Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems

4.7.3 INTERNATIONAL ELECTROTECHNICAL COMMISSION

The International Electrotechnical Commission (IEC) is the international standards and conformity assessment body for all fields of electrotechnology. This is an important body, as they are involved in global standards that eventually are adopted by the harmonised EU and become European standards. More information concerning IEC can be found at www.iec.ch

The ICE fuel cell committee, TC 105 (Fuel cell technologies), was created in 1998 to prepare for the appearance of fuel cells on the market by developing the necessary safety and interface standards. TC 105 works on general requirements for all fuel cell technologies and applications, including fuel cell modules, systems, power plants and infrastructures.

TC105 is currently working in a number of standard areas including:

- IEC 62282-1 TR Ed. 1.0 — Fuel cell technologies – Part 1: Terminology
- IEC 62282-2 Ed. 1.0 — Fuel cell technologies – Part 2: Fuel cell modules
- IEC 62282-3-1 Ed. 1.0 — Fuel cell technologies – Part 3-1: Stationary fuel cell power plants – Safety
- IEC 62282-3-2 Ed. 1.0 — Fuel cell technologies – Part 3-2: Stationary fuel cell power plants – Test methods for the performance
- PNW 105-21 Ed. 1.0 — Portable fuel cell appliances – Safety and performance requirements
- PNW 105-23 Ed. 1.0 — Fuel cell system for propulsion and auxiliary power units (APU)
- PNW 105-24 Ed. 1.0 — Stationary fuel cell power plants – Installation

Work group progress can be monitored on the IEC TC105 dashboard.

4.7.4 USA

Normally, codes and standards are developed in the USA by voluntary bodies and are then adopted at the appropriate level by the government and made mandatory. The number of bodies making regulations is large. They include departments of the federal and state governments and professional bodies such as the Institute of Electrical and Electronics Engineers and the Society of Automotive Engineers. As in the UK, most building regulations do not specifically cover fuel cells; fuel cells are covered by other regulations that have not been framed specifically for fuel cells – rules that cover electrical connections, fuelling, safety and noise levels of such an installation, for example.

In *Fuel Cell Today*, David Jollie set out the following as the steps in the process of developing and implementing codes and standards relating to installations:

- development of standards
- revision of codes to reference standards and ensure safety
- adoption by government agencies
- verification that the technology meets the standards
- submission of plans to use the technology concerned
- approval based on codes and standards
- installation and inspection for compliance.

In the same article, he also draws attention to some of the more notable developments in fuel-cell standards in the USA. The Society of Automotive Engineers is working on automotive fuel-cell standards; the US National Hydrogen Association on standards for hydrogen systems and components; and CSA International on general standards for fuel-cell power plants of up to 1000kW. Other interested parties include such organizations as The National Evaluation Service, the IEEE, the International Code Council, the American Society of Mechanical Engineers, and Underwriters Laboratories. [22]

4.7.5 THE WORLD FUEL CELL COUNCIL

The World Fuel Cell Council (WFCC) was founded as a non-profit association in 1991 by a number of fuel cell manufacturers and material suppliers. Its objective is to promote rapid commercialisation of fuel cell technology worldwide.

During October 2001, the WFCC released a statement condemning the energy review published by the UK Cabinet Office's Performance and Innovation Unit (PIU) for its lack of detail on fuel cells. The statement concludes by pointing out that the WFCC, which includes members from all over the world, only has one from the UK. There is a clear indication that the UK is being left behind in this field.

For further information on the activities of the WFCC see http://www.fuelcellworld.org.

5.0 Power Storage Components

Over recent decades advances and developments in the areas of material and electrical science have enabled the development of alternative components suited to the storage and delivery of electrical power. The development of ultracapacitors, sometimes termed ‘supercapacitors’, was a direct outgrowth of diverse applications of electrochemical technology. Representing a fusion of battery electrochemical technology and capacitor developments, ultracapacitors are a combination of electrochemical charge-discharge capability and capacitor technology. The result has been high-value capacitors with much higher energy storage capabilities than are found in normal electrical and electronics applications.

Identified for over a century as a double-layer capacitor, they have only been exploited commercially for about ten years. The ultracapacitor stores energy by moving charged ions close to an electrode with the opposite charge. This electron potential is then considered stored energy. The capacitor accomplishes this energy storage task by moving positive charges in one direction, negative charges in the other, hence the double layer.

The development of ultracapacitors with electrodes having a high surface area, through the use of materials such as porous graphite and nano-fabricate structures, and an electrolyte with a large number of ions, such as sol or aero gels, allows the manufacture of a capacitor capable of storing energy on the order of 5 to 10 Watt-hours per kilogram.

In a sense they resemble batteries because the charge is stored by ions as in a battery. However, no chemical reaction need take place, so an ultracapacitor also resembles a traditional capacitor. Significantly, ultracapacitors differ from batteries in that their voltage increases linearly with the state of charge and the problems of electrochemical irreversibility, so common with batteries, have been minimized or eliminated. Measured in farads, capacitance measures the ability to store electrical charge, and depends on both the geometry of the system and the dielectric constant of the insulating layer between the plates. Ultracapacitors have been developed with capacitance values of up to 2,500 F (farads).

5.1 Market Overview

The principal market for ultracapacitors is within the realm of power-source back-up. They are ideally suited to connection in parallel with an existing power supply from which they can draw their electrical charge. Should there be a change in the status of the main power supply, then the capacitor will perceive this as an electrical load and will subsequently discharge to regulate the power around a set level. In this role, ultracapacitors are able to outperform many battery back-up power systems and deliver significant levels of power to sensitive equipment such as PCs for a period of a few seconds to several minutes.

Recent developments in ultracapacitor technology have taken them closer to the role filled by stacked battery systems. In these applications, the ultracapacitor is charged from the primary power supply to provide a back-up power source when the primary source fails.

Ultracapacitors are commercially available that provide extra power for portable computers on initial power-up and during the operation of hard-drives. They enable manufacturers to use smaller batteries for the less demanding energy requirements of a computer. One of their major roles will be in the delivery of power in next-generation electric vehicles, where they will be an integral part of the vehicles' energy management systems. They are an ideal companion technology for automotive fuel cells and hybrid-electric vehicles, delivering additional power where required and recovering energy from activities such as braking.

It is clear that if developments within the field continue on their current course then future ultracapacitors will develop capabilities that will make them highly applicable for use as secondary power sources for a wide range of power-demanding mobile devices.

5.2 Power Storage Component Selection

Ultracapacitors extend the life of conventional batteries by boosting the output when power demand is at a peak. This boost is helpful because batteries deliver energy quite effectively but are relatively poor at providing power.

Table 11 Performance of ultracapacitor versus battery and capacitor technologies

Performance	Battery	Ultracapacitor	Capacitor
Specific energy (Wh/Kg)	10 to 100	5 to 10	0.01 to 0.1
Specific power (W/Kg)	<1000	<10,000	<100,000
Cycle life	1000	>500,000	>500,000
Charge/discharge efficiency (%)	50 to 85	85 to 98	>95

Source: FullPower Technologies[23]

Table 11 demonstrates that the battery is the better solution for storing a lot of energy when delivering low power. A standard capacitor is best for delivering a high-power burst without the need to store energy. The ultracapacitor will provide the middle ground, both high-energy storage and high-power delivery.

Ultracapacitors enjoy numerous advantages. They:

- offer up to ten times the energy of conventional capacitors.
- can deliver ten times the power of ordinary batteries.
- provide extended power availability, allowing functions to remain during outages in the main power source.
- feature accessible terminals and an electrostatic storage capability that can cycle hundreds of thousands of charges and discharges without performance degradation.
- are virtually maintenance-free over the life of any product in which they are used (and so need not be disposed of, making them a green form of energy storage).
- have a significantly extended lifetime compared to conventional batteries, so that when used in appropriate temperature conditions, they are expected to last longer than six years.
- offer a reliable and durable energy source that is about one third the weight and one-half the volume of conventional batteries.

In the real world of electronics, power and energy requirements are often at odds. In many cases, a designer must use excessive battery volume or expensive battery chemistry in order to meet power-delivery requirements. In other cases, size and weight limitations for the application restrict the battery size and result in a degradation of performance or functionality. Balancing power and energy requirements is critical to the most efficient use of energy.

One key aspect of ultracapacitors is that they have excellent cycle life. This is because it is possible to cycle ultracapacitors very quickly and deeply without seeing the large decrease in cycle life experienced by most chemical batteries. They also have a high cycle efficiency compared with chemical batteries. The primary obstacle for ultracapacitors at this point is their low specific energy, which is in the range of 5 to 10 WH/kg.

Ultracapacitors also have the unique feature that their voltage is directly proportional to their state-of-charge (the measure of how much energy is left in them). Therefore, either their operating range must be limited to high state-of-charge regions, or control electronics must be used to compensate for the widely varying voltage.

The form factors of ultracapacitors today rule out their use in current generations of portable electronics due to size incompatibility. They range from approximately the size of a postage stamp to the size of a small aluminium drinks can. However, the technology is rapidly advancing and suitable forms are under development.

As manufacturers becomes more sensitive to the production and efficient use of energy, the ultracapacitor industry is pushing towards the introduction of commercially viable micro ultracapacitors. Companies like NESS in Korea, Panasonic in Japan, and Maxwell in the U.S. have already demonstrated the ability to build large, high-performance ultracapacitor cells with capacitance values in excess of 2,500 Farads.[24] New companies, like FullPower Technologies in the USA, are starting to develop low-cost implementations of high-performance ultracapacitors through refining routes to high-volume manufacture, making ultracapacitors available to a wider and wider audience.

Whilst ultracapacitors will not completely replace batteries, their strength lying in the delivery of high power rather than high energy, they will offer an additional option for powering portable devices in a supportive role to a main energy source.

5.3 Standards and CE Marking

The guidance on the construction of capacitors is laid down within numerous UK and international standards. In the main, standards and regulations will surround the specific application to which ultracapacitors can be applied. For example within the USA, manufacturers have sought to get their devices approved to the Underwriters Laboratories’ component-recognition requirements under the category (BBBG2) for ‘capacitors, standby energy storage’.

As with the majority of electronic components ultracapacitors are no exception to European Directives on electronics waste. The devices themselves usually contain a significant proportion of raw material such as aluminium and, depending upon their design, can contain an organic electrolyte, which is regulated as hazardous material requiring disposal at an approved outlet. Prior to recycling or disposal, ultracapacitor are required to be electrically discharged and should be securely shorted.

Within the EU, the Low Voltage Directive and the 1994 Regulations apply to electrical equipment. In general, components are not covered as such by the requirements of the 1994 regulations. Only components which in themselves constitute 'electrical equipment' need satisfy the requirements of the 1994 Regulations and in particular bear the CE mark.

The term 'electrical equipment' is not defined in the Low Voltage Directive and should therefore be given the ordinary dictionary meaning. 'Electrical' is defined as 'operated by means of electricity' or 'of or pertaining to electricity'. Equipment' is defined as 'apparatus' which is in turn defined as 'the things collectively necessary for the performance of some activity of function'. An item is only subject to the requirements of the 1994 Regulations if it is 'electrical equipment' as so defined.

Certain components of electrical equipment may in themselves be considered to be electrical equipment. In such cases, steps should be taken to ensure that they satisfy the requirements of the 1994 Regulations if it is intended that they are to be supplied as separate items. For example, a manufacturer of control devices will need to ensure that these devices satisfy the 1994 Regulations' requirements if the manufacturer supplies it. This will apply whether supplying for retail sale or to other manufacturers for incorporation into other electrical equipment. Manufacturers of small components which in themselves constitute electrical equipment may under the 1994 Regulations apply CE marking to the packaging, instruction sheet or guarantee certificate of such components. However, it is important that component (and indeed all) manufacturers ensure that the mark is present particularly when moving their products around the European Economic Area (EEA).

6.0 Mechanical Power Sources

Mechanical power, widely used in the early industrial period, is making somewhat of a comeback as an energy solution for the future. Wind-up power sources have been used to provide energy for devices such as watches, clocks and toys for hundreds of years.

They are currently characterised by simple hand-cranked winding mechanisms converting mechanical power into stored energy in the potential of a wound spring or similar, the energy within the spring being capable of release upon demand. The example of the dynamo, typically used to convert the mechanical rotation of a bicycle wheel into electrical energy, is another example of a direct mechanical-to-electrical energy conversion.

For a technology with such a long pedigree it is surprising to consider that it was not until the invention of the mechanically powered Freeplay radio by Trevor Baylis in 1991, that the potential of wind-up and mechanical power sources again emerged into the public light. The Freeplay radio was intended for developing countries, where electricity was not readily available, but since 1996 Freeplay has sold more than a million wind-up radios to Western consumers, catering to their environmentally friendly lifestyle and ensuring they do not electrocute themselves in the bathroom.

Broadening the scope of what they term ‘manual charging or personal power’, Freeplay have introduced a manual mobile phone charger that enables users to make calls when the phone’s internal battery has run flat. Freeplay have partnered with Motorola on the development, who have taken responsibility for marketing. The charger consists of a small hand crank attached to a dynamo. Turning the crank generates mechanical energy, which is converted to electrical energy within the charger and then stored within a small internal battery. The whole assembly, which weighs 7 ounces and is the size of a cell phone, needs just 45 seconds of cranking to generate enough power for 5 to 6 minutes of cell phone life.

The handheld charger does have one drawback. Turning the crank causes charge to be stored on its internal battery, so the mobile phone must be plugged into the charger whilst the call takes place. It is not possible to recharge the phone's own internal battery.

Other organisations are involved in the development of mechanical charging devices. Atkin Design and Development in Harrogate, North Yorkshire, have developed prototype wind-up units designed to power anything from electric razors to laptops. The systems also use a hand-cranked generator, but instead of a rechargeable battery they have a supercapacitor as the energy storage device.

Supercapacitors can absorb large amounts of charge in seconds, which would be an advantage for mechanical power devices. Supercapacitors can also be charged and discharged many more times than a rechargeable battery. They cost about the same and are more efficient, releasing 92% of the energy you put in a compared with 85% for a nickel metal hydride battery. The current downside is that supercapacitors discharge quickly, so they are good for pulses of power but not a steady stream. However, this situation is changing as capacitor technology evolves.

The ever increasing miniaturisation of consumer electronics and mobile devices is enabling researchers to consider other, more sustainable methods of powering mobile devices. It is envisaged that the approaching era of wearable computers will spark the development of new techniques for electricity generation and reuse.

Trevor Baylis, a firm advocate of the concept of 'personal power', is seeking to develop shoes that channel sufficient energy from the action of walking to power a mobile phone or similar device. It is suggested that other sources of human activity or human biology may also be used to power a new generation of body worn electronics, among these power systems may be the recovery of energy from body heat, breathing, and blood pressure. [25]

6.1 The Potential of Mechanical Charging

Wind-up or human activity generated electricity has the clear advantage that it is free and it is always there. The development and adoption of mechanical power systems removes the need to purchase batteries, a big economic barrier in the developing world, along with a reliance ofn an electricity supply infrastructure. Thus, mechanically powered devices offer the potential of enabling wider access to a range of portable electronic devices.

Aside from access to devices when a reliable electricity supply is not available, mechanically powered devices also offer the potential for a significant reduction in the number of batteries and chemicals cells used to power mobile devices. The widespread development of mechanical power sources offers the potential for reduced usage and demand for the valuable raw materials required in the manufacture of the new generation of batteries. It also alleviates the problems attendant on the recycling of these products.

6.2 Market Overview and developments

The market for mechanical charging devices is in its infancy and little information regarding sales and likely future market size is available. Aside from the clockwork radio other devices either currently available on, or proposed for, the market include a wind-up torch, boots that derive energy from walking, a wind-up shaver, and a mechanically chargeable GPS receivers amongst many others.

Performance data for today's mechanical power systems are not readily comparable, hence it is not currently possible to compare the capabilities of the various recharge options available. However, as new materials become available and new techniques are developed to optimise the return on mechanical energy input versus electrical energy output, the capabilities of mechanical charging systems look set to improve significantly.

The limiting factor for wind-up systems is their short power time relative to the amount of winding effort that must be supplied. The original Baylis radio provided 14 minutes of play time for one minute of winding. This has now been improved to over an hour's worth of play after a one minute wind. Likewise, the Freeplay torch supplies six minutes worth of light for a one minute wind.

The current generation of sophisticated portable devices consume significantly more power than the Freeplay radio and torch. Improvements in electronic component manufacturing techniques and the development of digital systems – those that can be reduced to chip scale and replicated on single silicon chips, that is – have significantly reduced the power consumed by a whole host of devices. Yet the issue remains that mechanical systems are not 'winding economic' with regards to the 'active' power time they can provide for today's generation of portable products. Consequently, it is not practical to power appliances such as laptops with mechanical technology given the current technology levels. However, as manufacturers work to improve energy efficiency, the development of a new generation of more sophisticated mechanical mechanisms for powering portable devices will become more appealing.

7.0 Trends Within Battery And Emerging Power Source Technologies

The market for rechargeable batteries has quickly evolved over the last ten years and this trend is expected to continue. OEMs and consumers are likely to have access to rechargeable batteries with higher energy densities and longer run times. As improvements and innovations continue within the mobile-IT and telecommunication-devices markets rechargeable batteries are expected to evolve simultaneously.

Currently, rechargeable batteries represents the mainstay of the portable energy source market but there are a number of trends within the mobile power sector that look set to shape what will be a much more diverse future mobile power-source market. Market analysts have identified some of the key technology trends that will impact most to the current domain of the battery. [9,26]

7.1 Phasing out of NiCd Batteries in IT and Telecommunication Applications

NiCd batteries are one of the most commonly used rechargeable batteries for various applications and are widely used in many IT and telecommunication devices such as PDAs, cordless telephones and low-end cellular telephones. Although NiCd has the advantage of being a high-rate capability and low-cost battery chemistry, its use in such applications is expected to decline, as form, size, weight, and potential dangers to the environment are making it an unattractive option.

7.2 Development of Portable Fuel Cell Batteries

The Direct Methanol Fuel Cell (DMFC) is based on solid-polymer technology but uses methanol directly as a fuel. Prototypes exist but development is at an early stage. There are principal problems including the lower electrochemical activity of the methanol as compared to hydrogen, giving rise to lower cell voltages and thus lower efficiencies. Also, methanol is miscible in water; some is liable to cross the water-saturated membrane and cause corrosion and exhaust-gas problems on the cathode side.

Despite this disadvantage, further research and development is expected to improve capacity and energy densities. Portable fuel cells are expected to ripen into miniaturised micro fuel cells. As the rapid expansion of cellular communication and portable devices continues, micro fuel cells are expected to become the common battery chemistry.

7.3 Reduction in Thickness of Lithium Ion Polymer Batteries

The thickness of lithium ion polymer batteries has been consistently decreasing. The thickness of such batteries dropped from 8mm in 2000 to 3.5mm in 2001. Companies such as Panasonic during the last quarter of 2000, announced the introduction and production of 2.5mm lithium-ion polymer batteries. As battery manufacturers invest in research and development, the industry is likely to witness a further reduction in thickness.

7.4 Metallic Fuel-Air Batteries Expected to Gain Popularity

These battery chemistries generates power through the electromechanical reaction between a particulate metal fuel such as aluminium or zinc placed in an alkaline solution and oxygen from the air. Electricity is produced as the metal oxidises in the alkaline solution. The essence of the cell's efficiency is its high energy output resulting from the characteristic energy density of the metal fuel.

Aluminium-air cells are prime candidates for research in comparison to other metals such as magnesium, zinc, and iron. In a typical arrangement these materials release two electrons for every metal atom reacted, as opposed to aluminium's three electrons. Aluminium-air batteries thereby have the potential to use less material to produce the same amount of energy. Aluminium is also the most abundant metal in the Earth's crust and is readily mined.

In addition, unlike NiCd and lithium-ion batteries, aluminium-air batteries are environmentally friendly. The battery technology is expected to serve a multitude of applications including electric vehicles, emergency power sources and portable electronic devices.

8.0 Conclusions

The growth in portable electronics is a reflection of changing consumer demands and changing consumer lifestyles. It is predicted that the convergence of computing and communications technology, coupled with developments in microelectronics and fine-line circuitry, will herald a new generation of universal mobile handsets capable of undertaking such tasks as voice communications, Internet searching, data processing and wireless networking, all on the move.

With the proliferation of an increasing array of mobile devices has come the challenge of developing suitable mobile power sources. Today's rechargeable batteries have proved adequate for the task of energy delivery to contemporary devices, but it is also increasingly obvious that they are now the limiting factor in blocking manufacturers from developing their products further. Battery technology is cited as a major and growing inconvenience by users because of their weight, the limited talk and standby time they offer, their long recharge times and the inconvenience they occasion when they go flat.

The area of battery and electrochemistry technology has always been an area of intense research and development, sitting at the forefront of a multi-billion pound industry. It is clear that innovation and new developments are bound within the field and a number of emerging technologies hold significant promise for supplementing or replacing battery technology in a number of portable equipment applications in the medium-to-long term.

One such technology is fuel cells, which hold out the possibility of greater power density than batteries and otherwise improved performance. However, issues surround the miniaturisation of fuel cells into form factors which suit today's portable equipment and it is not anticipated that they will make significant entry into markets for mainstream portable consumer equipment for five to ten years.

Another emerging technology is that of metal-air fuel cells, which are not in reality fuel cells as they sit at the boundary between battery and fuel-cell technology and offer a combination of benefits. The first generation of metal-fuel power sources are already on the market and it is anticipated that in the short term the technology will emerge for various applications in the portable power sector.

The concept of personal power, typified by the wind-up radio, is an appealing one. However, the current status of the technology is behind the demands of today's power-hungry devices. Whilst such approaches will no doubt find niche markets in a number of applications, it is anticipated that they will not make a significant contribution to the portable-devices market until improvements in the electronic component technology and silicon micro machining enable a new generation of products that demand less power.

Overall, the level of development of portable power sources points to the increasing availability of a number of technology solutions that should enable equipment manufacturers to mix and match technologies to innovate and differentiate their products.

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