FUEL CELL TODAY

Opening doors to fuel cell commercialisation

Direct Methanol Fuel Cells (DMFC)

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Fuel Cell Today – August 2007

Introduction

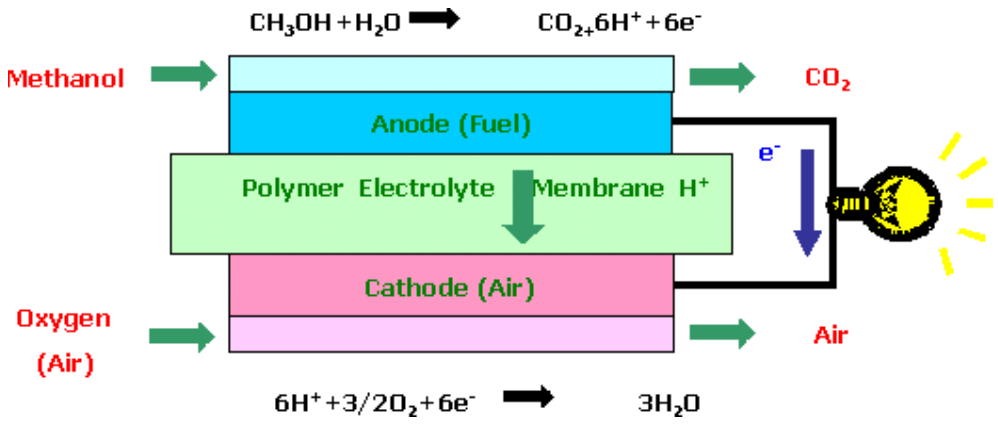
This is the fifth of six articles designed to focus on each of the fuel cell technology types in turn. The reviews will provide a brief overview of the technical aspects of each system, the developmental milestones achieved, an estimate of the number of units currently in operation and a review of the key companies involved in the development, manufacture and commercialisation of each fuel cell type. Looking forward, the reports will also aim to provide details of any goals set by fuel cell companies for each system.

Previous articles have examined PEM, AFC, SOFC and MCFC technology and this instalment will take an in-depth look at DMFC. The final report will cover PAFC and will be published towards the end of 2007.

Technological Overview

Direct methanol fuel cells (DMFC) employ a polymer membrane as an electrolyte. The system is a variant of the polymer electrolyte membrane (PEM) cell however, the catalyst on the DMFC anode draws hydrogen from liquid methanol. This action eliminates the need for a fuel reformer and allows pure methanol to be used as a fuel.

The pure methanol is mixed with steam and fed directly in to the cell at the anode. Here, the methanol is converted to carbon dioxide and hydrogen ions. The electrons are then pushed round an external circuit to produce electricity (before returning to the cathode) whilst the hydrogen protons pass across the electrolyte to the cathode, as occurs in a standard PEM fuel cell. At the cathode, the protons and electrons combine with oxygen to produce water.



Schematic of a direct methanol fuel cell (Courtesy of Toshiba)

The operating temperature for DMFCs is in the range of 60-130^{0}C but is typically around 120^{0}C, producing an efficiency of about 40%. DMFC units are best suited to portable applications and have been used in a wide variety of portable electronic products such as mobile phones and laptop computers.

Due to the low temperature conversion of methanol to hydrogen and carbon dioxide the DMFC system requires a noble metal catalyst. The cost associated with this catalyst is outweighed by the ability of the unit to function without a reforming unit. By using liquid methanol as a fuel some of the storage problems related to hydrogen are eliminated. In addition, liquid methanol is often considered to be easier to transport and supply to the public using current infrastructure.

DMFC Developmental Milestones

In 1951, Kordesch and Marko reported on the development and performance of new carbon electrodes and identified the possibility of using methanol as a fuel for fuel cell systems. However, the major developmental milestones for DMFC technology did not come until the 1960s. At this time, methanol was being steam reformed to produce hydrogen which was subsequently used in fuel cell systems. In developing DMFC systems, researchers hoped to find a way of removing the reforming step and enabling the direct use of methanol to produce electricity.

In 1963, researchers at Allis-Chalmers tested a methanol fuel cell which used potassium hydroxide as an alkaline electrolyte. The degradation of the alkaline electrolyte by carbonate formation was observed as part of this work and the theory of regenerating carbonate ions to hydroxide ions was proposed.

By 1965 both Shell and ESSO were heavily involved in the development of DMFC systems. Shell chose to research the use of aqueous sulphuric acid electrolyte in favour of alkaline electrolyte as this was unaffected by the carbon dioxide produced in the electrochemical reaction. ESSO also produced a direct methanol-air fuel cell which utilised a sulphuric acid electrolyte. This system was developed for the US Army Electronics Laboratories for use in portable military communications equipment.

Also in 1965, Binder was developing catalysts for DMFC technology based on noble metal alloys. He studied the performance of these catalysts in both acid and alkaline electrolytes.

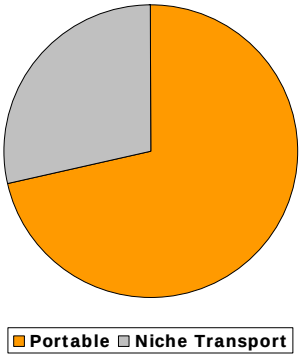
In 1992, Jet Propulsion Laboratory, Giner and the University of Southern California developed a DMFC which operated with a Nafion membrane. The solid nature of the membrane meant that it became necessary to deliver methanol fuel to the anode rather than through the electrolyte as had been the case in the sulphuric acid system. This new fuel delivery method thus began to resemble the modern day design of DMFC technology much more closely.

The Current DMFC Market

DMFC systems are used to power portable applications and in some niche transport sectors (such as marine and submarine vessels, scooters and motorbikes and as auxiliary power units, APU, for niche transport vehicles). In the year 2000, Ballard and Daimler Chrysler introduced a DMFC powered light duty vehicle but since this time no other DMFC passenger cars have been developed and this appears to have been a one off.

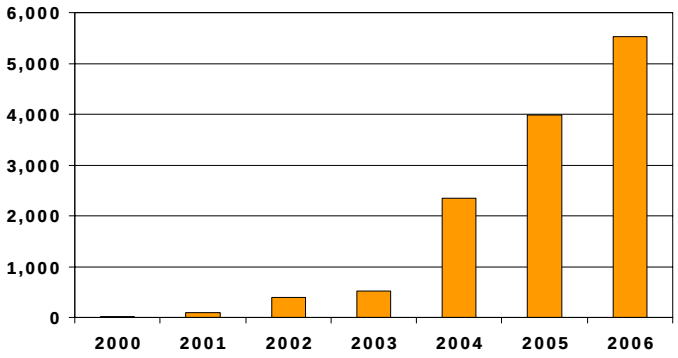
It is clear to see from the following graph that nearly three quarters of DMFC units installed across the globe are being used for portable applications. (For the purposes of this report, it should be noted that the Fuel Cell Today definition of the portable

market segment includes units up to 1.5kW which are clearly intended to be moveable and are not used for powering a vehicle or moving contraption).



Total Number of DMFC Units Installed Globally by Application (Copyright Fuel Cell Today)

DMFC technology is particularly suited to portable applications thanks to the fact that pure methanol can be used as a fuel and the need for a fuel reformer is eliminated. The graph below illustrates the cumulative number of DMFC units installed globally in portable applications.

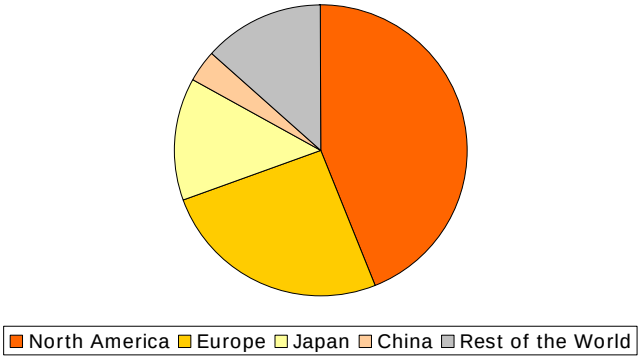


Cumulative DMFC units installed globally in portable applications (Copyright Fuel Cell Today)

Since 2003, there has been a significant year-on-year increase in the number of units installed. As highlighted in the MCFC technology report, there are a number of reasons behind such growth trends. Decreasing barriers to adoption, specifically cost, has enabled the increased production of DMFC units. In addition, companies are working hard to ensure the technology meets customer requirements rather than consumers having to meet the technology requirements. This is of particular importance when working in the consumer portable electronics sector. Furthermore,

the industry is operating in a period where a number of complimentary drivers have come together to create a space in which technology such as DMFC meets both the needs of the adopter now and in the medium term future. Together, these factors indicate that portable DMFC markets are moving away from the research and development phase and towards a period of commercialisation.

In terms of where DMFC units are installed across the globe, North America accounts for around 44% of the geographical split. Europe is the second largest global region in terms of DMFC activity but is closely followed by Japan and the Rest of the World countries. It is perhaps unsurprising that North America (including Canada) and Europe together account for the majority of global share of DMFC activity as historically, this is where most of the investment for research and development has been made.

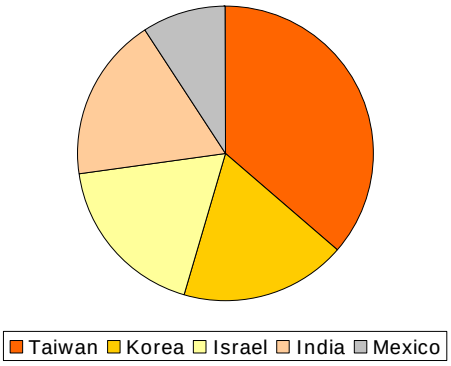


DMFC activity by country based on a discrete sample of companies listed in the Fuel Cell Today Industry Directory (Copyright Fuel Cell Today)

The military accounts for a significant part of DMFC development programmes for portable electronic products. Military investment for the development of fuel cell powered equipment remains a high priority, particularly in North America and Europe and this can go some way to explaining why these regions dominate DMFC activity on a global scale. In addition, consumers in these two regions tend to be affluent and can therefore afford to purchase the newest technological products. This consumer pull for top end products might also explain why DMFC activity in North America and Europe is high.

It is not surprising to see that the Japanese share of DMFC activity is significant. Historically, Japanese consumers have been known for their desire to own high end,

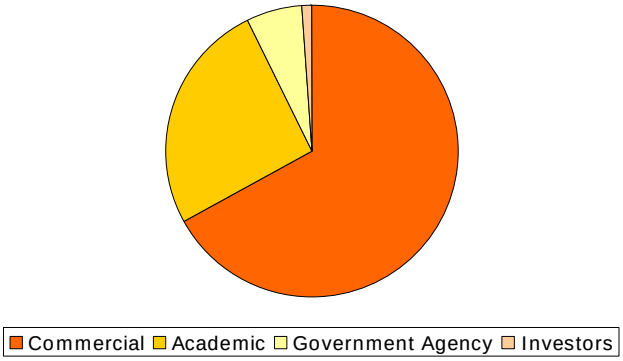
cutting edge technology products. This is particularly true in the consumer electronics market. For this reason, we would expect to see Japan with a large share of global DMFC development as consumer demands in this region have influenced the development of fuel cell programmes. What is slightly more surprising, however, is the large share commanded by the Rest of the World countries.



DMFC activity in the Rest of the World regions based on a discrete sample of companies listed in the Fuel Cell Today Industry Directory (Copyright Fuel Cell Today)

DMFC activity in the rest of the world regions is distributed across a wide range of countries. Taiwan commands the biggest share of the market (around 36%) with Korea, Israel and India close behind. The development of DMFC technology in these countries can be attributed to the corresponding development of consumer electronic goods in these regions and the need to find new, innovative and longer lasting solutions to power such products. It is encouraging for the DMFC industry to see development occurring in such varied global regions and this trend should be taken as a sign that as the industry nears commercial development, countries across the globe are ramping up efforts to develop the technology and be among the first to reach market with DMFC powered consumer electronic goods.

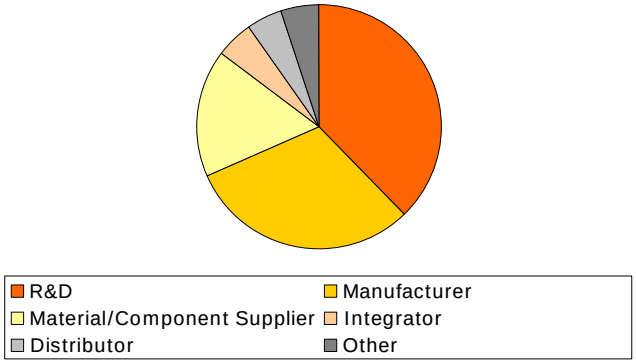
When looking at the DMFC sector by business type, an overwhelming majority of fuel cell companies consider themselves to be commercial entities. In fact, the graph on the following page shows that 67% of the sampled organisations in the DMFC industry describe themselves as being ‘commercial’.



DMFC activity by business type based on a discrete sample of companies listed in the Fuel Cell Today Industry Directory (Copyright Fuel Cell Today)

The next biggest sector is 'academic' activity, which accounts for almost 26% of total activity. The fact that commercial and academic business types compose the majority of the sampled DMFC sector would suggest that whilst the industry believes it is operating in a commercial market, there is still a great deal of ongoing research and development activity to produce next generation products. This observation can be confirmed by looking more deeply at the DMFC sector in terms of activity.

As one might expect, the graph below shows that the majority of activity in the DMFC sector is either classed as being research and development based or as manufacturing activity.



DMFC activity by sector based on a discrete sample of companies listed in the Fuel Cell Today Industry Directory (Copyright Fuel Cell Today)

The third biggest sector is shown to be component and materials suppliers. This fits well with previous observations and suggests that these organisations are either

providing materials/components for commercial purposes or for research and development projects.

Key Company Review

This section of the report is designed to give a brief overview of some of the key companies working within the DMFC industry and is by no means a complete list of all organisations operating in this space. The key company review focuses on some of the key DMFC manufacturers and does not include research organisations and institutes like, for example, **Forschungszentrum Julich (FZJ)**.

Taiwanese firm **Antig Technology** has been developing a 16W battery charger which can be used for MP3 players, mobile phones, GPS receivers, PDAs and portable multimedia players. Antig has also suggested that the system will act as a secondary power source for laptops extending overall battery life to nine hours. It is widely believed that the fuel cartridges will be supplied by **BIC**. The MEA incorporated in the fuel cell is supplied by **DuPont**. Along with partner **AVC Corporation (Asia Vital Components)**, Antig has also launched a CD-ROM size fuel cell pack which runs on methanol fuel and is integrated into notebook PCs.

Direct Methanol Fuel Cell Corporation (DMFCC) manufactures disposable fuel cartridges for direct methanol and other liquid hydrocarbon fuel cells. The company has achieved several milestones including the completion of development of a new test device for liquid fuel cell cartridges, the application for a patent for a new miniature fuel cartridge valve and cartridge design and manufacturing agreements with **Elentec, Nypro** and **Hyun Won**. These agreements see the companies producing DMFCC methanol fuel cartridges designed for use in fuel cell systems powering laptops, mobile phones and other portable devices. DMFCC has stated that its goal is to establish a global network of partners to manufacture and distribute fuel cartridges.

DMFCC completed product development of its first methanol fuel cell cartridge in 2006 and announced plans to begin sampling with customers. The cartridge was co-developed with and manufactured by DMFCC's Korean partner, **SMC**. The cartridge holds 50 cm^3 of 100% methanol and is designed for laptop computers and similar applications. One cartridge is expected to provide five to ten hours of computer

operation depending on the efficiency of the fuel cell. DMFCC plans to work with customers to develop cartridges with custom sizes and shapes for their particular applications. DMFCC is a subsidiary of **Viaspace.**

DMFCC's prototype fuel cartridges (Courtesy of DMFCC)

Although **Giner Electrochemical Systems** specialises in PEM systems, the company was awarded a one year US$830,000 contract in 2006 by the US Army's Communication Electronics Research Development and Engineering Centre (CERDEC) to develop and deliver for field testing a 250W field ruggedised DMFC unit. Giner is working with **Teledyne Energy Systems** on this programme.

Hitachi continues development work on DMFC battery chargers. The fuel cell is equipped with a capacitor that can store electricity before charging the mobile devices and rather than using a detachable fuel cartridge, methanol is injected directly in to the fuel cell body. Hitachi has also worked with **KDDI** to produce a prototype fuel cell mobile phone.

Mesoscopic Devices designs, fabricates and integrates portable fuel cell generators for military and industrial applications. The DMFC units offered by the company are designed to be used with portable electronic devices and the company claims that they offer up to five times the run time of lithium ion batteries for the same weight.

MTI Micro Fuel Cells developed a DMFC system known as Mobion, a version of which has been successfully demonstrated to the US Air Force Research Laboratory. The prototype system, which can deliver up to 600W hours of operating time, is designed to power laptops and other portable telecommunications devices used for military purposes. Additionally, the company has delivered further prototypes of the

Mobion system to two other military organisations. In 2006 it was reported that MTI was to develop a power source prototype for a series of **Samsung** mobile phones and accessories based on its DMFC micro-fuel cell technology. Samsung will commit US$1 million to the joint effort and under the agreement the companies will jointly research, develop, test and evaluate the use of methanol based fuel cell technologies for mobile phone applications.

Neah Power is developing fuel cells for use in military applications, notebook PCs and other portable electronic devices. The publicly held company was founded in 1999 and is based in Washington. Neah has recently announced the successful testing of a 16 cell fuel cell stack.

PolyFuel manufacturers engineered membranes for DMFC systems designed to be used with portable electronic devices such as laptops, PDAs and mobile phones. Customers include **Sanyo Electric** and **NEC** as well as military and industrial fuel cell system developers. PolyFuel has announced an agreement to provide **Johnson Matthey** with its hydrocarbon DMFC membrane which Johnson Matthey will use in the manufacture of catalyst coated membranes (CCMs) and membrane electrode assemblies (MEAs) for the portable fuel cell market.

SFC Smart Fuel Cell supplies fuel cell technology for leisure, industrial and military applications. Towards the end of 2006 the company announced that it had delivered its latest portable fuel cell product (a DMFC power generation system branded 'Jenny') to a total of eight defence ministries including the German federal army and defence ministries of Finland, Norway, the Netherlands, Sweden, Switzerland, South Africa and the UK. The fuel cell is designed to power remote equipment and applications in the military field. The company is also developing a Fuel Cell based on a Lightweight Portable Power System for US Battlefield Airmen. The value of the development order amounts to US$500,000. In addition, SFC Smart Fuel Cell's EFOY unit is now employed in several types of motor home and the company is currently developing a 250W fuel cell for the US Army Operational Test Command.

SFC Smart Fuel Cell's portable DMFC product: 'Jenny' (Courtesy of SFC Smart Fuel Cell)

Toshiba has developed DMFC applications for laptops and portable music players although no word has yet been given as to when the fuel cells might become commercially available.

Future Prospects for DMFC Systems

The general consensus amongst electronics manufacturers is that they will have commercially available portable fuel cell products by 2008. DMFC systems remain to be the technology of choice for the majority of developers and for this reason future market opportunities for DMFC are potentially very significant. However, despite this buoyant atmosphere in the portable markets, several manufacturers are encountering delays in being able to launch their products from external sources such as shipping channels, regulatory governance and insurance processes. Throughout 2006 there was a distinct lack of announcements made by the big electronics companies regarding firm dates for mass commercialisation and many commentators believe that a 2007/2008 launch is unrealistic.

However, there is little (if any) dispute that DMFC will be used to power portable electronic products at some point in the future. The technology is expected to be used across the globe in applications ranging from laptops and mobile phones to PDAs and personal music systems. When these markets reach their full potential DMFC technology will enjoy a leading market position.

The driving force behind the commercial development of fuel cells for portable applications remains to be consumer pull for more effective products and cutting

edge technology. Consumers require fit-for-purpose technology and as this desire increases, DMFC is well placed to provide solutions to power and energy demands for next generation portable electronic goods. DMFC technology has been given first mover advantage in the portable electronic sector thanks to the development and investment made by companies such as SFC Smart Fuel Cell and DMFCC.

In addition to finding applications in portable consumer electronic markets, DMFC technology will also receive support from military organisations in the future. The military has a desire and requirement to develop the most efficient, cutting-edge technology and sufficient funding for such development is not a barrier. As a result, it is reasonable to assume that development of DMFC systems for the use in portable electronics will be maintained in future through military lead/initiated programmes. This will ensure that new technological developments continue to be made and that with each innovative programme the future prospect of DMFC will grow stronger.

The introduction of various laws, codes and standards and regulations will have an impact on the future prospects of DMFC systems. As of January 1 2007, the International Civil Aviation Organization (ICAO) permitted methanol cartridges (and some other selected fuels) onboard commercial aircraft. This enables DMFC products to be taken onboard aircraft as 'carry-on' baggage and used during the flight by passengers and crew. This decision could potentially increase the appeal of owning a fuel cell powered laptop and removes a significant barrier in terms of practical use of the technology.

Furthermore, in early 2006 the International Electrotechnical Commission (IEC) published a safety specification for fuel cells powering personal electronic devices. Fuels covered by this specification include methanol, formic acid, borohydride, butane and hydrogen. Fuel cells for use in devices such as mobile phones, music players, gaming consoles, flashlights and laptop computers will be considered by the specification which will include rigorous testing and design requirements to ensure safety during use and transportation. Compliance with the specification is currently voluntary but is required of devices that would be transported on passenger aircraft under the ICAO regulation previously mentioned.

On a more general level, countries and organisations across the globe continue to develop roadmaps, codes and standards for DMFC systems. Whilst the targets set out

in such documents do not often refer directly to portable applications and end use markets within this sector, goals continue to be set for the fuel cell types employed by the portable markets and the supporting infrastructure required to develop a fully commercial industry.

DMFC units for portable applications still have some advances to make in terms of size, weight, power and cost. Manufacturers must continue working towards making their products compatible with lightweight, miniaturised portable electronic products that provide extended run-time and are affordable on a mass market scale.

In summary, whilst there are still some hurdles to be overcome for DMFC technology (including unit size, weight, power and cost, shipping and insurance delays) there are many positive aspects connected with DMFC. DMFC remains to be the technology of choice in a sector that will one day be fully commercialised. There is a sufficiently strong technology pull from both the public sector and the military (where sufficient funding can be provided for development programmes) to continue with the development of DMFC solutions for powering portable electronic products. In addition, codes and standards and other regulations are being put in place to support the widespread adoption of DMFC technology. Together, these observations suggest that the future prospects for DMFC technology are very promising.

About the Author

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