



## FUEL CELL TODAY

Opening doors to fuel cell commercialisation

### Proton Exchange Membrane (PEM) Fuel Cells

Gemma Crawley, Fuel Cell Today – March 2006

#### Introduction

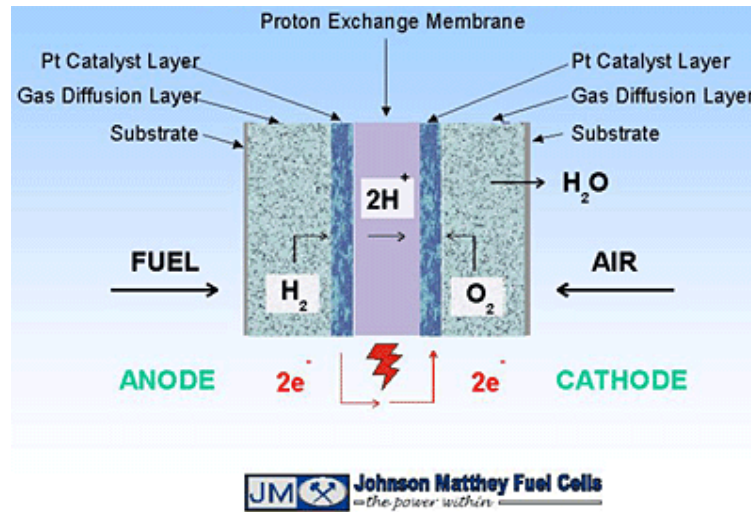
This is the first of six articles designed to focus on each of the fuel cell technology types in turn. The reviews will provide a brief overview of the technical aspects of each system, the developmental milestones achieved, an estimate of the number of units currently in operation and a review of the 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.

The articles start by looking at PEMFC technology and will eventually cover SOFC, DMFC, AFC, MCFC, and PAFC over the course of the next year.

#### Technological Overview

The Proton Exchange Membrane (PEM) fuel cell uses a thin, permeable polymeric membrane as the electrolyte. The membrane is very small and light and in order to catalyse the reaction, platinum electrodes are used on either side of the membrane.

Within the PEM fuel cell unit, hydrogen molecules are supplied at the anode and split in to hydrogen protons and electrons. The protons pass across the polymeric membrane to the cathode while the electrons are pushed round an external circuit in order to produce electricity. Oxygen (in the form of air) is supplied to the cathode and combines with the hydrogen ions to produce water.



In-depth PEM Schematic (Courtesy of Johnson Matthey Fuel Cells)

Compared to other electrolytes (which require temperatures up to 1,000°C to operate effectively) PEMFCs operate at very low temperatures of about 80°C allowing rapid start-up. The efficiency of a PEM unit usually reaches between 40 to 60 per cent and the output of the system can be varied to meet shifting demand patterns. Typical electric power is up to 250 kW. In addition, PEM fuel cells are often compact and lightweight units. As a result of these characteristics, PEM units tend to be the best candidates for cars, buildings and smaller stationary applications.

As the electrolyte is a solid rather than a liquid, the sealing of the anode and cathode gases is far easier and this in turn makes the unit cheaper to manufacture than some other types of fuel cell. Furthermore, the solid electrolyte can lead to a longer cell and stack life as it is less prone to corrosion than some other electrolyte materials.

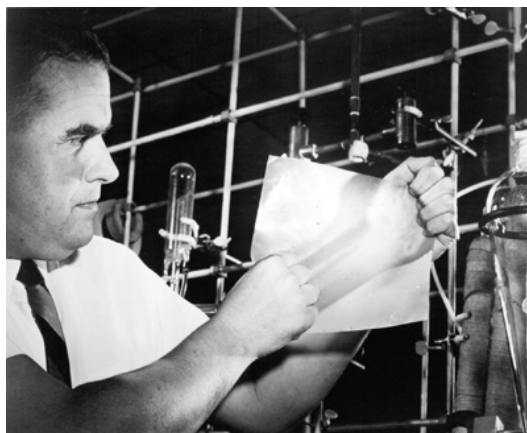
However, there are also some disadvantages associated with PEM operation. Although the low operating temperature of the unit is usually seen as an advantage, in some instances temperatures as low as 80°C are not high enough to perform useful cogeneration. Furthermore, in order to achieve the most effective operation of the unit the electrolyte must be saturated with water. Control of the moisture of the anode and cathode streams therefore becomes an important consideration.

The PEM fuel cell is also sometimes referred to as a polymer electrolyte fuel cell (PEFC).

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### PEM Developmental Milestones

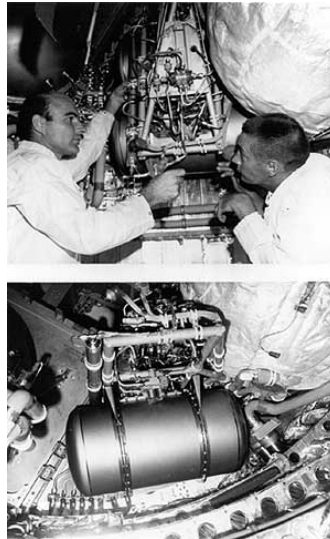
PEM fuel cell technology was first developed by General Electric in the early 1960s. The company used a PEM unit as part of a research programme with the U.S. Navy's Bureau of Ships (Electronics Division) and the U.S. Army Signal Corps and although the cell was compact and portable it was highly expensive to produce.



**General Electric's Russell Hodgdon with a polymer electrolyte in 1965**  
(Courtesy of Smithsonian Institute, Fuel Cell History website)

The first major breakthrough for PEM systems came as part of NASA's space programme, Project Gemini. One of the main objectives of this project was to test the operational durability of fuel cell systems with a view to replacing batteries with fuel cells to provide electric power and drinking water to the shuttle. Despite initial technical difficulties, General Electric continued to modify its PEM unit and the new model was used for a significant number of flights during the Gemini programme.

Although NASA decided to operate the next space programme with alkali fuel cell systems, General Electric continued working on its PEM units and by the mid 1970s had developed PEM water electrolysis technology and began work on the U.S. Navy Oxygen Generating Plant. The British Navy adopted this technology in the 1980s for its submarine fleet and other companies began to look at PEM systems for development and end-use applications.



**PEM fuel cell in the Gemini Space Programme**  
(Courtesy of Smithsonian Institute, Fuel Cell History website)

In the early 1990s, Ballard developed its Mark 5 fuel cell stack. This PEM unit was capable of generating 5 kW total power at a power density of 0.2 kW per litre of stack volume. The product was developed further by Ballard and DaimlerChrysler in the late 1990s and the companies achieved a total power output of 75 kW with their Mark 900 unit. This signalled that the stack was finally able to meet the performance targets for transportation applications and to this day PEM technology remains the choice of the automotive industry.

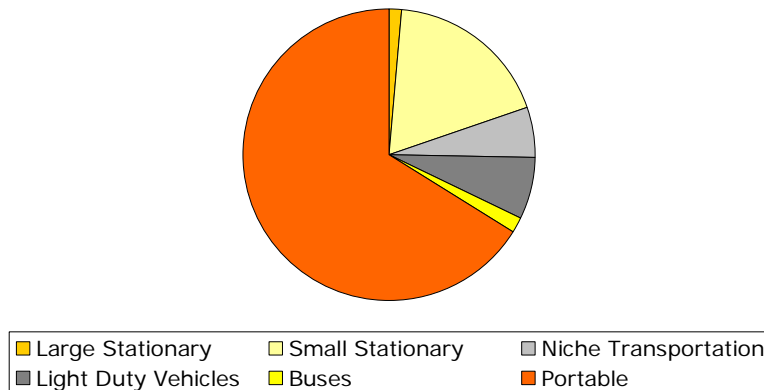
The last five years have seen some major developments in terms of PEM technology and the transportation industry. Several large OEMs have made very public commitments to the development of fuel cell vehicles and most have cars operating on the roads in demonstration programmes. The high level of activity in this sector has given a natural boost to PEM research and development.

In addition, the use of PEM units for portable and small stationary applications has rapidly increased over the last few years as these sectors have begun to expand and are currently enjoying a strong period of growth. This has also helped contribute to PEM development programmes as market pull begins to match technology push.

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## The Current PEM Market

PEM fuel cell systems are currently used in many different applications however, the end-uses can be classified in to three main groups: Transportation (including niche applications, light duty markets and buses), Stationary (large and small applications) and Portable.

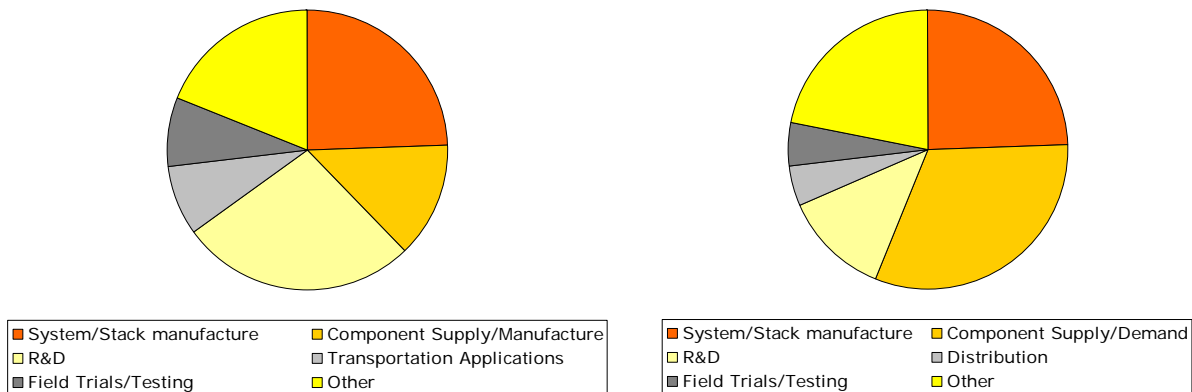


**Total Number of PEM Units Installed Globally by Application**

It is clear to see from the graph that the majority of PEM units installed across the globe are being used for portable applications. One explanation for this is that portable markets tend to be the most developed and the closest to reaching commercialisation of all the sectors. As such, this is the market where most units have been produced. The second largest sector of use is for small stationary units and thanks to the demonstration programmes operating in this sphere of activity numbers of PEM units are quite significant in this area. Together, niche transportation applications, light duty vehicles and buses account for around 15% of the total installed PEM units. However, transportation remains likely to be the last sector to reach full commercialisation. Actual numbers of cars, buses etc. are still fairly low compared to the number of systems required for the other markets.

In terms of where these units are installed, Europe and North America account for the lion's share of demand. Within Europe, PEM activity is split fairly evenly across the board with an almost equal number of system/stack manufacturers compared to component suppliers and manufacturers. In North America, there is also a fairly even split between system/stack manufacturers and component suppliers/manufacturers and together with companies operating under the banner of "others" (which includes

gas generation, infrastructure, education and machinery companies) these sectors account for the majority of PEM activity in this region.



**PEM Activity in North America and Europe (left to right) by Application.**  
 (Data based on a discrete sample of companies listed in the FCT Industry Directory)

Approximately 75% of the organisations involved with PEM activity are operating as commercial entities. The remaining 25% of companies describe themselves to be academic institutions, government agencies or investors. This high percentage of commercial businesses compared to investors and academic groups suggests that the PEM sector has moved beyond the initial research and development stage and has entered an era of commercial development.

In 2005, the majority of new PEM units installed across the globe were for portable applications. In fact, the portable and small stationary sectors together accounted for approximately 88% of all new PEM installations in this year. This confirms the view that the portable and stationary markets for PEM units are the closest to mass commercialisation and whilst the transportation sector provides a significant potential for PEM systems, the full extent of this will not be realised in the short term. Whilst development and demonstration programmes for the transportation sector remain ongoing, the current market for PEM units in terms of actual numbers operating and prospects for commercialisation lies very much with portable and stationary applications.

In terms of current government involvement in the development of PEM technology, most regions have been supported to some extent. In the USA, the Department for

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Energy Efficiency and Renewable energy has specified two main aims for fuel cell research and development programmes: to reduce costs and increase efficiency for transportation and stationary applications. For PEM systems designed for distributed generation this means that by 2010 units must

- cost no more than US\$45/kW (to be reduced to US\$30/kW by 2015),
- be fuelled by natural gas/propane,
- exhibit a 40% electrical efficiency and 40,000 hours durability.

In addition, a US consortium of government, industry and academia has been formed by the DOE to undertake research in to areas including fuel cells and hybrid fuel cell vehicles. FreedomCar has proposed research targets to cover longer term, high risk research and for hybrid fuel cell vehicles (likely to be operating with a PEM unit) this specifies operating temperature, lifetime, cost, weight and efficiency.

Elsewhere, the European Union set targets in 1995 for a 10 year research, development and demonstration strategy for Europe up to 2005. These targets were revised in 1998 with specific reference to PEM systems. Goals included:

- The development of a PEMFC that can operate up to 200°C thus allowing it to work with “dirty” hydrogen.
- Development of low cost stacks.
- Design of recyclability of components.
- Design and development of fuel cell vehicles (especially buses).
- Development of cheap and cost effective manufacturing processes.
- Aim for first commercialisation of combined heat and power PEMFC between 2003 and 2008. *Although at the latter end of the time frame this target has been achieved.*
- The improvement of PEM stack performance is also called for elsewhere in the EU report.

The EU is now working towards producing the 7<sup>th</sup> Framework Programme for fuel cell development which will cover the time span 2007-2014.

In Japan, the government has invested significantly in a large residential (predominantly PEM) fuel cell programme. This is reviewed at a later stage.

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## Key Company Review

As PEM fuel cell systems remain the technology of choice for transportation applications, many of the automotive companies which manufacture their own stacks are likely to be producing PEM units. For example, **Honda** was originally an early licensee of stack technology from Ballard but like **Toyota** and **General Motors** eventually decided to manufacture its own PEM based stacks.

**Ballard** continues to be active in PEM markets and system development. In 2005 the company announced a road map on the timescale for deployment of its fuel cell systems within the automotive sector. At this time, Ballard set the goal of a 2010 demonstration to show its technology will have 5,000 hours of lifetime, the ability to start at -30°C and a cost of US\$30 per net kilowatt. The company hopes to have sold around 500,000 units by 2010.

Ballard is also involved in the Clean Urban Transport for Europe (CUTE) project and since 2003, Ballard powered buses have operated for more than 78,000 hours delivering over four million passengers to their destinations. At the beginning of 2006, Ballard secured a US\$8.3 million contract to continue servicing and powering the buses in the CUTE fleet as the programme received a one year extension.

**General Electric** was the first company to develop PEM fuel cell technology and maintains a high level of interest in this sector. **General Electric Fuel Cell Systems (GEFCS)** is a joint venture between General Electric Corporation and Plug Power. GEFCS acts as a worldwide distributor and service provider for Plug Power PEM fuel cell products.

**HydroGenics** designs and develops PEM fuel cell systems for transportation, stationary and portable power applications with a specific focus on the development and manufacture of fuel cell power modules and fully integrated power generators. HydroGenics has recently been awarded a contract to supply hydrogen generators to two of China's largest energy companies. The company is also working with IdaTech in a DOE funded project to develop 50kW stationary PEM fuel cells. **Gore Fuel Cell Technologies** provides the MEAs for Hydrogenics' systems.

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**Intelligent Energy** is a British fuel cell and hydrogen generation development company and has developed PEM fuel cell stacks in the 50-100kW range. The company targets transportation, distributed energy, military and portable power markets as the main applications for its stacks and in March 2005 launched the ENV (emissions neutral vehicle) hydrogen powered fuel cell bike. Intelligent Energy has recently announced a number of small stationary demonstration projects in South Africa centering on the use of PEM fuel cells in three different rural applications.

**Plug Power's** primary focus is on the development of PEM systems for clean, on-site power generation. Plug Power's units can be used for commercial and residential stationary applications but also by the automotive markets. In 2006, Plug Power announced a new agreement with Honda to continue joint development of the "Home Energy Station", a fuel cell unit which can be used to provide electricity and heat to a home or business in addition to providing hydrogen fuel for a fuel cell car.



**Plug Power small stationary PEM fuel cell outside a McDonald's outlet in the USA.  
(Courtesy of Plug Power)**

Plug Power's fuel cell systems are available for commercial purchase and in addition to its patented GenCore and GenSys technology the company has also developed an on-site hydrogen generation system. In addition to use as uninterrupted power supply (UPS) systems Plug Power units can also be used in telecommunications applications.

**UTC Fuel Cells** (previously known as International Fuel Cells) has historically concentrated its research and expertise on phosphoric acid fuel cell (PAFC) units. Whilst UTC remains active in this field the company has also turned its attention to

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the development of PEM fuel cells for use in large commercial, residential and transportation applications. In early 2003, UTC announced an agreement with Nissan to jointly develop PEM systems for transportation applications. In 2006, a UTC fuel cell was used to power a shuttle bus for spectators at the winter Olympics. The company has also recently begun to operate a fleet of four fuel cell hybrid buses in California and is working with a major Belgian bus manufacturer to deliver a fuel cell powered bus to the largest fleet operator in Belgium.



**Nissan's X Trail Fuel Cell Vehicle is powered by a UTC PEM unit (Courtesy of UTC Fuel Cells)**

**Voller** is a British manufacturer of PEM based portable fuel cell systems. The units are designed to be battery chargers and mobile power generators particularly for the construction, leisure and military markets. The company has recently signed an agreement with Calor Gas to work together to develop the market for fuel cell generators and battery chargers where the hydrogen feed is obtained from Calor Gas products.

### **Future Prospects for PEM Systems**

Since the first commercial development of the PEM unit in the 1960s the technology has evolved a great deal. The general consensus amongst electronics manufacturers is that they will have commercially available portable products by 2008 and although direct methanol cells (DMFC) remain the technology of choice for the majority of developers, PEM units are still considered to be the most prevalent alternative. The level of interest in PEM technology for such applications is likely to grow from strength to strength in future, particularly as more high profile companies begin to provide hydrogen storage solutions.

In terms of stationary applications the outlook for PEM technology is also promising. The off-grid power sector (which favours the use of a PEM system) is enjoying a certain amount of growth at present. In the UK, UPS Systems (a distributor for uninterrupted power supply systems) has a market ready PEM product and is able to sell its fuel cell powered uninterruptible power supply (UPS) units to consumers for approximately US\$25,000 per unit. The company has also become the first in the UK to install an APC fuel cell unit and intends to run its mainstream business-critical IT applications on this standby PEM power system. Other power providers are following a similar pattern and British Gas aims for consumers to walk in to a showroom and purchase a fuel cell generator by 2008.

Elsewhere, the Japanese government sponsored residential fuel cell demonstration programme continues to move from strength to strength. This very large and very substantial project will see at least 2,400 small stationary units subsidised by the government over the next three years, leading to a significant increase in the total number of residential and uninterrupted power supply systems across the globe. The majority of units employed in this scheme are likely to be PEM based, with Ebara Ballard being particularly strong. In the future, other global regions may choose undertake similar programmes thus boosting the number of PEM units in operation worldwide.

The transportation market is likely to provide the most significant long term potential for PEM fuel cell units and these systems remain unchallenged as the technology of choice for primary powertrains in fuel cell vehicles. Many automotive companies have been particularly vocal in the past six months and have made public announcements regarding their timetables for development and commercialisation.

**Fuel Cell Vehicle Manufacturers Current Timetable for Launch**

<b>Manufacturer</b>	<b>Year</b>	<b>Number of Vehicles</b>	<b>Notes</b>
<b>DaimlerChrysler</b> (Germany)	2012 2015	10,000	Initial launch, Mass Market
<b>Ford</b> (USA)	2015		"commercial readiness"
<b>GM</b> (USA)	2010-2015 2025		Commercial viability Mass Market
<b>Honda</b> (Japan)	2010 2020	12,000 (in USA) 50,000 (in USA)	Start production
<b>Hyundai</b> (Korea)	2010		Road tests 2009
<b>Toyota</b> (Japan)	2015		Will cost US\$50,000

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As can be seen from this table 2012 – 2015 is currently looking to be a critical time for fuel cell vehicles. Unlike the hype surrounding production targets in 2004 though, this time we feel that these dates are far more realistic. However, as with all aspects of commercialisation, an element of caution should still be exercised.

The future for PEM fuel cell systems is certainly promising as the technology can be utilised in several key market sectors which span growth opportunities over the short, medium and long term timeframe. However, as with any new and evolving marketplace, there are still several challenges to be overcome.

Some of the materials used in the production of PEM units are very costly and despite some manufacturers making efforts to reduce the amount of material costs, this remains a significant challenge for many producers.

The lack of a hydrogen infrastructure for the automotive community remains one of the largest barriers to commercialisation for this sector. Hydrogen filling stations are not available on a widespread scale and even a smaller scale infrastructure is not yet in place. In the future, local networks (such as California) and co-operation with other companies regarding hydrogen storage solutions may go some way to alleviating this problem but a significant investment by either government and/or industry is also required.

In conclusion it can be said that the future for PEM fuel cells is dynamic and evolving but there is still some way to go before full commercialisation and market penetration can be achieved.

### **About the Author**

Gemma Crawley works as a Market Analyst for Fuel Cell Today. Her area of interest is the adoption of fuel cell technology in developing countries. Gemma can be contacted via [gemma@fuelcelltoday.com](mailto:gemma@fuelcelltoday.com).