The Eleventh Grove Fuel Cell Symposium

Fuel cell technology turns a corner in commercial exploitation

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The Eleventh Grove Fuel Cell Symposium was held at the Queen Elizabeth II Conference Centre in Westminster, London, UK, on the 22nd to 24th September 2009 together with its accompanying Exhibition (1). This event marked the twentieth anniversary of the Grove Fuel Cell Symposium series, which began in 1989. Reflecting a combination of foreign travel restrictions due to the global recession and the threat of an influenza pandemic, the conference was less well attended than on previous occasions, with a total of 207 delegates, divided roughly equally between academics and industrialists. However, the atmosphere was generally very optimistic, as fuel cell technology appears to have turned the corner in terms of commercial exploitation in several areas and mass production of components and complete fuel cell systems is being ramped up.

Because of the wide range of fuel cell types and applications being developed, this review is mainly restricted to the use of the platinum group metals (pgms), in line with the coverage of this Journal.

The Grove Medal

The Grove Medal was presented to the Honda Motor Company by Kit Malthouse, Deputy Mayor of London, in recognition of its achievement in developing the Honda FCX Clarity hydrogen-powered passenger vehicle (Figure 1). Malthouse stated that ground based transport is responsible for 22% of London's carbon dioxide emissions, as well as a significant proportion of pollutants such as nitrogen dioxide and particulate matter, and fuel cells are seen as a long-term solution to these challenges. In a very upbeat speech, he expressed the wish to be the first owner of a hydrogen-powered electric vehicle in London. One reason that the manufacturers of fuel cell-powered cars have given for not staging demonstrations in London is the lack of hydrogen refuelling facilities. This will be addressed by the installation of six refuelling stations across the capital, built by Air Products, and sponsored by the Greater London Authority bodies together with the London Hydrogen Partnership. Following on from participation in the European Clean Urban Transport for Europe (CUTE) project, five hydrogen fuel cell buses will undergo trials starting in

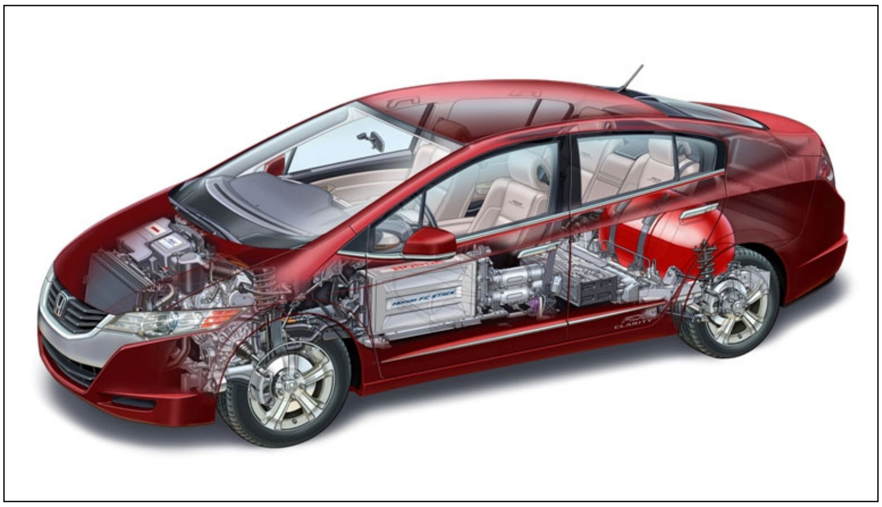

Fig. 1. Schematic illustration of the Honda FCX Clarity hydrogen fuel cell vehicle. Courtesy of Honda Motor Company

spring 2010 and these will be used as part of the transport provision for the 2012 London Olympic Games. In collaboration with Intelligent Energy, UK, twenty London taxis fuelled by hydrogen will also be deployed. The 2012 Olympic Games will require a fleet of 4000 vehicles, and it is hoped that 150 of these will be fuel cell powered.

Accepting the Grove Medal on behalf of Honda, Yuji Kawaguchi (Honda R&D Ltd) forecast that half the light vehicle market will be taken by fuel cell and electric vehicles by 2050. The Honda FCX Clarity has been in development since 2000, and has been demonstrated particularly in the Japanese and North American markets, where vehicles are being leased to the public. Technical and stylistic improvements have been made during this time, and the car provides room for four passengers and their luggage. It has double the fuel economy of its petrol equivalent, and one and a half times that of a petrol-electric hybrid on an energy efficiency basis in the United States Environmental Protection Agency Dynamometer Drive Schedule, known as the LA4 mode. The car incorporates a 100 kW platinum-catalysed polymer electrolyte membrane (PEM) fuel cell containing thin metal stamped separators with wave-shaped gas channels, weighing only 67.3 kg, and a lithium-ion battery, which together provide a range of 240 miles on 3.92 kg of hydrogen, stored at 34,470 kPa (5000 psi). Although Honda are beginning limited mass production of 200 vehicles, they acknowledge that cost reduction and improvements in durability and reliability are still needed in order to bring the technology to a level equivalent to that of the internal combustion engine.

Fuel Cells and Climate Change

It is generally acknowledged that fossil fuels must be used more efficiently, both to conserve natural resources and to alleviate climate change. In his talk, 'The Roles of Business and Government in Developing Clean Energy Technologies' Tom Delay (The Carbon Trust, UK) explained the role of the Carbon Trust in providing expert advice, accrediting emission reductions and promoting labelling schemes to help companies and organisations to cut their carbon dioxide emissions. The UK is committed to reducing carbon emissions by 20% by 2015, and by 80% by 2050 relative to a 1990 baseline. The long-term target can only be met through technological innovation. The UK has relatively few producers of complete fuel cell systems, but it does have a large number of second and third tier manufacturers who provide materials, components and expertise to the global fuel cell industry.

In a talk entitled 'Fuel Cells for Sustainability in Transport and Stationary Applications: A User's Perspective' Martin Blake (Royal Mail, UK) expounded the reasons why Royal Mail are examining alternative technologies. Royal Mail have 33,000 vehicles travelling 1.8 million miles carrying 75 million items of mail each day from 113,000 collection points. They have an obligation to reduce fuel and energy consumption, but their price structure is fixed, while factors such as oil prices are variable. They are currently investigating options including biogas, the use of double decked trailers and hydrogen and fuel cell-powered vehicles in order to reduce their greenhouse gas emissions.

The Changing Environment for Fuel Cells in Buildings

Various incentives are being explored by the UK government as a means to improve the efficiency of energy use in buildings, including feed-in tariffs (FiT) for electricity sold back to the grid by domestic and industrial users, and Renewable Heat Incentives (RHI). Several technologies are competing in this area, including photovoltaic generators, heat pumps, and microgenerators such as fuel cells and Stirling engines. In a talk entitled 'The Potential for Microgeneration in the UK' Martin Orrill (British Gas New Energy, UK) mentioned that Centrica (the owner of British Gas) is collaborating with fuel cell developer Ceres Power, UK, and BAXI, Germany, who are also developing a Stirling engine, with the aim of helping domestic and business customers to use less energy and also cleaner fuels. The potential market for microgeneration systems is estimated to be between 6 million and 16 million units by 2020 in the UK alone.

Dwellings consume almost 30% of the primary energy supply in many European countries. Micro combined heat and power (mCHP) production – the simultaneous generation of heat and energy – presents an ideally efficient means of consuming fuel. Micro-CHP is being widely developed in Europe and Japan as a way to decentralise energy generation and potentially use renewable fuel supplies. In his talk 'Pre-Series Fuel-Cell-Based Micro Combined Heat and Power (CHP) Units in Their Field Test Phase' Philipp Klose (BAXI INNOTECH GmbH, Germany) described the latest generation of small domestic units on trial (Figure 2). These use platinum-catalysed low-temperature PEM fuel cells manufactured by Ballard, Canada, with an output of 1.0 kWe (electrical power) and an efficiency of 32%, together with an integrated boiler producing up to 20 kW of thermal energy, with an overall combined efficiency exceeding 95%.

BAXI have joined with De Dietrich Remeha GmbH, Germany, and are producing mCHP units for use as part of the Callux project, in which the German Ministry for Transport, Construction and Urban Development (BMVBS), together with nine partners from industry, will carry out Germany's biggest practical test of fuel cell heating systems for domestic applications.

Residential mCHP was also the subject of a talk by David Morgado (Delta Energy and Environment, UK) entitled 'The Six Ingredients for Micro-CHP Fuel Cell Heaven'. Fuel cells have a better electric energy to heat ratio for modern homes than do Stirling engines since they are not limited by the Carnot energy cycle, and are three to four more times more efficient. There are currently 32 developers of mCHP, and in Japan there are over 2000 PEM fuel cell units on field trials together with 36 solid oxide fuel cells supplied by Kyocera, Japan. In Germany, the Callux trial will evaluate 800 units by 2012.

Fig. 2. The GAMMA 1.0 micro-CHP unit for domestic installation built by BAXI INNOTECH, Germany, with an electrical output of 1 kWe and a thermal output of 15 kW or 20 kW

Fuel cells are also finding niche markets as standby power supplies in commercial buildings such as the Palestra building in London, explained Bill Ireland (Logan Energy Ltd, UK) in his talk 'The Commercial Application of Stationary Fuel Cells in the Built Environment'. Phosphoric acid fuel cells (PAFCs), which are also catalysed by pgms, have been highly developed over the past 30 years, and may be grid-linked or independent generators which also act as standby power supplies. They are used by organisations such as the US military in locations varying from desert to Arctic conditions, as well as in more conventional industrial and commercial premises. The Palestra building contains computers that require highly reliable power supplies to operate many of the services essential to the efficient running of London. It has a 200 kWe United Technologies Corporation PAFC that runs on natural gas, and provides absorption chilling as well as high and low-grade heat for the building.

Vehicle Applications

Environmentally conscious California, USA, is leading the way by implementing low pollution small passenger cars and transit buses, and encouraging a network of hydrogen refuelling stations. In her talk 'On the Road in California: Moving Toward an Early Market' Catherine Dunwoody (California Fuel Cell Partnership, USA) explained that they now have 300 fuel cell vehicles operating from 26 refuelling stations, which have collectively travelled over 2.8 million miles. With the aid of US$180 million funding (US$120 million contributed by government and US$60 million by industry) three main areas are currently being addressed: passenger vehicles, transit buses, and codes and regulations. Forty-six new hydrogen filling stations are being built in Santa Monica, Torrance, Newport Beach, San Francisco and Sacramento and by 2011 there will be 15 fuel cell buses and 40 other fuel cell vehicles, and by 2014 this will increase to between 20 and 60 fuel cell buses and 680 other vehicles.

Relatively little independent evidence on the performance of various vehicles is available to policy makers, explained Gregory Offer (Imperial College London, UK) in his talk 'Comparative Analysis of Battery Electric, Hydrogen Fuel Cell and Hybrid Vehicles in a Future Sustainable Road Transport System'. Road transport is responsible for over 20% of carbon dioxide emissions in London and it is currently almost entirely dependent on oil supplies. Studies comparing battery electric vehicles (BEVs) with fuel cell/battery hybrid and purely fuel cell-powered vehicles indicate that the fuel cell/battery hybrid is the most economical for a wide range of vehicles and applications. A battery pack as small as 10 kWh is sufficient to cover 80% of vehicle journeys, and may be recharged either from the electricity grid or by the fuel cell during vehicle operation.

Several projects to build and operate fuel cell electric vehicles are being carried out partly as education exercises in British universities. One such project, to construct racing cars, was described by Michael Cordner (Imperial College London, UK) in his talk 'Designing, Building, Testing and Racing a Low Cost Fuel Cell Range Extender for a Motorsport Application'. Three zero emission vehicles have been constructed at Imperial College since 2007. The first incorporated an 8.5 kWe Ballard PEM fuel cell stack in conjunction with supercapacitors providing a maximum of 40 kWe, and was raced by students in Formula Zero events in 2008. The current vehicle (shown in Figure 3) will be raced in the Formula Student race series, to be arranged by the Institute of Mechanical Engineers in 2011. The 5 kWe PEM fuel cell is provided by Nedstack, The Netherlands. In combination with a lithium battery, it will provide a

Fig. 3. A PEM fuel cell-powered racing car, one of a series built and raced by students at Imperial College, London, UK

power of up to 100 kWe and acceleration of 0 to 60 mph (0 to 97 kph) in 4 seconds. This single seat vehicle is capable of speeds over 70 mph (113 kph) with a motor on each wheel.

Kevin Kendall (University of Birmingham, UK) described a series of five small PEM fuel cell/battery hybrid delivery vans in use on the University's campus, in his talk entitled 'Hydrogen Fuel Cell Hybrid Cars in Birmingham'. The vehicles were designed by MicroCab, UK, and built by a consortium of specialist local companies in collaboration with the University (see Figure 4). An Air Products filling station provides a hydrogen supply for this fleet, which is being monitored to provide practical experience of operating such zero emission vehicles. The hybrid fuel cell vans each have a 1 kWe fuel cell with 10 kWe of battery power, which is sufficient to meet the needs of deliveries within the campus where there is a 20 mph (32 kph) speed limit. Development work is being undertaken to increase the capacities of the fuel cell and battery with the aim of increasing the top speed to 50 mph (80 kph).

Fig. 4. One of a fleet of five PEM fuel cell/battery hybrid delivery vehicles in daily use on the campus of the University of Birmingham, UK

A novel development in electric vehicles was described by J. G. Williams (University of Glamorgan, UK) in his talk 'Tribrid – Taking the Fuel Cell Hybrid Bus to the Next Development Stage'. A conventional IVECO delivery van has been converted to a minibus with a power plant comprising a PEM fuel cell, an ultracapacitor and a lead acid battery, in conjunction with an electric motor drive train. A 12 kWe auxiliary power pack is combined with a novel bipolar lead acid battery pack supplied by Atraverda Ltd, UK, which has a 42% reduction in weight and 22% reduction in volume compared to conventional lead acid batteries. A fuzzy logic controller monitors the motor current and state of charge to determine the most efficient rate of charging or power boost. The ultracapacitor pack enables increased regenerative braking and improved acceleration. The vehicle has a maximum power of 75 kWe, a range of 190 miles, a top speed of 55 mph (88 kph) and is capable of climbing a 20% gradient. Its CO_2 output is 278.69 g mile^{-1} compared to 401.5 g mile^{-1} for the diesel van equivalent covering the same hilly drive cycle around Pontypridd, Wales, supervised by the Motor Industry Research Association (MIRA).

Direct Methanol Fuel Cells

Primary or secondary batteries provide the power for most of today's portable electronic devices, and rapid development of these products is closely linked to the availability of improved power supplies. The reaction to oxidise methanol to yield electrical power is more difficult than that for hydrogen, particularly at relatively low temperatures, and reasonable outputs can only be achieved using pgm catalysts. Alexander Dyck (FBW GmbH, Germany) in his talk 'Direct Methanol Fuel Cells for Small Industrial Applications' described progress made in developing small, planar direct methanol fuel cells (DMFCs) for a wide range of consumer devices such as cameras, mobile telephones, global positioning systems, MP3 players and television sets. These often require in excess of 8 Wh of energy storage for adequate periods of use. This can be facilitated by rapidly refuelling the devices using liquid methanol, which has a theoretical energy density of 1000 Wh kg^{-1}, and a realistically achievable density of over 300 Wh kg^{-1}. The realisable energy density is invariably less than the theoretical energy density due to cell inefficiencies, and the weight of the device and fuel container. Standard refuelling containers for the safe carriage of methanol on public transport including aircraft have been approved the US Department of Transport and the United Nations Committee of Experts on the Transport of Dangerous Goods.

The FWB concept includes constructing flat cells with planar connectors to provide a multivolt output. The cells need no air circulation fan, and the fuel cell can be used in a hybrid system with a lithium battery to meet peak power demands. The complete system can be fitted into existing battery compartments so as to be compatible with existing equipment. FWB plan to introduce DMFCs into niche markets during 2010 for tracking, video and monitoring systems, proceeding into mass market applications as costs are reduced.

Since mobile device power and run time needs are outpacing battery performance, DMFCs are also being developed for larger applications such as portable power sources for military battery recharging and logistics, as well as larger electronic devices such as laptop computers. Young-Soo Chang described work in this area by the Korea Institute of Science and Technology and Korea University in a talk entitled 'Experimental Study on Performance Analysis of Direct Methanol Fuel Cell for Efficient Operation'. A fuel cell unit is being developed with a stable output of 10 W, although the stack itself is capable of supplying a maximum of 20 W. The fuel cell stack incorporates 20 cells, each having an area of 50 cm^2 and a loading of 2 mg cm^{-2} of platinum/ruthenium alloy on the anode and 2 mg cm^{-2} of platinum on the cathode. The system includes pumps for methanol and a blower for cathode air supply, together with a DC-DC converter to stabilise the output voltage. Tests have shown that for maximum efficiency of operation, methanol concentration should be controlled to maintain a constant voltage of 6 to 8 volts from the stack.

DMFCs are being sold commercially for a wide variety of applications including recreational vehicles, leisure boats, remote cabins, telecommunications and highway signs, and disaster recovery (2). The cells offer an 80% reduction in weight compared to conventional batteries, which also makes them desirable for military use. In his talk 'Portable Fuel Cells – A Commercial Success Story' Peter Gray (Johnson Matthey Fuel Cells, UK) explained that due to the 60% reduction in cost achieved during the past five years, unsubsidised sales are now being made directly to consumers, driven by the shortcomings of existing battery systems. Johnson Matthey produces pgm catalysts and membrane electrode assemblies, collaborating with numerous fuel cell manufacturers, including SMART Fuel Cells in Germany. A marketing and distribution network has been developed for fuel cells and their fuel which has resulted in sales of over 15,000 fuel cells and 100,000 fuel cartridges into markets including the camping and caravanning industry, where devices and fuel are stocked by camping shops. These have collectively operated for over 6 million hours, saving over 600,000 kg of CO_2 emissions. At the end of life of the fuel cell, up to 99% of the pgms can be recovered from scrap materials. The recovery rate also depends on the form of the scrap and the level of pgm it contains.

New Markets for Fuel Cells

During the past decade, a whole series of new and exciting markets have become apparent for fuel cells, including manned and unmanned flying machines. Many diesel-electric submarines have been supplied new or retrofitted with auxiliary power systems by IKL/HDW GmbH in Germany, while fuel cell-powered boats are operating on inland waterways and fuel cell-powered railway locomotives are being used as shunting engines.

Gerd-Michael Würsig (Germanischer Lloyd, Germany) offered the prospect of yet another large potential market in his talk 'Shipping – A Market for Fuel Cell Systems? – Challenges and Opportunities for Fuel Cell Technology in Shipping'. Germanischer Lloyd carry out classification of ships and offer guidelines for their construction and operation. They are carrying out a market study supported by the local environmental authority BSU in Hamburg. The German National Innovation Program managed by the Nationale Organisation Wasserstoff (NOW) in Berlin is supporting hydrogen and fuel cell technologies, with the aim of introducing these technologies within the next decade. Guidelines for fuel cell ship construction were issued in 2003 (3) and have been used in building several vessels, including the "Alsterwasser" which has been operating on Lake Alster in Hamburg since 2008 and uses a PEM fuel cell. The Hy-Ferry project headed by Beluga Shipping will introduce fuel cell technology into passenger transport to the islands on the North Sea coastline of Germany, using a PEM fuel cell supplied by Proton Motor Fuel Cell GmbH, Germany. There are considerable numbers of smaller craft already approved for fuel cell power, including pleasure boats up to 24 kW, and whale watching boats of up to 100 kW.

For large vessels, 70% of all emissions occur within 400 km of coastlines, and even giant cargo ships require auxiliary power while in harbour which would benefit from pollution-free operation. There are about 90,000 merchant ships worldwide, and 3000 are built annually. If 10% of these new build ships (i.e. 300) each required 2 MW of auxiliary power this would amount to 600 MW per annum. However, these vessels are built to the very lowest capital cost, and run on heavy fuel oil, which represents the most difficult market to attack. The initial market for large ships is probably higher value types, such as cruise liners, roll on/roll off passenger ('RoPax') ferries and mega-yachts.

There are 284 large cruise liners, each of which require 10 MW of auxiliary power, particularly while in harbour, and 35 are built each year. There are 2489 RoPax ferries and 46 are built annually, each of which requires 5 MW of auxiliary power. Finally, there are around 33 mega-yachts built annually, each of which need 1.2 MW of auxiliary power. All of these passenger-carrying vessels represent a potential market for fuel cells due to their need for low pollution and absence of noise and vibration.

Exhibition and Poster Presentations

The Symposium was accompanied by a daily trade Exhibition which was well attended, and where exhibits such as those shown in Figures 2 and 3 could be seen. A range of posters reported the latest developments in catalysis, electrode structures and fuel cell construction and operation under extreme conditions. The posters were too numerous to mention all of them in this short review, but many involved the preparation and use of pgms in the form of carbon-supported nanometre scale catalysts. The entries were judged by members of the Grove Steering Committee, and three prizes were awarded, one for each category of posters:

Category One: Poster 1.16, 'A Reverse Flow Reactor for Efficient, Heat-Integrated Decentralised Hydrogen Production by Methane Steam Reforming', C. Tellaeche-Herranz, B. Glöckler, G. Eigenberger and U. Nieken, University of Stuttgart and Evonik Degussa GmbH, Germany

Category Two: Poster 2.19, 'Lifetime Estimation Method for PEFC by Electrode Polarization Model', Y. Mugikura and K. Asano, Central Research Institute of Electric Power Industry (CRIEPI), Japan

Category Three: Poster 2.31, 'Effect of Cold Start on PEMFC Performance and Durability', J.-P. Poirot-Crouvezier, E. Pinton, Y. Fourneron, S. Rosini and L. Antoni, Laboratory for Innovation in New Energy Technologies and Nanomaterials, CEA-LITEN, France

Conclusions

Fuel cells are finding new and quite substantial markets in telecommunications and portable power. Standby power supplies for computers and disaster recovery, as well as mobile telephone networks, are being widely sold. Small combined heat and power units for domestic use are being assessed in large trials in Japan and Europe, while larger utility and industrial CHP units are becoming popular as a means of energy conservation. Fleet transport including buses, taxis, fork lift trucks, airport vehicles and other specialised applications are rapidly growing. However, it is recognised that penetration of the huge passenger car market will be achieved more slowly, due to the long life of internal combustion engine vehicles and the need to reduce costs. The need for a fuel supply infrastructure for hydrogen-powered vehicles has been recognised, and implemented in local areas which are being joined to form "hydrogen highways" in North America and Europe. Virtually all of these applications have a role for pgms, either in generating pure hydrogen fuel or utilising it in highly efficient fuel cells.

Slides from the various presentations can be found on the Grove Fuel Cell Symposium website (4). The next conference in the Grove series will be Fuel Cells Science and Technology 2010: Scientific Advances in Fuel Cell Systems and will take place on 6th and 7th October, 2010, in Zaragoza, Spain. Further information will be available *via* the website (5).

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The Reviewer

Donald Cameron is an independent consultant on the catalysis of fuel cells and electrolysers. As well as scientific aspects, his interests include the commercialisation of these systems. He is Secretary of the Grove Symposium Steering Committee.

