The Seventh Grove Fuel Cell Symposium

ISSUES OUTSTANDING IN THE RACE TOWARDS COMMERCIALISING FUEL CELLS

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The Seventh Grove Fuel Cell Symposium was held in London at the Queen Elizabeth II Conference Centre from the 11th to 13th of September 2001, with the theme “Commercialising Fuel Cells: The Issues Outstanding”. This reflects the growth of a new industry, and progress towards developing fuel cells as an established means of power generation. The technology is rapidly approaching commercial exploitation, led by low temperature polymer electrolyte membrane fuel cells. These are currently being demonstrated in a wide range of stationary power plants for industrial, residential and portable applications, and in road vehicles. These fuel cells, which use platinum group metals catalysts, represent a huge new market. This selective review of papers deals mainly with major trends in fuel cell research and development, and focuses on a few large demonstration programmes currently in use.

As well as the now traditional poster displays, the Symposium featured an exhibition by 34 fuel cell and component manufacturers, including four fuel cell powered vehicles, and an electric bicycle. The programme included presentations from fuel cell developers, power utilities, oil companies, motor manufacturers, and government bodies. It concluded with a session presented by financial institutions, who are facilitating investment in the growth of fuel cell technologies.

The Symposium attracted more delegates than any previous European fuel cell meeting, with over 600 attendees, and an additional 100 exhibitors. It was supported by ten organisations including the International Energy Agency Advanced Fuel Cell Programme, the European Fuel Cell Group and the World Fuel Cell Council, and was organised by Elsevier Advanced Technology.

Opening the Symposium, Nicky Gavron the Deputy Mayor of London, highlighted the problems of traffic congestion and pollution that London, the largest European city, faces. London is participating in a major demonstration of fuel cells...
A go-kart built by the rider, Christian Schleier of Ballard Power Systems, powered by a 5 kW Ballard fuel cell running on hydrogen. The go-kart is able to reach speeds of 50 km per hour. The drive characteristics of this electric vehicle demonstrate excellent acceleration, as would be expected from a race kart, but without producing any emissions. The dynamic behaviour of this kart is derived directly from the fuel cell – no buffer battery is needed.

cell buses and is committed to develop clean power sources. With a population and gross domestic product similar to those of Switzerland, London could provide a huge market.

The Symposium was divided into six main aspects. The first was 'Stationary Power Generation', including market development, critical issues, demonstration programmes, and a discussion on exploitation. Second, 'Research and Development', which is fundamental in the quest to improve performance and to reduce costs. Here, sessions on advanced materials and fuel processing and storage were included. The ability to implement a fuel infrastructure and to operate on a variety of fuels, particularly from renewable sources is regarded as essential to the new technology. Other aspects included sessions on new developments of 'Fuel Cells for Defence Applications' and 'Portable Power' applications and 'Fuels Cells for Transportation'. The Symposium was concluded by a series of papers and a discussion on the role of the banking industry in providing funding for the emerging fuel cell industry to provide sustainable growth. Poster sessions and an exhibition were integrated into the proceedings to stimulate discussion.

Grove Medal and Future Symposia
The sixth Grove Medal was presented by Alan Lloyd of the California Air Resources Board to Gary Acres, marking his retirement as Chairman of the Grove Symposium Steering Committee. Apart from chairing the committee from its inception, the award recognised his many years of experience in catalyst research in both pollution abatement and fuel cells. The possibility of an annual Grove Symposium is being discussed, and the new Chairman, Professor Lars Sjunnesson of Sydkraft AB, Sweden, hoped that Dr Acres would continue to provide an input to the Steering Committee in his new role as Honorary President.

Stationary Power Generation
This session examined three aspects: the Market, Critical Issues and Demonstrations. In a keynote presentation, Heinz Bergmann of RWE
Fuel cells as used for domestic appliances. In Germany, EWE and Vaillant are to produce about 150 fuel cell pilot units. The PEM fuel cells will have output of 4.6 kW and a thermal output of 7 kW

AG, the German utility company, described the importance of new technologies for dispersed generation of power and heat products. By 2015 it is anticipated that 30 per cent of power production in Germany will be from relatively small, dispersed sources which can provide useful heat as well as electricity, some of which will be small enough to be installed in individual homes. Of the options available, including internal combustion engines, gas turbines and microturbines, wind, solar power and fuel cells, the latter offer the most promise, combining high efficiency with low exhaust emissions, and ease of maintenance. RWE has formed collaborative ventures with fuel cell producers including Nuvera, Plug Power and MTU, together with other companies such as central heating boiler manufacturers to make systems for residential and industrial applications. A range of molten carbonate, solid oxide and polymer electrolyte fuel cells are being extensively evaluated, and RWE anticipate entering the market in 2004.

In his talk entitled 'A Commercialisation Strategy for Fuel Cell Micro-Generation Systems', Jacques Smolenaars described how Plug Power, Inc. have linked into a consortium with General Electric Corporation, Engelhard Industries (providing reformer catalysts), Celanese (supplying polymer membranes), RWE Engineering, and boiler manufacturers Vaillant to build dispersed power generators. To date, they have built 217 systems, and achieved certification by numerous bodies including the Canadian Standards Association, Underwriters Laboratory, the German TUV and the US Fuel Cell Council. As well as 50 units for a European Union sponsored programme, the consortium is building 75 distributed generators for the Long Island Power Authority and 44 for New York State Energy Research and Development Authority, due for completion by the end of 2001.

In the Critical Issues session, Werner Tillmetz of the International Electrotechnical Commission (IEC) described a programme to develop worldwide standards for fuel cell power plants. In 1999 the IEC established Technical Committee TC105 to prepare standards for all fuel cell technologies and all applications. This activity is being integrated with other organisations such as the International Standards Organisation: ISO/TC197 is on the hydrogen infrastructure and ISO/TC22 SC21 is for electric road vehicles. Other agreements with the Society of Automotive Engineers are in preparation. The scope of TC105 includes standards for fuel cell modules, safety of stationary power plants and their installation, fuel cell propulsion and auxiliary power plants in transportation, and portable units. Some of the sub-committees aim to establish guidance on the first standards within the next 2 years to assist the emerging fuel cell industry. Other speakers during the Symposium highlighted the process of certification for stationary fuel cell installations and gaining acceptance for them as a major expense.

Included in the Demonstration section was a paper by Andreas Ballhausen of EWE AG, a North German service provider for energy, the environment, telecommunications and information technology. In collaboration with Sulzer Hexis, a 1 kilowatt solid oxide fuel cell has been evaluated since 1998 in a combined heat and power mode. This has led to an order for 155 units
from Sulzer Hexis over the next 3 years, as well as for 150 solid polymer electrolyte fuel cells, each of 4.6 kilowatts output from Vaillant for delivery in 2002 to 2003. EWE have already received 400 enquiries from their German customers offering to help in their demonstration programme.

Zeljiko Barisic of ALSTOM Ballard GmbH described the joint venture between ALSTOM in Paris and Ballard Generation Systems of Canada to demonstrate stationary power plants throughout Europe. These polymer electrolyte fuel cells are designed for outdoor installation, operating on reformed natural gas to produce 250 kilowatts of electric power in parallel to the grid. They can be operated for electric power only or in a combined heat and power mode, and may be remotely monitored. Following experience of installing and operating the first unit, a CE-Mark for safety approval is being set up to facilitate installation, and a further five units are being installed in Germany, Switzerland, and France for operation between 2001 and 2003.

Michael Gnann, of MTU (Motoren- und Turbinen-Union Friedrichshafen) GmbH, Germany (part of DaimlerChrysler) and Hans Maru, of Fuel Cell Energy (FCE), U.S.A., described trials internal reforming molten carbonate fuel cells. In a licence and technology cooperation with FCE, MTU developed the 250 kilowatt HotModule fuel cell and has operated a first pilot co-generation plant at the University of Bielefeld since 1999. A second unit began operating at a hospital (the Rhön Klinikum in Bad Neustadt/Saale) in May 2001, while FCE is planning trials of units of up to 2 megawatts in the United States. Achievements of the joint programme to date include improvements in cell technology that should result in an operating lifetime of 40,000 hours. The design of the highly integrated HotModule combines all the components of the carbonate fuel cell system in a common thermally insulated pressure vessel. The operation of field test units has demonstrated the feasibility, operability and reliability of the concept. A manufacturing facility has been established in Torrington, Connecticut, and by the end of 2001 it will be capable of producing 50 megawatts/year of components. Alliances with other companies for key component manufacture and for equipment and distribution are under discussion. It is planned to sell units for commercial and industrial applications, including operation on digester gas (methane and carbon dioxide) and gasified coal.

Phosphoric acid fuel cells have been developed to a high level of reliability and longevity in the United States and Japan, and details of their installation and operation were described by Toshiyuki Ito of Tokyo Gas Company. Fuel cell power plants are made by Fuji Electric in 50 kilowatt and 100 kilowatt sizes, while 200 kilowatt units are
supplied by both Toshiba International Fuel Cells and Mitsubishi Electric. In total, there are 199 fuel cells in Japan, with 10 additional units installed annually. Of these 61 fuel cells are being evaluated in the Tokyo Gas distribution area, mainly in programmes sponsored by the New Energy and Industrial Technology Development Organisation. High operating reliability and availability have already been demonstrated, and lifetimes can be confidently predicted to be in excess of 5 years. However, they are still relatively expensive at $3,000–$4,000 per kilowatt, and efforts are in progress to reduce capital costs. The high reliability of phosphoric acid fuel cells has led to their being used in premium applications such as uninterruptible power sources for computer installations and water treatment works in Japan and they are being used in demonstration programmes throughout the world.

**Research and Development: Advanced Materials**

Research and Development was divided into two aspects on Advanced Materials and also Fuel Processing and Storage, both vital to the success of fuel cell technology and commercialisation.

Thomas Guth of DaimlerChrysler AG outlined cost and performance targets needed to be met for fuel cells in transport applications. The performance of polymer electrolyte fuel cells is limited largely by the membrane characteristics. Advanced cells will preferably work at low pressure without the need to humidify air, and at higher temperatures (90–110°C) to aid heat rejection. The latter will also enable platinum metal loadings to be reduced – further improving system economics.

As a means to reduce the volume, weight and cost of polymer electrolyte fuel cells, INEOS Clor (formerly ICI Chlorchemicals) have developed a range of coated bipolar metal plates to replace the graphite materials typically used. David Hodgson explained that these 'PEMcoat' coated separators incorporate the gas flow channels and exhibit improved corrosion resistance and electrical conductivity. Currently titanium and stainless steel are in use as an alternative to graphite separators, and INEOS are hopeful of using coated aluminium.

Professor Ray Gorte, of the University of Pennsylvania, talked about his work on high temperature solid oxide fuel cell anodes which are capable of the direct oxidation of hydrocarbons. By using copper cerments instead of the usual nickel-based materials, it is possible to avoid the growth of carbon fibres which typically occurs during hydrocarbon oxidation at temperatures above 700°C. Small cells have been operated on a variety of liquid fuels including n-decane, toluene and synthetic diesel, and analysis of the products of oxidation indicate that no reforming has occurred – the fuels have been directly and stochiometrically oxidised to carbon dioxide and water. Even when sulfur was deliberately added

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**Portable power sources require high energy densities. Barry Lakenham of Defence Science and Technology Laboratory (Dstl) reported these theoretical capacities for hydrogen storage/generation, which assumes 0.7 V/cell in a PEMFC. Container weight is included for compressed gas and liquid H, but not ancillaries. In the U.K. MoD/Dstl, via QinetiQ, is working on ammonia borane; in the U.S., CECOM/ARO is working with lithium aluminium hydride/ammonia. The effectiveness of H storage in carbon nanotubes has been the subject of some controversy.**

to the fuel stream to poison the anodes, performance could be restored by treatment with a steam/nitrogen mixture.

Research and Development: Fuel Processing and Storage

John Speight (University of Birmingham) reviewed the options for storing hydrogen for fuel cells. A typical fuel cell powered passenger car requires 5 kilograms of hydrogen on board to provide an adequate range. The use of liquid hydrogen in cryogenic stores imposes a 40 per cent energy penalty in the liquefaction process, and results in up to 3 per cent daily losses due to the gas boiling off. High pressure gaseous storage is used, with advanced technology cylinders providing up to 12 per cent by weight of hydrogen. Various materials are being considered for absorbing hydrogen as intercalates or hydrides; these provide storage densities of up to about 11 per cent by weight.

Finally, for certain applications, hydrogen may be generated by controlled decomposition of chemicals (sodium borohydride and lithium aluminium hydride); these provide 7 per cent by weight.

Talks by representatives from several major companies, including Texaco, ExxonMobil, General Motors and XCELLSIS, highlighted the need for efficient on-board reformers to convert liquid hydrocarbon fuels to hydrogen, if large numbers of fuel cell vehicles are to be rapidly introduced. This will avoid waiting for a hydrogen refuelling infrastructure to be developed.

Defence Applications

Angela Psoma of HDW in Germany described the use of polymer electrolyte fuel cells in an air-independent propulsion system for submarines. A combination of high efficiency, low noise levels, low magnetic signatures and low heat transfer to sea water confers on these boats many of the attributes of nuclear power. This influenced the decision to equip all new German submarines with the system. Six units of Class 212A are in production for the German and Italian Navies. In February 2001 production started on submarines of a new Class 214 for the Greek and South Korean Navies. While a 30–50 kilowatt fuel cell module is used for Class 212A, an advanced 120 kilowatt module of similar size and weight has been developed by Siemens AG. Two of these modules forming a 240 kilowatt system will be used in the Class 214 and to retrofit Class 209 submarines, and are foreseen as being used in a Class 212B. For all submarine fuel cell systems to date, hydrogen is stored within metal hydrides in cylinders, and oxygen is stored in cryogenic liquid form. However, to improve the operating range, methanol reformers are being developed to provide a means of storing greater volumes of fuel in liquid form. In combination with a palladium diffusion system, the devices deliver sufficient high purity hydrogen for the 240 kilowatt fuel cell power plants.

Portable Power

Military applications represent a substantial niche market for small fuel cells, and the low temperature polymer electrolyte type provides a unique combination of high power density with low detectability. The ability to refuel these with small hydrogen sources such as chemical
'Fuel Cell Today' – The New Internet Portal

Johnson Matthey announced the introduction of a new internet fuel cell portal, 'Fuel Cell Today' (http://www.fuelcelltoday.com/) at the Grove Fuel Cell Symposium. The portal aims at being the fuel cell industry's most comprehensive and authoritative website and is designed to help accelerate the global commercialisation of fuel cell technology. The portal offers a free service via a single online location where the latest fuel cell news, research, commentary, analysis and resources can be accessed and where users can learn about and participate in this important developing technology and industry.

Through the portal users can locate new contacts from the Industry Directory within the 'Knowledge Bank' which aims to be the most comprehensive database of suppliers, investors and customers in the industry, together with information on patents, and legislation. Via 'Community' – the online forums and discussions – users can meet and interact with other industry participants, including industry experts and investors. Via 'Events' users can consult the listings of worldwide fuel cell events and activities. The 'Reference Centre' has libraries of links, glossaries, FAQs, and background information for educational establishments. There is a rapid response facility covering the whole website. A 'Careers' section carries postings of fuel cell related positions.

'Fuel Cell Today' provides sound views, and information on resources and business opportunities. The portal has no commercial or national bias, being aimed solely to support the growing fuel cell industry as a whole and to help everyone who seeks information or contacts. 'Fuel Cell Today' provides users with:

- A single location to gather, disseminate, and share current and useful industry information.
- A forum to increase the visibility of any fuel cell industry and to identify, contact and communicate with a range of possible industrial partners.
- The opportunity to contribute to, and participate in, the fuel cell community and to collaborate with other users on fuel cell activities and initiatives.
- An interactive platform for fuel cell matters where the function and purpose of fuel cells can be explained and potential industry players and consumers can gain greater awareness regarding their value and benefits.
- An educational facility on a range of fuel cell technologies and their potential.
- A dynamic resource allowing users to remain in touch with the latest market developments.

'Fuel Cell Today' can be contacted at: www.fuelcelltoday.com; 40–42 Hatton Garden, London EC1N 8EE, U.K.; Tel: +44 (0)20 7269 8326; Fax: +44 (0)20 7269 8169; E-mail: info@fuelcelltoday.com.

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Generators makes them commercially competitive with military primary and secondary batteries. A target energy density for very small man-portable fuel cell/hydrogen store systems is 1,000 watt-hours per kilogram, with larger units possibly operating on liquid fuels offering up to 3,000 watt-hours per kilogram. Work on small portable power units for the United Kingdom Ministry of Defence was described by Jon Moore of Advanced Power Sources. Robert Nowak described work being undertaken by the United States Defense Advanced Research Projects Agency (DARPA).

Fuel Cells for Transportation

In his keynote presentation Alan Lloyd, Chairman of the California Air Resources Board, explained the efforts being made to demonstrate electric vehicles in California. Due to a rapidly
increasing population and growth in vehicle use, 90 per cent of Californians still breathe unhealthy air for part of the year despite huge advances in pollution control. Many of the world's major automotive, oil companies and fuel cell producers are participating in the California Fuel Cell Partnership to demonstrate fuel cell vehicles, methods of refuelling and to identify commercial paths to exploitation. The Partnership currently has ten cars and one bus operating in California, all of which are fuelled by hydrogen. Plans include demonstrating up to 60 passenger vehicles operating on hydrogen, methanol and on-board reformed gasoline. Some 20 fuel cell buses will be in operation in regular transit services by 2003. In addition, the California Power Authority has an ambitious target of acquiring 20 megawatts of stationary power generation by 2002 and 100 megawatts by 2003 as a means to improve the environment and also provide reliable power supplies in the State.

For Europe, Eric Ponthieu of the European Commission outlined three demonstration programmes being carried out which involve 31 buses in 13 cities from eight European countries and also Iceland. These include the Fuel Cell Bus for Berlin, Copenhagen and Lisbon, the Clean Urban Transport for Europe (CUTE), and Ecological City Transport System (ECTOS) in Iceland. These will be carried out in collaboration with fuel supply companies such as Shell, BP Amoco and Norsk Hydro in Amsterdam, Berlin, Copenhagen, Stockholm, Hamburg, Stuttgart, Madrid, Barcelona, Berlin, Luxembourg and London. The buses will be manufactured by DaimlerChrysler and MAN in Germany, with hydrogen provided from different routes including crude oil, natural gas or renewable energy sources, with the first buses appearing in 2002.

With plentiful supplies of hydroelectric power, countries such as Norway, Iceland and Canada are able to generate hydrogen fuel economically by water electrolysis. Christopher Kloed of Norsk Hydro Electrolysers explained that before tax, electrolytic hydrogen is comparable in cost to gasoline. In other countries it is possible to use wind, solar and biomass energy to generate hydrogen as a means of smoothing out variations in power availability. As part of the European-sponsored ECTOS demonstration scheme, in Iceland, three DaimlerChrysler buses will be evaluated.

Four vehicles were on show at the Symposium: a newly developed General Motors S10 Sports Utility Vehicle, which included an on-board reformer for gasoline fuel with a 25 kilowatt fuel cell, and two ZeTek vehicles powered by alkaline fuel cells – a London taxi and a light commercial vehicle, and a go-kart powered by a Ballard fuel cell. The latter attracted considerable attention during mobile demonstrations of its 50 km h⁻¹ capability, manouvvrability and rapid acceleration.

Investing in Fuel Cells

Three talks were presented by representatives of investment bankers, venture capitalists and investors. John Dean of UBS Warburg predicted a $30 billion market for fuel cells by the year 2010. Although there are still barriers to be overcome, fuel cell technology is close to reality. However, growing businesses need capital, and the fuel cell industry is no exception, and this is where the banking community can be of help. In terms of reaching commercialisation, to attract the large institutional investors, fuel cell manufacturers need to demonstrate that they are selling profitably into their main market, and that they have several large customers.

Conclusion

Fuel cells are now regarded as an established technology, and most effort is being devoted to tailor it to specific applications. Large demonstration programmes are being carried out in Europe and the United States, particularly for polymer electrolyte fuel cells. International codes and standards currently being developed for their construction and installation will facilitate fuel cells becoming commonplace in the home and in industry.

Many of the papers and posters will be published as a special edition of the *Journal of Power Sources*.

The Author

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