The Eighth Grove Fuel Cell Symposium

DEVELOPING A FUEL CELL MANUFACTURING INDUSTRY

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The Eighth Grove Fuel Cell Symposium was held at the ExCeL Exhibition Centre in London Docklands from the 24–26th September 2003, with the theme "Building Fuel Cell Industries". Fuel cells have already been widely demonstrated as highly efficient, reliable and durable power generators with emissions characteristics superior to any conventional technology. The main barrier to their being generally adopted is the need to reduce their initial cost, and the means to achieve this formed the underlying theme of the Symposium.

As an indication of the growing importance of fuel cells, the Symposium was sponsored by seventeen organisations, including the U.K. Department of Trade and Industry (1), the European Fuel Cell Group, and the U.S. Fuel Cell Council, in addition to a host of commercial organisations. The Symposium, organised by Elsevier Advanced Technology, attracted almost 600 delegates. Thousands more attended the accompanying exhibition, where the 110 stands gave an indication of the rapid growth of the industry. Static exhibits as well as mobile vehicles were on display and visitors were invited to ride some of the fuel cell powered scooters and cycles. In total, this constituted the largest display of fuel cell technology ever seen in Europe.

The Symposium was formally opened by Jenny Jones, the Deputy Mayor of the Greater London Authority, who highlighted the three hydrogen powered fuel cell buses which will become operational in London this year. These form part of the 30-bus Clean Urban Transport for Europe (CUTE) programme, complementing the efforts by the London Hydrogen Partnership to promote the use of renewable energy.

Jenny Jones also presented the Grove Medal to Professor Ferdinand Panik of DaimlerChrysler AG for his pioneering work in developing fuel cell road vehicles. Professor Panik suggested that fuel cell powered buses may be commercially viable within the next ten years, partly due to the feasibility of refuelling them from a central point. More general implementation for passenger vehicles will require a hydrogen refuelling infrastructure to be set up. The commercial viability of small passenger vehicles will also be dependent on the cost of fuel cells approaching the \$45 kW^{-1} target proposed by the U.S. Department of Transport. Professor Panik expected them to begin to become commercially viable by about 2012, with Toyota, Honda and DaimlerChrysler already demonstrating their small fleets (around 60 vehicles in total) in North America, Europe, Japan and Singapore. A number of collaborative efforts such as the California Fuel Cell Partnership, and the European bus project will help to gain acceptance of the technology.

The Symposium was divided into ten sessions, some being held in parallel, and covered all types of fuel cells, hydrogen provision, demonstrations of technology, and associated topics, such as financing and possible government incentives. It began with talks by representatives from a number of major industries on their company's experience of entering the fuel cell market. These included component suppliers, fuel cell manufacturers, an electric utility and an energy supplier. However, this review is limited to developments involving the uses of the platinum group metals (pgms).

The Exhibition

The exhibition was a major feature of the Symposium, with a wide variety of organisations emphasising the range of technologies needed to manufacture and market fuel cells, and a growing number of specialist material and component suppliers. The static devices on display included: a HotModule 300 kW molten carbonate fuel cell (MCFC) built by MTU CFC Solutions (2), Ballard AirGen PEMFC (proton exchange membrane fuel

An Airgen portable generator built by Ballard Power Systems in Canada, based on a 1.2 kW PEM fuel cell. Its applications include uninterruptible power supply (UPS) for computers and on-site power generation.
Its retail price is ~ U.S. $6000.
The generator is presently fuelled by compressed hydrogen, however, hydrogen stored in metal hydride canisters is expected to be available soon

cell) portable generators, a TCP solar powered traffic light system, Heliocentris Energiesysteme educational fuel cells, and many others.

An area large enough to drive full size passenger vehicles was set aside for regular demonstrations of fuel cell powered vehicles. The fuel cell powered vehicles on display included a DaimlerChrysler F-Cell (the fuel cell powered version of the Mercedes A-class), two examples of the Ford Focus powered by fuel cells, and vehicles built by the Scottish Fuel Cell Consortium, REfuel, and others. Significantly, there were also a number of small two wheeled scooters and motor assisted bicycles, several of which were available to be ridden by members of the public.

Market Issues

David Jollie (Fuel Cell Today) emphasised the need for cost reduction in the fuel cell industry, comparing the cost of power in internal combustion engines for cars at U.S.\$100 kW^{-1} with the current cost of fuel cells at \$4000 kW^{-1} to \$10,000 kW^{-1}. However, there are a considerable number of less cost-sensitive applications, such as portable computers, mining locomotives, buses and military generators. In terms of fuel cell technologies, transport will be dominated by low temperature PEMFCs, while small portable and micro devices are likely to be methanol or hydrogen fuelled PEMFC types. Small stationary and residential fuel cells of 1–10 kW will probably be dominated by

A Ford Focus FCV at the Fuel Cells Canada stand. A similar vehicle was driven from the Canadian Embassy in central London to the exhibition in very heavy traffic, to give regular demonstrations.
• Peak power: 67 kW (90 hp)
• Peak torque: 190 Nm (140 ft-lb)
• Peak efficiency: 91%
The fuel cell is a PEM of the Ballard Mark 900 Series

A motor scooter displayed on the PEM Technologies Inc. stand. This company is focusing in particular on small to medium size fuel cell power systems with an electric output of less than 10 kW. The fuel cells are aimed at use in portable power systems, light/personal and non-road industrial electric vehicles

PEMFCs or solid oxide fuel cells (SOFCs), while local power stations larger than about 250 kW are likely to be solid oxide or molten carbonate electrolyte types. It is likely that success in reducing the cost of PEMFCs for motor vehicles will also lead to a higher proportion of PEMFCs being used for other applications. The number of fuel cells built to date is increasing rapidly, with some 3500 at the end of 2002 and 6500 anticipated by the end of 2003, and there are now 20,000 people employed in the fuel cell industry.

Platinum Availability

It has sometimes been suggested that the full exploitation of low temperature fuel cells may be limited by the availability of the pgms. Mike Steel (Johnson Matthey) posed the question of how much platinum is likely to be required, and whether the increased demand can be met. Bill Ford of the Ford Motor Company, has forecast that by 2025, one quarter of all light vehicles will be powered by hydrogen. Assuming that each car will require about 75 kW of fuel cell power, and using the U.S. Department of Energy target of 0.2 g kW^{-1} of platinum, Mike Steel estimated that platinum demand for fuel cell cars could be 150–300 tonnes per year by 2025. This compares with a production rate of 180 tonnes per year in 2000, and proven reserves of 5000 tonnes, with inferred reserves of 30,000 tonnes of platinum, but does not include platinum recovered and recycled, a practice already developed for automotive emissions control catalysts in the advanced economies of the world. Mike Steel reached the conclusion that platinum is a key catalyst for PEMFC development, and that there should be sufficient resources available to meet the needs for the foreseeable future.

0.2 g kW^{-1} Pt U.S. Dept. of Energy target for cars

Pt demand for fuel cell cars could reach 150 to 300 tonnes per year by 2025

Fuel Cell Users

Andreas Willeke (E.ON Energie) presented an interesting perspective from a fuel cell user. The E.ON Group was formed by the union of the German VIAG and VEBA groups, which then incorporated Ruhrgas in Germany, and PowerGen in the U.K. With annual sales exceeding € 37 billion, E.ON is purely a technology user company, interested in evaluating fuel cells for industrial and residential use. They are willing to evaluate pre-commercial fuel cells in practical field tests, and offer suitable facilities.

Currently E.ON have 5 of 250 kW units in operation or planned using a range of fuel cell technologies. For residential fuel cells, E.ON is working with affiliated companies on two publicly funded projects with 9 systems in operation. Their largest project, which is internally funded, involves a field test of up to 200 systems in the homes of customers. However, few systems in a suitable 'pre-commercial production' stage are available from fuel cell manufacturers. To date, 6 units have been installed, and this number is expected to rise to over 100 units in the next 3 years. Should these prove successful, E.ON plans to purchase fuel cells and operate them at the premises of customers, and sell the power and heat. This may help to overcome the capital cost and credibility barriers which invariably beset new technologies.

Materials and Components for PEMFCs

Low temperature PEMFCs, which utilise pgm catalysts, are being developed for a wide variety of applications. A number of papers emphasised efforts being taken to reduce the cost of individual components, particularly the polymer membranes and separator plates which incorporate gas flow channels. At the same time, the intrinsic costs of catalysts are being reduced by their more effective utilisation and by increasing the power density of the fuel cells.

Simon Cleghorn (W. L. Gore & Associates) described improvements made to their membrane electrode assemblies (MEAs) since the 1990s. Validation tests on their PRIMEA® Series 56 MEA for stationary fuel cells suggest that lifetimes in excess of 20,000 hours are achievable. Operating at 70°C and 75% relative humidity of fuel and dry air at 25 psig pressure and 2 × stoichiometric flow rate, typical voltage decay rates are 4–6 μV/hour at 800 mA cm^{-2} current density, compared to an ultimate target of 1 μV/hour for a 40,000 hour lifetime.

The PRIMEA® Series 57 MEA is intended for automotive systems, using less than 1 g kW^{-1} of platinum, and operating at less than 50% relative humidity at 80°C and 270 kPa pressure, with high power density and 1500 hours durability in frequent start/stop duty cycles. The PRIMEA® Series 58 MEA, currently under development, is intended for hydrogen fuelled portable power applications, with no external reactant humidification and using forced air cooling.

Accelerated voltage decay rate tests are also being used to assess membrane characteristics. Fluoride ion release rates provide an indication of the degradation of the membrane. Typically, a membrane can lose up to 25% of its total fluoride ion concentration before failure occurs. The latest life test data suggest that technologies are available which may be capable of meeting the 40,000 hour life target in stationary applications (this is generally accepted as an adequate length of time for stationary applications). Advanced electrode development is also being carried out for cell operation at over 95°C, with new membranes capable of operating at up to 120°C.

Improved membranes can contribute to the success of the PEMFC, and Dennis Curtin (DuPont Fuel Cells) outlined work being carried out on Nafion® perfluorosulfonic acid (PFSA) polymer separator materials, which are some of the ones most widely used in the industry. Membrane conductivity is a function of its water content, and membranes are typically used at temperatures lower than 90°C, with relative humidity greater than 80%. The formation of peroxide species is largely responsible for degradation of the membranes, with attack by the peroxide radical on polymer end groups having residual H-containing terminal bonds generally believed to be the principal mechanism. The peroxy radical attack is most aggressive at low relative humidity (30% RH) and temperatures exceeding 90°C. Chemical modifications are being used to reduce the number of end groups and thereby stabilise the polymer.

Solvent-based and water-based processes are used to convert the polymeric materials into dispersions used to formulate inks and catalyst coatings, while membrane films are prepared by solution casting to prepare continuous rolls for subsequent processing into MEAs.

Steven Grot (Ion Power Inc.) detailed their efforts to manufacture lower cost MEAs for fuel cells and electrolysers using DuPont Nafion®. This is achieved first by reducing the thickness of the solution-cast membranes to only 25 μm, and second, by replacing the expensive ion-exchange membrane material around the peripheral sealing area of the cell by DuPont Kapton® polyimide film.

Separator plates also constitute a major cost component of fuel cells, and Falko Mahlendorf (ZBT, University of Duisberg-Essen) described their efforts to produce low cost bipolar plates using injection moulding techniques. Thermoplastic materials, mixed with high loadings of carbon to provide electrical conductivity, are prepared and then injection moulded into flat plates. The filled polymer conductivity is directly proportional to the amount of carbon incorporated, over a wide range of compositions, although typical loadings of 50% carbon provide rather less conductivity than pure graphite. However, experience with small (50 cm^2 area) 20-cell fuel cell stacks indicates that the lower intrinsic conductivity of injection moulded plates is partially offset by the better homogeneity and production tolerances of the injection moulded product. Separator plates of 140 mm × 140 mm × 4 mm are projected to cost as little as €0.6 each, depending on the numbers required.

Micro Fuel Cells

The functions of many items of electronic equipment are limited by the power supplies available. To improve on existing primary and secondary storage batteries, several electronic manufacturers are working on small direct methanol oxidation fuel cells, and also combinations of miniature reformers and PEMFCs.

Stefan Wagner (Fraunhofer Institute for Reliability and Microintegration, Germany) described the construction of miniature PEMFCs of 1 mm^2 to 1 cm^2 intended to be used as battery replacements. In long term tests on pure hydrogen, the 0.54 cm^2 cells operated at 100 mA cm^{-2} with a voltage of 400 mV, using naturally convected air at room temperature.

Robert W. Reeve (QinetiQ, U.K.) described the cylindrical fuel cells they have developed which can operate on a range of fuels, although the use of alkaline electrolyte, combined with the direct oxidation of methanol or sodium borohydride is preferred. The cylindrical structure allows a weight ratio of stored fuel to cell hardware of 1:1, with an active electrode area of 10 cm^2. Individual cells can be joined at their ends to provide useful output voltages.

Yet another option is to operate micro scale PEMFCs using hydrogen supplied from miniature reformers running on hydrocarbons. Jamie D. Holladay (Battelle Pacific Northwest Division, U.S.A.) described the construction of steam reformers running on methanol, natural gas, diesel or jet fuel (JP-8). Initially, Battelle is developing a steam reformer for a hybrid system with 25–100 W electric power operating on reformed methanol. The 25 W system, with a reformer volume under 20 cm^3 and mass of less than 150 g is postulated to have a total 14-day mission weight of 8 kg compared to 38 kg for primary batteries or 57 kg for secondary batteries. This equates to an energy density of 1500 Wh kg^{-1}. Even higher energy densities (1732 and 1600–2150 Wh kg^{-1}) should be achievable for 50 and 100 W systems, respectively.

Demonstrations of Fuel Cells

Mike Binder (U.S. Army Engineer Research and Development Center (ERDC)), provided an update on the trials of their 30-strong fleet of fuel cells which have been in progress for 10 years in regions ranging from the Alaska to the Mojave Desert. These 200 kW phosphoric acid type fuel cells supplied by ONSI have provided high reliability and availability for over 825,000 operating hours, and verified the manufacturer's claims for low pollution characteristics. ERDC also manages the Department of Defense Climate Change Fuel Cell Program, which provides a rebate of \$1000 kW^{-1} to applicants who purchase a U.S.-manufactured fuel cell. So far this has helped to fund 18.8 MW of phosphoric acid fuel cells, 170 kW of PEMFCs, 1.0 MW of MCFCs and 505 kW of SOFCs. Emphasis is currently on 1–20 kW residential fuel cells for installation at U.S. military or related facilities. The devices must be turnkey installations, needing no more than annual maintenance, and providing over 90% availability for use. To-date, 21 residential-type fuel cells have been operated under the 2001 programme with over 93% availability. The best of these, 5 kW units supplied by Plug Power achieved 98.8% availability over the last 11.5 months of the trial. A further 32 units are being purchased under the 2002 budget and others are planned from the 2003 appropriations. It is hoped to install one such device in the U.S. Embassy in London.

Andre Martin (Ballard Power Systems AG, Germany) mentioned that over 1000 of their Nexa™ 1200 W power units have been sold. These have achieved certification by Underwriters Laboratories (UL) in the U.S.A. and Canadian Standards Association (CSA) and can operate on reformate gas as well as pure hydrogen. They are being incorporated by the original equipment manufacturers (OEMs) into uninterruptible power supplies, standby generators and small electric vehicles. Several examples of these were displayed in the exhibition.

Considerable progress has been made by MTU CFC Solutions and Fuel Cell Energy Inc. in developing MCFC generators. These were presented by Michael Gnann. Following the first field trial in Germany, 9 of these large combined heat and power installations are operating in Europe and the U.S.A. Locations include hospitals, a shipyard, an electric utility, and a car factory, and further units are being delivered to North America and Japan. Overall energy recovery from these plants varies between 70% and 90% depending on the installation. The 300 kW HotModules are being adapted to run on secondary gases such as biogas, sewerage and synthesis gas, and are being scaled up to 1 MW modules for multi-MW generators. Although these high temperature fuel cells are not dependent on pgms for their operation, they could well utilise them in future to improve the efficiency of the fuel processing stages. An example of the HotModule fuel cell was on display.

Several different approaches to SOFCs were presented. Gerry Agnew (Rolls Royce Fuel Cell Systems, U.K.) described plans to build multi-MW systems integrated with gas turbines to form a 1 MW hybrid. Under an EU 'Fifth Framework Programme', it is intended to demonstrate a multi-kW stack test rig. Effort to date has concentrated on developing manufacturing techniques for low-cost ceramic components stable at high temperatures (900°C).

In contrast, Brian Borglum explained that Global Thermoelectric Inc. has focused on low-cost, intermediate temperature (750°C) planar anode-supported technology for their SOFCs. Their main effort has been to develop a 2 kW class prototype operating on reformed natural gas. Five of their RP-2 units have operated for 20,000 hours in 2002 to 2003 and have demonstrated peak net electrical efficiencies of 29%. Their next generation prototype is expected to yield an electrical efficiency of 30–35%, and fuel utilisation of 60–80%.

Nigel Brandon (Imperial College, London) provided details of intermediate temperature SOFCs, capable of operating at 500–600°C, that enable the extensive use of stainless steel components. The technology developed at Imperial College has been spun out into a venture company – Ceres Power Ltd. – for commercial exploitation. Markets being addressed are those needing 1–25 kW units combined heat and power, auxiliary and uninterruptible power units.

The Poster Session

A record 144 posters were displayed at the Symposium, and four of these were selected to receive prizes. Most of the oral papers and many of the posters will be published as a special edition of the *Journal of Power Sources*.

Conclusion

The technical feasibility of fuel cells has been widely demonstrated in extensive trials in numerous stationary and mobile applications. The industry is rapidly developing, with increasing numbers of companies supplying materials, components and balance of plant as well as building fuel cell stacks and devices utilising them. This parallels the initial developments of the motor industry where early pioneers were forced to design and fabricate every part, whereas nowadays modern vehicle assemblers are able to source components from competing specialists. This pattern will be a key factor in making fuel cells fully competitive with existing power plants. The fuel cell industry also needs to familiarise the public with the technology, and the rapidly increasing number of demonstration programmes will help in this.

References

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The Author

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