The Fifth Grove Fuel Cell Symposium

By Donald S. Cameron

The Interact Consultancy, Reading, England

The Fifth Grove Fuel Cell Symposium was held at the Commonwealth Institute in London from the 22nd to 25th September, attended by almost 400 delegates from 28 countries. The theme "Fuel Cells - Investing in a Clean Future" was intended to encompass the views of fuel cell users and producers in the light of demonstration programmes worldwide, and to promote commercial exploitation of this highly efficient, clean method of electric power generation. The symposium was sponsored by the Energy Technology Support Unit (ETSU) on behalf of the U.K. Department of Trade and Industry, the International Energy Agency Advanced Fuel Cells Programme, the European Fuel Cell Group, and Elsevier Advanced Technology.

Mrs Eryl McNally, CoChair of the Research and Energy Committee of the European Parliament opened the meeting. Later, she presented the platinum Grove Medal to Firoz Rasul, President and Chief Executive Officer of Ballard Power Systems, Canada, in recognition of their role in developing proton exchange membrane fuel cells to the point where these are being demonstrated in a host of applications, including passenger and public service vehicles.

Present and Future Capabilities

The conference was structured to show the present and future capabilities of fuel cells, and to gauge their likely progress against the challenges still to be overcome. To encourage questions and observations from all participants, two discussions were held.

Developing a thriving fuel cell industry will require major investments on a number of levels in order to:

- provide exploitable technology
- demonstrate viability and commercial prospects
- generate interest and commitment among potential purchasers.

All the speakers emphasised that fuel cells will only become a commercial reality if they offer clearly definable financial benefits to the purchaser, and provide a profit to the manufacturer. Other characteristics, such as high efficiency and freedom from pollution are additional bonuses, but alone will not be sufficient to result in widespread exploitation.

Currently, fuel cells are more expensive than conventional power plants such as gas turbines and diesel generators, and several speakers addressed the efforts being made by their organisations to reduce costs. These include developing less expensive materials of construction, increasing the power obtained from each cell, and scaling up the number of power plants sold in order to benefit from mass production. For some fuel cells, niche markets have emerged even at their present prices, which justify continued development of the technology while the numbers of sales increase.

Fuel Cell Technology

Phosphoric Acid Fuel Cells

Platinum catalysed phosphoric acid fuel cells, operating at about 200°C are the most highly developed. Rick Whitaker, of ONSI, reported that 144 of their 200 kW PC25 generators have been sold, and 91 are operating in North America, Japan and Europe. Early models have been in service for over 37,000 hours, with over 95 per cent availability for service. One unit has established a record for any power plant by running for 9500 hours (13 months) continuously at full rated load. Their reliability is such that they are being marketed as un-interruptible power sources (UPSs) for installations such as computer facilities and hospitals.

Operating on natural gas, they are 40 per cent efficient for electrical output, providing a further 45 per cent of low grade heat. Their twenty year development has cost $200 million, funded by United Technologies Corporation, Toshiba (Japan), Ansaldo (Italy), the U.S. Government, and the Electric Power Research Institute (U.S.A.). Costs are being reduced partly by design simplifications, and also by increasing production. The early units were sold for about half their construction cost of almost $1 million each. However, ONSI predict that at present cost levels there is a market for un-interruptible power sources, and other applications will become feasible as prices are reduced.

Proton Exchange Membrane Fuel Cells.

These fuel cells languished after their success in the early U.S. Gemini space programme until intensively developed by Ballard Power Systems. Progress was hindered by the need for expensive construction materials and high platinum content. The use of less expensive polymers, graphite separator plates and dramatically reduced platinum requirements have transformed their prospects. Their solid polymer electrolyte provides freedom from possible leakage, and their operating temperature of less than 80°C means that they can be quickly started from cold. Hence they are ideally suited to transport and vehicle applications. Platinum metal loadings have been reduced from around 15g/kW to less than 1 g/kW with present cells and this figure is still falling.

Proton exchange membrane fuel cells are susceptible to poisoning by impurities such as carbon monoxide in the hydrogen supply. Efforts were reported first to render the fuel cells more tolerant of contaminated hydrogen, by using alloy catalysts such as platinum-ruthenium at the anode, and secondly to develop reformers supplying high purity hydrogen.

Reinhart Rippel described the Siemens AG efforts on fuel cells, which include development of a 100 kW alkaline fuel cell air independent propulsion system for the German Class 205 (U1) fuel cell submarine trials. In 1989 Siemens began work on proton exchange membrane cells, culminating in development of a 34 kW module of 72 cells, producing 650 amps at 52.3 volts, at 70 to 80°C, and operating at 72 per cent efficiency at 25 per cent of rated output.

At present Siemens are collaborating with MAN and Linde to produce a low-floor city bus, which will have 120 kW of proton exchange membrane fuel cell power, with the hydrogen fuel stored in pressurised cylinders.

Molten Carbonate Fuel Cells

The 650°C operating temperature of molten carbonate fuel cells offers the option of reforming natural gas or other hydrocarbon fuels inside the fuel cells (internal-reforming) or outside (external reforming), and also the benefit of high temperature recovered heat. However, the high operating temperature and corrosive alkaline electrolyte continue to provide many challenges in finding materials of construction.

Michael Bode of MTU, Germany, described their programme to develop and manufacture these fuel cells as 300 kW to 10 MW stationary generators. MTU claim to have made breakthroughs in the main problems of high degradation rates and migration of electrolyte, and, with their 280 kW unpressurised "Hot Module", to have operated the largest molten carbonate fuel cell stack module to date.

Hiroo Yasue, of the MCFC Research Association, Japan, described the Japanese collaborative effort on molten carbonate fuel cells, supported by the Government Moonlight and New Sunshine programmes. With three companies developing stacks and four companies building the balance of plant, a 1000 kW system is being assembled to evaluate the technology. This will have an external reformer running on natural gas, providing an overall electrical efficiency of 45 per cent, and a target life of 5000 hours, when it comes into operation in November 1998.

Solid Oxide Fuel Cells

Operating at around 1000°C, solid oxide electrolyte fuel cells are capable of reforming hydrocarbon fuels internally. A 25 kW generator built by Westinghouse Electric Corporation in the U.S.A. has been operated in Japan for over 13,000 hours with degradation rates of less than 0.1 per cent/1000 hours and 11 start-up cycles.

It is acknowledged that production costs need to be reduced by orders of magnitude to make the system commercially successful, and Allan

Casanova of Westinghouse Electric Corporation described their programme to achieve these reductions. This is being addressed by first increasing the size of individual cells (up to 150 cm long ceramic tubes), and by manufacturing them on a larger scale. A 100 kW unit is being constructed by Westinghouse for a demonstration in The Netherlands, with start-up due in November 1997, and a 250 kW unit is planned for Fort Meade, Maryland, U.S.A. Ultimately, static generators of 250 kW to 7 MW are planned.

Demonstration Programmes

Phosphoric Acid Fuel Cells

Most fuel cell demonstration programmes to date have involved phosphoric acid fuel cells. Lars Sjunnesson, of Sydkraft, the largest power utility in Sweden, explained the reasons for their trials with two units, built by ONSI and Fuji Electric, and operating on natural gas. They are attractive for many reasons, including their ease of siting at, or close to, the consumer, with the option of using them in a combined heat and power mode. However, plants of less than 5 MW face competition from diesel generators costing less than U.S. $1500 per kilowatt, while larger generators must compete with gas turbine power plants priced at less than $1000 per kilowatt.

One issue which must be addressed at an early stage is the regulatory system controlling their installation. Fuel cells represent new, unfamiliar technology which is regarded with suspicion by local authorities and safety regulators. Hence the need for demonstration and familiarisation programmes in parallel with technology development.

Tom Damberger related the experience of using fuel cells at several hospitals run by Kaiser Permanente, a major health care provider in the United States. On several occasions, cuts in electricity supplies to hospitals have been followed by failure of their emergency diesel generators. For this reason, fuel cell generators have been evaluated at Anaheim, Sacramento and Riverside, California since 1993. Two ONSI PC25 generators at Riverside have provided 99.5 per cent and 98.2 per cent availability for power generation, and in 1995 Kaiser signed orders for six further units. As an indication of the potential market, a 300 bed hospital typically requires 1 to 4 MW of power with high security of supply. Kaiser Permanente have 70 MW of connected power demand in California, with an estimated market for 160 fuel cells in that state, and 500 across North America. Ideally, the system would provide high grade steam for heating and sterilising, although all the hot water provided by the PC25 units has been utilised.

Kiyokazu Matsumoto of Osaka Gas Company gave the reasons why Japanese gas and electricity industries have supported development of phosphoric acid fuel cells – they anticipate the need for an additional 172 gigawatts of electricity generating capacity in Japan, by the year 2010. The need for efficient utilisation of gas is emphasised by the annual import of 44 million tonnes of liquid natural gas – 95 per cent of Japanese requirements. To date, 87 fuel cells, mostly phosphoric acid types from various suppliers in sizes ranging up to 11 MW, have been evaluated.

Proton Exchange Membrane Fuel Cells

Exciting developments include two prototype passenger vehicles powered by proton exchange membrane fuel cells, shown recently at the Frankfurt Motor Show by Daimler Benz and Toyota, and a fuel cell powered submarine under construction for both the German and Italian Navies.

In a deal worth $340 million, Daimler Benz have formed a joint venture, DBB Fuel Cell Engines, with Ballard Power Systems of Vancouver, Canada, to exploit fuel cell technology. Dr Ferdinand Panik described how Daimler Benz have constructed a series of vehicles, culminating in the NECAR III. This is based on a Mercedes Class A subcompact, which incorporates a reformer, enabling it to operate on liquid methanol fuel, which together with the 50 kW proton exchange membrane fuel cell fits under the floor and bonnet of the vehicle. Daimler Benz have also built the NEBUS fuel cell powered passenger bus for demonstration and testing.

Ballard Power Systems have built the power plants for a first 3-bus demonstration programme for Chicago Transportation Authority which was started on 18th September, with a second 3-bus trial in Vancouver due to start shortly. These buses have 250 kW of fuel cell power, operating at between 45 to 55 per cent efficiency depending on load conditions, running on hydrogen stored under pressure. The bus field trials are scheduled to last through 1997/98, with commercial sales due to begin in the year 2000, and full production starting in 2004.

A host of automotive manufacturers, such as Chrysler, Ford, General Motors, Honda, Nissan, Volkswagen AG, and AB Volvo are involved in fuel cell vehicle programmes, many using fuel cells supplied by Ballard. Shigeyuki Kawatsu of Toyota Motor Corporation described their activities, which include building a RAV4 sport utility vehicle incorporating a methanol reformer. A 25 kW fuel cell and auxiliary battery together provide a total of 50 kW, giving a maximum speed of 125 km h^{-1} and a 500 km range. The entire power train is sufficiently compact to fit under the bonnet and floor of the vehicle.

Ballard Generation Systems, a joint venture between Ballard Power Systems and U.S. energy company, GPU International, are constructing two 250 kW stationary power generators which will be installed and tested by the latter.

Gunter Sattler of Ingenieurkontor Lubeck, a privately owned naval construction company in Germany, detailed the development of airless power systems for submarines by the German Navy. Initial trials were carried out with a Class 205 submarine using alkaline fuel cells, fed with hydrogen from a hydride store, and oxygen carried as cryogenic liquid. A second, Class 212 vessel is under construction and will be commissioned in 2003, with 300 kW proton exchange membrane fuel cells, supplied with hydrogen generated by a methanol reformer, which will provide for cruising at 8 knots. Liquid oxygen stores supply the fuel cell, reformer and crew breathing requirements. Efficiency of power generation varies from 70 per cent at 5 per cent load to 50 per cent at 100 per cent of rated load. Fuel cell stacks have been supplied by Ballard, although Siemens are developing modules of 30 to 50 kW with suitable characteristics for operating on pure oxygen. An agreement has been signed enabling the Italian Navy to build the Type 212 submarine in Italy.

Molten Carbonate Fuel Cells

A 2 MW fuel cell installation has been built at Santa Clara, California, based on internal-reforming, molten carbonate electrolyte fuel cells built by Energy Research Corporation. Paul Eichenberger described the construction and commissioning of the power station, and extensive testing of the balance of plant, before starting up the sixteen fuel cells. These ran for 720 hours connected to the grid, supplying 1710 gigawatt hours of power, before the plant was shut down due to voltage anomalies. Following various difficulties, the plant was shut down in March this year, and new fuel cell stacks are currently being built. The programme was intended mainly to provide experience of constructing and operating the plant, and it is hoped to re-start trials in the first quarter of 1999.

Al Figueroa, of San Diego Gas and Electric Utility, described a molten carbonate electrolyte fuel cell installation at a naval air station at Miramar, San Diego. This uses a flat plate heat exchange reformer of advanced design, with an MC Power fuel cell, the system being commissioned in February 1997. Maximum output was lower than anticipated at 210 kW, which was attributed to voltage losses at the cathodes, although the plant was operated for 300 hours, producing 160,000 kWh of power and 346,900 pounds of steam. The trial has provided valuable experience of plant construction and operation, including automated control.

Solid Oxide Fuel Cells

A significant development proposed for the solid oxide fuel cell is to integrate the system with a gas turbine, with the fuel cell power section replacing the combustion stage of the turbine. The overall efficiency is potentially as high as 60 to 70 per cent, some of the electrical power being derived directly from a turbine-driven alternator, and some from the fuel cells. The solid oxide fuel cell efficiency is improved by running at elevated pressure using air from the turbine compressor. The system poses problems of integration and control during operation, but the potential benefits are substantial.

Advances in catalysts for both molten carbonate and solid oxide fuel cells were described by Andrew Dicks of BG plc. Internal reformer catalysts can be adversely affected by alkali metals migrating from the electrolyte, while carbon formation can provide complications in solid oxide fuel cells. The latter can be largely overcome by subjecting the fuel to a pre-reforming process before entering the cell, which has the added benefit of minimising temperature differences across the electrodes due to the endothermic reactions taking place. In several cases, addition of small amounts of platinum group metal catalysts such as platinum or ruthenium supported on inert substrates, as well as potassium and molybdenum, have been beneficial in minimising carbon formation.

Conclusions

The overall consensus was one of confidence that technical development is almost complete, and that fuel cells have entered a demonstration and exploitation phase. The number of attendees representing the power utilities and oil supply companies reflected the increasing degree of interest from these groups. After numerous trials, the views of future users are being taken into consideration in designing new generators. All the fuel cell developers emphasised their efforts to make products which will directly compete on capital cost with conventional power generation equipment, without relying on other factors, such as higher efficiency or lower pollution, to influence the market.

One of the most important points raised is the need for fuel cells to be available for purchase and demonstration. Until they are widely demonstrated it will be difficult to increase the level of public, utility and regulator awareness to the point where they are accepted as commonplace. Would-be purchasers are unlikely to be attracted by just one attribute, such as high efficiency, therefore the fuel cell must be shown to have a combination of desirable features, for example simple installation and maintenance, reliability and durability, as well as competitive capital cost.

Proton exchange membranes fuel cells have made giant strides, both in technology and in credibility as power sources for transport and stationary applications. The disclosure at the Symposium that they are being installed in a submarine illustrates their degree of safety and reliability. Most of the major automotive manufacturers plan to evaluate them in passenger or public transport vehicles. Daimler Benz and Toyota, notably, have built small vehicles, with on-board reformers to enable the use of liquid fuel, while several bus trials are in progress or planned.

According to Firoz Rasul, the Ballard Power Systems strategy is to produce fuel cells which have generic applications, for engineering into a variety of systems and applications. By collaborating with numerous system developers, and providing almost a commodity "off the shelf" product, with the maximum number of uses, it is hoped to promote sufficient sales to gain the maximum benefits from mass production.

The technical viability of phosphoric acid fuel cells is well established, and they continue to gain acceptance as highly reliable generators for combined heat and power applications. Increased competition among power companies will lead to greater demand for dispersed generators incorporating combined heat and power, particularly in applications such as hospitals, prisons and hotels, where security of supply is paramount.

Molten carbonate and solid oxide fuel cells lag several years behind the platinum catalysed, low temperature types, mainly due to challenges posed by conditions of operation. Faith in both technologies will be considerably enhanced when long term demonstrations at the 250 kW scale can be accomplished. In particular, the integration of solid oxide fuel cells with gas turbines, offering upwards of 60 per cent efficiency, is an exciting prospect for the future.

Proceedings of selected papers of the conference are expected to be published in a forthcoming issue of the *Journal of Power Sources*.