Clean Fuel Cell Energy for Today

DEVELOPMENTS IN PROTON EXCHANGE MEMBRANE FUEL CELLS

The great interest in fuel cell technology was again demonstrated last November when 1100 delegates from all continents gathered at the Palm Springs Convention Center, California, for the 1998 Fuel Cell Seminar. The organisers aimed to show that fuel cells are no longer just a potential electric power generation technology, but are now providers of clean energy.

For large stationary MW power plant applications, progress is being made in molten carbonate and solid oxide fuel cell technologies which operate at 600 to 700°C and 750 to 1000°C, respectively: sufficiently high for the waste heat to be used to raise system efficiencies. At such high temperatures platinum-based electrocatalysts are not required. It is in the lower temperature fuel cell systems, where reaction rates are low on non-platinum catalysts, that platinum is necessary to promote oxygen reduction at the cathode and hydrogen or methanol oxidation at the anode of the fuel cell.

In the last few years the Proton Exchange Membrane Fuel Cell (PEMFC) which operates at around 80°C has shown much progress by a diverse range of demonstration projects and an abundance of research and development.

The Phosphoric Acid Fuel Cell (PAFC) operating at close to 200°C is now considered a mature technology. The number of installed PAFC stationary power plants has almost doubled over the last two years. ONSI have installed over 160 PC25™ units rated at 200 kW running on natural gas. The first PC25™ units have demonstrated the necessary 40,000 hours of operating lifetime. Cost is now an issue, needing to be lowered from \$3,000/kW to \$1,500/kW, but improvements underway in fuel processing (the latest reformer is half the size and weight) and power conditioning should reduce costs.

Proton Exchange Membrane Fuel Cells

The PEMFC has the most compatible properties for transport applications. The 80°C operating temperature offers rapid start-up. The high power densities give acceptable speeds and there is good acceleration and braking from the rapid response of the stacks.

Transit Bus Application

Ken Dircks (Ballard Power Systems) outlined progress in the bus programmes of the Chicago Transit Authority and British Colombia Transit, who are each evaluating three Ballard fuel cell powered buses running on compressed hydrogen (H_2) and air. The first fee-paying passengers travelled on-board in March 1998 in Chicago. Each bus is powered by a 275 HP fuel cell engine, comprising 20 × 13 kW Ballard stacks, which occupies the same space as a diesel engine. The performance is comparable to a diesel engined bus in all respects, except that pure water vapour is the only tail pipe emission. The evaluation is planned to last for a further two years. This could lead to the serial production of bus engines. Ballard Power Systems would produce the stacks, the engines would come from dbb Fuel Cell Engines and Ecostar would provide the electric drive systems.

Automobile Application

The car market is more demanding. A higher stack performance is required and there is not sufficient space to store H_2 on-board. A fuel processor system to provide H_2 of the correct purity from fossil fuels, consisting of a reformer and subsequent CO clean-up unit, has to be integrated with the stacks. Further, the target system cost of around \$50/kW is one tenth the target cost of a transit bus system.

However, dbb Fuel Cell Engines have run a Mercedes A class car using 2 × 25 kW Ballard stacks and an on-board methanol reformer and CO clean-up unit. Nine-tenths of the system power was available within 2 seconds. A full tank of methanol (40 litres) gave a range of 250 miles.

International Fuel Cells (IFC) have developed a 50 kW ambient pressure automotive stack which has been under test at Ford Motor

Company. IFC believe that operating the stack at ambient pressure benefits the efficiency of the system. IFC are presently working on a power plant which combines the ambient stack with a fuel processor system. The processor consists of a desulphuriser, an autothermal reformer, a shift convertor and a selective oxidiser to lower the CO to acceptable levels.

Stationary Power Plant Applications

The low operating temperature of PEMFCs means that only low grade waste heat is available, but the compactness and high electrical efficiencies (> 40%) have resulted in PEMFCs also being developed for stationary power applications. Ballard Generation Systems, a venture between Ballard Power Systems and GPU International, which has alliances with ALSTOM in Europe and EBARA Corporation in Japan, is developing 250 kW units for distributed power generation to, for example, hotels, hospitals and industrial sites. The first unit, running on natural gas, was commissioned in August 1997, with the aim of producing a commercial product in 1999. Ballard Generation Systems believe that the cost targets will be met for this application, where it will compete with the PC25™.

Residential power plants (5 to 10 kW) are also being developed. A major backer of this application is Plug Power LLC in Lantham, NY, who in June 1998, demonstrated a H_2-fuelled version of a 7 kW system. They plan to commence production of the '7000 system' in two years' time using a fuel processor system, to be selected following tests. At a cost target of \$500/kW for the system, the potential market is huge: over 20 million homes in the U.S.A. and 80 million in Europe, besides the undeveloped world.

However, R. Fiskum (U.S. DOE) pointed out that satisfying the Building Regulations for a new technology is a formidable task and must be planned for early in a programme alongside developments in the technology.

Portable and Other Applications

Low power applications (< 1 kW) may be the first to be commercialised. H Power Corporation has been producing systems commercially since the second quarter of 1998. Much effort has been devoted to reducing the size and weight of the stack. Atmospheric pressure operation of the stack without reactant humidification and with air cooling simplifies the system. Systems are available which deliver from 35 to 500 W for a range of specialist applications; for example, a 100 W (2 × 50 W stacks) backup power system is being supplied to the New Jersey Department of Transportation for its solar powered variable message signs. The fuel cell system can operate on H_2/air continuously for twelve days using only 50 W. The H_2 is supplied from four gas cylinders, readily replaceable in the field. Compared with the battery originally in use, the fuel cell requires less maintenance and has a longer life.

H Power are also developing 50 and 150 W light-weight military power sources and A. F. Sammer are developing the chemical hydride source for H_2 supply. The military market is large, with the U.S. Army spending some \$10 to \$20 million/annum on batteries. However, in contrast to these specialist markets, for use around the home, the H_2 fuel supply has to be resolved and a lower system cost is required.

Technical Progress

These examples demonstrate the potential of PEMFCs to meet various markets, but for commercialisation a reduction in the cost of the stack and the further development of fuel processor technology is necessary.

In the stack the machined graphite flow field plates used to distribute the reactant gases must be replaced by lower cost material (< \$5/kW), and cost-effective membrane electrode assemblies (MEAs) consisting of the platinum-containing electrodes and the membrane are needed.

Flow Field Plates

K. Ledjeff-Hey (University of Duisburg) described the injection moulding of carbon black-polymer composites with a projected cost of \$3/kW. While perhaps acceptable for low power applications, the specific resistance will be at best probably 0.1 Ω cm, which is an order of magnitude too high for automotive applications.

Promising results using a compression moulded composite prepared using a thermosetting resin, such as vinyl ester, with a high loading of graphite powder (68%) were shown by D. Busick and M. Wilson (Los Alamos National Laboratories, LANL). Tests on this material at Plug Power LLC showed comparable performance to machined graphite plates.

In addition to moulding techniques another approach is to use thin stamped metal plates. Most metals have a bulk resistivity at least an order of magnitude less than graphite, but contact resistance is a problem. C. E. Reid (University of Victoria, Canada) showed that a performance close to that of graphite could be achieved at high current densities using 316 stainless steel (SS). The treatment the surface receives is, however, important. LANL have shown that 316SS can be run for up to 3,000 hours without loss of MEA performance provided the membrane does not contact the metal plate. In a stack, however, shunt currents could be a problem, so careful cell design will be required and some form of metal coating will probably be necessary.

MEAs

Johnson Matthey, 3M Corporation and W. L. Gore & Associates are all currently pursuing the manufacture of MEAs with cost-effective platinum cathode and platinum/ruthenium anode loadings. Platinum/ruthenium improves the CO tolerance of the anode. Acceptable performance at platinum loadings as low as 0.3 mg Pt cm^{-2} on each electrode, and lower in small cell tests, has been clearly demonstrated. There is now a need to reduce the costs of other MEA materials, to develop volume manufacturing technology and to raise performance.

Johnson Matthey's approach is to work with selected stack developers to tailor the MEA performance to the stack using the mass manufacture of catalysts, electrodes and MEAs. Johnson Matthey are the major supplier of catalysed products to various Ballard programmes.

3M Corporation is using a continuous process to prepare nanostructured catalyst support films and depositing < 0.2 mg Pt cm^{-2} on both cathode and anode films. The films are then bonded to conventional membranes and the package is compressed to gas diffusion backings, also prepared by a continuous process, to give a 5 layer MEA product. Single cell testing has shown good kinetic performance with H_2/O_2 operation. However, the gas diffusion backings need to be improved to raise the mass transport performance for acceptable H_2/air performance.

At present W. L. Gore & Associates are the only company to have MEAs available for sale, albeit at high cost. Their PRIMEA™ MEA technology is based around the PTFE-reinforced GoreSelect™ membrane. The membrane has a high performance since it is very thin (15 to 40 μm), even though the specific resistance is much higher than, for example, that of Nafion® membranes. Very high power densities ~ 1 W cm^{-2} have been reported. A third generation PRIMEA™ 5560 MEA for reformate operation was announced. This MEA responds well to an 'air bleed'; this involves the gas phase oxidation of CO to CO_2 by air injection into the reformate stream just before it enters the stack. At economical platinum/ruthenium anode loadings an air bleed is necessary to give complete tolerance to tens of ppm of CO. PRIMEA™ MEAs are undergoing durability stack tests.

Fuelling Issues

While the use of methanol in the direct methanol fuel cell (DMFC) offers a promising alternative to H_2, particularly for low-power applications, it requires better anode electrocatalysts than platinum/ruthenium and membranes less permeable to methanol than Nafion®. For high-power applications the aim is to develop a reformer and platinum group metal-based CO clean-up technology for H_2/air PEMFCs. There is much activity here; Johnson Matthey have developed the HotSpot™ reformer and the Demonox™ CO clean-up unit, based on selective oxidation.

For stationary applications steam reforming of natural gas is being investigated, while for transportation, partial oxidation (POX) or autothermal reforming of methanol and gasoline are being pursued. With hydrocarbon fuels an initial catalytic hydrodesulphurisation stage is necessary to convert the sulphur to H_2S which is then adsorbed in a bed of zinc oxide.

Epyx and Hydrogen Burner Technology are developing fuel-flexible 50 kW fuel processors and S. Ahmed (Argonne National Laboratory) showed that a 3 kW POX reformer is capable of reforming both hydrocarbon and alcohol fuels at below 800°C. W. Mitchell (Epyx Corporation) explained the integration of a 10 kW POX reformer operating on ethanol and California Phase II reformulated gasoline, which has high temperature shift (HTS) and low temperature shift (LTS) convertors, with a 10 kW preferential oxidation (PROX) CO clean-up reactor and a fuel cell stack. The reformer produced H_2 with < 1% CO for over 300 hours. The PROX reduced the CO to < 10 ppm, with a loss of 0.1 to 2% H_2 as water.

The development of higher surface area versions of commercially available shift catalysts for the fuel-flexible POX reformer (F^3P) was described by J. Cuzens (Hydrogen Burner Technology). Testing the HTS and LTS catalysts reduced CO levels from 16% to < 50 ppm under steady state operation and to 500 ppm under transient operation.

LANL have developed a 4-stage PROX reactor. Using inlet CO levels of 8000 ppm it was possible to achieve outlet concentrations of 35 to 50 ppm CO. The PROX will be integrated with the POX reformers being developed by Epyx and Hydrogen Burner Technology.

R. Dams (WCJB) showed progress in the JOULE project to produce a compact methanol steam reformer and a gas clean-up unit. Compact aluminium heat exchangers are used, where one face is coated with a commercial reformer catalyst (Cu/Zn) and a platinum group metal selective oxidation catalyst; the other face is coated with a Pt/AlO_2 combustion catalyst to promote burning of the fuel off-gas to raise the overall system efficiency.

Work at Loughborough University identified platinum/ruthenium catalysts as the most effective for the selective oxidation of CO with almost complete CO conversion at close to 100°C. In the JOULE project the reformer and CO units are typically operated at 275 and 160°C, respectively. Start-up times of 150 s have been achieved with CO contents of < 10 ppm and H_2 concentrations approaching 75%.

Asahi Chemical Industry Co. announced recently that a ruthenium-based selective oxidation catalyst produces < 1 ppm CO from reformate mixes, with no H_2 loss, at temperatures from –20 to 110°C. This approach could further improve selective oxidation reactors. In addition B. Vogel and colleagues (Fraunhofer Institute for Solar Energy Systems) had compared steam and autothermal reforming and found that the latter could decrease start-up times, at the expense of lower H_2 yields.

Future Costs

To conclude, there is much activity in developing PEMFCs; the technology is clearly capable of delivering clean electrical power. In addition, progress is being shown in reducing costs and in resolving fuelling issues. T. R. RALPH

Sixth Grove Fuel Cell Symposium

Ten years after the First Grove Fuel Cell Symposium, the sixth meeting in the series, entitled "The Competitive Option for Sustainable Energy Supply", will be held in London on 13th to 16th September 1999 at the Queen Elizabeth II Conference Centre. Attention will be focused on the achievements throughout this period with papers on technical progress and advances towards commercialisation. The contribution of the fuel cell to sustainable energy supplies will be of particular interest.

Further topics will include marketing developments and the science and technology of fuel cells. It is hoped that there will be demonstrations of various small-scale fuel cell applications.

Invited authorities from all sectors of the fuel cell industry, academia and government will speak. There will also be a poster display for which contributions are requested.

For further information contact Phillipa Orme, Sixth Grove Fuel Cell Secretariat, 12 Church Street, West Hanney, Wantage, Oxon OX12 0LN; tel: +44(0) 1235 868811; fax: +44 (0) 1235 868811; E-mail: p.orme@dial.pipex.com. The Grove Fuel cell website is at http://www.elsevier.nl/locate/fuelcell99.