Demonstrating the Benefits of Fuel Cells

FURTHER SIGNIFICANT PROGRESS TOWARDS COMMERCIALISATION

The continuing worldwide growth of interest in fuel cells, used for power generation in a variety of applications, was reflected by the record attendance of 700 delegates from 20 countries at the fourteenth Fuel Cell Seminar, held in San Diego, California, U.S.A. from 28th November to 1st December 1994. The theme "Demonstrating the Benefits" was chosen to reflect the view that fuel cells are now on the threshold of commercialisation. The exploitation of this high efficiency, low pollution technology is currently dominated by the low operating temperature, platinum-catalysed fuel cells.

Fuel cell owners from North America reported positively on their experiences with the first commercial phosphoric acid fuel cell (PAFC) cogeneration plants. Clear evidence was presented that these units are showing the necessary reliability to compete with the existing mature natural gas-fuelled engine and turbine technologies. In the next generation 200 kW fuel-cell system, to be launched in 1995 by ONSI, a subsidiary of International Fuel Cells (IFC), manufacturing costs have been reduced by over a half.

The conference also heard from Ballard Power Systems and Dow Chemical Company of their joint plan to enter the market with a compact product based on the rapidly emerging proton exchange membrane fuel cell (PEMFC) technology.

The development of fuel cells as the primary power source in a variety of transport applications is now being spurred on not only by the

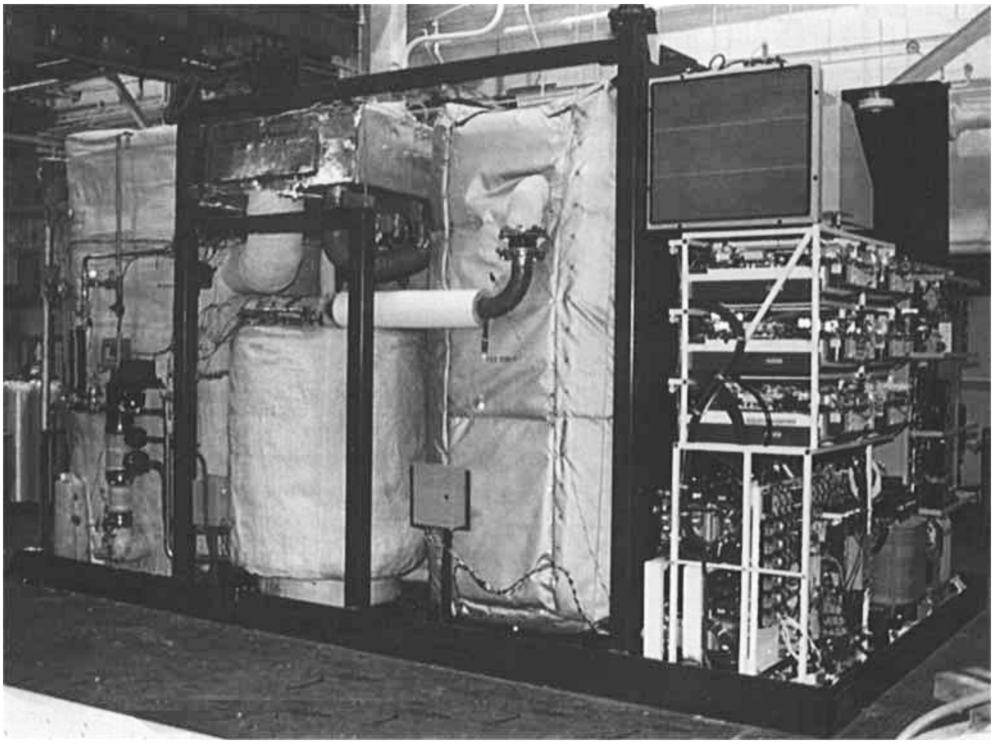

Fig. 1 ONSI's 200 kW PC25C phosphoric acid fuel cell production prototype during assembly, showing the three major subsystems, from left to right, the fuel processor, cell stack and power conditioner

impending zero emission standards, due to be enacted in California from 1998, but also by the U.S. Government programme – "Partnership for a New Generation Vehicle" – aimed at producing an 80 miles per gallon vehicle. This has led to the instigation of PEMFC programmes at General Motors, Ford and Chrysler. However, fuel cell powered heavy-duty vehicles are likely to be commercialised before cars and vans. This was demonstrated by the impressive H Power Corporation/U.S. Department of Energy methanol-fuelled, PAFC powered, 30-foot long transit bus displayed at the conference.

Stationary Applications

The PAFC remains the fuel cell closest to widespread commercial exploitation. Over the past two years the ONSI fleet of fifty-six PC25A 200 kW co-generation power plants has provided fuel cell owners around the world with valuable operating experience. Around 50 per cent of the fleet has now been operated for over 10,000 hours, with 17,000 hours being the longest operation.

The average fleet availability has been 96 per cent. The views of the users, particularly those of the North American Fuel Cell Owners Group, representing thirteen gas and electric utility companies, was very encouraging. The results have demonstrated that service personnel could operate and maintain these fuel cells to a high degree of reliability. Over the past two years the mean interval between plant power down time has increased from 1010 to 3290 hours. This compares to 507 hours for comparable natural gas co-generation engines rated at over 80 kW.

Fig. 2 Ballard's 30 kW hydrogen-fuelled proton exchange membrane fuel cell is the world's largest PEM stationary power plant. The unit is grid connected and in operation at an industrial facility

However, the PC25A units are still too costly for large volume commercial sales. On-going developments at IFC and ONSI have resulted in the recent installation of a more compact PC25 Model C manufacturing prototype plant, see Figure 1. At 1800 ft^3 and 40,000 lbs, this is one third smaller and lighter than the PC25A and costs half as much to manufacture. A 25 per cent reduction in the number of mechanical parts is predicted to improve further the system reliability. Production units will be available for delivery in 1995. The user groups indicated that with the benefit of proven reliability, the PC25C could be cost competitive in the premium quality power markets, such as data and communications centres and healthcare facilities. However, unless the significant environmental advantages of fuel cells can be economically accounted for, it will be necessary to reduce capital costs further to enable the fuel cell to compete head-on with current generating technologies. This point was noted by T. Page of the San Diego Gas and Electric Company in his keynote address opening the conference. He emphasised that with the likely future deregulation of electricity generating businesses in the U.S.A., a key priority for fuel cells in this application was the need to be a low cost energy supplier. A further reduction in selling price of approximately 50 per cent for the ONSI PC25 plants is being targeted for 1998, if sufficient production volumes are achieved.

Operation of the PAFC plant at around 200°C provides an opportunity to produce useful heat for co-generation applications. The lower operating temperature of PEMFCs, typically below 100°C, has resulted in transportation being their principal use. However, Dow Chemical Company and Ballard Power Systems reported on progress to develop and commercialise jointly

Fig. 3 The first methanol-fuelled, phosphoric acid fuel cell powered transit bus, produced by H Power Corporation in the U.S. Department of Energy sponsored programme. This meets all the required performance criteria but with improved fuel efficiency and significantly reduced exhaust emissions and noise pollution

PEMFC power plants for stationary power markets. A grid-connected 30 kW hydrogen-fuelled plant and the first of several 10 kW natural-gas fuelled plants are already in operation (Figure 2). They plan to launch a prototype 250 kW system in 1996 and enter low-volume production of power plants in 1998. The size and weight specification of the plant are 1184 ft^3 and 27,600 lbs, respectively, and it is designed to be cost competitive with conventional power generation technology. Heat at a temperature of 74°C will be available at 810 MBTU/h.

The Japanese PAFC-Technology Research Association is co-ordinating programmes to develop and commercialise larger stationary power plants. The building of 1 MW and 5 MW plants for large scale on-site co-generation and dispersed utility power, respectively, are nearing completion. These plants are due to become operational in 1995. However, in the longer term, the intrinsically more efficient high-temperature fuel cell systems are also being developed for multi-megawatt power generation. Energy Research Corporation and M-C Power Corporation in the U.S. are currently constructing a 2-MW plant and 250-kW plants, respectively, based on the molten carbonate fuel cell. However, significant movement towards commercialisation of this technology is not expected before the end of the 1990s.

Transportation Applications

Urban transit buses represent the earliest and technically least demanding entry point for fuel cells in the transportation market. Consequently there are several programmes which have reached the demonstration stage. The first of three fuel cell powered buses to be built during Phase II of a programme managed by H Power Corporation and co-sponsored by the U.S. Departments of Energy and Transportation and the South Coast Air Quality Management District (SCAQMD) was on show (Figure 3). It provided clean, quiet and smooth rides for the conference delegates. The power system employs a methanol steam reformer and a Fuji 50 kW PAFC engine, with necessary control equipment and ancillaries, including a nickel-cadmium surge battery for hill climbing and acceleration. Toxic emissions from the hydrocarbon-fuelled vehicle are orders of magnitude lower than demanded by 1998 U.S. Federal Standards. To-date it has demonstrated over 1000 hours of operation. It is planned that the programme will eventually set the stage for the production of fuel cell powered transit buses towards the end of this decade. Significant weight and volume reductions, together with cost reductions across the board, are planned.

Most transportation programmes are focusing on the PEMFC because of its rapid start-up from room temperature and the significantly higher power densities that can be achieved. Ballard Power Systems have already demonstrated a prototype 32-foot long transit bus, fuelled on compressed hydrogen and meeting the zero emission vehicle (ZEV) standards. However, if PEMFCs are to take advantage of the California ZEV mandate, which requires 2 per cent of all vehicles to be ZEV in 1998 and 10 per cent in 2003, there are several crucial technical issues that have to be resolved.

For all light-duty vehicles, on-board reforming of a hydrocarbon fuel appears to be the preferred fuelling option. This is one of the most challenging technical hurdles. General Motors and the Los Alamos National Laboratories (LANL), in a U.S. Department of Energy sponsored project, have demonstrated the feasibility of integrating a compact methanol steam reformer with two 5 kW Ballard PEMFC stacks. The steam reformer has three beds, consisting of the primary reformer, water-gas shift reactor and preferential oxidation reactor. Under steady state conditions the output from the fuel processor is less than 10 ppm carbon monoxide, a level which is considered tolerable for the platinum-based anode catalyst. Transient levels of around 100 ppm carbon monoxide are not tolerable.

Vickers Shipbuilding and Engineering Ltd. and CJB Developments have also developed a prototype methanol reformer based on a similar concept, but the 15 minute start-up time needs to be improved in the next phase of the programme. While methanol steam reforming is favoured in the above programmes, others, including Arthur D. Little, Argonne National Laboratories and Chrysler Corporation, favour partial oxidation with its advantage of fuel flexibility. This technology is less well developed than the steam reformers which are themselves at an embryonic stage. Thus there is still a significant technical challenge to be met in developing compact, rapid start-up and responsive reformer technology. It appears likely that to cope with transient behaviour, the fuel cell anode will have to display significantly greater tolerance to trace levels of carbon monoxide than current stacks possess. This provides an opportunity to develop improved platinum-based catalyst materials, and promising results with low loading carbon-supported platinum-ruthenium alloy catalysts were reported by the groups from General Motors, LANL and Johnson Matthey.

In addition to reformer developments there are other important technical issues concerning the PEMFC stack itself. At present the demonstration stacks are too costly and also need to show improved performance (higher power density), even on pure hydrogen/air operation. Savings in cost through the development of component manufacturing processes and reductions in the cost of materials by using lower platinum cell loadings, cheaper membrane materials and cheaper bipolar plate materials, were emphasised frequently during the conference.

Considerable progress in these areas has been shown in single cell studies. Dow Chemical Company, LANL, Johnson Matthey, ECN and General Motors all showed single cell performance at electrode platinum loadings close to 0.1 mg/cm^2 comparable to the performance of the 4.0 mg/cm^2 of unsupported platinum black used in current stacks. Dow showed single cell data on the recently developed membrane material, XUS13204.20, of resistance 0.04 Ωcm^2, which is approximately 50 per cent lower than the earlier developmental material. This has a large impact on performance, particularly at higher current densities. Dow also believe that a membrane material of ohmic resistance 0.02 Ωcm^2 could be developed.

ECN have demonstrated that it is possible to run cells using stainless steel bipolar plates, instead of graphite, without severe degradation due to membrane contamination by impurities in the plate. Cell voltages are lower, however, probably because of higher contact resistances.

There is also a resurgence of interest in direct methanol oxidation fuel cells, particularly with regard to their operation in a PEMFC environment. Siemans reported a performance of 400 mA/cm^2 and LANL quoted 300 mA/cm^2, both at 0.5 V, with Nafion 117 electrolyte and platinum/ruthenium anode catalysts. While these performances are considerably higher than those achieved in the past using systems based on a liquid sulphuric acid electrolyte, there is still a need for major catalyst development to reduce the anode overpotential and increase the current density. A further significant problem in this system is methanol permeation through the polymer electrolyte membrane to the cathode.

Other Applications

Fuel cells continue to be developed for numerous military related applications. Analytic Power Corporation reported on portable hydrogen-fuelled PEMFC units, rated from 50 to 500 W, for applications such as powering backpack microclimate cooling systems. Studies show that the units can effectively replace batteries on performance and cost, in situations involving long mission times. Direct methanol fuel cells are also being developed for these applications under U.S. Government Advanced Research Projects Agency contracts.

Ballard PEMFC systems are being developed as power sources for submarines. A one-tenth scale 40 kW technology demonstrator, fuelled on reformed methanol with liquid oxygen as the oxidant, is due to be developed by 1996. Design studies on an 850 kW PEMFC for application as the service generators of ships are also being undertaken. A particularly challenging target in this programme is to develop a multi-fuel reformer, which can operate on logistic fuels. IFC have also demonstrated a high power-density 10 kW prototype of a 20 kW PEMFC system, designed to be installed in a 44-inch unmanned undersea vehicle, as a higher energy-density replacement for the currently used silver-zinc batteries. IFC believe that this power plant will have high reliability, durability and mission duration. This is due to design features in which the hydrogen side of the power plant is dead-ended, and on the cathode side a passive water removal system is used, thereby avoiding the circulation of gaseous reactants.

Conclusions

The 1990s will be the most significant period in the long development of fuel-cell power generation systems. The first PAFC co-generation plants are proving to be highly efficient and reliable generators, but further developments of the fuel cell, or the emergence of PEMFC stationary plants, are required before a fully commercial, cost effective product is available, near the end of the decade. Opportunities for using fuel cells in transportation have been provided by the impending legislation in the U.S.A. and the U.S. Government programme to improve vehicle fuel economy. Rapid progress is being made in overcoming technical and economic hurdles in the development of PEMFC based systems, and the late 1990s should see the start of a large scale use of this clean, efficient technology for powering vehicles – with the first markets likely to be heavy-duty transit buses. G.A.H., T.R.R.

Nanocatalysis Uses Platinum-Rhodium Tip

Studying the atomic structures involved in catalysis under catalytic conditions is possible using the recently developed scanning tunnelling microscope (STM) that operates inside a reactor cell. This equipment has enabled the STM tip to pattern a surface and manipulate atoms. Researchers at the University of California, Berkeley, have suggested that the tip can be made to act catalytically to produce investigable surface reactions (B. J. McIntyre, M. Salmeron and G. A. Somorjai, *Science*, 1994, **265**, (5177), 1415–1418).

With a platinum-rhodium STM tip in a reactor cell and a propylene atmosphere ordered propylidyne structures were formed on the platinum surface. Carbon monoxide and propylene-hydrogen mixtures were introduced into the cell to observe the reaction, and characteristic clusters were seen after activation of the tip by short electric pulses. The catalytic action caused by the tip may be atomisation of hydrogen from the gas phase and hydrogenation of the carbon bonds of the clusters under it.

This method provides possible insights into atomic-scale structures and the kinetics of local catalytic activity, which presently is only studied in an average way by more conventional tools.