Fourth Grove Fuel Cell Symposium

FROM TECHNICAL SUCCESS TO THE CHALLENGES FACING COMMERCIALISATION

"Opportunities, Progress and Challenges" was the theme chosen for the Fourth Grove Fuel Cell Symposium, held at the Commonwealth Institute, London, from 19th to 22nd September 1995. Some 250 delegates from 23 countries heard that fuel cells, used for clean and efficient power generation, had made tremendous technical progress over the two years since the last Grove conference. Most advances had been made with the phosphoric acid fuel cell (PAFC) and the proton exchange membrane fuel cell (PEMFC), both of which operate at low temperatures and employ platinum-catalysed electrode materials.

The growing acceptance that fuel cell technology is now proving itself in use was demonstrated by the considerable attention paid at this conference to cost reduction, market entry opportunities and the issues surrounding fuelling and infrastructure.

Fuel Cell Technology Status

The PAFC is the fuel cell closest to widespread commercial exploitation. The leading world developer is ONSI, a joint venture between International Fuel Cells (IFC) and Toshiba. Their fleet of fifty-six PC25A 200 kW co-generation power plants have been successfully operated by their owners over the past three years. H. D. Ramm of IFC reported that the PC25A units have now accumulated 750,000 fleet hours of operation, with a remarkable worldwide average availability of 94 per cent and a mean time interval between power plant down time of 2,200 hours. This unprecedented reliability is already significantly better than the conventional mature co-generation technology.

The next generation PC25C system is one third smaller and lighter than the PC25A, and costs half as much to manufacture. The plant is available at $3,000/kW and ONSI already has buyers for two-thirds of the 50 plants it intends to build over the next two years.

The PEMFC can operate at higher power densities than other fuel cell types and, because of this and its intrinsic simplicity, it is considered suitable for both stationary and transportation applications. Progress by Ballard Power Systems of Canada, in the development of a commercial product for both applications, was described by K. B. Prater. A prototype stationary 250 kW power plant, operating on natural gas and producing grid quality AC power, is due for completion in early 1996, with a demonstration of pre-commercial units in a utility environment being on schedule for field trials in 1997 to 1999.

A more tangible indication of the potential of this fuel cell was demonstrated by its application in powering transit buses. Following the first phase feasibility demonstration in 1993, Ballard have now produced the pre-commercial prototype of a fuel cell powered zero emission transit bus. In this full sized 40 ft commercial bus, a PEMFC engine comprising twenty Ballard second generation stacks, produces a total of 200 kW (275 hp) – the same power as the diesel engine normally installed in the bus.

Further evidence of the commercial viability of this application is the fact that the fuel cell engine occupies the same space as the diesel engine, see Figure 1, and provides at least the same performance. The fuel cell supplies the entire motive power for the bus, and also the power for lighting and air conditioning. The buses are powered by hydrogen stored in compressed gas cylinders in the roof space, and have a range of 400 km (250 miles). Refuelling with hydrogen at the bus depot is expected to take only minutes and is seen as a workable fuelling option for fleet vehicles.

These second generation stacks produce 13 kW under standard operating conditions at an average cell voltage of 0.58 V. The power density output of 300 W/l is double that of the original 5 kW stacks employed in the first bus.
Ballard also reported that the third phase in the commercialisation of the transit bus involves fleet trials by transit companies in routine operation. The first of these, to start in 1996, has recently been announced by the Chicago Transit Authority. The scheduled date for full bus commercialisation, powered by a third generation stack, currently under development, is 1998. These buses will be designed to have a range of 560 km (350 miles).

Progress was also reported between Ballard and Daimler-Benz on the development of stacks with very high power density for use in small passenger vehicles. The target power density for this, the most demanding application, is usually regarded as 800 to 1000 W/l. Ballard used this conference to announce that they had produced a stack with a volume of 31.9 litres delivering a continuous output of 32.3 kW at a high average cell voltage (thus high efficiency) of 0.68 V. The stack operates at lower-than-standard operating pressures to increase efficiency further, and easily meets the 1000 W/l target. This stack exceeds the power density targets identified in the U.S. programme – “Partnership for a New Generation Vehicle” (PNGV). Recent progress has been so successful, that even for this application, the emphasis will shift away from the achievement of key performance criteria, towards maintaining this performance in stacks manufactured in high volumes at costs comparable to those of the present day internal combustion engines.

Optimising Platinum Use
An example of the progress being made in cost reduction is shown by the requirement of the platinum electrocatalyst. The early generation PEMFC stacks use high platinum loadings of around 4.0 mg/cm² of electrode area. This is economically unfeasible for most applications. The PNGV programme is aiming to achieve loadings of 0.1 mg/cm² by the year 2004, and although loadings of less than 0.5 mg/cm² have frequently been demonstrated in small laboratory fuel cells, this now needs to be confirmed.
on full scale stacks. Ballard believe that total cell platinum loadings of less than 1.0 mg/cm² are attainable and they are working to achieve this with mass production techniques in their programme with Johnson Matthey.

The low operating temperature fuel cells (<200°C) of the PAFC and PEMFC types, continue to use exclusively platinum or promoted platinum based electrocatalysts for both electrode reactions. The technical poster session highlighted some of the current research into new electrocatalytic materials. Many researchers are modifying platinum so it is able to tolerate trace levels of carbon monoxide, present in reformed hydrogen, for PEMFC applications. Promising initial results using tungsten oxide promoted platinum/ruthenium alloys were described by A. C. C. Tseung, K. Y. Chen and P. K. Shen of Essex University.

**Fuelling Fuel Cell Powered Vehicles**

It is presently anticipated that small vehicles, unlike buses, will have to be fuelled with a high energy density liquid fuel, since it is unlikely that hydrogen storage technology will advance sufficiently for them to be able to store on-board adequate quantities to give acceptable vehicle ranges. To-date the favoured option has been to reform liquid methanol on-board the vehicle in order to produce a hydrogen-rich fuel for the fuel cell stack.

This approach has been adopted by Daimler-Benz in their fuel cell vehicle programme, as reported by T. Klaiber, and also by General Motors in their U.S. Department of Energy/ PNGV programme. Although steam reforming is the most highly developed process, there is growing interest in partial oxidation reforming, which, because it is an exothermic reaction, can achieve a more rapid start up and response under dynamic conditions. The intrinsic simplicity of the latter approach and potential lower cost is viewed as the most important factor at this stage in the commercialisation of fuel cell powered vehicles.

The most elegant solution to the technical challenge of on-board reformer development is the direct use of liquid methanol oxidation in the fuel cell stack (DMFC). Current work on this technology was described by M. Waidhas, W. Drenckhahn, K. Mund and W. Preidel of Siemens. They reported considerably improved levels of cell performance when a polymer membrane, similar to that used in the hydrogen fuelled PEMFC, was employed as the electrolyte (SPE-DMFC). Previous cell current densities of 50 mA/cm² at 0.4 V have been too low to be of practical use, due to poor kinetics of the methanol electro-oxidation reaction, but Siemens have now been able to achieve current densities of up to 400 mA/cm² at 0.5 V and Faradaic efficiencies of over 90 per cent. Better kinetics at the platinum based catalyst/membrane interface may contribute to this improvement, although the best results have been obtained at 140°C using pure oxygen, which is impractical for most high volume applications.

In the United States the Jet Propulsion Laboratory is at the forefront of renewed interest in DMFCs, and in a poster presentation (H. Frank, S. R. Narayanan, W. Chun, B. Nakamura, T. Valdez, S. Surampudi and G. Halpert) on the SPE-DMFC programme, reported that platinum/ruthenium remained the electrocatalyst of choice for methanol electro-oxidation, and that performances on air operation of up to 300 mA/cm² at 0.4 V were being achieved.

Although these performances are creating greater interest, there is still need for further improvement, through advances in the catalysis of both the methanol oxidation and oxygen (air) reduction reactions.

**Diesel/Gasoline Fuel**

The growing maturity of fuel cell stack technology was demonstrated by discussion of the key issue of fuel infrastructure, particularly for mobile applications. C. Borroni-Bird of Chrysler strongly advanced the view that the preferred choice of fuel should not be methanol but existing fuels such as gasoline/diesel. This is due to a belief that existing oil pipelines cannot be used for distributing methanol, due to its highly corrosive nature.

Additional factors, such as the high cost of investing in new methanol plant, the cost of
methanol and its lower energy density were cited by others supporting this stance. It was suggested that the very low efficiency of reforming petroleum based fuels, for example diesel fuel, if used in a partial oxidation reactor, would be offset by the much higher efficiency of diesel production, relative to that of methanol.

The U.S. Department of Energy (DoE) is supporting a programme being undertaken by Arthur D. Little, that has a target of a 50 kW gasoline fuelled partial oxidation reformer by 1997. Laboratory results have shown that gasoline can be successfully reformed to a hydrogen containing fuel.

**High Temperature Fuel Cells**

The most advanced high temperature fuel cell is the ERC (Energy Research Corporation) 2 MW molten carbonate fuel cell (MCFC) demonstration at Santa Clara, California. This system, which was described by D. R. Glenn of Fuel Cell Engineering Corporation, is due for completion and start up in early 1996. The higher intrinsic efficiency of this fuel cell (design target is > 52 per cent) gives it the potential to compete with existing generating technologies in the multi-megawatt power generation range. A further key advantage is its fuel versatility, since it can operate on, for example, natural gas, landfill gas, biogas or fuel obtained from coal gasification.

Stacks of the type to be used in the plant have successfully accumulated 100,000 hours of operation in controlled environments, and ERC are confident of their performance capability. A market entry for a 2.8 MW power plant is targeted for 1999.

The success of both this and the other significant MCFC demonstration – M-C Power's two 250 kW power plants – will be critical to the future of this fuel cell technology.

The even higher temperature operated (~1000°C) solid oxide fuel cell (SOFC) can be designed with either tubular or planar cell geometries. A 25 kW unit of the former type, is being developed by Westinghouse and was reported to have now achieved over 7,000 hours of operation, whereas the development of a planar 10 kW type as a mobile electric power generating system was described by L. J. Frost, R. M. Privette and A. C. Khandkar of SOFCo.

**Market Opportunities**

Reducing cost was the key topic for discussion and in particular how to reduce production costs to enter the market; however, in order to achieve the necessary lower costs, volume manufacturing resulting from market penetration is first needed!

Many speakers, including H. D. Ramm of IFC, emphasised the targeting of high value niche applications; such as reliable power for hospitals, high quality power for computer, telecommunications and data centres, and as alternatives to centralised power generation where transmission, distribution and the provision of new lines is a contentious issue. The entry market has to be specialised and clearly focused on applications where the benefits offered by fuel cells can be fully valued.

Indeed, for stationary applications the real cost of fuel cell power generation should be assessed against the complete life-cycle costs, which should include capital cost, installation, operation costs (maintenance and fuel) and overhaul. Ramm reported that the PC25C were now approaching a figure of 1.5 cents/kWh over a 20 year life cycle.

The cost issue was taken a step further by P. Bos of Polydyne, who suggested that minimising the financial risk was critical to fuel cell commercialisation. The cost of commercialising a 2 MW utility system was estimated to be 200 times larger than that of a 2 kW system. As fuel cell use in transport is unlikely to provide an early commercial market, due to the low market value caused by the low cost of the internal combustion engine, he identified the stand-alone micro-co-generation residential application as a high value entry market. A consortium of 12 major utilities have formed the “Small Scale Fuel Cell Commercialisation Group” to demonstrate 50 to 100 2 kW units per utility, probably based on PEMFC technology, by 1998.

The opportunity offered by the residential market was identified by other groups, including...
B. Barp, R. Diethelm, K. Honegger and E. Batawi of Sulzer Innotec, who are working on developing the SOFC for this application.

For transportation, heavy-duty vehicles such as transit buses or trucks represent the best opportunity for early market entry. The U.S. DoE figures show that in North America the current annual demand is for 25,000 buses and 900,000 trucks (> 10 klbs). S. Chalk, of the U.S. DoE, reported that if the forthcoming zero emission regulations were adopted by California and the North Eastern states, there would be a total requirement of 353,000 zero emission vehicles (ZEVs) in the year 2003.

In the near term these will be geared to battery cars, and the DoE predict that fuel cell cars will not enter the market until 2007, and will attain 8 to 10 per cent of new annual sales by 2030 (currently 16 million new vehicles per year in North America). The DoE model makes the assumption that fuel cells and all other competing new technologies would be equally successful in meeting technical and economic goals.

Since cost was viewed by several speakers as the most critical factor influencing the rate of commercialisation, they believed that stack developers should not put undue emphasis on factors such as stack efficiency at this stage. For example, the much simpler partial oxidation now appears the more acceptable fuel processing route despite the slightly lower system efficiency projected by most model analyses.

**Conclusions**

The PAFC co-generation plants continue to demonstrate highly efficient and reliable operation, but large markets are needed before a fully cost effective product can become widely available. The PEMFC system has made rapid progress with the development of high power density stacks which meet targets for transportation applications. Early market opportunities lie with fleet vehicles, such as transit buses, which can tolerate larger sizes, higher costs, and on-board hydrogen fuel storage and depot refuelling. Commercialisation is on schedule for the end of the decade. Opportunities for light-duty passenger cars have been provided in the United States by the zero emission regulations, to be enacted in 1998, and the programme to improve vehicle fuel economy.

The technical progress over the past three years is such that attention is moving away from fuel cell stack technology issues of cost, market entry opportunities and the fuelling infrastructure. These are the key challenges for the latter half of the 1990s, in the development of a commercial market for power generation based on fuel cell technology.

G.A.H.

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**Osmium, the Densest Metal Known**

Until recently much confusion existed in the literature as to which is the densest metal, osmium or iridium. Crabtree reviewed the experimental data, but his calculated densities of 22.59 ± 0.02 g/cm³ and 22.57 ± 0.02 g/cm³, respectively, led to an overlap in the uncertainties and a suggestion that the problem had not been solved (1). However, in a similar review by the present author, calculated densities at 20°C of 22.588 ± 0.015 g/cm³ and 22.562 ± 0.009 g/cm³, respectively, suggested that the problem just may have been resolved in favour of osmium (2).

Although the uncertainties calculated for the densities are usually dominated by the accuracies assigned to the lattice parameters, the accuracy of the atomic weight can also contribute significantly – if it is poorly known, as was the case for osmium until quite recently. However with newly accepted atomic weights of 190.23 ± 0.03 for osmium and 192.217 ± 0.003 for iridium the contribution to the uncertainties of the densities is now minor (3). Using the lattice parameters selected previously by the present author (2), the calculated density of osmium is revised to 22.587 ± 0.009 g/cm³ while that for iridium remains the same. On these grounds it is suggested that osmium can now unambiguously be considered to be the densest metal at 20°C.

J.W.A.

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**References**