# INTRODUCTION TO FUEL CELLS

Technology-specific input to the CERT Ministerial Paper. Prepared by Heather Haydock, Secretary to the IEA Advanced Fuel Cells Executive Committee, November 1998.

## 1. BRIEF DESCRIPTION OF THE TECHNOLOGY

Fuel cells are a rapidly developing energy conversion technology. Offering higher efficiencies and significantly lower emissions than conventional technologies, they also operate quietly and have a modular construction that is easily scaleable. These features mean that fuel cells are attractive for a range of potential applications, including combined heat and power (CHP), distributed power generation and transport. In the longer term, fuel cells may also be used for large scale power generation, probably in combination with gas turbines (GT).

Fuel cells are electrochemical devices which convert the energy of a chemical reaction directly into electricity, with heat as a by-product. They are similar in principle to primary batteries except that the fuel and oxidant are stored externally, enabling them to continue operating as long as fuel and oxidant (oxygen or air) are supplied.

Each cell consists of an electrolyte sandwiched between two electrodes. Fuel is oxidised at the anode, liberating electrons which flow via an external circuit to the cathode. The circuit is completed by a flow of ions across the electrolyte that separates the fuel and oxidant streams. Practical cells typically generate a voltage of around 0.7-0.8 volts and power outputs of a few tens or hundreds of watts. Cells are therefore assembled in modules known as stacks and connected electrically in both series and parallel to provide a larger voltage and output.

The other major components of a fuel cell system are a fuel processor and a power conditioner. The fuel processor converts fuels such as natural gas, methanol, gasoline or bio-ethanol into the hydrogen-rich fuel required by the fuel cell stack.

Fuel cells are usually classified by their electrolyte. The main types and their potential applications are listed in Table 1 below.

**Table 1 Main Types of Fuel Cell**

| | Electrolyte | Operating Temperature (°C) | Potential Applications |
|---|---|---|---|
| **PEFC** | Polymer | 50-80 | Transport, CHP, Distributed Power Generation |
| **AFC** | Alkaline | 50-200 | Space, Transport |
| **PAFC** | Phosphoric Acid | 190-210 | CHP, Distributed Power Generation |
| **MCFC** | Molten Carbonate | 630-650 | CHP, Distributed (+ Centralised?) Power Generation |
| **SOFC** | Solid Oxide | 700-1000 | CHP, Distributed (+ Centralised?) Power Generation |

## 2. TECHNOLOGIES AVAILABLE TODAY

The only fuel cell system commercially available today is a 200kW PAFC system used for CHP and distributed power generation manufacturer by ONSI (USA). There are currently over 200 PAFC systems installed world-wide, with a total generating capacity of about 50 MW. These systems have proved to be very reliable, efficient (over 40% LHV) and clean, but the price of $3,000/kW is currently a major barrier to wider application. Costs are reducing and ONSI expects the selling price to fall to about $1,200/kW once 3,000 units have been produced. This would make the PAFC cost competitive in many countries where pipeline natural gas is available and electricity is expensive relative to gas. Distributed PAFC systems may also be attractive for areas where the electricity distribution network is weak or where additional transmission lines cannot be installed.

Other fuel cell technologies are developing rapidly and will start to impact in the 2004-2010 timeframe, as discussed below.

## 3. NEAR-TERM TECHNOLOGIES AND TECHNOLOGY IMPROVEMENTS

Extensive fuel cell research, development and demonstration programmes are underway world-wide for both transport and stationary applications.

In the transport sector, all of the world's major car makers are now actively involved in evaluating fuel cells for cars. Daimler Benz (Germany) has already demonstrated a technically advanced methanol-powered fuel cell car and is heading an ambitious programme aimed at manufacturing 40,000 vehicles per year by 2004 and 100,000 vehicles per year by 2006. Other companies such as Toyota, General Motors, Mazda, Renault and PSA are also aiming for production-ready fuel cell cars by 2003-2005.

These programmes have been encouraged by significant performance gains over recent years, such as an improvement in PEFC stack power density from less than 0.2 kW/l to over 1 kW/l. Although further performance improvements are expected, the main focus is now on specific weight reduction and on cost reduction through improved design for low-cost manufacture. There is considerable scope here too; researchers from Ford have recently predicted that a PEFC stack could be produced for as little as $18-28/kW based on known technology.

Fuel cell developers, car companies and oil companies are working on improved fuel processor technology. Recently there has been increased interest in gasoline fuel processing which, though technically difficult, could avoid the difficulties associated with introducing a new fuel infrastructure for fuel cell vehicles.

Buses are likely to offer an important early market for fuel cells in transport. A number of fuel cell buses have already been delivered to transit authorities for user evaluation and it expected that the first commercial products will be available within two years.

If developers' predictions for fuel cell cars and buses are fulfilled then there will be sufficient vehicles on the road within the next ten years to start making a contribution to meeting Kyoto commitments, but the main benefits will not be seen until later. However the introduction of fuel cell vehicles may have a significant impact on local air quality in some urban areas within a shorter timescale.

Fuel cell technology for power generation is also progressing, with the first commercial PEFC, SOFC and MCFC systems expected within the next 5-7 years. Recent demonstrations include a 250 kW PEFC CHP system (Ballard Generation Systems), a 100kW SOFC system (Westinghouse/Siemens) and a 2 MW MCFC system (ERC). Westinghouse/Siemens expects to demonstrate a 2.5 MW SOFC/GT system in 2002 with a target efficiency of 60-70% and an anticipated capital cost of $1,300/kW once production levels of 100 MW/year are achieved.

## 4. TECHNOLOGIES FOR THE LONGER TERM

The fuel cell technologies due to be introduced between 2004 and 2010 could have a large impact on energy use and emissions in the following decade and beyond. There is scope for major $CO_2$ savings since fuel cells are much more efficient than competing technologies in most applications. In power generation, for example, an advanced SOFC/GT system is expected to operate at over 70% electrical efficiency, producing only 50-70% of the $CO_2$ emitted from an equivalent combined cycle gas turbine plant.

A fully sustainable energy system can be envisaged for the longer term, where the fuel is a biofuel or hydrogen produced from electrolysis using a renewable energy source. In the very long term, fuel cells could be a key component of any hydrogen economy.

## 5. ADDITIONAL QUESTIONS

### a) Barriers

Cost is likely to be the major barrier to the widespread deployment of fuel cells. Although costs in volume manufacture are predicted to be competitive with conventional technologies, early products will be more expensive. Mechanisms such as the current US Government subsidy for PAFC systems and the Zero Emission Vehicle (ZEV) Mandate in California can help to overcome this barrier.

Other potential barriers include the provision of fuel infrastructures, safety and regulatory issues and lack of awareness of the technology. The introduction of new fuel infrastructures would be a major issue for methanol or hydrogen vehicles, but not for gasoline fuelled vehicles or natural gas power plant. Most of the regulatory issues for mobile and stationary systems are only just starting to be addressed and there are no specific safety concerns with fuel cells, although there may be problems of public perception with hydrogen-fuelled systems. A PAFC demonstration project in Hamburg has successfully addressed both public perception and regulatory issues, and a hydrogen fuelled fuel cell system has been installed next to a school. Lack of awareness by potential users is another barrier that is reducing as a result of ongoing demonstration and dissemination activities.

Experience with renewable energy technologies and electric vehicles may be valuable in overcoming many of these non-technical barriers.

### b) Roles of the public and private sector

In the past, research activities were mainly undertaken by Government organisations and research laboratories but now they are increasingly led by car makers and power engineering companies who recognise the potential threats and opportunities offered by fuel cells. Global partnerships have developed, typified by the collaboration between Daimler Benz, Ballard Power Systems (Canada), Ford (USA) and Shell (Netherlands). Collaboration is very important because no one company or country will have the resources necessary to commercialise fuel cell technology on its own.

Future demonstration and commercialisation activities will require the close involvement of potential customers for fuel cell systems and other relevant organisations such as fuel supply companies, local authorities, transport planners and legislators. The IEA Advanced Fuel Cells Implementing Agreement is providing a useful mechanism for interaction between fuel cell developers, utilities and car companies through two application-oriented annexes. The Implementing Agreement also provides a forum for collaborative research and information exchange under its technology-oriented annexes on MCFC, SOFC and PEFC.

Public funding is still very important to the fledgling fuel cell industry because it allows industry to develop longer term technologies with significant technical and commercial risks, and it helps to encourage the development of an industrial base. Public funding for fuel cell development is often justified by the potentially important contribution to government policy objectives such as $CO_2$ reduction and air quality. Major funders include national government departments such as the US Department of Energy and NEDO (Japan), and the European Commission.

### c) Potential for developing countries

Fuel cells offer the same benefits of higher efficiency and lower emissions to developing markets for transport and power generation. However, they likely to be applied in the developed world first, as early models will require local technical support and maintenance. Once developed, fuel cells could be very attractive to developing countries as they have few moving parts and are therefore potentially very reliable. Power generation applications may be limited by the availability of pipeline natural gas although fuel cell systems could be adapted to run on LPG, coal or biofuels. There may also be niche applications for fuel cells running on waste hydrogen from refineries and chemical industries.