

## **Practical Application of fuel cells in building services**

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### **Summary**

In the present climate of reductions in greenhouse gases and a drive towards greater energy efficiency, fuel cells have the potential to play a significant part as they can produce power, both electrical and thermal, with reduced emissions and also, in terms of energy efficiency, offer means of distributed energy and CHP applications at high efficiency.

This paper presents the results of a DTI sponsored project, under the Partners in Innovation programme, looking at the applications and integration of fuel cells in building services. It briefly discusses the technologies available and their operation. It then describes the range of applications for which fuel cells can be used and briefly presents case studies completed as part of the project.

The paper concludes with a brief discussion of the present economics of fuel cell applications in building services and their prospects in the near future.

## 1.1 Introduction

A fuel cell is an electrochemical device that converts the chemical energy of a reaction into electrical energy and heat as a by-product. There is no combustion involved and hence the process is free of the inefficiencies inherent in present methods of power and heat generation.

There are six types of fuel cell presently being developed. These are:

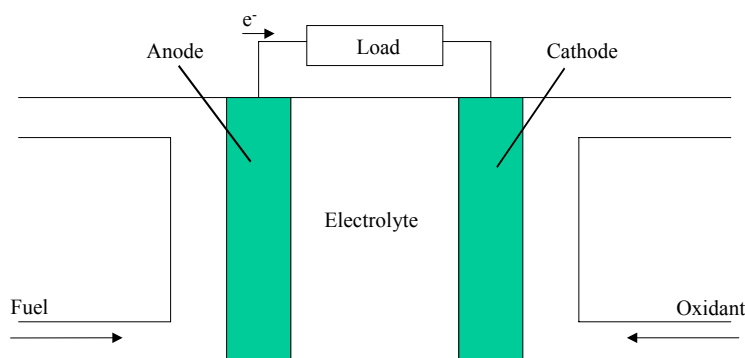
- Alkaline (AFC)
- Phosphoric Acid (PAFC)
- Molten Carbonate (MCFC)
- Direct Methanol (DMFC)
- Solid Oxide (SOFC)
- Proton Exchange Membrane (PEMFC).

Only four of these types are being developed for stationary applications relevant to building services, PAFC, MCFC, SOFC and PEMFC. Only PAFC's are available commercially (see Figure 1), though all the other types have been installed as part of demonstration or proof of concept projects, and prototype SOFCs and MCFCs can be acquired. The majority of installations are presently in the USA and Japan. Installations are increasing in Europe predominantly in Germany, and there is presently only one commercial installation in the UK at Woking.



**Figure 1 UTC PC25C PAFC - The only commercially available fuel cell**

The basic components of a fuel cell are an electrolyte, an anode, and a cathode (see Figure 2). Gaseous fuels are fed continuously to the anode while an oxidant (oxygen from the air) is fed continuously to the cathode. The anode and cathode are separated by the electrolyte. It is the electrolyte that is used to designate the type of fuel cell, i.e. phosphoric acid, solid oxide etc. Ions flow through the electrolyte between the anode and cathode. Electrons generated at the anode flow through an external load to the cathode, completing the electric circuit.



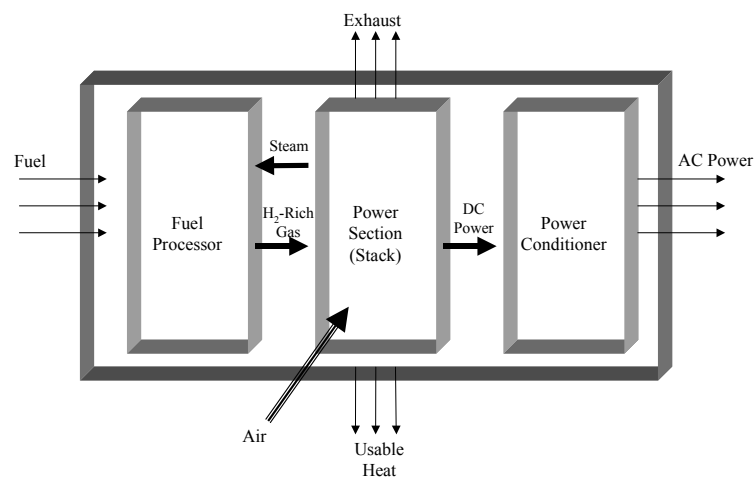
**Figure 2 Basic Fuel Cell Operation**

Each fuel cell generates in the region of 1 V and in order to provide a useful voltage a number of cells are connected together in a stack. A stack will typically comprise over 100 cells[1].

Hydrogen is the ideal fuel because its high reactivity minimises the need for expensive catalysts and it allows the fuel cell to operate with zero emissions when the hydrogen is generated from renewable energy technologies. In practice hydrogen as a fuel source is not currently available for building related applications and so alternative carbon-based fuels are used, the most common being natural gas.

In order for the fuel cell to operate and produce useful heat and power it requires various peripherals, or balance of plant (Figure 3). These include:

- **A reformer:** To reform hydrogen from the carbon-based fuels
- **Power conditioners:** Fuel cells generate DC electricity. Inverters, to convert DC to AC, and transformers, current, voltage and frequency control to ensure the quality of the electric power
- **Water management system:** Fuel cells produce de-ionised water and this can be utilized within the fuel cell or for other applications.
- **Thermal management system:** Fuel cells produce heat and this can be utilized as in CHP systems.



**Figure 3 Schematic of fuel cell system**

## 1.2 Types of Fuel Cell

**Proton exchange membrane fuel cells (PEMFC)** are also known as solid polymer fuel cells (SPFC) and polymer electrolyte fuel cells (PEFC). A PEMFC uses a solid polymer as its electrolyte. The operating temperature of a PEMFC is low at 80°C. While this has benefits in terms of fast start-up times, typically a few seconds, and low thermal insulation requirements, the low operating temperature means that external fuel reforming is required[2].

**Phosphoric acid fuel cells (PAFC)** uses concentrated liquid phosphoric acid as the electrolyte. PAFCs operate at temperatures between 150 to 220 °C. This means that the fuel does not have to be reduced to pure hydrogen. Reduced fuel reformation costs greatly reduce the cost of the fuel cell.

**Molten carbonate fuel cells (MCFC)** use a molten carbonate salt mixture as the electrolyte. The operating temperature of a MCFC is around 650°C. The cell utilizes nickel catalysts rather than expensive precious metal catalysts, reforming can take place within the cell providing a reforming catalyst is added and the heat rejected is of sufficiently high temperature to drive a gas turbine and/or produce high-pressure steam for use in a steam turbine.

**Solid oxide fuel cells (SOFC)** make use of a solid ceramic as the electrolyte. In order to obtain adequate ionic conduction an SOFC must operate at around 1000°C. This high operating temperature allows internal reforming to take place and waste heat can be used to power gas turbines.

Table 1 compares the conditions for operation of the different fuel cell types. The operating temperature is particularly important for a number of reasons:

- Lower operating temperature gives better response and start up times and require lower thermal insulation
- High operating temperature (MCFC & SOFC) enables internal reformation of fuel
- Lower operating temperature, particularly PEM fuel cells, require higher grade hydrogen as fuel, i.e. more stringent reformation of the fuel
- The operating temperature determines the applications available for the by-product heat, i.e. a PEM fuel cell operating at 80 °C cannot be used for steam process applications.

	<b>PEMFC</b>	<b>PAFC</b>	<b>MCFC</b>	<b>SOFC</b>
Electrolyte	Polymer	Phosphoric acid	Molten carbonate salt	Ceramic
Operating temperature	80°C	190°C	650°C	1000°C
Fuels	H <sub>2</sub> Reformate	H <sub>2</sub> Reformate	H <sub>2</sub> /CO Reformate	H <sub>2</sub> /CO <sub>2</sub> /CH <sub>4</sub> Reformate
Reforming	External	External	External/internal	External/internal
Oxidant	O <sub>2</sub> /air	O <sub>2</sub> /air	CO <sub>2</sub> /O <sub>2</sub> /air	O <sub>2</sub> /air
Efficiency (HHV)	40-50%	40-50%	50-60%	45-55%

**Table 1 Comparison of fuel cell types**

Table 2 presents typical efficiencies for various generating plant. It should be noted that the power stations efficiency is for electrical generation only. Boiler plant is for heating only. CHP takes account of the recovery of most of the available heat. The fuel cell figure is for electrical generation only and has figures similar to CHP when the by-product heat is recovered.

<b>Plant</b>	<b>Efficiency %</b>
Conventional coal fired power station	30
Modern gas fired power station	45-50
Boiler plant	75-80
Small scale CHP (ICE)	80
Fuel cell	45-55

**Table 2 Comparison of efficiency of various generating plant**

### 1.3 Applications

The applications listed are predominantly for larger fuel cells, i.e. 100 kW<sub>e</sub> +, but can be applied to small scale fuel cells as in one of the case studies detailed below.

**Electrical Power:** Fuel cells can be used in the following ways to supply electrical power[3]:

- Dedicated to an isolated load: runs as a stand-alone generator
- Backup power to a load normally connected to the local utility: provides backup power when the grid fails
- Operated in parallel with the local utility while supplying power to a buildings power distribution system: runs in parallel with the grid
- Electrical power supply connected to the local utility: provides a means to export power to the grid, i.e. sell surplus electricity to the utility.

**Heat Generation:** The waste heat generated by a fuel cell can in principle be used in a wide range of CHP applications. In practice the temperature and flow rate of the waste heat and the demand profile for the waste heat and its required temperature need to be assessed.

Reported applications include[4]:

- **Domestic hot water:** The thermal output from a fuel cell can be used for domestic hot water requirements. A peak heat boiler operates when required to supplement the fuel cell heat

- **Space heating:** An interface between the fuel cell and the return from a space heating circuit enables water to be pumped through the fuel cell heat exchanger and back into the space heating circuit, this could be supplemented by a boiler if necessary
- **Boiler make-up:** When boiler make-up water is required, this water can pass through the fuel cell heat exchanger to provide preheated water. The fuel cell interface is located after the water softeners to avoid introducing high temperature water into the water softeners
- **Swimming pool:** A fuel cell can be used in conjunction with a pool heater to provide preheated make-up water. In this instance an intermediate heat exchanger is required to keep the corrosive pool water separate from the fuel cell's heat exchanger
- **Absorption chiller:** A fuel cell can be used as the heat source for an absorption chiller.

Fuel cells can also be used for any applications that presently utilize CHP units and are particularly suited to projects that require minimal noise pollution and lower emissions.

### 1.3 Maintenance

Maintenance associated with fuel cells has yet to be fully developed to the extent that is taken for granted with other building services systems and plant. As an indication of the maintenance requirements of fuel cells, the UTC PAFC requires quarterly maintenance consisting of de-ionised water bottle change out and air filter replacement. In addition, an annual maintenance shutdown is needed, in order to clean the condenser and water tank, replace water and nitrogen filters, lubricate the pumps and fans, and inspect valves, sensors and power electronics. The maintenance of the Vaillant/Plug Power 4.6 kW<sub>e</sub> fuel cell is comparable to a standard 5 kW<sub>e</sub> CHP system and includes, filters, heat exchangers, and water treatment system.

## **1.4 Case Studies**

### **Commercial CHP**

4 UTC 200 kW<sub>e</sub> phosphoric acid fuel cells installed as part of a reliability system. The cost of the fuel cells was negligible in comparison to the cost of power failure. Fuel cells used as this was an indoor installation. As well as supplying electricity the fuel cells supply heat, low grade at 140 °F and high grade at 250 °F, which is used for space heating, dehumidification and snowmelt. Issues included high nitrogen content (>4%) in the natural gas supply, so a nitrogen removal system had to be fitted.

### **Reliability System**

2 UTC 200 kW<sub>e</sub> phosphoric acid fuel cells utilized for demonstration and development of reliability systems, operating with no heat recovery. High-pressure nitrogen bottles were installed to purge fuel cell during start up and shut down. Issues included no natural gas supply at the site, so a supply had to be installed.

### **Fuel cell/Gas turbine hybrid**

A Siemens Westinghouse 180 kW<sub>e</sub> (pressurised 3 atm) solid oxide fuel cell with 70 kW dual shaft microturbine was utilised in a proof of concept cogeneration system not connected to the grid. High-pressure turbine drives compressor to compress air to 3 atm and low-pressure turbine to drive AC generator. Issues included the need for a high temperature heat exchanger and to match the microturbine to the output flow rate and temperature of the fuel cell. Using a dual shaft turbine, variable compressor speed and air rate control helped in this instance. Average electrical efficiency of 53% was achieved.

### **Fuel flexibility**

A Siemens Westinghouse 25 kW<sub>e</sub> solid oxide utilised in research of operation of fuel cells using different fuels; natural gas, diesel and jet fuel. Main requirements were due to varying extent of reformation of the fuel. Nominal electrical generating efficiency was 47%.

### **Domestic cogeneration**

A Vaillant/Plug Power 4.6 kW<sub>e</sub> proton exchange membrane fuel cell is utilised for cogeneration in multi-family dwellings. The fuel cells are grid connected and additional heating capacity in the form of condensing boilers are installed as required. The heat is utilised in a standard un-vented heating system at 75 °C/55 °C. Issues included installation and commissioning times, which presently take 3½ days, but looking to reduce to a day.

### **CHP demonstration**

A MTU 250 kW<sub>e</sub> molten carbonate fuel cell was utilised in a demonstration programme of cogeneration applications. Approximate electrical efficiency of 55% and total system efficiency of 76% were achieved. The stack comprises approximately 1/3 of the total cost and this has implications for 5 yearly stack replacement.

## **1.5 Fuel Cell Viability**

There are various issues to consider when determining the viability of a potential fuel cell installation. These include:

- **Determination of building requirements:** Need to know electrical and thermal loads and their daily profile
- **Resolve practical issues of installation:** Electrical and thermal interface, source of fuel, available space (the UTC PAFC measures 3.0 m x 5.5 m and requires space around it) and location to minimise piping and reduce installation costs and energy losses

- **Financial considerations:** Need to determine electrical and thermal loads replaced by fuel cell, fuel utilised, electricity sold back to utility, efficiency and capital cost of fuel cell. This information can be used to give pay back period and hence viability
- **Other considerations:** These include greater reliability, environmental benefits of lower emissions, lower emissions of noise and higher quality electrical supply, image and advertising.

The costs associated with a fuel cell include the initial purchase and installation, annual maintenance, and periodic replacement of the fuel cell stack, every 5 years, though this is presently 1-2 years for the PEM fuel cell. The UTC PAFC units currently cost \$4000/kW<sub>e</sub>, prototype MCFC fuel cells are similarly priced, while prototype SO and PEM fuel cells can be acquired for around \$6000/kW<sub>e</sub>.

Target capital costs range from \$800/kW<sub>e</sub> to \$1500/kW<sub>e</sub> and predicted costs published by the DTI this year are shown in Table 2.

Category	Short-term 2003-2007	Medium-term 2008-2012	Long-term 2013-2023
Markets	Niche applications	Premium applications	Significant passenger car penetration at end of period
Sales Volumes	~10MW/year	10-100MW/year	100+MW/year
Costs	£2000-3000/kW	£200-300/kW	£50-100/kW

Table 2 Projected costs of fuel cells based on markets and sales volumes

The long-term projects include research and development producing lower cost materials and manufacturing[5].

## 2.0 Conclusion

Fuel cell systems provide reliable, high quality electricity and heat at high efficiencies. They have lower emissions than present distributed generating sources and also have lower noise pollution. The present cost of fuel cells precludes their use in many applications and this can

only be resolved by the commercialisation of other fuel cells, which would require an associated demand on the part of the consumer. One obstacle to this is presently grid connection issues requiring permission from the utility and as fuel cells would be competing with them, the utility companies are less than enthusiastic.

It is unlikely that this commercialisation will take place within the next 2-3 years as the major manufacturers are embarking on further demonstration projects and it would not be realistic to believe that commercial products would precede the results of these demonstration projects. The Carbon Trust/DTI report issued this year further suggests dates of 2005 for certain environmental applications and closer to 2010 for wider commercialisation[6].

The future applications of fuel cells cannot be predicted, as competition from renewable energy technologies could either limit their application or possibly even promote their use through low emission generation of hydrogen.

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