Fundamental

SERIES 8 MODULE 6

CURRENT THINKING ON...

Fuel cells for non-domestic buildings

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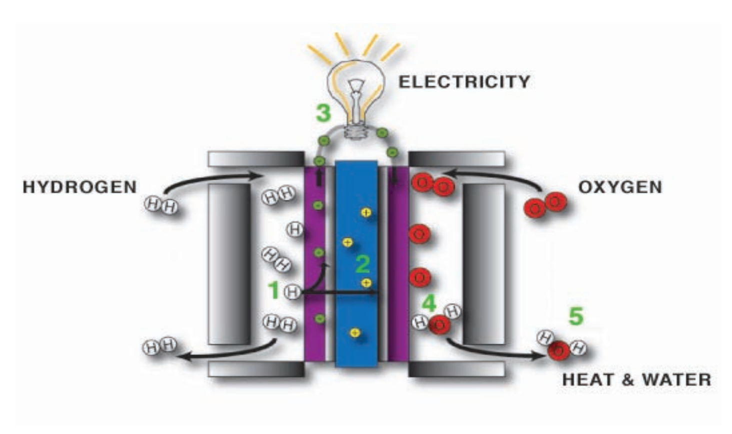
A fuel cell is an electrochemical device that converts the chemical energy in fuel into electrical energy directly, without combustion, with high electrical efficiency and low pollutant emissions.

They have the potential to play a significant role in a low-carbon economy yet the technology is far from new. The principles were discovered in 1838 and a working fuel cell was demonstrated a year later. However, it was not until the 1950s that developments in the application of platinum as a catalyst enabled the first commercial fuel cell to be produced for the NASA space programme.

More recently, global interest in fuel cell technology has been sparked because of its potential as a low-carbon power source for a range of applications:

- stationary power generation and combined heat and power (CHP) for buildings;
- transport – cars and buses;
- portable applications - mobile phones and laptops.

Basic principle of a fuel cell



1. **When a hydrogen atom (from the fuel source) is in contact with the negative anode it splits into a proton and an electron.**
2. **The protons pass straight through the electrolyte**
3. **The electrons produce electricity as they pass through the external circuit.**
4. **The circuit returns the electrons to the positive side of the electrolyte layer where they bond and join with an oxygen molecule.**
5. **Creating water and heat in the positive cathode catalyst layer.**

Schematic diagram courtesy of Greenspec (http://www.greenspec.co.uk/fuel-cells.php)

Rapid progress

The technology of fuel cells has made considerable progress in recent years. Across the range of applications some types of fuel cell are commercially available and viable today and "niche" sales are providing valuable support to the development of larger mainstream markets.

In terms of fuel cells for large-scale power generation and CHP for non-domestic buildings the numbers of installations is growing as the technology nears commercialisation.

A fuel cell is an electrochemical power conversion device that directly converts the chemical energy of a reaction into electrical energy in a constant temperature process. It combines oxygen from the ambient air and hydrogen as the fuel to produce direct current electricity with the only emissions being water and heat.

A fuel cell is analogous to a battery, but possesses the advantage of being constantly recharged with fresh reactant. In contrast to a battery, the reactant for a fuel cell is stored outside the cell and is fed to the cell only when power generation is required.

By the nature of the electrochemical reaction a fuel cell can be up to twice as efficient as traditional thermal generation plant where fuel provides thermal energy which is converted into mechanical energy and finally electricity. A fuel cell produces electricity, water and heat directly from hydrogen and oxygen.

The key benefit of the hydrogen fuel cell is that it generates electricity with low or zero carbon emissions.

All fuel cells have the same basic configuration, an electrolyte sandwiched between two electrodes, but there are several types each operating slightly differently.

In general terms, hydrogen is fed into the fuel cell at the anode where a chemical reaction strips the hydrogen atoms of their electrons. The hydrogen atoms are now "ionized," and carry a positive electrical charge. The negatively charged electrons provide the direct current (DC) to be utilised through the load.

Electrolyte's key role

Oxygen enters the fuel cell at the cathode and in some cell types like that shown (left) it combines with electrons returning from the electrical circuit and hydrogen ions that have travelled through the electrolyte from the anode. In other cell types the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with hydrogen ions.

The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances travel through the electrolyte the chemical reaction is disrupted. Whether they combine at anode or cathode, the hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen it will generate electricity.

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Although all fuel cells have the same basic configuration there are a number of different types and can be classified primarily by the electrolyte used. The electrolyte determines the chemical reaction that takes place in the fuel cell and the operating temperature required. It also determines the application for which the fuel cell is most suitable as well as its advantages and limitations.

Fuel cells can also be grouped into low-temperature and high-temperature types. Low-temperature fuel cells require a relatively pure supply of hydrogen as a fuel. This means that either pure hydrogen fuel or a fuel processor to convert or 'reform' a primary fuel (e.g. natural gas) into pure hydrogen is required. In general high temperature fuel cells do not need this external processor because they 'internally reform' the fuel at the elevated operating temperatures.

The main fuel cell groups are:

- alkaline (AFC) ;
- proton Exchange Membrane (PEMFC) ;
- phosphoric acid (PAFC) ;
- molten carbonate (MCFC);
- solid oxide (SOFC).

There are other types of innovative fuel cells that are relatively new to the above family of fuel cells but which are not covered in this CPD Module.

Alkaline fuel cell (AFCs)

The electrolyte is a solution of potassium hydroxide and the fuel cell can use a variety of non-precious metal catalysts at operating temperatures of 50 to 250°C. Fuelled by hydrogen gas alkaline fuel cells have a high chemical reaction rate and offer a high electrical efficiency of up to 60 per cent.

One disadvantage of this type of fuel cell is that it is very sensitive to carbon dioxide that may be present in the fuel or air. The CO2 reacts with the electrolyte, poisoning it rapidly, and severely degrading the fuel cell performance. AFCs are, therefore, limited to closed environments such as space and undersea vehicles and must be run on pure hydrogen and oxygen.

Proton exchange membrane fuel cell (PEMFC)

These are also known as polymer electrolyte fuel cells (PEFC) and work with a polymer membrane in the form of a thin permeable sheet. Efficiency is about 40 per cent and the operating temperature is between 80 and 100°C.

Compared with other fuel cells the PEM fuel cell generates more power for a given volume or weight. This high-power density characteristic and low operating temperature makes this type suitable for transport and domestic applications. The low operational temperature necessitates a highly purified fuel and a platinum catalyst which adds to the cost. If natural gas is used as a source it needs to be externally reformed to render it suitable.

Direct methanol fuel cells are a relatively new development within the PEMFC category. These use methanol as the fuel but operate at slightly higher temperatures and have lower electrical efficiencies. The main advantages are the relative ease of transport of methanol and the lack of complex fuel reforming operations. Development of this type of fuel cell is directed towards small mobile power applications such as laptops and cell phones using replaceable methanol cartridges.

Phosphoric acid fuel cell (PAFC)

Phosphoric acid fuel cells were the first type of fuel cell to be commercialised for building applications following field testing during the 1970s. Continued development has improved cost and performance and this type of fuel cell probably has the greatest track record in non-domestic building applications.

PAFCs use liquid phosphoric acid as an electrolyte with a platinum catalyst and require hydrogen as the fuel. The ionic conductivity of phosphoric acid is low at low temperatures so operating temperatures around 150-220°C are required. The hydrogen fuel is usually generated by reforming light hydrocarbon fuels such as natural gas. Electrical efficiency is relatively low between about 35 and 50 per cent but overall efficiencies up to 85 per cent are possible when operating with heat recovery for CHP applications.

Molten carbonate fuel cells (MCFCs)

These fuel cells operate at 600 to 750°C and use a molten alkali carbonate mixture as the electrolyte. Single molten carbonate fuel cell systems typically range between 75 and 250 kW in electrical output.

These fuel cells can be operated on either hydrogen or other hydrocarbon fuels with internal reforming. Electrical efficiencies are typically around 55 per cent with total efficiencies up to 85 per cent with heat recovery for CHP applications.

Solid oxide fuel cells (SOFC)

These use a hard ceramic compound of metal oxides as an electrolyte. The properties of the electrolyte allow high operational temperatures at up to 1000°C which provides a greater flexibility for a wider range of hydrocarbon fuels to be used with internal reforming. The electrical efficiency is relatively high at up to 60 per cent. These fuel cells are potentially well-suited to stationary power generation and CHP applications with total efficiencies up to 85 per cent with heat recovery.

The development challenges for both SOFC and MCFC focuses on reducing operational temperatures, reduction of cost and physical size and increased durability and continued research into materials for the high temperature operating environment.

The general characteristics of the different fuel cell types are shown in the table based on typical data from a range of reference sources. Details of individual fuel cells from specific suppliers may vary to suit particular applications and because the technology is under continued development to optimise cost and performance.

Fuel cells use the energy released when electrons are transferred from one of the reactants to the other to directly convert chemical energy into electricity rather than using combustion of the fuel. Fuel cells are, therefore, not subject to the thermodynamic laws which limit the efficiency of traditional electricity generation.

A single fuel cell typically produces around 0.7V DC at full rated load. To deliver the desired amount of energy individual fuel cells are combined together to form a fuel cell stack. The term "fuel cell" is often used to refer to the entire stack as well as to the individual cell.

The efficiency of a single fuel cell is dependent upon the current drawn. Increasing the current drawn from the cell increases the losses which manifest themselves as a voltage drop in the cell. This means that the efficiency of a cell is almost proportional to its voltage and for this reason it is common to provide a voltage versus current curve (often referred to as a polarisation curve) for fuel cells.

A typical cell running at 0.7V might have an efficiency of approximately 50 per cent, meaning that 50 per cent of the energy content of the hydrogen is converted into electrical energy with the balance being converted into heat. The choice of electrolyte, electrode design and architecture of a stack of individual fuel cells all effect fuel cell system efficiency.

Hydrogen is the ideal fuel for fuel cells because of its high reactivity and although hydrogen is one of the most abundant elements on the planet it does not occur naturally as a fuel.

Industrial production of hydrogen is mainly from steam reforming of natural gas and less often by more energy intensive hydrogen production methods such as electrolysis of water. Hydrogen can also be derived from sustainable, carbon-neutral sources of methane such as biomass or land-fill gas and is available as a waste gas in some industries. If electricity from renewable sources is used to generate hydrogen by electrolysis of water it could be considered a renewable fuel for transport applications.

For non-domestic building applications the greatest experience to date has been with phosphoric acid fuel cell systems incorporating a "fuel reformer" as part of the fuel

Fuel cells for non-domestic buildings

	Fuel Cell Types				
	Low temperature fuel cells			High temperature fuel cells	
Fuel Cell Type	**Alkaline**	**Proton Exchange Membrane**	**Phospohoric Acid**	**Molten Carbonate**	**Solid Oxide**
Acronym	AFC	PEMFC	PAFC	MCFC	SOFC
Electrolyte	Alkaline solution	Polymer membrane.	Liquid phosphoric acid.	Molten carbonate salt.	Ceramic.
Operating temperature (°C)	50 - 250	80 - 100	150 - 220	~650	500 – 1,000
Electrical efficiency (%)	Up to 60	~50	~35 - 50	Up to 55	Up to 60
Fuels	Pure hydrogen.	Pure hydrogen.	Pure hydrogen.	Most hydrocarbon fuels.	Most hydrocarbon fuels.
Applications	Military. Space.	Passenger cars. Portable power. Back-up power.	Power generation & CHP for buildings. Large vehicles.	Power generation & CHP for buildings. Large scale power generation.	Power generation & CHP for buildings. Large scale power generation.
Advantages	High performance. Low temperature.	Solid electrolyte reduces corrosion. Low temperature. Quick start-up.	Increased tolerance to fuel impurities. Suitable for CHP.	High efficiency for building applications. Fuel flexibility. Variety of catalysts. Suitable for CHP.	High efficiency for building applications. Fuel flexibility. Variety of catalysts. Suitable for CHP & hybrid turbine systems.
Disadvantages	Requires removal of carbon dioxide from fuel and air streams.	High cost catalyst. High sensitivity to fuel impurities. Waste heat temperature too low for CHP.	High cost catalyst. Large size/weight.	High temperature operation. Slow start-up. Complex electrolyte management.	High temperature operation. Slow start-up. Brittleness of electrolyte.

cell system to produce hydrogen from hydrocarbon fuels (typically natural gas). High temperature fuel cells (MCFC and SOFC) offer the potential to be operated directly on hydrocarbon fuels because these fuels can be internally reformed within the fuel cell.

Phosphoric acid, molten carbonate and solid oxide are the main fuel cell types currently being developed for stationary power generation and CHP systems applications.

The phosphoric acid type relies on high cost platinum catalysts and requires hydrogen fuel, normally provided at the site using additional plant to externally reform hydrocarbon fuels such as natural gas.

High temperature (molten carbonate and solid oxide) fuel cells offer the advantage that they can internally reform a range of hydrocarbon fuels, use lower cost catalysts and have high-grade heat available for CHP or hybrid applications. These benefits are balanced by the material and design challenges caused by the higher operating temperatures. High temperature fuel cell developers are starting to reach early markets at moderate powers while larger powers are generally at the demonstration stage.

While in concept an individual fuel cell is relatively simple in operation a complete fuel cell system requires sophisticated operating sub-systems to function correctly and efficiently. These peripheral systems include an external reformer unless pure hydrogen is available or high temperature internal reforming fuel cells are used. Power conditioners to convert DC to AC, transformers and power quality controls plus heat and water management systems are also needed.

Fuel cells offer a clean, efficient source of energy and represent one of a number of technologies that could help meet long-term climate change targets. For distributed power generation and non-domestic CHP applications, even if reformation of a carbon-based fuel is required, a fuel cell should offer carbon reductions because of the higher efficiency. Since fuel cells are solid state devices producing electricity without combustion there are no nitrogen or sulfur oxide emissions at the point of use and noise emissions are low.

A recent market review conducted by Fuel Cell Today indicated that some 24,000 fuel cell units were shipped worldwide in 2009 representing a 41 per cent increase over the previous year. Most were manufactured in Asia where production of stationary fuel cells was stimulated by CHP installations subsidised by the Japanese government. In North America there was an increase in installations of uninterruptible power supply units and fuel cells for forklift trucks, both markets being supported by US government schemes.

For stationary applications a number of medium scale fuel cell technologies are coming to the market. While individual fuel cell types and solutions are at different stages of development, capital costs are starting to become competitive for some types but long-term performance and reliability has to be fully proven. Fuel cell costs today reflect relatively low production volumes but are forecast to fall with increased volumes as markets develop.

References:

- Review of UK Fuel Cell Commercial Potential Carbon Trust CT/2003/01 (www.carbontrust.co.uk)
- Fuel Cells UK (www.fuelcellsuk.org)
- US Fuel Cell Council and the National Hydrogen Association (www.fchea.org/welcome.html)
- Fuel cells2000 online resource (www.fuelcells.org)
- Practical Application of fuel cells in building services BSRIA Report S Galliers.
- Fuel Cells for Buildings CIBSE Fact Sheet www.cibse.org/pdfs/Datasheet04.pdf
- Fuel Cells (www.americanhistory.si.edu/fuelcells/basics.htm#q4)

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How to obtain CPD accreditation

Energy in Buildings and Industry and the Energy Institute are delighted to have teamed up to bring you this Continuing Professional Development initiative.

This is the sixth of ten modules in the eighth series and focuses on fuel cells for commercial buildings. It is accompanied by a set of multiple-choice questions. To qualify for a CPD certificate readers must submit at least eight of the ten sets of questions from this series of modules to ***Energy in Buildings and Industry*** for the Energy Institute to mark. Anyone achieving at least eight out of ten correct answers on eight separate articles qualifies for an Energy Institute CPD certificate. This can be obtained, on successful completion of the course, for a fee of £15 (for members) or £25 (for non-members).

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The modules in the coming months will focus on: smart meters; air conditioning; LEDs; and power quality. Should you miss any of the modules please let EiBI know (mark.thrower@btinternet.com) and we will send you the missing modules in 'pdf' format to you either by e-mail or on a CD. The first five modules in the series focused on the CRC Energy Efficiency Commitment, insulation, heat pumps, training, and district heating.

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MARK THROWER, MANAGING EDITOR

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SERIES 8 MODULE 6: QUESTIONS

Fuel cells for non-domestic buildings

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. Which of these statements about fuel cells is not correct?

☐ It is an electrochemical device
☐ It converts the chemical energy in fuel into electricity without combustion
☐ It produces low pollutant levels
☐ It has a low capital cost

2. Compared with traditional electricity generation a fuel cell is?

☐ Twice as efficient
☐ Half as efficient
☐ Five times as efficient
☐ Ten times as efficient

3. Which of the following fuel cell types is not suitable for stationary CHP applications?

☐ Phosphoric Acid (PAFC)
☐ Molten Carbonate (MCFC)
☐ Alkaline (AFC)
☐ Solid Oxide (SOFC)

4. Which fuel cell type has the greatest track record in non-domestic building applications?

☐ Proton Exchange Membrane (PEMFC).
☐ Phosphoric Acid (PAFC)
☐ Molten Carbonate (MCFC)
☐ Solid Oxide (SOFC)

5. What is the range in electrical efficiency that fuel cells can provide?

☐ Less than 25%
☐ 35 to 60%
☐ 70 to 80%
☐ Over 85%

6. A fuel cell polarisation curve shows what fuel cell performance characteristic?

☐ Voltage versus current performance
☐ Total voltage available from the entire fuel cell stack
☐ Total current available from the entire fuel cell stack
☐ Hydrogen consumption

7. Which of the following sub-systems would not form part of a Phosphoric Acid CHP Fuel Cell operating on natural gas?

☐ An external fuel reformer
☐ Power conditioning controls
☐ An engine prime mover
☐ A thermal management system

8. Which of the following benefits is not true a characteristic of fuel cell technology?

☐ High electrical efficiency
☐ Zero or low carbon emissions
☐ Low noise emissions
☐ Low capital cost

9. Which of the following fuel cells can internally reform a hydrocarbon fuel?

☐ Solid Oxide
☐ Alkaline
☐ Proton Exchange Membrane
☐ Phosphoric Acid

10. Which of the following is not correct about hydrogen as a fuel?

☐ Can be produced by reforming natural gas
☐ It occurs naturally as a fuel
☐ Is available from carbon-neutral sources of methane such as biomass
☐ Can by produced by the electrolysis of water