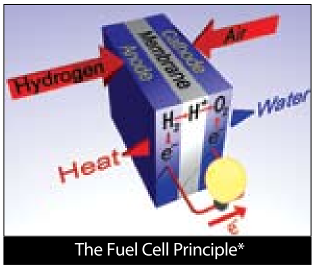
Fuel Cell Characterization:

Nature of the Electrode

Challenges Facing Fuel Cell Development

The current dynamic interest in fuel cell (FC) technology reflects strong technological and economical implications. This technology offers more advanced, more efficient and more environmentally friendly ways of generating energy compared to that based on traditional internal combustion engines. Practical applications of FC become more feasible in light of recent advances in modern technology of new materials and processes.

But, despite that several FC applications have been built and are currently working, this technology is still in the early stages of development. Significant research is still needed in developing, understanding and optimizing materials for FC components. Additional requirements of the FC technology are storage and handling of fuel especially hydrogen; efficient and safe storage of H_2 still being an unresolved issue. Many researchers and others expect that new materials such as carbon nanotubes and other nano-materials may play an important role. The variety of possible FC configurations and the necessary materials are illustrated below.



The Fuel Cell Principle*

- **proton exchange membrane (PEM)**

PEM fuel cells are also known as polymer electrolyte membrane, solid polymer electrolyte and polymer electrolyte fuel cells. In this FC the electrolyte is a thin polymer membrane (such as poly[perfluorosulphonic] acid), which is permeable to protons, but does not conduct electrons, and the electrodes are typically made from carbon. Hydrogen flows into the fuel cell on to the anode and is split into hydrogen ions (protons) and electrons. These protons permeate across the electrolyte to the cathode, while the electrons flow through an external circuit and provide power. Oxygen, in the form of air, is supplied to the cathode and combines with electrons and hydrogen ions to produce water. A thin layer of platinum on each electrode catalyzes these reactions.

- **alkaline fuel cells (AFC)**

The design of an alkaline fuel cell is similar to that of a PEM cell, but with an aqueous solution or stabilized matrix of potassium hydroxide as the electrolyte. The electrochemistry is different in that hydroxyl ions (OH-) migrate from the cathode to the anode where they react with hydrogen to produce water and electrons.

- **phosphoric acid fuel cells (PAFC)**

These cells use liquid phosphoric acid as the electrolyte, usually contained in a silicone carbide matrix. Phosphoric acid cells work at around 150 to 200°C. They require platinum catalysts on the electrodes to promote reactivity. The anode and cathode reactions are the same as those in the PEM fuel cell.

- **molten carbonate fuel cells (MCFC)**

These cells use either molten lithium potassium or lithium sodium carbonate salts as the electrolyte. When heated to a temperature of around 650°C these salts melt and generate carbonate ions that flow from the cathode to the anode where they combine with hydrogen to give water, carbon dioxide and electrons.

The high temperature at which these cells operate means that they are able to internally reform hydrocarbons, such as natural gas and petroleum, to generate hydrogen within the fuel cell structure. The excess heat generated can be used in combined heat and power plants.

- **solid oxide fuel cells (SOFC)**

These cells work at 800 - 1,000°C. They use a solid ceramic electrolyte, such as zirconium oxide stabilized with yttrium oxide. Energy is generated by the migration of oxygen anions from the cathode to the anode to oxidize the fuel gas, which is typically a mixture of hydrogen and carbon monoxide.

- **direct methanol fuel cells (DMFC)**

The direct methanol fuel cell is a type of PEM fuel cell that uses methanol directly without prior reforming. The methanol is converted to carbon dioxide and hydrogen at the anode. The hydrogen then goes on to react with oxygen as in a standard PEM fuel cell. These cells operate at around 120°C. One drawback is that the low temperature conversion of methanol to hydrogen and carbon dioxide needs a larger quantity of platinum catalyst than in conventional PEM cells.

Carbon Black: Catalyst Support

Materials Characterization In Fuel Cell Technology

Most commonly used characterization and testing procedures are related to the electrical and energy performance of FC assemblies. However, in developing and characterizing the materials and components there are three main areas that are especially important:

- **catalysis**

Most FC's use a metal catalyst (usually platinum) on one or both electrodes. Catalysts are also used in reforming and in CO removal processes that accompany the use of FC. Testing and characterization of metal catalyst typically include evaluation of the active metal surface area, dispersion and metal nanocluster size by isothermal chemisorption (Autosorb-1-C), and catalyst activity by temperature programmed reduction and oxidation (Autosorb-1-C or ChemBET Pulsar, both Quantachrome Instruments, Boynton Beach, FL).

- **porosity/surface area characterization**

An important role of electrodes, and the so-called gas diffusion layers, is to allow for transport of gaseous and/or liquid species. In this role the critical factors that affect diffusion and flow of fluids are overall porosity and pore size or pore size distribution. These important characteristics are obtained using gas (physi-) sorption and mercury intrusion porosimetry. Single and multiple sample analyzers, like the NOVA and PoreMaster respectively (both Quantachrome Instruments) can be used equally effectively in R&D and QC/QA.

Carbon nanotubes and other nanoporous materials are being investigated as potential hydrogen storage media. Since storage in these media is based on physical adsorption of hydrogen in their pores, the most appropriate method to characterize their porosity is via gas sorption methods. Here in addition to the standard surface area and porosity analyses, new approaches such as CO_2 micropore analysis, and cryogenic adsorption of hydrogen itself (Autosorb-1-MP, Quantachrome) are recommended.

- **hydration characterization**

A key element in PEMFC is a proton conducting polymer membrane used as the electrolyte. The best-known membrane of this type is Nafion™ by DuPont de Nemours and Company. This membrane must remain hydrated in order to be proton conductive, which makes water management a central issue in PEMFC development. Therefore, water sorption isotherms as a function of temperature and pressure (relative humidity) can be of central importance. Hi-resolution yet robust analyzers such as the Hydrosorb 1000 (Quantachrome) are very suitable.

Looking Forward

Fuel cell development is no different than other applied technologies based on surface phenomena. Industries such as petrochemical, ceramics and pharmaceuticals have long recognized the impact that pore structure has on material performance, and routinely use the analysis techniques outlined above. Those in the fuel cell arena are urged to adopt similar capabilities to quickly advance the understanding of material properties in order to meet the commercial need for rapid development into the marketplace. ■

For more information about fuel cells and related measurement instruments, contact Quantachrome Instruments by phone: (561) 731.4999, fax: (561) 732.9888, email: qc.support@quantachrome.com or visit www.quantachrome.com.

PEM/PAFC
- **Anode Reaction:**
  $2H_2 \rightarrow 4H^+ + 4e^-$
- **Cathode Reaction:**
  $O_2 + 4H^+ + 4e^- \rightarrow 2H_20$
- **Overall Reaction:**
  $2H_2 + O_2 \rightarrow 2H_2O$ + energy

AFC
- **Anode Reaction:**
- $2H_2 + 4OH^- \rightarrow 4H_20 + 4e^-$
- **Cathode Reaction:**
  $O_2 + 2H_20 + 4e^- \rightarrow 4OH^-$

MCFC
- **Anode Reaction:**
  $CO_3^{2-} + H_2 \rightarrow$
  $H_20 + CO_2 + 2e^-$
- **Cathode Reaction:**
  $CO_2 + {}^1\!/_2 0_2 + 2e^- \rightarrow CO_3^{2-}$

SOFC
- **Anode Reaction:**
  $H_2 + O_2^- \rightarrow H_20 + 2e^-$
- **Cathode Reaction:**
  $CO + O_2 \rightarrow CO_2 + 2e^-$
- **Cell Reaction:**
  $O_2 + 4e^- \rightarrow 2O_2^-$

DMFC
- **Anode Reaction:**
  $CH_3OH + H_20 \rightarrow$
  $CO_2 + 6H^+ + 6e^-$
- **Cathode Reaction:**
  ${}^3\!/_2 0_2 + 6H^+ + CO_2 + 6e^-$
  $\rightarrow 3H_20$
- **Cell Reaction:**
  $CH_3OH + {}^3\!/_2 0_2 \rightarrow$
  $CO_2 + 2H_2O$

FUEL CELL REACTIONS

* Image courtesy of Fuel Cell Today (www.fuelcelltoday.com).