FUEL CELL - BASICS

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Introduction

A fuel cell is an electrochemical device that produces electricity without combustion by combining hydrogen and oxygen to produce water and heat. The Fuel Cell was first developed by William Grove, a Welsh judge with intense scientific curiosity. In 1839, Grove was experimenting on electrolysis (the process by which water is split into hydrogen and oxygen by an electric current), when he observed that combining the same elements could also produce an electric current. Other scientists paid sporadic attention to fuel cells throughout the 19th century. From the 1930s through 1950s Francis Thomas Bacon, a British scientist, worked on developing alkaline fuel cells. He demonstrated a working stack in 1958. This technology was licensed to Pratt and Whitney where it was utilized for the Apollo spacecraft fuel cells.

Fuel cells offer many advantages over conventional energy sources:

- Fuel cells produce energy through electrochemical conversion of the fuel. Therefore they produce zero or very low emissions, especially Green House Gases (GHGs) depending on the fuel used.
- Fuel cells produce power at efficiencies much higher than conventional power systems such as the internal combustion engine. This efficiency contributes to the environmental benefits of the fuel cell.
- Fuel cells have few moving parts and thus require minimal maintenance, reducing life cycle costs of energy production.
- Fuel cells operate efficiently at part load and in all size configurations.
- Fuel cells are modular in design, offering flexibility in size and efficiencies in manufacturing.
- Fuel cells can be utilized for combined heat and power purposes, further increasing the efficiency of energy production.

Basic Working and Types of Fuel Cells

A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte sandwiched between two thin electrodes (a porous anode and cathode). While there are different fuel cell types, all work on the same principle:

Hydrogen, or a hydrogen-rich fuel, is fed to the anode where a catalyst separates hydrogen's negatively charged electrons from positively charged ions (protons).

At the cathode, oxygen combines with electrons and, in some cases, with species such as protons or water, resulting in water or hydroxide ions, respectively.

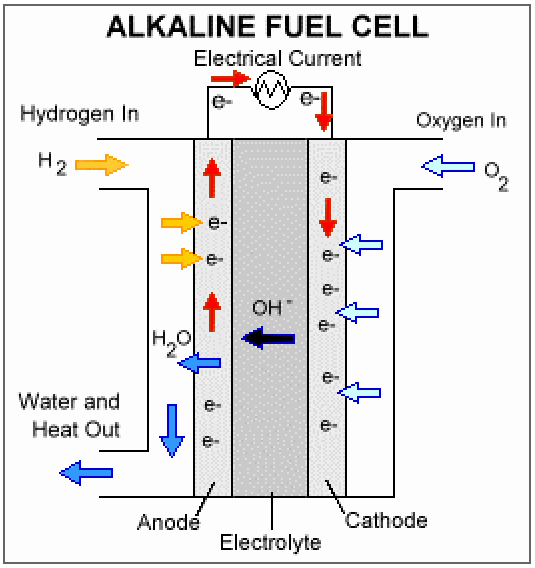
The electrons from the anode side of the cell cannot pass through the membrane to the positively charged cathode; they must travel around it via an electrical circuit to reach the other side of the cell. This movement of electrons is an electrical current.

The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure at which the gases are supplied to the cell. Still, a single fuel cell produces enough electricity for only the smallest applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells.

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. A few of the most promising types include

Alkaline Fuel Cells (AFC) : The alkaline fuel cell uses an alkaline electrolyte such as potassium hydroxide. In alkaline fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons.

It was originally used by NASA on space missions. NASA space shuttles use Alkaline Fuel Cells. Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water onboard spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. High-temperature AFCs operate at temperatures between 100°C and 250°C (212°F and 482°F). However, more-recent AFC designs operate at lower temperatures of roughly 23°C to 70°C (74°F to 158°F).



AFCs are high-performance fuel cells due to the rate at which chemical reactions take place in the cell. They are also very efficient, reaching efficiencies of 60 percent in space applications.

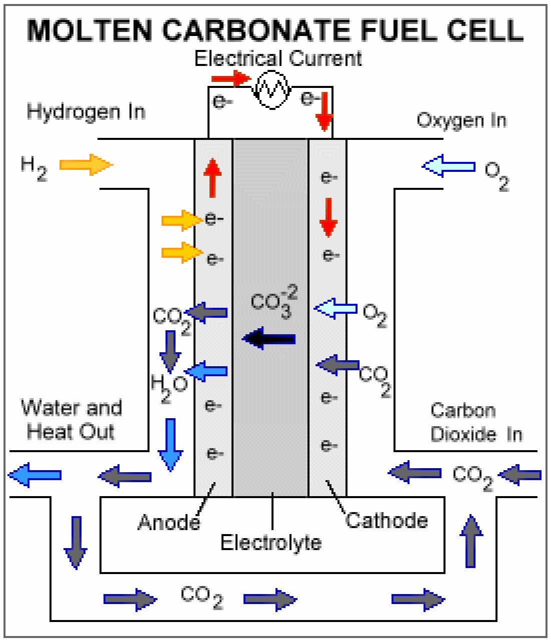
The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO_2). In fact, even the small amount of CO_2 in the air can affect the cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. This purification process is costly. Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost.

Cost is less of a factor for remote locations such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours. To be economically viable in large-scale utility applications, these fuel cells need to reach operating times exceeding 40,000 hours. This is possibly the most significant obstacle in commercializing this fuel cell technology.

1. **Direct Methanol Fuel Cells (DMFC):** As a relatively new type of fuel cell, the direct-methanol fuel cell (DMFC) is similar to the PEM cell in that it uses polymer membrane as an electrolyte. However, a catalyst on the DMFC anode draws hydrogen from liquid methanol, eliminating the need for a fuel reformer. Therefore pure methanol can be used as fuel.

Molten Carbonate Fuel Cells (MCFC): The molten carbonate fuel cell uses a molten carbonate salt as the electrolyte. It has the potential to be fuelled with coal- derived fuel gases, methane or natural gas. These fuel cells can work at up to 60% efficiency and this could potentially rise to 80 per cent if the waste heat is utilised. In molten carbonate fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons.

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide ($LiAlO_2$) matrix. Since they operate at extremely high temperatures of 650ºC (roughly 1,200ºF) and above, non-precious metals can be used as catalysts at the anode and cathode, reducing costs.



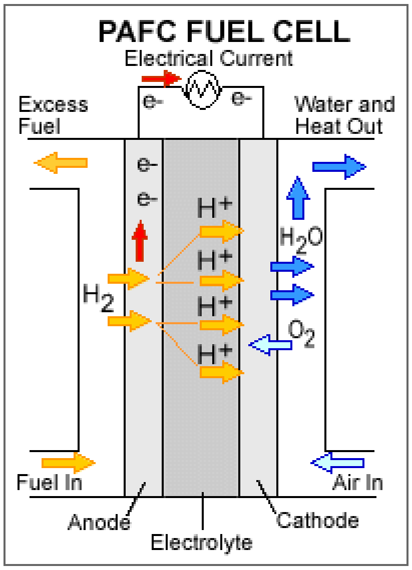
Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells (PAFCs). Molten carbonate fuel cells can reach efficiencies approaching 60 percent, considerably higher than the 37-42 percent efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be as high as 85 percent.

Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which they operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost.

Molten carbonate fuel cells are not prone to carbon monoxide or carbon dioxide "poisoning"—they can even use carbon oxides as fuel—making them more attractive for fueling with gases made from coal. Although they are more resistant to impurities than other fuel cell types, scientists are looking for ways to make MCFCs resistant enough to impurities from coal, such as sulfur and particulates.

The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that increase cell life without decreasing performance.

Phosphoric Acid Fuel Cells (PAFC): A phosphoric acid fuel cell (PAFC) consists of an anode and a cathode made of a finely dispersed platinum catalyst on carbon and a silicon carbide structure that holds the phosphoric acid electrolyte. In phosphoric acid fuel cells, protons move through the electrolyte to the cathode to combine with oxygen and electrons, producing water and heat.



This is the most commercially developed type of fuel cell and is being used to power many commercial premises.

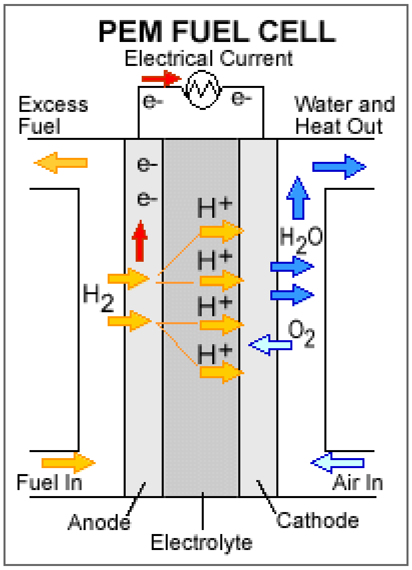
Phosphoric acid fuel cells use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in the diagram to the right. The phosphoric acid fuel cell (PAFC) is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses. Most fuel cell units sold before 2001 used PAFC technology.

PAFCs are more tolerant of impurities in the reformate than PEM cells, which are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are

85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt to operate.

Polymer electrolyte membrane (PEM) fuel cells (PEMFC): In polymer electrolyte membrane (PEM) fuel cells, protons move through the electrolyte to the cathode to combine with oxygen and electrons, producing water and heat.

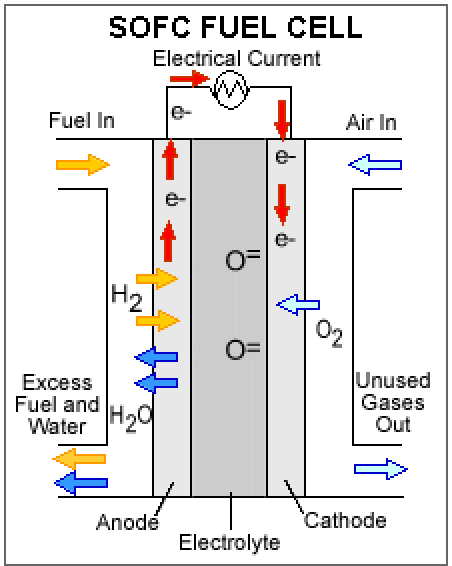
Polymer electrolyte membrane (PEM) fuel cell uses a polymeric membrane as the electrolyte, with platinum electrodes. These cells operate at relatively low temperatures and can vary their output to meet shifting power demands. These cells are the best candidates for cars, for buildings and smaller applications. Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers.



Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80°C (176°F). Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.

PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen onboard to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, typically 300-400 miles. Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though less than that emitted from current gasoline-powered engines.



Solid Oxide Fuel Cells (SOFC) : Solid oxide fuel cells work at even higher temperatures than molten carbonate cells. They use a solid ceramic electrolyte, such as zirconium oxide stabilised with yttrium oxide, instead of a liquid and operate at 800 to 1,000°C. In solid oxide fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons.

These cells can reach efficiencies of around 60 per cent and are expected to be used for generating electricity and heat in industry and potentially for providing auxiliary power in vehicles. Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte. Since the electrolyte is a solid, the cells do not have to be constructed in the plate-like configuration typical of other fuel cell types. SOFCs are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 80-85 percent.

Solid oxide fuel cells operate at very high temperatures—around 1,000ºC (1,830ºF). High temperature operation removes the need for precious-metal catalyst, thereby reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system.

SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types. In addition, they are not poisoned by carbon monoxide (CO), which can even be used as fuel. This allows SOFCs to use gases made from coal.

High-temperature operation has disadvantages. It results in a slow startup and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation and small portable applications. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.

Scientists are currently exploring the potential for developing lower-temperature SOFCs operating at or below 800ºC that have fewer durability problems and cost less. Lower-temperature SOFCs produce less electrical power, however, and stack materials that will function in this lower temperature range have not been identified.

2. **Regenerative Fuel Cells (RFC):** This class of fuel cells produces electricity from hydrogen and oxygen, but can be reversed and powered with electricity to produce hydrogen and oxygen; effectively storing energy or electricity.

3. **Metal Air Fuel Cells (MAFC):** Metal air fuel cells are not fuel cells in a conventional way. They work similar to batteries, generating electricity using metal and oxygen, although they are rechargeable.

Of the above, the PEMFC has exciting prospects for use on Railway Locomotives.
For alkaline, molten carbonate, and solid oxide fuel cells, negative ions travel through the electrolyte to the anode where they combine with hydrogen to generate water and electrons.

Is it a battery?

No. Fuel cells and batteries are both electrochemical devices that produce electricity, however the fundamental distinction between them is that batteries store "fuel" (the chemicals that react to produce electricity) internally, whereas fuel cells use external fuel storage. The implication of this difference is that when a battery's "fuel" is spent, the battery must either be disposed or recharged whereas with a fuel cell, one can simply refill its storage tank and go, without having to replace the entire cell or wait for it to "recharge" (i.e. restore the chemicals to their original state).

Possible uses of fuel cells

The possible uses for fuel cells are boundless. A fuel cell is simply a device that takes a fuel and, in combining it with oxygen (air), produces electricity. Therefore it can be used in virtually any application requiring electrical power. Fuel cells can be used instead of internal combustion engines or batteries to power vehicles ranging in size from small mopeds to large transit buses and locomotives, or in small consumer devices such as laptops and mobile phones. Large fuel cells can replace existing power plants to provide electricity for a large number of users, or in smaller, distributed power generation plants to supply the electrical needs of a factory, a neighbourhood, or an individual home. Basically, a fuel cell can supply clean (low or no emissions), quiet, vibration-free electricity without the need to frequently dispose of the cell when its fuel is spent or wait long periods of time for recharging.

Fuelling the fuel cell

A variety of fuels may potentially be used with fuel cells since a fuel cell operates on the simple reaction of hydrogen (H_2) and oxygen (O_2) to produce water (H_2O). The oxygen may be taken directly from air, while the hydrogen may be delivered either in pure form, from liquid or gaseous storage tanks, or extracted from hydrocarbon fuels including methanol (CH_3OH), gasoline (a mix of various hydrocarbons), natural gas (CH_4), propane (C_3H_8), and others through the use of a reformer. Much research and development is currently focused on developing either standalone or integrated reformers for extracting hydrogen from hydrocarbon fuels or fuel cells that can be powered directly by fuels such as methanol. Even biogas may potentially be used either directly or indirectly (after undergoing reformation) in fuel cells.

Direct hydrogen fuel cells produce pure water as the only emission. This water is typically released as water vapor. Fuel cells release less water vapor than internal combustion engines producing the same amount of power.

Most fuel cells systems use pure hydrogen or hydrogen-rich fuels, such as methanol, gasoline, diesel, or gasified coal, to produce electricity. Both fuel types have advantages and limitations.

1. **Pure Hydrogen :** Most fuel cell systems are fueled with pure hydrogen gas, which is stored onboard as a compressed gas. Since hydrogen gas has a low energy density, it is difficult to store enough hydrogen to generate the same amount of power as with conventional fuels such as gasoline. This is a significant problem for fuel cell vehicles, which need to have a driving range of 300-400 miles between refueling to be competitive gasoline vehicles. High-pressure tanks and other technologies are being developed to allow larger amounts of hydrogen to be stored in tanks small enough for passenger cars and trucks.

   In addition to onboard storage problems, our current infrastructure for getting liquid fuel to consumers can't be used for gaseous hydrogen. New facilities and delivery systems must be built, which will require significant time and resources. Costs for large-scale deployment will be substantial.

2. **Hydrogen-rich Fuels:** Fuel cell systems can also be fueled with hydrogen-rich fuels, such as methanol, natural gas, gasoline, or gasified coal. In many fuel cell systems, these fuels are passed through onboard "reformers" that extract hydrogen from the fuel. Onboard reforming has several advantages:

   - It allows the use of fuels with higher energy density than pure hydrogen gas, such as methanol, natural gas, and gasoline.

   - It allows the use of conventional fuels delivered using the existing infrastructure (e.g., liquid gas pumps for vehicles and natural gas lines for stationary source).

   There are also several disadvantages to reforming hydrogen-rich fuels:

   - Onboard reformers add to the complexity, cost, and maintenance demands of fuel cell systems.
   - If the reformer allows carbon monoxide to reach the fuel cell anode, it can gradually decrease the performance of the cell.
   - Reformers produce carbon dioxide (a prominent greenhouse gas) and other air pollutants, but less than typical fossil combustion processes.

> High-temperature fuel cell systems can reform fuels within the fuel cell itself—a process called internal reforming—removing the need for onboard reformers and their associated costs. Internal reforming, however, does emit carbon dioxide, just like onboard reforming. In addition, impurities in the gaseous fuel can reduce cell efficiency.

Generation of Heat in the Fuel Cell

In any process, there are inefficiencies and/or losses. In a fuel cell, the useful work is electricity; however, not all of the energy contained in the hydrogen and oxygen can be turned into electricity. Inefficiencies in the fuel cell turn some of the available energy into heat. In a fuel cell, the inefficiencies are associated with four distinct processes:

1) Activation Losses;
2) Fuel Crossover Losses;
3) Ohmic or Resistance Losses;
4) Mass Transport Losses.

Activation losses are associated with the activity of the fuel cell - i.e. its ability to dissociate hydrogen and drive the chemical reaction at low temperatures. Activation losses are governed by the temperature and pressure of the reactants, the construction of the cell, and the type and amount of catalyst used.

Fuel crossover losses are caused by leakage or diffusion of fuel between the fuel cell anode and cathode. Essentially the fuel is "short-circuiting" its normal reaction path and reacting with oxygen directly at the cathode. As the electrons participating in the reaction have not been forced to travel through an electrical circuit to complete this reaction (and do useful work), the only energy produced is in the form of heat.

Ohmic or resistance losses are the result of the electrical resistance of the cell to current.

Mass transport losses occur when the ability to maintain adequate concentrations of hydrogen and oxygen in the fuel cell is limited by high demand.

All of these losses combine to produce heat in the fuel cell.

Size

Fuel cells can be manufactured as large or small as necessary for the particular power application. Presently, there are micro fuel cells that are the size of a pencil eraser and generate only a few milliwatts of power while there are others large enough to provide the electrical needs of hundreds of homes. Since an individual fuel cell may theoretically produce an open circuit voltage of approximately 1 V, their power output is fully scalable by varying the cross-sectional area of each cell to obtain the desired current and by stacking multiple cells in series to obtain the desired voltage.

Advantages of using fuel cells

Fuel cells are clean, highly efficient, scalable power generators that are compatible with a variety of fuel feed stocks and can therefore be used in an assortment of power generation applications. In particular, they offer several advantages over other technologies:

Fuel cells produce electricity without combustion, which means that, unlike internal combustion engines, they generate little (if any) noise, vibration, air pollution, or greenhouse gases and operate at high efficiencies over a wide range of loads.

In small consumer devices and for powering zero emission vehicles, fuel cells, unlike batteries, avoid the need to replace the cell or undergo a lengthy recharging cycle when its fuel is "spent". Additionally, since fuel cells store their fuel in external storage tanks, the maximum operating range of a fuel cell-powered device is limited only by the amount of fuel that can be carried.

In distributed power generation applications, fuel cells reduce the load on the grid and also eliminate (or reduce) the need for overhead or underground transmission lines, which are expensive to install and maintain, and result in power losses/efficiency reductions.

Since fuel cells are scalable and can be installed on site, they reduce the need for large power generation plants (and the environmental impacts of such large scale plants).

Fuel Cell Systems

The design of fuel cell systems is quite complex and can vary significantly depending upon fuel cell type and application. However, most fuel cell systems consist of four basic components:

1. **A fuel processor:**
2. **An energy conversion device (the fuel cell or fuel cell stack)**
3. **A current converter**
4. **Heat recovery system (typically used in high-temperature fuel cell systems used for stationary applications)**

Though they are not discussed here, most fuel cell systems include other components and subsystems to control fuel cell humidity, temperature, gas pressure, and wastewater.

Fuel processor

The first component of a fuel cell system is the fuel processor. The fuel processor converts fuel into a form useable by the fuel cell. If hydrogen is fed to the system, a processor may not be required or it may only be needed to filter impurities out of the hydrogen gas.

If the system is powered by a hydrogen-rich conventional fuel such as methanol, gasoline, diesel, or gasified coal, a reformer is typically used to convert hydrocarbons into a gas mixture of hydrogen and carbon compounds called "reformate." In many cases, the reformate is then sent to another reactor to remove impurities, such as carbon oxides or sulfur, before it is sent to the fuel cell stack. This prevents impurities in the gas from binding with the fuel cell catalysts. This binding process is also called "poisoning" since it reduces the efficiency and life expectancy of the fuel cell.

Some fuel cells, such as molten carbonate and solid oxide fuel cells, operate at temperatures high enough that the fuel can be reformed in the fuel cell itself. This is called internal reforming. Fuel cells that use internal reforming still need traps to remove impurities from the unreformed fuel before it reaches the fuel cell.

Both internal and external reforming release carbon dioxide, but less than the amount emitted by internal combustion engines, such as those used in gasoline-powered vehicles.

Energy Conversion Device - The Fuel Cell Stack

The fuel cell stack is the energy conversion device. It generates electricity in the form of direct current (DC) from chemical reactions that take place in the fuel cell.

Current Inverters &Conditioners

The purpose of current inverters and conditioners is to adapt the electrical current from the fuel cell to suit the electrical needs of the application, whether it is a simple electrical motor or a complex utility power grid.

Fuel cells produce electricity in the form of direct current (DC). In a direct current circuit, electricity flows in only one direction. The electricity in your home and work place is in the form of alternating current (AC), which flows in both directions on alternating cycles. If the fuel cell is used to power equipment using AC, the direct current will have to be converted to alternating current.

Both AC and DC power must be conditioned. Power conditioning includes controlling current flow (amperes), voltage, frequency, and other characteristics of the electrical current to meet the needs of the application. Conversion and conditioning reduce system efficiency only slightly, around 2 to 6 percent.

Heat Recovery System

Fuel cell systems are not primarily used to generate heat. However, since significant amounts of heat are generated by some fuel cell systems—especially those that operate at high temperatures such as solid oxide and molten carbonate systems—this excess energy can be used to produce steam or hot water or converted to electricity via a gas turbine or other technology. This increases the overall energy efficiency of the systems.

Challenges

Although the potential benefits of fuel cells are significant, many challenges, technical and otherwise, must be overcome before fuel cell vehicles will be a successful, competitive alternative for consumers.

Cost

Cost is the greatest challenge to fuel cell development and adaptation, and it is a factor in almost all other fuel cell challenges as well. Several fuel cell designs require expensive, precious-metal catalysts, while others require costly materials that are resistant to extremely high temperatures. Costs are also associated with fuel cell durability and operating lifetime, fuel delivery and storage, and other aspects of fuel cell use.

Durability & Dependability

Another technical challenge facing fuel cells is the need to increase durability and dependability. High-temperature fuel cells, in particular, are prone to material breakdown and shortened operating lifetimes. PEM fuel cells must have effective water management systems to operate dependably and efficiently. Finally, all fuel cells are prone, in varying degrees, to catalyst poisoning, which decreases fuel cell performance and longevity. Research into these areas is ongoing, and the Department Of Energy in USA is sponsoring and participating in demonstration programs to test the durability of new components and designs.

Fuel Issues

A number of fuel-related challenges exist for fuel cells, especially those powered by pure hydrogen.
Production. Hydrogen is currently more expensive to produce than conventional fuels, such as gasoline, and many of the more cost-effective production methods generate greenhouse gases.

Delivery. The current system for delivering conventional fuels to consumers cannot be used for hydrogen. New infrastructure will have to be developed and deployed. Unfortunately, since several potential technologies are evolving at this stage of development, the exact infrastructure requirements have not been determined.

Storage. Hydrogen has a low energy density in terms of volume, making it difficult to store amounts adequate for most applications in a reasonable-sized space. This is a particular problem for hydrogen-powered fuel cell vehicles, which must store hydrogen in compact tanks. High-pressure storage tanks are currently being developed, and research is being conducted into the use of other storage technologies such as metal hydrides and carbon nano-structures (materials that can absorb and retain high concentrations of hydrogen).

Safety. Hydrogen, like gasoline or any other fuel, has safety risks and must be handled with due caution. While we are quite familiar with gasoline, handling hydrogen will be new to most of us. Therefore, developers must optimize new fuel storage and delivery systems for safe everyday use, and consumers must become familiar with hydrogen's properties and risks.

Public Acceptance Finally, fuel cell technology must be embraced by consumers before its benefits can be realized. This is especially true for transportation, stationary residential, and portable applications, where consumers will interact with fuel cell technology directly. Consumers may have concerns about the dependability and safety of fuel-cell-powered equipment, just as they have about other modern devices when they were introduced.