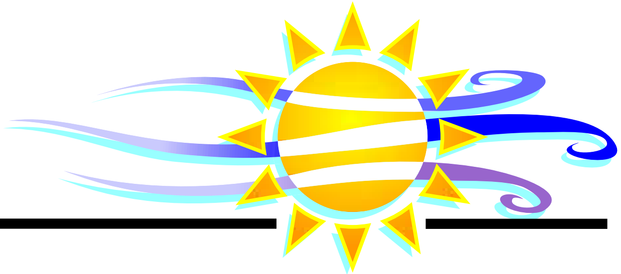
Fuel Cells



Introduction

Did you know that the appliances, lights, and heating and cooling systems of our homes requiring electricity to operate consume approximately three times the energy at the power plant to generate that electricity? That equates to an energy efficiency of about 33%, which is very low. The remaining 67% is waste heat lost to the atmosphere. Increasing the efficiency of generating electricity would help save consumers money, as well as benefit the conservation of natural resources and decrease emissions associated with fossil fuel combustion.

One very promising technology that has received increasing attention because of its ability to increase overall energy efficiency is fuel cells. Simply put, a fuel cell is an electrochemical device that converts hydrogen and oxygen into electricity without combustion. Fuel cells have been around since the mid 19th century, and the space program has used them since the early 1960s. A fuel cell operates much like a battery, turning oxygen and hydrogen into electricity in the presence of an electrically conductive material called an electrolyte. But unlike a battery, it never loses its charge and will generate electricity as long as there is a source of hydrogen and oxygen.

Fuel Cell Basics

Figure 1 illustrates the fuel cell concept. Fuel cells consist of three basic components: a fuel reformer or processor, a power section, and a power conditioner. The reformer or processor extracts pure hydrogen (H2) from hydrocarbon fuels such as natural gas. The power section is where the H2 &

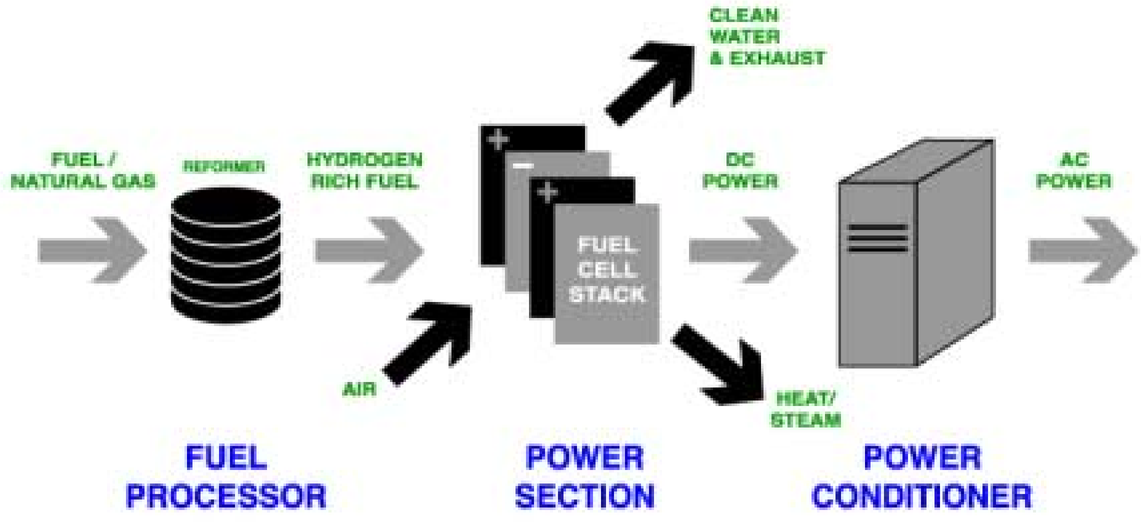


Figure 1. Basic Fuel Cell Concept

oxygen (O_2) are combined to generate electricity and waste heat. If alternating power is required, then a power conditioner is needed to convert direct current power to AC power.

A variety of fuels can be used to power a fuel cell with the most common being natural gas (methane), but ethanol, methanol, landfill gas, and liquefied petroleum gas can all be used as hydrogen feedstocks. Pure hydrogen can be generated from a variety of sources, most commonly from the electrolysis of water. One interesting approach to produce pure hydrogen involves using electricity generated from wind power to electrolyze hydrogen and oxygen from water. The hydrogen gas could then be pressurized and used in a fuel cell equipped vehicle or possibly pumped through pipelines for use at later times.

Types of Fuel Cells

The general design of most fuel cells is similar except for the electrolyte. The five main types of fuel cells, as defined by their electrolyte, are alkaline fuel cells, proton exchange membrane fuel cells, phosphoric acid fuel cells, molten carbonate fuel cells, direct methanol fuel cells, and solid oxide fuel cells. Alkaline and solid polymer fuel cells operate at lower temperatures and are mainly designed for use in transportation applications, while the other three operate at higher temperatures and are being developed for use where the waste heat can be used (cogeneration) or in large central power plants.

Alkaline fuel cells (AFC), used by NASA, have very high power generating efficiencies, and discharge only pure water. Unfortunately, only very pure hydrogen and oxygen can be used and the electrolyte, alkaline potassium hydroxide, is expensive. It is expected that these types of fuel cells will be used only in niche markets and applications.

Proton-exchange membrane (PEM) fuel cells are the most common type of fuel cells for light-duty transportation use, because they can vary their output quickly (such as for startup) and fit well with smaller applications. Chief advantages of PEMs are that they react quickly to changes in electrical demand, will not leak or corrode, and use inexpensive manufacturing materials (plastic membrane).

Phosphoric acid fuel cells (PAFCs) are the most commercially developed type and are being used in hotels, hospital, and office buildings. The PAFC plant also makes use of the waste heat for domestic hot water and space heating.

Turnkey 200-kilowatt plants are now available and have been installed at more than 100 sites in the United States, Europe, and Japan.

Molten carbonate fuel cells (MCFCs) operate at high temperatures which mean that they can achieve higher efficiencies and have a greater flexibility to use more types of fuels. Fuel-to-electricity efficiencies approach 60%, or upwards of 80% with cogeneration.

Solid oxide fuel cells (SOFCs) also operate at higher temperatures and have demonstrated very good performance in combined-cycle applications. SOFCs are a promising option for high-powered applications, such as industrial uses or central electricity-generating stations.

Direct methanol fuel cells (DMFC) use methanol instead of hydrogen and are being considered for use in the transportation industry. DMFCs differ from the other types of fuel cells in that hydrogen is obtained from the liquid methanol, eliminating the need for a fuel reformer.

Benefits of Fuel Cells

Fuel cells have several important advantages over conventional electrical energy generation from sources such as coal. First, they are more efficient at converting fuel sources to end-use energy. Fuel cells are projected to achieve overall efficiencies of around 70%-80%, when utilizing the waste heat. The “fuel-to-wire” efficiencies will be higher than common generation units - more electricity per unit of fuel is produced <u>and</u> CO_2 emissions, are reduced for a given power output compared to conventional generation.

Second, because combustion is not involved, no combustion by-products, such as nitrogen oxide (NO_x), sulfur oxide (SO_x), or particulates, are produced. For example, the direct hydrogen fuel cell vehicle will have no emissions, even during idling, which is especially important during city rush hours.

Third, significant potential exists for waste heat utilization in combined heat and power, or cogeneration, units which serves to raise the overall efficiency.

One final benefit of fuel cells stems from their ability to be built to a certain size and then have their power output quickly and easily increased by adding more stacks of fuel cells, when and if demand for electricity increases. Fuel cells are ideal for power generation, either connected to the electric gird to provide supplemental power and backup assurance for critical areas, or installed as a grid-independent generator for on-site service in areas that are inaccessible by power lines.

Applications of Fuel Cells

Fuel cells are also being used in the transportation sector to power cars, trucks, and buses. A fuel cell car will be very similar to an electric car, but with a fuel cell and reformer instead of batteries. Major automobile manufacturers, such as Toyota, Honda, and Nissan are planning limited production of fuel cell cars in the near future. They are intended to operate on pure hydrogen, which eliminates the need for an on-board reformer. Fuel cell-powered buses such as the ones shown in Figure 2 are already running in several cities. Buses

Figure 2. City of Chicago Fuel Cell-powered Transit Buses

were one of the first applications of the fuel cell because initially, fuel cells needed to be quite large to produce enough power to drive a vehicle.

Fuel cells are highly suitable for on-site power generation. Since they do not contribute to smog and because they operate very quietly, fuel cells are uniquely suited to the world of distributed generation, in which electricity is produced by relatively small power plants at or near the end uses, especially in urban areas. Presently 8-10% of generated electrical power is lost between the generating station and the end user. Stationary fuel cells are currently being used in hospitals, nursing homes, hotels, office buildings, schools, and utility power plants providing primary or backup power. In many of these types of applications, fuels cells are used because they are extremely reliable and/or have no harmful emissions.

Two of the more interesting stationary fuel cell applications involve a major credit card center and at large solid waste landfills and sewage treatment plants. The credit card center uses a fuel cell as its primary electricity supply due to its extremely high reliability of providing uninterrupted power. The landfill/sewage treatment plants utilize the methane gas generated by the decomposition of wastes/sewage as their primary fuel source to generate electricity which is sold to nearby communities. Even the building shown in Figure 3 in New York City's Times Square is powered by fuel cells.

Fuel cells can also be used to provide power for your home by producing electricity and significant amounts of waste heat, for use as space and water heating. Overall efficiencies could be as high as 70%-80% with waste heat utilization, resulting in a considerable savings because there could be no additional energy costs related to space and water heating. The picture shown in Figure 4 is of a typical residential-scale fuel cell.

Figure 3. Building in New York's Times Square Powered by Fuel Cells (photo courtesy of Fuel of Fuel Cells 2000)

Figure 4. Residential-scale Fuel Cell (photo courtesy of Plug Power)

There are even fuel cells that are portable and small enough to be used as power devices for laptop computers (shown in Figure 5) and cellular phones. The chief advantage of fuel cells in these applications is that they will provide power many times longer than conventional batteries. Fuels cells may also see application in smoke detectors and burglar alarms. Methanol will probably be used as the hydrogen feedstock.

Transportation Fuel Cell Efficiencies vs. Conventional Gasoline Engines

In most transportation applications, fuel cells will probably operate on methanol, which has been estimated to have fuel economies (miles per gallon, mpg) of anywhere from 1.74 to 2.6 times greater than a conventional gasoline engine. Projections of gasoline-based fuel economies in 2010 are a little over 31 mpg; therefore, a fuel cell vehicle operating on methanol can expect to achieve something around 55 miles per gallon. This represents a significant energy and cost savings, and would provide a substantial decrease in harmful pollutants associated with petroleum-based transportation fuels.

Figure 5. Portable fuel cell for use with laptop computer (photo courtesy of Ballard)

Fuel Cells and Biomass Energy Resources

Fuel cells are superior in many respects compared to conventional power generation technologies. Another advantage is that biomass energy resources such as agricultural crop residues, animal wastes (manures), municipal solid waste, wood wastes, and landfill gas can serve as the hydrogen supply feedstocks. These biomass resources can be converted into a combustible gaseous fuel (low Btu methane) or into ethanol or methanol, both of which can be reformed into the H_2 source for the fuel cell.

The combination of using biomass fuels in conjunction with fuel cells has several important benefits. First, biomass energy is a renewable, domestic energy resource which can be used to offset petroleum imports, decreasing our trade imbalance, and increasing our energy security. Second, most biomass waste resources can be obtained at little or no cost, thereby helping to decrease the end-use cost. Third, most biomass resources have a “closed-carbon loop.” The CO_2 released during conversion to a useful fuel source will be taken back up in plant growth. This will contribute to decreasing global warming, commonly associated with fossil fuel combustion. Capturing and utilizing these waste resources in a fuel cell would be of significant benefit to the environment because release of methane from landfill gas or animal manures has 21 times the heat-trapping potential than CO_2. The use of biogas generated from these two sources does require significant “clean up” before it can be used, contributing to the overall cost of the delivered energy.

The major drawback to the conversion of biomass resources for use in fuel cells, at least in the immediate future, lies in its economics. Since other energy sources, such as natural gas, are relatively inexpensive. Biomass resources may first find applications in niche applications such as using landfill gas or in rural areas.

Present and Projected Future Costs of Fuel Cells

The biggest drawback presently associated with fuel cells is their cost. Today, the most widely marketed fuel cell costs from $1,500 - $4,500 per kiloWatt, depending upon the type of fuel cell and end-use application. By contrast, a diesel engine costs $800 to $1,500 per kilowatt, and a natural gas turbine even less. Costs are expected to decrease in the future (projections are for around $400/kW) as more fuel cells are produced and utilized. Techniques have also been developed to separate hydrogen from natural gas inside the fuel cell ("internal reforming"), eliminating the expense of a separate system.

While the “up-front” cost of fuel cells is greater than conventional power sources, the life-cycle cost has been determined to be significantly less. This is due to lower (virtually non-existent) maintenance costs for fuel cells versus those of fossil fuel-powered vehicles. Because the chemical conversion efficiency is much greater in a fuel cell than in an internal combustion engine, fuel costs will be lower on a per-mile basis.

Conclusion

Fuel cells can promote energy diversity, provide a transition to renewable energy sources, and benefit the environment through their higher fuel-to-electricity conversion. Alternative fuels such as hydrogen, methanol, ethanol, and landfill gas can be produced from renewable energy sources such as biomass and wind. With only a 10% market penetration by fuel cell vehicles, an imported petroleum displacement of 800,000 barrels per day could be achieved, which is 8% of projected total petroleum use in the United States by the year 2007.

Where to get more information

www.fuelcells.org

www.eren.doe.gov/RE/hydrogen_fuel_cells.htm

www.fetc.doe.gov/products/power/fuelcells