

# GRAPHITE AND CARBONS

## For FUEL CELL APPLICATIONS



### Asbury Carbons Fuel Cell Products: Introduction

The last half of the 20<sup>th</sup> century saw a dramatic increase in world-wide energy demand.



This demand was accompanied by a corresponding increase in the use of fossil fuels, and due in some part to concerns raised by the Chernobyl and Three Mile Island incidents, a decrease in the use of nuclear energy.

Growing fear of possible global warming, fueled by perceived changes in climate, have resulted in international concern regarding the long term effect of carbon dioxide

emissions from the combustion of fossil fuels including coal, oil, and natural gas. Since all fossil fuels are carbon-based substances the primary product of combustion is carbon dioxide, a known “greenhouse” gas. Concern for the long term “state of the planet” has evolved into a serious global effort to decrease the amount of carbon dioxide emissions, while at the same time increasing the efficiency of energy generation. Fuel cells make both of these goals possible.



The elimination of CO<sub>2</sub> emissions as waste product in power generation can only be achieved by eliminating carbon from the power generation cycle. This pathway to power generation is possible with hydrogen based fuel cells. In these devices power, in the form of electrical energy, is generated by oxidizing hydrogen provided as fuel. The waste product of this process reaction is simply water. Carbon dioxide is not generated because no carbon is “burned” in the process. The oxidation of hydrogen is performed electrolytically so that little heat is produced and subsequently wasted.



There are as many ways to generate energy as there are fuels available. And although no one generation method or fuel will ever provide all of our energy requirements the fuel cell, using hydrogen or a hydrogen containing substance, is the system being touted as a viable



method to provide localized energy for a variety of applications. There are fuel cells sized to provide power for cell phones and computers, cars, trucks, and buses, as well as large office buildings. The fact that fuel cells can provide “spot energy” at any location is a big part of the reason they are so efficient.



$\Delta H \equiv \Delta U + P\Delta V$ : A single unit of fuel can produce a limited amount of energy; that finite enthalpy ( $\Delta H$ ) will never change. However if a generation system is installed at the location where the power is consumed the energy typically used to transmit the power



from traditional remote generation sites through hundreds of miles of wire is conserved. The lack of long distance transmission, and the reduction in supporting infrastructure results in a method of power generation that is potentially more efficient than other systems. When used to provide energy for personal or public transportation, personal items such as computers, or to augment the power requirements of public facilities or remote housing, hydrogen PEM fuel cells provide an efficient power source without the carbon-based emissions.

Please take the time to read the other articles on the Asbury Carbons Web page that discuss fuel cells and other applications that utilize carbon and graphite.

# HOW A FUEL CELL WORKS



Although a detailed explanation of the workings of fuel cell devices is beyond the scope of this article a brief explanation of a fuel cell is described below.

A fuel cell is an electrochemical device that, like any battery, converts chemical energy into electrical energy. The concept of the fuel cell is not new; the first working cell was developed in the late 1830's by William Robert Grove (1811-1896), who referred to his device as a "gas battery". "Battery" is a good descriptive term for a fuel cell, which in the strictest sense can be looked upon as a primary battery whose chemical fuel is constantly replenished.

The operating principle of the proton-exchange-membrane-hydrogen-based fuel cell is relatively simple. The overall fuel cell as a unit is composed of a number of stacked cells (similar to the cells of a car battery). Each cell in the stack is composed of a cathode and anode which are separated by the proton exchange membrane. The PEM serves as an insulator between the adjacent "half cells" while providing a pathway for migration of hydrogen protons created during the process. Hydrogen is fed to the anode side of each cell and air or oxygen to the cathode side. Electrons are given up by hydrogen on the anode side, directed through an external circuit and then return to the system on the cathode side where they recombine with hydrogen ions and oxygen to form water. The process is described in a bit more detail below.

The PEM fuel cell cathode and anode are constructed of graphite. The "plates", as they are known, are manufactured by mixing graphite with a supportive matrix, typically a polymer, and molding this mixture into the desired size and shape. The graphite is the filler material of choice because it is electrically conductive, light weight, inert, and low in cost.

Both the cathode and anode plates have "flow" channels either machined or molded into their respective surfaces. These channels provide a pathway for the gaseous fuel and oxidizer, that are typically hydrogen gas and air. The anode and cathode are assembled with the flow channels facing each other with the proton exchange membrane between them. The PEM forms an electrically insulated barrier between the graphite plates that allows the conduction of positive ions (protons) but restricts the passage of electrons.

The process of power generation begins with hydrogen at the anode side of the cell. The proton exchange membrane is coated with a special platinum catalyst that causes hydrogen molecules coming in contact with it to split into two  $H^+$  ions (hydrogen ions). The formation of the positive hydrogen ion requires that each hydrogen atom, from the original hydrogen molecule, give up an electron (electrons have a negative charge). This is where the graphite comes in, as these now "free" electrons are conducted away by the highly conductive graphite anode and are directed through an external circuit where they provide energy. At the anode the hydrogen is *oxidized* (its electrical charge is increased due to the shedding of electrons which results in an increased positive charge).

The newly formed hydrogen ions (protons) continue to move through the proton exchange membrane while on the cathode side of the cell oxygen molecules moving into the surface of the proton exchange membrane are cleaved into two highly reactive oxygen atoms (the oxygen molecule,  $O_2$ , is relatively stable while oxygen atoms are not). While all of this is occurring the electrons released from the hydrogen molecules, previously at the anode, return from the external circuit through the highly conductive graphite cathode. At the interface of the proton exchange membrane and cathode one oxygen atom, two hydrogen ions, and two returning electrons combine to form a water molecule. At the cathode the overall reaction is a *reduction* (electrons are added to oxygen reducing its charge).

Overall in the cell stack, hydrogen is oxidized, oxygen is reduced, electrons are liberated and reunited, and the “chemical pressure” of all of this is used to provide power. The byproduct of this electrolytic “combustion” is water, which is vented to the atmosphere. If this type of FC were to be used in space travel the by-product water could be consumed by astronauts.

The above process occurs in each cell of the stack as long as fuel is provided. Each cell is pumping electrons released from the previous cell resulting in an overall stack pressure, or *voltage*, which is equal to the voltage of each cell multiplied by the number of cells that are in series (the total number of cells in the stack). In theory, a 100 cell stack made up of 0.7 volt cells in series will have a 70 volt output.

In summary, the PEM fuel cell assembly uses hydrogen and oxygen as reactants and provides electrical energy and water as products. No green house gases are emitted.

Please read the other fuel cell related entries on the Asbury Carbons Web page.

# Graphite and The Proton Exchange Membrane Fuel Cell

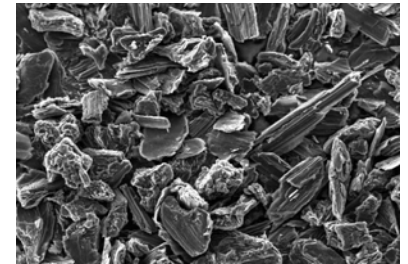


On a weight basis the anodes and cathodes that make up the individual half-cells of a fuel cell stack account for a significant portion of the total mass of the FC device. Typical plates are compounded mixtures containing up to 90% graphite so each FC unit can have a substantial quantity of graphite in its workings.



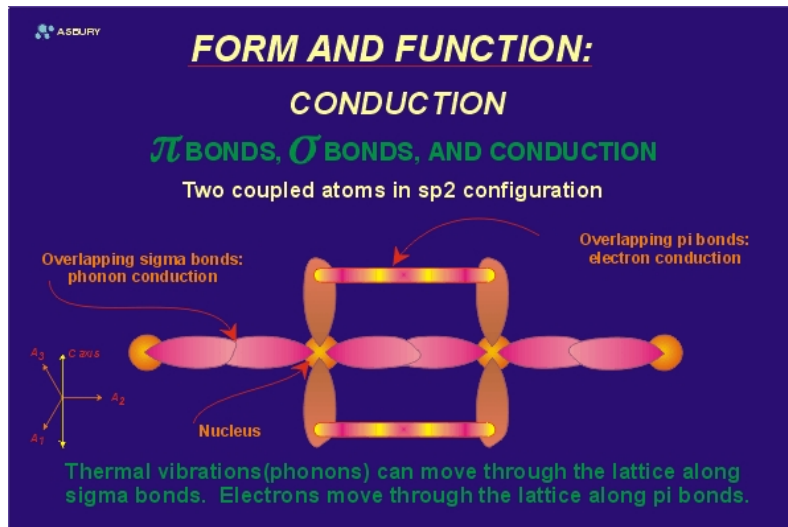
Graphite is the material of choice for the PEMFC anode and cathode assemblies. The selection of graphite as the right material is obvious since graphite is highly conductive, low in density compared to other conductive materials, inert, and cost effective.

Graphite is one of the few non-metallic substances that are both electrically and thermally conductive. Both of these physical attributes contribute significantly to the success and importance of graphite in the PEMFC application.

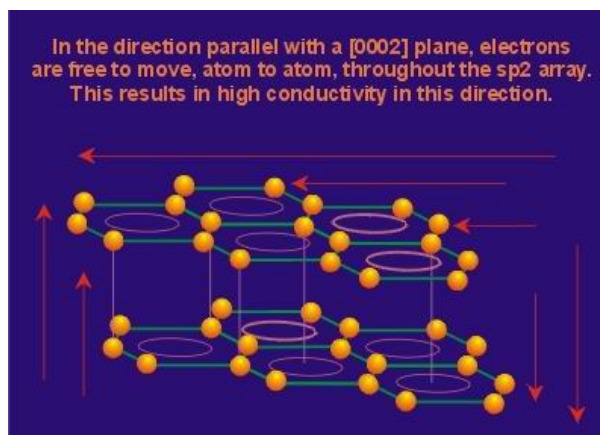


Electrical conductivity is affected by the molecular structure of graphite, which contains carbon atoms in a unique bonding arrangement that allows the bonding electrons to be

mobile within the graphite crystal. These mobile electrons provide a mechanism for electrical conduction since they act as “charge carriers” and flow with little resistance when exposed to voltage pressure. Thermal conductivity in graphite is affected by this same unique bonding system but the mechanism is a bit different. Thermal vibrations (heat) are conducted along the “hard” molecular bonds



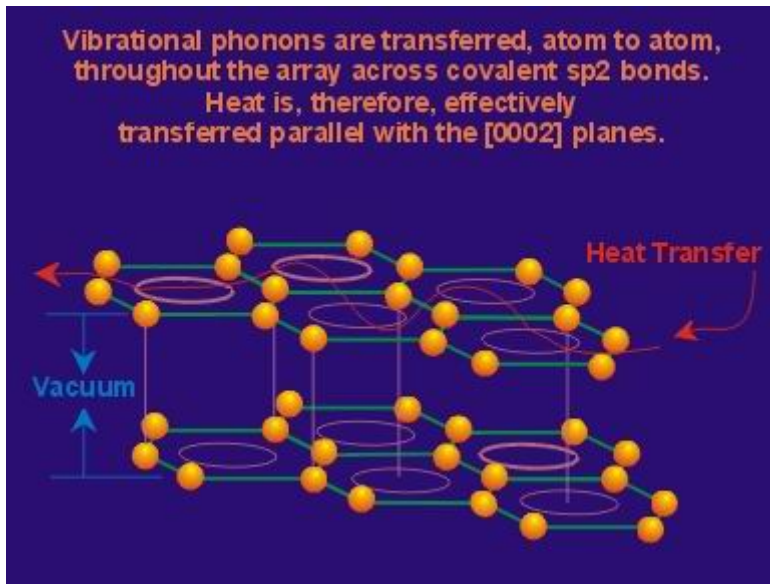
that join the centers of individual carbon atoms within a graphite crystal.



Graphite plates that make up the anode half of individual cells perform the function of a collector of those electrons released by hydrogen atoms as they are oxidized to hydrogen ions (protons). These electrons enter the anode “collector” where they are directed to an external circuit. Graphite that makes up the plates in the cathode half of

the individual cell performs the function of an electron “distributor”. Electrons returning from the external circuit enter the cathode and are then returned to the interface of the proton exchange membrane and cathode where they combine with hydrogen ions and oxygen atoms to form water.

The benefit of high thermal conductivity to a FC cell may not be as obvious an attribute as the benefit of high electrical conductivity.



However, thermal conductivity is very important because it prevents the formation of “hot spots” on half cell surfaces. Heat resulting from the chemical reactions occurring in the proton exchange membrane and at the PEM cathode-anode interface is conducted to cooler portions of the cell maintaining an even distribution of thermal

energy throughout the cell stack. This helps to prevent the built up of heat at any single location within the stack, which results in an overall system that is easier to keep cool or heat up.

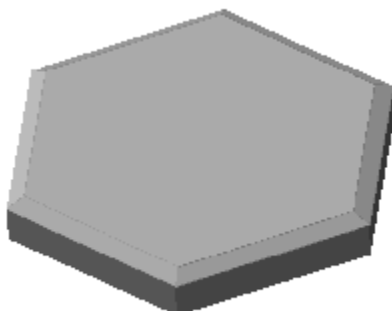
Graphite is relatively low in density, especially when compared to more traditional metallic conductors such as copper and aluminum.



The crystallographic density of graphite (perfectly solid graphite) is 2.26 gram/cc. Graphite is 20% less dense than aluminum, and four times less dense than copper.



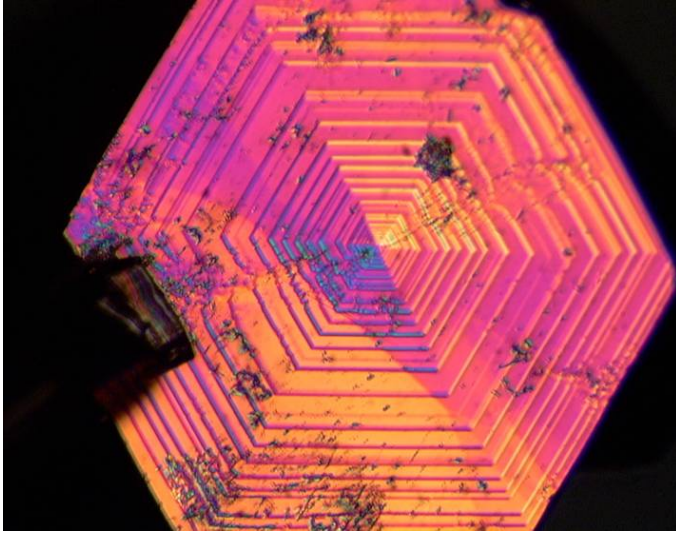
Graphite is known to be chemically inert, especially when compared to metallic conductors. At the temperatures at which a fuel cell operates graphite has virtually no known solvent. Even at high temperatures graphite is very difficult to dissolve in anything except molten metal such as iron.



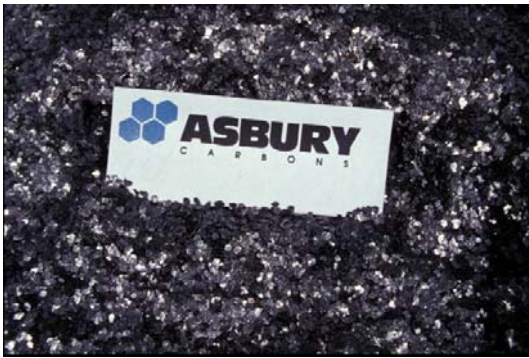
Although the role of graphite in the FC stack is of paramount importance its role can still be considered as “passive”. Graphite simply provides a substrate where reactions can occur and electrons can be transferred to and from the half cells. It is very important that the graphite retains this passive role and contributes nothing to the system that may affect reaction rate, ion

solubility or motility, catalyst activity, and other cell parameters affected by soluble ions or other contamination. In this respect graphite is the ideal material to use as a conductive structural element for fuel cell construction.

In recent years much research has been performed and results show that graphite is the material of choice for cathode and anode plates in a PEM fuel cell stack. Formulators and fabricators have been very successful in forming plates from both natural and



synthetic graphite using powders and particles ranging in size from micrometers to millimeters in dimension. Although researchers differ widely in their opinion regarding the best graphite “type” and particle size distribution they prefer to use, most do agree that graphite materials should be at least 99% pure. Only by the utilization of high purity graphite can the fuel cell researcher or manufacturer be confident that no unwanted side-reactions or other unpredictable chemical effects will interfere with fuel cell performance.



Asbury Graphite Mills is a leader in the carbon industry established in 1895. We have supplied the fuel cell industry with powdered and granular graphitic carbons for over 20 years. Asbury offers a complete line of natural and synthetic graphite powders and granulated products that are 99++% pure. Custom sizes can be tailored to your engineered specifications.

Please read the other fuel cell related entries on the Asbury Carbons Web page.