Fuel Cells

Fuel cells were first suggested as a means to produce energy from raw materials in 1839. Due to technical difficulties, the development of fuel cells lagged behind other technologies, such as the steam engine, until both the US and Russian space programs chose them over riskier nuclear power, more expensive solar energy and batteries in the 1960's. Since then, fuel cells have been used to furnish power for the Gemini and Apollo spacecraft; they are still used today to provide electricity and water for space shuttles[1]. Like batteries, fuel cells use a chemical reaction to generate electricity. However, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat for as long as fuel is supplied.

Fuel cells offer several advantages over traditional combustion methods of generating electricity. A fuel cell operating on pure hydrogen and oxygen produces no NO_X, CO_2, CO, or hydrocarbon emissions. A fuel cell operating on other types of fuels, such as natural gas or methanol, produces emissions well below all current environmental standards. Fuel cells contain no moving parts and therefore are low in noise and vibration[1]. Finally, a fuel cell is not a heat engine, and therefore is not subjected to the Carnot efficiency limitation. Efficiencies as high as 60% are possible, or in excess of 80% if the generated waste heat energy is utilized[2].

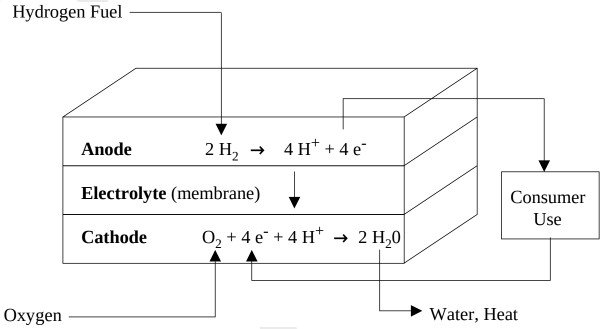

Figure 1: A diagram of a PEM fuel cell.

All fuel cells work on the same basic principle, which is the use of spontaneous electrochemical reactions to generate electricity. Figure 1 illustrates this process for the specific case of a proton exchange membrane (PEM) fuel cell. Oxygen is passed over one electrode, and hydrogen over the other. As diatomic hydrogen molecules come into contact with the anode, they are split first into individual hydrogen atoms and then again into protons and electrons. The electrons flow out of the cell to be used by the consumer as electrical energy. Meanwhile, the protons pass across the PEM to reach the cathode. Molecular oxygen is split into atomic oxygen at the cathode, where it combines with protons crossing the PEM to form water molecules. Other than water, the only by-product from this process is heat[1,3]. The process used to generate electricity in other classes of fuel cells is similar; the main difference is the chemical reactions employed.

Unfortunately, even when running at peak efficiency, a single fuel cell can only generate a potential difference of about 0.7 volts. In order to create a useful device, many fuel cells must be connected together in series and run simultaneously; the result is known as a fuel cell stack. Wires generally are not used to connect the individual fuel cells in a stack, as this has been shown to be inefficient[1]. Rather, a piece known as a bipolar plate is inserted between each individual cell, as illustrated in Figure 2. A bipolar plate must serve several functions simultaneously. These tasks include the transport of fuel to the cell, the transport of water from the cell, the circulation of cooling fluids, and the conduction of current from one fuel cell to the next.

Much time has been devoted to the development of bipolar plates. Despite these efforts, the bipolar plate remains an expensive, fragile and bulky component. For example, in most fuel cell stacks, the bipolar plates make up over 80% of the volume and nearly all of the mass. They must be machined from select materials as they are required to withstand humid and extremely corrosive conditions (caustic in the case of alkaline fuel cells) over extended periods of time. Furthermore, they must maintain good electrical conduction properties over a wide range of temperatures[1]. The cost of this component is so high that it has been implicated as one of the top two reasons that fuel cells (primarily PEM) are not in widespread use for vehicular and portable energy applications today, the other being cost of the proton exchange membranes themselves[4].

The aim of this project is the development of alternative, low cost materials for use as bipolar plates. We are collaborating with Custom Materials, Inc., for the development and characterization of plates made from wood and wood by-products. Such products have a very uniform and controlled pore structure. Starting from a variety of sources, including wood, sawdust, cardboard, or masonite, the structure is carbonized by slowly heating under controlled conditions. The resulting material retains its uniform pore structure without forming microcracks. An example of this kind of product is shown in Figure 3.

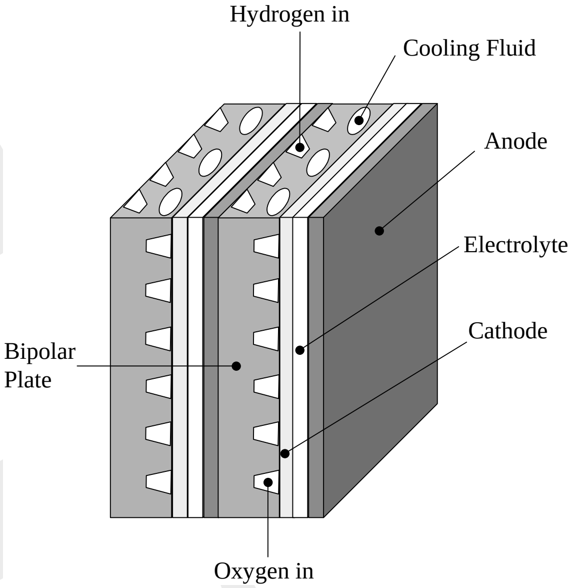

Figure 2: A piece of a fuel cell stack. The bipolar plate is responsible for transporting hydrogen, oxygen, and cooling fluid to the electrodes, and removing excess water.

Materials made from wood and wood by-products have several advantages over conventional bipolar plates, which are commonly machined from graphite or carbon-carbon composites. The largest advantage is that wood products and the plates made from them are very inexpensive. They can be easily machined or shaped into any desired geometry before the carbonization process. Furthermore, pore size can be controlled through materials selection and processing conditions. The result is that these materials can be made very thin, so that multiple units can be stacked together in a small volume. The resulting product maintains its integrity in harsh environments, including high temperature, high pressure and corrosive conditions. Finally, the generation of anisotropic pore structures is possible, which could be used as an alternative to machining grooves for fuel and cooling fluid transport.

This project involves the development and performance testing of novel plates made from wood and wood by-products. To aid with the characterization process, we are collaborating with the Center for Nondestructive Evaluation to image the interior of the plates. It is expected that these novel bipolar plates will be an efficient and cost-effective solution which will help

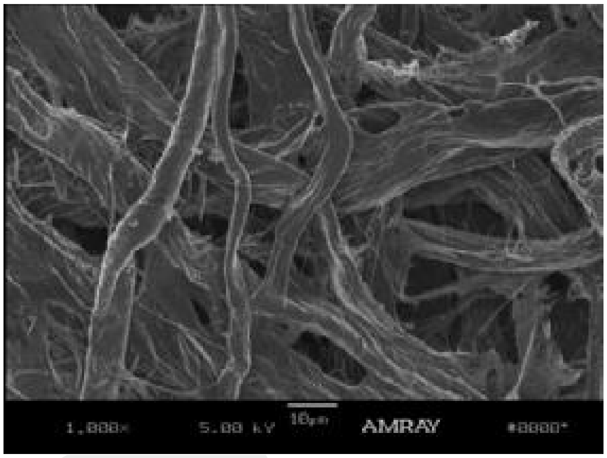

Figure 3: Scanning electron micrograph of carbonized filter paper.

drive the widespread acceptance of fuel cells as alternative power sources. We have developed collaborations with several private companies for commercialization of the final product.

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[4] http://www.electricboat.com/serv01.htm