Hydrogen Fuel Cell

The goal is to design a hydrogen fuel cell and an in-house manufacturing process for the fuel cell. The purpose of the design is to determine the potential for applying this technology in practice by designing a prototype and a method for mass production of this fuel cell. A fuel cell is a device that separates a combustion reaction into its two half reactions. The electrons are forced to travel an external circuit, which creates electricity, before completing the reaction. Hydrogen is a typical fuel used with fuel cells because its combustion reaction only produces water and heat. A storage and delivery method for the fuel is an important aspect to consider when designing a fuel cell. The purity of the hydrogen fuel is one area of concern that was investigated. The reason for this concern is due to possible catalyst poisoning from any impurities. The catalyst aids in the oxidation reaction that liberates the electrons.

The fuel cell will incorporate an enzymatic catalyst, hydrogenase, instead of the typical platinum catalyst currently used in most fuel cells. Hydrogenase is an enzyme produced by many species of bacteria that oxidizes hydrogen. Hydrogenase is less susceptible to poisoning by impurities in the fuel feed. Before being applied to the electrodes, the hydrogenase enzyme must be harvested from the bacteria and purified. Enzymes have the potential to denature, which makes them useless, so single-walled carbon nanotubes (SWCNT) will be used to immobilize the hydrogenase. This immobilization will eliminate the possibility for the enzyme to denature. Design of the fuel cell includes determining potential applications, a manufacturing process for all the components, and the final assembly of the fuel cell.

Fuel Cell Technology

Fuel cells are used today to generate power for a variety of applications. With a recent societal emphasis on protecting the environment, hydrogen-based fuel cells are receiving an increasing amount of interest due to their benign combustion products. The general principle of a fuel cell is to separate a combustion reaction into two half reactions and force the electrons to flow around a circuit to complete the reaction. This method leads to significantly higher efficiencies when compared with electrical power generation from the combustion of the fuel. A variety of fuel cells exist utilizing many different fuel sources. The type investigated for this design was a proton exchange membrane (PEM) fuel cell, designed to utilize hydrogen gas as a fuel source.

A PEM fuel cell operates at low temperatures (ranging from 50 to 100ºC), exhibits high power density, quick start-up, and responds quickly to varying power loads[1]. These characteristics make the PEM fuel cell applicable to many situations. A wide range of power outputs can be achieved by stacking single fuel cells together in series. This coupling is known as a fuel cell stack. The number of cells required to reach a desired output varies based on the design of the fuel cells. Figure 1 illustrates the major components of a fuel cell stack.

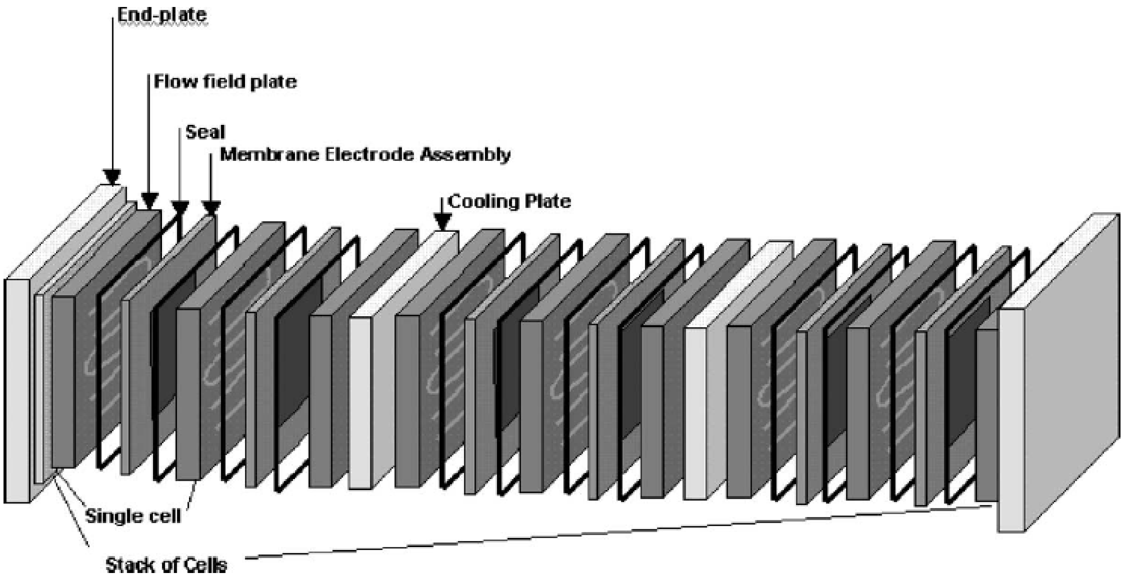

Figure 1: Basic Arrangement of PEM Fuel Cell Stack[1]

A single PEM fuel cell is made up of a membrane-electrode assembly (MEA) surrounded by two flow-field (or bipolar) plates and two end plates. Cooling plates are also used within fuel cell stacks for heat management. The bipolar plates distribute the flow of fuel and oxidant in the cells, manage the water within the cell, and separate cells in the fuel cell stack. The MEA is the main design focus, because the current-generating oxidation reaction occurs there. Figure 2 illustrates the major components and basic operation of the MEA[2].

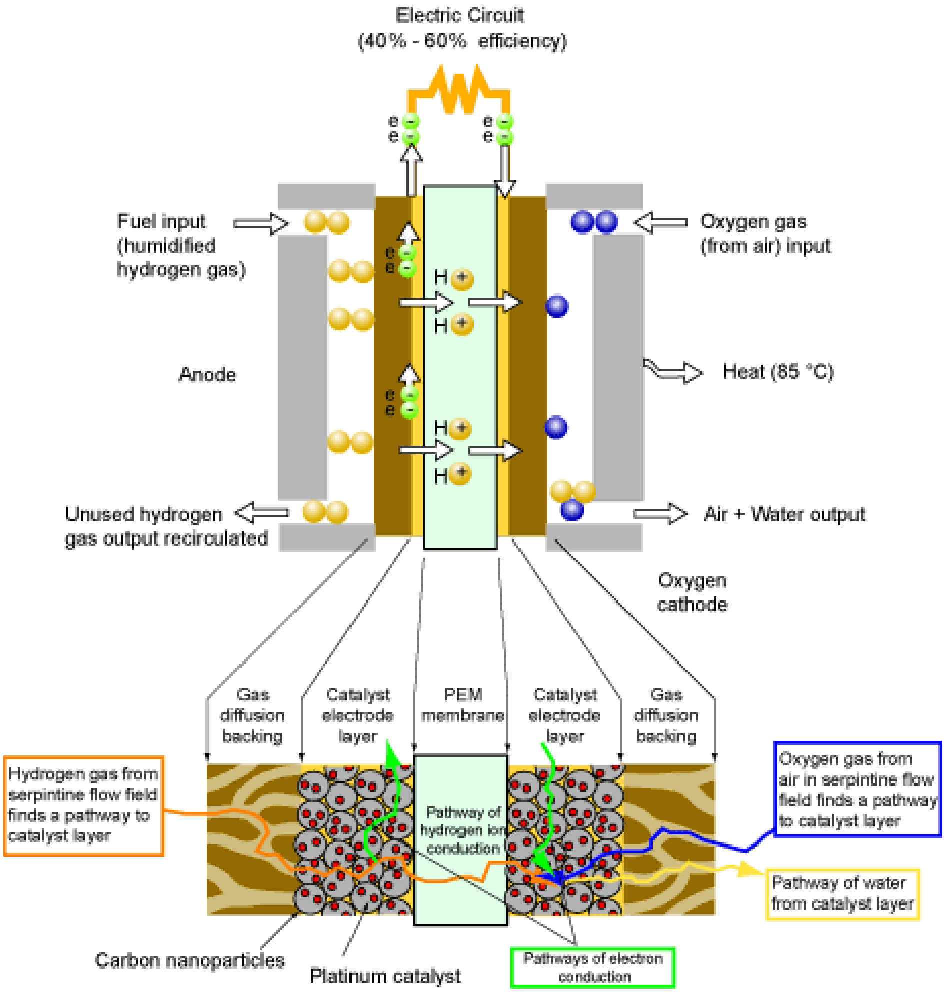

Figure 2: Basic Layout and Operation of the MEA in a Fuel Cell[2]

Hydrogen Storage Technology

Several hydrogen-storage technologies can be used in a fuel cell. Metal hydrides, both in powder and in slurry form, are possible technologies. Compressed hydrogen is the standard technology.

Carbon Nanotube Manufacture

Plasma-Enhanced Chemical Vapor Deposition

Plasma-enhanced chemical vapor deposition (PECVD) is a method for producing carbon nanotubes at atmospheric pressures, which simplifies the fabrication process. A laboratory-scale apparatus was investigated and is shown in Figure 3[3].

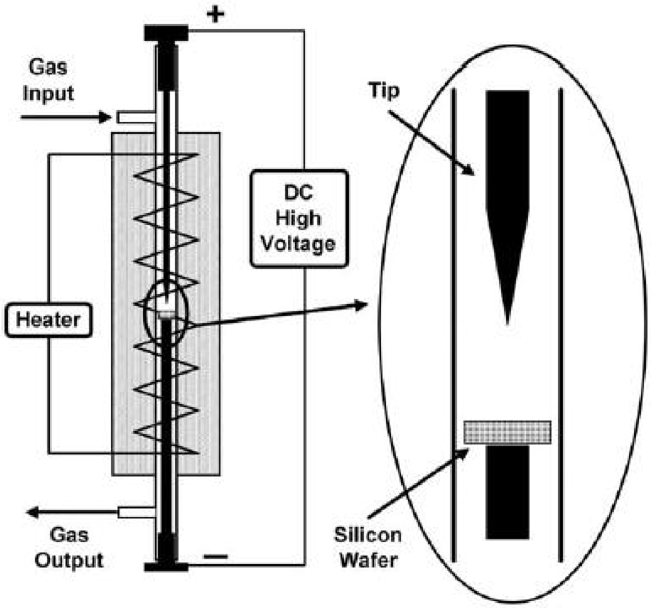

Figure 3: Lab-scale apparatus for PECVD nanotube growth[3].

Growth of *Desulfovibrio baculatum*

Desulfovibrio baculatum is used to produce hydrogenase. After receiving the bacteria, it may be necessary to store it depending on how soon the bacteria will be used. If the bacteria will not be used immediately, it should be stored below 5°C. When ready to be revived, 0.3 to 0.4

mL of the appropriate liquid medium will be added to the freeze-dried bacteria. The specific liquid medium will be specified by the vendor. The solution should be mixed thoroughly and then transferred into a culture vessel containing the medium. The vessel of choice for this application is a 100 L fermenter.

Hydrogenase Purification

The process begins once the *D. baculatum* is grown and the cell walls are broken by suspending the cells in 50 mM Tris/HCl buffer and freezing at -80°C for 60 hours. This purification process is based on 700 g of cells suspended in 500 mL of the buffer. This weight of bacteria is a wet weight; however, the water weight is negligible. It is recommended to use liquid nitrogen from a pressurized cylinder for this step (boiling point of -196°C at 1 atm). The solution is allowed to thaw at 4°C, and the cells are separated from the buffer by centrifugation at 20,000 rpm for 1 hour. The reddish-brown supernatant liquid should be collected and contains mostly the periplasmic proteins. The pellet is then resuspended in an equal volume of buffer and recentrifuged. The two supernatant liquids are combined and diluted to 420 mL in an Amicon Diaflo apparatus using a YM-30 membrane. This is the starting material for the purification of the periplasmic hydrogenase[4].

Fuel Cell Manufacture

For a pilot fuel-cell manufacturing process, one batch of hydrogenase will be refined per day. (One batch refers to 700 g wet weight of bacteria entering the first column.) One batch produces enough hydrogenase to catalyze 21 fuel cells. At this rate of production, approximately 7500 fuel cells can be produced per year. Table 1 contains the list of the tasks, in order, that must be completed to produce the fuel cell.

Table 1: Fuel Cell Construction Times

Process	**Time (days)**
Culture	7.00
Freezing	2.50
Column	0.17
Dialysis	0.40
Application to Nanotubes	0.50
Assembly	0.33

Carbon nanotube production is done in parallel with the rest of the process. One welder produces 0.2 g/min of carbon nanotubes. One fuel cell requires 70 g of nanotubes. This means that approximately 1500 g of nanotubes must be produced per day (70 g/cell x 21 cells/day). To produce this amount of nanotubes, 6 welders must be operated in parallel. This allows for 1730 g of nanotubes to be produced per day. Since this is more than the required amount, a surplus amount can be produced and held in reserve. Nanotubes have a limitless shelf life, so the reserve can grow until storage space is consumed.

References

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2. "PEM Fuel Cells." *Neutron Imaging Facility*. July 2004. National Institute of Standards and Technology. <http://physics.nist.gov/majresfac/nif/pemfuelcells.html>.

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4. Teixeira, Miguel et al., “Nickel-[iron-sulfur]-selenium-containing hydrogenases from *Desulfovibrio baculatus* (DSM 1743) Redox centers and catalytic properties” *Eur. J. Biochem* **167** (1987): 47-58.