CONSTRUCTION, OPERATION, AND TESTING OF A PROTEN EXCHANGE MEMBRANE FUEL CELL SYSTEM AND TEST STAND

Project Proposal

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Abstract

The construction of a fuel cell test stand is proposed as a senior design project. A basic knowledge of fuel cell principles is demonstrated. The existing design is reviewed and the test stand requirements are given. Proposed fixes and instrumentation is listed. The tasks necessary are listed, and the project timeline is detailed.

1. Introduction

The fuel cell is a device that generates electricity by converting Hydrogen and Oxygen gas into water. Though the inputs and outputs are quite simple, the fuel cell process requires precise control of the gases and a proper interface between them in order to function properly. The commonplace fuel and non-polluting output make the fuel cell a very attractive option for numerous applications, but design and operation of fuel cell-powered devices is not as simple as it seems.

Fuel cell designs are not exceedingly complicated, but they require precision and control. Thus the fuel cell makes for a good lab experiment because, once operational, the effects of varying the inputs can be seen in variations of the outputs. By measuring these inputs and outputs, the efficiency and other measures of performance can be determined. A typical lab experiment will thus consist of varying the pressure and flow rates of the input gases and seeing how the output power, voltage, and efficiency vary as a result of these changes.

2. Technical Discussion

a. Fuel Cell Theory

The fuel cell is the inverse of the electrolysis of water. In this process, often performed as a middle or high school science experiment, two electrodes, one each attached to the positive and negative ends of a battery, are placed in a tub of water. Bubbles form at each electrode; oxygen gas at one and hydrogen at the other. The fuel cell reverses this procedure, taking the two gases, mixing them to create water and electricity.

All fuel cells powered by hydrogen and oxygen produce electricity using the following three equations:

$$H_2 \rightarrow 2\,H^+ + 2\,e^- \quad (1)$$

$$O_2 + 4\,e^- \rightarrow 2\,O^{2-} \quad (2)$$

$$2\,H_2 + O_2 \rightarrow 2\,H_2O \quad (3)$$

Both gases ionize as a result of the fuel cell operation. The hydrogen gas gives off electrons when it ionizes (Equation 1). These electrons are made to pass through the electric load of the fuel cell before they are used as the electrons used to ionize the oxygen (Equation 2). Finally, the two ions are combined to form water, the byproduct of the fuel cell operation (Equation 3).

The Swarthmore fuel cell uses a proton exchange membrane to facilitate this reaction. The membrane is the key to the fuel cell operations. It is a thin sheet usually made of carbon or a polymer. The membrane is covered in platinum powder to catalyze the ionization of hydrogen and oxygen[1]. The membrane allows the hydrogen ions to pass through it, but blocks the passage of electrons. Thus the electrons have to around the membrane through the electrical load. This process is shown in Figure 1.

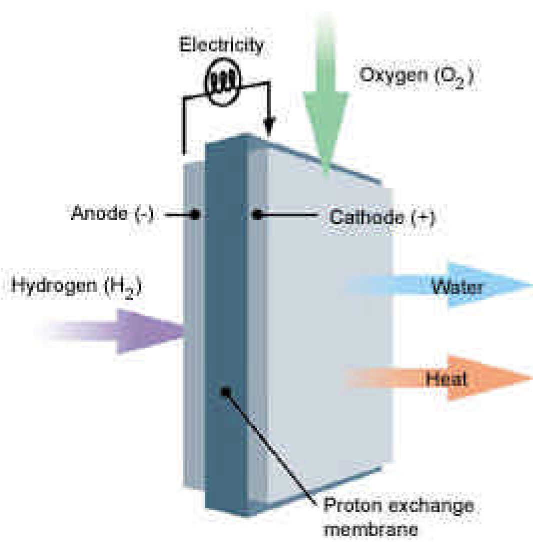

FIGURE 1: Proton Exchange Membrane Fuel Cell Operation[2]

For the final paper, this section will be greatly expanded to include details on other fuel cell types and to go into much greater detail of the mechanics of fuel cell operation, but more research must be conducted to complete this section.

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[1] "How Fuel Cells Work." Web Site. Updated 27 Nov. 2004. http://science.howstuffworks.com/fuel-cell2.htm

[2] "Fuel Cell Testing." Web Site. Updated 1 Dec. 2004. http://www.sae.org/automag/features/fctest/

b. Existing Design

The current fuel cell was designed by David Collins ’03 as an E90 project. The cell and associated apparatus was constructed as part of this project. The design of his cell assembly is shown in Figure 2. The membrane is the key to the process, as described above. The carbon blocks, shown in Figure 3, conduct the potential generated across the membrane and provide the channels through which the gases flow and interface with the membrane. The copper plates, shown in Figure 4, take on the electrical potential generated by the fuel cell process. The tabs are for connecting electrical devices to the fuel cell to measure the amount of electricity generated. The silicone gasket provides electrical insulation, containing the potential and charge to the copper plates and assembly within. The aluminum plates are structural – they hold the cell assembly together. The gas pipes are attached to these plates using Swagelok fittings. The plate is shown in Figure 5. The entire assembly is shown in Figure 6. In this picture, the hydrogen side of the cell is on the right and the oxygen side is the left.

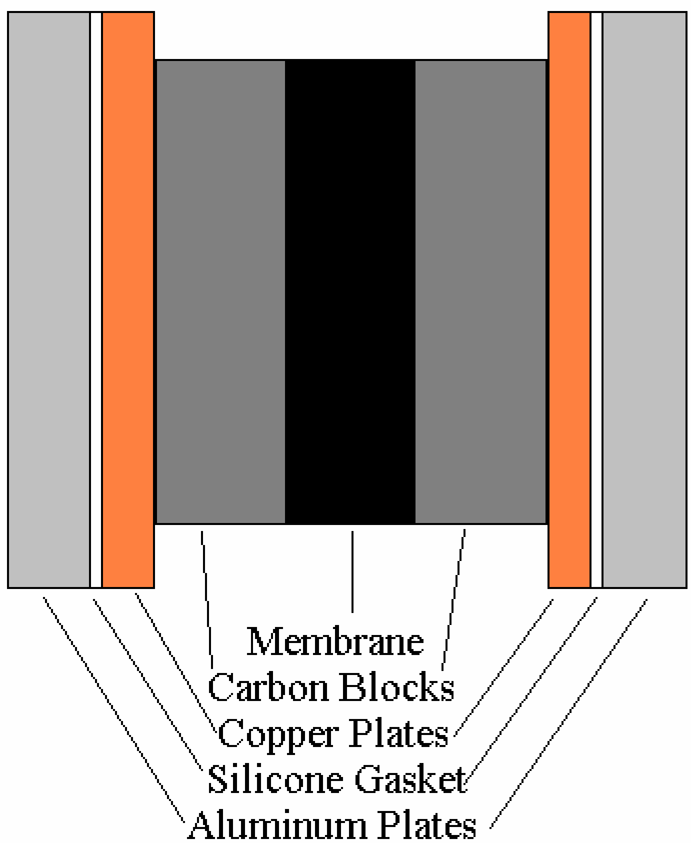

FIGURE 2: Design of Fuel Cell Apparatus

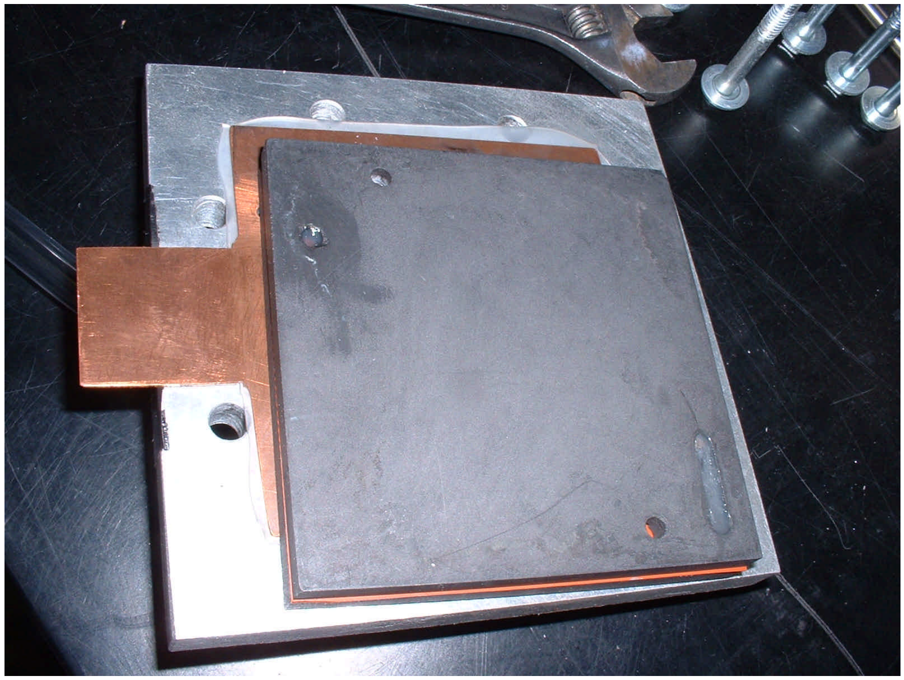

FIGURE 3: Carbon Block

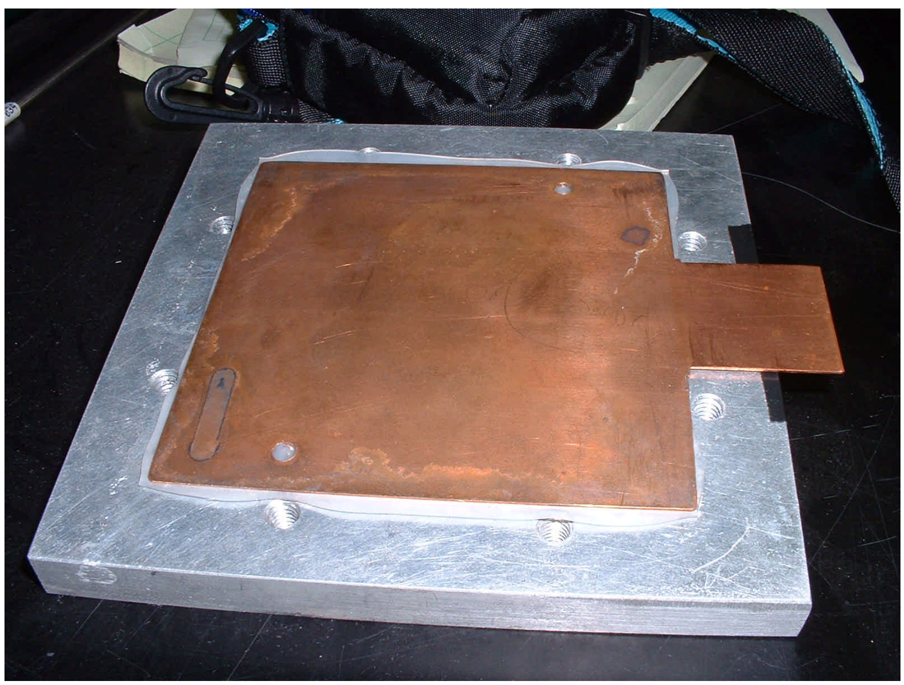

FIGURE 4: Copper Plate

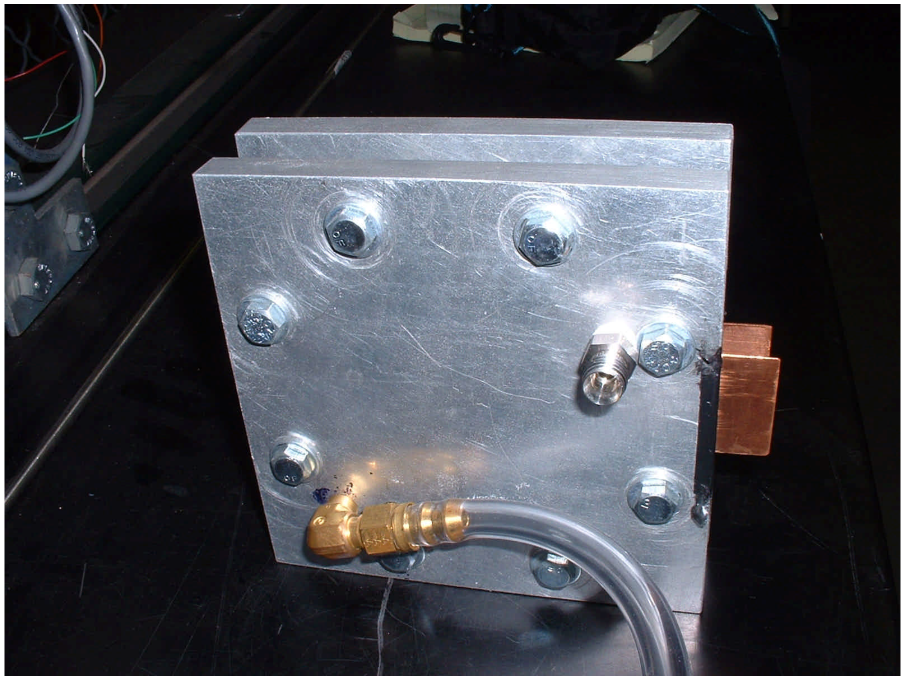

FIGURE 5: Aluminum Endplate

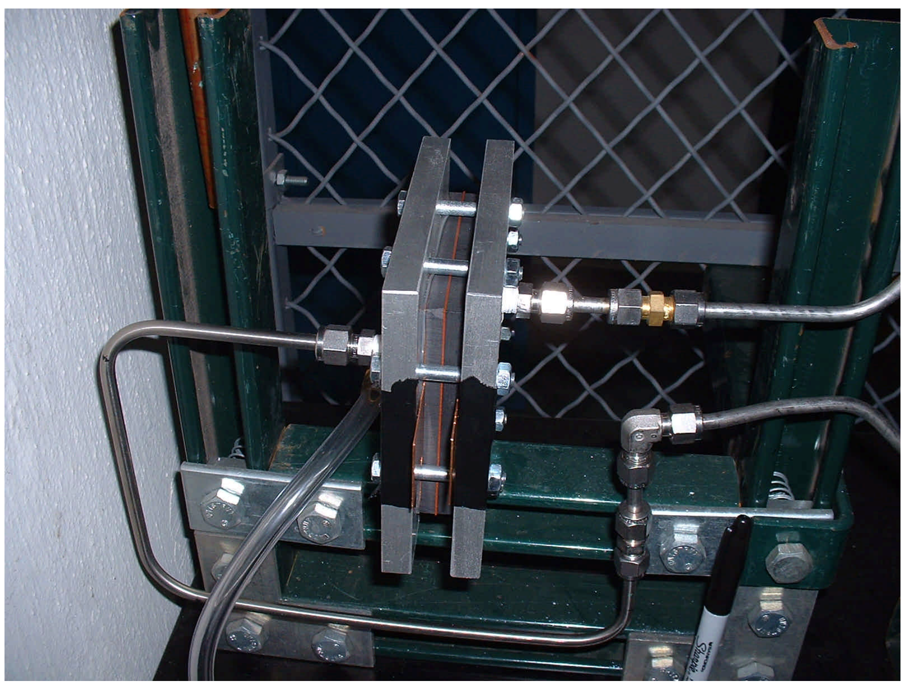

Figure 6: Fuel Cell Assembly

A network of pipes and valves, shown in Figure 7, serves to transport the gases from storage tanks to the cell. The valves are used to regulate the pressure of the gases. Two flow meters are used to determine the gas flow, more information on these is provided below. The white PVC tank is a humidification bubbler. The Hydrogen passes through this device, picking up enough moisture to prevent the membrane from drying out.

FIGURE 7: Gas Delivery Pipes

The flow meters used are gas-specific. The oxygen flow meter is a Sierra Instruments Mass Trak 810C. It provides a linear output ranging from 4-20 mA over the full range of the instrument, 0 – 5 standard liters per minute (SLPM). The hydrogen flow meter is a Webco 5860 IR. It too provides a linear output from 0-5 VDC over the range of the instrument, 0-5 SLPM.

During testing, Collins encountered ignition of the two gases, interfering with the operation of the cell[3]. Further testing revealed that the ignition was coming from the Hydrogen exhaust line. The cell was redesigned by Jesse Hartigan '04 as an E81 final project. Hartigan rebuilt the cell so that the two gases entered the cell assembly on different sides. Hartigan's final observation was that the cell leaked gas, and a new gasket was the best way to solve this problem[4]. Hartigan was unable to construct this gasket within the time frame of his project. Initial testing shows that the cell leaks

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[3] Collins, David. *Construction and Operation of a Proton Exchange Membrane Fuel Cell System*. E90 Final Project Report. Spring 2003. p. 20.

[4] Hartigan, Jesse. *Design and Development of a Proton-Exchange Membrane Fuel Cell*. E81 Final Project Report. May 10, 2004. pp. 7-8.

significantly; a solution to this problem is necessary before any additional progress can be made.

3. Project Goals and Proposed Solutions

The fuel cell project has four goals. The first goal is to make the fuel cell operational. This will require the cell to be leak-free, non-igniting, and capable of sustained operation. The second goal is to develop a reliable means of recording flow and power output data. The third goal is to calculate efficiency based on experimental data. This will require the meeting of the first two goals to complete. The fourth goal is to accurately and comprehensively document the fuel cell operation procedure and instrumentation – something lacking in Collins's report.

Initial experimentation has revealed that the cell does have a leak problem. While a gasket is in place between the aluminum and copper plates, no other leak prevention measures are in place, excepting tightening the bolts that hold the cell together. It has been theorized that use of *Dow Corning* 732 Multi-Purpose Sealant to seal the edges of the cell will solve any leak problems. Sealant 732 is a silicon rubber sealant that is sold as a paste. It can be applied to the entire cell exterior; it is thought that this will prevent all leakage. It is not currently known whether Hartigan's redesign has solved the ignition problem; this will be determined once the current leak problem is solved, and if necessary a solution will be devised.

The instrumentation is still in place from Collins's work on the fuel cell. This consists of a flow meter for both gas supply lines. The calibration factors for these two instruments are given above. Collins's report indicates that he simply used multimeters to read the flow meters[5]; part of the completion of the test rig will be connecting the flow meters to a data logger and using MATLAB to automatically read and process data.

Once the first two steps are completed, the fuel cell test rig will be fully operational. The cell can then be operated and the efficiency calculated. If time permits, additional improvements can then be made to improve the efficiency of the cell or of the test rig as a whole.

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[5] Collins p. 18.

Ongoing throughout this project will be the development of a complete documentation that can serve as a reference to the fuel cell test stand. Collins's report is very short on documentation; for example, nowhere does it include the pin-outs for the flow meters. A concise reference for the cell will be very useful and aid future users of the cell in setting up the cell and conducting experiments.

4. Specific Tasks Necessary for Project Completion

(1) Cell Reassembly

The fuel cell and test rig is partially disassembled for identifying components, determining the details of Collins's design, and leak testing. The main problem in reassembly is aligning the cell properly so that the holes through the different elements line up, allowing gas to pass into the core of the cell. This should only take an hour to complete, but will likely need to happen several times throughout the project.

(2) Order Materials

It is theorized, but not certain, that additional materials will be necessary to complete the cell. If it can successfully be used to seal the cell, an additional tube of 732 Sealant will likely be necessary. Initial research indicates that this should cost less than ten dollars, but a supplier has not yet been chosen. It is a common product that should take no more than two weeks to ship. It is also possible that a supply exists in the machine shop and ordering will not be necessary. There are currently two membranes available for use in the fuel cell. One is in very poor condition; this is likely the membrane Collins used while testing and having ignition problems[6]. Another membrane is available and appears to be undamaged. An additional membrane will be ordered as a backup. Electrochem was Collins's source for his MEA; a price quote of $280 was received for a new membrane. Ground shipping time was estimated as requiring only a few days. If possible, two membranes should be ordered to allow for unforeseen difficulties and to be prepared for future fuel cell use. New flow meters will be quite expensive – the Mass Trak 810C was quoted at around $900. Additionally, two to three weeks would be necessary for Sierra Instruments to build and ship the meters. It likely won't be

[6] Collins p. 21.

necessary to order new meters. Overall six weeks has been estimated as ordering and shipping time.

(3) Leak Testing

The cell needs to be leak free before operation can be attempted. As mentioned above, Sealant 732 has been proposed as a solution and will be tested shortly; if no leaks are detected following the application of the sealant than full operation can be attempted. This task should take no more than two weeks if the Sealant 732 is a viable solution to the problem.

(4) Preliminary Testing

Due to the previous ignition problems, the cell must be tested and ignition-free operation must be confirmed. The full instrumentation suite need not be finished for these testing operations because this step is only to confirm that the cell does in fact function. A multimeter can be used to determine whether the cell is producing electricity. This should also take two weeks if no major difficulties are encountered.

(5) Development of Instrumentation

The instrumentation must be fully functional before determination of efficiency can be calculated. This will require ensuring the calibration of the flow meters and developing a MATLAB program to read and record data from the flow meters and the fuel cell power output. This can happen in parallel to leak and preliminary test, but should take no more than a month.

(6) Final Testing

Once the cell is found to be leak-free and functioning properly, data will be recorded to calculate cell efficiency. If this is successful and time permits, then additional modifications can be made in an attempt to improve efficiency. One month will be more than enough time to complete this task, but it can be compressed into a week or two if other steps take longer than necessary.

(7) Development of Documentation

Comprehensive instructions and notes on fuel cell operation are a necessary part of the project to ensure future use of the cell. As testing is undertaken, more and more can be added to the notes as the details of the cell's operation are obtained. This is an ongoing process that must be completed by the date of paper submission; it should take only two weeks to prepare.

(8) Final Paper

The final paper must detail the design and experimentation process. It will take two weeks to prepare a draft once the experimentation is complete.

5. Project Timeline

Critical path analysis has shown that, using the times for each step given above, that this project can feasibly be finished before the deadline. Figure 8, below, shows the timeline for accomplishing the project goals. Note that much of the time allotted for ordering materials falls over winter break; businesses will be open to ship supplies for this time, so school not being in session should not impact the completion of this task.

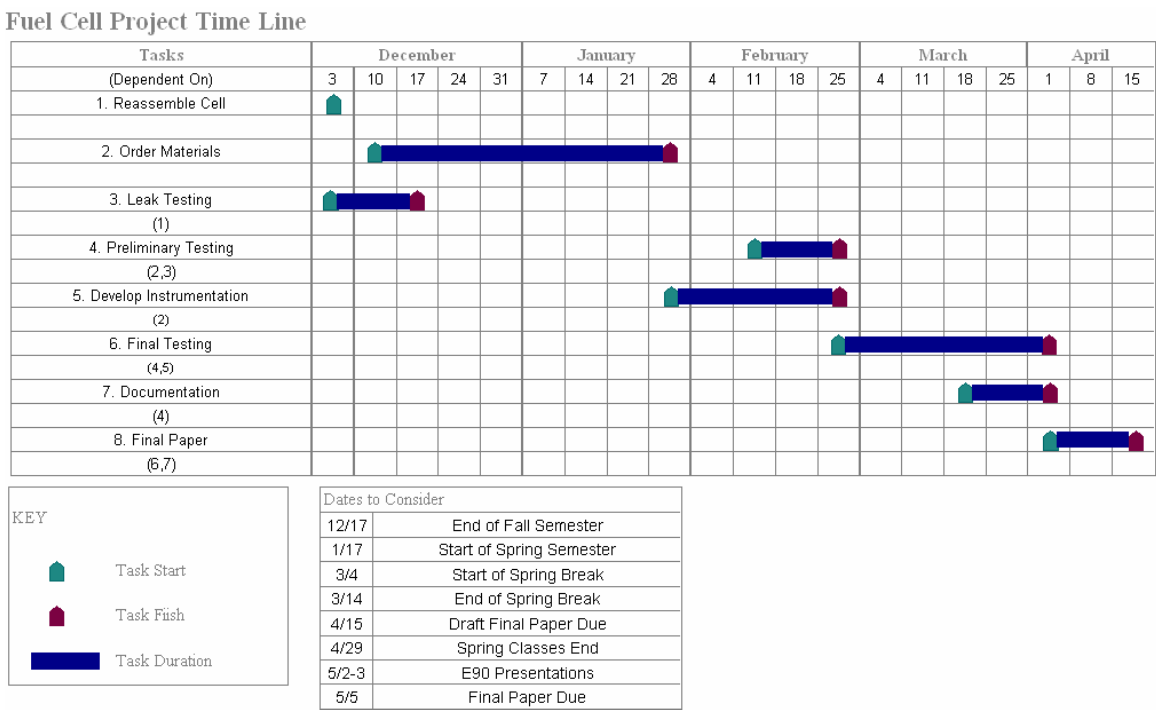

FIGURE 8: Project Timeline

Works Cited

Collins, David. *Construction and Operation of a Proton Exchange Membrane Fuel Cell System*. E90 Final Project Report. Spring 2003.

"Fuel Cell Testing." Web Site. Updated 1 Dec. 2004. http://www.sae.org/automag/features/fctest/

Hartigan, Jesse. *Design and Development of a Proton-Exchange Membrane Fuel Cell.* E81 Final Project Report. May 10, 2004.

"How Fuel Cells Work." Web Site. Updated 27 Nov. 2004. http://science.howstuffworks.com/fuel-cell2.htm