Design for Manufacturing Reliability and Economics for an Alkaline Membrane Fuel Cell Educational Kit for High School and College Level Laboratory Demonstration

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Brazil Team Leader

Ben is a senior graduating from Florida State University in May, 2015 with a Bachelor of Science in Mechanical Engineering. He is currently working in Curitiba, Brazil at Universidade Federal do Paraná performing research using a prototype alkaline membrane fuel cell with a team of American and Brazilian students.

Bryan Anderson – (banderson40@gmail.com)
Financial Advisor

Bryan is a senior graduating in May of 2015 with his BS in Mechanical Engineering. He works as the team's financial advisor ensuring the project is allocating their resources in the most productive way. Bryan hopes to use his degree to analyze the social fabric that governs the world's finances.

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FSU Assistant Mechanical Engineer/Web Master

Mustafa is a senior in mechanical engineering with a thermal fluids track. As a tutor in math and sciences for Florida State University, he believes success is a part of hard diligent work as everything can be a challenge. His knowledge with web development makes him a great web editor.

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In addition, we would like to extend our gratitude towards our faculty project advisors. Here at Florida State University we would like to thank our advisor Dr. Juan Ordonez for providing the guidance and support with our decisions. We would also like to thank Dr. Jose Vargas from Brazil for also providing essential feedback and knowledge about our project.

None of this would have been accomplished without the help of our sponsors and advisors. The team members of our senior design team 10 would like to extend our sincere thanks to all participants.

1 Introduction

The design for the fuel cell demanded a focus on many different aspects to be considered a good design. The reasons for our design decisions are expressed in the sections of this report. We wanted our design to have an overall focus on functionality and reliability so that the average user could set up the cell with little difficulty. This was accomplished by making many changes to the mounting system of the cell. We also wanted to improve the reliability by selecting corrosive resistant materials like the stainless steel for our bipolar plates and the polycarbonate mounting bracket. Our design was also influenced by a strong economic need to keep the costs as low as possible so our kit can be marketed. The budget for the project as a whole does not accurately reflect the exact costs that would go into a kit. This is mainly because many of the components that we purchased needed to be purchased in bulk so we could run proper tests and collect enough data. As a result we reflected our budget as percentages. This give a more accurate reflection of how much each aspect of the design costs. Based off of this data we have made some important conclusions about the economic feasibility of our project.

2 Design for Manufacturing

Our overall goal for the AMFC kit was to make it as accessible as possible to an average user. This means that when designing all of the necessary components we wanted them to fit together in the assembly process as simply and conveniently as possible. The first step in this process is to prepare the electrolyte solution as well as the anode and cathode sheets. We cut the anode and cathode sheets to the surface area of the cell which has the dimensions of 2.5 length and height. Also, we cut the electrolyte to match the 2.5 inch length and height of our bipolar plates. This allows the plates not to be touching during operation. The next step for this process is to place the anode, the electrolyte and the cathode in that order within the cell and put the bipolar plates together. The bipolar plates will then be placed in our mounting brackets. Once the bipolar plates are placed in the mounting bracket the bracket will be secured using four bolts on the corners of the bracket. It is important that during this step you apply equal torque to each bolt in the mounting bracket. This will result in even pressure being applied to secure the cell in place. Now we must screw in our four inlet and outlet nozzles to the four holes on the bipolar plate. To make sure that the threads are as sealed as possible to prevent leaks a small amount of Teflon tape can be applied to the threads of the nozzle. The next step is to now set up the electrolysis kit which will be producing our hydrogen and oxygen. In order to do this we filled our tub with water as well as our cylindrical tubes for collecting gases. It is important to leave enough room in the tubes to allow the hydrogen and oxygen to gather. Then we insert our tubing into the top of the hole drilled into our cylinders and then seal the edges accordingly. Before attaching our electrical leads to the battery we first must place the negative lead in one cylinder to produce hydrogen and the positive lead in the other cylinder to produce oxygen. We did not apply power to this system until we were ready to begin running the cell. Now that the electrolysis system is set up we attach the hydrogen output from the electrolysis to the appropriate input side of the fuel cell and the oxygen output to the opposite side. One outlet tube will be venting a small amount of hydrogen into the air while the other outlet will produce water. Both the hydrogen and water are produced in such small amounts they are not an inconvenience or safety problem for the user. Once all connections are made power can then be applied to the electrolysis kit and the cell can begin its operation.

When assembling our project in the FSU Magnet Lab it took us about fifteen minutes to assure the assembly was ready for testing. We had three team members working on it which helped to reduce the time needed. Since this was our first time assembling the kit there were some tasks that we needed to complete that the user will not need to concern themselves with during assembly. First, we had to cut the electrolyte, anode and cathode sheets to the specific dimensions. This will not need to be done by the user since they will be cut to the appropriate size already in the kit. Also, the electrolyte solution will be previously mixed for the user while we had to mix it ourselves. So if this is taken into consideration and single person is assembling the fuel cell we estimate that it will take no more than ten minutes until the fuel cell is ready to be used.

Our design is actually a simplified version of a previous setup that was used in Brazil. The Brazil team expressed issues with the time it took to assure that the mounting bracket was properly secured. We wanted our cell to be easy to use for the consumer and therefore the mounting bracket had to be changed. We chose to have a system in which the cell is resting within a section of our mounting bracket as seen in our design. The mounting bracket encompasses the border of the cell guaranteeing that it will stay in place during operation. Also, this applies equal pressure to the border of the cell to form a more complete seal during operation. As a result if we decided to go with a more complicated design for the mounting system and overall ease of use for the cell we would indeed suffer from a marketing standpoint and a performance standpoint due to sealing issues. If we wanted to market this cell to a consumer it needs to be as simple as possible since there are other fuel cells on the market.

The fuel cell design has a total of 6 different parts used. Seen below in figure 1 is the exploded view of our fuel cell and all of the components needed for assembly. Also, in table 1 each part is listed as well as the quantity of that part. Based off of this table we have an appropriate amount of parts for our application. If we had too many parts it would be too difficult to assemble and manufacture. If there were any parts the cell could not be assembled and still perform as needed with a simple easy to use design.

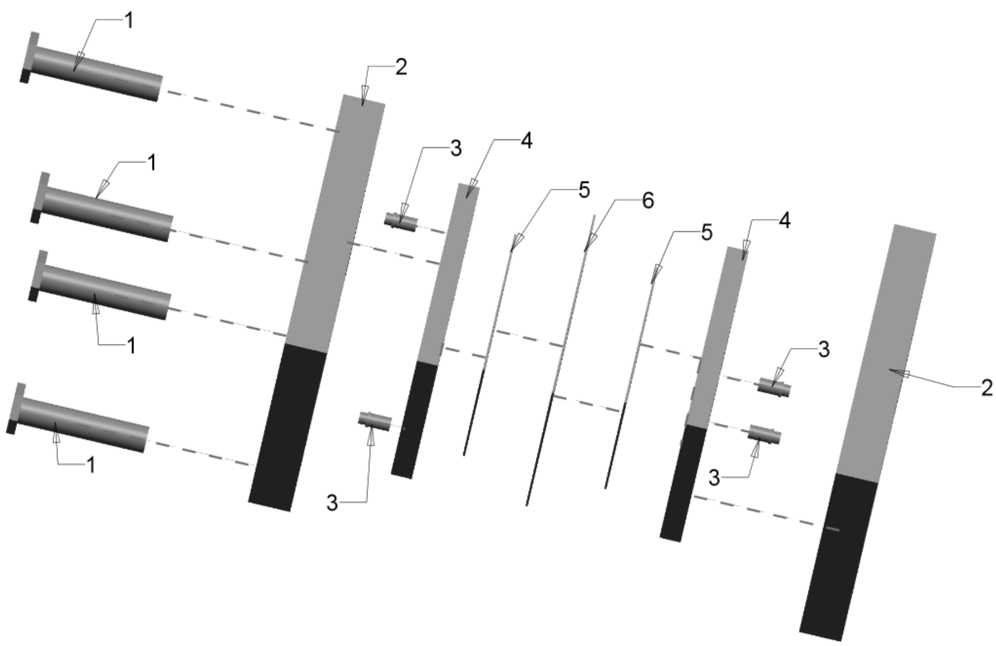

Figure 1. Exploded View of Fuel Cell

Table 1 List of Fuel Cell Components

Part Number	Part Name	Quantity
1	Mounting Bolt	4
2	Mounting Bracket	2
3	Barbed Nozzle	4
4	Bipolar Plate	2
5	Anode/Cathode Sheet	2
6	Electrolyte Sheet	1

3 Design for Reliability

Reliability in this project is of utmost concern when operating the fuel cell as it ensures that a quality product has been developed. The fuel cell was first analyzed by its material properties. The outer plate casing the fuel cell is made of polycarbonate material. As a transparent plastic-like material, it has the durability and toughness that will keep the inner bipolar plates in place as well as fully insulate any electricity produced. In the case that the fuel cell were to fall on the floor, the outer casing will not break due to its high impact strength of 16 ft-lbs/in. In addition, the 4 holes located on the corners will provide pressure to the edges of the fuel cell which will seal it and prevent it from moving. Since the fuel cell will be in a stationary setup, there are no significant forces that will harm the fuel cell. A failure mode affects analysis (FMEA) was done for our main reliability concerns and is attached in the appendix.

Some of the other main reliability concerns while running the fuel cell focus primarily on the different parts involved while testing. Using compressed gases provided to us by the FSU MAGLAB required us to use a specific pressure regulator for the hydrogen and oxygen in order to provide a steady flow of gas into the fuel cell. While operating, it is important to note that all the tubing and connections to both the tank and the fuel cell must be securely fastened. Any loose connections can affect the performance of the cell. In order to fasten the connection to the fuel cell, brass fittings were added. Due to its corrosive resistance and its thermal properties, the fitting will provide a secure connection.

The other final concern for our educational kit is the addition of the electrolysis. This will allow any user to create the hydrogen and oxygen gases without the expensive purchase of compressed tanks. The development of the gas will depend on factors such as time and the battery voltage. The process to make the gas isn't instantaneous and in order to produce enough gas to reach our power output, the electrolysis should be started prior to using the fuel cell. Also, the flow of the gases need to be controlled into the fuel cell. During testing, the pressure regulators will mimic the atmospheric temperature. The fuel cell will perform at a stable condition as long as the concerns have been addressed.

After performing testing on our cell we were able to make some assumptions about the longevity it will have without replacing any components. We were able to determine that the cell can run for 24 hours without replacing any components. The components that would need to be replaced are the anode/cathode sheets as well as the electrolyte sheets. This is because they are the key component to provide the reaction and as the reaction is taking place they lose the material properties needed to operate. If these components were replaced when needed the cell could run an estimated 100 times before other problems arose. The stainless steel that was chosen will not corrode as long as it is rinsed after use. The problem would come from the plastic fittings that we have chosen to secure are tubing. Since they are not made from a non-corrosive metal they will need to be replaced. For our bipolar plates and mountings they should last 500 uses which is a long time considering the amount of runtime one can get out of a single use.

4 Design for Economics

This section will dissect the alkaline membrane fuel cell, it will be broken into two succinct sections. The first discussion will be the vision handed to us by the sponsor for the marketability of this product versus the team's analysis, and conclusion for the realistic and more profitable vison for this fuel cell. The second section will discuss the fuel cell cost and how it compares to similar products currently on the market.

The project description handed to team 10 at the beginning of the semester was to create a prototype that could be used as an educational kit. This is the project summary that was provided to team 10.

> This project will investigate the feasibility of transforming a newly proposed AMFC single cell into an educational kit for high school and college level laboratory fuel cell functional demonstration. For that, a previously developed cellulose-based AMFC prototype will be studied and modified to produce a commercial item. The methodology will consist of redesigning all components to fit into a small suitcase for easy transportation. The new system will contain all necessary parts for independent operation. A standard operation procedure and a product specification sheet will be written, and should be included in the final kit. A series of demonstration experiments will be designed, and conducted to demonstrate the educational kit operation and feasibility. Therefore, after experimental quantification, it is expected that the proposed alkaline membrane fuel cell (AMFC) educational kit system could be commercialized as a market product.

As shown, the kit has the intention of being commercialized, the inherent issue from an economic prospective is that the market for such cells is miniscule. Even with a streamlined prototype the cost will be high enough that the profit potential will be a maximum of 20% profit, and this does not include any accessory items that would likely be desired nor any shipping costs. If a complete electrolysis kit as well as protective case was to be included in the mass produced kit the cost would be higher than the market by around $70. Because of these issues and the lack of demand team 10 recommends an amended marketing approach. This would not look to the educational field, instead look to the private energy sector. It is well known that the private energy sector spends more money on potential new products and technologies on a daily basis than the educational sector spends typically in an entire year. Using an alkaline membrane as well as electrolysis, this fuel cell and fuel cell technology has great technological potential. Not only is the electrical efficiency higher than any other fuel cell at this time, it also allows the cell to be run continually if the gas and membrane conditions are idealized. If this kit were to be marketed as a prototype technology that with private funded research can be made for large scale energy production means. Yes this has a great deal of ifs', however with the potential of this fuel cell technology it is likely that the private energy sector would be willing to spend a good deal of money to research this technology. What this does in the big picture is gives Florida State University and UFPR the potential to make net thousands of dollars in profit but millions. On top of that having the universities name out there additionally as research institutions on the cutting edge of renewable energy could lead to additional funding from both public and private sectors.

The fuel cell kit developed by team 10 is a true testament to getting quality work done despite numerous obstacles. On every stage of the cell development, issues were encountered due to lack of equipment and facilities provided by the college of engineering. Even with all the issues,

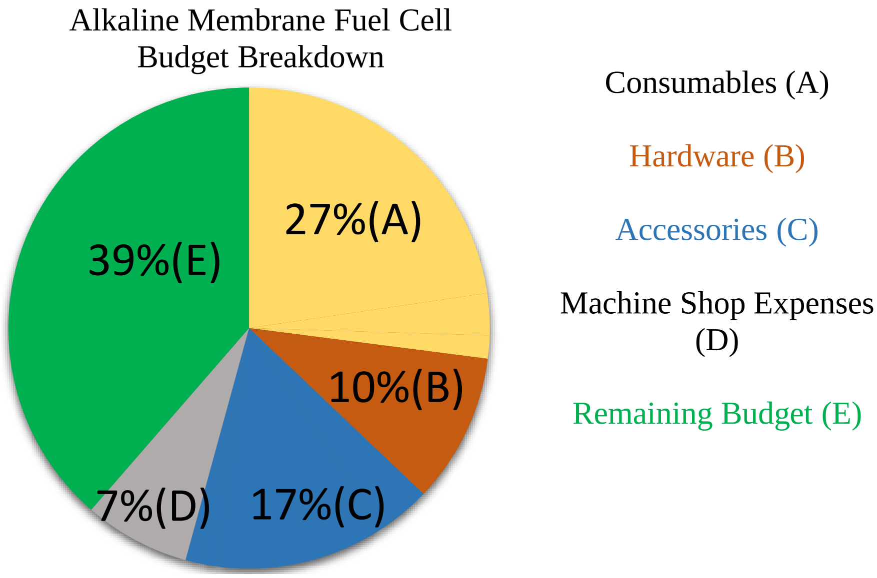

Figure 2. Breakdown of the fuel cell budget

team 10 has produced a competitive viable fuel cell educational kit. Above in figure 2 is a pie chart breakdown of the different categories of expenditures. There are 13 slices of the pie, but they have been labeled into five categories for the sake of simplicity. The seciton labeled (A) is the consumables, this consists of the platinum membrane, KOH solution, and Chromatography paper. Of this the cost per fuel cell is $84.40, which is 31.3% of the cost to the budget, $270. This is due many of the consumable products are only sold in large quantity, but this has been taken and broken into cost per fuel cell for a more appropriate cost analysis. The section labeled (B) is the fuel cell hardware cost, this includes all components of the actual physical fuel cell. There is little to no maintanence expected on this assuming proper care is taken with the cell. The section labeled (C) is the fuel cell accessories cost, this includes the casing. The reason it was not included into the hardware is during market research, most fuel cell educational kits do not include any item of the sort. They could be purchases with the fuel cell kit but for the sake of competitive pricing they will not be included in the base pricing. The section lableed (D) category is the unexpected cost of machine shop end mills. This would not be a cost if this were to be produced in a professional environment. The section labeled (E) is the remaining budget, having 39% of the thousand dollar budget has been a great challenge as the team's goal was to keep cost down as much as possible. Shown on the next page in figure 3 is the price comparison between the team 10 prototype and the similar products on the market. The alkaline membrane fuel cell constructed is $1.12 more expensive than the most similar cell on the market. There are substantial differences between the two however the main difference is alkaline membrane versus polymer electrolyte membrane. The alkaline membrane technology has more potential for large scale power production then the PEM. The other difference is the team 10 prototype includes an electrolysis kit for the hydrogen and oxygen, the H-TEC cell includes solely the cell itself with connections to connect other products. Though the team 10 cell needs a small power source for the electrolysis, it is a much more complete kit than the H-TEC fuel cell. The other cell shown above is a much cheaper cell which does include an electolysis kit. There are two huge differences between the AMFC and the Horizon Fuel Cell

Technologies Hydrogen Cell. These are the power production surface area of the membrane (AMFC & H-TEC: 6.25 in^2 Horizon: 1 in^2), the other area of great difference is build quality, both the AMFC and H-TEC are lab quality build whereas the Horizon cell is more of a toy demonstration type of kit. For these reasons the fuel cell prototype that team 10 produced does not have a real competitor on the market.

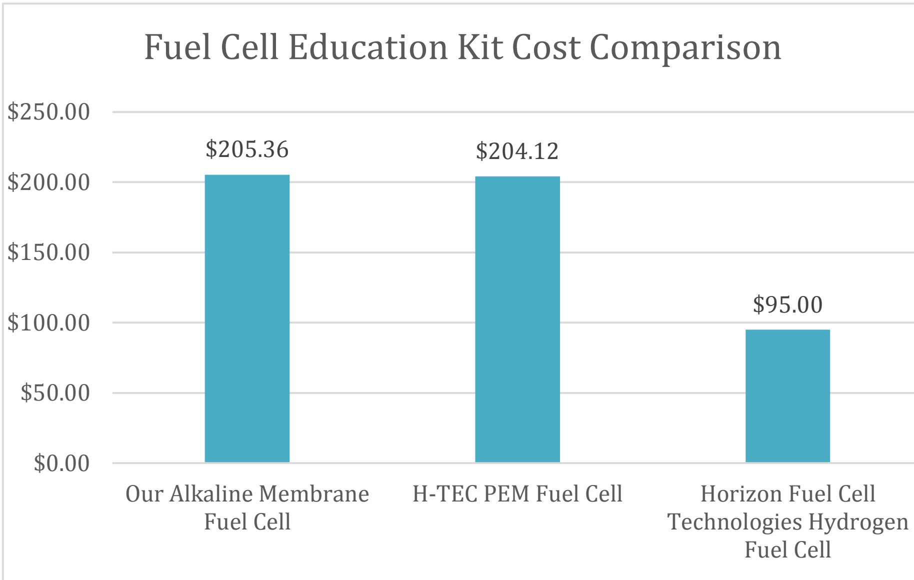

Figure 3. Fuel cell comparison

5 Conclusion

Our design has now been finalized to something that is as simple as possible to assemble and manufacture and still be functional. We did this by making adjustments to the mounting bracket that allows for easy access to the cell as well as a more secure seal when the cell is being operate. Also, the overall setup process is very quick and should only take the user around 10 minutes get the cell in operating condition. We have also concluded that with proper maintenance and replacement of disposables the cell can achieve around 500 uses which is an exceptional amount and will probably not be reached by the average operator. One of the biggest conclusions that we have made from the data in this report involves our financial feasibility. The original goal of our project was to design an educational kit for our fuel cell. Based off of the data that we obtained we determined the price of such a kit would be too high for an educational market. Instead we recommend this product and technology be marketed to private companies. Overall this is still a very feasible project but it should be approached from another angle.

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Appendix

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken
Fuel Cell											
Platinum Electrode	Tearing/Ripping	Fuel Cell will not run, customer must replace and purchase electrode	7	Have excessive amount of pressure coming out of gas tanks, human error	2	Pressure regulators attached to tank to regulate pressure of gas coming into cell	1	14	Regulators have been purchased and have been used	MAGLAB, Dr. Ordonez,	2/13/2015
Tubing	Leaks	Efficiency will drop. If leak is severe, fuel cell may not run	2	Improper connection with fuel cell caused by human error	5	Proper tubing attachments of appropriate size	1	10	Double check all seals and connections before running the fuel cell	Team 10	2/24/2015
Seals/Connections	Loose Connection	Gases will not flow properly into fuel cell	1	Human error	3	Tighten connection	1	3	-		2/24/2015
Compressed Gases	Too much pressure coming out of tank into fuel cell	Platinum Electrode will tear and break	8	Misuse of equipment	2	Pressure regulators for monitoring	3	48	Use pressure regulators when testing		4/3/2015
Electrolysis											
Gas (amount)/flow	Not enough gas flow into fuel cell, purity of gas/concentration	Power output drop/efficiency of fuel cell will also drop.	6	Not enough battery voltage used, setup design	3	Store gases in graduated cylinders in setup	5	90	Run electrolysis for longer period of time, and increase power source		