Final Design Report for an Alkaline Membrane Fuel Cell Educational Kit for High School and College Level Laboratory Demonstration

Team Number: 10

Submission Date: 04/10/2015

Deliverable Name: Final Design Report

Sponsor: FIPSE

Advisors: Dr. Juan C Ordonez, Dr. Jose Vargas

Submitted To: Dr. Nikhil Gupta

Authors:

Collin Heiser (cjh10h)

Mustafa Nek (mn11h)

Nicole Alvarez (nda10)

James Richardson (jbr10)

Bryan Anderson (ba10f)

Table of Contents

Table of Figures iv

Table of Tables v

Abstract vi

Acknowledgement vii

1 Introduction 1

1.1 Problem Statement 1

1.2 Project Objectives 1

1.3 Design Requirements 2

2 Background Research and Literature Review 3

3 Concept Generation 5

4 Final Design 8

4.1 Design for Manufacturing 9

4.2 Design for Reliability 12

4.3 Design for Economics 13

5 Operations Manual 17

5.1 Function Analysis 17

5.2 Product Specification 18

5.3 Operation Instructions 19

5.4 Troubleshooting 21

5.5 Regular Maintenance 22

5.6 Spare Parts/Inventory Requirements 22

6 Considerations for environment, safety and ethics 23

7 Design of Experiment 24

8 Project management 26

8.1 Schedule 26

8.2 Resources 26

8.3 Procurement 27
8.4 Communications.. 28

9 Conclusions.. 30

10 References.. 32

Appendix A: Troubleshooting 33

Appendix B: Gantt Chart.. 34

Appendix C: Calculations 35

Team Bios 36

Table of Figures

Figure 1. Bipolar Plate Drawing 8
Figure 2. Mounting Bracket Drawing 9
Figure 3. Exploded View of Fuel Cell 11
Figure 4. Breakdown of the Fuel Cell Budget 15
Figure 5. Fuel Cell Comparison 16
Figure 6. Basic Schematic of Fuel Cell Control Volumes 17
Figure 7. Voltage Response over Varying Resistances 24

Table of Tables

Table 1. Advantages and Disadvantages of an Alkaline Membrane Fuel Cell 3
Table 2. Decision Matrix 5
Table 3. List of Fuel Cell Components 12
Table 4. List of Components 19
Table 5. Bill of Materials 28

Abstract

The overall goal of this project is to deliver a fully functioning Alkaline Membrane Fuel Cell educational kit. This technology is not currently on the market since it has been developed by Dr. Ordonez and Dr. Vargas at FSU. Through the educational kit students can learn about this new technology and the opportunities that it can provide. Team 10's fuel cell is 6.25 in^2 and can provide a maximum power of 0.937 mW. The flow rates of the gasses in the cell are able to maintain relatively low values at 0.2678 L/hr of hydrogen and 0.133 L/hr of oxygen. These values and results were expected based off the size of the cell. Also, the cell consists of a mounting bracket that allows it to remain upright during operation and a portable kit that allows it to be safely transported. The cell also uses a parallel pattern of channels to allow the gasses to disperse as quickly as possible throughout the cell. Finally, in order to overcome the issue of transporting the compressed gasses the team decided on switching to electrolysis.

Acknowledgement

Team 10’s efforts for this project would have been impossible without the continuing assistance from Team 10’s advisors and sponsors for Team 10’s guidance and financial assistance.

The team would like to thank the Fund for the Improvement of Post-Secondary Education (FIPSE) for sponsoring Team 10’s FSU students and the Universidade Federal do Paraná in Curitiba, Brazil for allowing Team 10’s students abroad to use and conduct research with their facilities. The team would also like to thank Florida State University with providing Team 10’s budget for this project.

In addition, the team would like to extend Team 10’s gratitude towards Team 10’s faculty project advisors. Here at Florida State University the team would like to thank Team 10’s advisor Dr. Juan Ordonez for providing the guidance and support with Team 10’s decisions. The team would also like to thank Dr. Jose Vargas, Dr. Nikhil Gupta and Dr. Chiang Shih for also providing essential feedback and knowledge about Team 10’s project.

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

1 Introduction

This section will address the issue that Dr. Ordonez and Dr. Vargas are currently facing with the fuel cell, creating the need for this particular senior design project. Also, this section will cover the objectives the team has set for the year and how they have been met. Finally, the individual design requirements for the project are introduced.

1.1 Problem Statement

The sponsor for FIPSE Team 10 is Florida State University and Team 10's advisors, Dr. Ordonez and Dr. Vargas, who have been assisting the team in reaching the overall goal of the project. The design of the alkaline membrane fuel cell was based on a similar set up in a laboratory in Brazil that was 20.25 in^2 and ran off compressed hydrogen and oxygen. Dr. Vargas and Dr. Ordonez would like for the entire setup to be inside of a portable case. This means shrinking the setup to a more manageable size and finding an alternative solution to the compressed gasses. By making the alkaline membrane fuel cell fit into a suitcase, Florida State University hopes to create a prototype of an educational alkaline membrane fuel cell kit that will demonstrate the technology to interested parties such as high school students. The team plans to deliver a fully operational alkaline membrane fuel cell prototype kit smaller than a standard suitcase by April 16, 2015.

"The current AMFC setup is too large requires compressed gas to be a portable educational kit alkaline membrane fuel cell."

1.2 Project Objectives

"Deliver a fully functional alkaline membrane fuel cell in a portable case to Florida State University by the end of the spring 2015 semester."

Team 10 has determined a number of objectives that are to be accomplished this year. The first objective was to determine the overall design of the cell so that it functions optimally and is portable. This objective has been completed and the cell designed has managed to create a voltage in a laboratory setting. Team 10's second main objective was to ensure the fuel cell can run on electrolysis and not compressed gasses. As of now this objective is still being optimized. The team is making some changes to this process to ensure the optimal amount of hydrogen and oxygen are being produced. The third objective that the team have put in place is to ensure that the fuel cell and all of its components can be safely stored in a portable kit. This goal has been completed and all of the components fit perfectly in the kit and can undergo a reasonable degree of stress with no issue.

1.3 Design Requirements

In the design process there a few requirements that the team must consider in order have an operating cell and a successful kit. One of the constraints is that the active surface area of the cell will be limited based off the size of the platinum electrode sheets. These are the most expensive part of the project so in order to maintain a reasonable budget the active surface area for the cell will remain small. The size that was decided on for Team 10’s cell is 6.25 in^2. Another design constraint is that the entire kit must be below 20 lbs. to ensure portability. Also, it is crucial that all of the components the team design fit inside a standard briefcase of around 11.375in x 12.25in x 6.25in. Proper seals will be needed to ensure that gas leaks to not occur. In order to prevent the cell from shorting out the design must consider that the bipolar plates do not come into physical contact with each other. This was done through Team 10’s polycarbonate mounting bracket.

2 Background Research and Literature Review

Fuel cell technology today has been recognized in the field of alternative energy sources as a cleaner option for power generation. An educational kit using an alkaline membrane fuel cell is being created to demonstrate the technology and spread interest in the concept.

Some of the main learning points to Team 10's research was the science behind fuel cell operation. The main function of the alkaline membrane fuel cell is converting chemical energy occurring from the reaction between diatomic hydrogen and oxygen to provide a usable source of electrical energy. The fuel cell system consists of a few different components; two input valves (for hydrogen and oxygen), an anode and cathode (platinum membrane) electrode, and a potassium hydroxide electrolyte (KOH).

Team 10's project aims to build on this research done by both engineering departments of Florida State University and Universidade Federal do Paraná. Based on the work completed by Dr. Ordonez and Dr. Vargas in [1], a dynamic model was able to be produced to predict the response of a single alkaline membrane fuel cell according to the variation of physical properties, such as the concentration of the KOH electrolyte. However, the fuel cell setup used in previous research was too large to be used for an educational kit. Some advantages and disadvantages of using this type of cell can be seen in table 1 below. The design of the fuel cell educational kit should be optimized to lower costs and increase its functionality.

Table 1. Advantages and Disadvantages of an Alkaline Membrane Fuel Cell

Advantage	**Disadvantages**
• No expensive polymer membrane is necessary – liquid alkaline solution as electrolyte	• High corrosivity of the electrolyte
• Liquid electrolyte may enable a simple cooling of the stack	• Electrolyte must be repeatedly concentrated during long testing periods
• Activation overvoltage is less than with an acid electrolyte	• Intolerance to CO_2 $CO\ +2OH^- \rightarrow CO^{2-} + H\ O$

Based on Team 10's research, polarization curves were developed to compare the fuel cell output voltage and current. This curve will allow for others to compare the outputs from Team 10's fuel cell and others with similar fuel cell characteristics.

Although there are many different types of fuel cell kits in the market, this will be the first educational kit to use an AMFC instead of other types of cells. The main advantage of using an alkaline fuel cell is that it is a more natural way of creating electrical energy. In addition, the cost of the electrolyte solution is fairly cheap and easy to obtain compared to proton exchange membrane fuel cells (PEM). A disadvantage of using the AMFC is that pure hydrogen and oxygen must be used in order to run the fuel cell properly. If pure gases are obtained, the AMFC can have a large potential for long run times due to the lasting of the KOH membrane. The fuel cell also can run at higher efficiencies with the proper conditions compared to PEM cells. Overall, the alkaline membrane technology shows promising characteristics based off the research seen in [2] such as a higher current density, lower cost of electrolytes which allows for the production of a more accessible and affordable kit.

3 Concept Generation

The progression of Team 10's design concepts were continually being updated to ensure a quality educational kit was developed. A decision matrix was made as seen in table 2 showing the progression of parts of Team 10's design shown below. The important design concepts that were analyzed include case design, fuel cell design, and production of gases to run the cell.

Table 2. Decision Matrix

Design	**Portability**	**Safety**	**Affordability**	**Machinability**	**Ease of Use**	**Sum**
Weight	4	5	2	3	4	
Case Design						
Tanks included, mounted to case	5	3	3	3	4	66
assembly hangs from case mount	5	3	2	1	1	46
Separate assembly from case	3	5	4	4	4	**73**
Gases						
Compressed Gases	1	4	1		2	34
Electrolysis	3	5	5		4	**63**
Fuel Cell Design						
Serpentine Pattern			2	1	4	23
Rectangular Pattern			3	3	3	**27**

The goal of Team 10's project from the start was to focus on fitting all necessary components of Team 10's fuel cell into a portable case. After much research and obtaining price estimates for each compressed gas tank, it was concluded that compressed gases were too expensive and resulted in a significant liability due to safety and transportation concerns. In addition, many additional parts were required to use the tanks, such as pressure regulators. This pressure regulator adjusted the outgoing pressure into the tank. The price of each pressure regulator (one for each tank) proved to be beyond Team 10’s existing budget if all parts were to be purchased.

In addition, some other assumptions were made based on the existing setup in Brazil. The main goal with these assumptions, in the beginning, were that it would be most practical to mimic the scenario of the existing setup to make sure similar results would be obtained. Therefore, Team 10’s previous design included the case and a mechanism to hang the fuel cell. The purpose of hanging the fuel cell was mainly due to the fact that it would provide a simple setup and a visual for users to see. Other design considerations made in the fall of 2014 were also made in order to run the fuel cell inside the kit. These design considerations would have complicated the running of the experiment.

Towards the end of the fall semester, however, the casing of the fuel cell became less important thus the focus of Team 10’s design included having all the necessary parts to the educational kit so that experiments can be done in a classroom setting. The design of the AMFC fuel cell was modified to include an outer polycarbonate casing which served two purposes. The polycarbonate casing, due to its high impact resistance and thermal properties, was made so that the fuel cell can be standing on its own instead of hanging the cell as previously considered. The inner indent of the polycarbonate casing, with the size of the fuel cell, ensured that the cell would have a tight fit so that the hydrogen and oxygen gases could consistently flow throughout the potassium hydroxide membrane electrolyte.

The design of the fuel cell itself also had changes throughout the year. In the beginning, fuel cell size was of most importance, as Team 10’s goal was to design a fuel cell small enough to fit in a case. The fuel cell design in Brazil was about (YAY) inches. In order to provide a similar voltage output, the fuel cell was made at a size of 6 inches by 6 inches. However, the cost of the electrolyte was the most expensive part to Team 10’s design. Because the electrolyte was sold in sheets of a standard size, the fuel cell design was made smaller at about 2.5 inches by 2.5 inches to get the most out of Team 10’s electrolytes. The material for the fuel cell used was initially Aluminum 2024 due to its light weight and heat transfer rate which in theory would speed up the reaction. However, upon further material investigation, it was determined that using stainless steel would conduct electricity better than that of aluminum. Therefore, a stainless steel fuel cell was designed.

The pattern in the fuel cell which directed the flow of the gases was also analyzed and updated based on current manufacturing processes. In the previous existing fuel cell setup, a serpentine pattern was used to direct and mix the gases properly. Due to complications with machining such a small pattern, the design was simplified using a rectangular shape. A triangular indent was also designed in order to induce the gases to flow through the pattern and mix.

A solution for providing the gases to run the fuel cell was to design an electrolysis mechanism. Using a similar concept like the fuel cell, the electrolysis will use a power voltage to split the hydrogen and oxygen. This electrolysis method will provide simplicity when running it in a classroom setting. This is because the gases can be made without having strict safety and transportation regulations with compressed gases.

4 Final Design

When deciding on Team 10's final design there were a few important variables that the team needed to consider. All of Team 10's dimensions for the bipolar plate can be seen below in figure 1.

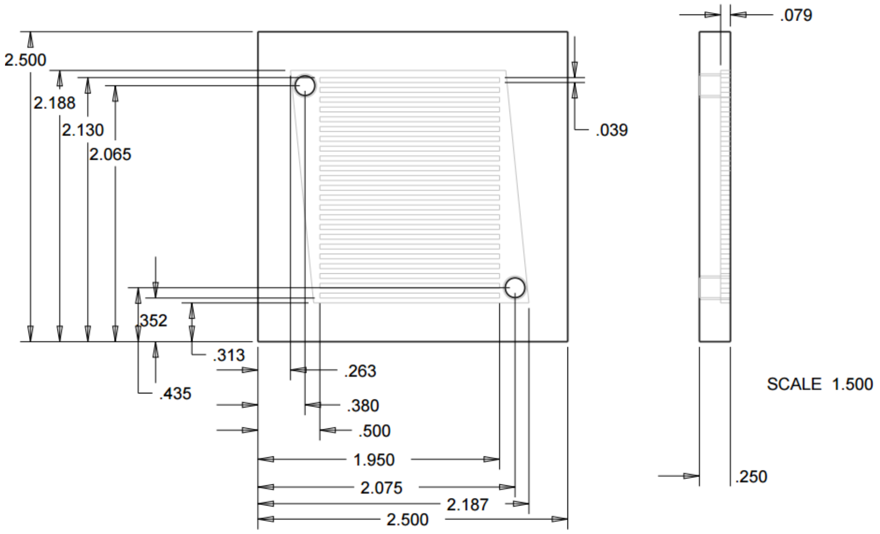


Figure 1. Bipolar Plate Drawing

The first thing the team needed to consider was the outer dimensions of the bipolar plates. This was crucial because if the cell was too big, then the team would not be able to maintain the necessary portability for Team 10's educational kit. Another main factor in sizing was the sizing of anode and cathode sheets the cell would be using since this was a limited resource for the group during testing. In the end the team decided the outer dimensions of the bipolar plates would be 2.5" by 2.5". The second major decision was how the team would design Team 10's channels within the bipolar plate in order to disperse the hydrogen and oxygen gas throughout the potassium hydroxide membrane as efficiently as possible. The team heavily researched previous papers written by Dr. Ordonez and Dr. Vargas as well as a few others to determine the effects that each design could have to Team 10's cell efficiency. The team narrowed Team 10's choices down to do different patterns. The first pattern involved the channels arranged parallel 1 mm apart and 2 mm deep in the plate. Team 10's second pattern involved serpentine channels with the same spacing and depth as the parallel. The benefit of using this design is that the team would have a higher current density in parts of the cell but it would not be as evenly distributed when compared to the parallel channels. Also, after consulting with the machine shop at the COE the team were told that the serpentine pattern would be too difficult to machine due to the very small channel width and depth. This resulted in the group deciding to use the parallel channel design. The final main deciding factor for Team 10's fuel cell design was the method the team was going to use to mount the bipolar plates together. The first step the team took was to first look at the mounting system that they were using for their fuel cell. The system was very complicated and did not allow the cell to stand by itself. The team decided to use a polycarbonate plastic for the mounting bracket which was very easy to machine, as well as its consideration as a durable plastic. The specific dimensions for this can be seen below in figure 2.

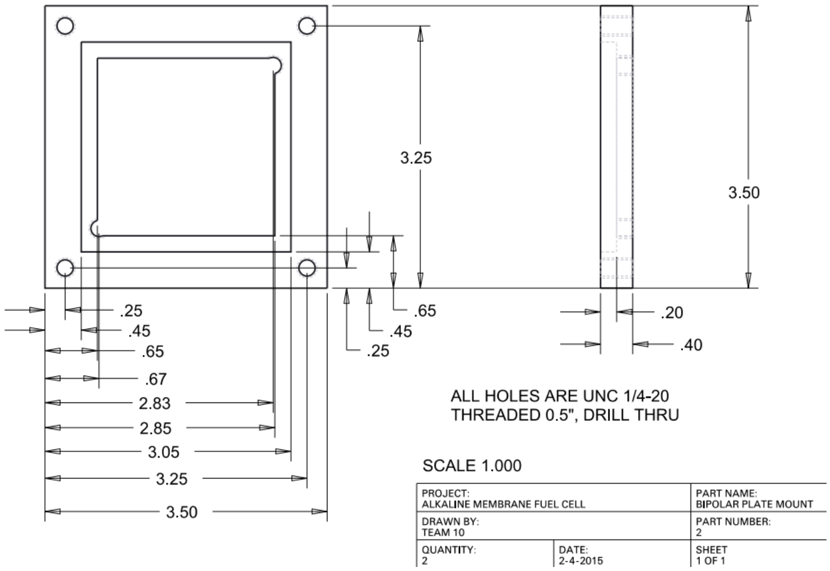


Figure 2. Mounting Bracket Drawing

4.1 Design for Manufacturing

Team 10's 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, the team 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. The team cut the anode and cathode sheets to the surface area of the cell (2.5" x 2.5"). Also, the team cut the electrolyte to match the 2.5" length and height of the bipolar plates. This allows the plates to be separated 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 Team 10’s 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 the team must screw in Team 10’s 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 Team 10’s hydrogen and oxygen. In order to do this the team filled Team 10’s tub with water as well as Team 10’s cylindrical tubes for collecting gases. It is important to leave enough room in the tubes to allow the hydrogen and oxygen to gather. Then the team insert Team 10’s tubing into the top of the hole drilled into Team 10’s cylinders and then seal the edges accordingly. Before attaching Team 10’s electrical leads to the battery the team first must place the negative lead in one cylinder to produce hydrogen and the positive lead in the other cylinder to produce oxygen. The team did not apply power to this system until the team were ready to begin running the cell. Now that the electrolysis system is set up the team 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 Team 10’s project in the FSU Magnet Lab it took the group about fifteen minutes to assure the assembly was ready for testing. The team had three team members working on it which helped to reduce the time needed. Since this was Team 10’s first time assembling the kit there were some tasks that the team needed to complete that the user will not need to concern themselves with during assembly. First, the team 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 the team had to mix it on location. So, if this is taken into consideration and single person is assembling the fuel cell, the team estimate that it will take no more than ten minutes until the fuel cell is ready to be used.

Team 10's 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. The team wanted Team 10's cell to be easy to use for the consumer and therefore the mounting bracket had to be changed. The team chose to have a system in which the cell is resting within a section of Team 10's mounting bracket as seen in Team 10's 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 the team decided to go with a more complicated design for the mounting system and overall ease of use for the cell the team would indeed suffer from a marketing standpoint and a performance standpoint due to sealing issues. If the team 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 3 is the exploded view of Team 10's fuel cell and all of the components needed for assembly. Also, in table 3 each part is listed as well as the quantity of that part. Based off of this table the team have an appropriate amount of parts for Team 10's application. If the team 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.

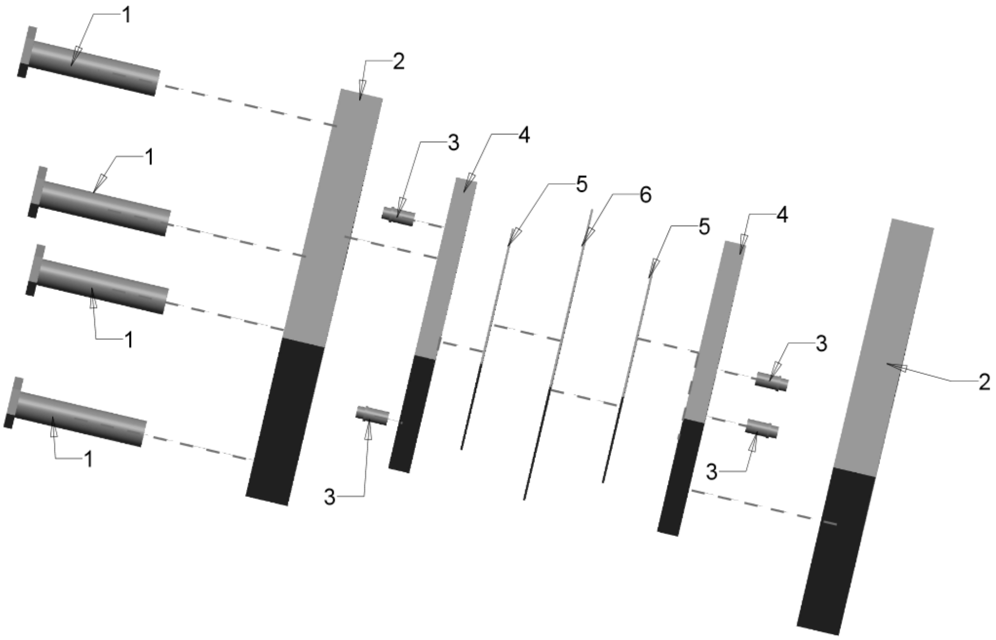


Figure 3. Exploded View of Fuel Cell

Table 3. 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

4.2 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 Team 10's 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 the group by the FSU MAGLAB required the group 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 Team 10’s 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 Team 10’s 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 Team 10’s cell the team were able to make some assumptions about the longevity it will have without replacing any components. The team 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 for a significant amount of time as long as it is rinsed after use. For Team 10’s bipolar plates and mountings they should last 500 uses which is significant considering the amount of runtime one can get out of a single use.

4.3 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 the group 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.

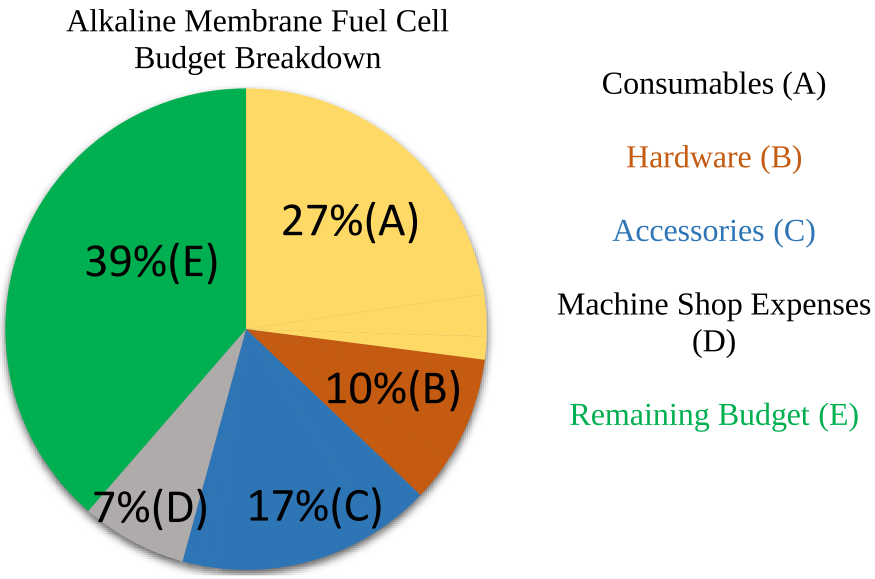


Figure 4. Breakdown of the Fuel Cell Budget

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, team 10 has produced a competitive viable fuel cell educational kit. Above in figure 4 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 5 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.

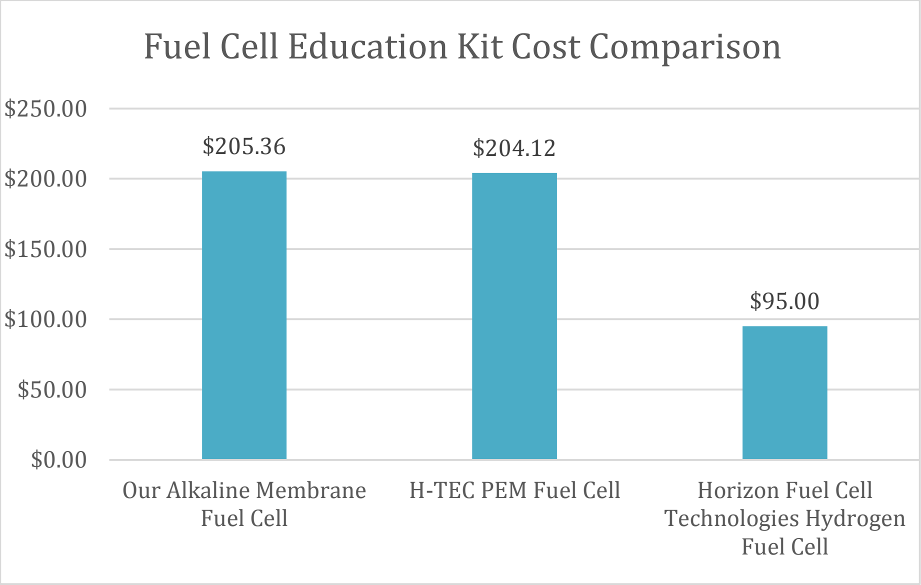


Figure 5. Fuel Cell Comparison

5 Operations Manual

This section of the report will be going into detail of the procedure that the user should follow in order to operate the fuel cell properly. Also, the team will be addressing troubleshooting techniques, the required maintenance and any spare parts that are included in the kit.

5.1 Function Analysis

A fuel cell generates electricity through an electrochemical reaction between hydrogen and oxygen. The two bipolar plates that conduct the power output are separated by electrode sheets and an electrolyte membrane, and have inlet and outlet ports for either hydrogen or oxygen. As seen in figure 6 the two electrodes (CV3 and CV5) allow for the collection of charged particles on its surface, while the electrolyte (CV4) allows for the flow of ions from between the anode and cathode. The charged particles are generated through the chemical reactions in the anode and cathode side as seen in the stoichiometric reactions below:

Anode side (an oxidation reaction): $2H_2 => 4H^+ + 4e$
Cathode side (a reduction reaction): $O_2 + 4H^+ + 4e^- => 2H_2O$
Net reaction (the "redox" reaction): $2H_2 + O_2 => 2H_2O$

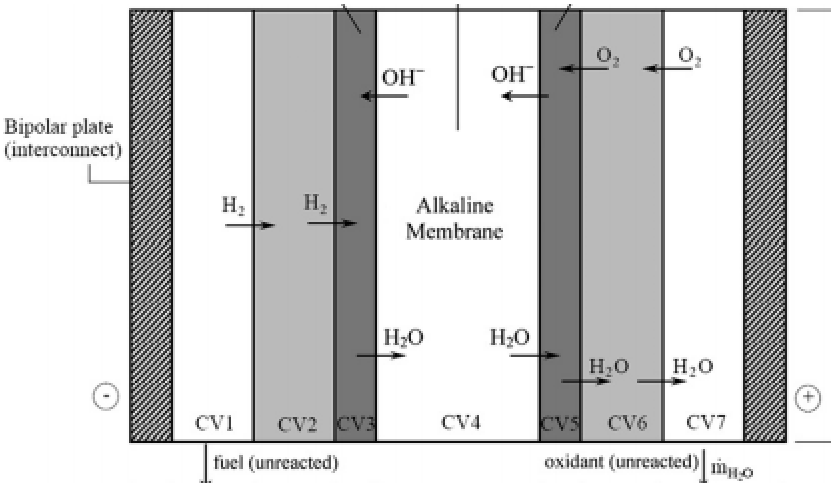


Figure 6. Basic Schematic of Fuel Cell Control Volumes

The educational kit also demonstrates the process of electrolysis, where a direct electric current is used to drive an otherwise non-spontaneous chemical reaction. In this case, a 9V battery and liquid water will be used to produce oxygen and hydrogen gas as seen in the reaction below:

$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$

The electricity supplied by the battery excites the atoms in the liquid water solution and allows for the necessary energy to break chemical bonds.

5.2 Product Specification

The entirety of the kit fits into a carrying case of 18 x 12.75 x 6.5 in^3. As part of this kit, the fuel cell (2.5 x 2.5 in^2) is placed in polycarbonate mounting brackets that will ensure the even distribution of compression between the bi-polar plates of the fuel cell. Refer to figure 3 for visual representation of the product assembly.

Case:

- Internal dimensions: 17.375 x 12.25 x 6.625 in^3
- External dimensions: 18 x 12.75 x 6.5
- Cut-to-fit, high density foam interior
- Aluminum alloy frame with high impact ABS plastic side panels

Bipolar plates:

- The difference in electrical potential across the bipolar plates produces the maximum voltage (1.23 V for a single fuel cell producing liquid water). The fuel cell is machined to consist of 24 parallel flow vanes (1 mm x 2 mm x 36.83 mm), which result in a more even distribution of pressure and mass flow rate of the fuels across each bipolar plate (see Appendix C).
- The bipolar plates of the fuel cell are machined out of stainless steel (2.5 x 2.5 in^2) in order to reduce the corrosive properties of the potassium hydroxide electrolyte over extended use.
- Each plate has an inlet and outlet port for either one of the gases used in the chemical reaction of the fuel cell.

Electrode Sheets:

- The most influential aspects of the fuel cell are the anode and cathode sheets which are 2.5 x 2.5 in^2 and consist of 40% platinum content, which should deliver a significantly greater efficiency than lower platinum content electrodes.

Membrane:

- A 40% potassium hydroxide (KOH) concentration should be used in the chromatography paper membrane due to the increased energy output and efficiency at this concentration as proven by Elisa M. Sommer [1].

Electrolysis Kit:

- The electrolysis kit being supplied with this fuel cell consists of two modified 500 mL graduated cylinders with 1/8” internal diameter tubing to connect to the gas inlets of the fuel cell, a 9V battery, and two sections of wire to be connected to either terminal of the battery.
- 0.05” soldering wire will be used to disperse the voltage and current from the battery to the fluid within the graduated cylinders.

Circuit Board:

- The breadboard (1 x 1.375 x 0.25 in^3) over which the polarization curve will be formed consists of several 220 Ω resistors, of which the energy output can be measured using a voltmeter (allows for the measurement of current and voltage of the bipolar plate through $I = V/R$ relation.). As the resistance increases, the voltage will decrease and the current will increase as R → infinity.
- A blue LED will also be included to act as an observable output for the voltage generated by the fuel cell.

Voltmeter:

- A RadioShack 29-Range Digital Multimeter is included to measure the output voltage and current being produced by the electrochemical reaction taking place in the fuel cell.
- The RadioShack 29-Range Digital Multimeter is a standard multimeter that can measure various ranges of voltage (V) and current (A), with three ports; A ground terminal, communications terminal, and a positive terminal.

5.3 Operation Instructions

The following operating procedure was formed to reduce any unnecessary risks involved with operating the fuel cell, as well as reduce external influences that could affect the obtainable results. The instructions were made for the consumer’s safety and should be strictly followed.

(1) Place the kit on a clean, stable surface

(2) Before operation, take care to inventory all parts and carefully inspect them for defects. If there are any doubts about the quality or function of each component, please contact the FAMU-FSU College of Engineering. Refer to Appendix A for a list of components.

Table 4. List of Components

- (1) Professional Series Metal Frame Hard Case
- (2) Bi-polar Plates
- (2) Polycarbonate Mounting Brackets
- (4) ¼” Hex-head Mounting Bolts
- (4) ¼” Washers
- (4) ¼” Nuts
- (8) Chromatography Sheets (consumable)
- (4) Platinum Electrode Sheets (consumable)
- (8) 1/8” Barb Fittings
- (2) 500 mL Modified Graduated Cylinders
- (1) 9V Battery
- (2) Sections of 14 gauge wire
- (1) Breadboard
- (5) 220 Ω Resistors
- (1) RadioShack 29-Range Digital Voltmeter
- Sections of 0.05” soldering wire
- 1/8” Internal Diameter tubing
- 0.21 oz. VersaChem Graphite Powder

Electrolysis Kit Assembly

(1) If all components are accounted for, proceed with assembly by removing the modified graduated cylinders, graphite powder, battery and corresponding soldering wire.
(2) Place the graduated cylinders open-face down in a container of reasonable size, and run one section of 0.05” soldering wire into each cylinder
(3) Fill the container to a reasonable level, and attach the 9V battery. This will start the electrolysis process
**The team suggest adding salt and graphite to the water solution to increase the reaction process*

KOH Electrolyte Solution

(1) Weigh 20 grams of KOH and place it in a separate container that can withstand up to 150 ° F, and add 100 mL of water to the solution. Stir until the solution has completely reacted (flakes can no longer be seen) taking precaution of the considerable heat production generated by the reaction.
(2) Let the solution return to room temperature. This can be achieved by waiting, or by accelerating the cooling of the solution using an insulated material to hold the container in a surrounding container of cooler liquid.
(3) Pour the room temperature solution into a container large enough to place the entirety of one chromatography paper horizontally on the bottom surface, allowing the paper to absorb the solution for approx. 10 minutes (5 minutes on each side).

Circuit Board Assembly

(1) With the breadboard on a stable surface, attach resistors in either series, parallel or a combination of both, noting the resistances and configuration of the board.
(2) An LED can also be placed in the circuit to create an observable display of the fuel cells power generation.
**Suggested configuration:* four 220 Ω resistors connected in series for simplicity

Fuel Cell Assembly

(1) Remove the mounting brackets, hex-head bolts, washers, and nuts from the case and insert the hex-head bolts with a washer through the mounting holes of one polycarbonate mounting bracket with the threaded section in the direction of the square offset. Place the bipolar plates in the offsets of the mounting brackets, taking care of the soldered wires attached to each.
(2) Place an electrode sheet centered on the now face-up bipolar plate (refer to step 1) with the fabric-like surface facing the flow channels. The electrode sheets are brittle and should be handled with care.
(3) Carefully place the pre-soaked chromatography membrane centered on the electrode sheet
(4) Place another electrode sheet with the fabric side facing upwards centered on top of the membrane. You can now take the other half of the fuel cell (mounting bracket and bipolar

plate) and place it on the stack with the flow channels facing the “fabric” side of the top electrode sheet, completing the single cell.

(5) Place a washer on each of the bolts, followed by a hex nut and tighten in a star pattern (preferably with a torque wrench) to 30 ft*lb. Equal torque on each of the nuts will improve performance by provide more even compression.

(6) Hand-tighten the barb fittings into each of the four holes of the bipolar plates (two on each plate) You can now attach the hydrogen and oxygen inlet/outlet hoses on either side of the fuel cell. This begins the electrochemical reaction.

(7) Attached the circuit board to the fuel cell by connecting the soldered wires to the breadboard. After short period of time there should be an observable increase in voltage displayed on the multimeter.

Once the fuel cell has begun the electrochemical reaction, the voltage can be read across varying resistances of the breadboard to form a polarization curve. Voltages should be recorded at regular intervals over a testing period once the reaction within the cell has reached steady state (constant voltage production). The time period between measurements should be reasonable, at least 10 minutes. Voltages should first be recorded for an open circuit (i = 0), and subsequently recorded with increasing resistance (i increases as V decreases). With consideration to accuracy it is suggested to record at least 5 sets of voltages.

Depending on the duration of the testing period, the electrolysis water in the beaker may or may not need to be refilled. To ensure statistically sound results, the water level in the electrolysis container should not be allowed to drop below an inch from the bottom of the graduated cylinders.

The potassium hydroxide electrolyte being used for the educational kit is not safe to ingest and should be kept away from the eyes and bodily orifices. However, it is non-toxic and with significant dilution the remaining solution not absorbed by the chromatography paper can be disposed of in a sink. The membrane itself should be discarded in a trash can after each test. It is recommended to handle the potassium hydroxide solution with gloves, however it is not necessary as long as it is thoroughly washed off.

5.4 Troubleshooting

All troubleshooting for the cell can be seen in appendix A.

5.5 Regular Maintenance

Due to the simplicity of the fuel cell design, little maintenance is required to maintain the fuel cell in working condition. After each operation, the graduated cylinders and beaker should be dried out, and the bipolar plates should be thoroughly rinsed off and dried.

The electrode sheets are delicate and should be handled with care. After each testing, the sheets should be dried (press dry, do not rub) and stored without any bending or folding.

5.6 Spare Parts/Inventory Requirements

Several spare parts of some key components are included in the kit to ease consumer operation. **For replacement components, contact the FAMU-FSU College of Engineering.*

Reusable

Two spare barb fittings are included in the kit due to the exposure to wear and shear stresses from the application and removal of the gas inlet/outlet tubing. Also, an excess of resistors are included to allow for flexibility in the configuration of the breadboard circuit.

Consumable

The platinum electrode sheet has been shown to operate without significant depreciation of energy output for over 24 hours of continuous operation. For this reason, two sets of electrode sheets are supplied to allow for continued use of the kit. Eight chromatography membranes are included, allowing for eight separate tests. The 9V battery required to perform the electrolysis process will eventually need to be replaced, however this is left up to the consumer.

6 Considerations for environment, safety and ethics

When reviewing Team 10’s project from an environmental, safety and ethical standpoint the team wanted to make sure that the KOH solution that is used in the cell was handled properly to not cause harm to the user. This affected Team 10’s design because instead of providing pre mixed KOH in Team 10’s kit the team chose to ship it in its solid form. This will let the user mix the solution themselves and eliminate the risk of exposure during shipping. Finally, this KOH solution does not pose a risk to the environment due to its small amount and its dilution.

Team 10’s second main safety concern was the transportation of hydrogen and oxygen gasses. This had a major influence on Team 10’s final design because the team decided that shipping these gasses with the kit would pose too much of a safety hazard for the consumer. Instead the team are using an electrolysis kit to produce the gasses. This eliminates the risk during shipping and provides another visual for Team 10’s kit.

7 Design of Experiment

All testing for the fuel cell was performed in the National High Magnetic Field Laboratory cryogenics lab. The lab provided the necessary compressed oxygen and hydrogen gases, as well as the equipment necessary to regulate the gases to levels necessary for optimized fuel cell operation. The hydrogen and oxygen entering the fuel cell were regulated to 0.2678 L/hr and 0.1333 L/hr, respectively. Any excess fuel (H_2) or oxidant (O_2) that was not able to react during the process was passed through the anode or cathode and out of the outlet port on either side. Proper safety equipment, such as lab coats, protective eyewear, and gloves were worn when handling the potassium hydroxide, and the solution was formed under a fume hood along with the actual testing of the fuel cell to prevent gaseous buildup.

In order to produce a polarization curve, the voltage was measured first as an open circuit, then across each resistor in order to demonstrate the current response related to increasing resistance. These measurements were taken every 10 minutes after an initial 5 minute startup period was allotted. The circuit being measured consisted of a small breadboard with positive and grounding wires, as well as four 220 Ω resistors connected in series to provide the necessary increasing resistance.

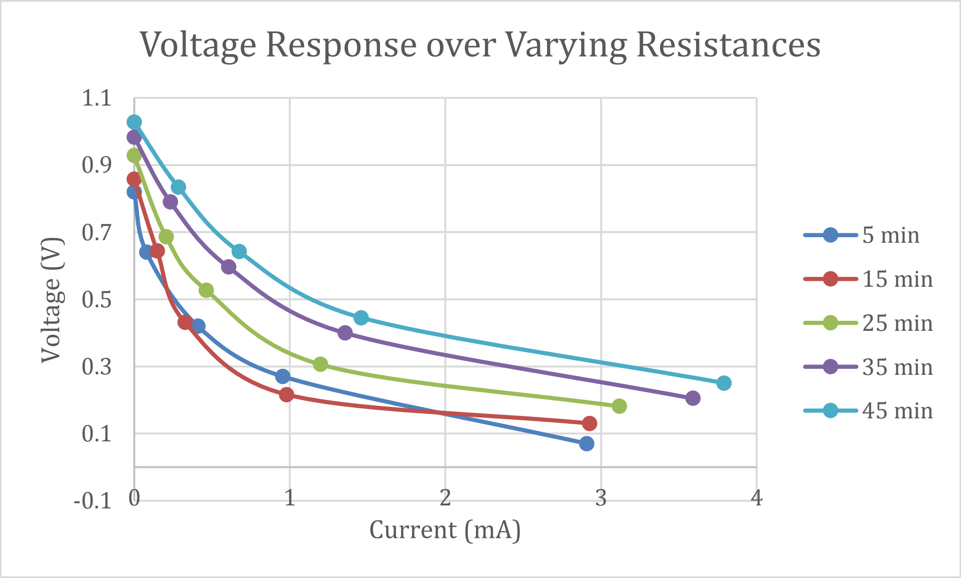


Figure 7. Voltage Response over Varying Resistances

As can be seen in Figure 7 above, the power output of the cell steadily increases as the time of operation increases.

This will continue until the cell reaches steady state operation, at which the cell will produce a nearly constant voltage until the KOH membrane begins to dry, which negatively impacts the power generation. The results measured at 5 minutes and 15 minutes clearly demonstrate that the fuel cell had not yet reached steady state operation at this time. The alkaline membrane takes while to “set in” until the KOH and electrode find an optimum working condition, which causes fluctuation values to be recorded until the equilibrium is reached. The fuel cell should have reached steady state significantly quicker than what was seen during our experiment, however due to time constrictions of Team 10’s testing permissions within the cryogenics lab, we were not able to repeat the test to see if these results are consistent with this cell design.

8 Project management

This section of the report will address the project management process that the team went used throughout the year. The team will be going into detail about scheduling, resources, procurement and communications. Also, the team encountered many issues along the way in these categories that will be addressed in this section.

8.1 Schedule

The Alkaline Membrane Fuel Cell Educational Kit hit bumps along the way as to be expected when attempting to engineer an item with limited access to the proper facilities to support such creation. This was handled by expert delegation and constantly having a back-up plan. Two issues that put team 10 behind the ball were the specialty machining of the bipolar plates, as well as not having a location to conduct needed testing at Florida State University nor the FAMU-FSU College of Engineering. The expected machining time was 2-4 weeks, considering the small scale and quantity of machining this was a conservative time frame. The actual machining process ended up taking 7 weeks. This presented the enormous challenge since testing could not occur until this machining was completed. The team combatted this challenge by working ahead on deliverables, presentations, and all reports. Through a cohesive effort, team 10 was able to overcome the issue and get the project timeline back on track. During the time waiting for machining the team also spent a large deal of time reaching out to facilities in the Tallahassee area that could have compressed hydrogen, compressed oxygen, regulators for both, and the kindness to allow team 10 to use their facilities. After some searching, the team found that the cryogenics laboratory at the National High Magnetic Laboratory in Innovation Park had all the aforementioned necessities needed for testing along with the willingness to let the team test in their lab. With diligence the team was able to keep the project on time and though the events did not follow the Gantt chart seen in appendix B exactly, the team was able to have everything back in line and according to the Gantt Chart by the final Poster Presentation.

8.2 Resources

Resources were an area of difficulty for this project from start to completion. To illustrate a metaphor, the team was given the task of assembling a mountain bike, but only provided with a single multi tool. The fuel cell consumes two gases continuously; oxygen and hydrogen. However, the school was unable to provide the team with any facilities with these two commodities, nor the budget to afford either one of the compressed gases (because a very expensive regulator is required for gas usage). Despite this issue, the team handled the gas supply by contacting a nearby research facility containing a cryogenics laboratory, and luckily one the team members had worked as a teaching assistant under the head of the cryogenics laboratory for a couple semesters. This was a huge success to attain the needed gases along with all the facilities to conduct the testing of the fuel cell. The other needed facility needed for the fuel cell was a machine shop. Luckily the FAMU-FSU College of Engineering had a machine shop that all senior designs projects had access too. Even this small victory was laden with challenges as the shop did not have the appropriate end mills for the needed machining, this cost was unexpected but the challenge was met, and the machine shop is now better equipped. The sponsors for team 10 themselves were also able to be used as a resource with their prior experience and knowledge of alkaline membrane fuel cell technology. With Dr. Vargas visiting from UFPR in Curitiba, Brazil where the initial prototype cell was located, he was able to provide invaluable suggestions for improvements on the initial design before the new prototype was machined as well as provide feedback and critique the presentations given throughout the spring 2015 semester.

8.3 Procurement

The budget has been handled with great care and has proven to be enough to generate a working electrolysis alkaline membrane fuel cell educational kit. However for this product to function at a high level, consistently, it should have a good deal of research investment into ideal proportions, ideal humidity for the prolonged operation of the membrane, as well as upscaling potential. Until this is done there is no profit potential off of the fuel cell kit. The fact that over 40% of the given $1000 budget remains is proof of the team’s financial fortitude and cleverness with the budget. Granted the team could not have met or even come close to within budget without the cryogenics laboratory, specifically Brian Mastracci, at the National High Magnetic Laboratory. There were also some small out-of-pocket expenses as well as donations such as resistors and LED’s that will not be accounted for in the bill of materials seen below in table 5.

Table 5. Bill of Materials

Component	**Cost**	**Category**
Platinum Electrode Sheet	$250.00	Consumables
Chromatography Paper	$31.00	Consumables
KOH	$17.09	Consumables
Tubing/waste water container	$9.90	Fuel Cell Hardware
Pipe Adapters	$15.25	Fuel Cell Hardware
Stainless steel	$52.00	Fuel Cell Hardware
Polycarbonate Cover	$33.85	Fuel Cell Hardware
Case	$39.99	Fuel Cell Accessories
Pressure Regulators	$125.08	Fuel Cell Accessories
Gas Storage Cylinders	$12.24	Fuel Cell Accessories
Wiring for Electrolysis	$11.76	Fuel Cell Accessories
Carbide End Mills	$78.54	Machine Shop Expenses
Total	$574.16	
Remaining Budget	$425.84	

8.4 Communications

During this year team 10 was met with substantial communication difficulties, this was in large part due to half of the team working in Brazil and half still in the United States at the FAMU-FSU college of engineering during the Fall 2014 semester. This challenge proved to be fruitful for both locations as all team members developed skill through experience in global communication. One such specific recurring issue the team had to learn to navigate was the internet in Brazil, as the chosen method for weekly meetings was through skype. This proved impossible during school hours in Brazil as the internet was not strong nor prevalent enough to power Skype internationally. This was remedied by having the weekly meetings while those in Brazil were at internet cafés. Another challenge stemming from the same root cause was the incorporation of those in Brazil into the live presentations. This was an important issue to face and was done so by archiving and zipping videos of the presentation from Brazil and sending them through email. Though not a perfect solution the method proved viable. All these communication challenges became an important part of the project and formed the cohesive team that exists today.

The sponsor of this project was FIPSE, the advisors, Dr. Ordonez and Dr. Vargas. Communication between the team in their respective countries, with their respective advisors occurred before all major decisions were made. Weekly meetings were scheduled between team 10 and Dr. Ordonez, at first these meetings were fruitful, but over time the meetings became scarcer and less beneficial. The team failed to achieve the advisor's differing vision for the educational kit and the project fell into a period of stagnation while trying to determine how to remedy the situation and pursue a new direction. This lull would be given a rude awakening when the fall semester ended, though the team spent hours engineering and re-engineering, the design did not come together and team 10 fell in jeopardy of not completing the cell to the standard the team as engineers must hold ourselves to. With the beginning of the spring semester blossomed a new passion to bring a viable completed fuel cell kit to the advisor. Even with this flame burning inside each team member, the project still did not have a clear vision and progress was hard to come by. This lack of direction finally found its path during the initial midterm presentation. Both Dr. Ordonez and Dr. Vargas shared their disappointment in the project's progress. From this critique the team decided to seize the opportunity that sat quietly in the shadows. The team used the critique to get useful information from the sponsors about their vision, information the team had not clearly understood until this time. The team now has a completed working fuel cell that is fully portable with no travel restrictions. Surely the design could remain to be tweaked, but the product does fill the requirements given.

9 Conclusions

Throughout the year our team has accomplished many things and encountered many difficulties. One major event that occurred for the team was the overall shift in design that occurred at the start of the spring semester. It was determined that the mounting systems that were previously considered were very unnecessary and impractical. The fuel cell is now using a polycarbonate mounting bracket design which is much simpler. Another major change that occurred was the shift from compressed gasses in the kit to using electrolysis as a method to provide the necessary hydrogen and oxygen. In the final design of the bipolar plates the team chose to use parallel channels due to a combination of increased gas flow and machining limitations. The team has also ran into many complications throughout the year. Team 10's first major complication was communication with the team in Brazil. The solution was communicating over internet services like Skype whenever possible. The second major complication was the advisors. In the beginning of the year weekly meetings were scheduled in order to keep the team on track. As the meetings continued they become less effective and were scheduled whenever they were needed instead of weekly. Also, even though the advisors were updated on the project as new developments were made team 10 was informed in the spring that our project goals did not match the goals the advisors had in mind. This was resolved as quickly as possible and the team managed to get back on track. Testing was another major issue that occurred due to a lack of proper facilities. The team managed to resolve this by establishing a relationship with the cryogenics lab at FSU in order to allow testing at their facilities. Through this testing though the team managed to obtain some valuable data. The cell has managed to produce a maximum voltage and current of 1.028 V and 3.7909 mA. Also, the cell has managed to produce a power of 0.947 mW. These values may seem small but they were to be expected due to the size reduction of the fuel cell.

Looking back on the year the team definitely believes that some changes could have been made that would have made the year much easier. The first change would have been to have made many more important design decisions in the fall semester. This put a lot of pressure on the team later in the year. Another thing that could have been done differently is the management of time. Throughout the year the team made estimated for how long things would take that did not accurately reflect any problems that would occur. On multiple occasions problems arose that caused unexpected delays and very tight deadlines. Though based off of these experiences the team has come up with future recommendations that would allow the project to continue. The first major recommendation would be to investigate the feasibility of stacking multiple cells together to increase output. This would allow much more elaborate demonstrations to be performed for the kit due to the higher power output. Another recommendation is that larger size cells should be researched to truly compare the benefits size has on budget and performance. Overall the team believes that all of the goals and objects that were put in place for the project have been accomplished.

10 References

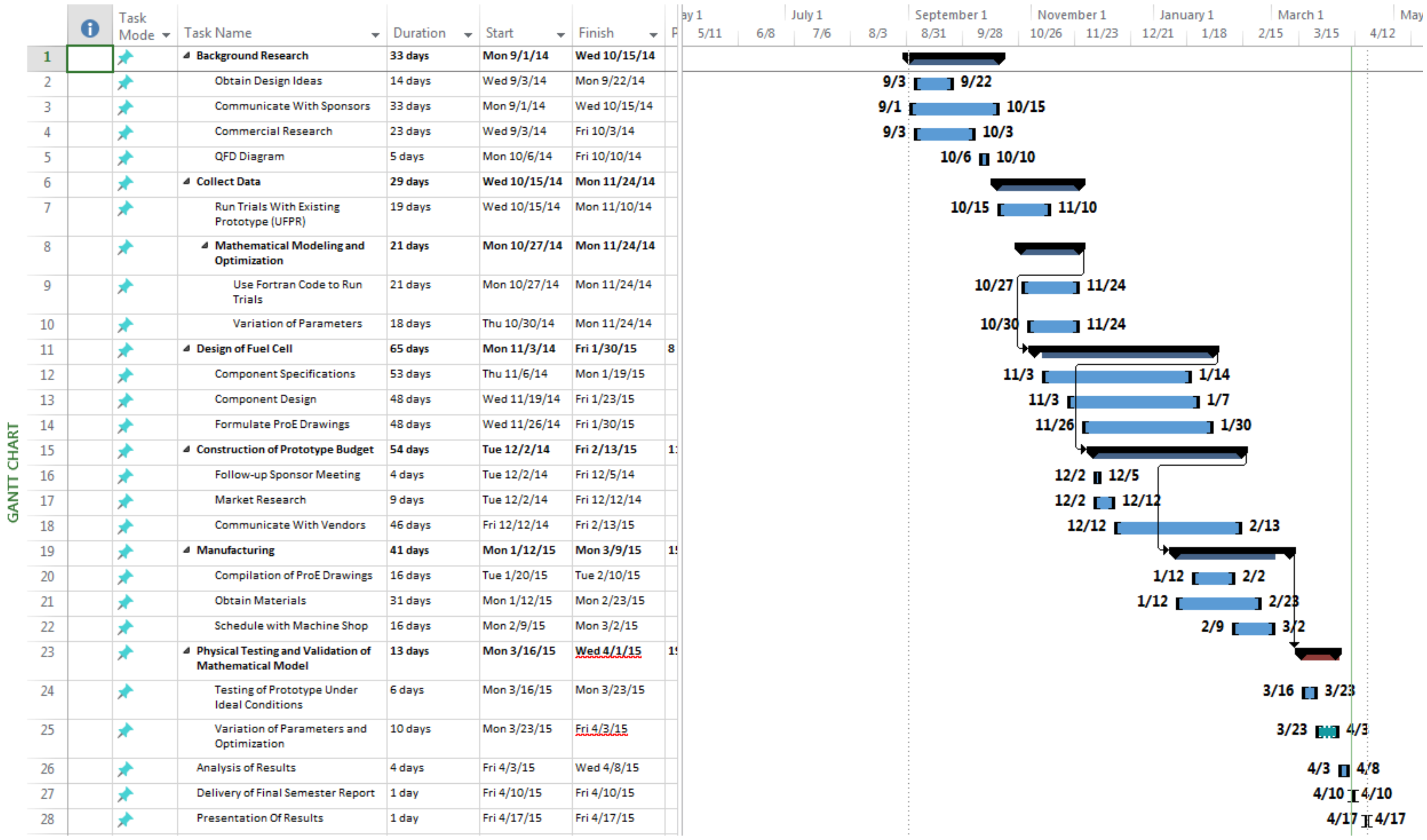
[1]Vargas, J.V C., and J. C. Ordonez. "Alkaline Membrane Fuel Cell (AMFC) Modeling and Experimental Validation." *Journal of Power Sources* (2012): 1-15.*Www.elsevier.com/locate/jpowsour*. Elsevier, 11 Apr. 2012. Web. 15 Sept. 2014.

[2]Ordonez, Juan, and Jose Vargas. *Design and Development of an Alkaline Membrane Fuel Cell (AMFC) Educational Kit for High School and College Level Laboratory Demonstration*. Tallahassee: Florida State Univeristy, n.d. PDF.

Appendix A: Troubleshooting

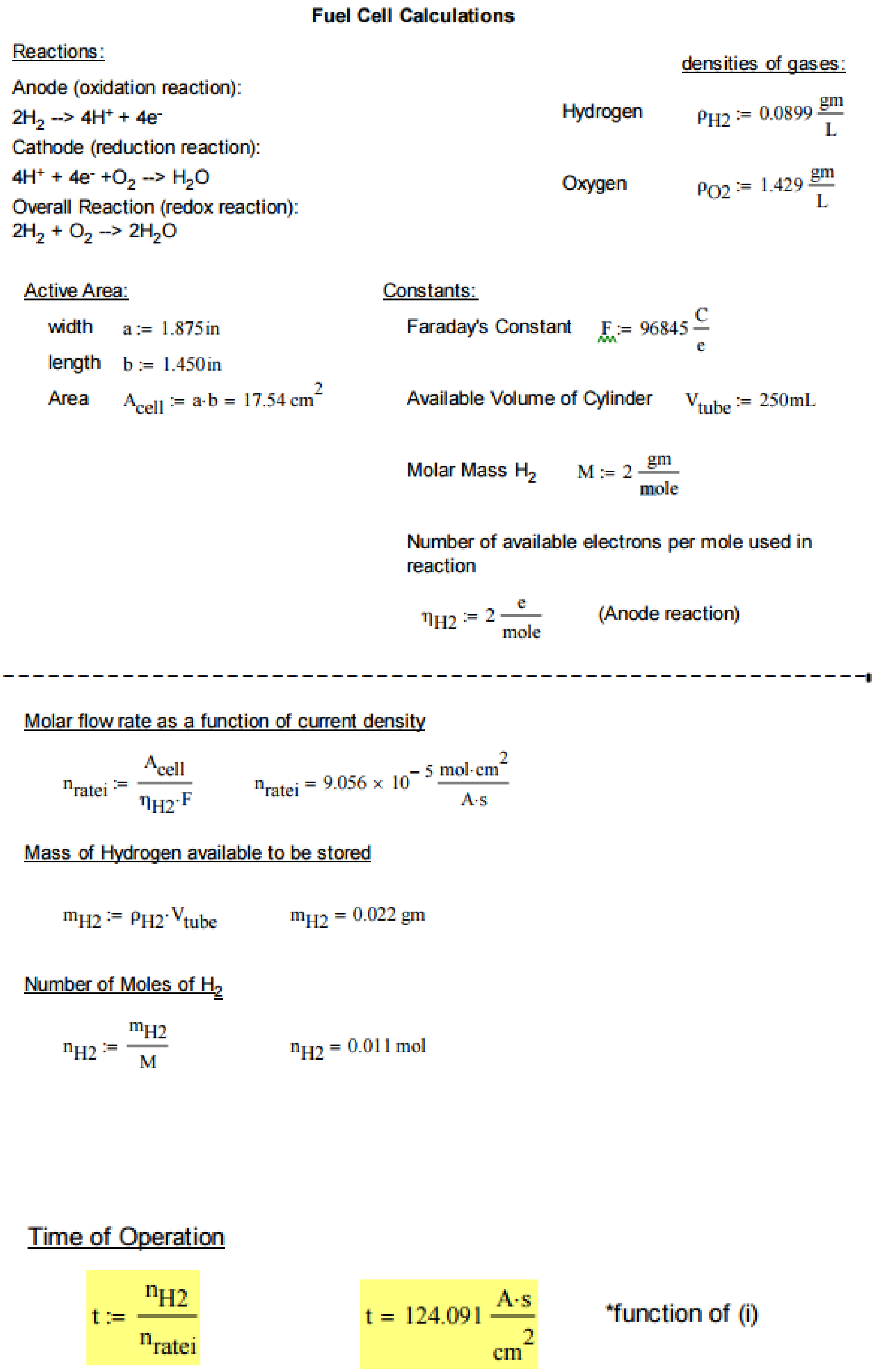
Problem	Solution
The alkaline membrane ripped off, can I use it anyway?	The AMFC has been designed for optimal functioning, and there were not made any test using ripped alkaline membrane, it may work, but probably not as well as it should with an intact membrane.
The platinum sheets are disintegrating, is it normal?	The platinum sheets do not last forever, after a certain time of usage, signs of deterioration will be shown. If it´s noticed that the efficiency of the cell is falling, it is time to substitute the sheet.
There is something dripping from the fuel cell, should I worry?	One of the byproducts of the reaction is water. If you made sure the alkaline membrane was properly prepared (there is no excess KOH solution on it), and there are very few drops (unlike a flowing stream) then the drops seen are most likely water.
There is no electrical current coming from the cell (the output does not work), what should I do?	The purpose of the fuel cell is generate electrical energy, if it does not generate a current then something is wrong. There are several reasons why it would not work, usually because of mistakes made during the operation. Please follow all steps again, making sure the channels in the bipolar plates are not obstructed, the assembly is correct, the KOH was properly prepared, and the electrolysis kit is assembled correctly. If the problem still persists, please contact the FAMU-FSU College of Engineering
I was handling the alkaline membrane and accidentally the solution touched my skin, will I be okay?	Yes. The alkaline solution, although a little concentrated is not harmful unless ingested, will not cause harm if thoroughly rinsed and washed after exposure. Observation: the solution can cause some irritation in the worst cases. In case of contact with the eyes wash immediately with abundant flowing water and contact a medical professional.

Appendix B: Gantt Chart



	Task Mode	Task Name	Duration	Start	Finish
1		**◢ Background Research**	**33 days**	**Mon 9/1/14**	**Wed 10/15/14**
2		Obtain Design Ideas	14 days	Wed 9/3/14	Mon 9/22/14
3		Communicate With Sponsors	33 days	Mon 9/1/14	Wed 10/15/14
4		Commercial Research	23 days	Wed 9/3/14	Fri 10/3/14
5		QFD Diagram	5 days	Mon 10/6/14	Fri 10/10/14
6		**◢ Collect Data**	**29 days**	**Wed 10/15/14**	**Mon 11/24/14**
7		Run Trials With Existing Prototype (UFPR)	19 days	Wed 10/15/14	Mon 11/10/14
8		**◢ Mathematical Modeling and Optimization**	**21 days**	**Mon 10/27/14**	**Mon 11/24/14**
9		Use Fortran Code to Run Trials	21 days	Mon 10/27/14	Mon 11/24/14
10		Variation of Parameters	18 days	Thu 10/30/14	Mon 11/24/14
11		**◢ Design of Fuel Cell**	**65 days**	**Mon 11/3/14**	**Fri 1/30/15**
12		Component Specifications	53 days	Thu 11/6/14	Mon 1/19/15
13		Component Design	48 days	Wed 11/19/14	Fri 1/23/15
14		Formulate ProE Drawings	48 days	Wed 11/26/14	Fri 1/30/15
15		**◢ Construction of Prototype Budget**	**54 days**	**Tue 12/2/14**	**Fri 2/13/15**
16		Follow-up Sponsor Meeting	4 days	Tue 12/2/14	Fri 12/5/14
17		Market Research	9 days	Tue 12/2/14	Fri 12/12/14
18		Communicate With Vendors	46 days	Fri 12/12/14	Fri 2/13/15
19		**◢ Manufacturing**	**41 days**	**Mon 1/12/15**	**Mon 3/9/15**
20		Compilation of ProE Drawings	16 days	Tue 1/20/15	Tue 2/10/15
21		Obtain Materials	31 days	Mon 1/12/15	Mon 2/23/15
22		Schedule with Machine Shop	16 days	Mon 2/9/15	Mon 3/2/15
23		**◢ Physical Testing and Validation of Mathematical Model**	**13 days**	**Mon 3/16/15**	**Wed 4/1/15**
24		Testing of Prototype Under Ideal Conditions	6 days	Mon 3/16/15	Mon 3/23/15
25		Variation of Parameters and Optimization	10 days	Mon 3/23/15	Fri 4/3/15
26		Analysis of Results	4 days	Fri 4/3/15	Wed 4/8/15
27		Delivery of Final Semester Report	1 day	Fri 4/10/15	Fri 4/10/15
28		Presentation Of Results	1 day	Fri 4/17/15	Fri 4/17/15

Appendix C: Calculations



Fuel Cell Calculations

Reactions:

Anode (oxidation reaction):

$2H_2 \rightarrow 4H^+ + 4e^-$

Cathode (reduction reaction):

$4H^+ + 4e^- + O_2 \rightarrow H_2O$

Overall Reaction (redox reaction):

$2H_2 + O_2 \rightarrow 2H_2O$

densities of gases:

Hydrogen $\rho_{H2} := 0.0899 \frac{gm}{L}$

Oxygen $\rho_{O2} := 1.429 \frac{gm}{L}$

Active Area:

width $a := 1.875 in$

length $b := 1.450 in$

Area $A_{cell} := a \cdot b = 17.54\ cm^2$

Constants:

Faraday's Constant $F := 96845 \frac{C}{e}$

Available Volume of Cylinder $V_{tube} := 250 mL$

Molar Mass H_2 $M := 2 \frac{gm}{mole}$

Number of available electrons per mole used in reaction

$\eta_{H2} := 2 \frac{e}{mole}$ (Anode reaction)

Molar flow rate as a function of current density

$n_{ratei} := \frac{A_{cell}}{\eta_{H2} \cdot F}$ $n_{ratei} = 9.056 \times 10^{-5} \frac{mol \cdot cm^2}{A \cdot s}$

Mass of Hydrogen available to be stored

$m_{H2} := \rho_{H2} \cdot V_{tube}$ $m_{H2} = 0.022\ gm$

Number of Moles of H_2

$n_{H2} := \frac{m_{H2}}{M}$ $n_{H2} = 0.011\ mol$

Time of Operation

$t := \frac{n_{H2}}{n_{ratei}}$ $t = 124.091 \frac{A \cdot s}{cm^2}$ *function of (i)

Team Bios

Collin Heiser – (cjh10h@my.fsu.edu)
FSU Team Leader

Collin Heiser is currently a senior of mechanical engineering at Florida State University and will be graduating in the spring of 2015 with a specialized track in thermal fluids. He’s had a project management internship with Jarden Consumer Solutions in previous summers and effectively brings that experience to the project.

Benjamin Richardson – (jbr10@my.fsu.edu)
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.

Mustafa Nek – (mn11h@my.fsu.edu)
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.

Nicole Alvarez – (nda10@my.fsu.edu)
Brazil Assistant Mechanical Engineer

Nicole is currently studying mechanical engineering at FSU and has held internship positions with Rolls-Royce and Pratt & Whitney. Her work within and outside of school has grown her interest to pursue a career in the aerospace industry.