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

Team Number: 10

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Abstract

The main focus of this report is to discuss the design of the fuel cell as well as the scheduling for what we want to accomplish. We discuss three different practical design ideas and decided to use one based off a variety of factors. Also, we are currently meeting all scheduling expectations which is addressed in section four of the report. Now that we have decided on a design for the kit we will shift our focus to practical marketing opportunities and manufacturing options.

1 Introduction

The objective of our project is to create a functional alkaline membrane fuel cell educational kit. By converting chemical potential energy to electrical energy with the fuel cell, we aim to have a kit such that it can be mass produced and sold to classrooms and universities for learning ventures. Previous research has been done on alkaline membrane fuel cells, yet the size of the fuel cell proves to be too large to make an educational kit.

Our designs include creating the AMFC kit in a portable case so that it can be compact and transportable. Some of the issues addressed are safety regulations for storing the tanks. In addition, the fuel cell should be such that it can be used and efficiently stored. Research and testing is currently being conducted in order to determine a proper size for the fuel cell in order to maintain the efficiency obtained in the larger fuel cell setups. Once this size is determined the dimensions for the designs can be finalized and the manufacturing process can officially begin.

2 Project Definition

2.1 Background research

Fuel cell technology has been increasingly recognized in the field of alternative energy as a clean option for future power generation. For this reason, an educational kit using an alkaline membrane fuel cell is to be created to demonstrate the technology and spread interest in the concept to future engineers.

This project aims to build on the research previously conducted on alkaline membrane fuel cells (AMFC) by the engineering departments of both Florida State University and Universidade Federal do Paraná. Professors such as Juan Ordonez (FSU) and Jose Vargas (UFPR) were able to produce and validate a dynamic model to predict the response of a single AMFC according to the variation of physical properties, as well as design and operating parameters[1]. Using this model, the fuel cell of the educational kit will be optimized to lower overhead costs and increase functionality.

Though similar kits already exist in today's market involving other types of fuel cells, this kit will be the first to use an AMFC to power the system. Alkaline membrane technology has shown promising characteristics when compared to other forms of fuel cells, such as a higher current density, lower cost electrolyte and higher operating temperatures, which should allow for the production of a more accessible and affordable educational kit[2]. There are also some disadvantages that will bring some different challenges to the design as seen in the table below. First, the reaction taking place in the fuel cell has an intolerance to CO_2 which will hurt the efficiency overall[1]. Also, pure H_2 and O_2 must be used as fuel for the chemical reaction to take place within the fuel cell. These problems have been addressed previously in larger scale designs and will soon be addressed for our smaller scale design as well.

Advantages	Disadvantages
• Inexpensive catalysts: - Nickel at the anode - Silver at the cathode • No expensive polymer membrane is necessary – liquid alkaline solution as electrolyte • Liquid electrolyte may enable a simple cooling of the stack • Activation overvoltage is less than with an acid electrolyte	• High corrosivity of the electrolyte • Electrolyte must be reconcentrated during long time • Intolerance to CO_2 $CO_2 + 2OH^- \rightarrow CO_3^{2-} + H_2O$ • Must use pure H_2 and O_2

Table 1. Advantages and Disadvantages of Alkaline Membrane Fuel Cells[1]

2.2 Need Statement

The sponsor for FIPSE Team 3 is Florida State University, however the needs are being conveyed through Florida State University Associate Professor Dr. Juan Ordonez. Currently the alkaline membrane fuel cell is set up in a laboratory in CAPS building, the size of the setup is in the neighborhood of 70 ft^2. Florida State and Dr. Ordonez would like for the entire setup to be inside of a portable case. This means shrinking the setup roughly 30 times its current size. 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 students can learn with. The team plans to deliver a fully operational alkaline membrane fuel cell prototype kit smaller than a standard suitcase by March 22, 2015.

“The current AMFC setup is too large and immobile to be a portable educational kit alkaline membrane fuel cell.”

2.3 Goal Statement & 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.”

- All contained components accessible for teaching purposes
- Reliable fully operational alkaline membrane fuel cell powering a visual aid (yet to be determined)
- Packet containing any specifications used, any engineering drawings used, and all components used including acquisition information
- Storage and distribution – the size and availability of the kit should be optimized
- Cost reduction and manufacturing – the kit should be affordable for the customers and be affordable to manufacture

- CO_2 poisoning – Filter off incoming oxygen supply to reduce/remove CO and CO_2
- Precipitate and liquid formation – Formation of potassium carbonate (if exposed to CO_2) and water in fuel cell through chemical reactions
- Creation of a thorough safety and installation manual to be put onto an instructional dvd included with the kit

2.4 Constraints

Before the use of fuel cells can be considered a practical means of energy production we must meet some specific constraints that are put in place for the design to succeed.

- Weigh under 20 lbs. to ensure portability
- Have all components of an alkaline membrane fuel cell contained within a standard sized suitcase (1.4 ft^2 – 2.0 ft^2)
- Filter off almost all of the CO and CO_2 in the system to prevent CO_2 poisoning

3 Design and Analysis:

3.1 Functional Analysis

Fuel Storage Tanks

There will be two fuel storage tanks, one will contain diatomic oxygen and the other will contain diatomic hydrogen gas. They will both have an excess flow valve, a solenoid valve, and a pressure release vent port. The tanks will be sized to fit into the suitcase as well as the amount needed to perform the test. The tanks will have cylindrical sidewalls and hemispherical ends to remove any pressure concentration points, as seen in Fig. 1. The gas storage tanks will be selected to tolerate the 30 psig pressure that the gasses will need be stored at. Since these are combustible gasses stored under pressure, safety is the primary concern.

Figure 1. Gas storage tanks

Fuel Cell

The primary function of the Alkaline Membrane Fuel Cell is converting energy from the reaction between diatomic hydrogen and oxygen into usable electrical energy. The system consists of seven control volumes; two input valves, two body plates, an anode, a cathode, and an electrolyte. The electrolyte we will be using is a 40% concentration of potassium hydroxide (KOH) contained between two platinum cloth sheets that act as the anode and cathode. The interior of the fuel cell consists of channels to increase the surface area of the reaction and also guide the water produced as a byproduct out of the fuel cell. At this stage of design, it is projected that the body of the fuel cell will be made of Aluminum 2024 to reduce weight and increase heat transfer, which will in turn speed up the reaction. From previous tests conducted with steel, we were able to obtain values of 0.818 V and 6.68 A. However, with our new design we can expect higher voltage and current outputs.

3.2 Design Concepts

We have decided on three different concepts for our fuel cell design. All of the drawings for these designs can be seen in the appendix at the end of the report. The first design that we came up with involves the fuel cell being placed on a stand that is separate from the case during operation. The cell itself will clip in to a plastic base that will result in it being upright and mostly stable. Also, the compressed gas canisters will be locked in to the same base as the cell. Another important thing to note with this design is that everything will be stored in the case. Within the case will be a foam that functions as padding and will be cut to our required dimensions. Our second design uses the same dimensions for the fuel cell as the first. This design can also be seen in the appendix and does away with the plastic base being used to support the fuel cell from the first design. Instead of this base fuel cell is being hung by a support pole that is being supported by the side arms of the case. These arms fold in as the case closes and stay locked while the case is opened until they are manually unlocked by the user. This allows the fuel cell to be easily supported from within the case itself. Also, lets the user quickly assemble the setup with little work. This design also works because the fuel cell does not have to be completely stationary during operation so the swaying caused by the hanging will not affect performance. The fuel cell will have two holes drilled into the top to allow for a hanger to thread through. Our third design takes advantage of the foam in the case to support the cell during operation. As seen in the appendix there is an indent in the foam where the cell can rest and it does not affect the cell while it is being stored. The tanks for this design are in the case as well. It is important to consider that with all three of these designs there are many things that need to be considered. First, since we are still gathering data for the fuel cell the official sized used has not yet been determined. This means that for all of the designs we will have to change a majority of the dimensions to accommodate this. Also, when looking at the fuel cell it is important to consider that it needs to remain perfectly sealed. This means that we can still make holes in the outer part of the cell in our designs as long as it is still sealed. So as a result the dimensions of the outer edge material of the cell will change depending on the size of the holes that are needed.

Since the design of the Alkaline Membrane Fuel Cell and its components remain unchanged regardless of design, the computational analysis of the system yielded the same results for each concept. Using the mathematical model in FORTRAN our team was able to predict the response of various aspects of the fuel cell, such as how the pressures of the fuels affect the generation of current and the transient behavior of temperature that occurs while the reaction takes place.

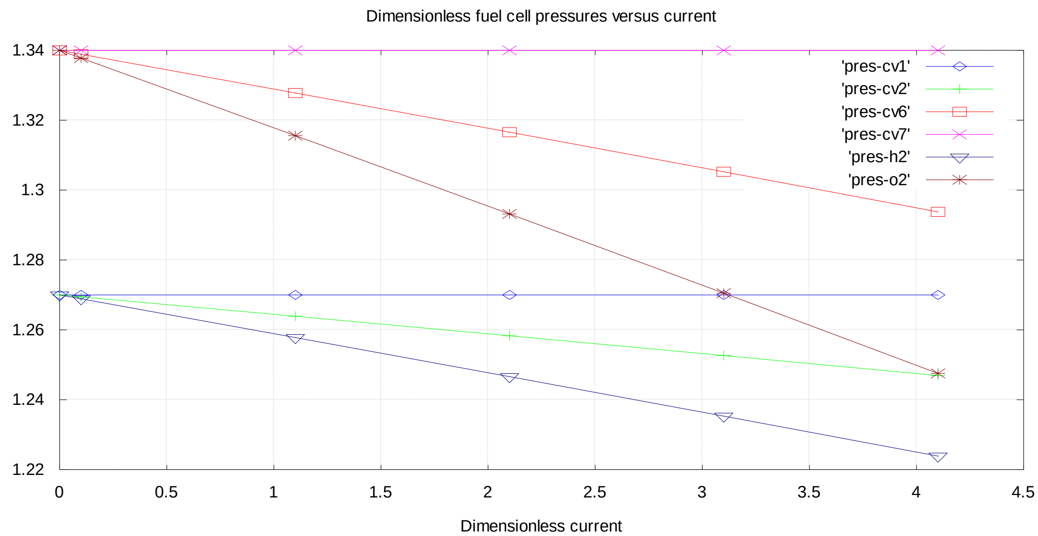


Figure 2. Dimensionless fuel cell pressure vs current

Figure 2 above depicts the theoretical pressures of select control volumes of the fuel cell, including the transient pressures of the diatomic hydrogen and oxygen gases as they flow through the fuel cell. It can be noticed that the inlet pressure of the gases (CV1 and CV7) were assumed to be constant, and yield a constant current throughout the test. However, when analyzing the other control volumes it’s apparent that the pressure of the fuel is inversely related to the energy generation of the fuel cell. As pressure steadily declines, the current produced by the AMFC increases. This parameter is intentionally left alterable by use of pressure valves in order to demonstrate the effects of fuel characteristics on energy generation, however the use of lower pressures would reduce the storage tank size requirement.

As the chemical reaction between the hydrogen and oxygen takes place, heat is generated within the control volumes of the fuel cell. In order to determine whether this poses a hazard to the consumer, each control volume was analyzed separately within the response projected by the mathematical model. As seen in figure 3 below, the overall temperature of the Alkaline Membrane Fuel Cell increases exponentially over time as the reaction takes place, however a temperature gradient is produced within the casing of the fuel cell. The temperatures at the inlets of the H2 and O2 gases (CV1 and CV7, respectively) are significantly lower than the other sections of the fuel cell due to the nature of chemical reactions, and the heat that is given off as atomic bonds are broken. Though the higher temperatures are found within the middle control volumes of the AMFC which would not be exposed, the gradient will be taken into account when forming design concepts in order to reduce the possible risk of injury to consumers.

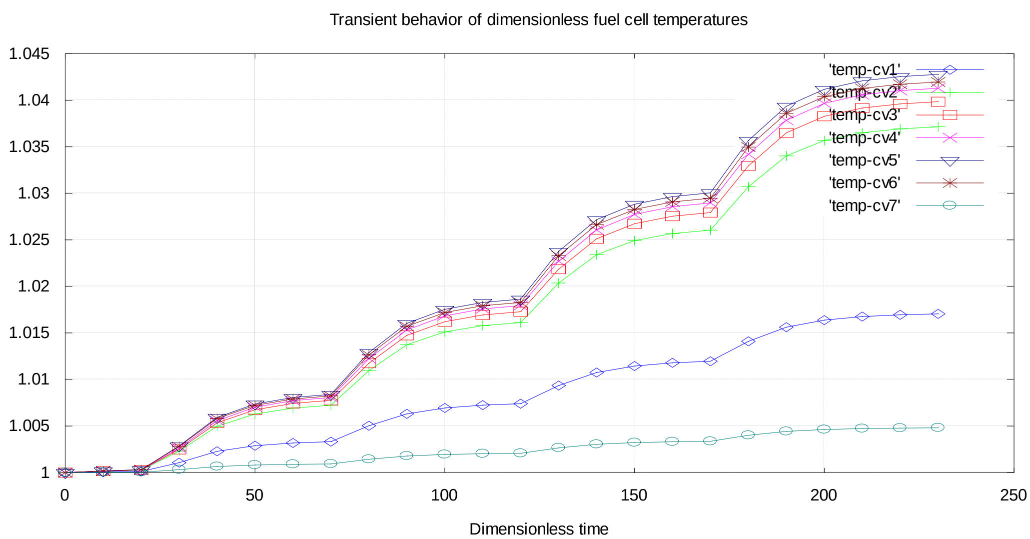


Figure 3. Transient Behavior of Dimensionless Fuel Cell Temperatures

The benefit of each of these design ideas is that they are relatively easy to manufacture. Actually the only major manufacturing issue that we would run into would be trying to produce the plastic base mentioned in the first design. This is due to the fact that it has very unique dimensions and will have to be 3D printed. This is a problem due to our budget being slightly restrictive as it is now. The foam that is in the case can be cut manually by us to any dimensions needed so that will not be a problem. Also, the case will be purchased separately so no additional manufacturing will be needed. For our second design we will need to manufacture the arms that are supporting the case and fuel cell. The design for these arms is simple and can be easily manufactured in the engineering machine shop. The third design actually involves no additional manufacturing due to the foam being the support. Finally, if any changes need to be made to the fuel cell they can be done in the machine shop without issue.

3.3 Evaluation of designs

Design	Portability	Safety	Affordability	Machinability	Ease of Use	Weighted Sum
Tanks Included, Mounted to Case	5	3	3	3	4	66
Seperate Assembly From Case	3	5	4	4	4	73
Assembly Hangs from Case Mount	5	3	3	5	5	74
Weight	4	5	3	2	4	

Table 2. Selection matrix comparing three different designs over five weighted design criteria.

3.3.1 Criteria, Method

The educational kit being produced in this project is unique in the fact that the design of the fuel cell itself and its accompanying parts doesn't have much room for fluctuation other than scalability; most other factors can be adjusted during assembly, such as electrolyte concentration and gas input pressures. Though adjustments of these aspects can be harmful or beneficial on performance, in our final design they will remain adjustable to allow the instructor or consumer to further understand the functionality of an Alkaline Membrane Fuel Cell and review how each parameter influences the reaction. However, three different design concepts were still able to be created based on how the educational kit would be packaged or contained when shipped/operated. After deliberation with our sponsor and the reviewing the needs stated in the project proposal, the five criteria found in table 2 were determined to be the most important aspects or standards of the AMFC educational kit that would be used to influence design selection.

This AMFC educational kit would ideally be used in an educational setting, teaching any interested parties about the possibilities and benefits associated with the alternative energy source. In order to make the fuel cell marketable and competitive, it was determined that safety should be the paramount concern when considering design concepts. Other criteria relative to the consumer, such as portability and ease of use were weighted higher than the aspects pertaining to the fuel cell construction in order to ensure proper functionality and durability of the educational kit and its components.

3.3.2 Selection of optimum ones

Of the three design concepts being considered, it was determined that the Alkaline Membrane Fuel Cell and its associated components would be better utilized by creating a kit that encompassed both the tanks and the fuel cell, with the assembly hung from a crossbeam running across the open case. This design reduces some of the frustration involved in the machining and streamlining of the kit for mass production as well as allowing for increased portability with one, self-contained kit. There are some trade-offs however, since including the tanks within the case allows for the possible transportation of combustible contents under pressure if proper safety measures aren't followed. This also increases the overall cost of the kit since more space is required within the case for the oxygen and hydrogen tanks, though the decrease in machining cost due to the simplicity of the packaging could offset some of this difference. One of the major advantages to this design concept is the reduction in area needed to operate the educational kit, as well as the ability to more easily demonstrate each step in the functionality and assembly of the Alkaline Membrane Fuel Cell.

4 Methodology

Methodology is a key part of the product in order to produce an alkaline membrane power cell with portable capabilities. A good representation for our methodology can be seen below in figure 4.

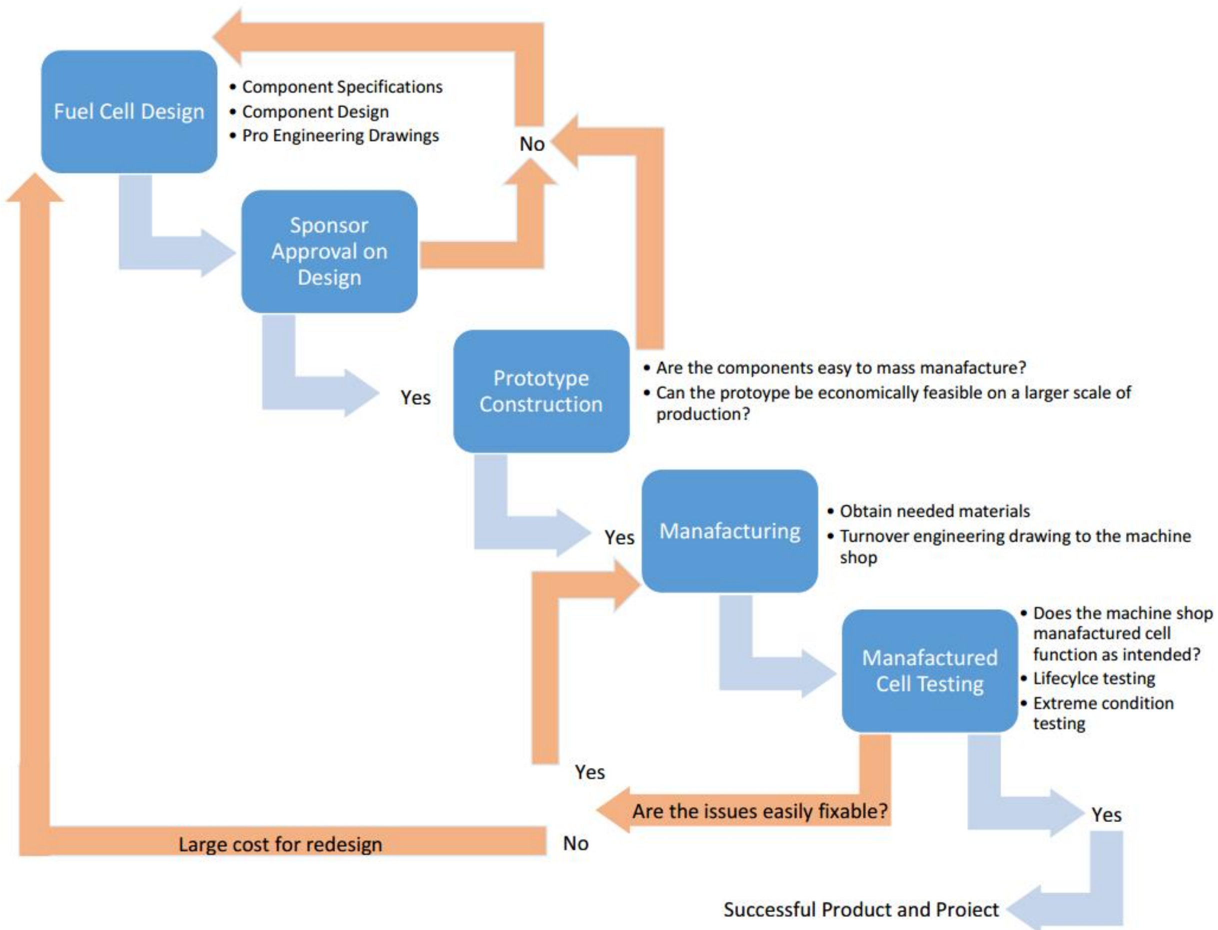


Figure 4. Methodology Block Diagram

At first, our goal was to understand the technology behind these fuel cells, this includes research of previous advancements in fuel cell technologies as well as understanding the basic theory behind the chemical energy transfers that occurs. Also, before testing occurred we made sure to understand the proper gas ratios needed in order to not damage the equipment being used. Now that the team has a grasp on the theory and background of AMFC technology, the next step is to verify the design process fits what is needed. The design process has been a joint effort with Brazil to ensure that the designs meet and exceed the expectations. Within each design flexibility has been included so that when construction occurs, any issues will have so room to maneuver and fit together seamlessly. The team is still in the design phase, and ahead of schedule on it. Below is a flow diagram outlining the requirements each stage has and the path for the future. After each milestone the team will ensure each objective is met before continuing, if the objective has been met the work will flow down (blue), if the objectives are not met then the project flows up (red) until the objectives can be met.

4.1 Schedule

The Gantt chart is designed to keep the team on pace to finish successfully, a large component of staying on pace is visualizing the steps needed to get to success.

The first large block of time is the background research. During the background research phase, the team will review current fuel cells to grasp a better understanding of what is needed to make a successful alkaline membrane educational kit. The members will focus on design inspiration while continuing communication with our sponsor. The expected timeframe for the background research is 33 days. This allows the team to feel comfortable as well as knowledgeable about fuel cells.

As previously mentioned the team has moved well through the background research stage, along with Brazil conducting testing to come up with the needed data. Brazil will continue testing so that small parameters can be adjusted on the currently existing model to optimize the power output vs. consumption for the alkaline membrane fuel cell educational kit. The parameter adjustment will include coding with Fortran, which is what the fuel cell setup in Brazil uses. This is expected to take three weeks.

Now the team is working on the Design of the fuel cell, this is a joint operation between Brazil and FSU. This has been difficult and holds as a continually changing process. This includes components, components specifications, along with engineering drawings for each. The timeframe for the Design portion is 65 days long. The timeline for the design phase has been ahead of schedule due to dynamic team communication amongst FSU and Brazil members. The team has designs and will continue to work on the chosen design, this design is expected to change through the spring semester as new issues are brought to attention. This flexibility was purposely included into the timeline.

Once the design process reaches an agreed on point the team will consult with the sponsor to get both FSU and Dr. Ordonez' approval on the design. The stages to success that follow the Design are a prototype budget, manufacturing of the kit, and finally ensuring the kit works as intended. These tasks are all set as spring semester tasks and more likely subject to date and length changes. Following the Gantt chart is vital to success and having such an organized and detailed outline will be pivotal.

4.2 Resource Allocation

Due to the unique situation of having the team split between two different locations resource allocation is very important. The background research was by all members of the team so everyone has a good understanding of the technologies being used. The Brazil team currently has the facilities to perform the data collection so James will be heading this process. While this is taking place the data will be sent to the team located at FSU for further analysis. After the appropriate data is obtained the FSU team mainly Collin and Mustafa will be creating a design that uses the fuel cell technology for educational purposes. This will consist of ProE drawings and the appropriate component specifications. Then Bryan will lead the budget for the prototype, this is a constantly evolving process and will change on each new step. After the design and budget is completed the prototype construction will begin. This will be led by the James and will be supported by all team members. Finally, once the construction of the prototype is complete all group members will be performing tests to optimize the power output for the final results.

5 Conclusion

The main thing that have resulted from this deliverable is the design. After discussing things with the group we decided that having the fuel cell hanging during operation is the best route to take. The main reason behind this is that it is a very stable and reliable design that will last through frequent use. Also, with our current manufacturing accessibility and budget restriction the hanging cell design is the most feasible. Also, this design still allows the fuel cell to maintain its portability which is one of the main goals of the project.

In the coming weeks we have set some very major goals for ourselves. First, we are going to begin researching different marketing opportunities for the product. For example, one idea we are currently looking into is having FSU loan out each kit to high schools in the area instead of selling them. Also, now that the testing in Brazil has picked up its pace we hope to have final dimensions to the fuel cell soon. Finally, by the end of the semester we hope to obtain all of our needed materials so we can begin manufacturing in the spring.

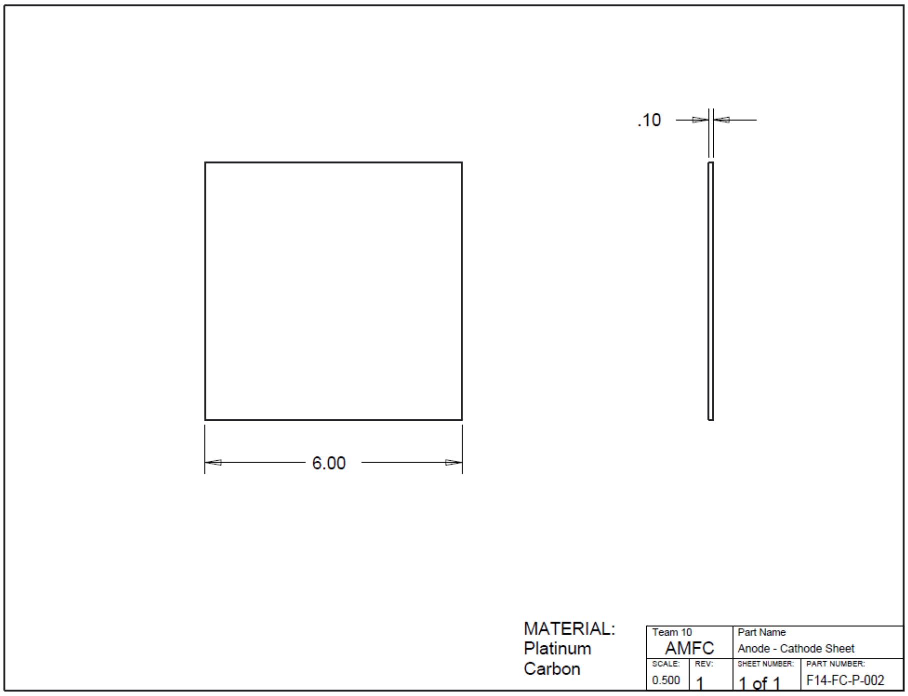
6 References

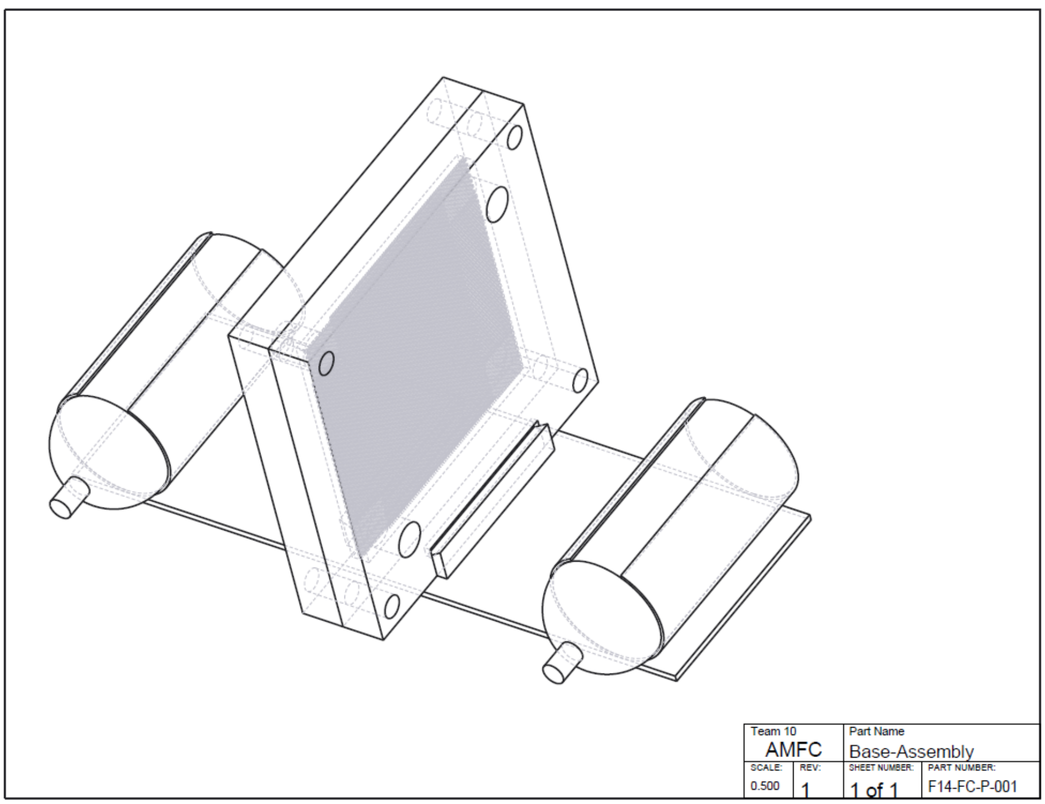
[1]Vargas, J.V C., and J. C. Ordonez. "Alkaline Membrane Fuel Cell (AMFC) Modeling and Experimental Validation." *Journal of Power Sources* (2012): 1-15.*Www.elsevier.com/locate/jpowsour*. Elsevier, 11 Apr. 2012. Web. 15 Sept. 2014.

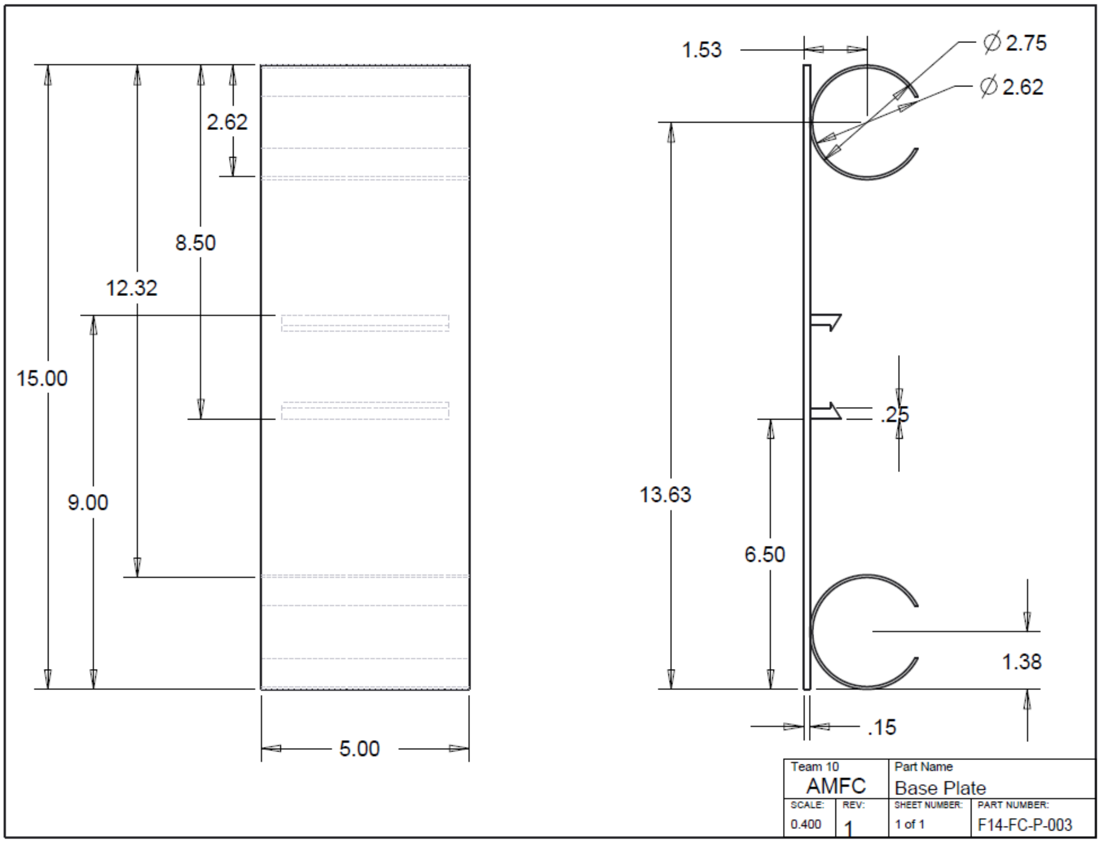
[2]Ordonez, Juan, and Jose Vargas. *Design and Development of an Alkaline Membrane Fuel Cell (AMFC) Educational Kit for High School and College Level Laboratory Demonstration*. Tallahassee: Florida State Univeristy, n.d. PDF.

7 Appendix

A. Separate Assembly From Case Design







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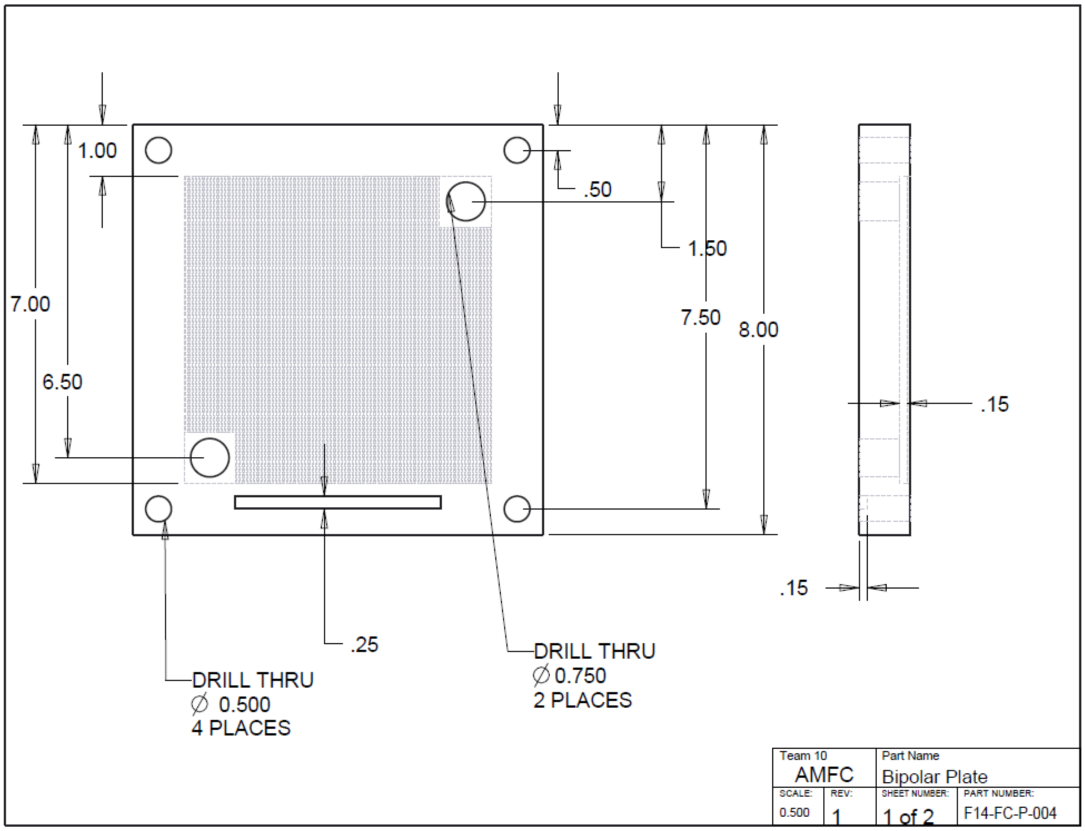
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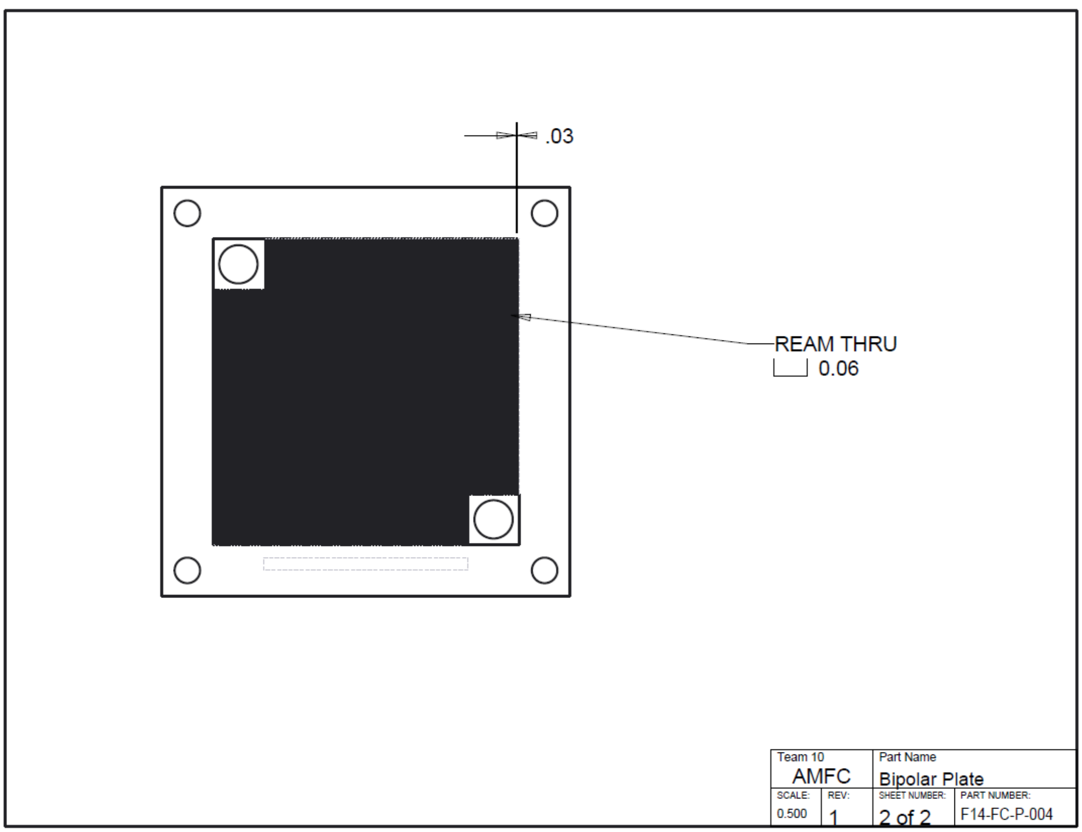
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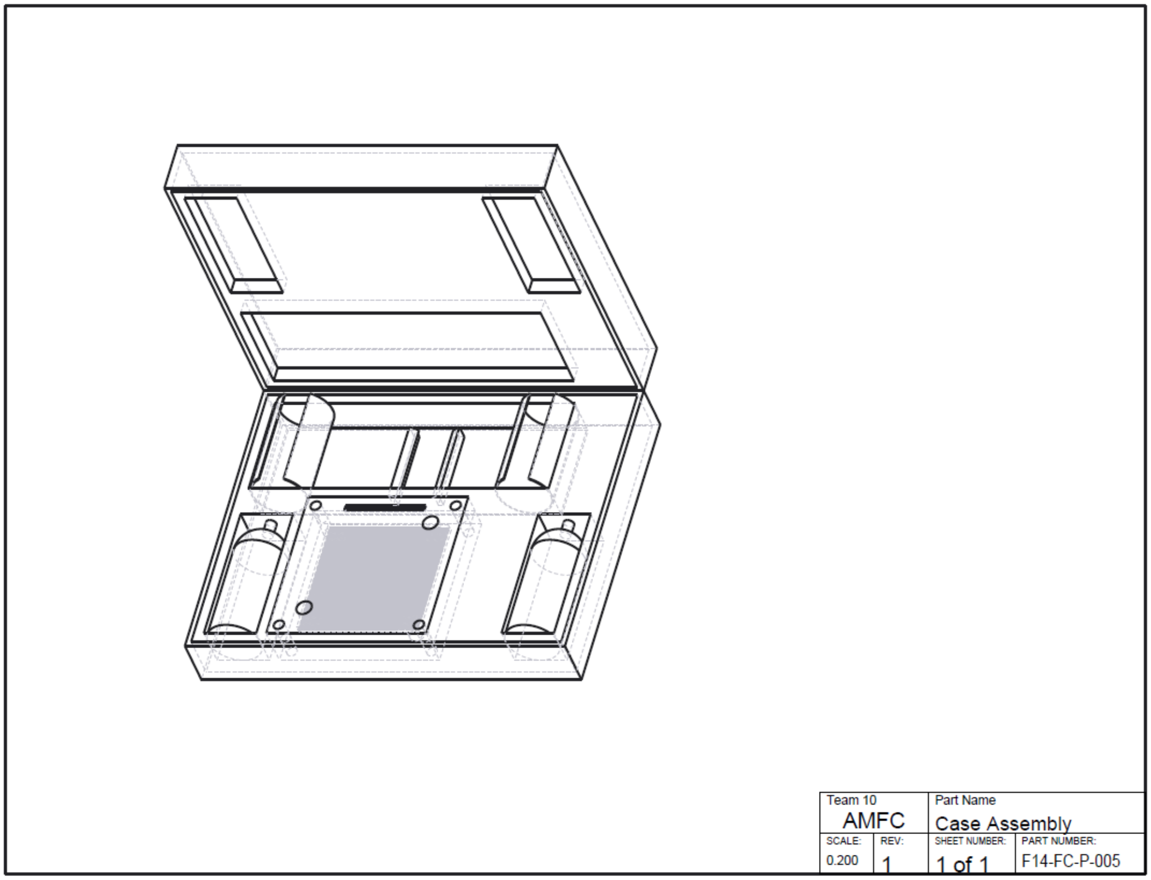
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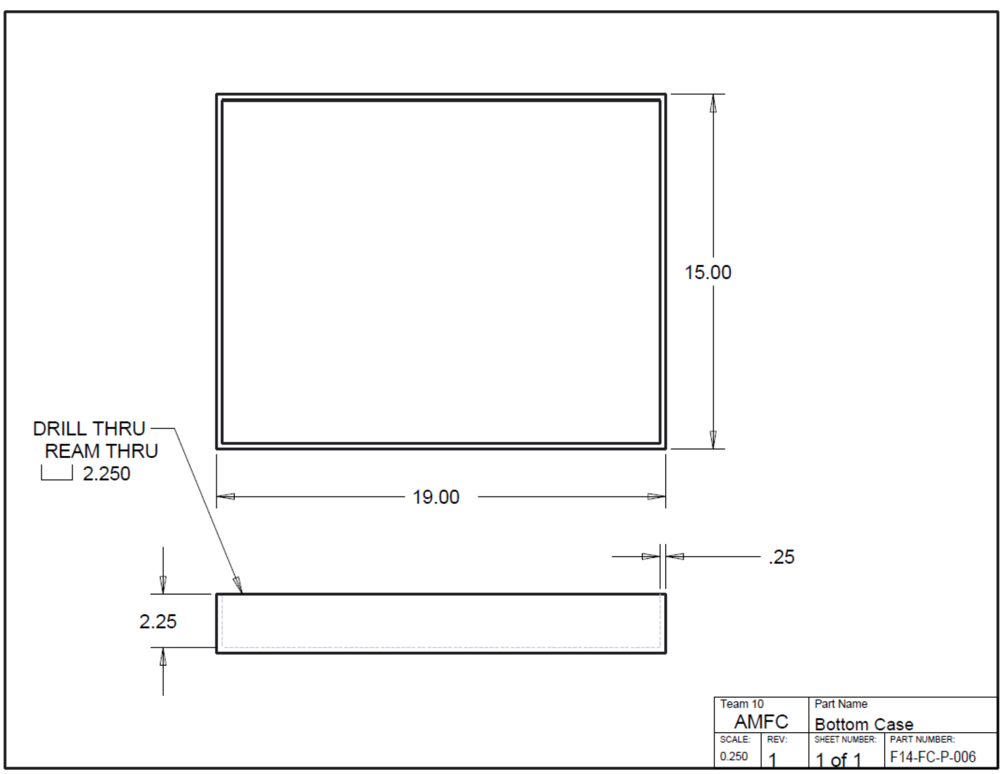
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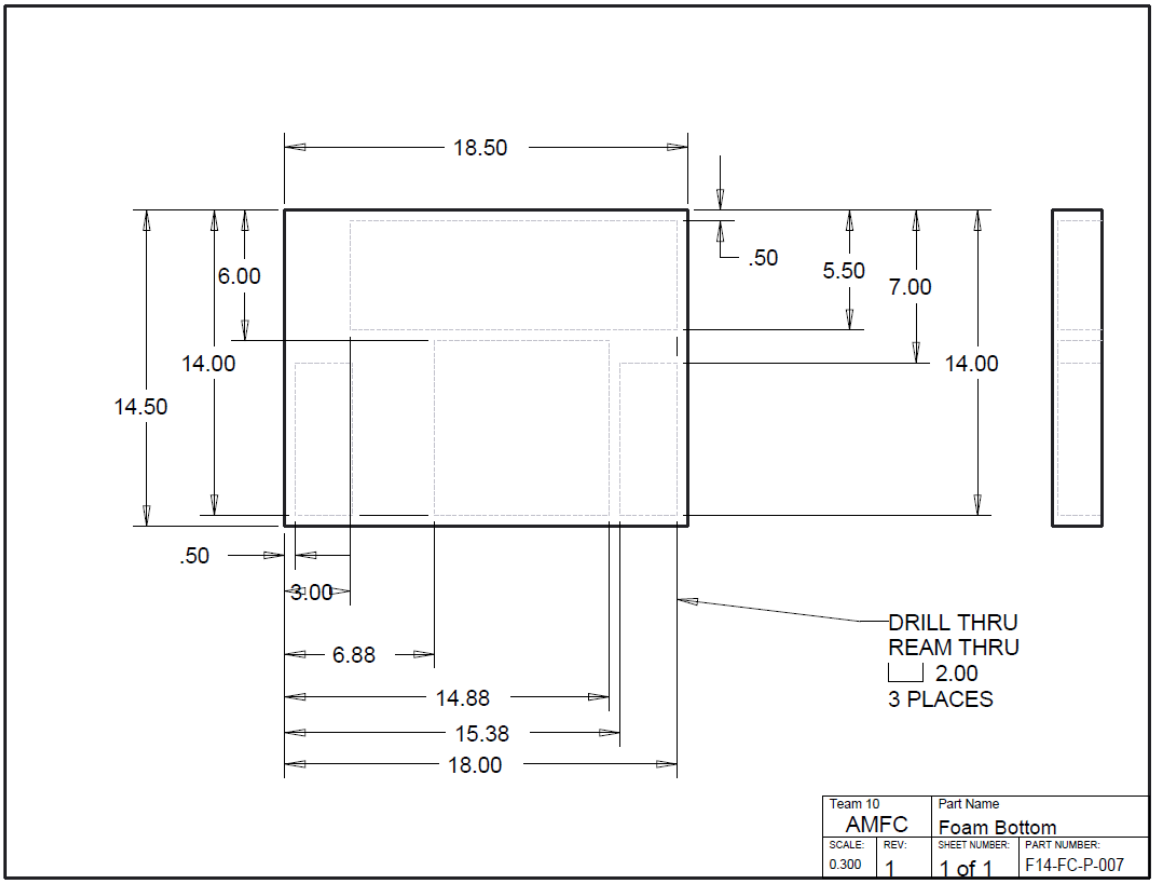
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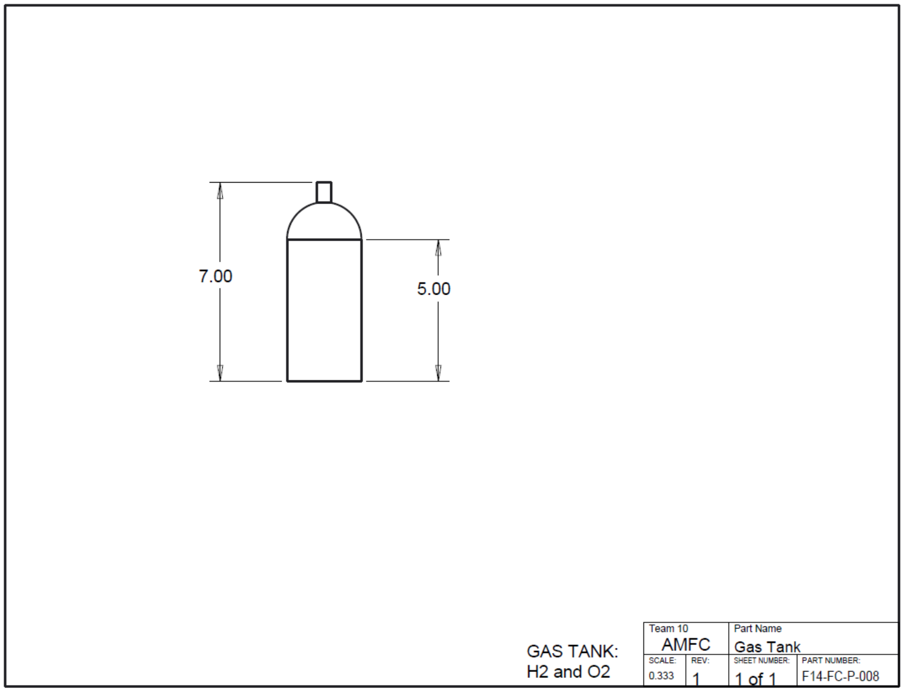
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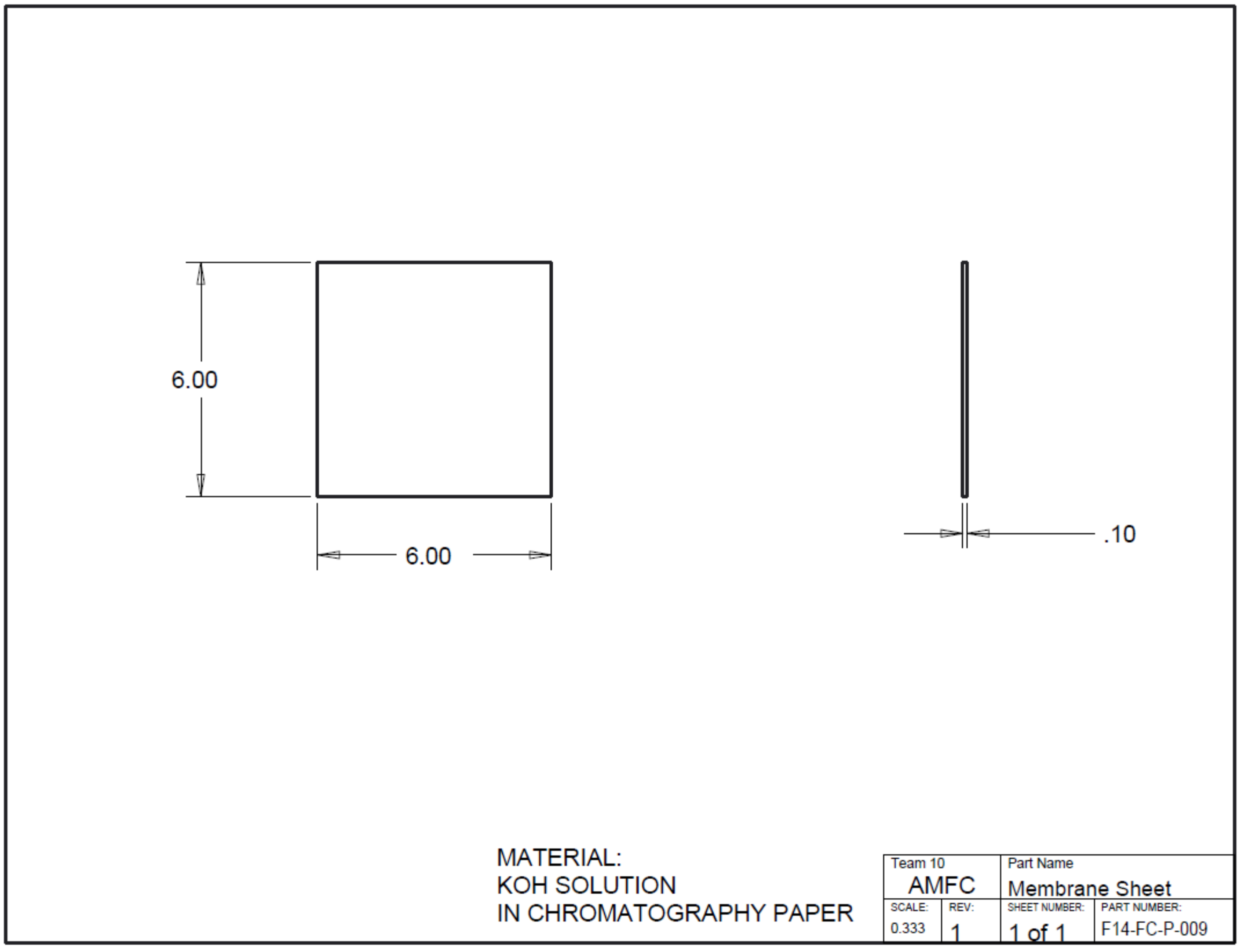
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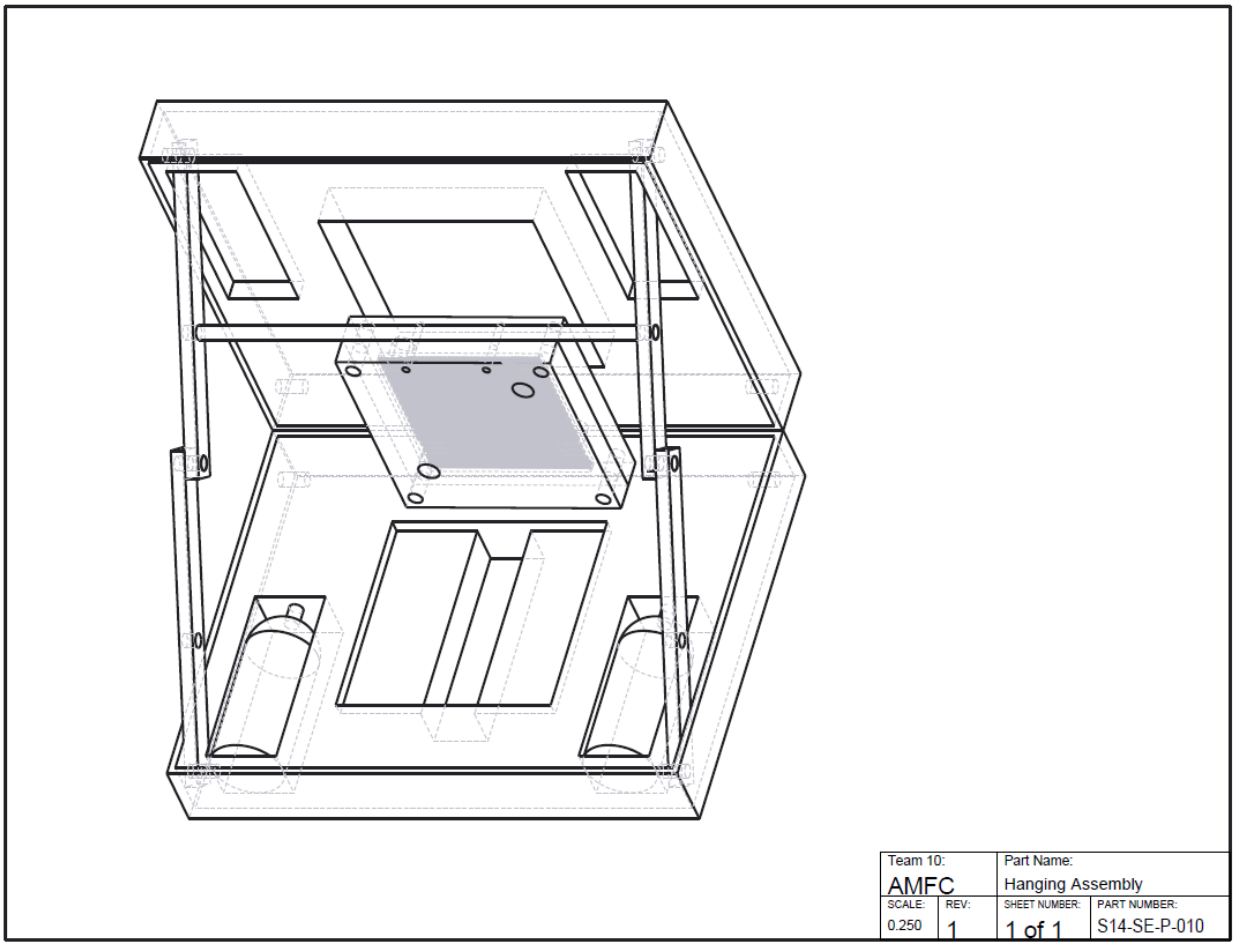

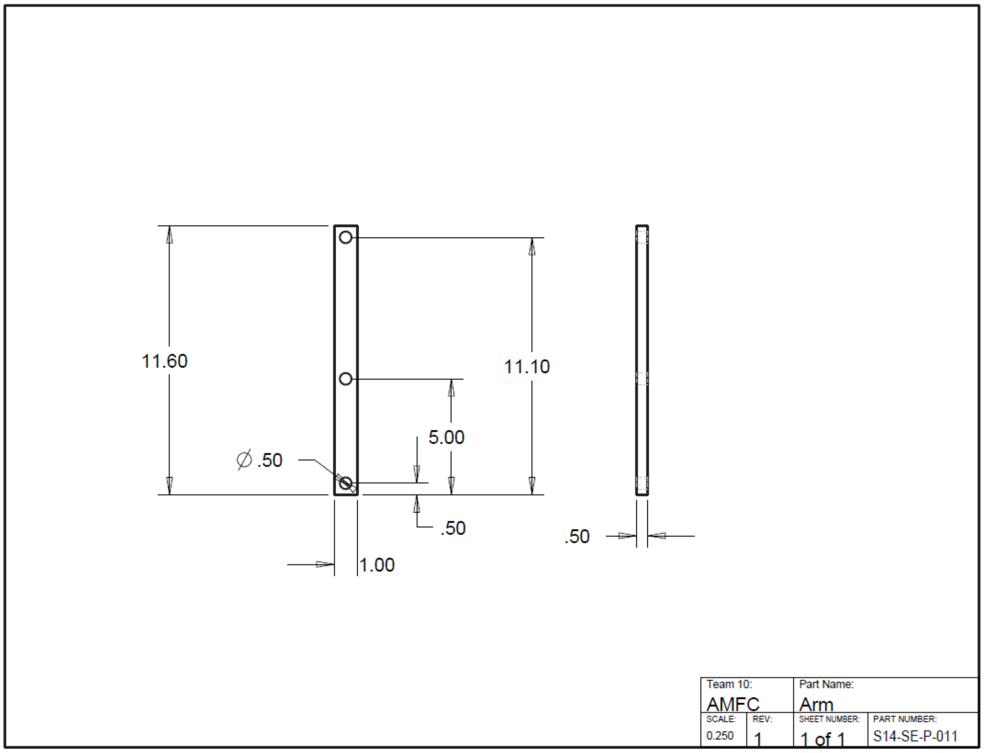
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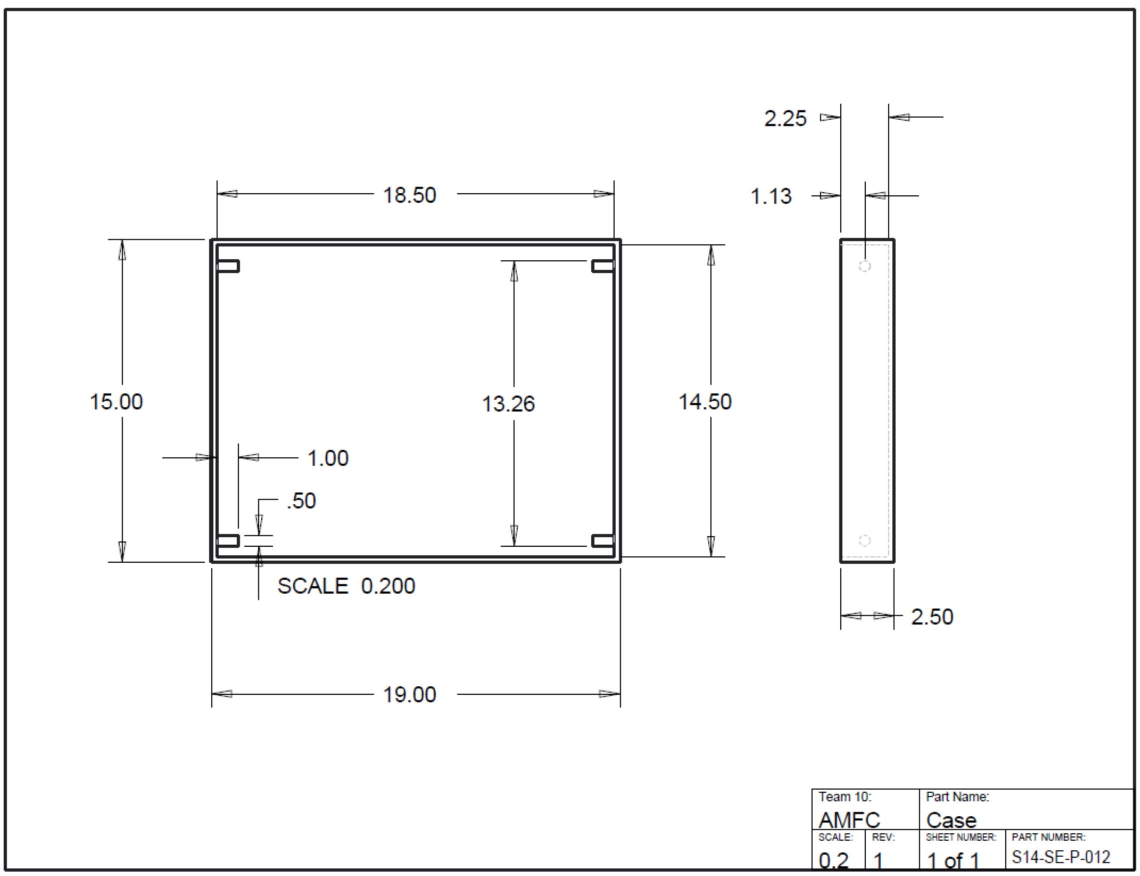
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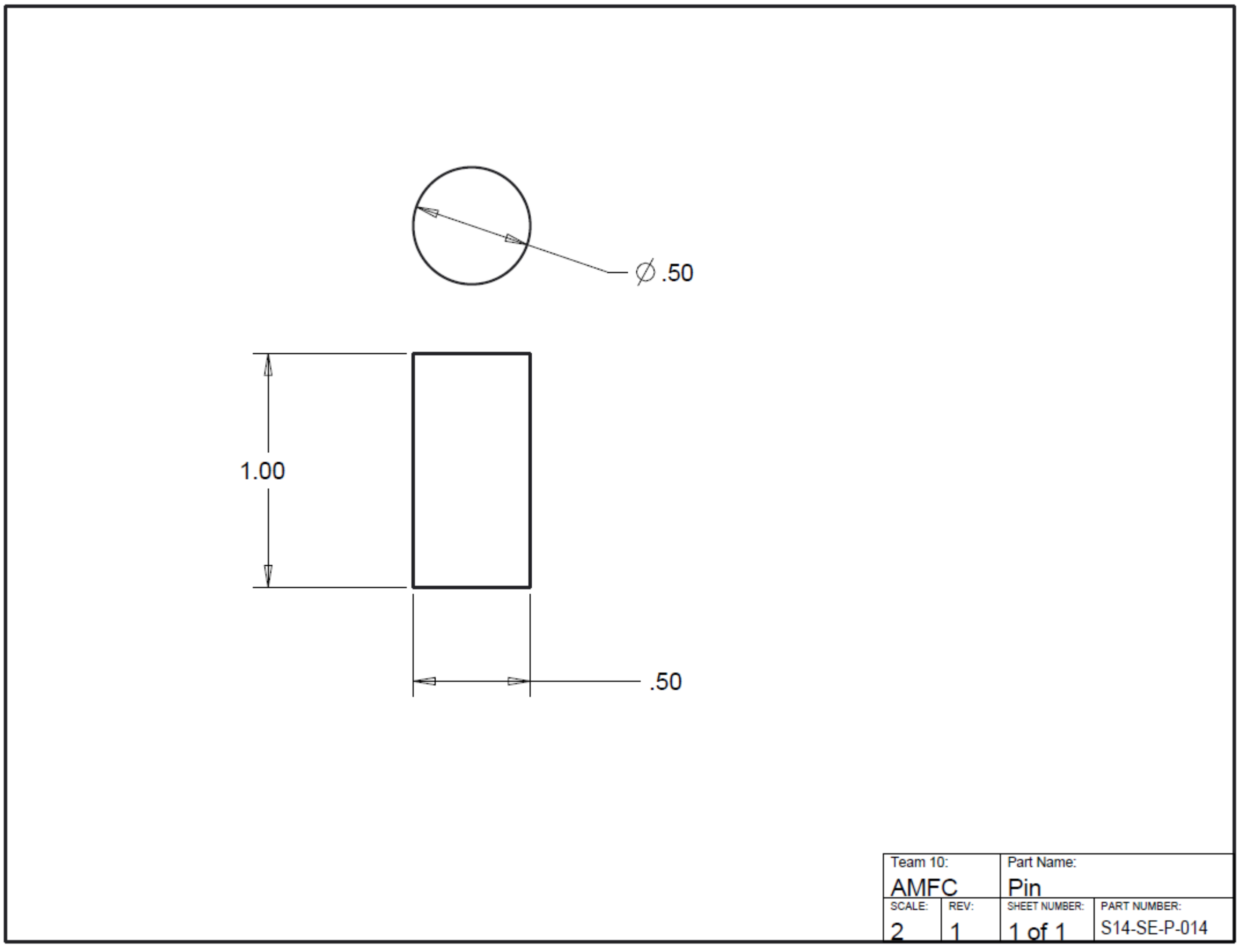

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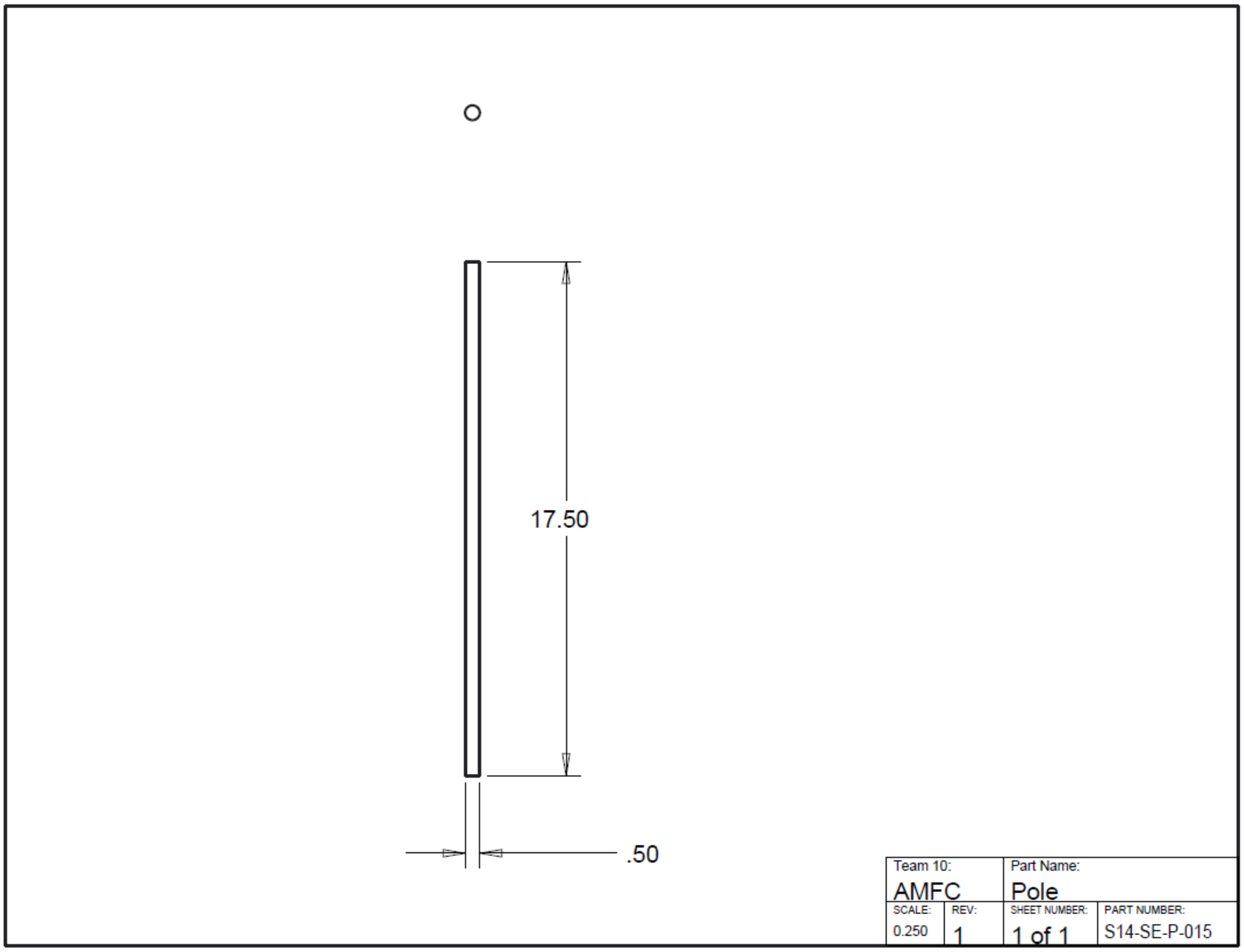
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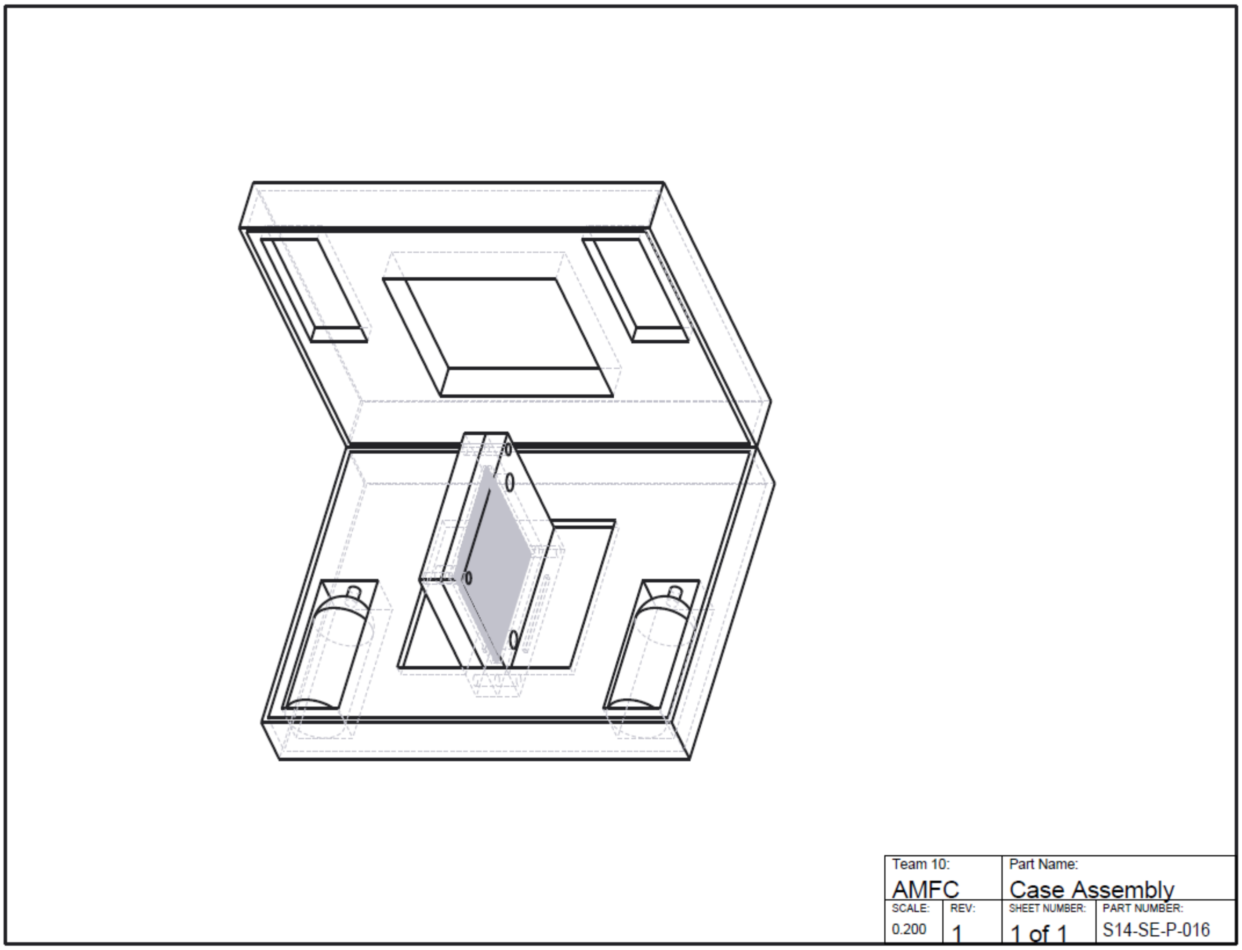
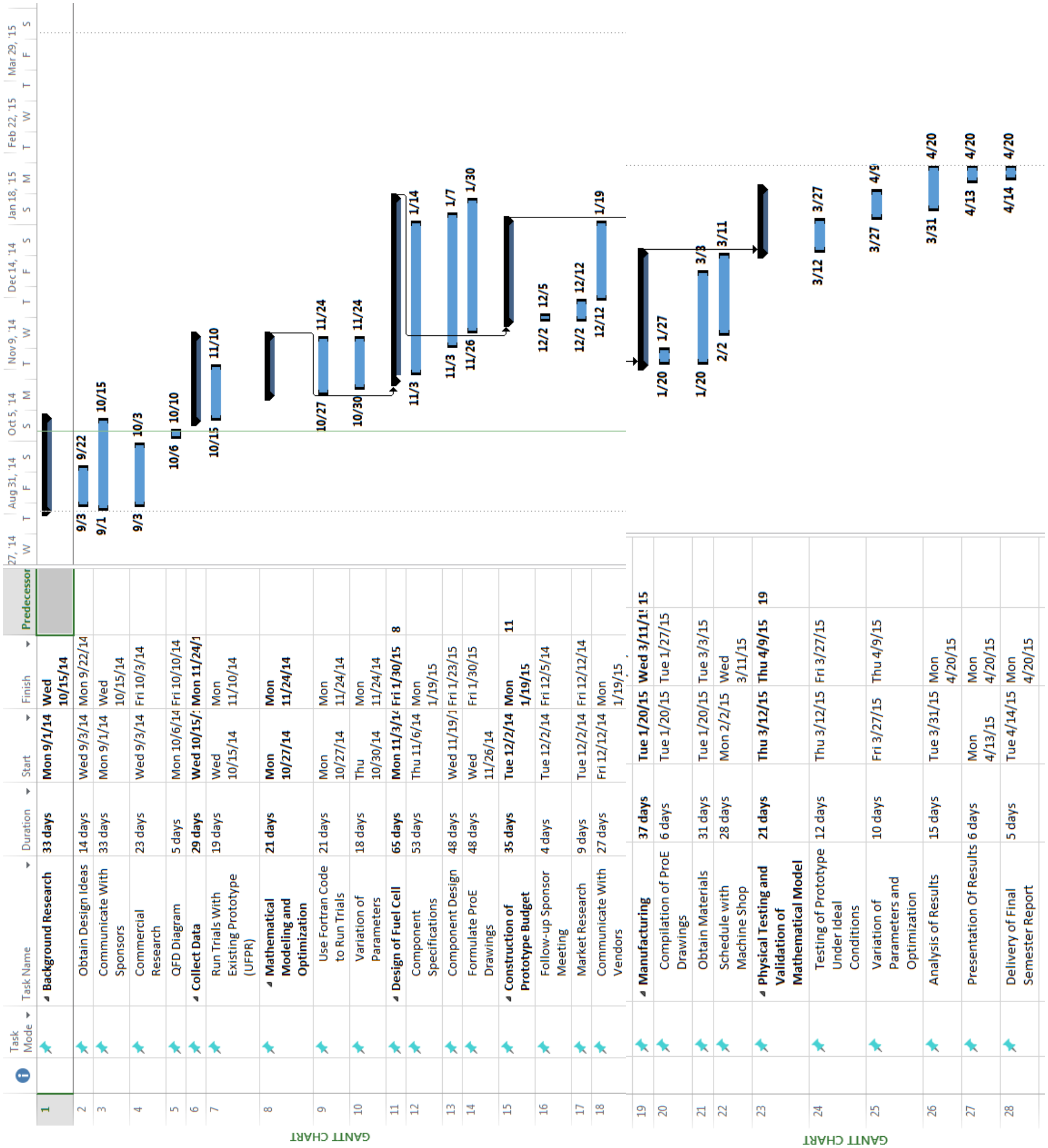
S14-SE-P-015

C. Mounted in Case Design



D. Gant Chart



GANTT CHART
Task Mode | Task Name | Duration | Start | Finish | Predecessors
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 | 8
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 | 35 days | Tue 12/2/14 | Mon 1/19/15 | 11
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 | 27 days | Fri 12/12/14 | Mon 1/19/15
19 Manufacturing | 37 days | Tue 1/20/15 | Wed 3/11/15 | 15
20 Compilation of ProE Drawings | 6 days | Tue 1/20/15 | Tue 1/27/15
21 Obtain Materials | 31 days | Tue 1/20/15 | Tue 3/3/15
22 Schedule with Machine Shop | 28 days | Mon 2/2/15 | Wed 3/11/15
23 Physical Testing and Validation of Mathematical Model | 21 days | Thu 3/12/15 | Thu 4/9/15 | 19
24 Testing of Prototype Under Ideal Conditions | 12 days | Thu 3/12/15 | Fri 3/27/15
25 Variation of Parameters and Optimization | 10 days | Fri 3/27/15 | Thu 4/9/15
26 Analysis of Results | 15 days | Tue 3/31/15 | Mon 4/20/15
27 Presentation Of Results | 6 days | Mon 4/13/15 | Mon 4/20/15
28 Delivery of Final Semester Report | 5 days | Tue 4/14/15 | Mon 4/20/15
Aug 31, '14 | Oct 5, '14 | Nov 9, '14 | Dec 14, '14 | Jan 18, '15 | Feb 22, '15 | Mar 29, '15
9/3 9/22
9/1 10/15
9/3 10/3
10/6 10/10
10/15 11/10
10/27 11/24
10/30 11/24
11/3 1/14
11/3 1/7
11/26 1/30
12/2 12/5
12/2 12/12
12/12 1/19
1/20 1/27
1/20 3/3
2/2 3/11
3/12 3/27
3/27 4/9
3/31 4/20
4/13 4/20
4/14 4/20