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Sunday, July 30th, 2023

To Maria Barichello and Dave Harris
Instructors of GENE 101
Faculty of Engineering
University of Waterloo
Waterloo, ON, N2L 3G1

Dear Maria, and Dave,

This report, “Fuel Cell Project Milestone #4: *Final Report*” has been prepared for the fuel cell project in the GENE 101 course. The purpose of this report is to summarize all that the team has learned so far by participating in this project.

This report brings the reader through each aspect of the design and creation of the fuel cell boat. Each team member has deepened their understanding of the fuel cell through trial and error while navigating the hardships of teamwork. The content and feedback from the previous reports were taken into consideration to effectively communicate the journey of the fuel cell project.

Team Two is composed of Daniel Khataiepour and George Chen, Electrical Engineers at the University of Waterloo.

Sincerely,

George Chen

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FUEL CELL PROJECT MILESTONE #4: ***Final Report***

GENE 101

Team 2

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EXECUTIVE SUMMARY

We are group #2, and we need a way to escape from a deserted island as soon as possible with no external communication. We chose to make a Hydrogen Fuel Cell powered boat that will transport us safely to the mainland. The Fuel Cell is an effective source of power for our boat because it runs on water. With limited time and resources, we must design a lightweight boat that is able to hold two of us with room for resources such as food and water. This boat is made of wood and will accommodate four people comfortably for an extended period of time.

We are using a Gantt chart to keep us organized and working efficiently (see Appendix C). We have successfully conducted research in order to proceed with the preliminary prototyping stages, then finally follow through and execute a final decision. We have also familiarized ourselves with the Fuel Cell in order to come up with effective solutions for propelling our boat. Completing these tasks allowed us to move on to the construction of our design as soon as possible. Using recycled and second-hand resources will help in maintaining a low cost as well as providing an eco-friendly solution to purchasing all new products. For this reason, we propose to spend less than $10 each on the boat, totalling $40 for the overall budget.

TABLE OF CONTENTS

INTRODUCTION

In our current situation, stranded on an island isolated from the world with limited resources, it has become evident that the only possible way to escape from the island is to use the resources available to us. Due to these conditions, we constructed a boat made of wood that could fit and transport all of us. Finally, we are presenting the design that is the most effective solution to our problem and will help us escape from the situation we are in right now.

PROJECT PLAN

In the beginning, each team member's goals for the boat were different. We had decided together that we wanted to make a fast and aesthetically pleasing boat, so the team would brainstorm multiple ideas and decide on the best one. A contract was agreed upon (*Appendix A*), making sure each person is participating equally in the team. To ensure we are making use of everyone's strengths, we created a group resume (*Appendix B*) depicting the team's skills. We planned on keeping ourselves on track using the Gantt Chart organization method (*Appendix C*). The plan consisted of four main portions; Research, Design, Construction, and Deliverables. For the construction of the boat, we planned on using mostly the resources available to us, trying to eliminate the need for buying any extraneous items.

MAIN DESIGN CONSIDERATIONS

1. *Buoyancy:*

When submerged, buoyancy is the upward force exerted by a fluid on an item [2]. This fluid may be a liquid or a gas. Anything that can float in water and is submerged in water is buoyant. The buoyancy of an object is determined by two unique components. The amount of water displaced by the object and its density.

According to real-life instances, if we toss a rock into the water, it will sink beneath the surface. However, if we throw a soccer ball into the water, it will partially stay on the surface and will float rather than sink. When these two things are tossed into the water, the results are mostly determined by the density of the object. Density is a measure of how heavy a thing is about its size. The density of an object is determined by dividing its mass by its volume. If an object is denser than water, it will sink in water; if the object is less dense than water, it will float. The soccer ball can float because its density is less than that of water. As a result, because the rock is denser than water, it sinks.

If an object's weight is equal to or less than the buoyant force exerted on it, the object will float. If the buoyant force is less than the weight of the thing, the object will sink. This is based on the Principle of Buoyancy, often known as the Archimedes Principle, which was developed in the third century BC by a Greek mathematician [3]. The buoyant force acting on an object absorbed in or floating on a fluid is equal to the weight of the fluid displaced by water, according to the principle. To put it another way, if the object displaces an amount of water equal to its weight, the buoyant force acting on it equals the force of gravity, causing the object to float. If the object weighs more than the amount of water it displaces, it will sink.

The biggest problem that Group Two may have with buoyancy is building a boat that is less dense than the water on which it is floating. When creating the boat, we must consider its weight and volume, which are density components. The volume of water displaces grows as the volume of the boat increases. The buoyant force increases as the volume increases, causing the boat to float. If the weight of the boat displaces an amount of water equal to its weight, the buoyant force acting on the boat equals gravity, causing the boat to float. If the boat is heavier than the water it displaces, the buoyant force acting on it will be less than gravity, causing it to sink. According to the rationale provided above, Group Two must construct a boat that is both vast in volume and light in weight. Making such a boat will offer us the best possibility of it floating on water.

2. *Shape of Haul:*

The shape of a boat's hull is another important aspect of how it floats on water. A hull is the part of a boat that rides in and on top of the water. Hulls are meant to keep boats steady on the water by displacing water or riding on top of it, a process known as planing. A boat hull can take on a variety of shapes depending on the condition of the water in which it is floating. Boats are utilized in either harsh or calm water.

Boats with flat-bottomed hulls are the most stable in calm water [1]. This design, however, becomes less stable in rough water, as the wind and swiftly moving water cause the boat to tip over or change course. For rough water sailing, the displacement hull, commonly known as the deep vee hull, is the ideal option. It is more stable in rough water than any other hull shape [5]. Over many decades of ocean travel, displacement hulls have shown to be one of the best hull shapes, being used in slow-moving boats, sailing boats, and huge vessels such as cruise liners and cargo ships.

As a result, it is the most common hull design for sailboats and canoes. Unfortunately, the most significant disadvantage of displacement hulls is their lack of stability in calm water. This is because displacement hulls ride at an angle in the water, with the bow up and the stern low. The boat has a huge frontal surface area to deal with wind and water resistance. Because each hull has advantages and disadvantages depending on the water's condition, the Group Two design team must determine which hull to develop for the boat. If the water on which the boat will be floating is calm, the optimal hull design for good stability should be a flat-bottomed hull. If the water is rough, Group Two must build a displacement hull to ensure the boat's balance.

3. *Material:*

Finally, the material from which the boat will be constructed must be considered. It is better to build a boat out of a material that is inexpensive, widely available, and water resistant. We believe that cardboard would be the ideal material to use in the construction of our boat. Cardboard is a significantly thicker paper-based substance than regular paper. The extra thickness of cardboard makes it more substantial, and it is utilized for packaging and protecting items of many kinds.

Another reason cardboard would be an excellent material is that it is light in weight and less dense than water, allowing it to float more easily. Although cardboard is inexpensive and widely available, it is not water resistant. The biggest disadvantage of this material is that it is not waterproof. When cardboard is submerged in water for an extended period, it becomes soggy and disintegrates. This is a concern because we require long-lasting, waterproof material. If cardboard becomes wet, its mass increases, making it impossible for the material to float on water. To remedy this problem, we can coat the cardboard with either duck tape or transparent acrylic paint to make it more water resistant.

Although it will not be completely waterproof, wrapping the material in duck tape or acrylic paint will make it much more resilient in water and will allow it to endure water for a longer period.

NEEDS ASSESSMENT

It has been two months now since our plane crashed, leaving us stranded on this island with limited resources and food provisions. There is no radio connection nor any sightings of rescue planes or boats, leading to the assumption that we are either in an uncharted region or that our location before the crash wasn't tracked by air support. With no current possibilities of incoming exterior aid, rationing our food and creating an effective water supply is crucial for survival. However, despite our efforts, the supplies found in the abandoned village and foraged plants from the nearby jungle are depleting and won't last us another month. Furthermore, the majority of the vegetation is poisonous with no discovery of animal life. Additionally, the inhabitants of the island appear to be hostile towards foreign visitors, with several close encounters resulting in one of our group members being injured. The hostile people seem to be at bay for now, although it is not long before they find us again, and we fear it will cost more than a few measly lacerations. One thing is for sure, we need to leave this island as fast as possible.

PROBLEM FORMULATION

PROBLEM STATEMENT

Considering the possible dangers of remaining on the island for an extended period, the best decision for our well-being is to construct a boat and escape the island. With no external communication available, we must implement our engineering knowledge to assemble a functional and secure vessel for our getaway using only our current supplies and provisions.

FUNCTIONAL DESCRIPTION

Our ship must sustain the weight of the fuel cell, as well as four people (an estimated 340 kg), while also maintaining buoyancy and a reasonable speed during operation. Furthermore, the durability should withstand most natural obstructions including wind and minor ripples or waves in the water's surface. Although previously we mentioned including a sail attachment, we quickly disregarded this idea because it reduces the aerodynamics of the boat and will hinder our movement through the water.

OBJECTIVES

The boat must first take us to a place with a civilization so that we may contact our home nation for assistance from the government. For the duration of the voyage, the ship must be watertight and able to sustain buoyancy with little interference from the environment. The boat needs to be carefully planned to assure that it will be water-resistant and sturdy against the weather to accomplish this. We decided on wood since it is waterproof, lightweight, and would provide the required durability for our ship. It will be a test of our technical prowess to see if our ship can return to the mainland before its resources run out by maintaining 8 km/h or more for around 15 days. We have a limited amount of time before malnutrition or dehydration since the supplies we took into the ship will inevitably be used up or start to deteriorate. The boat must move quickly and be sturdy to ensure our survival and prevent these catastrophes from happening. Because there is no way to gauge the vessel's tolerance, the design and construction phases must be extremely precise.

CONSTRAINTS

Due to the limited access to resources on the island, manufacturing costs must not exceed $40. Also, the ship must fit four people with room for additional resources, the fuel cell, and a reservoir for distilled water. Furthermore, the total weight must be under 2 lbs to provide appropriate buoyancy for the vessel. Additionally, the volume must be under 2 m^2 of solid material (excluding open space) to remain buoyant. Lastly, the mass must be limited to 3 kg.

During our weigh-in on Demo Day, our approximate weight was about 500 grams, staying within the constraints for mass and weight. Our calculations shown in Report 2 were extremely flawed as our determined weight was 2.5 kg, differing greatly from the measured value. This was likely due to utilizing the incorrect density of wood and therefore affecting the entire calculation for volume and mass. The cost was almost exactly satisfied, with the actual total cost being approximately $40.84, exceeding the budget by a mere 84¢.

CONCEPTUAL DESIGNS

DESIGN #1

For our first design, we chose a boat with a flat bottom, plenty of interior room, and a triangular front (see *Appendix D.1 Figure 2*). A flat-bottomed haul provides the finest stability on calm water, making moving much safer and manageable. Flat-bottomed hauls are intended to float on the water and move very little while sailing. The triangular front is a useful feature that improves the boat's agility in turning left and right without slowing it down. Finally, we chose to build a boat that is wide and spacious on the interior, allowing it to be less dense than the water it is sailing on. Creating a boat with a low mass and a huge volume would result in a lower density, allowing it to float on the water.

One issue that the team may face with this design is stability in rough water. Because this boat has a flat-bottom haul, it will be tough for it to maintain stability because it lacks features that will assist it in cutting through the water when sailing. Another significant challenge that this boat design will encounter is the storage of the battery fuel cell engine. There is no container or shield on this boat to protect the battery from water. Because this boat design has a limited freeboard, water can readily enter the ship if it is in stormy seas, causing the boat to become heavier in weight and sink.

DESIGN #2

For our second design, we opted to build a boat similar to the first, with a flat-bottomed haul and the best stability in calm water (see *Appendix D.2 Figure 3*). This design differs from the preceding one in that it has a narrow width in the front but a wide width in the back, forming a v-like shape. The boat's front has a triangular shape with a 45-degree inward dent added for agility support in choppy surface water. The shield/cap that protects the battery fuel cell from water and other damage distinguishes this boat from other designs. This will keep the battery fuel cell in a stable and secure position throughout the sail. The battery fuel cell will be positioned in a position that will provide balance on the water, preventing the boat from flipping over. Placing the battery in the middle of the boat will provide the best balance, enhancing the boat's buoyancy.

The stability of this design in choppy seas will be an issue. Despite being more stable than design number one, owing to its shape and front, this boat may suffer in choppy surface water due to its flat-bottomed haul. This boat will also have a higher density than the first design due to the additional weight of the shield installed on top of the boat.

DESIGN #3

The third design is based on a pontoon-style boat (*Appendix D.3 Figure 4*). The pontoon style could be favourable because it does not displace a large amount of water, therefore can be very buoyant and support more mass. Water bottles act as the pontoons of the boat and a shallow flat container can be used to support the fuel cell and all the components. The water bottles would also act as stabilizers for the boat that way the design is adaptable for rough and calm waters without tipping over. The final key component of this design is a 3-D printed propeller. 3-D printed plastic can be strong as well as lightweight which will be highly effective to propel the boat.

Difficulties could arise if the motor is not placed perfectly in the center or if there is an uneven weight distribution. This would cause the boat to veer to one side, perhaps going in circles. For this reason, much attention needs to be paid to how the motor and fuel cells are installed

CHOSEN SOLUTION

We chose design number two after thoroughly assessing all three boat designs due to various compelling features (see *Appendix E* for picture). One key feature that distinguished this boat from the others was the possibility to extensively test it. We spent the majority of our time and effort during the design phase refining and improving this model. Furthermore, the materials used in design number two proved to be extremely convenient and cost-effective, as they were easily accessible and economical. We put the boat to the test on the water on the much-anticipated demo day, and it exceeded our expectations. The boat floated and functioned wonderfully thanks to the fuel cell batteries, reinforcing our trust in the choice.

BUOYANCY CALCULATION

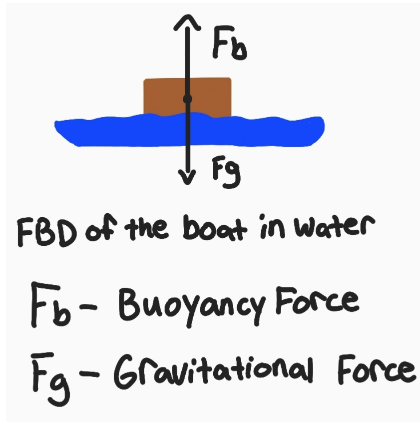


Figure 0: Free Body Diagram Depicting the Forces Acting On a Floating Vessel

Assume no air resistance or disturbances from the waves of the water. Then the only two forces acting on the boat will be the buoyancy and gravitational forces. According to Archimedes's principle, the buoyancy force of an object is equal to the water that it displaces [4]. The scenario set for the calculations is that the boat is completely submerged in water. Meaning the volume of displaced water will be equal to the volume of the boat, a quantity found from Report 2 to be approximately 1.66 cubic meters. With the specific weight of water known, the buoyancy force being exerted on the ship could then be found. Furthermore, the buoyancy force of an object will be constant regardless of its current depth. Meaning the buoyancy force of a completely submerged object will be equal to the buoyancy force when it is just floating on top of the water [39]. Therefore, this scenario is correct and the method to determine the force is valid. In calculating the buoyancy force of the boat, it was found that it can easily float with zero difficulties. The gravitational force acting on the boat in the water was determined to be approximately 24.37 newtons, while the buoyancy force was 16243.58 newtons, much larger than Fg. Because this is true, our boat will therefore float according to Archimedes's principle.

However, this calculation is severely inaccurate for many reasons. First, the computations involved in finding the volume of the boat were very flawed and greatly differed from the actual measurement found on Demo Day. Also, the material of the boat was not taken into account as incorporating this aspect involves physics beyond our scope. By using a flutterboard as our base, our boat was almost certain to float due to the physical properties of the material used in the board, which was styrofoam. With its large volume and minuscule mass, the buoyancy force acting upon the board would be significant. Furthermore, this object was created for the sole purpose of being a flotation device. And with prior experience using a flutterboard, any individual will be able to recognize how it can support the weight several times its mass. But within our capabilities, we managed to correctly determine the buoyancy of our vessel using relevant physics properties, despite having inaccuracies in our calculations.

VOLTAGE AND CURRENT MEASUREMENTS

In analyzing our results from the experiment and comparing it with other teams, our measurements significantly varied despite following the appropriate steps. Furthermore, with guidance from the lab TA, we are led to assume that our fuel cell is either functioning at a lower efficiency or is faulty from prior mistreatment and aging. To investigate this issue, our team is conducting a second experiment with another external fuel cell.

As seen in *Figures 7 & 9* (see *Appendix G*), our new measurements yield significantly greater results, clearly displaying the inadequacy of our old fuel cell. For voltage, the lowest value of the new fuel cell was higher than the highest in our old fuel cell. In comparing the current, our new fuel cell exhibited far greater efficiency than the old, thus proving our previous claim of possessing a faulty fuel cell to be true.

FUEL CELL CHEMISTRY QUESTIONS

1. WHAT DID OUR TEAM DO TO WORK SAFELY WITH THE FUEL CELL?

Our team remained proactive when it came time to use the fuel cell. We would ensure that we had paper towels on hand so that we could clean up any spills as soon as possible to avoid any incidents related to slipping or electrical shock. We ensured that when we were working that we kept our workstations clear to avoid any confusion or error caused by clutter. We also made sure our bags remained tucked away to avoid incidents of tripping or other injury. Due to the combustibility of hydrogen gas, we did not have any open flame nor did any of us smoke while working the fuel cell, just to be safe.

2. HOW MUCH GAS (IN MOLES) IS IN EACH OF THE GAS STORAGE CYLINDERS IF YOU RUN THE ELECTROLYSIS PROCESS UNTIL THE HYDROGEN GAS (H_2) JUST STARTS TO BUBBLE?

The amount of gas in moles produced by the fuel cell is approximately $3.862E^{-4}\ mols\ O_2$ and $7.724E^{-4}\ mols\ H_2$. This was calculated by measuring the current temperature and pressure, as well as the volume of the gas bell in the storage cylinders (see *Appendix H.1* for calculations).

3. HOW MUCH O_2 AND H_2 IS LOST BY STORING THE GAS IN CONTACT WITH THE WATER?

By calculating the pressure, and researching the Henry's law constants of the gasses, we can apply Henry's law $C_i = k_i P_i$ to determine the concentration (in $\frac{mols\ solute}{kg\ solvent}$). The concentration is then used to calculate The percentage (by mass) present of each gas that has dissolved into the water. We have determined that 12.9% of O_2, and 3.9% of H_2 by mass is lost by storing the gasses in contact with water (see *Appendix H.2* for calculations).

4a. CALCULATE THEORETICAL VOLTAGE (V) ASSUMING STANDARD CONDITIONS

The theoretical Voltage of the fuel cell is $1.229\ Volts$ (see *Appendix H.3* for calculations).

4b. CALCULATE THEORETICAL CURRENT (I)

The theoretical Current of the fuel cell is $0.310\ Amps$ (see *Appendix H.3* for calculations).

4c. ESTIMATE THE EFFICIENCY OF THE FUEL CELL

Using the data measured in the WEEF Lab (*Appendix G*), as well as the equations to calculate power ($P = IV$), we are able to compare the actual and theoretical powers of the fuel cell. The calculated efficiency of our fuel cell is approximately 44.2% (see *Appendix H.3* for calculations). The values calculated are consistent with the measured values from the lab, so we know that they are somewhat realistic. The measured current was found to be smaller than the calculated current, which affected the overall power of the fuel cell.

TYPES OF FUEL CELLS

Fuel cells generate electricity cleanly and efficiently by utilizing the chemical energy of hydrogen and other fuels. If hydrogen is regarded as the fuel, the byproducts are water, electricity, and heat. Fuel cells have the potential to be used in a wide range of applications, such as providing electricity for systems as large as utility power plants and as small as laptop computers [34]. Fuel cells function similarly to batteries, except they do not require charging. Fuel cells produce power and heat as long as fuels such as hydrogen are available and equipped. Fuel cells are made up of two electrodes, negative and positive, that are compressed around an electrolyte. The negative electrodes receive fuel, such as hydrogen, while the positive electrodes receive air. The negative electrodes break down hydrogen molecules into protons and electrons, which subsequently flow to the positive electrodes [35]. The electrons generate an electric current, whereas the protons move through the electrolyte via the positive electrodes, where they combine with oxygen and electrons to produce heat and water [34]. The type of electrolyte used in fuel cells is the primary constraint. This condition governs the sort of electrochemical processes that occur in the cell, the type of catalysts required, the temperature range at which the cell functions, and a variety of other aspects. These factors influence the operation to which these cells are best suited. Although there are various types of fuel cells, they all work in the same general way. It's worth noting that fuel cell technology is still in its early stages of development, and other types of fuel cells may arise in the future. In this paper, we will discuss the most regularly utilized fuel cells in society. Proton Exchange Membrane fuel cells, Solid Oxide fuel cells, and Phosphoric Acid fuel cells are examples of these fuel cells [36].

Proton Exchange Membrane (PEM) fuel cells are lighter and smaller than other fuel cells while yet giving excellent power densities. PEM fuel cells use a solid polymer as an electrolyte and use porous carbon electrodes with platinum or platinum alloy catalysts [35]. They only need water, airborne oxygen, and hydrogen to function. They are typically powered by pure hydrogen fuel from reformers or storage tanks. PEM fuel cells operate at relatively low temperatures ranging from 60°C to 100°C. When running at low temperatures, they can start faster (with less warm-up time) and have less system component wear and tear, increasing their durability. It does, however, raise the system's cost because a noble-metal catalyst, platinum, is required to separate the electrons and protons in the hydrogen. If the hydrogen is produced from a hydrocarbon fuel, an additional reactor will be required to remove carbon monoxide from the fuel gas, as the platinum catalyst is also extremely sensitive to carbon monoxide poisoning. This reactor increases costs as well. PEM fuel cells are commonly used in stationary and mobile applications. PEM fuel cells are appropriate for use in automobile applications such as light-duty trucks, buses, and automobiles.

In Solid Oxide Fuel Cells (SOFCs), the electrolyte is a dense, impermeable ceramic substance. The efficiency of these fuel cells in converting fuel to electricity is approximately 60%. Co-generation solutions, which capture and use waste heat from the system, may reach overall fuel consumption efficiencies of more than 85% [35]. These fuel cells typically run at temperatures ranging from 600°C to 1,000°C. High-temperature operation reduces expenses by eliminating the need for a precious-metal catalyst. Furthermore, it enables SOFCs to internally reform fuels, expanding the range of fuel sources and minimizing the cost of inserting a reformer into the system. SOFCs are the most sulfur-resistant fuel cell kind, with the ability to withstand significantly more sulfur than other cell types. This property allows for the use of biogas, natural gas, and coal-derived gases in SOFCs. The high-temperature operation has downsides. It slows beginning and requires a lot of thermal shielding to keep heat in and protect people, which is common for utilities but not for transportation. Furthermore, because of the high working temperatures, materials must meet stringent durability demands. The development of low-cost materials with good durability at cell operating temperatures is the major technological concern for this technology. Researchers are investigating the idea of developing less expensive, lower-temperature SOFCs that run at or below 700°C and have fewer durability difficulties [35]. However, because lower-temperature SOFCs have not yet equalled the performance of higher-temperature systems, materials that will work in this lower-temperature range must be stacked.

Phosphoric Acid fuel cells (PAFCs), use liquid phosphoric acid as an electrolyte; the acid is contained in a Teflon-bonded silicon carbide matrix and porous carbon electrodes with a platinum catalyst. The PAFC is considered the "first generation" of modern fuel cells. It was the first commercially used cell type and one of the most developed. However, some PAFCs have been used to power large vehicles such as city buses. This type of fuel cell is mostly utilized to generate stationary power. PAFCs are more forgiving of impurities in fossil fuels that have been converted into hydrogen than PEM cells, which are quickly "poisoned" by carbon monoxide because carbon monoxide binds to the platinum catalyst at the anode and decreases the fuel cell's efficiency. PAFCs are more than 85% efficient when used to create both heat and electricity, however, they are only 37%-42% efficient when producing simple electricity [35]. PAFCs are only slightly more efficient than combustion-based power plants, which typically operate at around 33% efficiency. PAFCs are also less powerful when compared to other fuel cells of the same weight and capacity. As a result, these fuel cells are frequently large and heavy. PAFCs are similarly expensive.

Fuel cells are a promising technology for converting energy in a clean and efficient manner. Proton Exchange Membrane fuel cells, Solid Oxide fuel cells, and Phosphoric Acid fuel cells are just a few of the several varieties of fuel cells, each with its own specialties and use [37]. The decision to use fuel cell technology is influenced by variables such as operating temperature, fuel availability, required power density, and economic concerns.

FUEL CELL SUSTAINABILITY AND ENVIRONMENTAL IMPACTS

Fuel cells are systems that utilize oxygen and hydrogen in a chemical reaction called reverse electrolysis to generate electricity, heat, and water [38]. During this process, hydrogen is supplied to the system, where a catalyst splits the hydrogen atoms into protons and electrons [39]. Protons pass through an external circuit to produce electricity, while the protons integrate with oxygen to create water and heat. This electrochemical reaction only demands hydrogen, a natural compound that doesn't create harmful pollutants. Although reverse electrolysis is harmless, other components of the fuel cell must be considered, including hydrogen and the acquisition of platinum, the primary catalyst employed in a fuel cell.

Platinum is scarce and is one of the most valuable materials found on Earth, due to the rigorous procedure involved in mining and refining the metal [41]. Consequently, there are many environmental consequences that arise from this process. Currently, popular methods to mine platinum are drilling holes that are then filled with explosives and blown up and processing nickel and copper ore [40]. Conventionally, when beginning to mine, the surrounding area must be excavated to prepare for the mining operation [41]. This includes destroying vegetation and constructing roads, and infrastructure including tunnels within mountains or other terrains, all while using machinery that emits carbon emissions. Also, "metal contamination increased in water and sediment downstream of mining activities", with macroinvertebrate families displaying signs of bioaccumulation [42]. Due to the environmental impacts of acquiring this metal, the platinum found within fuel cells is therefore not environmentally safe.

Ethical problems arise subsequently during the process of platinum mining. Since the soil in South Africa is rich in platinum, it has become one of the largest exporters of platinum for fuel cells. South Africa has had a bad history regarding forced and unfair labour laws [44]. Mining has led to village relocation, exploitation, and modern-day slavery, which can be deeply traumatizing for a person. Reducing the amount of platinum that is imported by sourcing material from local mines, could increase the sustainability of the fuel cell and emit fewer greenhouse gasses that are created by the need to transport the material over long distances, as well as eliminate unethical mining in South Africa.

CONCLUSION

After weeks of tireless efforts, collaboration and resourcefulness we are proud to present our final boat construction. Stranded on this isolated island with limited resources, we have revealed that our best chance of escape lies in using the materials at hand to build a vessel capable of carrying us safely.

Throughout this journey, our team's diversity and individual skills played a big role in the success of our boat's design and shaping. In the beginning, we had many different ideas and goals, but with good communication, our visions emerged as a fast and aesthetic boat that we all agreed on. A boat that could resist any challenges of the water. Our collaborative brainstorming sessions led us to the most effective solution, which is the design we are presenting today.

We had difficulties with our fuel cells during the testing of voltage and current. We thought it was human error and that we might have done something wrong with the fuel cells. After some external help and consulting, we were advised to try new fuel cells. We tried the new fuel cells and got better and more realistic numbers for voltage and current. We felt very excited and believed that we would be safe

In conclusion, to ensure fairness and inclusiveness, we made a team contract that held each member accountable for their responsibilities. Looking at this, it shows our group's collaboration and success. We are grateful for our final product that carries such significance for our survival. We are confident that our boat will help us escape from this isolated island, and return to the world that we left behind unexpectedly.

APPENDIX
Appendix A: Group Contract

We think that the best approach is to have multiple leaders in charge of separate tasks. We will all work together to be the leader to not make anyone feel left out. Each individual will be in charge of different aspects of the project like project planning, design, ensuring consistent formatting, etc. This way, one individual won't have to bear the responsibility of overseeing multiple components of the project, allowing for more productivity and organization.

If we have problems in our group or cannot come to a unanimous decision, we will decide by vote and the majority will rule. Although we may end up incorporating multiple ideas to develop a combination of these propositions. Beforehand, we would discuss all the possibilities presented by the group members, and determine which ones are the most relevant to our current situation and the most realistic to implement. From there, we will use the majority vote as the final deciding factor.

We will meet weekly on Thursdays at 2:30 after the GENE Lecture. We will stay in RCH 306 if there are no classes. If there are, we will relocate to the hallway or Dana Porter. If we find we need to meet more times in a week for any reason, Friday at 3:30 is a time that also works for the team.

We expect each team member to show up to the Thursday meetings unless you inform the team. Each team member is to carry the weight and complete the tasks given to them. We will aim to finish the work a couple of days before the due date so that we can collaborate on the final project. Each team member will have their ideas heard and will have their turn to speak. Only the Fuel Cell Project will be discussed and worked on during these times.

An absence must be reported to the team via iMessage group chat. Absences are acceptable and understood by all team members. The absent team member is expected to read the minutes of the missed meeting and complete their portion of the work despite the absence.

One of our main goals as a group is to make an effective boat that floats and moves somewhat fast. We would like to hand everything in on time and in an organized fashion while meeting all the given criteria. We would like to see a grade of 80% or more for this project while also exploring creative options within the scope of maintaining this grade.

We would like to have our milestone reports started as soon as we hand in the last one. This will allow us to spend as much time as possible on each report while also having time for design. We would also like to aim to have the reports done early if possible to relieve some stress, preferably one to two days in advance.

Team members are expected to regularly contribute to team meetings and provide insight with their knowledge on the topic. Furthermore, by following our allocated roles, every member will provide a diverse range of unique insights.

If a teammate fails to complete the tasks assigned to them, we would have a team meeting and discuss the team member's behaviours with the team. We will explain that each person must provide their portion of the work and success will only come when we operate as a collective. For situations where personal dilemmas occur, the team will discuss future steps to assist the member under consideration.

If this behaviour continues, we will have to get the professor involved to discuss changing individual marks reflected on participation. We will ask them to execute a 5%-10% grade deduction based on the severity of the infraction. In drastic instances, this deduction may be increased when consulting with the instructors and other group members.

Team Member Roles -

Daniel: Designer, Submitting Deliverables, Agenda, Researcher
George: Gantt Chart, Formatting, Researcher

By signing below, I state that I have;

a) participated in formulating the standards, roles, and procedures of this contract
b) agreed to abide by the terms and conditions of this contract

Daniel: George:

Appendix B: Group Resume

Team Two

Soft Skills

- Time Management
- Problem-Solving
- Leadership
- Communication
- Detail-Oriented

Experience

- Design Team - FIRST Robotics
- Design CO-OPs
- Soldering
- SolidWorks
- AutoCAD - Civil 3D

Team Two, are a group of passionate, young engineers determined to win the 2023 Waterloo Fuel Cell Boat Race. Each team member is a Student enrolled in First Year Engineering at the University of Waterloo. One-half of the team, George and Daniel are hard-working Electrical Engineers. The group thoroughly enjoys collaborating to share ideas and find innovative solutions to the boat design. Each member has prior experience using engineering design practices and software. Daniel and George have been employed at design co-op positions this past work term and are eager for more. Each member has included a statement about what they contribute to group work.

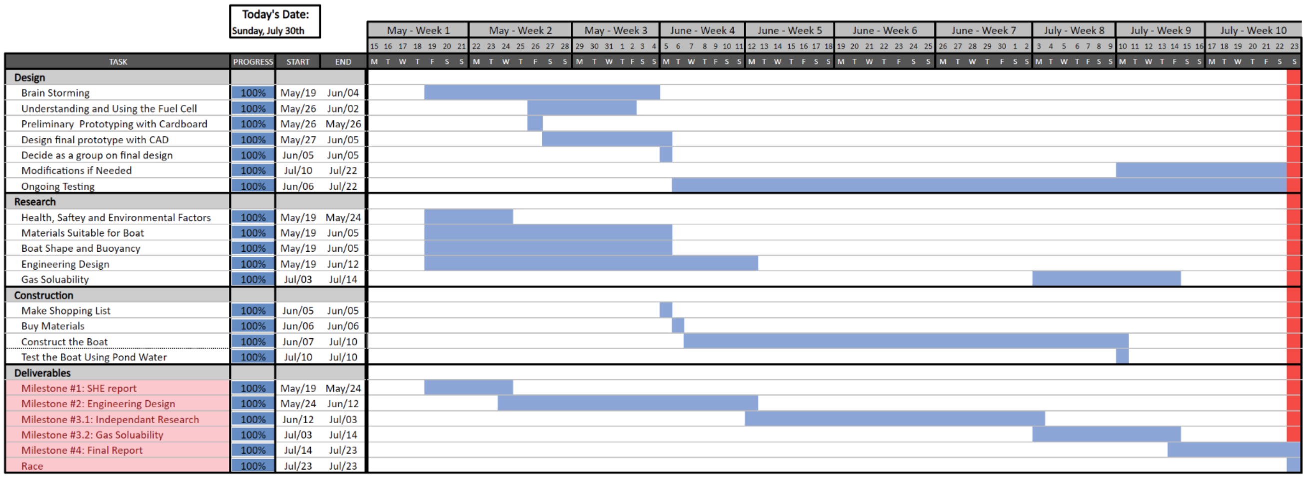
"Looking forward to completing the project with Group Two Engineers. A valuable group that brings a different set of skills and experiences to the table."

- **Daniel Khataiepour, 2023**

"The Fuel Cell is an intriguing project that I am eager to explore with the diverse capabilities of our group. I believe my knowledge of electric systems will aid in the optimization and efficiency of our creation."

- **George Chen, 2023**

Appendix C: Gantt Chart



TASK	PROGRESS	START	END
Design			
Brain Storming	100%	May/19	Jun/04
Understanding and Using the Fuel Cell	100%	May/26	Jun/02
Preliminary Prototyping with Cardboard	100%	May/26	May/26
Design final prototype with CAD	100%	May/27	Jun/05
Decide as a group on final design	100%	Jun/05	Jun/05
Modifications if Needed	100%	Jul/10	Jul/22
Ongoing Testing	100%	Jun/06	Jul/22
Research			
Health, Saftey and Environmental Factors	100%	May/19	May/24
Materials Suitable for Boat	100%	May/19	Jun/05
Boat Shape and Buoyancy	100%	May/19	Jun/05
Engineering Design	100%	May/19	Jun/12
Gas Soluability	100%	Jul/03	Jul/14
Construction			
Make Shopping List	100%	Jun/05	Jun/05
Buy Materials	100%	Jun/06	Jun/06
Construct the Boat	100%	Jun/07	Jul/10
Test the Boat Using Pond Water	100%	Jul/10	Jul/10
Deliverables			
Milestone #1: SHE report	100%	May/19	May/24
Milestone #2: Engineering Design	100%	May/24	Jun/12
Milestone #3.1: Independant Research	100%	Jun/12	Jul/03
Milestone #3.2: Gas Soluability	100%	Jul/03	Jul/14
Milestone #4: Final Report	100%	Jul/14	Jul/23
Race	100%	Jul/23	Jul/23

***Figure 1*: **Team Two's Project Plan Progress Depicted using the Gantt Chart Method (Fuel Cell Gantt Chart.xlsx)

Appendix D: Design Concepts

Appendix D.1: Design Concept 1

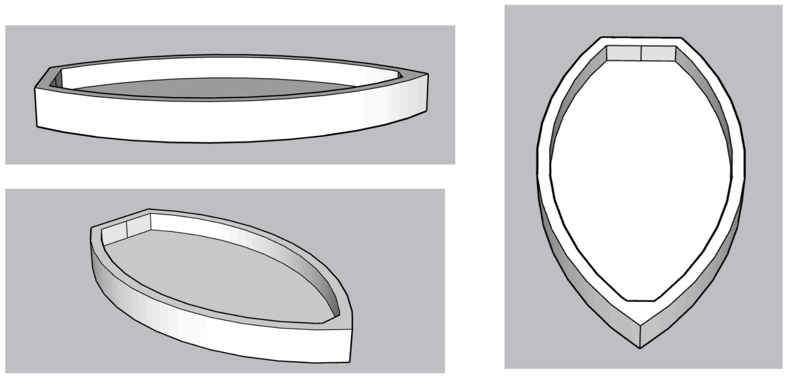


Figure 2: First Design Of Group 2 Boat Made On Sketchup.

Appendix D.2: Design Concept 2

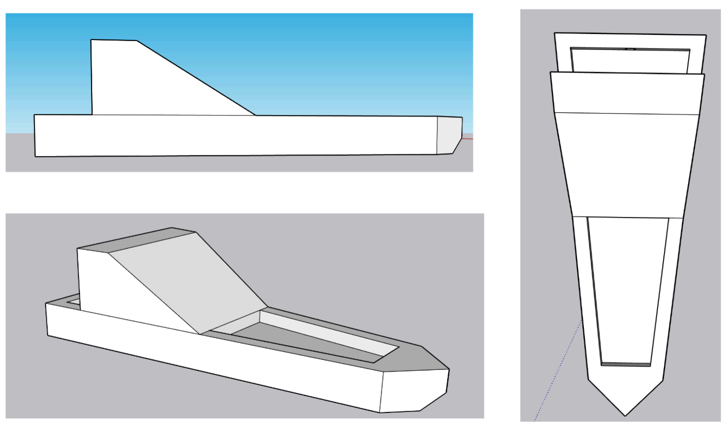


Figure 3: Second Design Of Group 2 Boat Made On Sketchup.

Appendix D.3: Design Concept 3

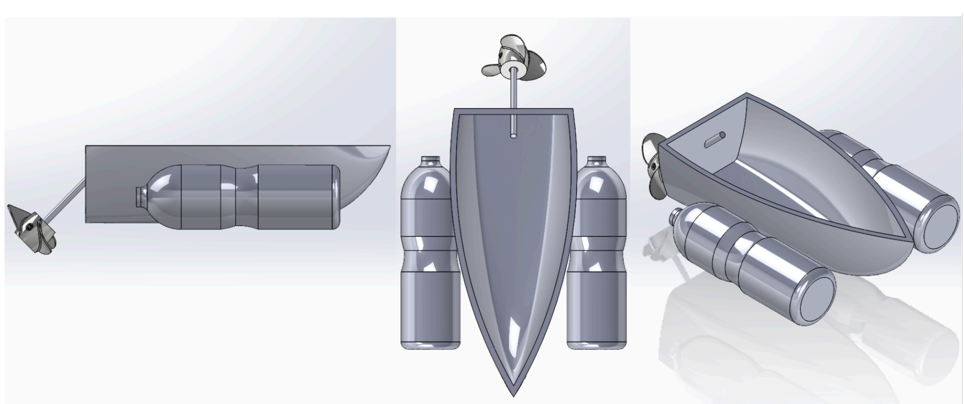
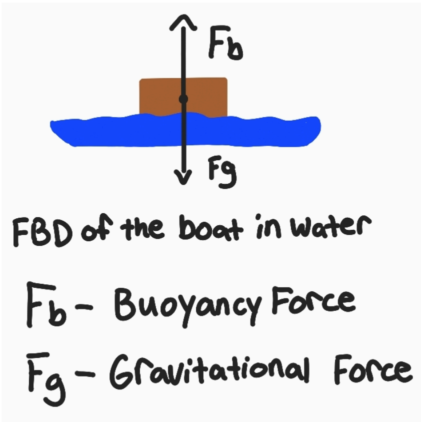


Figure 4: Third Design Of Group 2 Boat Made On SolidWorks.

Appendix E: Chosen Solution

Figure 5: Real-Life Model of the Chosen Boat Design.

Appendix F: Buoyancy Calculations



FBD of the boat in water
F_b - Buoyancy Force
F_g - Gravitational Force

$F_g = 2.48 * 9.81$
$F_g \approx 24.37$ N

The volume of the boat from report 2 is 1.656325 $m^3 \approx 1.66$ m^3

To calculate the buoyancy force acting on the boat, first assume the scenario where the boat is fully submerged. This means the volume of water displaced is equal to the volume of the boat.

In this case, if $F_b > F_g$, the boat will rise, meaning it can float when placed on water.

If $F_b \ngtr F_g$, the boat will stay submerged or sink more, This means when placed on water, the boat won't be able to sustain any weight and will sink

From report 2, the boat was determined to be approximately 2.4844875 kg ≈ 2.48 kg

F_b is in newtons, so to compare weight and F_b, convert the weight of the boat to newtons:

1 kg = 9.81 N
2.48 kg = 9.81 * 2.48 N
$\approx$ 24.37 N
So we require $F_b > 24.37$ N

$F_b > F_g$: Boat will float
$F_b < F_g$: Boat will sink
$F_b = F_g$: Boat is suspended at some depth

With $F_b = \gamma v$, where v is the volume of displaced water in m^3, $\gamma = 9.807$ kN/m^3 $= 9.807 \text{ x} 10^3$ N/m^3

Then, $F_b = 1.66 * 9.807 * 10^3$
$F_b = 16243.58$ N

As $F_b > F_g$, our boat will float and be able to hold the weight of our crew and all our supplies.

Appendix G: Voltage and Current Measurements

Appendix G.1: Old Fuel Cell

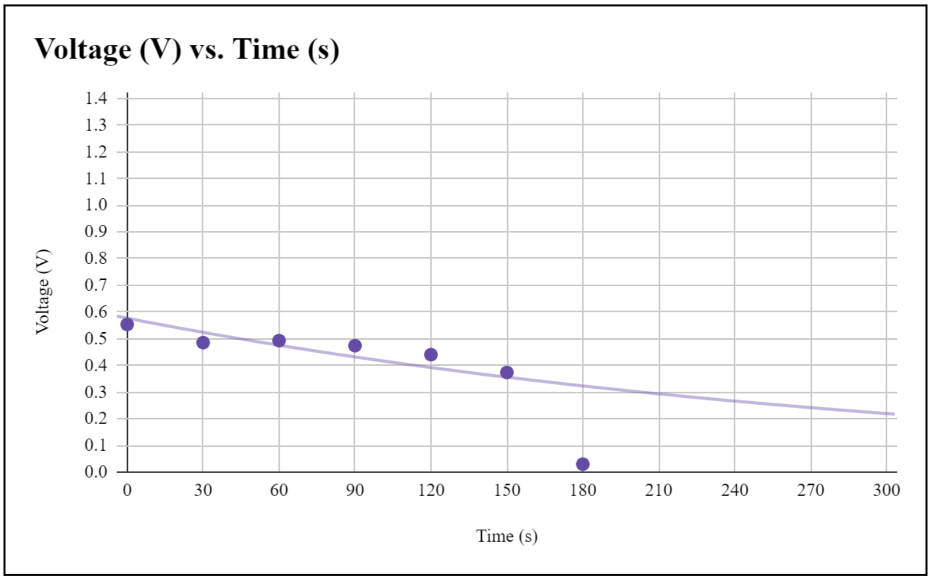


Figure 6: Graph Representing the Measured Voltage of the Old Fuel Cell over Five Minutes (300 Seconds). Data from ***Table 1***.

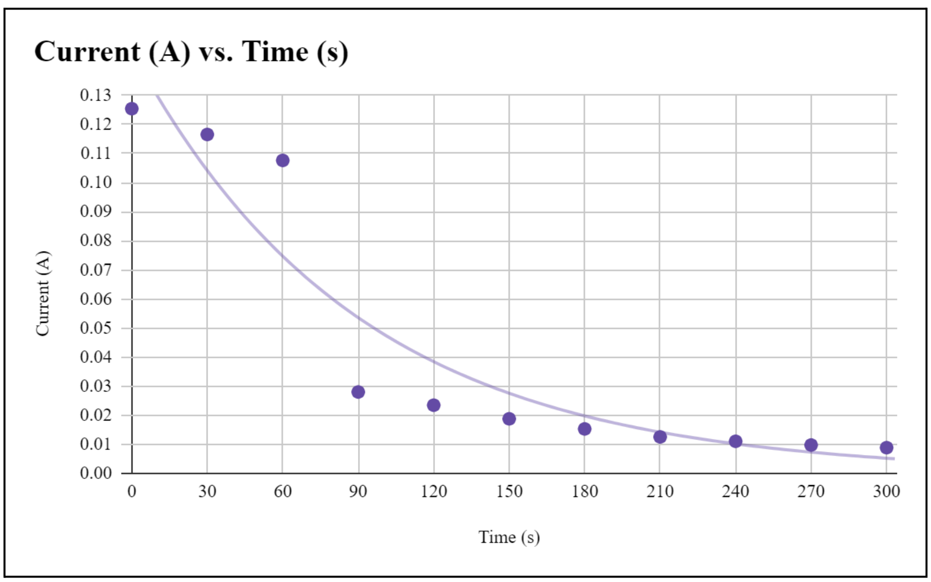


Figure 7: Graph Representing the Measured Current of the Old Fuel Cell over Five Minutes (300 Seconds). Data from ***Table 2.***

Table 1: Old Voltage Measurements

Time (s)	Voltage (V)
0	0.5532
30	0.4852
60	0.49275
90	0.47376
120	0.44007
150	0.37346
180	0.02973
210	
240	
270	
300	

Table 2: Old Current Measurements

Time (s)	Current (A)
0	0.12543
30	0.11656
60	0.10764
90	0.027995
120	0.023454
150	0.018765
180	0.015287
210	0.012545
240	0.011035
270	0.009751
300	0.008842

Appendix G.2: New Fuel Cell

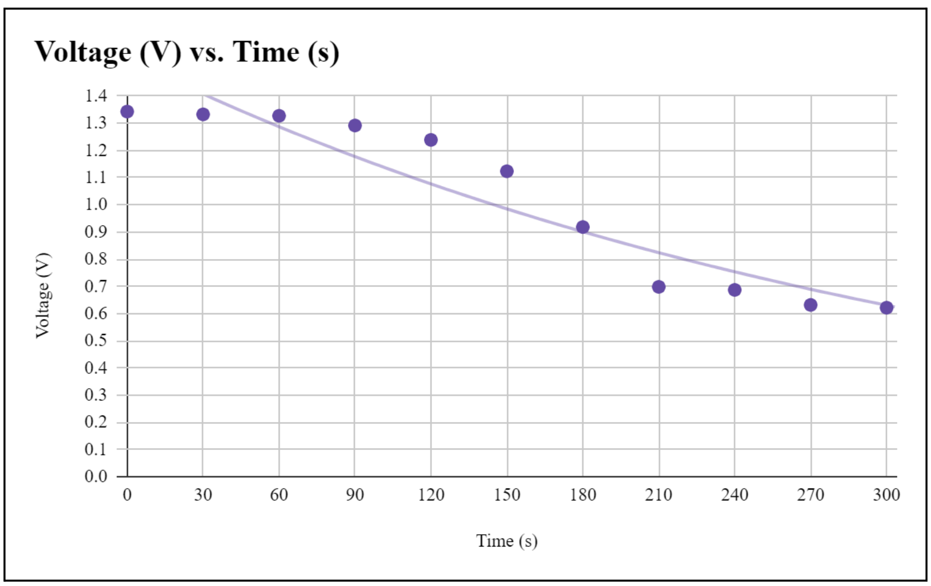


Figure 8: Graph Representing the Measured Voltage of the New Fuel Cell over Five Minutes (300 Seconds). Data from ***Table 3***.

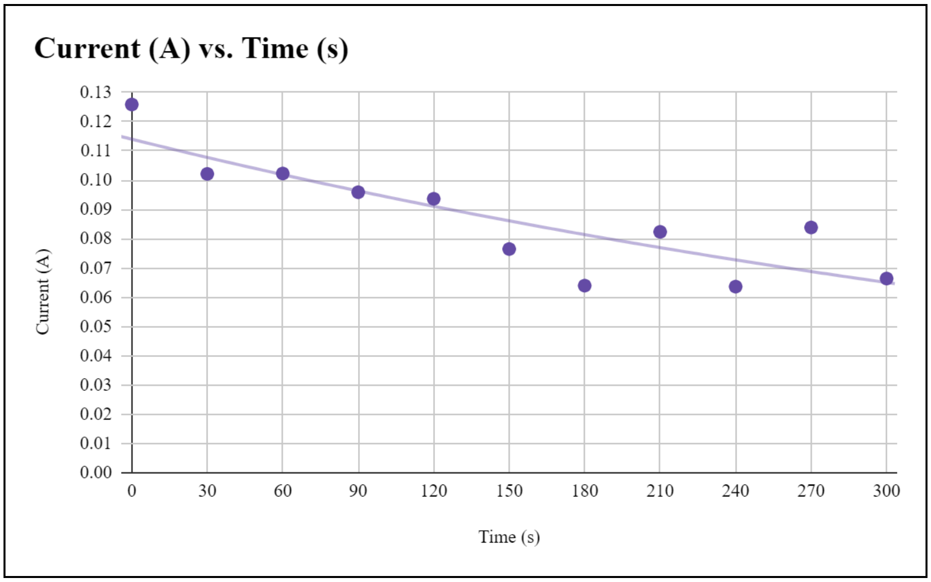


Figure 9: Graph Representing the Measured Current of the New Fuel Cell over Five Minutes (300 Seconds). Data from ***Table 4***.

***Table 3*:** New Voltage Measurements

Time (s)	Voltage (V)
0	1.3428
30	1.3325
60	1.3272
90	1.2916
120	1.2386
150	1.1233
180	0.9181
210	0.6981
240	0.6869
270	0.6316
300	0.6214

Table 4: New Current Measurements

Time (s)	Current (A)
0	0.12588
30	0.10215
60	0.10229
90	0.09589
120	0.09364
150	0.07647
180	0.06396
210	0.08234
240	0.06362
270	0.08384
300	0.06638

Appendix H: Fuel Cell Chemistry Calculations

Appendix H.1: Mole Calculation

→ By filling the bell with water and placing the water into the cylinder, we were able to measure the volume of the bell. The diameter of the cylinder was measured to be 4 cm.

$$\text{Measured Volume} = \pi r^2 \times h = \pi(2cm)^2 \times 1.5cm = 18.8cm^3 \times \frac{1\,ml}{1\,cm^3} = 18.8\,ml$$

→ We acquired the current temperature and atmospheric pressure of 101.2 kPa from The Weather Network [26]. The pressure of the water acting on the gas was calculated using the height of the water in the cylinder. The combined pressures make up the total pressure of each gas.

$$\text{Measured Temperature} = 25°C = 298K$$
$$\text{Atmospheric Pressure} = 0.999\,atm$$

$$2H_2O_{(l)} \rightarrow 2H_{2\,(g)} + O_{2\,(g)}$$

$$\text{Molar mass of Water} = 2(1.01\,g/mol\,H_2) + 16.0\,g/mol\,O = 18.04\,g/mol\,H_2O$$

$$\text{Water Pressure} = dgh = \frac{1\,g}{cm^3} \times \frac{9.81\,m}{s^2} \times \frac{100cm^3}{1m^3}$$
$$\times \frac{1\,kg}{1000\,g} \times \frac{0.03\,m}{} \times \frac{1\,atm}{101325\,Pa} = 0.003\,atm$$

$$P_{Total} = P_{Water} + P_{atm}$$

$$P_{Total} = 0.003\,atm + 0.999\,atm = 1.002\,atm$$

$$R = 0.08206\frac{L\,atm}{mol\,K}$$

$$PV = nRT$$

$$n_{H_2} = \frac{PV}{RT} = \frac{(1.002atm)(0.0188L)}{(0.08206\frac{L\,atm}{mol\,K})(298K)}$$

$$n_{H_2} = 7.724E^{-4}\,mols\,H_2$$

$$n_{O_2} = \frac{mols\,H_{2\,(g)}}{} \times \frac{1\,mol\,O_{2\,(g)}}{2\,mols\,H_{2\,(g)}}$$

$$n_{O_2} = 3.862E^{-4}\,mols\,O_2$$

Therefore, there is approximately $3.862E^{-4}\,mols\,O_2$ and $7.724E^{-4}\,mols\,H_2$ in the gas storage cylinders when the H_2 just starts to bubble.

Appendix H.2: Gas Solubility Calculation

→ Assuming that $7.724E^{-4}\ mols_{H_2}$ and $3.862E^{-4}\ mols_{O_2}$ are produced by the fuel cell, according to the results calculated in *Appendix H.1*.

→ To measure the volume of water used in the cylinder, we first measured the diameter of the cylinder (4 cm), we added the bell and the amount of water typically used to fill the cylinders. The bell was then removed and the height of the water was measured.

$$\text{Measured Volume}= \pi r^2 \times h = \pi(2cm)^2 \times 3cm = 37.7cm^3 \times \frac{1\ g}{1\ cm^3}\frac{1\ ml}{1\ g} = 37.7\ g$$

→ According to the National Institute of Standards and Technology [24], [25]: The Henrys constant for O_2 and H_2 in water at 298K are $k_{O_2} = 1.3 \times 10^{-3}\frac{mol}{kg\cdot bar}$ and $k_{H_2} = 7.8 \times 10^{-4}\frac{mol}{kg\cdot bar}$.

→ We acquired the current atmospheric pressure of 101.2 kPa from The Weather Network [26]. The pressure of the water acting on the gas was calculated using the height of the water in the cylinder. The combined pressures make up the total pressure of each gas.

$$P_{atmosphere} = 101.2\ kPa \times \frac{1000\ Pa}{1\ kPa} \times \frac{1\ atm}{101325\ Pa} \times 0.999\ atm$$

$$P_{water} = dgh = \frac{1\ g}{cm^3} \times \frac{9.81\ m}{s^2} \times \frac{100cm^3}{1m^3} \times \frac{1\ kg}{1000\ g} \times \frac{0.03\ m}{} \times \frac{1\ atm}{101325\ Pa} = 0.003\ atm$$

$$P_{total} = P_{water} + P_{atmosphere} = 0.999\ atm + 0.003\ atm = 1.002\ atm$$

$C_{O_2} = k_{O_2}P_{O_2}$:

$$C_{O_2} = 1.3 \times 10^{-3}\frac{mol}{kg\cdot bar} \times 1.002\ atm \times \frac{1.01325\ bar}{1\ atm}$$

$$C_{O_2} = 1.3199 \times 10^{-3}\frac{mol\ O_2}{kg\ water}$$

$$n_{O_2} = 1.3199 \times 10^{-3}\frac{mol\ O_2}{kg\ water} \times \frac{0.0377\ kg\ water}{}$$

$$n_{O_2} = 4.976 \times 10^{-5} mols\ O_2$$

$$m_{O_2} = 4.976 \times 10^{-5} mols\ O_2 \times \frac{(2\times16)\ g}{mol} = 1.593 \times 10^{-3} g\ O_2$$

$$\%m_{O_2} = \frac{1.593\times10^{-3} g\ O_2}{3.862\times10^{-4}\ mols\ O_2 \times \frac{(2\times16)\ g}{mol}} \times 100 = 12.9\%$$

$$C_{H_2} = k_{H_2} P_{H_2} :$$

$$C_{H_2} = 7.8 \times 10^{-4} \frac{mol}{kg\cdot bar} \times 1.002\ atm \times \frac{1.01325\ bar}{1\ atm}$$

$$C_{H_2} = 7.9192 \times 10^{-4} \frac{mol\ H_2}{kg\ water}$$

$$n_{H_2} = 7.9192 \times 10^{-4} \frac{mol\ H_2}{kg\ water} \times \frac{0.0377\ kg\ water}{}$$

$$n_{H_2} = 2.986 \times 10^{-5} mols\ H_2$$

$$m_{H_2} = 2.986 \times 10^{-5} mols\ H_2 \times \frac{(2\times1.01)\ g}{mol} = 6.031 \times 10^{-5} g\ H_2$$

$$\%m_{O_2} = \frac{6.031\times10^{-5}\ g\ H_2}{7.724E^{-4}\ mols\ \ H_2 \times \frac{(2\times1.01)\ g}{mol}} \times 100 = 3.9\%$$

Therefore, 12.9% of O_2, and 3.9% of H_2 by mass is lost by storing the gasses in contact with water.

Appendix H.3: Electrochemistry Calculations

→ The standard half-cell potentials for the hydrogen fuel cell that we are using are:

$$2(H_2 \rightarrow 2H^+ + 2e^-) \qquad E^o = 0\ V$$

$$O_{2(g)} + 4H^+_{(aq)} + 4e^- \rightarrow H_2O_{(l)} \qquad E^o = 1.229\ V$$

$$O_{2(g)} + 2H_2 \rightarrow H_2O_{(l)}$$

→ Knowing that electrons travel from low to high potential, and that voltage is the difference in potential between the cathode and the anode, we can use the equation:

$$E^o_{cell} = E^o_{cathode} - E^o_{anode}$$

$$E^{o}_{cell} = 1.229\,V - 0V$$
$$E^{o}_{cell} = 1.229\,V$$

→ Assuming that $7.724E^{-4}\ mols_{H_2}$ and $3.862E^{-4}\ mols_{O_2}$ are produced by the fuel cell, according to the results calculated in *Appendix H.1*.

→ Since oxygen is the limiting reagent, we will base the calculations on $3.862E^{-4}\ mols\ O_2$.

→ The measured run time of the motor on Demo Day was 480 seconds.

→ the number of moles of electrons flowing through the circuit is proportional to the number of mols of O_2 present:

$$n = 3.862E^{-4}\ mols\ O_2 \times \frac{4\ mols\ e^-}{1\ mol\ O_2}$$
$$n = 1.545E^{-3}\ mols\ e^-$$

→ The electric charge (Q) is proportional to the number of moles of electrons flowing through the circuit:

$$Q = (1.545E^{-3}) \times (96\,485)$$
$$Q = 149.05$$

→ Electric current (I) is the amount of charge (Q) flowing through a circuit per unit time (t):

$$I = \frac{Q}{t}$$
$$I = \frac{(149.05)}{(480)}$$
$$I = 0.310\ Amps$$

→ To determine the theoretical power of the fuel cell, the values from the previous questions as well as the equation:

$$P = IV$$
$$P = (0.310\ A)(1.229\ V)$$
$$P = 0.382$$

→ The actual power is determined from the voltage and current of the fuel cell was measured in the WEEF Lab (see Appendix G for data).

Highest Measured Voltage = $1.3428\ Volts$
Highest Measured Current = $0.12588\ Amps$

$$P = IV$$
$$P = (0.12588\ A)(1.3428V)$$
$$P = 0.169$$

→ The efficiency of the fuel cell can be measured with the equation:

$$efficiency = \frac{measured\ power}{calculated\ power} x100\%$$

$$efficiency = \frac{(0.169)}{(0.382)} x100\%$$

$$efficiency = 44.2\%$$

Appendix I: References

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