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July 30, 2023

Maria Barichello, Dave Harris and Mary Robinson
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Dear all,

We are delighted to present to you the final report encompassing the comprehensive outcomes of our collaborative project. As a team consisting of Wardah Anwer, Haya Irfan, Justin Medeiros, and Carina Sinbandhit, we bring together diverse academic backgrounds within the esteemed University of Waterloo. Leveraging our individual expertise in chemical and mechanical engineering, alongside the valuable knowledge acquired from ChE 102: Chemistry for Engineers, we have embarked on an exciting endeavor to develop a high-speed and energy-efficient model boat powered by a Proton Exchange Membrane (PEM) fuel cell.

The amalgamation of our distinctive skills and interdisciplinary perspectives has been instrumental in driving innovation throughout this project. Drawing upon our comprehensive understanding of fuel cells, we aim to demonstrate the immense potential of PEM fuel cells in many sectors. In line with our dedication to sustainability and the reduction of carbon emissions, our focus is on demonstrating the viability and benefits of this clean energy technology.

We carefully coordinated and completed every stage of the project from the outset, putting a strong emphasis on issues with safety, performance, and design. The direction of this project and its results have been defined by our unrelenting commitment to exhaustive study, testing, and in-depth analysis. In addition to advancing knowledge of PEM fuel cell applications, the research findings and conclusions in this paper also illustrate how revolutionary they can be for watercraft propulsion, providing a more environmentally friendly substitute for traditional internal combustion engines.

We want to express our sincere gratitude for your time and thought in reading our final report and would be delighted to continue the conversation, share our insights, and look into new joint ventures or prospects for further study. Please don't hesitate to get in touch with us if you need any more details or have questions.

Sincerely,

Wardah Anwer	Haya Irfan	Justin Medeiros	Carina Sinbandhit
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GENE101 REPORT: APPLICATIONS OF CHEMISTRY FOR THE DESIGN OF THE FUEL CELL BOAT

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Executive Summary

A hydrogen PEM fuel cell is used as an environmentally friendly alternative to generate power, in this case, to power a boat. This project draws on GenE 101, Strategies and Skills for Academic Success, where the instructors enlisted the class a prompt to design a feasible solution for an engineering problem: a person is stranded on an island surrounded with hostile people which beckons the person's need to escape there posthaste, however merely has limited resources to help build a watercraft to vacate the island. The class was dispersed into eleven teams to build a boat that would compete in a race. This boat must be able to travel the quickest of the length of the Engineering 2 fountain at the University of Waterloo. This project applies concepts from ChE 102, Chemistry for Engineers, course while implementing engineering judgement to fulfill the prompt.

The practicality of the boat's design was framed by considering factors such that the boat must float, balance, and move. From these design considerations, four designs were produced. To follow through with these considerations, functions, constraints, and objectives were devised. For the boat to float, there is a proper floating mechanism. A propulsion system and float amenity will be integrated into the design to initiate buoyant forces. Not only will the propellers help the boat float, but it will optimize the stability and speed of the boat. The shape of the propellers was selected to reduce air drag simultaneously increasing the boat's speed and efficiency. The design was chosen by considering the main functions, constraints, and objectives of the boat, nonetheless there will be modifications made throughout prototyping the boat. The entire manufacturing process is budgeted to a maximum 20 CAD dollars which the project costed only 2 CAD dollars. The type of material used for the boat was explored through research just before testing how it will react on water. The chosen material for the base of the boat was 3D printed using ABS filament and the floating mechanism was made from foam. The specific material will be selected regarding the objective of minimizing the weight of the boat while supporting the fuel cell.

An experiment that involved measuring the voltage and current produced by a hydrogen fuel cell to power a DC motor – within a specific time frame or until the boat came to a complete stop. The findings obtained were used to assess the need for modifications to reduce the boat's weight and improve its velocity. Additionally, calculations were performed to predict the boat's buoyancy and estimate the potential loss of hydrogen and oxygen when in contact with water, allowing for valuable insights into fuel cell efficiency and aiding in the optimization of the boat's design considerations. The experiment encompassed measuring the voltage and current generated by the hydrogen fuel cell to power the DC motor. We meticulously examined the trends in voltage and current, enabling us to evaluate the boat's weight and ascertain whether any adjustments were necessary to optimize its design. Throughout the experiment, we encountered occasional inconsistencies, such as issues with tubing or alligator clips, which were promptly addressed to ensure accurate measurements. Additionally, it was recommended to maintain proper hydration of the fuel cell to enhance its efficiency and maximize the boat's overall performance. By conducting these comprehensive experiments and analyses, we obtained valuable data and insights that served as a foundation for further improving the boat's design and operation. With the goal of achieving maximum fuel cell efficiency and optimizing the boat's float, balance, and maneuverability, the results of our experiment have provided us with a roadmap for enhancing the boat's performance and advancing the field of hydrogen fuel cell technology in the context of watercraft applications.

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1.0 Introduction

The fuel cell project combines the concepts learned from the ChE 102: Chemistry for Engineers course and applies them to building a boat powered by a hydrogen reversible proton-exchange membrane fuel cell (PEMFC) shown in **Figure 1**. This project proposes a possible solution to solve an engineering problem given a prompt from the GenE 101 course where a person is stranded on an island surrounded with hostile people; this beckons the person's need to escape there posthaste, but merely has limited resources to help build a watercraft to vacate the island.

Figure 1 *Image of the reversable PEM fuel cell [1]*

1.1 Hydrogen Reversible PEM Fuel Cell

A hydrogen reversible proton-exchange membrane fuel cell (PEMFC) produces power that seamlessly operates in both fuel cell mode and electrolysis mode. In fuel cell mode, it functions like a traditional fuel cell, skillfully converting the chemical energy stored in hydrogen and oxygen gases into electrical energy through an efficient electrochemical reaction. When a load is applied, the reversible fuel cell expertly harnesses the power of hydrogen and oxygen gases to generate electricity, delivering an impressive output voltage of 0.600 V (direct current) in parallel or series configurations [1]. In parallel and series configurations, it boasts an output current of 360 mA, enabling the generation of a substantial amount of electrical power that can cater to various needs. With a power output rating of 210 mW, this device proves itself as a practical and efficient solution for powering electronic devices, small-scale systems, and energy storage applications [1], [2]. In electrolysis mode, the fuel cell ingeniously employs electrical energy to facilitate an electrochemical reaction that effectively splits water into its constituent hydrogen and oxygen gases [2]. This allows the production of hydrogen gas, which can be stored and used as an exceptionally clean and renewable fuel source. The reversible nature of this fuel cell, effortlessly alternating between power generation and hydrogen production showcases its versatility and adaptability [2]. **Figure 2** shows a diagram where distilled water is being injected into the oxygen-side of the fuel cell to help power a propellor – to generally operate the PEMFC, hydrogen is used as fuel and oxygen as an oxidant [2].

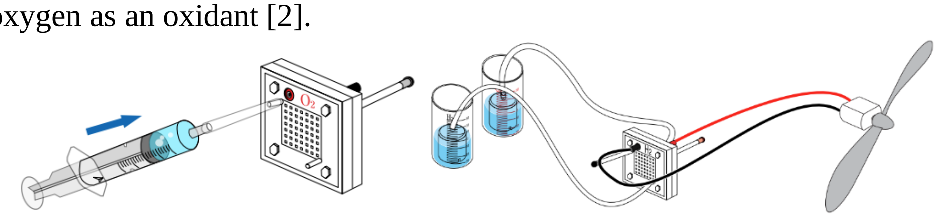


***Figure** 2 Using Fuel Cells to convert Hydrogen to Electricity operating a propeller [1]*

1.1.1 Procedural Precautions

There are several procedural precautions to beware of when an individual is using a hydrogen reversible PEMFC to produce power. One must look carefully to see if the positive and negative poles of the PEMFC is correctly connected (i.e., to the corresponding side where RED goes with O_2 and BLACK goes with H_2) to the power supply. Failing to do so may damage the fuel cell [1]. Once the tubes are in the correct place, the membranes in the fuel cell must be hydrated.

When injecting the distilled water into each side of the PEMFC, allow to fuel cell to soak for at least 3 minutes or until the air bubbles of the two tanks are full [1]. Otherwise, the membranes will be damaged if connected to a power supply when dry [1]. It is also highly recommended to use two new AA alkaline batteries with 1.5-Volts as a power supply [1].

1.1.2 Environmental Impacts

Reduced Greenhouse Gas Emissions:

One of the most notable environmental advantages of fuel cells is their capacity to reduce greenhouse fuel emissions. Unlike conventional power-era technologies that burn fossil fuels, fuel cells perform using hydrogen or other clean fuels, consisting of natural gas or methanol. When hydrogen is used as the fuel supply, fuel cells produce only water vapor and warmth as byproducts, resulting in zero direct emissions of greenhouse gases [3]. Furthermore, if hydrogen is produced through renewable energy assets like solar or wind, the general carbon footprint of fuel cellular systems may be appreciably reduced [4]. Fuel cells can keep excess energy from renewable resources and convert it into strength at some stage in periods of high call for, supporting to balance the intermittent of the renewable electricity era [3]. This flexibility in fuel resources and their capability for carbon-neutral hydrogen manufacturing make fuel cells an appealing option for achieving sustainable and low-carbon energy structures.

Air Quality Improvement:

Compared to traditional electricity manufacturing strategies, fuel cells offer considerable air high-quality benefits. Various toxic pollutants, consisting of nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM), and volatile organic compounds (VOCs), are launched all through traditional combustion processes. In contrast, fuel cells produce power through an electrochemical reaction, eliminating the formation of those harmful emissions [4]. The discount on air pollutants contributes to cleaner air, advanced public health, and a decrease in the prevalence of breathing illnesses in communities near power generation centers [5]. To decorate local air quality, fuel cell technology has been used in a whole lot of applications. For instance, fuel-mobile-powered automobiles have zero tailpipe emissions, reducing air pollution in cities and the poor effects on human health delivered by way of vehicle emissions [3]. This lessens the need for fossil fuel-based power plant life, which is a prime source of air pollution [5].

Reduced Noise Pollution:

Another widespread gain of fuel cells is their quiet operation, which helps in decreasing noise pollutants. Traditional power generation technologies, inclusive of inner combustion engines, fuel generators, or diesel turbines, are often noisy and might disturb residential regions or natural habitats. Fuel cells, then again, perform silently when you consider that they contain electrochemical reactions without any transferring elements [6]. This function makes fuel cells suitable for diverse applications wherein noise discount is critical, which includes residential neighborhoods, hospitals, and recreational regions [5].

1.1.3 Cost Effectiveness

Hydrogen fuel cells are a very popular alternate source of fuel for cars and other automated vehicles, as all they require is hydrogen and oxygen gas to produce electricity. Decades of research have been poured into the creation of these cells, and we’ve been seeing the beginnings of their implementation into society- major car companies, such as General Motors, Ford, and Honda have all developed fuel cell concept cars [7], and many major cities such as Rio de Janeiro, Beijing, and Perth have been trialing hydrogen fuel cell-powered buses to reduce their carbon footprint [8]. Still, high fuel and operation costs are the biggest roadblocks when it comes to fully introducing them into the market - for example, Platinum is a common catalyst used within fuel cells, as it works exceptionally well as an oxidation catalyst, as well as having a high melting point making it extremely durable. However, platinum is a very precious metal, and exceeds costs of even gold and silver, going for about $100 (USD) per 3 grams of platinum [9]. This drives up the cost to make these cells, and while researchers are working hard to find alternative materials, as of right now the cost to produce these hydrogen cells are still quite high. Another factor of increasing cost is storage of hydrogen; it has a low temperature density, which results in having low energy per unit volume, meaning that liquid storage of hydrogen requires cryogenic temperatures, something that requires a high financial and energy cost in and of itself [10].

As of right now, the average gas-powered vehicle converts 30% energy stored within gasoline to power the engine [11]; in comparison to fuel cell systems, which generate up to 60% fuel efficiency, its clearly a better option, however like stated above the technology is quite new. Even still, new technologies are being developed every day to make that reality possible. In Europe, an energy company known as Loop Energy has recently developed a fuel cell engine meant for fleet operations, which has been able to match the cost efficiency of diesel engines while working at a fuel efficiency of 60% [11]. For an average long haul diesel truck, fuel costs per 100km is about $80-$100 dollars; with Loop Energy's S1200 engine, since hydrogen costs about $10 per kg, cost for over 100km is just about $90 [11].

1.2 Project Plan

Before the research, designing and manufacturing process of the fuel cell project, this team first devised a contract to establish a code of conduct and responsibilities contributing to the development of this project (refer to **Appendix A.1**). This contract academically binds this team to respect one another's given roles for each phase of the project. This team will abide by the following responsibilities and deadlines assigned to each member which are determined to change throughout the project. For each report, the team worked on each section together in accordance with **A.2.4.** the Delphi Technique (refer to **Appendix A.1**). The team conducted individual research on each topic then condensed the information together as a group, so there are different perspectives on a topic to produce more comprehensive results.

A Gantt chart is used to organize this project (refer to **Appendix A.2**). This way, the team can visualize what tasks to prioritize to ensure that they are completed on time. The team will regularly review the Gantt chart to monitor the progress made at each milestone and what tasks are allocated to whom. To coordinate who should do what, the team assembled a group resume (refer to **Appendix A.3**) displaying the academic major, specialized knowledge, skills, and weaknesses of each group member. The individual who demonstrates the required qualifications in that part of the project will guide the team.

Haya and Carina contributed more to design-heavy tasks. They both possess experience in CAD modelling and prototyping which supported the manufacturing process of the boat's final design (i.e., 3d printing). Carina also used her digital camera to capture the progress of the boat design to provide a visual record of communicating design changes and project milestones. Justin demonstrated ability in analyzation skills and report writing skills which was utilized in calculating the chemistry component, then communicating that in the report. Justin's soft skills in proficient presentation skills from years of theatre experience, benefit in the script writing for the final presentation, also providing the group pointers on how to effectively communicate to the audience. Wardah's background in graphic design assisted Justin on the presentation portion of the project by organizing the PowerPoint slideshow to make it look aesthetically pleasing while ensuring the information is concise.

2.0 Safety, Health, Environment

This section outlines the safety, health, and environmental potential concerns that the hydrogen from a PEMFC poses – when its wirings are connected to a DC motor. The following three main hazards, that one must be wary of when handling hydrogen, are hydrogen spills, slips, and falls, flammability of the hydrogen gas, and electric discharge.

2.1 Safety Risks

2.1.1 Hydrogen Spills, Slips and Falls

Hydrogen, as the smallest and lightest atom, poses safety concerns due to its tendency to easily leak from sealing regions like plastic tubing [12]. Its small size allows hydrogen molecules to diffuse into impermeable materials or dissociate on surfaces, weakening their mechanical integrity and promoting crack formation and internal blisters [12]. The leakage of hydrogen gas has the potential to cause an explosion [12], [13]. This is because hydrogen self-heats when it leaks from a high-pressure source [13]. This leakage, if it gets to the operating motor connected to the wires, can also cause electric shocks as a result from an electrical short-circuit. There is also a chance that the distilled water used to hydrate the fuel cell can be spilled on the floor posing a slipping hazard.

2.1.2 Flammability of the Hydrogen Gas

Hydrogen's flammability is considered its most dangerous property compared to its other chemical or physiological properties [14]. The energy carrier property of hydrogen makes it highly flammable [14], with a lower minimum ignition energy and wide flammability range, leading to early ignition of hydrogen mixtures [12], [13]. A small spark is enough to ignite a mixture of hydrogen and air, making it prone to fire hazards [12]. Unlike other fuels, hydrogen has a wider flammability range and can easily transition to detonation [12]. A case where hydrogen is difficult to detect is when it burns with a colorless flame [13].

2.1.3. Electric Discharge

As an individual is working with an active electric cell, there is always a risk of electric shock. Leaving the battery running with the wires exposed could lead to a discharge of electricity. This discharge of energy means that static electricity or sparks can trigger ignition when handling hydrogen in certain conditions. This is because if the motor has such high currents, the probability of electric shock increases to pose a danger [15].

2.2 Addressing and Mitigating Safety Risks

There are ways to mitigate these hazards of hydrogen spills, slips, and falls; flammability; and electric discharge. Identifying and assessing risks such as flammability and potential hazards from neighboring facilities or activities [13], [16] is essential along with common and uncommon component failures, such as leaks in fittings and valves, power outages, and equipment rupture. To mitigate the chances of spills, slips, and falls, the work area must be kept clean. If distilled water is spilled at any point, it must be cleaned up immediately with a cloth or paper towel. If an excessive amount of water is spilled on the floor, it should be cleaned up using a mop, along with placing a "Caution Wet Floor" sign at the area of the spill. Regular inspection and testing of these components are necessary to detect and repair any leaks promptly [16] – i.e., if there is a leak from the piping. While working with dangerous gases, make sure that the fire triangle (as shown in **Figure 3**) is not completed to avoid the chances of flammability. This can be accomplished by working in well-ventilated areas, and keeping away from flames and smoke – reducing unwanted ignition sources. Adequate ventilation in storage and operation areas, proper storage containers or tanks designed for hydrogen, and compliance with fire safety measures are vital to minimize risks [16]. This project involves a hydrogen fuel cell to power a DC motor. When handling the wirings to power the motor, make sure that our hands and the area we are working at are dry, so we do not get shocked by the circuit. Even when handling dangerous gases, one is normally obligated to wear PPE (personal protective equipment. In this case, since the equipment we are working with is small, there is not a need to use PPE. This can actually make things worse since gloves make handling the fuel cell more difficult and masks affect line of sight especially when wearing glasses.

Figure 3 *The Fire Triangle*

3.0 Boat Design

This section cumulates the primary considerations that must be considered in the designing and building aspect of the fuel cell boat. This includes mounting the fuel cell (and the two hydrogen tanks) on the boat so that the boat floats on water, and that the design of the propellor needs to be able to accelerate the boat on water while balancing. This all corresponds to designing the boat and choosing a material that will satisfy these following design considerations.

3.1 Design Considerations

3.1.1 Float

The most basic constraint of the boat is that it should float when it is placed onto water. So, a huge consideration of this project is to minimize the weight of the boat enough that the boat is less dense than water [17]; in other words, the buoyant force of the water onto the boat must be equal to the force of the weight of the boat. This can be done by choosing specific materials that are lightweight and identifying the boat's center of gravity [17]. **Table 1** demonstrates the specifications of the fuel cell and specifically how much the fuel cell weighs [17] to help determine the material that should be used to design and manufacture the boat.

Table 1 *Specifications of the reversable PEM fuel cell [1]*

Information on the Reversable PEM Fuel Cell	
Dimensions (width x height x depth)	54.0 mm x 54.0 mm x 17.0 mm
Total Weight	66 g

Color	Blue or Transparent

3.1.2 Balance

The design consideration that the boat needs to float also ties into sufficient balance - so the boat does not tip over. There will be a place to mount the fuel cell and hydrogen tank which adds on extra weight to the boat. Therefore, the boat should be able to support the additional weight so that, not only, does it not fall off the boat when the boat is accelerating on the water, but it also maintains constant balance.

3.1.3 Maneuverability

One must also consider that this boat should move. The boat can navigate through the water when operating the rotors and propellers [17]. The number and shape of the blades should be determined depending on the weight of the boat and the speed of the rotor. The fuel cell should generate enough electricity that the boat's rotor accelerates the boat forward until the end of its destination. Further calculations will be conducted on the input voltage and input current as well as the hydrogen and oxygen production rate of the reversible fuel cell of D.C. power being applied, where the power generated from the reversible full cell help determine which propellor would be ideal for this boat.

4.0 Needs Assessment

Students of the reduced-load program are instructed to design and construct a boat in the GenE 101, Strategies and Skills for Academic Success, course. These boat designs will participate in a race conducted outside of the University of Waterloo's Engineering 2 building. The boats must cover approximately 2.28 meters across the pool to successfully complete the race. There exists a need to apply concepts from the ChE 102, Chemistry for Engineers, course to power a boat using hydrogen PEM fuel cells, so that the boat can accelerate at a fast rate of speed while attaining the electrical and safety requirements. The boat should also incorporate mechanisms to maintain buoyancy and stability to prevent sinking, tipping, or capsizing. The boat must be able to move efficiently through the water – maintaining desired speeds – utilizing the power generated by the fuel cell. In this report, a multitude of potential designs have been formulated, pulling inspiration from different types of boats and distinct mechanical components of boats to generate a variety of options to choose from. We have also detailed the specifics of the cell, how it works, and how we plan on implementing it into our boat. The final solution has been developed through the process of research, experimentation, and prototyping, and is a solution that we believe is best suited to meet the needs of the project and fits well within our constraints.

5.0 Problem Formulation

In order to build a race boat, the three design considerations were established. These include that the boat must float, balance, and move. The boat is required to be powered by a hydrogen PEM fuel cell to complete the distance of a rectangular-shaped kiddy pool for the race.

5.1 Problem Statement

The design and construction of the boat must address the need for optimizing the boat's speed and range to complete a race against the other teams' boats. To produce a feasible design and build a boat, factors like the hydrogen PEM fuel cell's energy output and the design constraints of the boat must be considered to cover the distance of at least 2.28 meters at a fast rate of speed.

5.2 Functional Description

The functional and non-functional requirements help produce four boat designs. The functional requirements derive from the three design considerations: the boat must float, balance, and move. The boat must be able to move efficiently on water, enabling it to attain desired speeds. The system should generate enough thrust to achieve the desired speed while keeping the fuel cell's overall energy efficiency in mind. A proper compartment setup for the hydrogen fuel cell and tanks is required to support the propulsion system, ensuring efficient energy conversion and storage for extended use. The non-functional requirements for the boats are intended to ensure optimal performance and safety. The floating mechanism must ensure the boat's stability to prevent excessive rocking or tipping. Long-term wear constraints must be considered to ensure the boat's durability and reliability throughout its operational longevity, and exposure to elements like heat, wind, and water.

5.3 Objectives

The vehicle should also have systems in place to prevent potential safety hazards such as leaks, flammability, or electrical malfunctions. The cost of manufacturing this boat should be 20 CAD dollars maximum. The weight of the boat should also be minimized, but also consider the additional weight from the fuel cell and tanks, so that the boat is able to float.

5.4 Constraints

The boat must accelerate at an optimal forward velocity of at least 0.500 m/s. To prevent tangling and reduce the risk of electric shock, the wiring system should be organized and properly secured. The fuel cell must be easily accessible to power the boat, but also be secured to the boat.

6.0 Conceptual Designs

The four conceptual designs listed in the following subsections are built from the three design considerations and functions. The chosen design is selected by identifying which fulfills the objectives and constraints.

6.1 Boat Design #1

This design was inspired by a Jon boat (a utility boat used mostly for speeding through shallow waters) with specific design elements taken from dinghies. A flat hull was chosen for this design based on the location that the model would be driven – this model will be tested in a pool [18]. Flat hulls sit on top of the water and can speed through calm waters with ease and finesse [19]. The downside of these hulls, however, is that they are less stable and require some careful aid to ensure stability [18]. To resolve this, the design incorporates two buoyancy pods on the back ends of the boat where the fuel cell and hydrogen tanks will be stored. To build these, materials such as empty water bottles or foam (e.g., fountain noodles) were considered. Like most speed boats, this design includes a long and narrow body to cut through water more easily [18]. While that also provides a potential balancing issue, if the fuel tanks are spaced properly and the floatation devices are in place, then that should not cause an issue. In terms of the propeller, the design incorporates two medium-sized propellers, both set at a higher pitch to ensure that it moves at a higher speed [18], [20]. To make sure that the propellers are working at their maximum efficiency, the blades are cupped at the tip of the blade to better grip the water, in turn increasing power to the boat and propelling it further forward [19], [21]. Boat design #1 is shown in **Figure B.1** in **Appendix B**.

6.2 Boat Design #2

This boat concept design drew inspiration from a seaplane. A seaplane is distinguished by its floating mechanism known as "floats" and propellers. This is critical when the boat is propelling itself quickly through the water which reduces air drag. The boat is designed to have a long length and narrow width [18]. The design pays special attention to adjusting the narrowness of the boat's body to accommodate the extra weight of the fuel cell. It has a three-blade propeller mechanism in a stern drive gearbox just outside the hull aft along with a rudder [18], [22]. This propeller has a medium diameter to maintain efficiency while minimizing drag [18], [22]. A three-blade Controllable-Pitch Propeller was considered for the water propeller, whereas a five-blade Fixed-Pitch propeller was integrated from aircraft propellers [20]. The additional Fixed-Pitch propellers are intended to help reduce air drag on the boat when the propeller is operating in the water. The boat is designed so that the weight of the boat is distributed in such a way that the boat tips backwards at an upward angle of approximately 30 degrees, increasing the boat's speed [18]. In this case, the floating mechanism is made of materials such as a recycled plastic water bottle and foam (e.g., swimming floaters) that will mate at the horizontal sides of the boat. The hull of the boat supports the propellers. This is a modified-v hull, most common amongst fast-speed boats which has a deadrise angle of 20 degrees [18]. Boat design #2 is shown in **Figures B.2** and **B.3** in **Appendix B**.

6.3 Boat Design #3

One particularly notable design involves laying the fuel cell system flat within the boat, carefully distributing its components evenly throughout the vessel [23]. This specific configuration not only ensures efficient space utilization but also maintains a lower center of gravity, leading to improved stability and maneuverability in various water conditions. Alternatively, another viable option explored is to position the fuel cell system in a more congested configuration at the center of the boat. It facilitates optimal weight distribution, thereby contributing to enhanced stability and improved handling, ensuring that the boat performs exceptionally well even in challenging or unpredictable water conditions [24]. The exploration of adjustable pitch propellers introduces an additional element of adaptability and responsiveness to the boat's propulsion system [20]. As an alternative to traditional propellers, the design also delves into the exploration of water jet propulsion systems [20]. To augment the boat's motility even further, a rudder and steering mechanism are integrated into its design enabling precise control of the boat's direction – as this allows for seamless navigation [19], [24]. Boat design #3 is shown in **Figure B.4** in **Appendix B**.

6.4 Boat Design #4

This boat is inspired by racing sailboats. These racing boats are storm sails, specifically a storm jib which is commonly used due to its aid in speed [18]. The jib is used to improve handling and to increase sail area on a sailboat, therefore helping to increase speed [18]. The only potential downside to this design could be accounting for wind resistance, but given the location of the pool, there will be adequate cover for it to be negligible [18]. The boat itself is quite long and narrow, so that it can better traverse through water, since longer boats create a larger displacement of water for them to travel farther distances [18]. In terms of the hull, most sailboats use a round bottomed displacement hull. These hulls are meant for the boat to move through the water by pushing it aside, allowing the boat to cut through any sort of water with ease. These types of hulls typically are limited to lower speeds, but the inclusion of a propeller blowing wind into the sail will offset that [18]. The propeller used to power the boat is a 4 blade, large-sized propeller to create a large enough wind current behind the sails to propel the boat forward [18]. Boat design #4 is shown in **Figures B.5** and **B.6** in **Appendix B**.

6.5 Chosen Solution

The best solution for building the race boat is Boat Design #2. The goal of Boat Design #2 is to reduce air drag, optimize weight distribution, and improve overall energy efficiency. A boat with a long length and narrow width is ideal for speed [18], but this design also adjusts the boat's dimensions to handle the extra weight from the fuel cell. Because of its 20-degree deadrise angle, the modified-V hull improves maneuverability and stability [18]. Boat design #2 incorporates a rudder and propellers to reduce air drag and thus increase speed [18], [22]. To maintain speed, it has a three-blade propeller (medium diameter) immersed underwater by the propeller axis approximately one diameter below the waterline [18], [22]. It also has a larger, five-blade fan propeller above water to reduce air drag on the water propeller. This not only increases the boat's speed, but it also improves its stability. A floating mechanism is used in this design to keep the boat afloat and stable while in motion. To accomplish this, the boat's material must have a density less than that of water [17]. The floating mechanism is expected to be made of recycled plastic water bottle or foam, which will mate on the boat's horizontal ends. As this design considers the additional weight from the fuel cell and tanks while aiming to reduce the boat's mass moment of inertia to angle the boat at approximately 30 degrees to generate speed [17], [22], the buoyant material aids in weight distribution. This also ties into one of the objectives, which is to keep the cost under the 20 CAD dollar limit. The layout of the fuel cell storage compartments ensures that the fuel cell is easily accessible for powering the boat while remaining securely attached to a mount. This design also eliminates the risk of electric shock by securing the wiring system with a plastic water bottle to prevent tangling and shielding the wires from submerging in water. Based on these factors, Boat Design #2 is the best option because it meets the functional description, objectives, and constraints specified in the problem formulation section.

7.0 Hydrogen PEM Fuel Cell Specifications

The crux of this project is the PEM fuel cell, which is what we will use to power the motor that will give our boat movement. Using water stored in two beakers that will then be transported into the cell, electrons separated from the hydrogen gas are sent through a circuit to give the cell its power [25]. Like all batteries, however, they require specific conditions to make it work. The hydration of the membrane and type of water used are two extremely important things to keep in mind when working with the fuel cell, so to ensure that it performs at its full capacity those factors need to be taken into account. This section will cover those specifics, as well as provide some more insight on the inner workings of the cell and the calculations that go into making it work.

7.1 Importance of Hydrating the PEM Fuel Cell

As shown in the diagrams below, **Figures 4** and **5**, these kinds of fuel cells use a proton-conducting polymer membrane as the electrolyte (the catalyst in the reaction) to separate the protons from the electrons within the hydrogen fuel; the protons pass through the cell with ease and interact with the oxygen in the atmosphere to create excess water. The electrons, on the other hand, get fed into an external circuit, allowing for an electric output. The reason for needing to hydrate the fuel cell is because if not properly humidified, then the conductivity of the membrane decreases significantly; in turn, more power and energy is consumed to properly separate the protons. If the membrane were to get too dry, it would essentially stop functioning as a proton transporter, and no power would be produced from the cell [25]. On the other hand, however, the membrane cannot become too wet; too much water around the membrane could block it from the H_2 gas entirely, rendering it useless. That is why a proper balance between the cathode and anode side are imperative to ensuring the fuel cell is working at max efficiency and power.

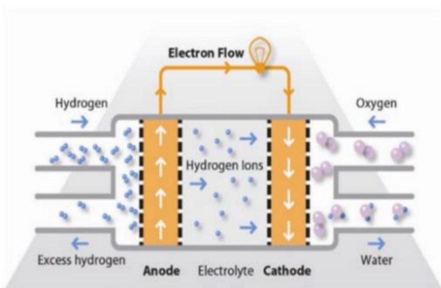


***Figure** 4 How hydrogen power works*

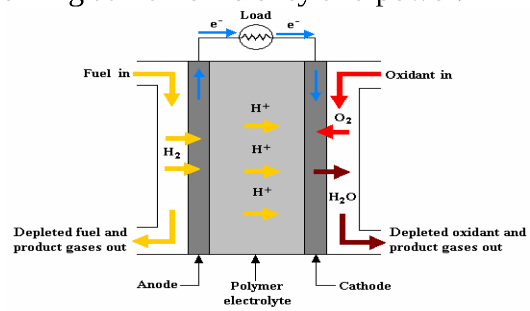


***Figure** 5 Schematic of a Hydrogen Fuel Cell*

7.2 Distilled or Deionized Water being used for the Fuel Cell Over Tap Water

When using a PEM fuel cell, it is imperative that the water used is free of other minerals or contaminants (such as calcium, copper, cadmium) as well as making sure it is in a neutral state with no charge. This is because having foreign materials within the fuel cell could cause a multitude of problems; unfiltered tap water is an excellent conductor of electricity, mainly because of the salts within the water that carry a charge. If it was run through the fuel cell, it could cause a potentially harmful electric discharge if foreign particles were to get into the circuit [26]. It is also important that the water is completely pure, to ensure accurate results on the electric output of the cell. In most chemical experiments, scientists will use deionized water, as it assumes the chemistry of whatever product is added, and doesn't introduce any foreign chemicals or elements to ruin the experiment. Likewise, pure, deionized water is critical to the fuel cell – only hydrogen and oxygen are necessary to make the cell functional, and it's imperative that only those two elements are able to enter the cell [26].

7.3 Amount of Gas (in moles) in Each of the Gas-Storage Cylinders When Starting the Electrolysis Process until the Hydrogen Gas (H_2) Bubbles

Anode

$H_{2(g)} \rightarrow 2H^+_{(aq)} + 2e^-$

Cathode

$\frac{1}{2}O_{2(g)} + 2H^+_{(aq)} + 2e^- \rightarrow H_2O_{(l)}$

Overall reaction

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

The reaction happens at SATP

$T = 25°C = 298.15\ K$

$P = 1\ atm$

$V = 80\ mL$ per cylinder (or $0.08\ L$)

$R = 0.082058$

$n = ?$

$PV = nRT$

$n = \frac{PV}{RT} = \frac{1(0.08)}{0.082058(298.15)}$

$n = 0.00326989\ mol\ H_2$

for O_2, $n = 0.0012262 \times \frac{1\ mol\ O_2}{2\ mol\ H_2} = 0.00163495\ mol\ O_2$

$\therefore$ 0.00326989 mol of H_2 gas and 0.00163495 mol of O_2 gas

As you can see from the equation, there would be about 0.0033 moles of H_2 gas, and 0.0016 moles of O_2 gas within the gas cylinders at the time that the process starts.

8.0 Buoyancy Calculations

Calculations were conducted through an experiment in the WEEF Lab at the University of Waterloo. The objective of the lab was to measure the voltage and current that a hydrogen reversible PEM fuel cell produces to power a DC motor within 300 seconds or until it comes to a complete stop. The findings were used to determine if modifications were necessary to reduce the boat's weight, thereby optimizing the boat's velocity. Calculations of the boat's buoyancy were computed to predict if the boat will be able to float on water. Further calculations were made using Henry's Law to estimate the amount of hydrogen and oxygen that will be lost in contact with water. The cumulative findings will help achieve fuel cell efficiency to aid the optimization of the three boat design considerations: float, balance, and maneuverability.

8.1 Determining the Mass

The buoyancy calculation is used to predict if the boat will float based on these criteria: the material of the boat and the estimated volume of the boat. The material that was chosen is PLA filament to 3D print the boat from a brand called OVERTURE® [27]. This was selected because there was an assumption made that since the filament is plastic essentially, it should be able to float since its density is less than water [27]. The calculated mass of the 3D printed parts labelled in **Table 2** was determined, refer to **Figure C.1** in **Appendix C** for an explanation. The rest of the masses were weighted using a scale. **Table 2** shows the estimated mass of each entity that will contribute to the boat's final product. The additive mass will be used to help calculate the buoyancy of the boat and if there are any modifications that can be made to minimize the boat's weight.

Table 2 *Mass of each Entity to Design the Boat*

Mass of each Entity to Design the Boat	
Type of Entity	Mass (in grams)
Hydrogen Reversible PEM Fuel Cell	66
Two Water and Gas tanks and Tubing	51
Amount of distilled water (x2 cylinders)	60
Body of the boat (3d printed)	478.7
DC motor and wiring	48

Mechanism of the boat (3d printed propellor)	10.5
Mechanism of the boat x2 (foam pool noodle floaties)	16.2

8.2 Determining if the Boat is Buoyant

Assume the volume of the boat to be 0.00131807223 m^3, refer to **Figure C.2** in **Appendix C** for an explanation on how to get the volume. The buoyant force is calculated using this equation:

$$F_B = V\gamma \quad \text{(Equation 1) [28], [29]}$$

Where, F_B is the buoyant force measured in Newtons (N)
V is the submerged volume measured in meters cubed (m^3)
γ is the specific weight of the fluid measured in the weight per unit volume (N/m^3)

When adding the mass from **Table 2**, the force due to gravity is calculated using this equation:

$$F_g = mg \quad \text{(Equation 2) [28], [29]}$$

Where, F_g is the force due to gravity the measured in Newtons (N)
m is the mass of the object measured in kilograms (kg)
g is the force that pulls an object toward the center of the earth measured in meters per second squared (m/s^2)

The buoyant force should possess a value equal to the force due to gravity for the boat to float [8], [19] as the weight of the water displaced is equal to the total weight of the boat and all it holds [20].

Since, $F_{NET} = 0$ where $F_{NET} = F_B - F_g$, $F_B = F_g$

To calculate the buoyant force,
Let $V = 0.00065671752\ m^3$ and $\gamma = 9.807\ \frac{kN}{m^3} = 9807\ \frac{N}{m^3}$,

Where the boat has a height of 60.0 mm, subtract the height measured when the boat is submerged in water which is 35.4 mm. When recreating the model on Solidworks, the volume that is not submerged under water is measured to be $0.000461061047\ m^3$.

$F_B = V\gamma = (0.00065671752\ \cancel{m^3})(9807\ \frac{N}{\cancel{m^3}}) = 6.440428719$ N ≈ 6.4 N

To calculate the force due to gravity,
Let $m = 655.2$ g and $a_y = g = 9.807\ m/s^2$
$F_g = mg = (655.2\ \cancel{g})(\frac{1\ kg}{1000\ \cancel{g}})(9.807\ \frac{m}{s^2}) = 6.4255464$ N ≈ 6.4 N

∴ Since the buoyant force equals the force due to gravity, the boat will float – in other words, the boat is buoyant.

Below in **Figure 5** is a free-body diagram of the boat design floating on a body of water, when it is at rest and when it is accelerating, respectively:

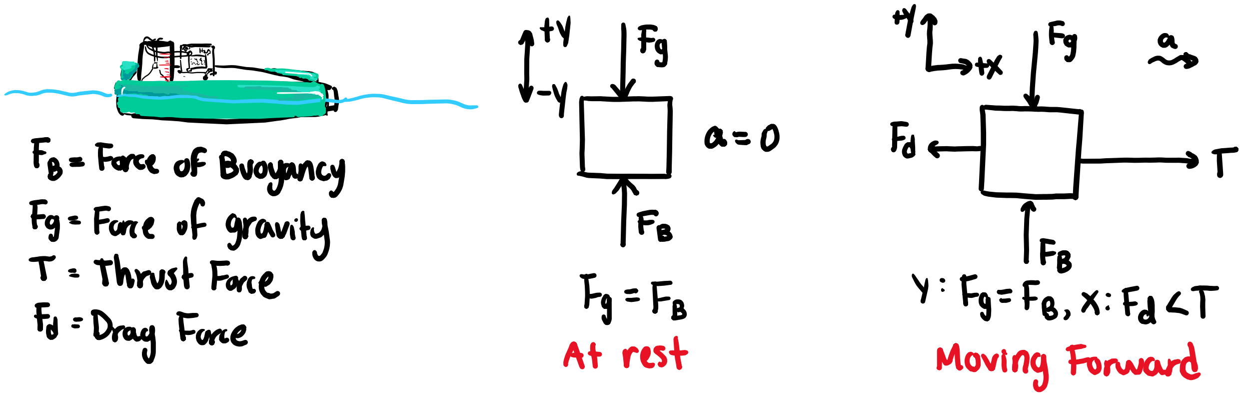


Figure 6 *Free-Body Diagram of the boat floating on water at rest and accelerating respectively*

9.0 Voltage and Current Measurements

Voltage and current measurements were taken from powering a DC motor using a hydrogen reversible PEM fuel cell. This will be used to determine if modifications need to be made to the boat design to help minimize the boat's weight.

If there is a rapid voltage drop observed during the measurements, it suggests that the voltage supplied to the DC motor is decreasing at a fast rate. This could be an indication of excessive power losses or inadequate power delivery due to various factors such as resistance, inefficient fuel cell operation, or excessive load on the system.

Similarly, if there is a rapid drop in current, it implies that the electrical current supplied to the motor is decreasing quickly. This may be due to factors such as increased electrical resistance, limitations in the fuel cell's current output, or excessive load demand. When a rapid current drop occurs, it is essential to evaluate the boat's weight and design to ensure that it is not placing unnecessary strain on the fuel cell system.

Conversely, if the voltage and current measurements show stable or gradual drops over time, it indicates a more efficient power delivery and suggests that the boat's weight might already be optimized. In such cases, modifying the boat's design to minimize weight may not be necessary, as the system is operating within an acceptable range of efficiency.

For the voltage measurements, the equation of the exponential function plotted is:

$$V_{DC}(t) = V_0 e^{-bt} \quad \text{(Equation 3) [29]}$$

Where, $V_{DC}(t)$ is the voltage drop at a certain time measured in Volts per second (V/s)
V_0 is the initial voltage measured in Volts (V)
b is the slope constant of the Voltage drop
t is the time measured in seconds (s)

The exponential function allows us to describe how the voltage changes over time. By examining the value of b, we can assess the slope or steepness of the voltage drop. A rapid voltage drop indicates potential issues with the system, suggesting that modifications to reduce the boat's weight may be necessary to help increase the power.

For the current measurements, the equation of the exponential function plotted is:

$$I_{DC}(t) = I_0 e^{-bt} \qquad \text{(Equation 4) [29]}$$

Where, $I_{DC}(t)$ is the current drop at a certain time measured in Amperes per second (A/s)
I_0 is the initial current measured in Amperes (A)
b is the slope constant of the Current drop
t is the time measured in seconds (s)

Similar to the voltage equation, the exponential function for current enables us to model the current drop over time. By analyzing the value of b, we can determine the rate at which the current decreases. A rapid current drop might indicate the need to reconsider reducing the boat's weight.

9.1 *Fuel Cell #1*

Using the values from **Table D.3** in **Appendix D**, it produced the graphs shown in **Figures 6** & **7**. **Figure 6** shows a scatter plot with the change in voltage over 300 seconds. As the voltage starts at 0.6721 volts in 0 seconds, the voltage decreases by 0.0003 volts per second. **Figure 7** shows a scatter plot with the change in current over 300 seconds. As the voltage starts at 0.0941 amperes in 0 seconds, the current decreases by 0.0006 amperes per second.

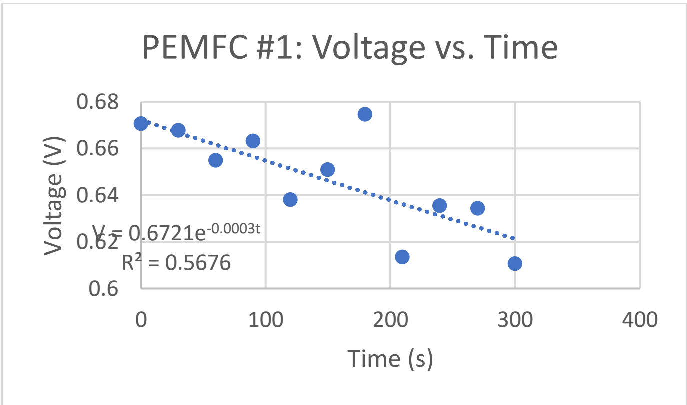


Figure 7 *Voltage vs. Time Graph for the first PEM fuel cell*

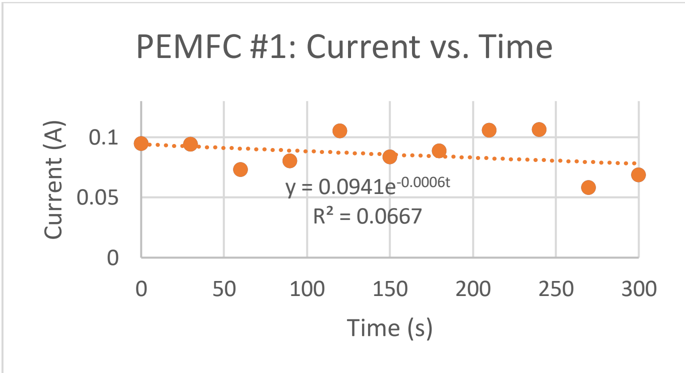


Figure 8 *Current vs. Time Graph for the first PEM fuel cell*

9.2 *Fuel Cell #2*

Using the values from **Table D.4** in **Appendix D**, it produced the graphs shown in **Figures 8** & **9**. **Figure 8** shows a scatter plot with the change in voltage over 300 seconds. As the voltage starts at 0.7005 volts in 0 seconds, the voltage decreases by 0.0001 volts per second. **Figure 9** shows a scatter plot with the change in current over 300 seconds. As the voltage starts at 0.08263 amperes in 0 seconds, the current decreases by 0.0005 amperes per second.

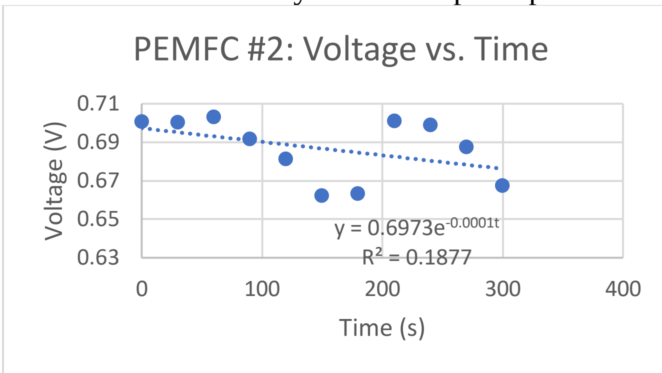


Figure 9 *Voltage vs. Time Graph for the second PEM fuel cell*

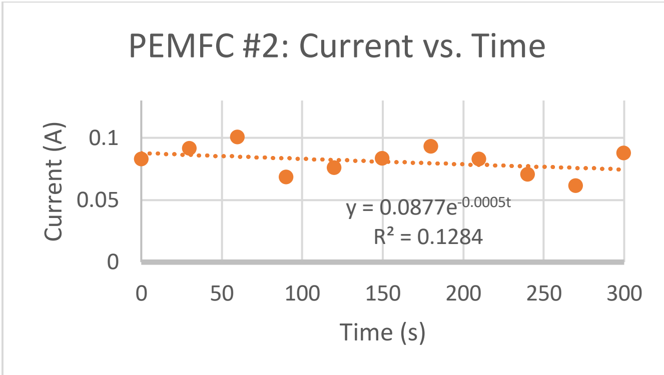


Figure 10 *Current vs. Time Graph for the second PEM fuel cell*

9.3 *Fuel Cells Connected in Series*

Using the values from **Table D.5** in **Appendix D**, it produced the graphs shown in **Figures 10** & **11**. **Figure 10** shows a scatter plot with the change in voltage over 300 seconds. As the voltage starts at 1.4124 volts in 0 seconds, the voltage decreases by 0.003 volts per second. **Figure 11** shows a scatter plot with the change in current over 300 seconds. As the voltage starts at 0.10621 amperes in 0 seconds, the current decreases by 0.001 amperes per second. The fuel cell connected in series has doubled the voltage and current in comparison to fuel cell #1 and #2. This is because there are two power sources.

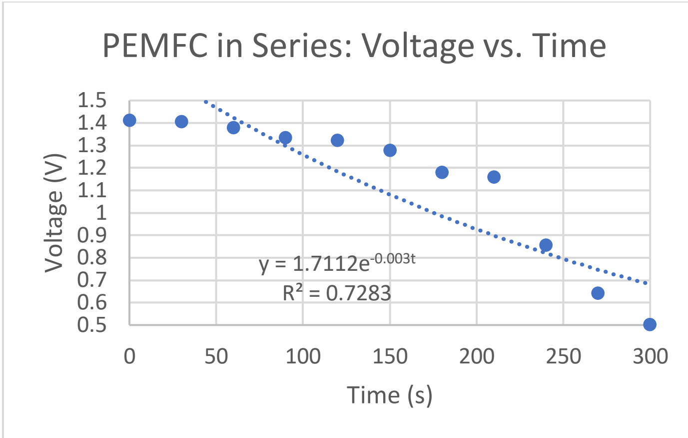


Figure 11 *Voltage vs. Time Graph for the PEM fuel cell connected in series*

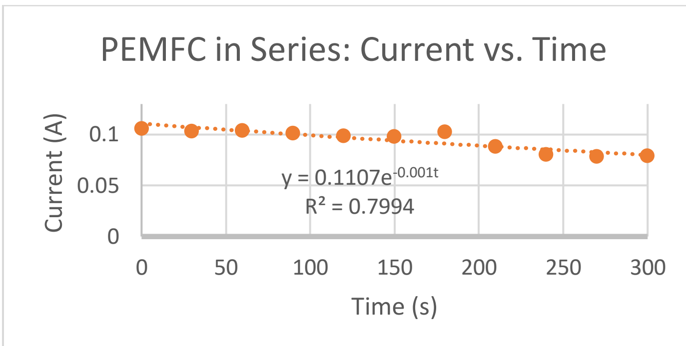


Figure 12 *Current vs. Time Graph for the PEM fuel cell connected in series*

Evaluating the three options: Fuel Cell #1, Fuel Cell #2, and the Fuel Cells connected in series, the fuel cells connected in series is the best option to power the fuel cells because it produces the most power. However, the extra added weight may not be a feasible solution because it dismisses one of the constraints, to minimize the weight of the boat (even the load) as much as possible. So, look at the next best option, Fuel Cell #1. This is because the voltage drop of the first fuel cell is more consistent than the second fuel cell. If the voltage and current drops drastically that affects the power of the fuel cell as the equation follows:

$$P = IV \qquad \text{(Equation 5) [30]}$$

Where, P is the Power measured in Watts (W)
I is the Current measured in Amperes (A)
V is the Voltage measured in Volts (V)

If either the voltage or current decreases, that will simultaneously decrease the power. So, there exists a need for the voltage and current to maintain the power efficiency of the fuel cell. If the fuel cell can maintain its voltage and current, this will also help maintain the speed of the boat.

9.4 Interpreting Errors in the Results

Although this may be the case, for each fuel cell, the R^2 has a value of under 0.50, meaning that approximately 50% of the variability in the outcome data has a lack of consistency. This lack of consistency was possibly affected by the tubing that connects the fuel cell to the tanks. There were moments when the motor would come to an abrupt stop. This was later discovered that one of the tubing was faulty. The fuel cell had to be held at an upwards orientation, putting pressure on the tubing into the inlet. Research suggests that increases in pressure drop are moderately synchronized with decreases in fuel cell voltage [31]. Thus, means that there requires a need to exert pressure of the tubing into the inlet; air from the faulty tubing was released prior which caused the pressure drop. Another reason for the fluctuating results may be due to the alligator clips moving out of place. While taking the tip of the multimeter test leads and measuring the voltage/current of the DC motor, even moving a bit away from the motor can increase the value of the voltage drop. In terms of the current, as the current decreases, the flow rate simultaneously also decreases. To increase the current again, the fuel cell must be hydrated [31]. However, in this case when comparing the voltage and current of the two fuel cells, it is difficult to precisely pinpoint which one has the greater current. On one hand, one fuel cell could be hydrated more than the other which skewed the results.

10.0 Fuel Cell Efficiency

The high efficiency is mainly attributed to the electrochemical reactions occurring at the anode and cathode of the fuel cell [32]. The maximum conversion efficiency occurs at the reactants' temperature of 298.15 K [31]. Performance of the fuel cell also increases due to lower diffusivity of the hydrogen resulting in the gas coming in contact with the catalyst surface to power the fuel cell [33]. To get this effect, the fuel cell should be set-up in the same condition where it will be used [33]. Air and hydrogen flow rates, through both sides of the PEMFCs, are comparatively slow and result in a loss of efficiency of about 1–3% [31]. The lowest value of the efficiency of a H_2-O_2 fuel cell, for the hydrogen fuel to convert directly into electrical energy, is approximately 60% [32] and the corresponding highest maximum efficiency is 82.7% [32].

10.1 Amount of O_2 and H_2 Lost by Storing the Gas in Contact with Water

O_2 k_i: 1.3×10^{-3} [34]

$$C_{O_2} = K_{O_2} P_{O_2} = 1.3\times10^{-3}(0.9687) = 1.25\times10^{-3}\ \frac{\text{mol } O_2}{\text{kg water}}$$

$$1.25\times10^{-3} \times 0.0377\text{ kg water} = 4.7\times10^{-5}\text{ mols } O_2$$

$$4.7\times10^{-5} \times 32\text{ g/mol} = 1.519\times10^{-3}\text{ g } O_2$$

$$\% = \frac{1.519\times10^{-3}}{3.4\times10^{-3}\times 32} = 13.96\%\ O_2 \text{ lost}$$

H_2 k_i: 7.8×10^{-4} [34]

$$C_{H_2} = K_{H_2} P_{H_2} = 7.8\times10^{-4}(0.9687) = 7.55\times10^{-4}\ \frac{\text{mol } H_2}{\text{kg water}}$$

$$7.55\times10^{-4}(0.0377\text{ kg } H_2O) = 2.848\times10^{-5}\text{ mol } H_2$$

$$2.848\times10^{-5}(2.02\text{ g/mol}) = 5.75\times10^{-5}\text{ g } H_2$$

$$\% = \frac{5.75\times10^{-5}}{6.8\times10^{-4}(2.02)} = 4.18\%\ H_2 \text{ lost}$$

$$P\text{ (for both)} = 0.9687\text{ atm}$$

10.2 Improving Efficiency of the PEM Fuel Cell

Dehydration of the fuel cell will cause its performance to degrade due to the starvation of gas at both cathode and anode sides. The starvation in hydrogen or oxygen will lead to a reduction in output voltage and thus affect the fuel cell's reliability and performance [31]. As the hydrogen flow rate increases, the output voltage decreases due to the dominance of oxygen partial pressure and water content in the membrane which increases the losses in the fuel cell, and performance drops at higher current density regions [33]. High airflow rate may cause damage to delicate components such as the membrane. When it becomes impossible to efficiently remove the water which has been collected in the cathode, the water flooding affects PEMFC's performance badly [31]. If the membrane operated for long periods under dehydrated conditions, the membrane becomes brittle, and it may develop cracks [31]. To ensure maximum efficiency in this aspect, we have to make sure that we properly and accurately hydrate the cell, ensuring no air pockets are left within the tubing or the cell itself, and making sure the cell is not running when it does not need to be, to preserve the hydration inside so it operates at its max efficiency [31].

One also must be cautious of flooding which may occur at the cathode side [31]. Water is generated by oxygen reduction reaction and the amount of water continues to increase with the increase of current density and load [31]. Under the influence of an electric field, water particles and protons are pulled from anode to cathode by ions, known as electro-osmotic drag [31]. The amount of water transferred is determined by the level of membrane humidity and can be increased by increasing the current density [31]. Over-humidified reactant liquid water injection and gases also causes flooding to occur [31]. If an individual wanted to specifically seek out what may be prompting the fault, refer to **Table 3**.

Table 3 *Location and consequences of flood faults [31]*

Fault location	The consequence of faults
Gas diffusion layer (GDL)	Loss of porosity and reduction in gas permeability
Gas channels	Low pressure in gas flow channels Low flow rate of gas channels Decay and change in gas channel geometry
Electrodes	Inhomogeneous pressures in bps Decay and change in flow-filled geometry
Membrane	Reduced mass transportation

High temperature in the fuel cell is another fault, as increasing the reactants temperature simultaneously decreases the efficiency [32]. The low conductivity caused by the high-resistance cell is linked to the membrane's radical correlation with relative humidity [31]. This will result in a significant reduction in cell effort and electrical power [31]. Although the temporary decrease in effort can be recovered by rehydrating the cell, operating the cell under dry conditions for an extended period causes irreversible damage to the cell, particularly the membrane [31].

To mitigate those faults, carefully control the behaviour of the fuel cell. Hydrating the cell will help minimize loss voltage in the fuel cell’s membrane as well as improve the fuel cell's efficiency and performance [31]. There exists a need to transport the fuel cell in the same conditions (e.g., temperature), otherwise, it may affect the performance of the PEMFC as it takes time to adjust to those conditions [31]. Though, if the fuel cell is damaged, the recovery time is determined by membrane thickness and water diffusion [31].

General setup is also important to ensure that the cell is optimized to work properly. Things like making sure that the cell is charged all the way from the battery, making sure that the gas outlets are open as to allow gas to be constantly diffusing through the tank, and ensuring that all wiring/piping within the cell is connected properly are crucial for the cell to perform at its max efficiency without needing to make any significant changes to our design [31].

Once the boat is fully assembled, it is imperative that the propeller that will be attached to the motor is not extremely heavy; the added weight on the motor would make it require more power to fully turn the propeller, which would in turn affect the cell and its energy output. Ensuring that the propeller is lightweight will provide a faster RPM, giving our boat more efficiency and power [31].

11.0 Electrochemistry

11.1 Theoretical Cell Voltage in Standard Conditions

$$H_2 \longrightarrow 2H^+ + 2e^- \quad \text{(anode, oxidizing)}$$

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O \quad \text{(cathode, reducing)}$$

$$E_{cell} = E_{red} - E_{ox}$$

$$= 1.229\,V - (0\,V)$$

$$= 1.229\,V \text{ overall}$$

In this first calculation, we took the two tanks; the hydrogen tank, which was the anode, and the oxygen tank, which was the cathode, and broke down the overall reactions into their separate half reactions. Using their cell potential values, we then calculated the voltage of the overall cell, which ended up being 1.229 volts.

11.2 Theoretical Current

for measured power, we use the voltage and current recorded at 0 seconds in one fuel cell

$$P = IV = (0.0941)(0.6721) = 0.06324461$$

for calculated power, we use the voltage and current calculated from parts 1 and 2

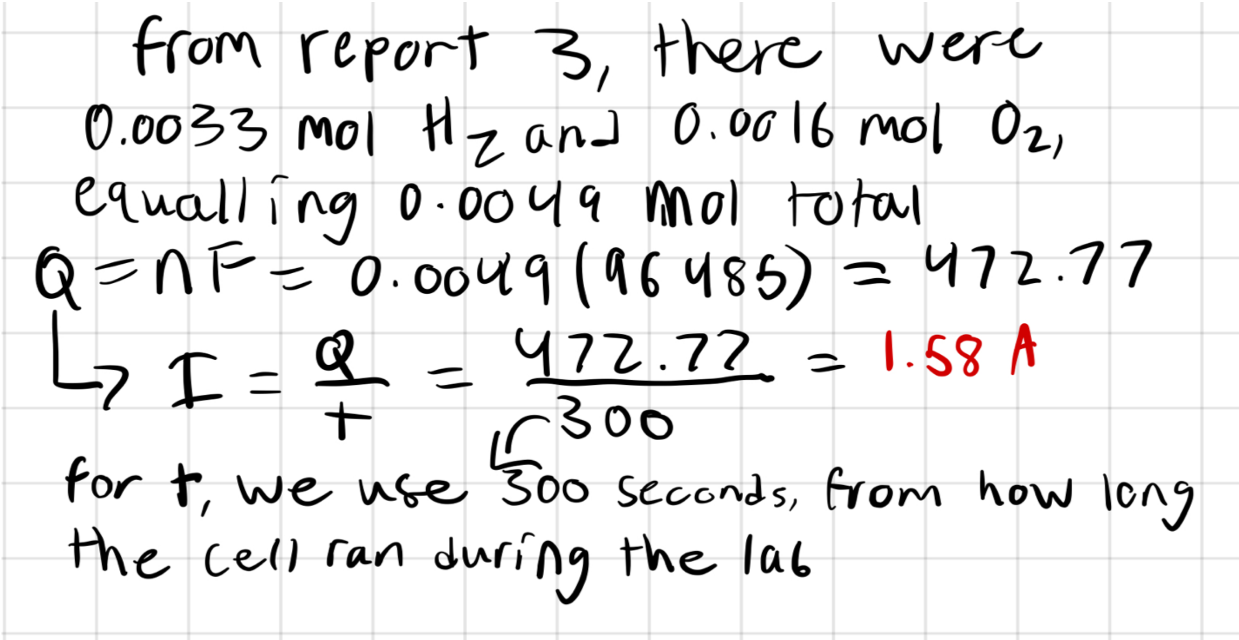
$$P = IV = 1.58(1.229) = 1.94182$$

to calculate efficiency;

$$\frac{0.062324461}{1.94182} \times 100 = 3.21\%$$

In this equation, we took the values of both H2 and O2 moles, and added them together to get the overall mole number that flows through the cell. Multiplying that by Faraday’s constant would equal out to about 472.77 Coulombs. Then, to calculate ur rent, we visited it by the time (in seconds) that the cell ran during our voltage lab, which then equaled out to about 1.58 Amperes of current.

11.3 Estimated Efficiency of the Fuel Cell



from report 3, there were 0.0033 mol H_2 and 0.0016 mol O_2, equalling 0.0049 mol total

$Q = nF = 0.0049(96485) = 472.77$

$\hookrightarrow I = \frac{Q}{t} = \frac{472.72}{300} = 1.58\ A$

for t, we use 300 seconds, from how long the cell ran during the lab

As shown by the calculations above, the electric efficiency of our cell chalks up to a measly 3.2%, in comparison to the values calculated. However, this can be explained through a multitude of things; the values calculated are a theoretical, perfect world type situation where every single part of the fuel cell runs at its peak capacity, working exactly how it should. What the measured value shows is other things being considered; human error, error with the wiring, improper cell priming, and other factors that could lead to a less than ideal efficiency. For example, the cell perhaps may not have been charged to its maximum, making the voltage and current displayed less than what it could be.

12.0 Conclusions

The experiment conducted aimed to optimize the efficiency of a hydrogen fuel cell boat by measuring the voltage and current outputs produced by the fuel cell, determining the boat's buoyancy based on calculations, and analyzing the potential loss of hydrogen and oxygen gases when in contact with water. Through calculations and precise measurements, the weight of the boat and its individual components were assessed, providing insights into its overall buoyancy and floating capability. The obtained data indicated a gradual decrease in both voltage and current over the course of the experiment, suggesting there is no need for weight reduction modifications, however a need to explore techniques to enhance fuel cell efficiency. As a result, the thorough research results and conclusions offered in this paper provide helpful suggestions and insights for upcoming efforts in the development, management, and optimization of hydrogen fuel cell boats. **Figure 13** shows the final result of the boat.

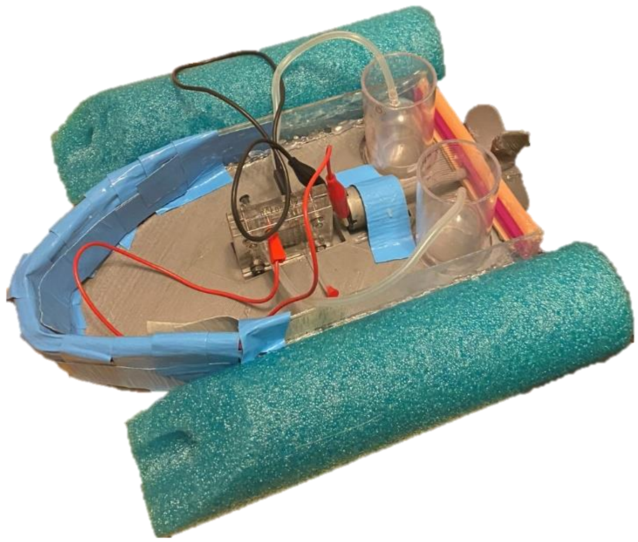


Figure 13 *Final boat design with the fuel cell kit mounted*

12.1 Recommendations

Backup Plan for 3D Printer Failure: During the fuel cell boat project, the team encountered significant setbacks arising from recurring 3D printer failures, which substantially hindered the timely production of critical boat components. The team ought to have taken a more proactive stance to prevent and alleviate such problems in the future. The project's inception would have benefited from a thorough risk assessment to detect potential issues and create workable backup plans. By anticipating the possibility of 3D printer failures, the team could have explored other viable resources for printing boat components. Having these backup plans in place would have ensured smoother progress and minimized disruptions caused by technical setbacks.

Optimized Propeller Design: In the fuel cell boat project, the propeller's design played a pivotal role in determining the boat's overall performance. To achieve better results, dedicating additional time to thorough research and development would have been essential. Throughout the project, unexpected challenges arose, notably the boat unexpectedly stopping in the water. This issue could likely be attributed to the propeller's design and other related factors. To address such unanticipated situations, the team could have prepared by having a backup propeller readily available. By having a contingency plan in place, the team could have ensured continuous boat movement during testing and demonstrations, preventing potential delays in achieving project objectives.

Motor Placement: The boat's stability and general performance on the water were greatly influenced by where the motor was mounted. A clever move to enhance the boat's balance and handling may have been to position the motor at the far back and connect it directly to the propeller. This design choice would have eliminated the need for an axis running through the middle, reducing potential points of failure and enhancing the boat's power efficiency. To ensure optimal motor placement, the team could have invested considerable time in thorough research. By studying motor placement principles for fuel cell boats and drawing insights from previous successful designs, the team could have made informed decisions without necessarily requiring expert consultation.

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Appendences

Appendix A

The present Appendix A exhibits how the project will be organized according to the skillset of the group members. This project will require a group contract to work on our accords, a group resume to view the group's skillsets, and a Gantt chart to organize what each member will be assigned to work on according to each group member's skills.

Team 8 Contract

Team-8 Contract for GenE 101 Fuel Cell Project

A. Discuss Team Leadership & Communication:

A.1 Team Leadership/Roles

A.1.1. Roles will be assigned prior to a meeting or, if this is not possible, at the beginning of a meeting.

A.1.2. The best approach would be to have shared leadership. Roles will rotate each meeting to allow every member to show their strength(s) at one point throughout the project – ergo evading conflict.

A.1.3. The Recorder is responsible for taking in-session notes and preparing presentation materials from these notes.

A.1.4. The Timekeeper is responsible for keeping track of the time allotted to each discussion and keeping the group aware of time remaining. The leader is responsible for deciding what to do when time is running out during a discussion.

A.1.5. The Devil's Advocate will keep his/her mind open to problems, possibilities, and divergent or opposing ideas.

A.1.6. The Harmonizer strives to create a harmonious and positive team atmosphere and reach consensus (while allowing a full expression of ideas).

A.2 Decision-making

A.2.1. The team will come to a decision by (i) unanimous agreement and discuss anything until we all agree on one thing (ii) a majority vote.

A.2.2. Decisions requiring unanimity can be made during meetings even if all team members are not present.

A.2.3. Anonymity can provide an additional layer of comfort that will allow introverts to actively participate or those who lack confidence. Therefore, each of us can write our ideas down on pieces of paper, and randomly read out our ideas to reach a decision.

A.2.4. The Delphi technique can be used to reach a group consensus for a major decision. We take all the ideas generated by our team and condense them into a smaller list of possible approaches. Those fewer options are up for further discussion and collective consideration.

A.2.5. Have a discussion on the advantages and disadvantages of each option. After comparing each option, we can choose the option with (i) the most advantages and least disadvantages (ii) the equal number of advantages and disadvantages but find a way to mitigate those disadvantages (iii) the most advantages and no disadvantages.

A.3 Submissions

A.3.1. No one is specifically in charge of anything.

A.3.2. We will assign aspects of this project to (i) a member(s) who prove competence to that aspect of the project (ii) if a group member is interested in doing it but does not have that skill, the member who has experience can teach them.

A.3.3. Carina is responsible for submitting ALL milestones on time. The following are due dates for each milestone:

A.3.3.i Fuel Cell Project Milestone #1: Safety and Group Contract **due Wednesday, May 24th**

A.3.3.ii Fuel Cell Project Milestone #2: Engineering Design and Gas Law **due Monday, June 14th**

A.3.3.iii Fuel Cell Project Milestone # 3.1: Independent Research **due Wednesday, July 5th**

A.3.3.iv Fuel Cell Project Milestone #3.2: Gas Solubility and Current & Voltage Measurements **due Monday, July 10th**

A.3.3.v Fuel Cell Project Milestone #4: Final Report **due Sunday, July 30rd**

A.4 Preferred Method of Communication

	Team Member Name	**Email**	**Telephone or Other Contact Information**	**Preferred mode of Contact**
1	Wardah Anwer	wianwer@uwaterloo.ca	416-936-9111	Text
2	Haya Irfan	hirfan@waterloo.ca	905-808-7221	Text
3	Justin Medeiros	j5medeir@uwaterloo.ca	905-866-8890	Carrier Pigeon
4	Carina Sinbandhit	cpsinban@uwaterloo.ca	647-278-4663	Text / in-person

B. Establish Team Meeting Norms and Expectations

B.1 Day, Time, Place, and Frequency for Regular Team Meetings:

B.1.1. Meet every week during our GenE 101 lab time on Thursdays in RCH 306 (i) meetings are note constrained to listed time (ii) meetings that happen other than the listed time must be arranged via preferred mode of contact where the group must come to a mutual agreement.

B.1.2. Text group members on group chat if there is a belief of an emergency meeting.

B.2 Punctuality and Participation at Team Meetings

B.2.1. Try to attend meetings on time. If someone is going to be late then they must let the group know.

B.2.2. Come prepared to share with the group at every meeting.

B.2.3. Be present in meetings (i) do not just sit and be silent, participate in discussions and provide ideas (ii) do not walk away midway of a discussion to talk to other friends (iii) keep cell phone usage and other distractors to a minimum (iv) try to stay on topic regarding the current milestone (v) listen actively to what others must contribute.

B.2.4. All group members will remain in the meeting until (a) all tasks for that meeting are completed, or (b) there is unanimous adjournment.

B.2.5. Breaks will be decided by unanimous consent, and breaks will not exceed twenty minutes in length.

B.3 Method for Setting and Following Meeting Agenda and Note Taking

B.3.1. Summary of discussions during the meeting written towards the end of meeting.

B.3.2. The group will discuss the agenda for the next meeting and divvy up work to be completed for next time.

B.3.3. One person will be responsible for taking notes at each meeting.

B.3.4. Documents of the notetaking will be shared with the rest of the group via Microsoft Word to be accessed at any time. Check section A.4 Preferred Method of Communication for each group member's email.

B.4 Procedures in the Absence of a Team Member

B.4.1. Make sure that the person who is absent is filled in ASAP on what they missed in the meeting.

B.4.2. If possible, loop them in through video/phone call so they can be present remotely.

B.4.3. Documents in minutes will be shared with everyone in the group, which can be checked at any time to see what was missed. The group member who missed the meeting is responsible for catching up by reading the meeting summary document.

C. Discuss Team and Individual Expectations

C.1. Desired Grade or Goal for the Project

C.1.1. Always aim for 100%. Aim higher so we do not get a failing grade if we aim for a pass. This can be done by (i) conducting weekly meetings (ii) equally allocating the work for each group member (iii) trying our best while producing high quality work.

C.1.2. The goal of our design of the cell powered boat includes (i) a constraint such as a functional boat (i.e., motor operates which accelerates the boat at a fast speed while balanced) (ii) a criterion such as the aesthetics of the boat.

C.1.3. A recommendation to develop engineering essential skills such as CAD modelling, 3D printing, laser cutting, and whatnot when manufacturing the boat where (i) if one person wants to learn a skill that someone else who already possesses that knowledge and/or skill should assist them.

C.2. Expectations for Completing Assignments and Meeting Deadlines

C.2.1. Wardah Anwer:

- Set daily goals to complete thus not procrastinating to make the workload more manageable as she simultaneously balances academics.
- Forcing deadlines will motivate her to complete the assigned tasks on time.
- Finishing ahead of time will leave time for final revisions for the betterment of the assignment.

C.2.2. Haya Irfan:

- Tend to procrastinate and crunch everything at the end.
- Start work super early but then do not finish it until close to the due date.
- Always manage to complete work.
- Prefers to work alone and then come together as a group after to polish the content of the assignment.

C.2.3. Justin Medeiros:

- Tends to procrastinate and leave everything to the day of.
- Sets small goals throughout the week to try and finish certain parts by a given date, so that everything is not left until the last second.
- Prefers working in groups as having people to give and receive feedback is always beneficial.

C.2.4. Carina Sinbandhit:

- Tends to work on everything early up until the due date (hates procrastinating).
- Would cover for an absent team member if they procrastinate.
- Prefers to work alone at first then come together as a group to discuss progress then combine the project, revising repetitiveness and consistency.

D. Managing Team Challenges and Conflict

D.1. In an Event of a Disagreement

D.1.1. The group will not avoid it or engage in gossip but will instead address it directly and respectfully.

D.1.2. Team members should be dealt with directly and without hostility if they fail to accomplish their allocated tasks unless given prior notice. After three strikes, the instructors will be informed.

D.1.3. On occasion, the person may need help, but they can be reluctant to ask for it. Therefore, it's crucial to first comprehend the fundamental causes rather than getting furious at them for their unfinished duty.

D.1.4. As it is a joint effort, if the task is not completed, we will all work together to support the team members, but that team member must also put in the effort to complete it.

D.1.5. Try and find common ground between two ideas to reach reconciliation.

D.1.6. Do not let personal feelings impact your work in the group. Focus on the task.

D.2. Breach of Contract

D.2.1. A meeting will be convened for all non-participating members to address the contract violation, and a fair and suitable consequence will be determined. Failure to attend will result in the instructors getting involved which may lead to a reduced grade.

D.2.2. During the meeting, members will deliberate on the allocation of additional tasks and decide on the recipients.

E. Other Considerations

E.1. Other tenants or agreements that your team has agreed are important to agree upon

E.2. Be respectful such that (i) everyone's opinions and ideas are not ignored (ii) aggressive and dominating behaviour is not acceptable (iii) sexist, racist, and other offensive and discriminatory remarks are not acceptable.

E.3. Not being afraid to receive or share constructive criticism.

E.4. Ask questions or seek help whenever you are confused.

E.5. Expectations of each member to contribute equally, producing high quality work.

E.6. Each group member has the right to point out whether any of these rules are being broken.

E.7. We are all competent in our own way. Do not look down on another for not knowing something or how to do something.

E.8. Submit the work about 30 minutes before the deadline.

E.9. Do not procrastinate and leave everything for the last second. Some members may be inclined to do your work out of anxiety.

Certification by Team Members:

In appending your signatures below, you are stating that:

(a) You participated in formulating the standards, roles, and procedures of this contract, and

(b) You have agreed to abide by these terms and conditions of this contract.

Wardah Anwer

Team Member #1 Name — Signature

HAYA IRFAN

Team Member #2 Name — Signature

Justin Medeiros

Team Member #3 Name Signature

CARINA SINBANDHIT

Team Member #4 Name Signature

Team 8 Gantt Chart

The Team 8 Gantt Chart is a visual schedule for organizing projected tasks for the fuel cell project and attempting to evenly assign them to team members based on experiences and skills. The grey shaded area of the Gantt Chart depicts the progression of a task. The purple shaded area of the Gantt Chart depicts the duration of a task. The Gantt Chart shows that the project is seperated into six sections: (1) Fuel Cell Project Milestone #1: Safety and Group Contract, (2) Fuel Cell Project Milestone #2: Engineering Design and Gas Law, (3) Design of the Boat, (4) Fuel Cell Project Milestone #3.1: Independent Research, (5) Fuel Cell Project Milestone #3.2: Gas Solubility and Current & Voltage, and (6) Fuel Cell Project Milestone #4: Final Report.

THE FUEL CELL BOAT PROJECT

W. Anwer, H. Irfan, J. Medeiros & C. Sinbandhit
TEAM 8 - MECHEMICAL 8

Project Start: Thu, 5-18-2023
Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Fuel Cell Project Milestone #1: Safety and Group Contract				
Report #1	Everyone	100%	5-18-23	5-23-23
Cover Letter	Carina, Justin	100%	5-18-23	5-20-23
Title Page	Carina	100%	5-18-23	5-23-23
Team Contract	Everyone	100%	5-18-23	5-21-23
Section A	Justin	100%	5-18-23	5-21-23
Section B	Haya	100%	5-18-23	5-21-23
Section C	Carina	100%	5-18-23	5-21-23
Section D	Wardah	100%	5-18-23	5-21-23
Section E	Everyone	100%	5-18-23	5-21-23
Gantt Chart	Everyone	100%	5-18-23	5-18-23
Project Plan	Everyone	100%	5-18-23	5-22-23
Considerations for Boat Design	Carina	100%	5-18-23	5-22-23
Float	Carina	100%	5-18-23	5-22-23
Balance	Carina	100%	5-18-23	5-22-23
Manuverability	Carina	100%	5-18-23	5-22-23
Safety Risks	Everyone	100%	5-18-23	5-22-23
Cite Info + Figures + Table + Appendices	Everyone	100%	5-18-23	5-22-23
Revision Check of the Report	Carina	100%	5-23-23	5-24-23
Fuel Cell Project Milestone #2: Engineering Design and Gas Law				
Report #2	Everyone	100%	6-1-23	6-14-23
Cover Letter	Carina, Justin	100%	6-1-23	6-1-23
Title Page	Carina	100%	6-6-23	6-3-23
Executive Summary	Everyone	100%	6-8-23	6-12-23
Table of Contents	Carina	100%	6-1-23	6-14-23
Needs Assessment	Carina, Justin	100%	6-8-23	6-12-23
Problem Statement	Wardah	100%	6-8-23	6-12-23
Functional Description	Carina, Wardah	100%	6-8-23	6-12-23
Functional Requirements	Carina, Wardah	100%	6-8-23	6-12-23
Non-Functional Requirements	Carina, Wardah	100%	6-8-23	6-12-23
Constraints	Carina, Wardah	100%	6-8-23	6-12-23
"Objectives"	Carina, Wardah	100%	6-8-23	6-12-23
Conceptual Designs	Everyone	100%	6-1-23	6-12-23
Boat Design #1	Justin	100%	6-1-23	6-12-23
Boat Design #2	Carina	100%	6-1-23	6-12-23
Boat Design #3	Wardah	100%	6-1-23	6-12-23
Boat Design #4	Haya	100%	6-1-23	6-12-23
Chosen Solution	Carina	100%	6-8-23	6-13-23
ChE 102 Component: Hydrogen PEM Fuel Cell Specifications	Justin, Haya	100%	6-11-23	6-13-23
Question #1	Justin, Haya	100%	6-11-23	6-13-23
Question #2	Justin, Haya	100%	6-11-23	6-13-23
Question #3	Justin	100%	6-11-23	6-13-23
Cite Info + Figures + Table + Appendices	Everyone	100%	6-1-23	6-14-23
Revision Check of the Report	Everyone	100%	6-13-23	6-14-23
Design of the Boat				
Sketches (then vote on the best)	Everyone	100%	6-13-23	6-13-23
Create List of Required Items	Everyone	100%	7-1-23	7-1-23
Purchase Items	Carina	100%	7-2-23	7-5-23
Prototyping	Wardah, Justin, Carina	100%	7-6-23	7-6-23
CAD Modelling	Haya	100%	7-9-23	7-15-23
Manufacturing	Everyone	100%	7-15-23	7-19-23
Testing	Everyone	100%	7-17-23	7-19-23
Photograph Design Development	Carina	100%	5-23-23	7-20-23
Fuel Cell Project Milestone # 3.1: Independent Research				
Report #3.1	Everyone	100%	6-12-23	7-5-23
Independent Research	Everyone	100%	6-12-23	7-5-23
PEM Fuel Cell Efficiency when Producing Power	Carina	100%	6-12-23	7-5-23
Environmental Impacts of Fuel Cells	Wardah	100%	6-12-23	7-5-23
Cost Effectiveness of Fuel Cells	Justin	100%	6-12-23	7-5-23
If Fuel Cells are Really Green	Haya	100%	6-12-23	7-5-23
Fuel Cell Project Milestone #3.2: Gas Solubility and Current & Voltage Measurements				
Report #3.2	Everyone	100%	7-3-23	7-10-23
Current + Voltage Measurement (@ WEEF Lab)	Carina, Wardah, Justin	100%	6-29-23	6-29-23
Calculations	Carina	100%	6-29-23	7-10-23
Cover Letter	Justin	100%	6-29-23	7-10-23
Title Page	Carina	100%	6-29-23	6-29-23
Executive Summary	Wardah	100%	6-29-23	7-9-23
Table of Contents	Carina	100%	6-29-23	7-10-23
Main Body	Carina, Wardah, Justin	100%	6-29-23	7-10-23
Introduction	Carina	100%	6-29-23	7-10-23
Buoyancy calculation	Carina	100%	6-29-23	7-10-23
Voltage and Current Measurements	Carina, Wardah	100%	6-29-23	7-10-23
Fuel Cell Specific Questions	Justin	100%	6-29-23	7-10-23
Conclusion	Wardah	100%	6-29-23	7-10-23
References	Carina	100%	6-29-23	7-10-23
Cite Info + Figures + Tables + Appendices	Carina, Wardah, Justin	100%	6-29-23	7-10-23
Demo Day	Everyone	100%	7-19-23	7-20-23
Fuel Cell Project Milestone #4: Final Report				
PowerPoint Presentation	Everyone	100%	6-12-23	7-24-23
Add Information on Slides	Everyone	100%	6-12-23	7-24-23
PowerPoint Aesthetic	Carina	100%	7-10-23	7-23-23
Write Presentation Script	Everyone	100%	7-10-23	7-24-23
Practise Presentation	Everyone	100%	7-24-23	7-26-23
Presentations	Everyone	100%	7-26-23	7-26-23
Report #4	Everyone	100%	7-10-23	7-30-23
Cover Letter	Wardah	100%	7-24-23	7-25-23
Executive Summary	Everyone	100%	7-24-23	7-30-23
Introduction	Carina	100%	7-24-23	7-30-23
Independent Research Component	Everyone	100%	7-29-23	7-30-23
Revise the Report from Given Feedback	Carina	100%	7-24-23	7-30-23
Chemistry Component	Justin	100%	7-24-23	7-30-23
Conclusion	Carina	100%	7-29-23	7-30-23
Cite Info + Figures + Tables + Appendices	Carina	100%	7-30-23	7-30-23

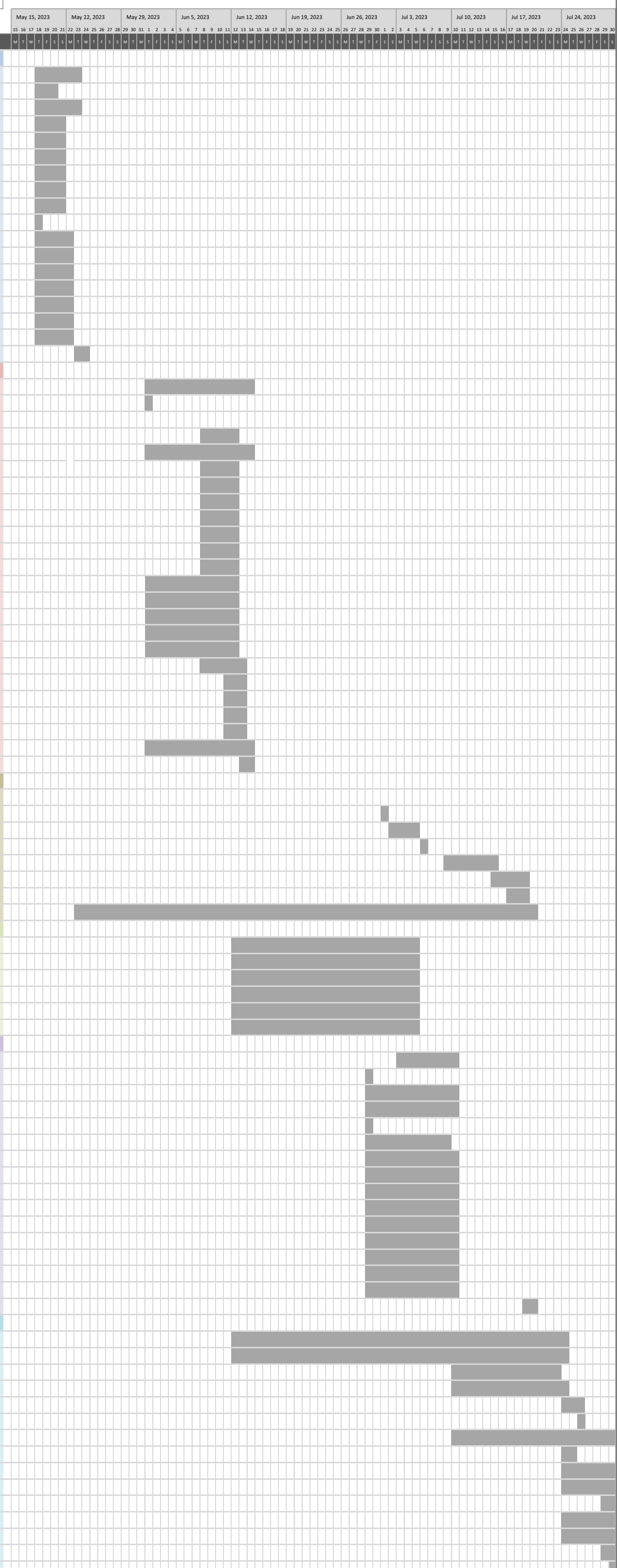

Figure A.1 *Team 8, Mechanical 8, Gantt Chart to serve as an organization tool for the entire fuel cell project*

Team 8 Resume

MeChemical 8

Transportation Manufacturing Company

Wardah Answer

Academic Major	Chemical Engineering
Technical Skills	- Coding and Programming (e.g., Python, JavaScript) - Graphic Design in Adobe Creative Suite - Data Entry/Analysis and Management - 3D Modelling and Rendering: AutoCAD Designs - Presentation Design/ Data Visualization
Soft Skills	- Active listening by listening attentively, empathizing with speakers, and ask clarifying questions to ensure accurate comprehension - Critical thinking by analyzing complex problems, assessing claims, and coming to wise judgements - Has a good memory through engaging in activities that enhance memory retention, such as regular practice, repetition, and mnemonic devices; additionally, utilizing organizational tools like notetaking, creating mental associations, and visualization to aid in remembering important information - Attention to detail has been refined through learning to focus on specifics, scrutinize information, and identify even the smallest of errors or inconsistencies - Encountered diverse situations that demanded flexibility, quick thinking, and the ability to adjust to new circumstances; by embracing change, maintaining a positive mindset, and proactively seeking opportunities to learn and grow, thus have developed the capacity to adapt to various environments and handle unexpected challenges effectively

	- Creativity is a result of actively engaging in activities such as brainstorming, experimenting with different approaches, and seeking inspiration from diverse sources
Weaknesses	- Prone to procrastination often leading to delayed or unfinished tasks, but is actively working on developing effective time management strategies, setting clear goals, and overcoming the tendency to delay important tasks - Self-criticism hinders personal growth which can lead to feelings of inadequacy and prevent necessary risks taking or pursuing new opportunities, though willing to actively cultivating self-compassion, recognizing strengths and achievements, and embracing a growth mindset to foster self-improvement - Struggled with a lack of confidence hindering personal and professional progress. It has resulted in missed opportunities and self-doubt, making it difficult to take on challenges, be assertive, or pursue set goals. To overcome this weakness, a willingness to work on building my self-esteem, recognizing strengths and achievements, seeking feedback and positive reinforcement, and challenging negative self-perceptions through personal affirmations and setting achievable goals.
Haya Irfan 	
Academic Major	Chemical Engineering
Technical Skills	- Coding and programming skills (python). - Creating presentations/Data visualization. - 3D modeling (Solidworks).
Soft Skills	- Collaborative. - Takes initiative. - Flexible. - Detail-oriented. - Good listener. - Good leadership skills. - Comfortable with public speaking. - Great at presenting data. - Creative.
Weaknesses	- Procrastinate and leave everything for the last second.

	- Lack of confidence in the work produced.
Justin Medeiros 	
Academic Major	Chemical Engineering
Technical Skills	- Proficient data entry/analyzation skills. - Comfortable with the entire Microsoft ecosystem (PowerPoint, Excel, etc.). - Coding and programming skills (python). - Exceptional report writing skills and a large vocabulary.
Soft Skills	- Excellent team player, can work with multitudes of people, will take lead if necessary but can also follow. - Extremely detail-oriented. - Attentive listener, and takes great care to listen to all ideas and inputs. - Proficient presentation skills, can speak to any size crowd of people with a clear and properly projected voice (thanks to years of theatre experience). - Good at following direction and taking criticism, and takes extra care to apply criticism to improve and perfect.
Weaknesses	- Somewhat of a perfectionist, and at times will take double the time needed to properly complete an assignment, so it is finished. - Procrastinator and will sometimes leave assignments sometimes to the last day to do them. - Sometimes have issues with voicing own opinions and will end up being silent during group discussion as not to rock the boat or start arguments about solutions.
Carina Sinbandhit 	

Academic Major	Mechanical Engineering
Technical Skills	- Report writing. - Drafting and creating sketches. - Building CAD models on Solidworks (e.g., surface modelling). - Use a digital camera (i.e., take photos of the progress of the boat design). - 3d print models using Solidworks. - Laser cut models using AutoCAD to draft model. - Microsoft Office (e.g., PowerPoint, Word, Excel, etc.). - Media design (i.e., Canva, Adobe Photoshop, etc.).
Soft Skills	- An active listener. - Takes lead depending on expertise (and if necessary) but does not mind following others. - Able to take criticism and make modifications from the given criticism. - Creative regarding design (i.e., the design of the boat). - Detail-oriented when it comes to design. - Takes initiative: will when something needs to get done.
Weaknesses	- Overthinks by spending too long writing a section then self-criticize but should ask group members to look over my part to see if it is adequate. - Uncomfortable with public-speaking but with practice rehearsals pre-presentation it would not feel as bad. - Lacks trust regarding if a team member does not complete their part a day before the due date (i.e., not a team player), and will do it all for them. Instead, should communicate such worries.

Appendix B

The Four Boat Conceptual Designs

The present Appendix B exhibits a cumulation of the four boat designs derived from the three main considerations: the boat's ability to float, balance, and move – along with considering the functional description of the boat. These designs were constructed from different types of boat to show the strengths and weaknesses of the variety. This helped determine which boat is the most suitable for racing with what material and resources are made available.

Boat Design #1

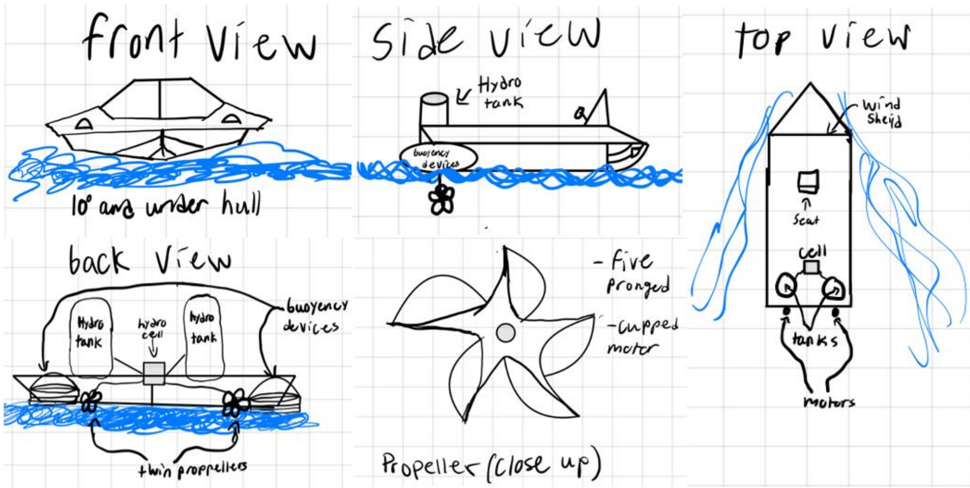

Figure B.1 *The front, side, top, and back view of Boat Design #1 with an additional close-up of the propellers*

Boat Design #2

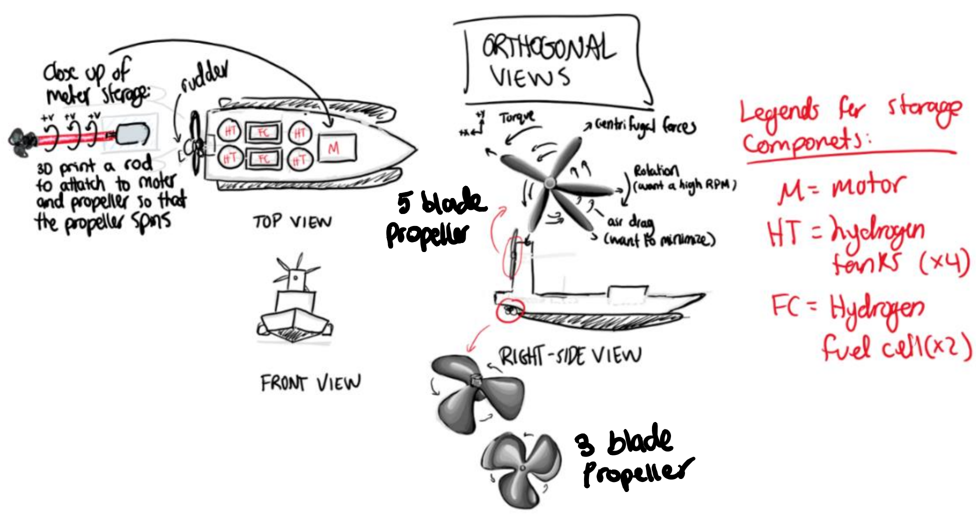

Figure B.2 *Orthogonal view of Boat Design #2 with a close up of the main mechanisms including the propellers, a propeller's connecting rod/axis, and rudder*

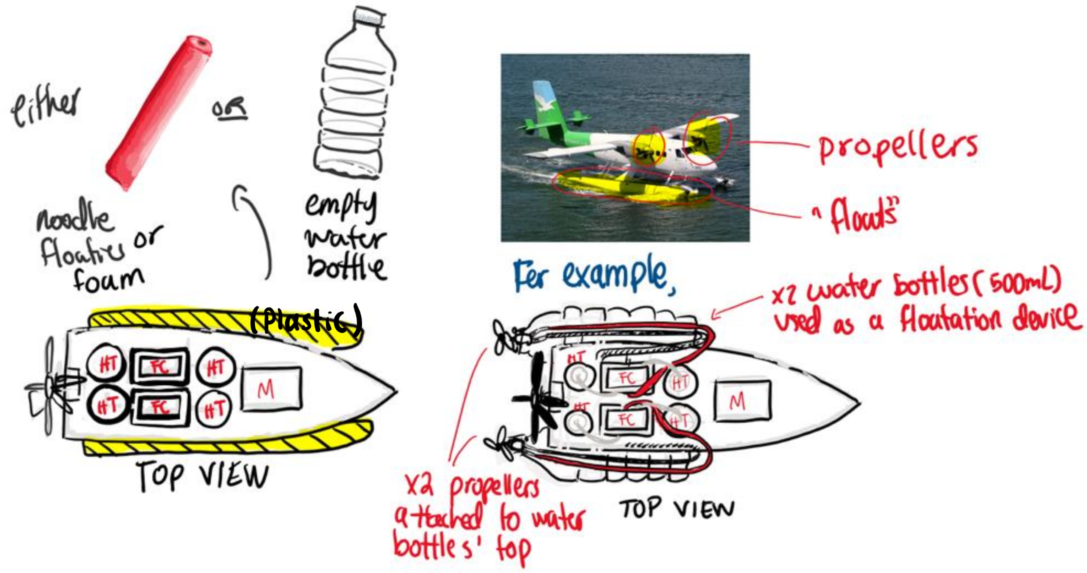

Figure B.3 *The top views of Boat Design #2 inspired by a seaplane including the materials that may be used for the floating mechanism*

Boat Design #3

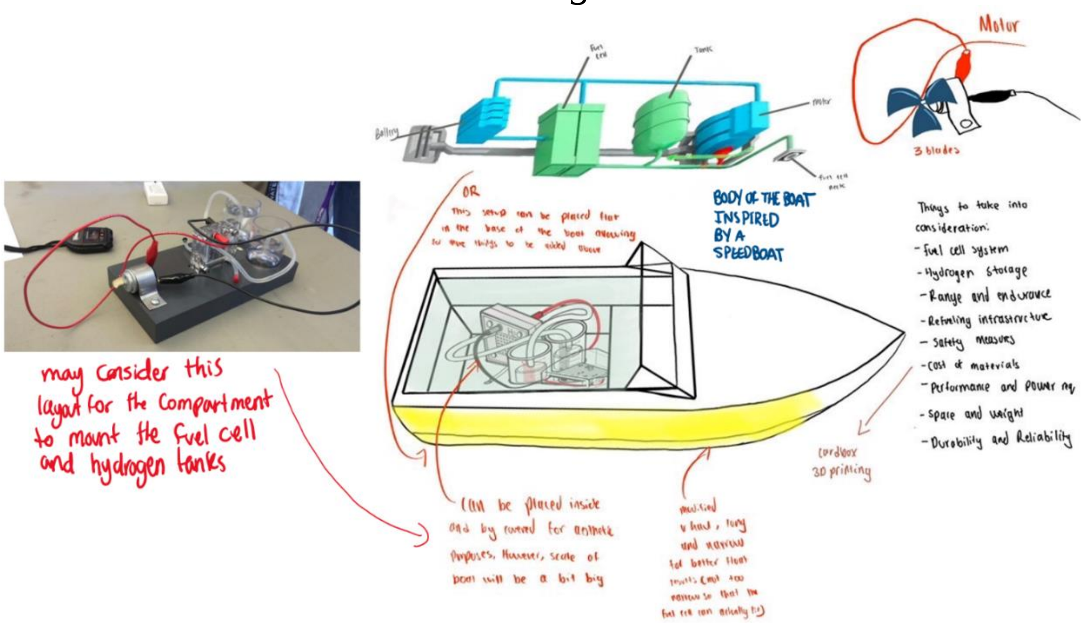

Figure B.4 *A layout of Boat Design #3 with an explanation of the mechanisms*

Boat Design #4

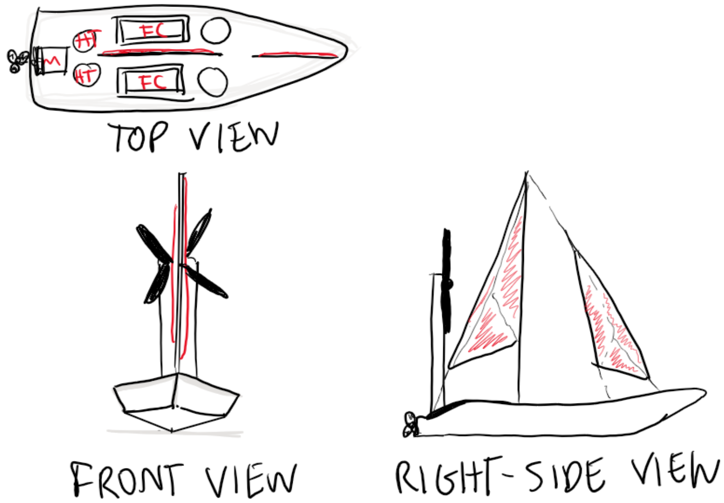

Figure B.5 *An orthogonal view of Boat Design #4 inspired by a sailboat*

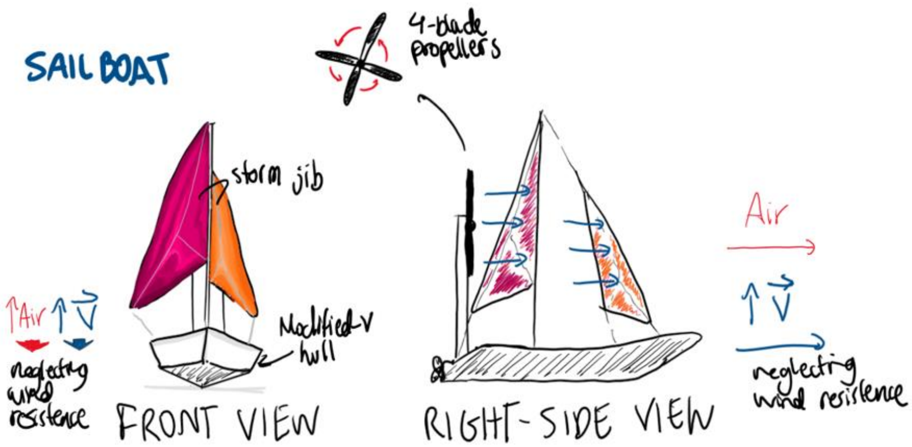

Figure B.6 *A front and right-side view of Boat Design #4 displaying its main mechanisms*

Appendix C

Derivation of Mass Quantities

The present Appendix C outlines how the mass of the 3D printed components such as the body and propellor of the boat was determined. The calculated weight of the 3D printed parts labelled in **Table 1.0** was built on Solidworks then converted the file into an STL file to a 3D slicer software used for 3D printing called ideaMaker. When the file was sliced for the same filament used for this boat, an information sheet including the 3D printed part's density appears, the mass in grams was utilized. The volume of a model can also be determined by looking at Solidwork's 'Mass Properties' setting.

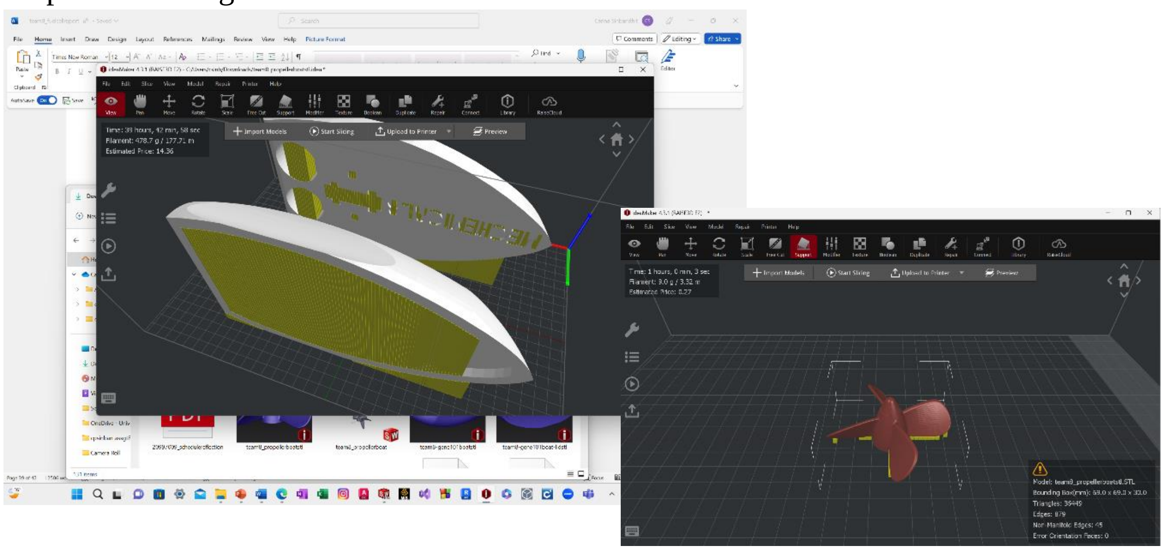

***Figure C.1** ideaMarker shows the estimated print result for both the body and propellor of the boat*

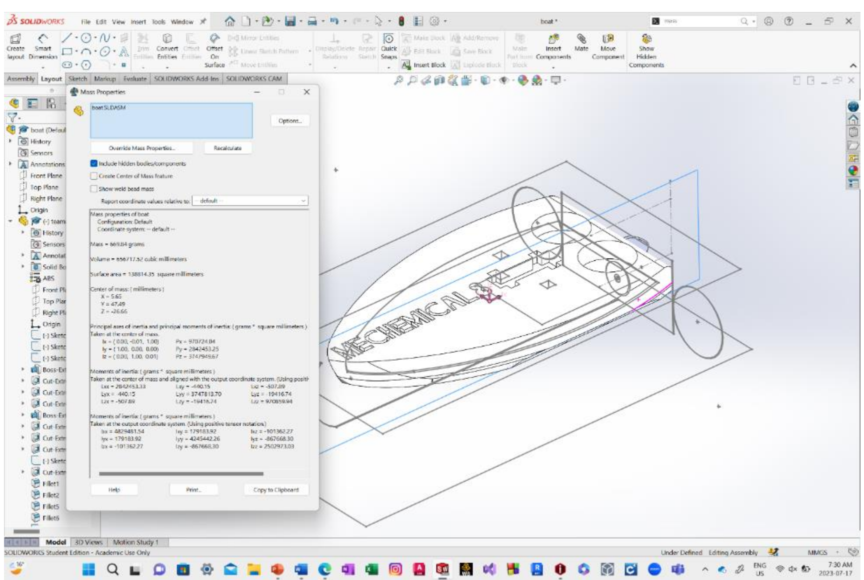

***Figure C.2** Solidworks shows the volume in cubic millimeters of the body of the boat under the 'Mass Properties' setting*

Appendix D

Fuel Cell Voltage and Current Measurements

The present Appendix D exhibits the values of voltage and current measurements within a 300 second interval, taken from the WEEFs lab experiments. The first experiment was measuring the voltage and current from one of the two hydrogen reversible PEM fuel cells. The second experiment was measuring the voltage and current from the other hydrogen reversible PEM fuel cell. The third experiment was measuring the voltage and current from the hydrogen reversible PEM fuel cells connected in a series.

Voltage and Current Drop of Fuel Cell #1

Table D.3 *Measurements of the Voltage/Current Drop for Fuel Cell #1 over 300 seconds*

Fuel Cell #1		
Time (s)	Voltage (V)	Current (A)
0	0.6705	0.09476
30	0.6676	0.09434
60	0.6548	0.07299
90	0.663	0.0805
120	0.6378	0.10526
150	0.6508	0.08356
180	0.6745	0.08884
210	0.6134	0.10568
240	0.6352	0.10612
270	0.6343	0.05789
300	0.6104	0.06868

Voltage and Current Drop of Fuel Cell #2

Table D.4 *Measurements of the Voltage/Current Drop for Fuel Cell #2 over 300 seconds*

Fuel Cell #2		
Time (s)	Voltage (V)	Current (A)
0	0.7005	0.08263
30	0.7002	0.09162
60	0.703	0.10038
90	0.6916	0.06839
120	0.6812	0.07595
150	0.662	0.08359
180	0.6631	0.09306
210	0.7009	0.08288
240	0.6988	0.07028
270	0.6872	0.06136
300	0.6672	0.08787

Voltage and Current Drop of Fuel Cell Connected in a Series

Table D.5 *Measurements of the Voltage/Current Drop for Fuel Cell Connected in Series over 300 seconds*

Fuel Cells Connected in Series		
Time (s)	Voltage (V)	Current (A)
0	1.4124	0.10621
30	1.406	0.10325
60	1.3787	0.10416
90	1.3351	0.10138
120	1.3213	0.0991
150	1.2782	0.09811
180	1.1804	0.10304
210	1.1593	0.08808
240	0.8553	0.08061
270	0.6432	0.07849
300	0.5026	0.07941