

I PRO 349: Fuel Cells for Unmanned Undersea Vehicles

The 349er's

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I. Team Information

IPRO 349 consists of a wide variety of engineers, ranging from biomedical to mechanical and aerospace; but is predominately chemical engineers due to its partnership with CHE 296/496. This IPRO combines various elements of chemical as well as mechanical, electrical and aerospace engineering and thus the varying team members' backgrounds are well suited for this combined undertaking. The team members and their affiliations are as follows:

Kevin Abankwa, Senior ChemE (CHE296)
Sahar Ashrafi, Senior ChemE (CHE496)
Ray Ballard, Senior ChemE (CHE496)
Ethan Baughey, Sophomore ChemE (CHE296)
Matthew Chaffee, Sophomore ChemE (CHE296)
Moses Cho, Sophomore ChemE (CHE296)
Chris Chock, Senior ChemE (CHE496)
Marcus Choy, Senior Aero/MechE (IPRO349)
Jennifer Guilfoyle, Senior ChemE (CHE496)
Matthew Hagopian, Sophomore ChemE (CHE296)
Elezar Kenig, Senior AeroE (IPRO349)
Chieh "Roger" Luo, Junior BME (IPRO349)
Daniel Miladinovich, Junior AeroE/MatSci (IPRO349)
Cheryl Mukai, Senior ChemE (CHE496)
Trang Nguyen, Junior MechE (IPRO349)
Kamaldeen "Kamal" Olorunoje, Junior ChemE (CHE296)
Brian Olson, Junior ChemE (CHE296)
Olakunle "Kunle" Popoola, Junior ChemE (CHE296)
Nic Sansone, Sophomore ChemE (CHE296)
Jainam Shah, Senior MechE (IPRO349)
Jaya Singh, Junior ChemE (CHE296)
Yukiya Takada, Sophomore ChemE (CHE296)
Chris Wolcott, Senior ChemE (CHE496)
Suk Hwan Yun, Senior ChemE (CHE496)

**A more exhaustive list of team members' information and strengths/desires for the outcomes of this project will be attached to the end of this document.*

These are the members of IPRO 349, with Dr. Vijay Ramani (ChemE) advising.

Team Purpose

The purpose of IPRO 349 is to design a fuel cell power and propulsion system for an unmanned underwater vehicle (UUV). The emphases of the design will be on stealth, range and propulsion design, focusing on the feasibility of both innovative and traditional means.

Team Objectives

The objectives of this program that the group has set out are as follows:

- Produce fully specified designs
- Have a working prototype fuel cell

II. Background

Customer and Sponsor Information

The goal of IPRO 349 is to produce a conceptual design of an unmanned underwater vehicle (UUV) that is powered by a fuel cell. The primary customer in consideration for this IPRO is the US Navy. The importance of submarines has long been recognized by the military and has caused drastic changes in modern warfare.

The first militaristic use of underwater vehicles occurred during the American Civil War in 1776. The Turtle, an egg shaped man powered device designed by David Bushnell, was used in an attempt to sabotage the British warship HMS Eagle in New York harbor. Unfortunately, the attempt failed and it was not until World War I would submarines be utilized as weapons of war. German U-boats changed the warfare in the Atlantic and would forever change the nature of warfare on the high seas. Submarines have enabled countries to spy on each other from beneath the waves and in the event of a nuclear war are able to annihilate the attacking countries. Submarines also pose a very deadly threat to shipping, battleships, and aircraft carriers that are operating on the high seas during times of war. Therefore the development of a long range UUV is essential in order to protect the American Navy. Furthermore the detection of enemy submarines has become increasingly difficult and a UUV that can be used in order to silently monitor enemy ports is invaluable.

A UUV is highly desired by the Navy because it is capable of operating in conditions that are hazardous to human life. Therefore if a stealthy and long range UUV can be developed it will be very appealing to the Navy and can be used for a plethora of missions from reconnaissance to sabotage.

Current Challenges to the Development of a UUV

In order to develop a functional and appealing UUV several obstacles need to be overcome. One problem is the development of the fuel cell itself. Despite the advances in fuel cell technology, fuel cells are still rather large and complex. Furthermore the UUV needs to carry all of its fuel onboard throughout the mission and does not have the opportunity to refuel until it returns to its mother ship. For instance in the event that there was an internal combustion engine within the submarine, both fuel and oxygen would need to be carried in order to operate the combustion engine. The selection of the type of fuel cell determines how much fuel needs to be carried by the UUV in order to perform a sortie with a specified mission time. This in turn affects the size of the UUV required in order to handle all of the fuel to power the fuel cell.

The second major challenge is the development of the propulsion system on the UUV. There are various options for the development of the propulsion system of the UUV. However, the IPRO has elected to come up with an innovative propulsion system that will mimic sea creatures. For instance squids, fish, and sharks are being examined as inspiration for the development of a cutting edge silent propulsion system. Unfortunately, there is little known about how these animals are able to efficiently propel themselves through the water. Information on the mechanics of how these animals propel themselves through the water is also limited because most of the studies done are based off of observations of a fish's movement in water. Therefore it would take large amounts of research and resources in order to build an animal inspired propulsion system. These resources are currently unavailable at the Illinois Institute of Technology and would require the sponsorship of an outside company such as the Navy.

Furthermore the amount of space required to house the propulsion system depends on the mechanical operation of the propulsion system. Without a general idea of how the propulsion system operates mechanically it will be extremely difficult to estimate the overall size of the submarine.

History of Fuel Cells

Fuel cells are electrochemical devices capable of producing electricity at a rate that is two or three times as efficient as compared to an internal combustion engine. In the simplest form a fuel cell combines hydrogen and oxygen in order to produce water, heat, and an electric current. This type of fuel cell is known as a Polymer Electrolyte Membrane fuel cell. Nevertheless there are four additional types of fuel cells. Alkaline, phosphoric acid, molten carbonate, and solid oxide fuel cells are also currently being researched. Each of these fuel cells have unique advantages and disadvantages which can be either beneficial or detrimental to the design of a UUV. For instance in 1998 Chicago incorporated a hydrogen powered fuel cell into their city busses. A similar technology could be examined for use in the UUV. Additionally, solar panels can be incorporated to enable the UUV to perform electrolysis on water. Enabling electrolysis aboard the UUV enables the UUV to produce its own fuel, thus greatly extending its range and mission capabilities.

Researchers are currently investigating the underwater propulsion of several different marine animals. One current project is the research and design of a propulsion system based off of the motion of fish. In Darmstadt, researchers have created a skeletal structure that mimics the swimming motion of fish. Researchers built this mechanical skeleton based off of the observations of live fish swimming in water and hope that this skeletal structure can eventually be implemented on ships in order to protect the marine environment from the adverse effects of current propulsion systems. Furthermore, at MIT, researchers are using studying the vortices that are shed off of the bodies of fish as they swim through the water. By using active flow control techniques researchers aim to control the wake and boundary layer that surrounds the submerged object. Additionally scientists are currently studying the method in which fish are able to extract energy from oncoming eddy currents. It has been found that the precise timing of the flapping motion of the fish with the oncoming vortex results in an increase in propulsion. Unfortunately, the phenomenon is not well understood and is further investigation into this phenomenon is ongoing.

Ethical Considerations

The primary ethical concern for hydrogen fuel cells is the fact that hydrogen is highly explosive. Similar to today's use of gasoline, standards would have to be set for the safe distribution of hydrogen to consumers. Hydrogen can be safer than gasoline for the environment and for minimizing chances for combustion. Since hydrogen is a gas it can disperse very quickly in the event of a leak and naturally it quickly decreases the risk of combustion. The detection of dangerous levels of hydrogen would have to be monitored using sensors. Hydrogen naturally occurs in the atmosphere so the use of hydrogen fuel cells could motivate an industry centered on the detection and safety of hydrogen at refueling stations. Hydrogen is difficult to detect hydrogen because it is colorless. It could require the training of professionals to inspect and safely handle hydrogen. While this could reduce the appeal towards companies wanting to invest in hydrogen fuel cells but would stimulate the economy as a whole.

Another ethical concern is the toxicology of fuels. Hydrogen is non-toxic to humans where as gasoline and other possible alternatives are toxic. This is good because in the event of a leak hydrogen dissipates into the atmosphere and there is no worry for it effecting the environment. Gasoline and other liquid fuels are not only toxic but they require a crew of trained professionals to clean a spill.

The environmental effects of hydrogen as a fuel is almost zero however, the refining of hydrogen into a gas can potentially be harmful to the environment because it requires energy. The energy could be supplied from coal which would emit carbon into the atmosphere. However, the same alternatives to energy exist for hydrogen refinement as the electricity supplied to homes. Hydrogen could be refined using a renewable fuel sources like solar, wind, or hydraulic dams.

Business or Social Costs

Hydrogen fuel cells require the use a new fuel that is not as easily accessible as gasoline. This would require a large initial investment by a business or many businesses to establish the necessary infrastructure like refueling stations, and refineries. Currently in this economy not many businesses are willing to make such a large investment. However, it is possible that government incentives for green energy alternatives exist and may grow in number to reduce the large financial burdens companies would encounter. The use of hydrogen fuel cells would create millions of jobs for the entire would thus boost the overall economy. This is because hydrogen is a relatively new energy source for transportation and thus would require the start of an entirely new industry. While this may initially seem financially burdensome there are alternatives exist to gradually and cheaply ease the industry into our economy. Large scale refueling stations like the gas stations that are seen today are not currently necessary because the demand for hydrogen in a vehicle is not high enough yet. The loss of jobs from the oil industry would be absorbed into the hydrogen fuel industry and even more would be created to support both. Society as a whole would improve.

The total cost for the hydrogen fuel is dependent on refining processes. Hydrogen is most commonly refined from natural gas in a process called "steam reforming" which is currently the most efficient large scale method to refine hydrogen. This method creates CO₂. However, there are other ways to create hydrogen. Electrolysis of water is possible where water is divided into hydrogen and oxygen. This process requires energy but it can be supplied from a renewable source. Currently the cost of refining hydrogen is about 8 dollar per gallon. However, it is important to remember that the efficiency of a fuel cell is roughly twice that of an internal combustion engine. That would bring the total expense of this fuel to about 4 dollars per gallon. While this is still more expensive than today's gasoline prices and increase in demand for this product and would surely generate competition which fuels the downward trend in prices.

As the cost of fuel for hydrogen fuel cells decreases over time the initial investment to establish the necessary infrastructure still remains as the largest financial burden for businesses. Large scale manufacturing of the fuel cell itself is another factor that the industry will have to tackle that has the same possible societal effects.

III. Team Values Statement

Our team will hold itself to what we would like to call A.R.C. This stands for: Accountability is fundamental; Respect is essential to our progress; Character is what sets us apart. This means that each member of the team will be accountable for their work and actions. As a team we will respect each other and that our character and the differences in each other will set us apart but will also add to our team. As a team we will abide by IIT's code of conduct regarding the

research our team does. We will give credit where it's due. All the members will be punctual for meetings and will contact the team leaders by email or phone more than an hour in advance of the meeting time if they are going to be late. Conflicts will be resolved by trying to talk one on one with the person there is the conflict with. If this is ineffective, the parties will speak with the sub-team leader to assist in resolving the conflict. From there if no resolution can be found the parties will go to the team leaders, and from there the faculty advisor.

IV. Work Breakdown Structure

Addressing the problem

The IPRO 349 team is going to do mainly research on the currently existing fuel cell technologies that can be of use for the generation of electrical energy to propel underwater unmanned vehicles also known as UUV. These kinds of vehicles are of special interest for military use and underwater exploration. The US Navy is currently doing some research in this particular project. So, there are some practical implications which are motivating us to work strongly in our project. There are two main challenges in this project:

- The field of fuel cells is quiet developed theoretically but hasn't been perfected practically because of the sophisticated nature of the technology, its components and the materials needed to build those components.
- The potential use of the UUV in military applications is a challenge to perfect the system in every possible way so that it cannot be detected and it can accomplish its task.

So, in order to perform the tasks efficiently, the IPRO 349 team which is made of 24 members has been divided into 3 sub-teams with a team leader for each team.

The Fuel Cell Team

This team will be led by Chris Wolcott. The main objective of this team is to look into the details of the fuel cell itself which includes:

- The types of fuel to be used.
- Reactions/Electrochemistry.
- Catalyst to be used.
- Membranes to be used.
- Amount of energy (electrical/thermal) produced by the fuel cell.
- Efficiency of the fuel cell compared to the next best alternative.

The Propulsion Team

This team will be led by Marcus Choy. This team will mainly deal with the following tasks:

- Conversion of the electricity produced by the fuel cell to its useable form (AC/DC).
- Type of the propulsion system to be used.
- Stability and buoyancy of the UUV.
- Calculation of the weight of the overall UUV including its components.

The Research Team

This team will be led by Brian Olson. The main purpose of the research team is to provide with the most up-to-date information on various aspects of this project to the other two sub-teams.

So, the tasks will be to find out:

- Same/similar current models if any.
- Available alternative options.
- Specifications – power requirement, available space, range, payloads, etc.
- Expected cost of the UUV.
- Expectations of other potential consumers.

V. Expected Results

The ultimate goal of the IPRO 349 team is to design a fuel cell power and propulsion system for an unmanned underwater vehicle (UUV). To accomplish this, the team has divided into three sub-teams: research, fuel cell, and propulsion. Each sub-team has its own expected goals which are summarized below.

The research team will be in charge of gathering information from various sources and relaying it to other teams for consideration. They will be chiefly responsible for researching information related to the specifications of existing UUVs, such as size, power requirements, and propulsion systems. They will also work with the fuel cell team to research different types of fuel cells. The research team will also work with the propulsion team to look at different methods of propulsion for underwater vehicles. Finding and conveying all of this information to the other sub-teams will be the principle challenge for this sub-team. Because of the immense amount of information available it will be necessary for the team to be able to concisely convey their findings in order for the other sub-teams to properly utilize their work.

The fuel cell team will be responsible selecting and designing the fuel cell power system for the UUV. This will include two main phases. The first phase will be working with the research team to review existing fuel cell technologies and selecting what fuel cell system to use. The second phase will involve developing a thorough design of the fuel cell system based on specifications found by the research team. Key challenges for this team will be communicating with the research team to select the best fuel cell system and working out the specifics of a detailed design for use in an UUV.

The propulsion team will select and design the best propulsion method to provide optimal range and sufficient thrust to meet design criteria. Stealth and silence are key and must be implemented in the final product. The selected type of propulsion system will have a low thermal signature and be noise-free. The DC current from the fuel cell may need to be converted to AC depending on the type of current needed. Types of propulsion systems to consider are shark based propeller, screw-drive, MIT “turtle” and jet. The team will also project range and efficiency of the system. The main challenges for this sub-team are similar to those for the fuel cell team. They will need to communicate effectively with the research and fuel cell teams to determine the exact demands placed on the propulsion system, as well as work out the technical aspects of a detailed design.

In short the expected results of this IPRO are to perform a background survey on existing UUVs, fuel cells, and propulsion systems; to select the most appropriate fuel cell system and propulsion system for use in UUVs; and to produce a detailed design of the fuel cell and propulsion system. An additional goal for the team would be to produce a working prototype of this system; however the feasibility of doing that during this same semester is skeptical at best. The main deliverables for the IPRO are to complete the background research and select appropriate fuel cell and propulsion systems, and to develop detailed designs of these systems.

VI. Budget

Activity	Cost	Description
Experimentation Fuel Cell Kits	\$350	Two fuel cell kits to be purchased to simulate the performance of our fuel cell
Experimentation Fuel, Oxidant, Membrane, and Catalysts	\$600	\$215 for borohydride \$50 for hydrogen peroxide \$150 for membrane materials \$150 for purchase of 2 catalyst \$35 DC motor kit These items will be used in conjunction with the fuel cell kit for research and simulation purposes
Team Building Activity	\$260	The purpose of this is to create camaraderie among the team to facilitate group work and enhance the IPRO experience for the sophomore students and all the other members of our IPRO team. The proposed cost will include an event and food for our IPRO team. 26 people*\$10 per person =\$260 total
TOTAL	\$1210	

VII. Designation of Roles

The Fuel Cell Team

For the literature survey the fuel cell team has split into two groups one researching fuels and one researching oxidants. The individuals on each team are as follows:

Fuels Research: Ray, Sahar, Sukhwan, Matt C., Roger

Oxidant Research: Chris W, Jenn

After a fuel and oxidant are selected, catalysts and a membrane will need to be selected. This is the first step of detailed design. The breakdown is as follows:

Membrane research: Jennifer, Sahar, Roger

Oxidant Catalyst research: Sukhwan, Matt C.

Fuel catalyst research: Raymond, Chris W

Once all of these components have been selected the specifics of the fuel cell system.

The design team will then work as a whole to develop a detailed design based on specifications provided by the research and propulsion teams about size and power requirements. This will include calculating the number of cells needed, calculating heating/cooling needs, and calculating rough fuel efficiency for the submarine. This will be an assignment for the whole sub team.

Existing designs research team (responsible for looking up specifics of existing fuel cells with similar configurations): Matt C., Roger, Sahar

Calculations team (uses theory and literature to calculate specifics for the exact model): Raymond, Jennifer, Sukhwan, Christopher

Lastly the team will attempt to build a fuel cell using the specifications selected. The fuel cell will be tested to see how it compares with what was calculated in the detailed design.

The Propulsion Team

The propulsion team will break into groups and develop their respective designs in the following manners:

Practical team:

Marcus-Conceptual Design

Dan-Modeling

296 Students: Research,

Materials
Specifications

Theoretical Team-Biomechanical system:

Kevin-Conceptual Design

Cheryl-Research

Trang-Materials

Kevin-Conceptual Design

Jainam-Modeling

The Research Team

The entire research team will be doing research for specifications of current UUVs and will be reassigned as needed as future needs are identified.

Appendix 1: Team Roster

Name	Phone	Email
Kevin Abankwa	630.452.3738	kanakwa@iit.edu
Sahar Ashrafi	630.709.1942	sashrafi@iit.edu
Ray Ballard	312.519.8930	rballard@iit.edu
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Matthew Chaffee	989.350.8003	mchaffee@iit.edu
Moses Cho	312.533.8334	mcho5@iit.edu
Chris Chock	808.294.0546	cchock@iit.edu
Marcus Choy	808.351.4238	mchoy@iit.edu
Jennifer Guilfoyle	630.209.9048	jguifoy@iit.edu
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Chris Wolcott	571.246.2237	cwolcott@iit.edu
Suk Hwan Yun	312.523.9827	syun3@iit.edu

Team Bios

Kevin Abankwa

Strengths: Conceptual ideas and design

Knowledge/skills to develop: Presentation skills and more in depth knowledge of fuel cells

Expectations: To develop a complete fuel cell system

Sahar Ashrafi

Strengths: Microsoft Office & Microsoft Visio. Experience with MATLAB ,Maple, HYSYS and LabVIEW. Very organized and good at planning.

Knowledge/skills to develop: deeper understanding of the technical aspects of fuel cells in an underwater setting

Expectations: To develop a sound concept for A UUV

Ray Ballard

Strengths: Written and verbal communication, team management, group strategy. Experience with C++, Maple, Matlab, Hysis, and of course Microsoft Office

Knowledge/skills to develop: Gaining expertise in managing a team in an engineering/scientific project (as opposed to a non-technical one) and presenting its results would be a great benefit.

Expectations: To accomplish the task set for us by analyzing the different techniques available with a great team of varying skill sets and backgrounds

Ethan Baughey

Strengths: Prior knowledge of fuel cells and research abilities

Knowledge/skills to develop: Gain more knowledge about current fuel cell technology

Expectations: To successfully develop a fuel cell system

Matthew Chaffee

Strengths: Web Design, Programming, Planning, Scheduling

Knowledge/skills to develop: To gain technical understanding of fuel cells in underwater applications

Expectations: To successfully combine fuel cell and propulsion technology

Moses Cho

Strengths: A hard worker who finishes everything to the end and believes that creativity is important.

Knowledge/skills to develop: To improve work ethics for a stronger push at the end

Expectations: To gain an experience of real project work

Chris Chock

Strengths: Photography, some web design, newspaper layout (with InDesign), MATLAB

Knowledge/skills to develop: To improve team leadership and speaking skills

Expectations: To create an encouraging environment for the development of a fuel cell powered UUV

Marcus Choy

Strengths: knowledge of mechanical systems and leadership skills

Knowledge/skills to develop: to gain more knowledge about how fuel cells can be incorporated into unmanned vehicles

Expectations: to develop a solid design for an unmanned submersible vehicle.

Jennifer Guilfoyle

Strengths: Computer programming: C++ and some Matlab, singing

Knowledge/skills to develop: Better management skills

Expectations: To use this experience to better understand projects

Matthew Hagopian

Strengths: Teamwork, design, research, communications and computer knowledge

Knowledge/skills to develop: More extensive knowledge with fuel cell designs

Expectations: To hone leadership abilities, communications and work more efficiently in groups and independently

Elezar Kenig

Strengths: Presentation, note taking, mechanical engineering

Knowledge/skills to develop: improve speaking and presentation skills

Expectations: To produce an innovative fuel cell powered UUV

Chieh "Roger" Luo

Strengths: Problem solving, RC knowledge, Java and machinery

Knowledge/skills to develop: Learn practical applications for fuel cells

Expectations: Successfully develop a fuel cell system

Daniel Miladinovich

Strengths: CAD

Knowledge/skills to develop: Application of Cad to do physical analysis on a design

Expectations: To model the UUV design

Cheryl Mukai

Strengths: Experience with MATLAB Maple, HYSYS and LabVIEW as well as working knowledge and some experience building a fuel cell

Knowledge/skills to develop: To develop knowledge on propulsion systems and how to integrate fuel cell technology into an actual system.

Expectations: To develop a UUV with real world applications be it for the navy or commercial use.

Trang Nguyen

Strengths: Microsoft Word, PowerPoint, Excel, Drawing, Painting

Knowledge/skills to develop: to gain experience and knowledge from working in a big project with a lot of team members such as this one.

Expectations: To develop an innovative propulsion system for a UUV

Kamaldeen "Kamal" Olorunoje

Strengths: Chemistry and programming

Knowledge/skills to develop: Better communication skills and the inner workings of fuel cell systems

Expectations: To develop a working fuel cell system

Brian Olson

Strengths: Strong ProE skills, machining skills if we need to make something, Microsoft Office, some C++, organizational skills

Knowledge/skills to develop: to improve my people/group skills, presentation skills

Expectations: Be a productive part of the project and contribute where I can to a high functioning team

Olakunle "Kunle" Popoola

Strengths: MATLAB, C++, Microsoft Office suite, editing, research and communications

Knowledge/skills to develop: Team working skills

Expectations: To gain knowledge in underwater submersibles

Nic Sansone

Strengths: Creativity and problem solving skills

Knowledge/skills to develop: More technical knowledge and functioning in a group better

Expectations: The process of an IPRO, more technical skills and honing team skills

Jainam Shah

Strengths: research, bringing new ideas, designs and helping everyone with their work

Knowledge/skills to develop:

Expectations: project-team commitment, flexibility and innovative ideas

Jaya Singh

Strengths: Microsoft Office, strong programming skills in MATLAB, very co-operative. likes to work in a team.

Knowledge/skills to develop: leadership, communication and presentation skills

Expectations: to contribute the best of me to the team, learn valuable skills for future IPROs, finish the project on time while accomplishing most work

Yukiya Takada

Strengths: Researching different topics

Knowledge/skills to develop: More skills researching different topics

Expectations: To better understand the inner workings of a fuel cell system

Chris Wolcott

Strengths: Strong technical background, leadership, some knowledge of fuel cells

Knowledge/skills to develop: Communication skills, leadership skills, presentation skills

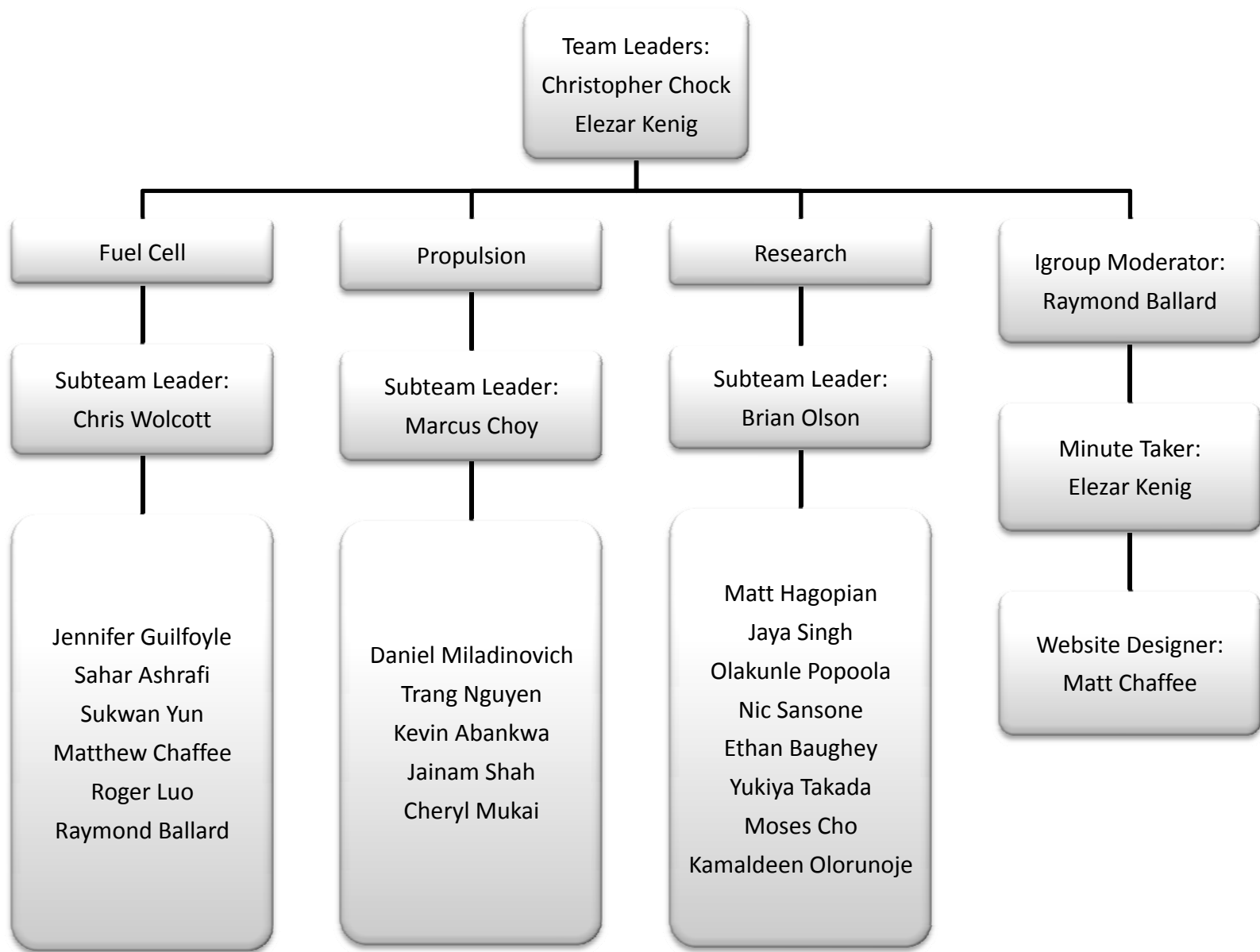
Expectations: Learn more about fuel cells, design fuel cell system

Suk Hwan Yun

Strengths: Knowledge of environmental issues

Knowledge/skills to develop: knowledge of MATLAB and HYSYS

Expectations: Become more familiar with fuel cells



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