Operation Manual

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Team 10: Alkaline Membrane Fuel Cell Educational Kit

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1.0 Project Overview

Fuel cell technology has been increasingly recognized in the field of alternative energy as a clean option for future power generation. For this reason our sponsors, Dr. Juan C. Ordonez of Florida State University and Dr. Jose V. C. Vargas of Universidade Federal do Paraná tasked the design team with investigating the feasibility of a newly proposed AMFC educational kit using a previously developed cellulose-based membrane.

Using only diatomic oxygen and hydrogen for a fuel source, the fuel cell produces an electrical output through an electrochemical reaction with only heat and water as its by-products. The educational kit is self-contained, portable, and aims to display some of the many practical applications and functionalities of an Alkaline Membrane Fuel Cell to all interested parties.

2.0 Acknowledgement

Our efforts for this project would have been impossible without the continuing assistance from our advisors and sponsors for our guidance and financial assistance.

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

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

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

3.0 Functional Analysis

A fuel cell generates electricity through an electrochemical reaction between hydrogen and oxygen. The two bipolar plates that conduct the power output are separated by electrode sheets and an electrolyte membrane, and have inlet and outlet ports for either hydrogen or oxygen. As seen in Figure 1. the two electrodes (CV3 and CV5) allow for the collection of charged particles on its surface, while the electrolyte (CV4) allows for the flow of ions from between the anode and cathode. The charged particles are generated through the chemical reactions in the anode and cathode side as seen in the stoichiometric reactions below:

Anode side (an oxidation reaction): $2H_2 \Rightarrow 4H^+ + 4e$

Cathode side (a reduction reaction): $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$

Net reaction (the "redox" reaction): $2H_2 + O_2 \Rightarrow 2H_2O$

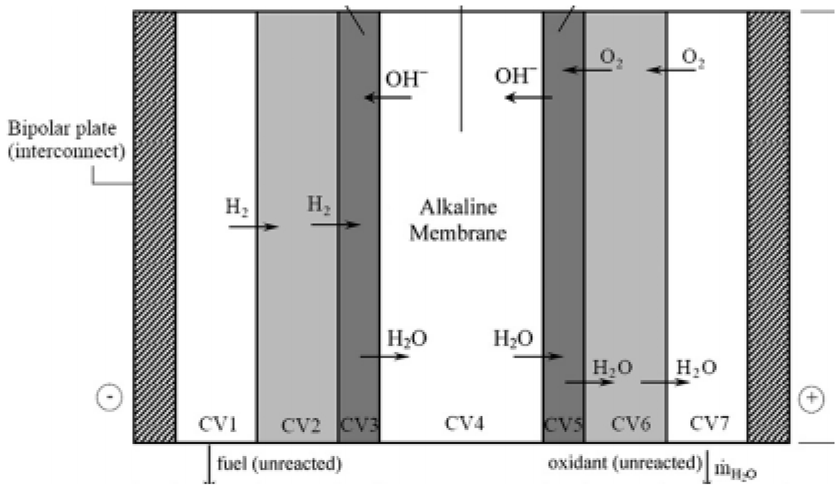


Figure 1. Basic schematic of fuel cell control volumes

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

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

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

4.0 Product Specification

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

Case:

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

Bipolar plates:

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

- ❖ Each plate has an inlet and outlet port for either one of the gases used in the chemical reaction of the fuel cell.

Electrode Sheets:

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

Membrane:

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

Electrolysis Kit:

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

Circuit Board:

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

Voltmeter:

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

5.0 Operation Instructions

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

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

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

Electrolysis Kit Assembly

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

KOH Electrolyte Solution

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

Circuit Board Assembly

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

Fuel Cell Assembly

(1) Remove the mounting brackets, hex-head bolts, washers, and nuts from the case and insert the hex-head bolts with a washer through the mounting holes of one polycarbonate mounting bracket with the threaded section in the direction of the square offset. Place the bipolar plates in the offsets of the mounting brackets, taking care of the soldered wires attached to each.
(2) Place an electrode sheet centered on the now face-up bipolar plate (refer to step 1) with the fabric-like surface facing the flow channels. The electrode sheets are brittle and should be handled with care.

(3) Carefully place the pre-soaked chromatography membrane centered on the electrode sheet
(4) Place another electrode sheet with the fabric side facing upwards centered on top of the membrane. You can now take the other half of the fuel cell (mounting bracket and bipolar plate) and place it on the stack with the flow channels facing the "fabric" side of the top electrode sheet, completing the single cell.
(5) Place a washer on each of the bolts, followed by a hex nut and tighten in a star pattern (preferably with a torque wrench) to 30 ft*lb. Equal torque on each of the nuts will improve performance by provide more even compression.
(6) Hand-tighten the barb fittings into each of the four holes of the bipolar plates (two on each plate) You can now attach the hydrogen and oxygen inlet/outlet hoses on either side of the fuel cell. This begins the electrochemical reaction.
(7) Attached the circuit board to the fuel cell by connecting the soldered wires to the breadboard. After short period of time there should be an observable increase in voltage displayed on the multimeter.

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

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

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

6.0 Troubleshooting

Refer to Appendix D

7.0 Regular Maintenance

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

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

8.0 Spare Parts/Inventory Requirement

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

Reusable

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

Consumable

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

9.0 References

[1] Sommer, E. M., Juan C. Ordonez, and Jose V.C. Vargas. "Alkaline Membrane Fuel Cell (AMFC) Modeling and Experimentation." *Alkaline Membrane Fuel Cell (AMFC) Modeling and Experimental Validation* (2012): n. pag.*Www.elsevier.com/locate/jpowsour*. Elsevier, 23 Mar. 2012. Web. 2 Apr. 2015

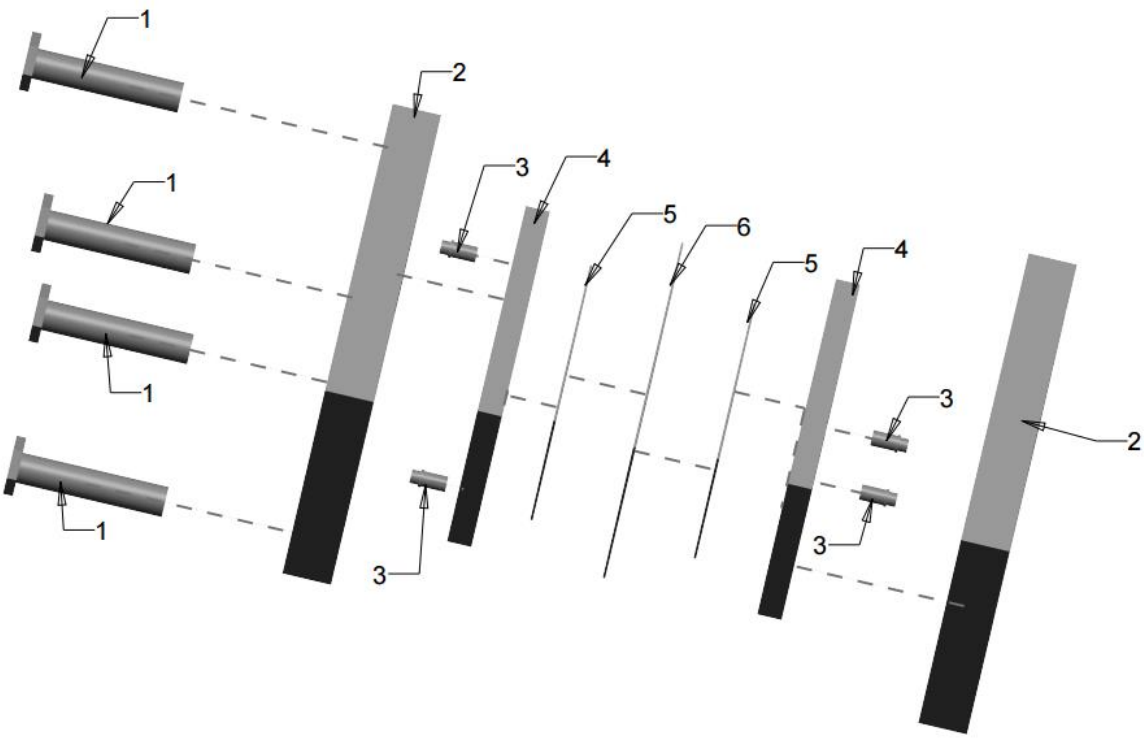
Appendices

Appendix A: Kit Inventory

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

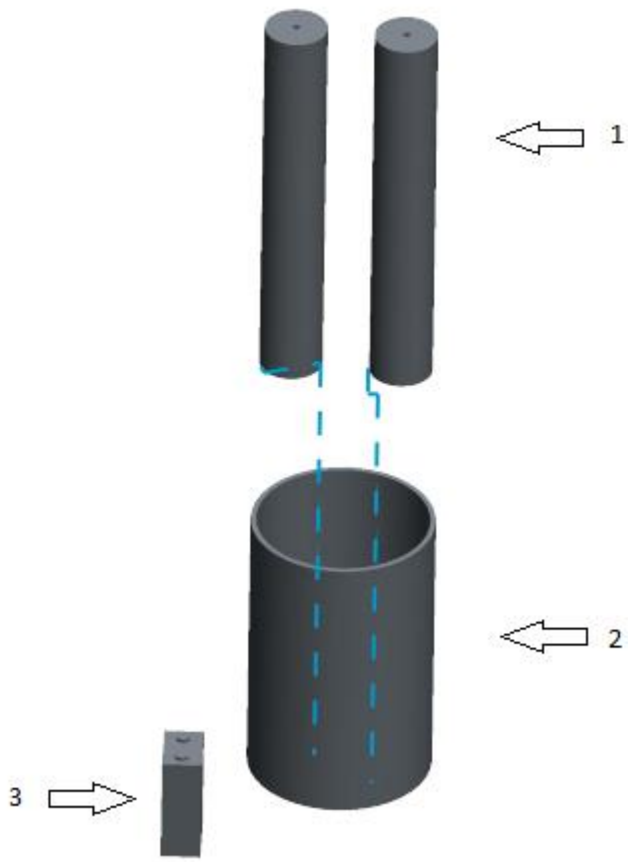
Appendix B: Product Assembly

Fuel Cell Assembly



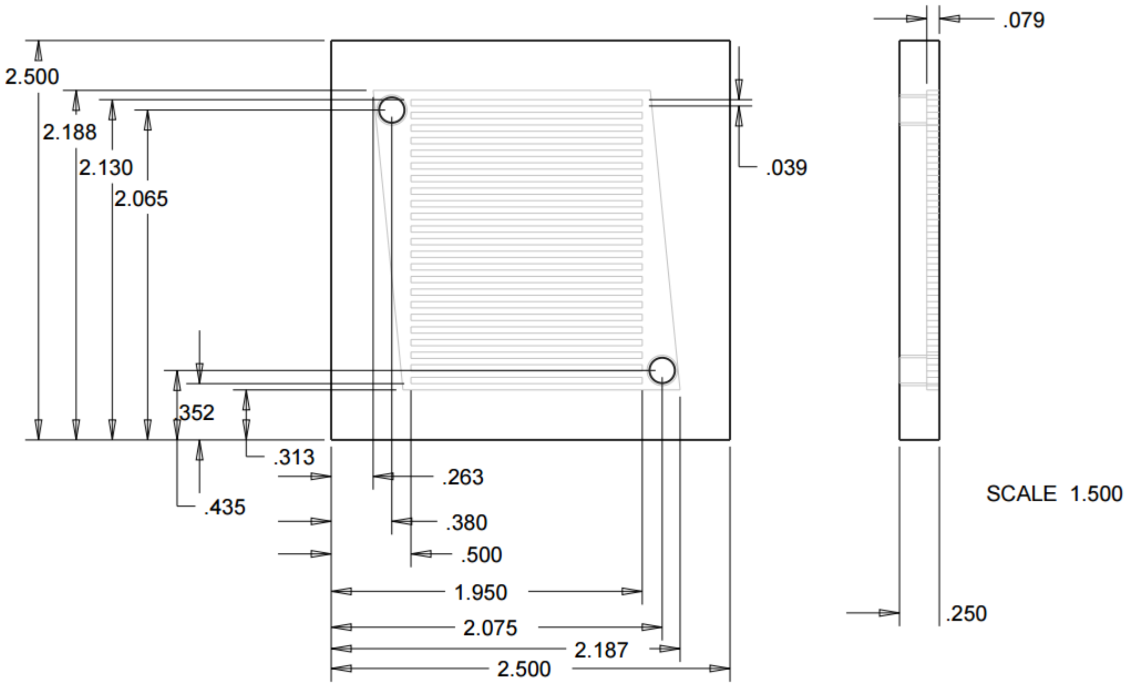
1. Hex-head Bolts
2. Mounting Brackets
3. Barb Fittings
4. Bipolar Plates
5. Platinum Electrode Sheets
6. Chromatography Membrane

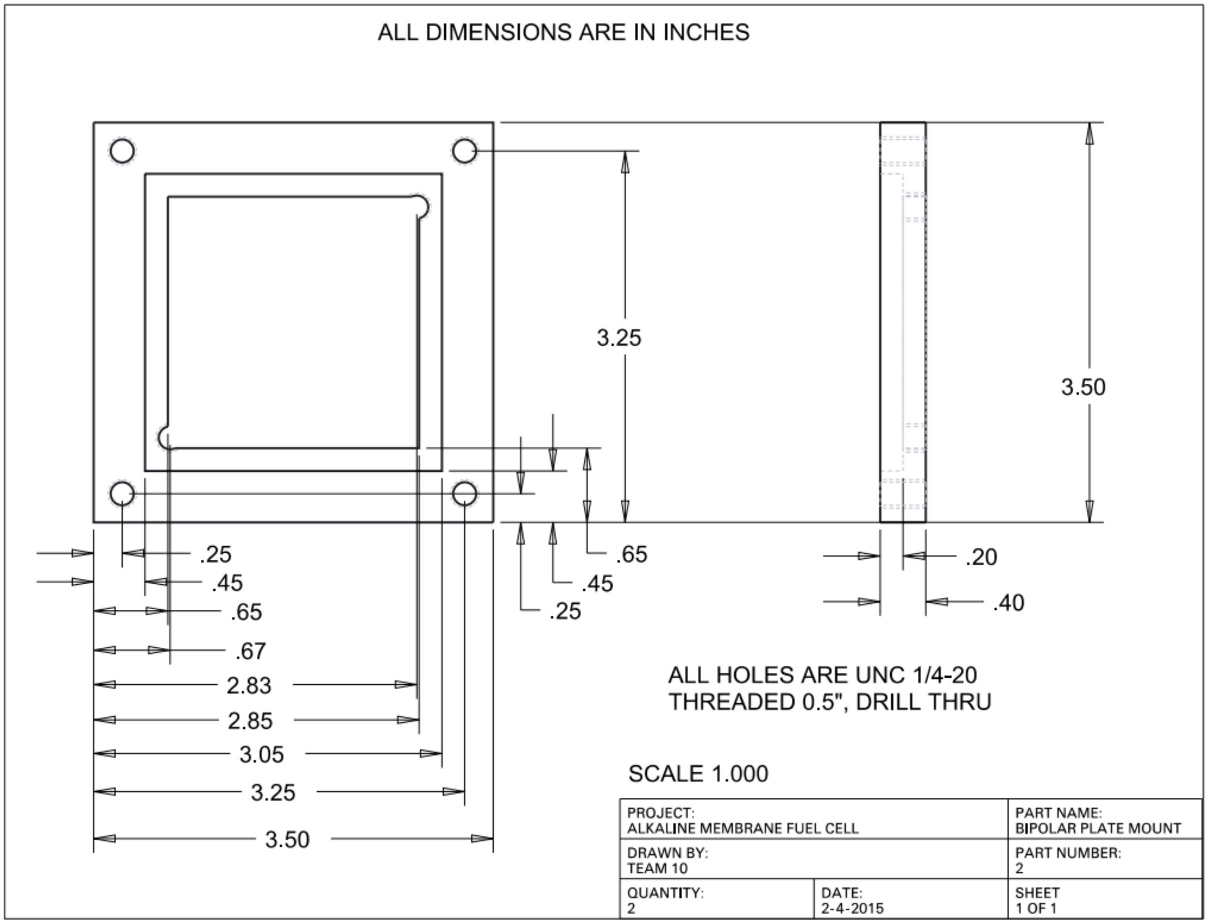
Electrolysis kit Assembly



1. 500 mL Graduated Cylinder
2. 500 mL Beaker
3. 9V Battery

Appendix C: Selected Part Drawings





Appendix D: Troubleshooting

Problem	Solution
The alkaline membrane ripped off, can I use it anyway?	The AMFC has been designed for optimal functioning, and there were not made any test using ripped alkaline membrane, it may work, but probably not as well as it should with an intact membrane.
The platinum sheets are disintegrating, is it normal?	The platinum sheets do not last forever, after a certain time of usage, signs of deterioration will be shown. If it´s noticed that the efficiency of the cell is falling, it is time to substitute the sheet.
There is something dripping from the fuel cell, should I worry?	One of the byproducts of the reaction is water. If you made sure the alkaline membrane was properly prepared (there is no excess KOH solution on it), and there are

	very few drops (unlike a flowing stream) then the drops seen are most likely water.
There is no electrical current coming from the cell (the output does not work), what should I do?	The purpose of the fuel cell is generate electrical energy, if it does not generate a current then something is wrong. There are several reasons why it would not work, usually because of mistakes made during the operation. Please follow all steps again, making sure the channels in the bipolar plates are not obstructed, the assembly is correct, the KOH was properly prepared, and the electrolysis kit is assembled correctly. If the problem still persists, please contact the FAMU-FSU College of Engineering
I was handling the alkaline membrane and accidentally the solution touched my skin, will I be okay?	Yes. The alkaline solution, although a little concentrated is not harmful unless ingested, will not cause harm if thoroughly rinsed and washed after exposure. Observation: the solution can cause some irritation in the worst cases. In case of contact with the eyes wash immediately with abundant flowing water and contact a medical professional.