Operation Manual

Team 16
Design and development of optimized flow channels for an alkaline membrane fuel cell (AMFC) educational kit

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1.0 Project Overview

A high demand for cleaner, more sustainable energy has fueled the development of methods of power generation which have less of an impact on the climate and the environment than typical fossil fuel methods [1]. The goal of this project is to design and manufacture a working alkaline fuel cell education kit which contains multiple flow channel configurations. This will allow users of the kit to compare the performances of different configurations, and study the fluid properties which contribute to said performances. The different flow configurations will be tested and optimized to ensure the fuel cell functions, and assist in the process of designing experiments which can be carried out by users of the kit.

The fuel cell produces an electrical current through an electrochemical reaction with only heat and water as its by-products and oxygen and hydrogen as a fuel source. The educational kit is portable, and aims to display how different flow configurations can affect the performance of an Alkaline Membrane Fuel Cell to all interested parties.

2.0 Acknowledgement

In its entirety, this project has required not only the hard work and dedication of team 16, but also a team of advisors, mentors, and assistants. Team 16 would like to first thank the FAMU-FSU College of Engineering for allowing us to broaden our horizons and further our knowledge in the pursuit of academic excellence in not only this project, but in all of our coursework. This includes all of the professors who have guided us along the way. We thank them for this opportunity and for providing the resources necessary to complete this project. Special thanks is given to Dr. Chiang Shih, teaching assistant Obie Abakporo, and Dr. Nikhil Gupta, for their contributions and insight into this project. We would like to thank Jeremy in the COE machine shop specifically for his hard work in helping us manufacture our fuel cell end plates. Our project would have been impossible without his assistance and strong attention to detail. We thank our advisor and sponsor, Dr. Juan Ordonez for the inspiration and assistance to complete this project. Finally, we would like to thank the Brazilian team in Federal University of Paraná (UFRP) for their advice on the project.

3.0 Functional Analysis

The purpose of a fuel cell is to convert chemical energy into electrical energy. The fuel cell provides an electrical current to an external circuit, providing on-demand power and requiring no moving parts. This is achieved by taking advantage of oxidation and reduction reactions, which release and capture electrons, respectively. The diagram of a standard alkaline fuel cell can be found below in figure 1. [2]

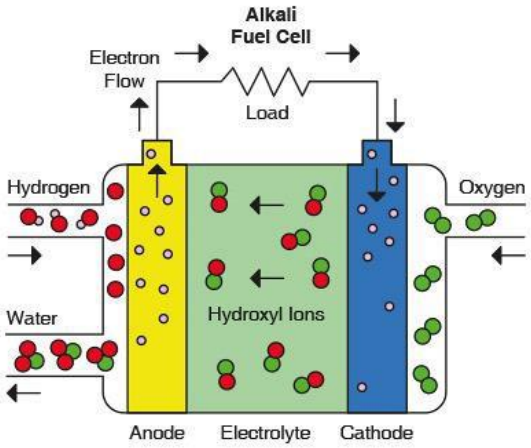


Figure 1: A diagram depicting an alkaline fuel cell [3]

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): $2H_2 + O_2 \rightarrow 2H_2O$

The kit originally contained a method for using electrolysis to produce fuel as needed. This method is being replaced by a third party advanced fuel delivery system which will produce and store hydrogen in a compressed cylinder. This will make the fuel cell more reliable and will also reduce the risk of electrical shock present in electrolysis. Another large portion of this project has been devoted to improving the safety of the fuel cell.

4.0 Product Specification

The Alkaline Fuel Cell Kit fits into a carrying case of 18 x 12.75 x 6.5 in^3. The fuel cell (2.5 x 2.5 in^2) is placed in between two 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 in3
- 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 electrical potential difference across the bipolar plates produces the maximum voltage 1.23 V for a single fuel cell. The fuel cells are machined to display three different flow configurations: parallel, serpentine and digital design.
- The bipolar plates of the fuel cell are machined out of stainless steel (2.5 x 2.5 in2) to reduce the corrosive properties of the potassium hydroxide electrolyte over extended use.
- Each plate consists of an inlet and outlet port for the fuel delivery and the by-product removal.

Electrode Sheets:

- The anode and cathode sheets are 2.5 x 2.5 in2 and consist of 40% platinum content, which deliver great efficiency at a cost-effective rate.

Membrane:

- A 40% potassium hydroxide (KOH) concentration should be utilized in the chromatography paper membrane due to the increased energy output and efficiency at this concentration [1].

Hydrogen Delivery System:

- HYDROFILL PRO (FCH-020) is a "hydrogen on demand" desktop refueling station designed for easy and automatic refilling of HYDROSTIK PRO metal hydride cartridges. It uses pure water and the AC grid (standard wall outlet) to produce 99.99% pure Hydrogen via electrolysis.

Oxygen Deliver System:

- The Petco Air Pump 9902 compresses air to deliver oxygen into the fuel cell.

Measurement Set:

- The H-TEC Measurement Set is an experimentation kit consisting of a decade resistor, two multi-meters, stopwatch, and cables.
- The decade resistor applies different load on the fuel cell to analyze the efficiency of the cell under different load settings.
- The multi-meters measure the voltage (V) and current (I) under these load conditions.

5.0 Operation Directions

The following procedures was constructed to minimize any risks involved with operating the

Educational Alkaline Fuel Cell Kit. These instructions were made for the consumer's safety in mind and should be strictly followed. Additionally, learning applications at different educational levels for the fuel cell kit can be found in Appendix E.

Portable Case

(1) Handle with care as it contains sensible equipment.
(2) Ensure that the working place is clean and leveled surface for proper operation.
(3) Before operation, ensure that students read thought the whole instruction list.
(4) Check part list and ensure that all parts are present. If any parts are missing please contact FAMU-FSU College of Engineering for assistance. Refer to Appendix A for component parts list.

Hydrogen Delivery System

(1) If all components are accounted for, proceed with assembly by carefully removing the HYDROFILL PRO (FCH-020) from the case. This machine is EXTREMELY sensible please refer to Appendix C for operation instructions.

Oxygen Delivery System

(1) Remove the Petco 9902 Air pump from the case. To operate plug in AC wall outlet and use knob to increase or decrease the flow as needed. Attach KOH filter to outlet when operating to ensure no foreign materials enters the cell besides air.

KOH Electrolyte Solution/Cell Membrane Preparation

(1) Weigh 10 grams of Potassium Hydroxide (KOH) and place it in a beaker that can withstand up to 150 º F, and add 50 mL of distilled water to the solution. Stir well until KOH is fully dissolved (KOH flakes no visible) taking precaution handling with gloves. Lab goggles are required during this process.

(2) Pour the solution into a large container large to place the chromatography paper horizontally on the bottom surface, allowing for the absorption of the solution for approx. 10 minutes.

Measurement Set Assembly

(1) On a stable surface, place the decade resistor box. Grab the two provided multi-meters and insert the one of the two 9 volts battery provided in each multi-meter.

(2) Set one multi-meter to voltage (V) and the other on current (mA). Attach one in port "I"

and the other in port "U". When ready to record data attach one end of the provided banana clips to port 1 or 2 and the other set to the fuel cell plate ensure that the right polarity at cathode and anode.

*Suggested configuration: Start at 0 Ω resistor then increase as needed for test.

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 one of the desired bipolar plate configurations in the offsets of the mounting brackets.

(2) Place an electrode sheet with the fabric side centered on the 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 away from the membrane. You can now place the other identical plate on top with the flow channels facing the electrode.

(5) Place the other polycarbonate mounting bracket on top of the plate to complete fuel cell configuration.

(6) Secure plate by placing a washer on each of the bolts, followed by a hex nut and tighten in a star pattern to 10 ft*lb. Equal torque on each of the nuts will provide an even compression distribution allowing for better performance within the cell.

(7) Hand-tighten the barb fittings into each of the four holes of the bipolar plates being tested. Attach the HydroStick Pro and the Petco 9902 Air Pump inlet/outlet hoses on either side of the fuel cell. This will begin the electrochemical reaction.

(8) Attached the banana clips from the H-TEC measurement set to the fuel cell plate connectors. After a short period of time there should be an observable increase in voltage and current displayed on the corresponding multi-meter.

Once the fuel cell has begun the electrochemical reaction, the voltage can be read across varying resistances by varying the load on the decade resistor board. 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 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). Using the decade resistor board 10 sets of voltages can be recorded.

Depending on the duration of the testing period, the membrane will begin to dry. To ensure statistically sound results, operation time is between 10-15 minutes. Ensure that the HydroStick Pro is fully charge before conduction test.

WARNING

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 strongly recommended to handle the potassium hydroxide solution with gloves, lab goggles, and standard laboratory attire.

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, wash bipolar plates with water and soap. For HydroFill and HydroStick Pro please refer to Appendix C.

8.0 References

[1] "FuelCellToday- The Leading Authority on Fuel Cells." Fuel Cell Applications. N.p., n.d. Web. 28 Sept. 2016.

[2] Sommer, E.M., L.S. Martins, J.V.C. Vargas, J.E.F.C. Gardolinkski, J.C. Ordonez, and C.E.B. Marino. "Alkaline Membrane Fuel Cell (AMFC) Modeling and Experimental Validation." Journal of Power Sowers (2012): pag. Web. 25 Sept. 2016.

[3] "Types of Fuel Cells." Department of Energy. Office of Energy Efficiency and Renewable Energy, n.d. Web. 29 Sept. 2016.

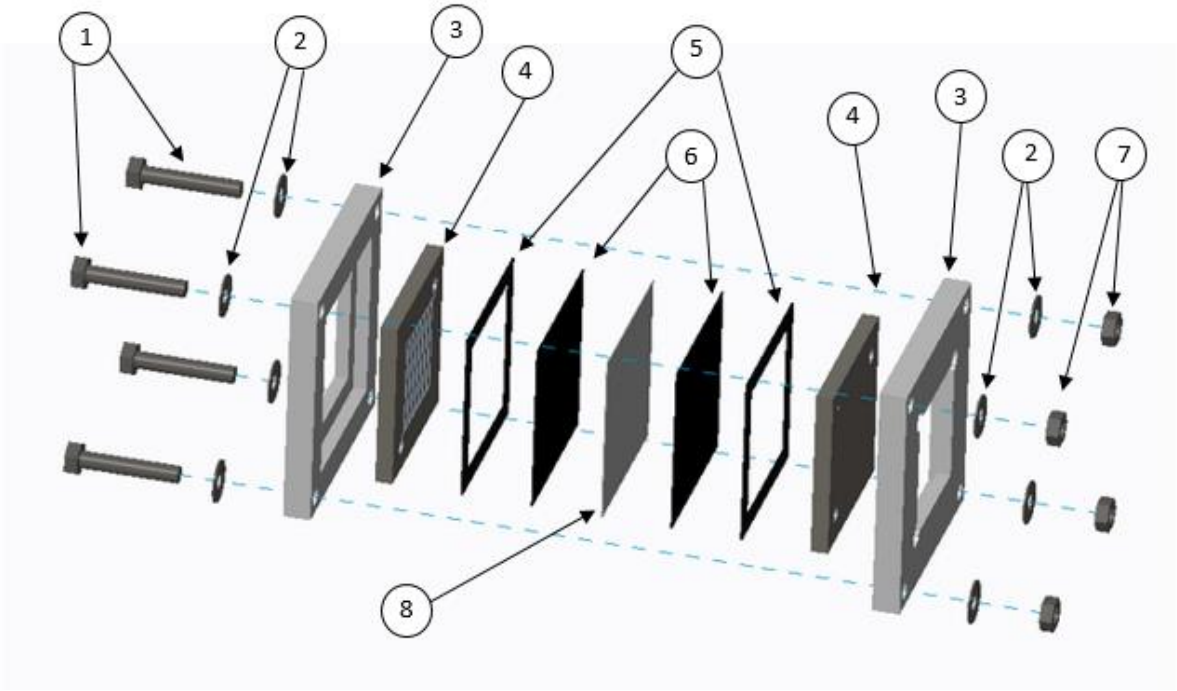
Appendices

Appendix A: Kit Inventory

(1) Professional Series Metal Frame Hard Case
(6) Bi-polar Plates
(2) Polycarbonate Mounting Brackets
(4) ¼” Hex-head Mounting Bolts
(4) ¼” Washers
(4) ¼” Nutsjy
(4) Platinum Electrode Sheets

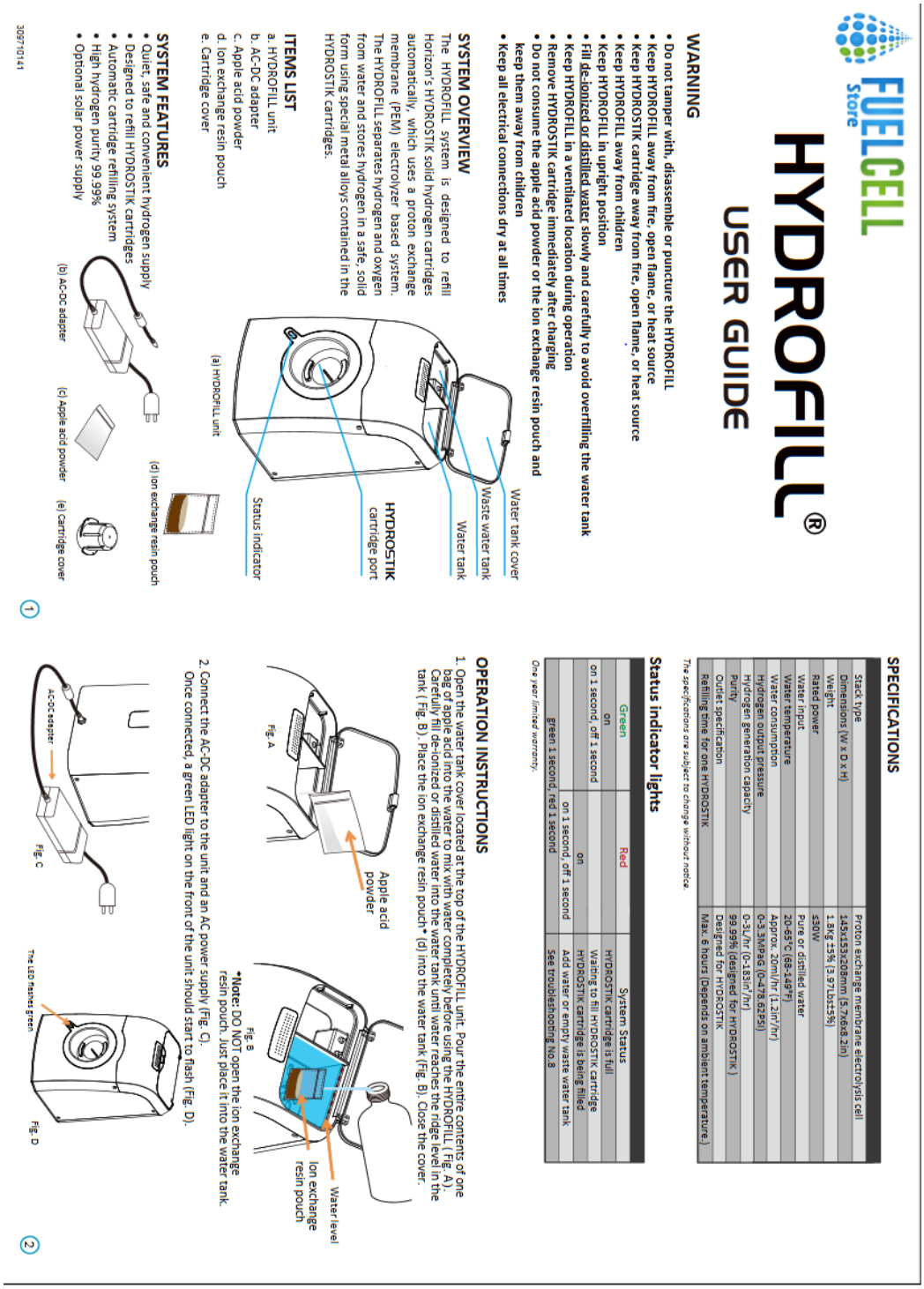
(1) HydroFill Pro
(1) HydroStick Pro
(1) Pressure Regulator
(1) Petco 9902 Air Pump
(1) Decade Resistor Board
(2) Multi-meter
(2) 9V Battery
(6) Banana Clip Connector
(1) 60ft Cut to fit Plastic Tubing

Appendix B: Fuel Cell Assembly



Part Name	Part Number	Quantity	Material
Mounting Bolts	1	4	Steel
Washers	2	8	Steel
Mounting Bracket	3	2	Polycarbonate
Cell Plate	4	2	Stainless Steel
Gasket	5	2	Rubber
Electrode Anode/Cathode	6	2	Electrode 40% Carbon Paper
Nut	7	4	Steel
Membrane	8	1	Paper

Appendix C: HydroFill and HydroStick Pro Operation



FUELCELL Store

HYDROFILL®

USER GUIDE

WARNING

- Do not tamper with, disassemble or puncture the HYDROFILL
- Keep HYDROFILL away from fire, open flame, or heat source
- Keep HYDROSTIK cartridge away from fire, open flame, or heat source
- Keep HYDROFILL away from children
- Keep HYDROFILL in upright position
- Fill de-ionized or distilled water slowly and carefully to avoid overfilling the water tank
- Keep HYDROFILL in a ventilated location during operation
- Remove HYDROSTIK cartridge immediately after charging
- Do not consume the apple acid powder or the ion exchange resin pouch and keep them away from children
- Keep all electrical connections dry at all times

SYSTEM OVERVIEW

The HYDROFILL system is designed to refill Horizon's HYDROSTIK solid hydrogen cartridges automatically, which uses a proton exchange membrane (PEM) electrolyzer based system. The HYDROFILL separates hydrogen and oxygen from water and stores hydrogen in a safe, solid form using special metal alloys contained in the HYDROSTIK cartridges.

Water tank cover
Waste water tank
Water tank
HYDROSTIK cartridge port
Status indicator

ITEMS LIST

a. HYDROFILL unit
b. AC-DC adapter
c. Apple acid powder
d. Ion exchange resin pouch
e. Cartridge cover

(a) HYDROFILL unit
(b) AC-DC adapter
(c) Apple acid powder
(d) Ion exchange resin pouch
(e) Cartridge cover

SYSTEM FEATURES

- Quiet, safe and convenient hydrogen supply
- Designed to refill HYDROSTIK cartridges
- Automatic cartridge refilling system
- High hydrogen purity 99.99%
- Optional solar power supply

1

SPECIFICATIONS

Stack type	Proton exchange membrane electrolysis cell
Dimensions (W x D x H)	145x153x208mm (5.7x6.8.2in)
Weight	1.8Kg ±5% (3.97Lbs±5%)
Rated power	≤30W
Water input	Pure or distilled water
Water temperature	20-65°C (68-149°F)
Water consumption	Approx. 20ml/hr (1.2in³/hr)
Hydrogen output pressure	0-3.3MPaG (0-478.62PSI)
Hydrogen generation capacity	0-3L/hr (0-183in³/hr)
Purity	99.99% (designed for HYDROSTIK)
Outlet specification	Designed for HYDROSTIK
Refilling time for one HYDROSTIK	Max. 6 hours (Depends on ambient temperature.)

The specifications are subject to change without notice.

Status indicator lights

Green	Red	System Status
on		HYDROSTIK cartridge is full
on 1 second, off 1 second		Waiting to fill HYDROSTIK cartridge
	on	HYDROSTIK cartridge is being filled
	on 1 second, off 1 second	Add water or empty waste water tank
green 1 second, red 1 second		See troubleshooting No.8

One year limited warranty.

OPERATION INSTRUCTIONS

1. Open the water tank cover located at the top of the HYDROFILL unit. Pour the entire contents of one bag of apple acid into the water to mix with water completely before using the HYDROFILL (Fig. A). Carefully fill de-ionized or distilled water into the water tank until water reaches the ridge level in the tank (Fig. B). Place the ion exchange resin pouch* (d) into the water tank (Fig. B). Close the cover.

Apple acid powder
Fig. A
Water level
Ion exchange resin pouch
Fig. B

*Note: DO NOT open the ion exchange resin pouch. Just place it into the water tank.

2. Connect the AC-DC adapter to the unit and an AC power supply (Fig. C).
Once connected, a green LED light on the front of the unit should start to flash (Fig. D).

AC-DC adapter
Fig. C
The LED flashes green
Fig. D

2

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3. Insert the HYDROSTIK into the cartridge port. Use one hand to hold the HYDROFILL, and with the other hand, fully insert the HYDROSTIK cartridge by turning it clockwise into the cartridge port. Check and make sure that the HYDROSTIK is fully inserted. Once fully inserted, position and push the cartridge cover into the protruding HYDROSTIK. Turn the cover clockwise until it locks into place. See Fig. E and F.


Fig. E


Fig. F

4. Once the cartridge is inserted, the LED indicator light on the front of the unit switches from green to red (Fig. G). Your HYDROSTIK cartridge is now being filled with hydrogen. When the indicator light turns green, the HYDROSTIK cartridge is fully charged (Fig. H). Disconnect the cartridge cover, then the HYDROSTIK cartridge from the HYDROFILL (turn both anti-clockwise to disconnect).

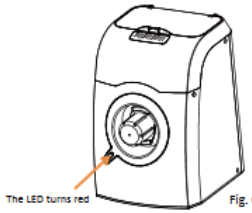

Fig. G

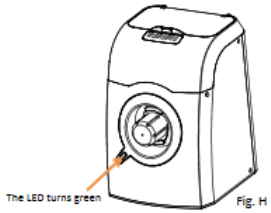

Fig. H

5. Once the procedure is completed, disconnect the HYDROFILL from the AC. If more cartridges need to be charged, repeat steps 3-5.

USEFUL INFORMATION / MAINTENANCE

- Use de-ionized or distilled water, do not use the tap water or drinking water containing minerals.
- Pour the entire contents of one bag of apple acid into the water to mix with water completely before using the HYDROFILL. It takes about 4 - 6 hours to fully charge a cartridge.
- Put the ion exchange resin pouch into the water tank before using the HYDROFILL.
- Keep the ion exchange resin pouch within de-ionized or distilled water for humidification when not in use.
- When waste tank is full, pour waste water out and refill water tank. Keep the ion exchange pouch into the water tank. Add one bag apple acid every time when water is refilled.
- If the LED light alternates between red for 1 second and off for 3 seconds, carefully add the entire contents of one apple acid bag (4g) (c) into the water tank allowing it to mix with the water without disconnecting the cartridge. Allow the HYDROFILL to hold the cartridge in place for more than 1 hour in order to keep it charging, this will not affect the HYDROFILL' operation and filling time.The contents of the bag will help to maintain the performance of the HYDROFILL.
- The HYDROFILL can still run and generate hydrogen even if the LED light alternates between red for 1 second and off for 3 seconds, but the hydrogen generating efficiency is lower.
- After using the apple acid, you may find some black particles on the inner wall of the water tank. You can wipe the black particles off with a tissue.

TROUBLESHOOTING

1. The LED light does not flash green after the power supply cord is connected.
   SOLUTION: Check the connection between the AC-DC adapter and the power supply.
2. The LED light does not turn red after the HYDROSTIK is connected to the HYDROFILL.
   SOLUTION (a): Disconnect the HYDROSTIK and re-connect it again slowly. Make sure the connection is smooth and the HYDROSTIK is fully inserted into the thread.
   SOLUTION (b): Check that the water level in the tanks are correct (see operating instructions)
   SOLUTION (c): Remove and re-connect the AC-DC adapter.

3. The cartridge has been charging for more than 6 hours, but the indicator light is still red.
   SOLUTION (a): Disconnect the cartridge and re-connect it tightly and correctly.
   SOLUTION (b): Disconnect the cartridge and connect it to the application you wish to supply to confirm there is hydrogen in the cartridge.
4. The LED light alternates between red for 1 second and off for 3 seconds.
   SOLUTION (a): It is suggested the water temperature in the water tank is between 40°C and 70°C.
   SOLUTION (b): Pour the entire contents of one apple acid bag (4g) (c) into the water tank allowing it to mix with the water without disconnecting the cartridge. Allow the HYDROFILL to charge the cartridge for more than 1 hour. The powder contained inside will help to maintain the performance of the electrolyzer (Fig. I).

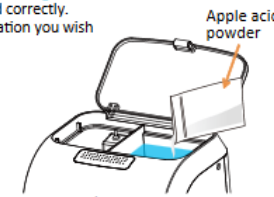

Fig. I

5. The LED light alternates between red for 1 second and off for 1 second.
   SOLUTION: Check the water level of the water tank and waste water tank is correct. Either add water to the water tank or remove water from the waste water tank as required (Fig. J).

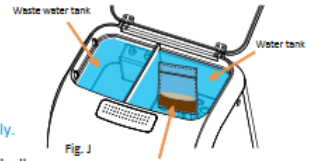

Fig. J

6. The LED light is red for 1 second and green for 1 second alternately.
   SOLUTION (a): Remove and re-connect the AC-DC adapter.
   SOLUTION (b): Contact customer services at support@horizonfuelcell.com
7. The light LED turns green (the cartridge has been charging for 6 hours), but no or little hydrogen is filled.
   SOLUTION (a): Check the HYDROSTIK being connected tightly with no leakage.
   SOLUTION (b): Check the water temperature (It is suggested the water temperature is between 40°C and 70°C).
   SOLUTION (c): If the hydrogen generating efficiency is low, pour 1 bag of apple acid into the water tank allowing it to mix with water and have the system charging the cartridge for more than 1 hour. The contents of the bag will help to maintain the performance of the HYDROFILL. If problem continues repeat this process once more.
   * A quick way to check the volume of hydrogen inside the cartridge is to weigh the HYDROSTIK before and after filling it respectively. The weight difference is around 0.9 grams, which shows the HYDROSTIK filled is over 10L.
8. The LED light is green 1 second, red 1 second at the same time.
   SOLUTION: Pour the water out from both tanks. Add one bag of apple acid into the water tank. And then pour 50°C water into the water tank for 3 minutes. After 3 minutes repeat that process 2 times.

If you still experience problems, please contact support@horizonfuelcell.com for help.

Ion exchange resin pouch

FREQUENTLY ASKED QUESTIONS

Q: How is hydrogen stored?
A: The hydrogen is stored in small cartridges (HYDROSTIK) at low pressure. When refueling, hydrogen gas is sent at high pressure into the cartridge, and the gas is adsorbed onto the surface area of a special metal alloy which is contained inside the cartridges, becoming a solid (hydride). This is the safest form of hydrogen storage since it is not stored at high pressure. When connected to the fuel cell, the small hydrogen tanks slowly releases hydrogen using a heat exchange process with the ambient temperature.

Q: How can I refill the HYDROSTIK cartriges with hydrogen?
A: All you need to do is add water into the tank, connect the AC-DC adapter and the empty HYDROSTIK cartridge. The HYDROFILL will split the oxygen and hydrogen from the water, sending hydrogen into your HYDROSTIK cartridge. It will take 4-6 hours to fully fill a HYDROSTIK cartridge.

Q: What is the purity level for hydrogen produced by the HYDROFILL?
A: The purity of hydrogen produced by the HYDROFILL is 99.99% under room temperature. The metal hydrides contained in the cartridges first adsorb hydrogen, then releases it at a high purity (99.999%) into the fuel cell.

Q: What is the apple acid powder and what does it contain?
A: The powder contained inside the apple acid bag is apple acid. Metal ions will strongly affect and poison the electrolyzer stack inside the HYDROFILL over time. Many acidic solutions have the ability to neutralize the ions and help to recover the performance of the HYDROFILL. Apple acid, a food additive, is very safe and can be used for system maintenance with no negative effect. Keep away from children and do not consume.

Q: Is it possible to produce renewable hydrogen fuel using solar or wind power?
A: Yes. The HYDROFILL uses a DC power input and a solar power accessory that can be adapted to the HYDROFILL to use as an initial power source. The result is a zero carbon fuel from production to consumption.

Appendix D: Part Drawings

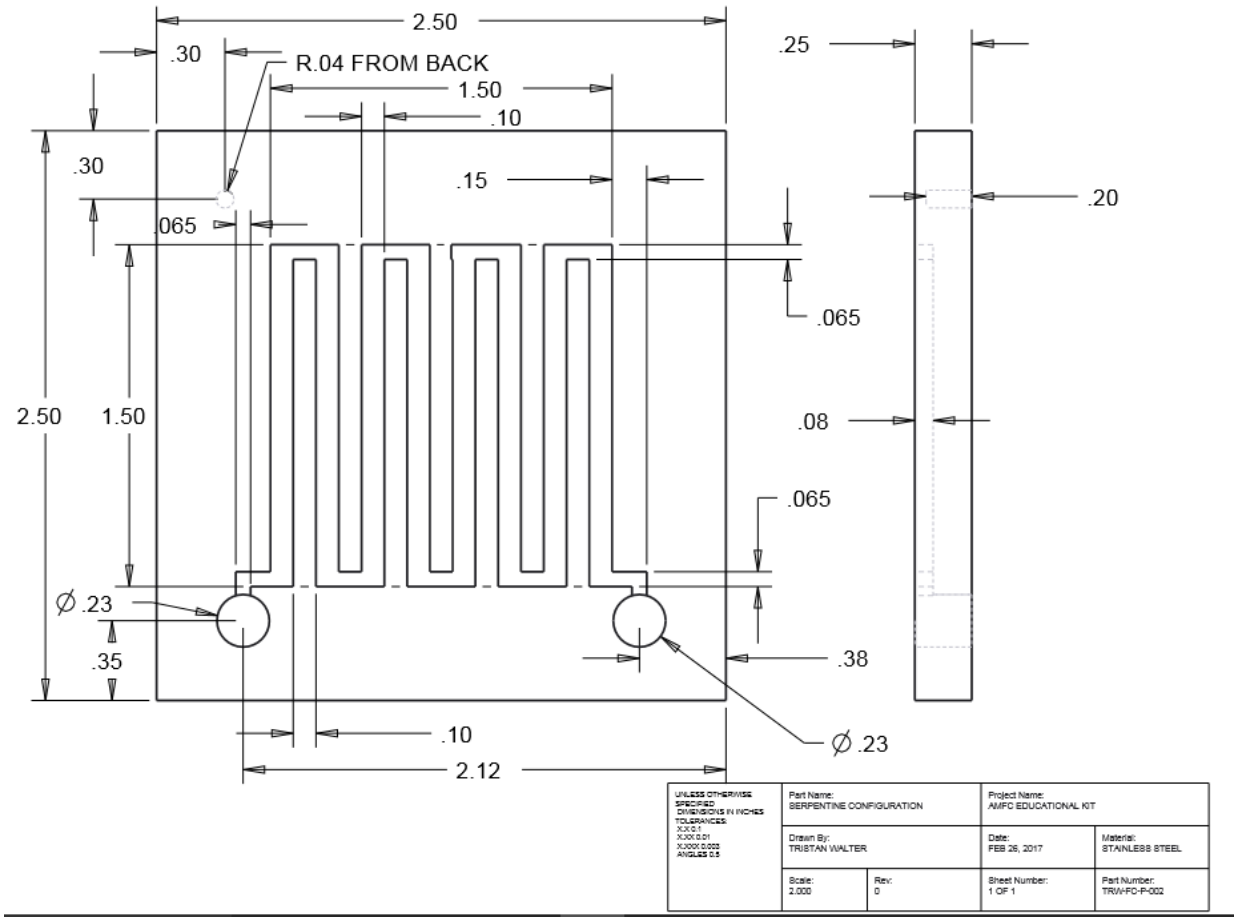

Figure C-1: Serpentine end plate drawing

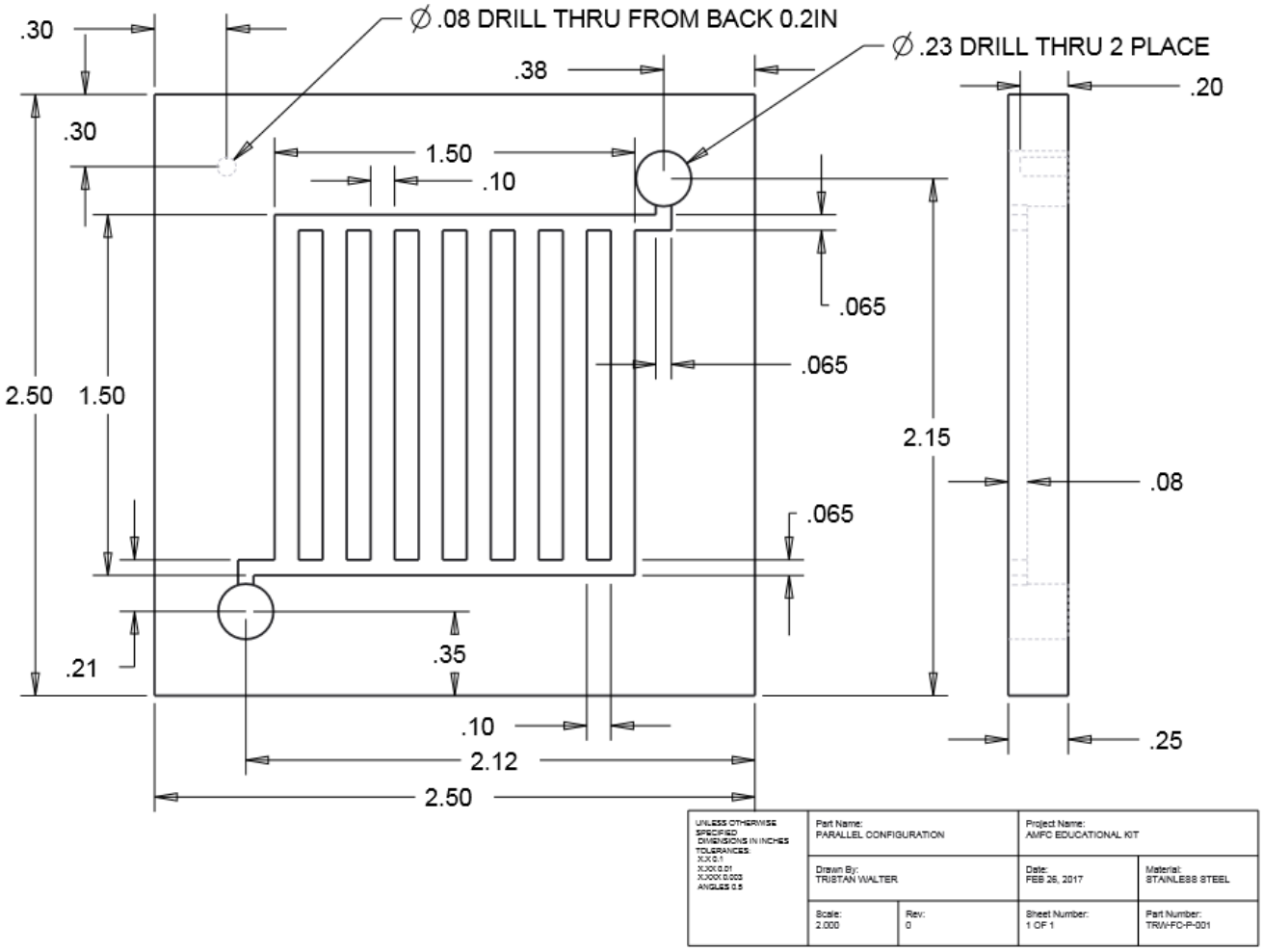

Figure C-2: Parallel end plate drawing

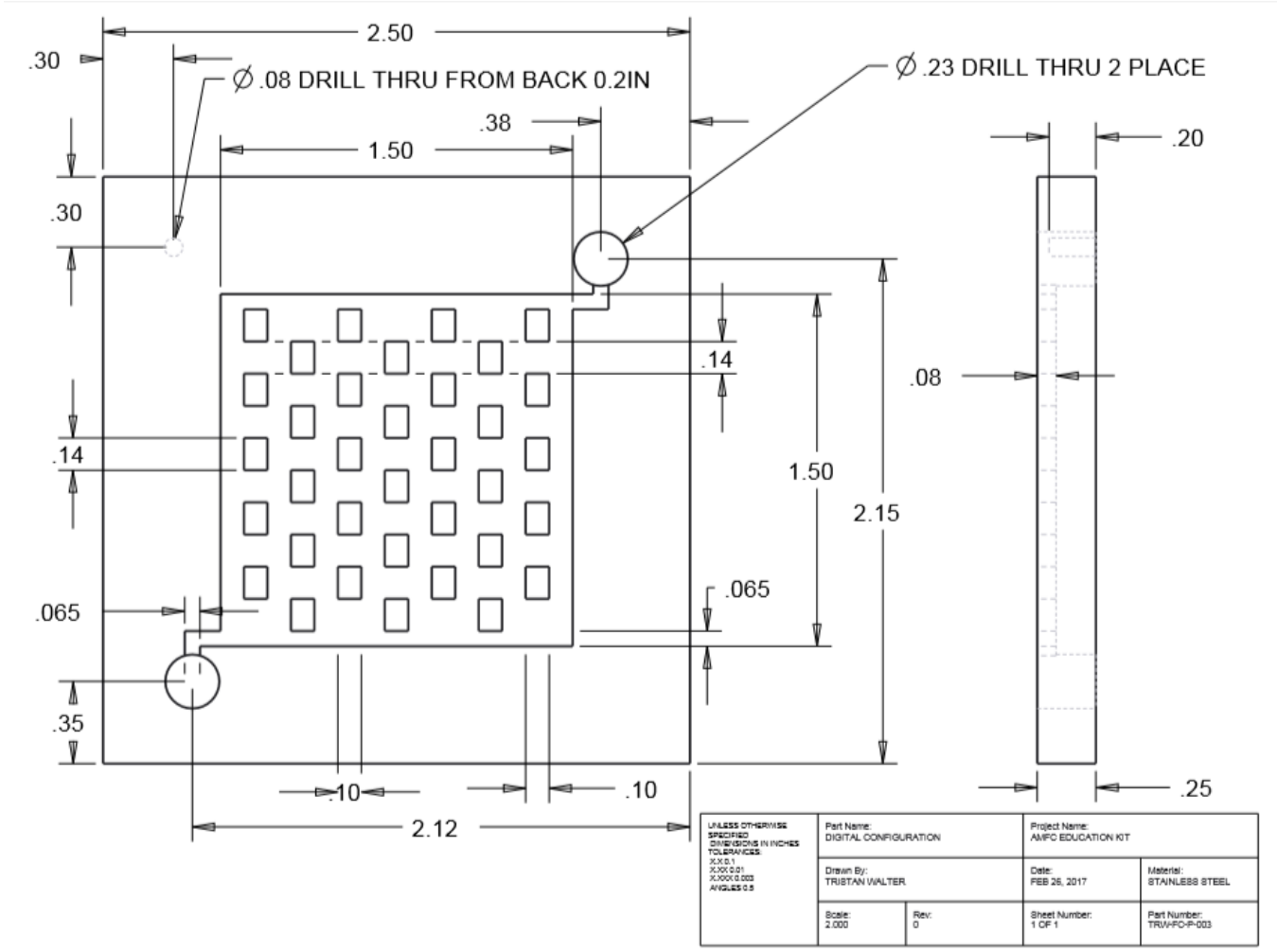

Figure C-3: Digital end plate drawing

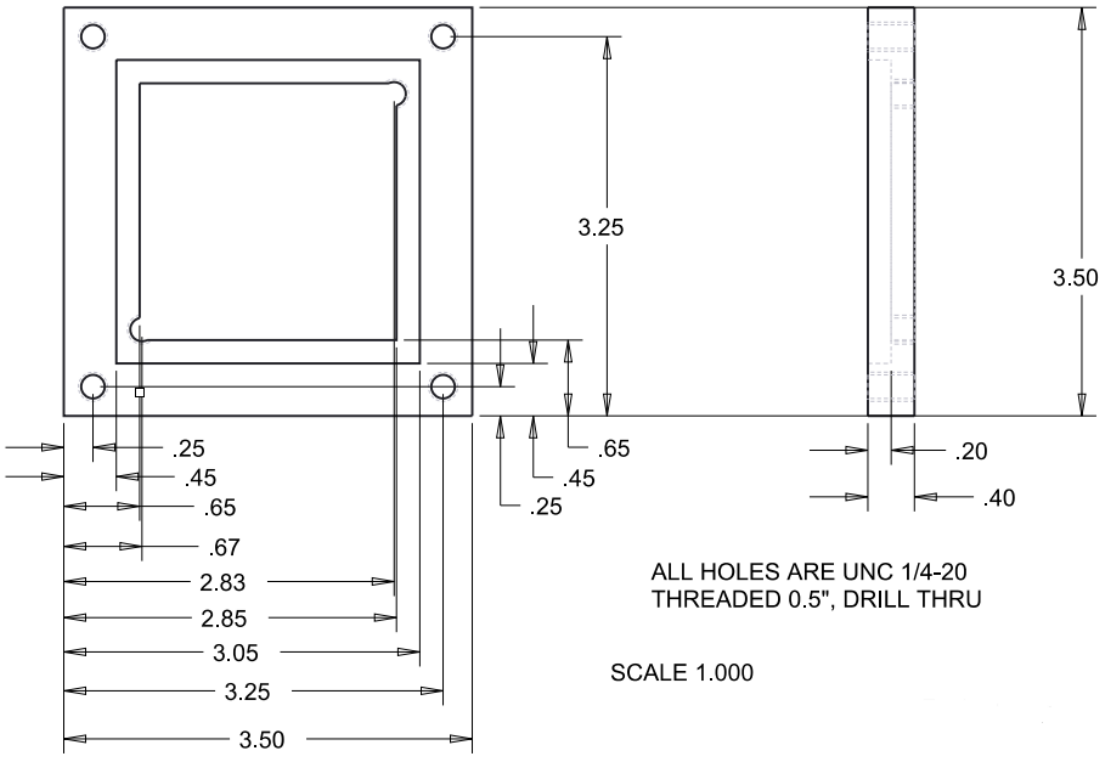

Figure C-4: Digital end plate drawing

*All dimensions shown are in inches

Appendix E: Learning Applications

Lessons and Courses	6th	7th	8th	9th-12th	College
Use data collection technology to gather and analyze data					
Organize and display data in a variety of ways					
Demonstrate the use of a device to accomplish a task					
Identify between independent/dependent variables					
Investigate energy transformation between forms					
Investigate how energy can't be created/destroyed					
Explore the atomic theory					
Differentiate chemical/physical changes					
Investigate renewable/nonrenewable energy sources					
Use scientific observation to develop scientific inferences					
Differentiate chemical/nuclear reactions					
Relate various electrical theories					
Investigate conductors, semiconductors, insulators					
Investigate relationship between current, voltage, resistance, power					
Explore Law of Conservation of Energy in closed/isolated systems					
Create chemical potential energy diagrams					
Distinguish endothermic, exothermic reactions					
Explain how factors affect rate of chemical reaction					
Describe oxidation-reduction reactions					
Relate basicity and hydroxyl ions and pH					
Characterize types of chemical reactions					
Apply mole concept/conservation of mass to calculate quantities of chemicals in reactions					
Chemistry I					
Chemistry II					
Physics II					
Electrical Engineering					
Chemical Engineering					
Mechanical Engineering					
Pre-Med					

Appendix F: Troubleshooting

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET
Preparation	HydroStick empty	No power output	5	Hydrofill out of Water, Not plugged in	8 3	Double Check System	10
Preparation	HydroFill Malfunction	Red Light Indicator on	10	Using non-distilled water	1	Buddy Check, Only use distilled water	4 10
Preparation	Dry Membrane	Reduced Power Output, Burnt Membrane	5 8	Not sufficiently soaked	4	Make sure properly soaked	6
Assembly	Mismatched Parts	No power output, Leaking Fuel	5 10	Human Error	6	Buddy Check, Follow Instructions	10
Assembly	Bolts not tightened	Leaking Fuel	8	Improper Tools, Human Error	4 6	Tighten bolts using correct sized wrench	10
Operation	Leaking Gases	Undesired noise, Fire Hazard	2 10	Damaged tubing, Bolts not Tightend	2 6	Inspect tubing before each use	8
Operation	Fuel Cell too Hot	Melted housing, Burnt Membrane	10 10	Unregulated gas flow, High ambient temperature	3 3	Gradually inc. flow rate, operate in A/C if necessary	8