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Introduction

Mission Statement

Power Solutions multidisciplinary team is focused on the client's success in every aspect of the projects in which the team is engaged. Through team work and innovation, Power Solutions strives to design, develop and market standard, safe and usable renewable energy systems to benefit society.

Problem Statement

With rising energy costs, fossil fuels polluting the environment and few viable alternative energy sources available, an affordable wind to hydrogen energy product is needed. Exploring the possible integration of wind to hydrogen through the process of electrolysis will provide homeowners and businesses the ability to produce and store clean energy.

Statement of Work

Engineering and Technology

Three components worked together to accomplish the mission and purposes, which include Engineering and Technology, Business and Economic Analysis, and Marketing and Communications. The first to be discussed is engineering and technology.

Second Semester Deliverables

Prototype

Test Alternatives

Detailed Alternative Analysis

Final Recommendation

Detailed Drawings and Plans

Safety Manual

User Manual

During the course of this project, a prototype drawing was completed and materials were gathered for the electrolysis cell. Figure 1 is a SolidWorks rendering cell. Once the electrolyzer was constructed, testing of the alternatives began. Tests of the electrolysis cell included

Electrode Surface Area

For this test, three electrodes of 316 stainless steel with differing surface areas were used including Ulrafine-Filtering Type 316 SS Wire Cloth Dutch Weave 24 X 110 Mesh, Super Corrosion Resistant SS (Type 316) #4 Satin Finish Sheet, and Particle Sifting Woven Wire Cloth Type 316 16 X16 Mesh. Sulfuric acid was used as the electrolyte for this test.

Electrode Material/Electrolyte

Once the optimal electrode surface area was found, this test was completed to yield the best electrode material and electrolyte. Electrode materials in this test included titanium, acid and salt water resistant nickel-plated copper (Monel), aluminum, and 316 stainless steel. The type of electrolyte used depended on the electrode material in each test. Electrolytes included H_2SO_4, KOH, NaOH. The sulfuric acid was used with electrode materials that were more corrosion resistant, which included stainless steel, titanium, and nickel-plated copper (Monel).

SPE

The final test included a Solid Polymer Electrolyte (SPE). The best electrode found in the first two tests was used with the Nafion SPE.

Business and Economic Analysis

From a business standpoint, many factors were considered. The first and most important is whether or not an electrolysis cell will be profitable. It has been shown through the analysis that this product can be profitable.

It has also been important to identify competitors and methods to differentiate the company and product from others in the same business sector. To date we have been unable to find, through the combined research, any companies which are selling this specific type of system. However the National Renewable Energy Laboratory (NREL), a government sponsored lab in Golden, Colorado, has set up a Wind-to-Hydrogen demonstration project. The NREL has partnered with Xcel Energy, an electric utility provider, to develop this demonstration. However at this point there is no indication of plans to market a system like the demonstration project.

It is likely that other companies are looking at a system such as the one we are proposing, there are currently no other companies we have found actively marketing a system.

Marketing and Communications

The marketing and communications campaign is an important part of the project. Therefore, a Web site was designed and created to promote AERO Component Repair LLC. The Web site serves as a means for customers and potential customers to learn about the company and its products and services. It has a professional look and is easy to navigate. Information about the company and industry information are included in the site.

Advertising is vital for the success of the product. Marketing instruments include advertisements for various publications, a brochure with product information sheets and company information, and various educational materials to inform of the importance and advantages of the product.

To ensure proper use of the product, educational and instructional materials will be created. A user's manual and safety manual will ensure appropriate and safe measures are taken when using the product.

Engineering Specifications

All tests were conducted using a single electrolysis cell to have consistent data for comparison purposes. A 7 X 18 X 12 inch electrolysis cell was chosen to conduct the tests in order to change the electrodes easily with plenty of space for wires and plumbing. The electrodes were separated either by a piece of Plexiglas or a Solid Polymer Electrolyte (SPE) as shown in Figure 1. Some tests compared the Plexiglas separator and the SPE.

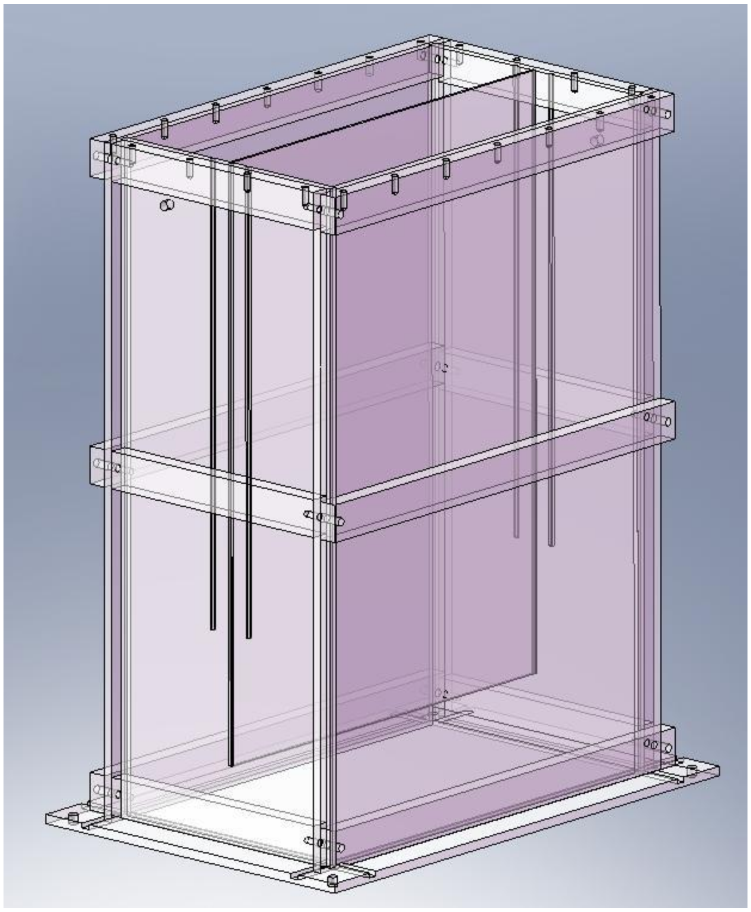


Figure 1: Represents the testing electrolyzer cell with an SPE in place between the electrodes

Due to the structure of the SPE, a housing was used to support and seal the electrolyzer's anodic and cathodic chambers from between the electrodes as in Figures 2. To achieve this, the SPE was "sandwiched" between two pieces of Plexiglas that had their center sections milled to expose the SPE membrane. Figure 11 illustrates the Plexiglas material that "sandwiched" the SPE membrane. An adhesive sealant was applied to the SPE and Plexiglas holders and the container walls to have accurate gas purification tests.

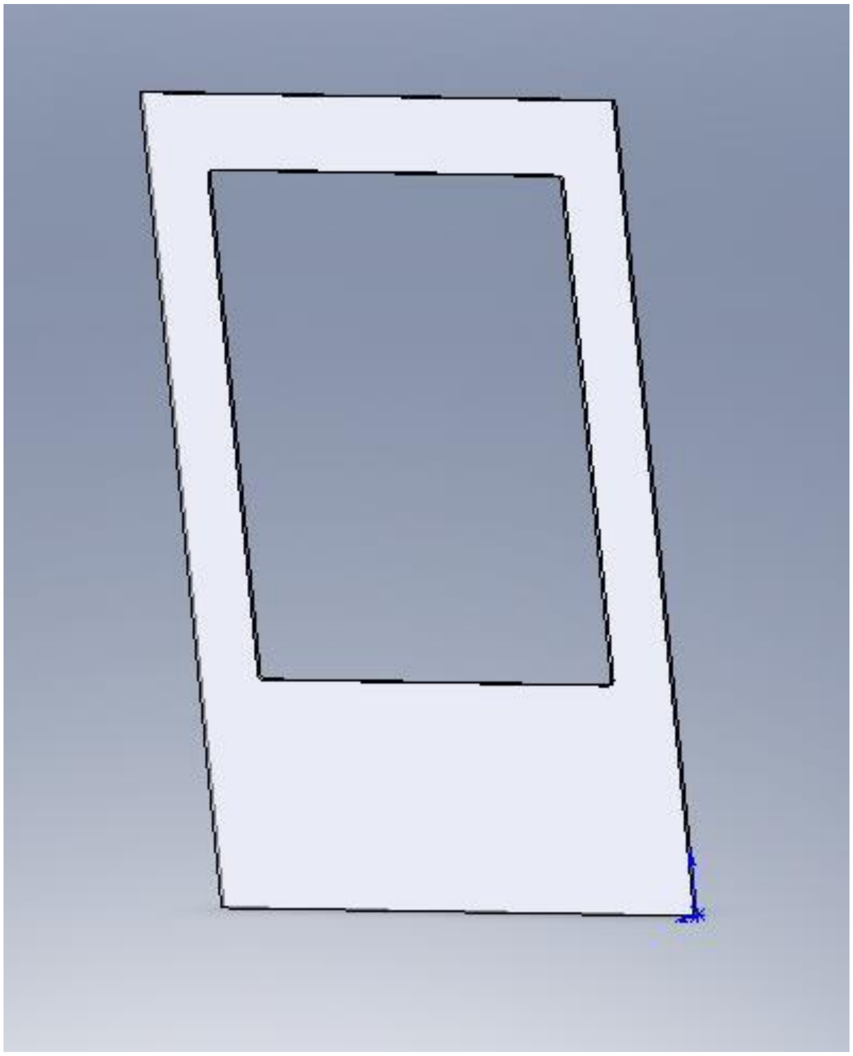


Figure 2: Illustrates the SPE membrane holder with center sections milled away

Under testing conditions without the SPE, a single piece of Plexiglas was used to separate the gases that were produced at each electrode. To change the electrodes and membrane material easily, the sides of the electrolyzer cell had a series of slots milled .0625 inches deep to create “housings” for each plate and electrode as illustrated in Figure 3.

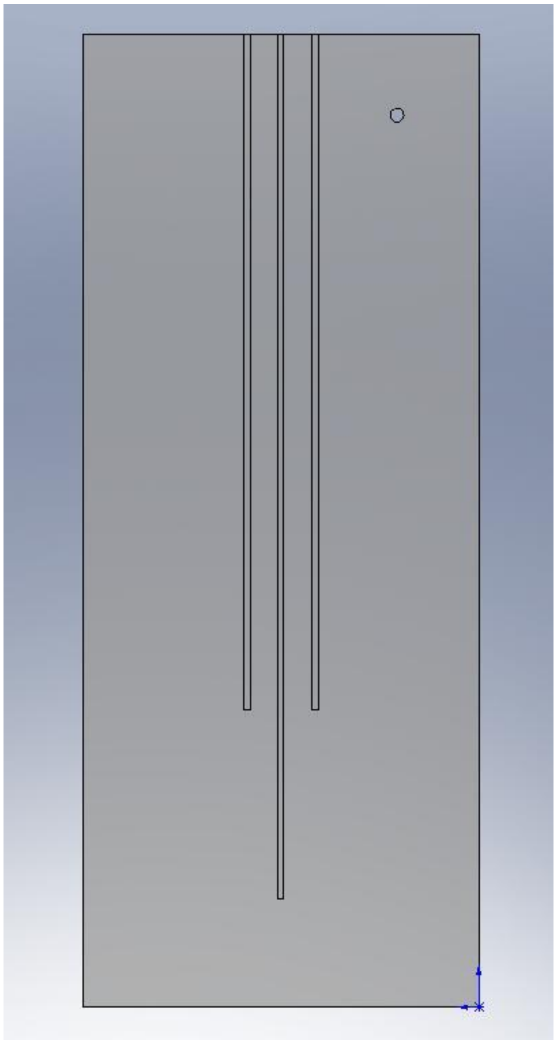


Figure 3: Illustrates the sides of the electrolyzer tank

The center slot, intended for the Plexiglas separator or SPE membrane, extends 4.5 inches lower in the cell than the electrodes to ensure complete gas separation. This slot also ends one inch from the bottom of the cell so the water can flow between each side of the electrolyzer. The Plexiglas tank was constructed from .25” Plexiglas, and the Plexiglas separator assemblies were constructed from .080” Plexiglas. The end plates of the electrolyzer were dimensioned so that a 12”X12” electrode could slide into the slots without any modification. Various Nylon and PVC fittings were needed to collect the gas for analysis/venting through the top of the electrolysis cell. To keep the top of the cell sealed from escaping gas, a rubber gasket was used as a seal. Screws and sealant were used in assembly. A full set of engineering drawings is located in Appendix C.

Experimental Process

In order to begin testing, a simple tank-type electrolysis cell was designed and assembled (Figures 1-3). A power source was obtained that supplied a voltage of up to 40 volts and a current of up to 10 amps power supply. Personal Protective Equipment (PPE) was also obtained to ensure safety when working with electrolytes. The types of PPE used during experimentation included, face shields (0.0075 in thick PETG), natural rubber gloves, long sleeves, pants, closed-toe shoes, laboratory coats, fume hood, chemical spill clean-up bucket handling up to 31 liters (spill socks, 20 pads, bags, gloves, and goggles).

Figure 4: Power Source

Nine tests were conducted to differentiate between components within the electrolysis cell. The tests were broken down into three categories: surface area tests, electrode/electrolyte combination tests, and a Solid Polymer Electrolyte (SPE) test. Tests that include the surface area of each electrode were beneficial in the analysis of hydrogen production rate and electrolyzer efficiency. Using a single tank type electrolyzer, different forms of stainless steel were compared. Stainless steel plate, stainless steel mesh, and stainless steel woven cloth were used for this particular test. Each of these electrode materials were used in combination with a 5% sulfuric acid solution. The second area of testing sought to discover the most efficient and cost effective combination of electrode and electrolyte with the application of the surface area results found in the first experiment, which showed the stainless steel plate provided the best surface area for hydrogen production. Therefore, the plate was the stainless steel electrode used for the electrode/electrolyte test. Titanium was the other electrode material used with the sulfuric acid electrolyte. Following the sulfuric acid electrolyte tests, potassium hydroxide and sodium hydroxide were each used in combination with nickel-plated copper, aluminum, and stainless steel electrodes. Following the electrode surface area and electrode/electrolyte tests, additional tests were conducted on prototypes of the same size and container make up as listed in previous sections utilizing SPEs instead of liquid/powder electrolytes and separators.

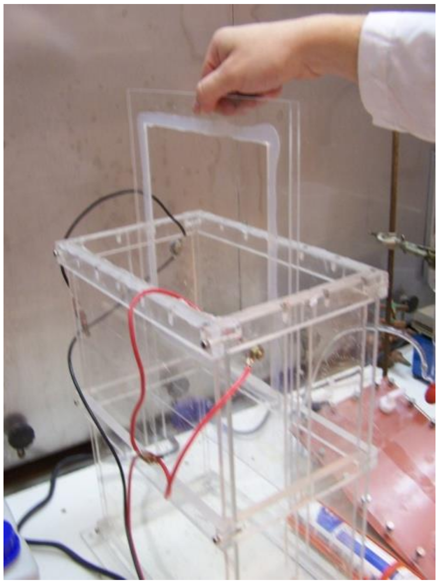


Figure 5: SPE Separator

Solid Polymer Electrolytes (SPEs) should serve the electrolysis cell as both a separator and an electrolyte. Peavey (1998) suggests that thinner solid electrolytes may accomplish the same task as liquid electrolytes. This reduces internal resistance by placing electrodes closer together without mixing the evolved hydrogen and oxygen gases. Because the solid electrolyte typically has a higher melting point, the cell may operate at elevated temperatures, thereby increasing efficiency. However, when the SPE was placed in the electrolysis cell with the stainless steel plates for electrodes (best producer of previous tests), no current draw took place, and no hydrogen was produced. Because of this, 14 mL of 18M H_2SO_4 solution were added to the cell (by continuously stirring with a stirring rod) to produce a 0.5% (m/v) H_2SO_4 solution. After producing favorable results, an additional 14 mL of H2SO4 solution were added to create a

1% electrolyte solution in the cell. Each of these tests were completed using the following standard operating procedure.

For each test, the appropriate amount of H_2SO_4, KOH, or NaOH to produce a 0.5% 1%, or 5% solution (depending on the test, as described above) was slowly added to 5000 mL of deionized water inside a 6000 mL Erlenmeyer flask. For a 5% solution, 140 mL (m/v%) of an 18M H_2SO_4 solution or 250 grams (w/v%) of granular KOH or NaOH were added to the 5000 mL of water. All mixing occurred under a fume hood to prevent asphyxiation. The solution was continually mixed using a Magna-4 magnetic mixer.

Figure 6: Mixing Chemicals

The appropriate electrodes were then placed inside the cell and connected to the circuit wiring. A precaution in this step was to always check to insure that the circuit was not live while wiring the cell. Next, the solution was added from the mixing flask into the cell. A precaution not to over fill the container was also taken into consideration.

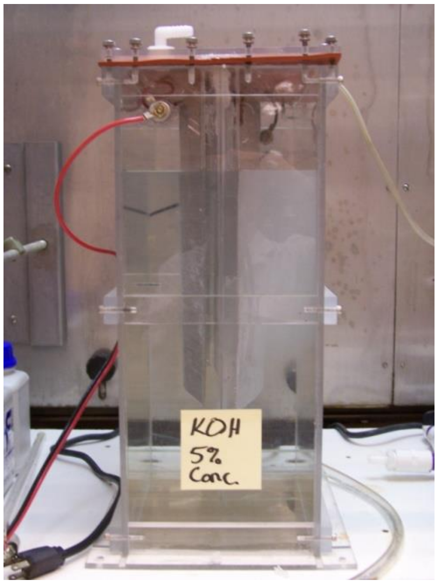


Figure 7: Cell w/ KOH Solution

Once the cell was completely secured, the power source was supplied to the cell at a rate of 9 amps and variable voltage. At this point, the produced hydrogen flowed through a line to a flow rate measurement device (bubble gage), and the oxygen flowed through a line in the opposite direction to a flow meter specifically designed for air and water flow rate measurement.

Figure 8: Bubble Meter

The purity of the hydrogen gas was tested by extracting a sample using a gas syringe and analyzing it in a gas chromatograph.

Figure 9: Gas Sampling with Gas Syringe

Excess hydrogen was vented to the atmosphere. As outlined by the hazard analysis (Appendix E), every potential precaution was taken to prevent any type of ignition source or mixture of the oxygen and hydrogen due to its highly combustible nature.

After one test was complete, depending on the sequence of testing, the cell electrodes were replaced. The power supply was turned off during this process for shock safety and natural rubber gloves were worn to protect exposed hands. First, the electrodes were removed and rinsed over a separate container insuring that the hazardous solution will be contained for disposal. Then the new electrode materials were inserted into the cell for another test cycle. This process will be repeated for all of the tests involving Sulfuric Acid.

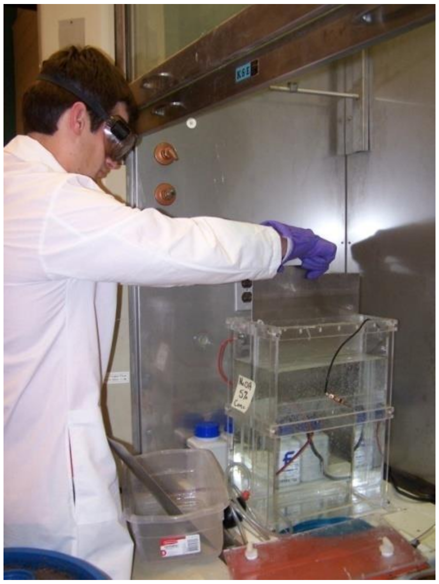


Figure 10: Electrode Removal

After testing of the solution was complete, the material inside the cell was prepared for disposal. First, the used solution was siphoned out into a container for disposal.

Figure 11: Chemical Disposal

The cell was then thoroughly washed with tap water and dried with disposable paper towels to insure that no chemical solution remained in the cell. The rinse solution was added to the container for disposal. The only waste generated from the procedure will be the left over solution after the test. This waste includes: 20 liters of 5% Sulfuric Acid Solution, 20 liters of 1% Sulfuric Acid Solution, 20 liters of 5% KOH Solution, 220 liters of 5% NaOH Solution, Saturated Nafion SPE, and rinse water. The materials were disposed using the guidelines supplied by the OSU Environmental Hazard Coordinator in accordance with OSU HAZMAT. The next chemical was then prepared for testing using the general operating procedure outlined above.

Lab Results

The following results were gathered by using the cell and procedure listed above. The tests are listed in descending production rate order. This section only includes an overview of the results, but the detailed results are included in Appendix D.

General Information

Initially, the group tested whether the amount of surface area in contact with the electrolyte had an effect on the resistance of the cell. It was believed that a larger surface area in contact with the electrolyte would decrease the resistance and actually increase the amount of current drawn. However, it was found that this was not the case and the current stayed constant. These results proved that the overall conductance of the cell was negligible when the surface area in contact with the electrolyte increased. It can also be generalized from these results that the majority of the current flows through the bottom of the plate. However, it can be seen from our results that the larger surface area allowed more area for the hydrogen and oxygen to dissociate out of the water.

In addition, it was initially found that for this particular electrolysis cell that a voltage of 1.8 V was necessary to begin the electrolysis process. Theoretically, this value should be around 1.23V, but due to the resistance in the wires and variable small volt drops it has experimentally found to be higher.

It is also important to note that the Nafion separator did not operate effectively as an electrolyte. It appeared as though for it to operate as an electrolyte it had to be in contact with the surface of the electrodes. However, it did prove to be very effective as a separator. To test its separation capabilities, we added only small amounts of sulfuric acid. These tests proved to be much more productive than those using a Plexiglas separator.

The production results were then primarily compared based upon their production rates and efficiencies. Efficiency for the tests was found by converting the hydrogen production to a kilowatt power equivalent using the higher heating value (HHV) of hydrogen. This HHV value of hydrogen (39 kWh/kg) was used opposed to the lower heating value (33 kWh/kg) because the HHV represents the heat of formation of a liquid opposed to the LHV which represents the heat of formation of a steam. All these tests were conducted using liquid water at standard temperature and pressure, therefore, the HHV value was used. Equation 1 demonstrates how we calculated efficiency.

$$Eff = \frac{Production\ Rate\ \left(\frac{Kg}{h}\right) * HHV\left(\frac{kWh}{Kg}\right)}{energy\ Input\ \ (kW)}$$

Equation 1: Production Efficiency

Production Tests

Stainless Steel Plates w/ 5% KOH

Observations

The beginning of this material test began with a change to the outlet valve on the hydrogen side. A simple hose adapter was added to size the 3/8in hose down to a 1/4in hose necessary to use the bubble meter. Previously, the 1/4in hose was forced over the 3/8 in barbed. The adapter was changed in order to prevent the hose from being pinched as it was prone to previously.

It initially observed that the cell was much cleaner using a base as opposed to an acid electrolyte solution. The electrolyte solution on the oxygen side stayed perfectly clear and the solution on the hydrogen side slowly became cloudy with production, but would clear up when the cell was turned off.

In addition, it was observed that the production was much higher on the outside of the electrodes.

Results

Stainless Steel Plates w/ 5% KOH	
Test	0-10ml
Separator	Plexiglas
Voltage (V)	8.6
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	101.24
Efficiency	27.2 %

Table 1: Stainless Steel Plates w/ 5% KOH

Pictures

Figure 12 demonstrates how clean the solution appears with this particular test. The hydrogen side (left side) is a little darker because the solution became cloudy on this side during operation.

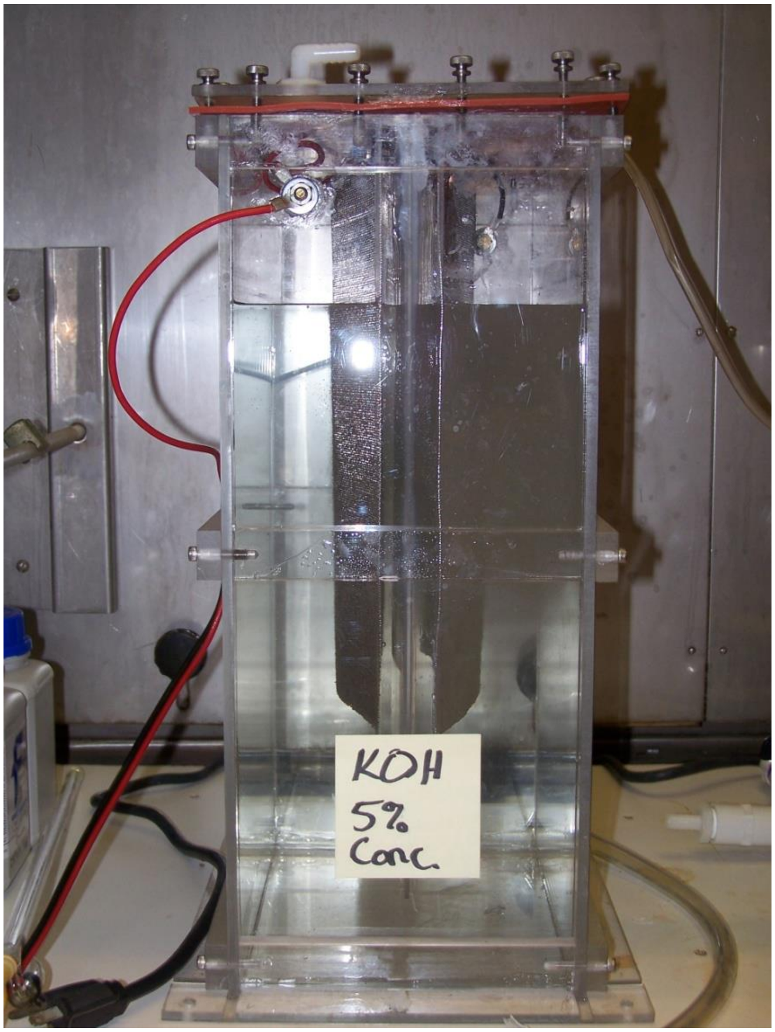


Figure 12: SS 316 w/ 5% KOH

Observations

It was first observed that the production on the inside of the plates had increased significantly from any other tests implying that the production rate would most likely be higher. The voltage drop was also significantly smaller across the cell. It appeared as though the current could now flow directly through the separator as opposed to all the way around it. This appearance theoretically was correct because the Nafion separator was designed to conduct current.

Results

Stainless Steel Plates w/ 1% H_2SO_4 w/ Nafion Separator	
Test	0-10ml
Separator	Nafion
Voltage (V)	7
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	92.9
Efficiency	30.7 %

Table 2: Stainless Steel Plates w/ 1% H2SO4 w/ Nafion

Pictures

Figure 13 demonstrates what the SPE looked like and how it was inserted into the cell.

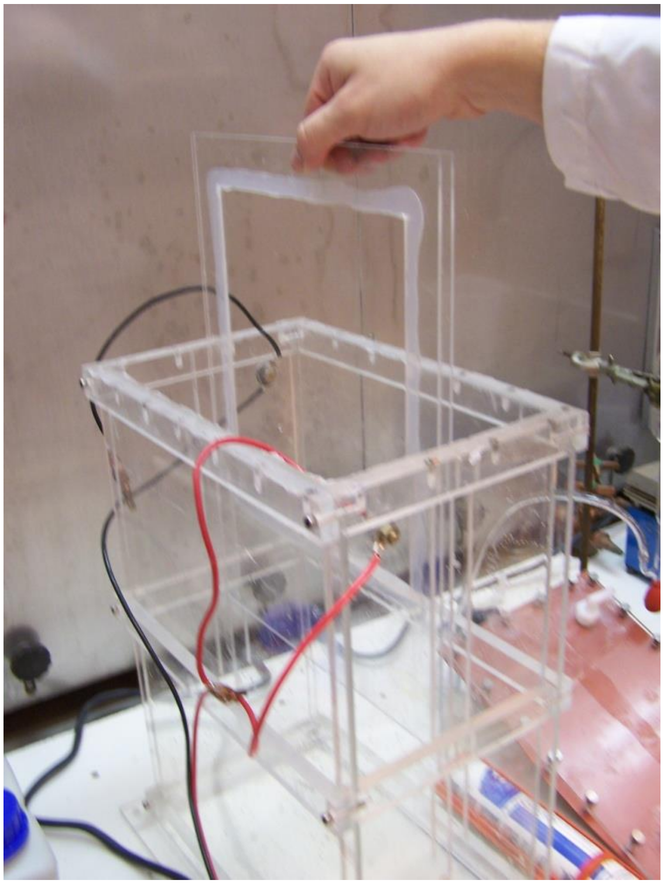


Figure 13: SPE Separator Instillation

Stainless Steel Plates w/ .5% H_2SO_4 w/ Nafion Separator

Observations

This test was actually conducted before the 1% concentration of H_2SO_4. This initial test was used to see if the electrolyte in combination with the Nafion separator would work efficiently without using a strong electrolyte. It proved to not only work, but also to have a fairly large production rate. Consequently, the same test was run using a slightly stronger electrolyte concentration as described in the test above.

Results

Stainless Steel Plates w/ .5% H_2SO_4 w/ Nafion Separator	
Test	0-10ml
Separator	Nafion
Voltage (V)	10.5
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	76.4
Efficiency	16.8 %

Table 3:Stainless Steel Plates w/ 0.5% H2SO4 w/ Nafion

Pictures

Figure 14 demonstrates the water coloration on the oxygen side during production when sulfuric acid was used as an electrolyte, and Figure 15 demonstrates the Nafion separator after it was removed. Surprisingly, the water solution caused the SPE to expand and ripple. However, after it had time to dry out it returned back to its normal size.

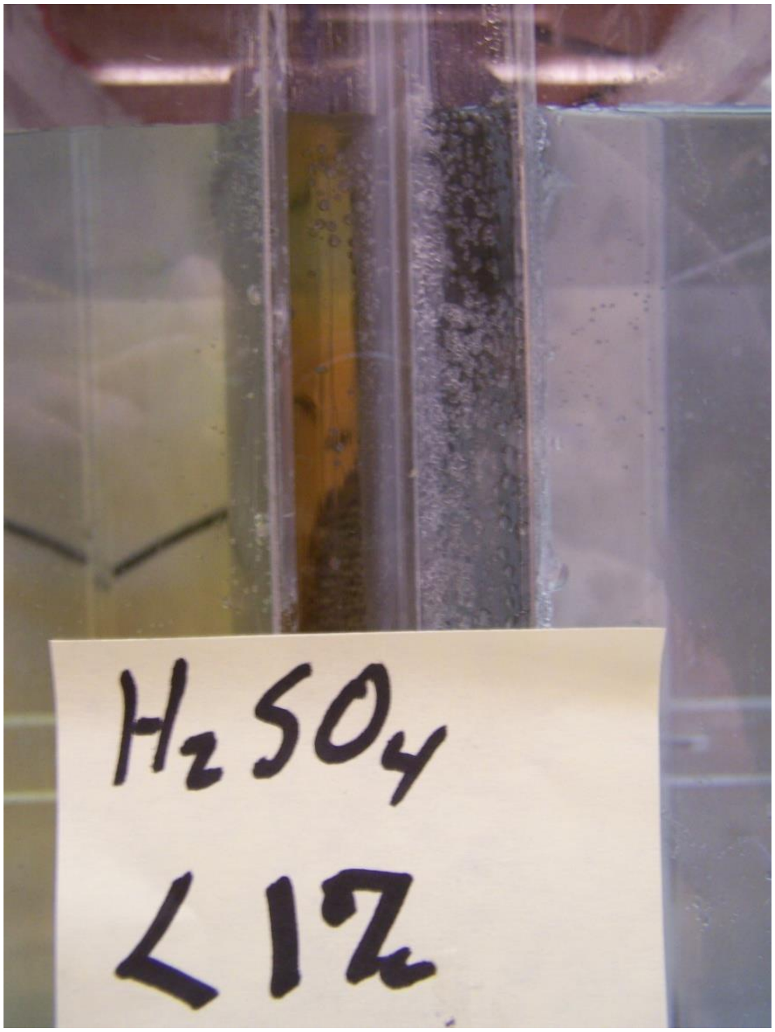


Figure 14: Effects of Sulfuric Acid Electrolyte

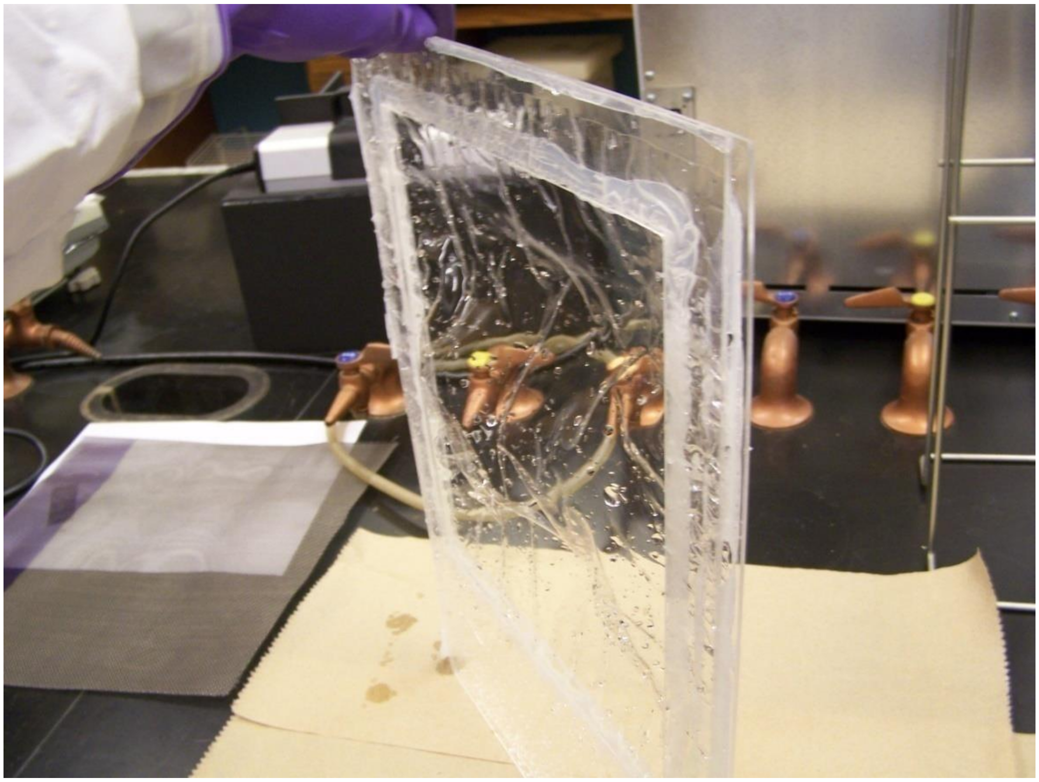


Figure 15: SPE Separator Directly after use

Observations

This test was the first test successfully ran. Initially, there were a few consistency issues with the bubble meter because of user error. Consequently, numerous data points were taken to dilute the novice user error in the measurement.

The color of the electrolyte solution also began to change. Apparently, the sulfuric acid was reacting with the steel and causing the plate to slightly corrode thus coloring the water. Although, it was interesting to note that only the solution on the oxygen side became discolored. The solution on the hydrogen side remained clear.

Results

Stainless Steel Plates w/ 5% H_2SO_4	
Test	0-10ml
Separator	Plexiglas
Voltage (V)	7.5
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	73.4
Efficiency	22.6 %

Table 4: Stainless Steel Plates w/ 5% H2SO4

Pictures

Figure 16 demonstrates how discolored the solution became when running the H_2SO_4 tests. It also demonstrates how well the separator was working. It can clearly be seen that the two sides are not mixing based upon the solution color on both sides of the separator. At first, it was only the oxygen side that became discolored. However, during the transition from one test to the next the solution began to mix and the entire cell became discolored.

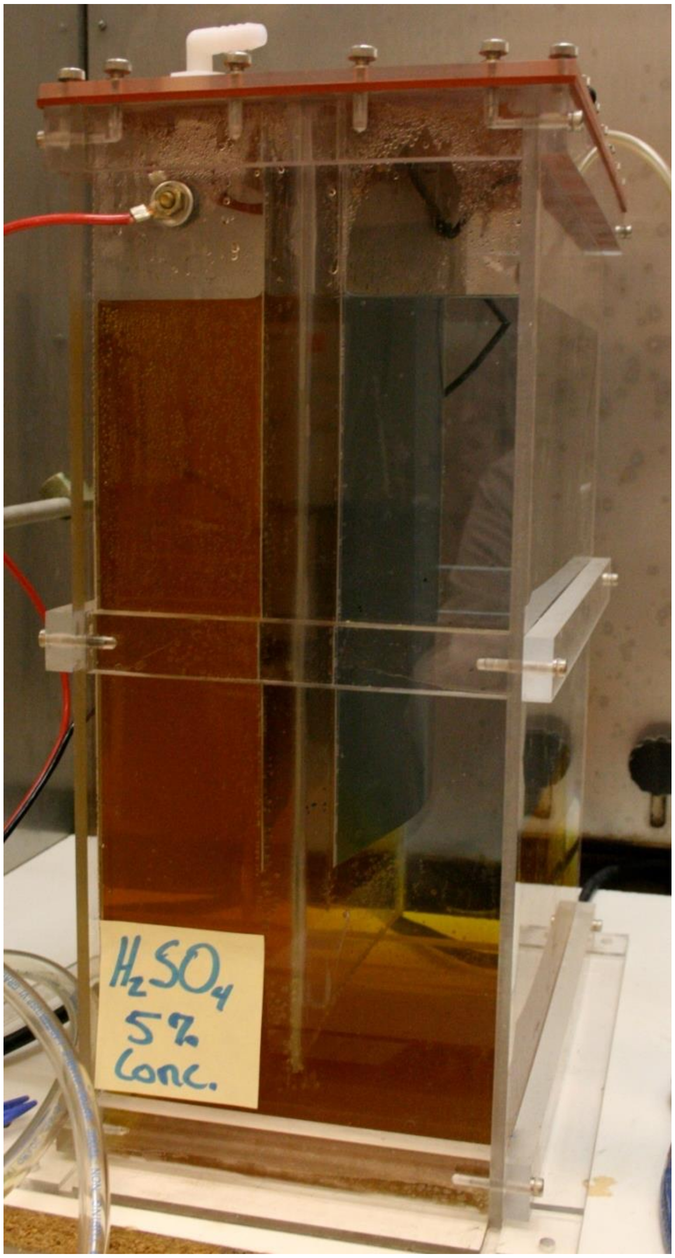


Figure 16: Stainless Steel Plates e/ 5% H2SO4

Observations

This test behaved very similarly to the stainless steel plate test. The only notable difference was that the weave material absorbed much more solution that the plates. This observation was made while exchanging the plates between tests. It would be important to note during maintenance of a cell that used this material.

Results

Stainless Steel Weave w/ 5% H_2SO_4	
Test	0-10ml
Separator	Plexiglas
Voltage (V)	9
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	40.9
Efficiency	10.5 %

Table 5: Stainless Steel Weave w/ 5% H2SO4

Stainless Steel Mesh w/ 5% H2SO4

Observations

The production rate during this test had to be changed to a 0-1ml rate because of the slow production rate. The bubble produced in the bubble meter would get held up in the cylinder until the pressure increased. This effect undesirably altered the production rate results.

In addition, the discoloration of the electrolyte on the oxygen side continued becoming darker over time.

Results

Stainless Steel Mesh w/ 5% H_2SO_4	
Test	0-1ml
Separator	Plexiglas
Voltage (V)	8.5
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	40.93
Efficiency	11.2 %

Table 6: Stainless Steel Mesh w/ 5% H2SO4

Observations

The production rate for this test also had to be conducted between 0 and 1ml because of the slow production rate and the pressure effects.

In addition, with all of the hydroxide solutions the electrolyte solution did not have and significant color change except for the cloudy effects on the hydrogen side during effects.

Results

Monel Mesh w/ 5% KOH	
Test	0-1ml
Separator	Plexiglas
Voltage (V)	8.9
Current (A)	9
Volume (L)	20.05
Avg. Production Rate (ml/min)	35.5
Efficiency	9.2 %

Table 7: Monel w/ 5% KOH

Observations

The production rate for this test also had to be conducted between 0 and 1ml because of the slow production rate and the pressure effects.

In addition, with all of the hydroxide solutions the electrolyte solution did not have any significant color change, except for the cloudy effects on the hydrogen side during production.

Results

Monel Mesh w/ 5% NaOH	
Test	0-1ml
Separator	Plexiglas
Voltage (V)	7.9
Current (A)	9
Volume (L)	19
Avg. Production Rate (ml/min)	34.13
Efficiency	10 %

Table 8: Monel Mesh w/ 5% NaOH

Pictures

Figure 17 again demonstrates the cloudy coloration effect on the hydrogen side of the cell when a hydroxide was used as an electrolyte.

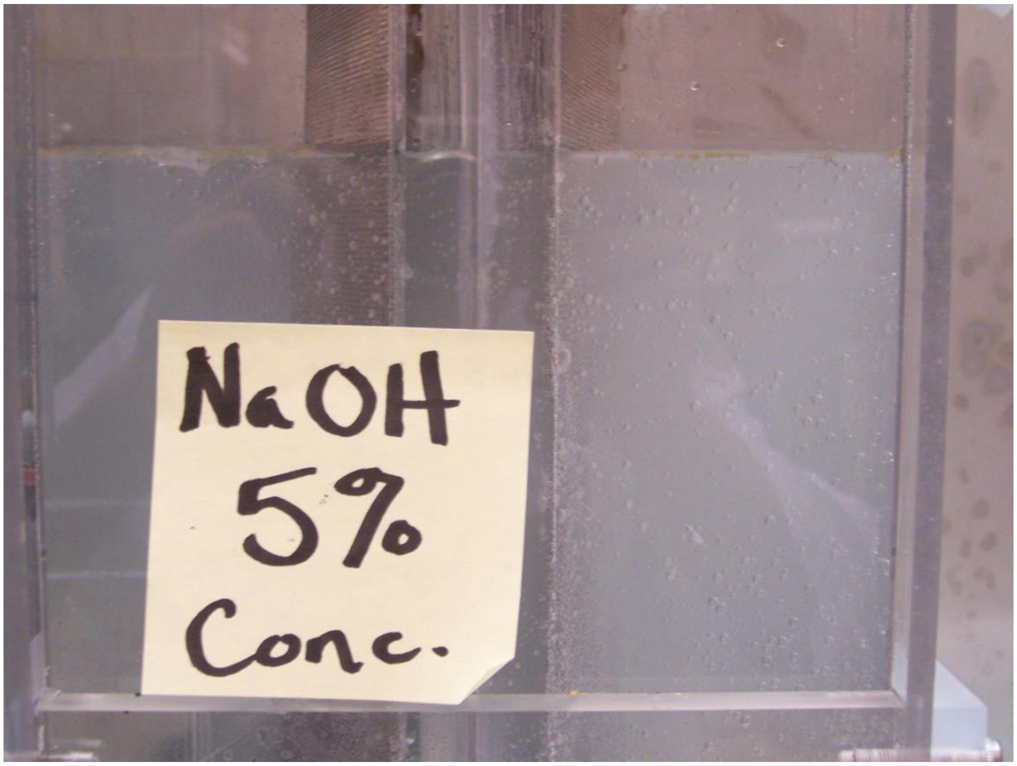


Figure 17: 5% NaOH Solution

Observations

The production rate for this test also had to be conducted between 0 and 1ml because of the slow production rate and the pressure effects.

In addition, with all of the hydroxide solutions the electrolyte solution did not have any significant color change, except for the cloudy effects on the hydrogen side during production.

Results

Stainless Steel w/ 5% NaOH	
Test	0-1ml
Separator	Plexiglas
Voltage (V)	7.9
Current (A)	9
Volume (L)	19
Avg. Production Rate (ml/min)	24
Efficiency	7%

Table 9: Stainless Steel w/ 5% NaOH

Comparison of Results

Table 10: Acid Test Comparisons

	SS Plate	SS Mesh	SS Weave	SS Plate	SS Plate
Separator	Plexiglas	Plexiglas	Plexiglas	Nafion	Nafion
Concentration	5%	5%	5%	1%	0.5%
Voltage (V)	7.5	8.5	9	7	10.5
Power (W)	67.5	76.5	81	63	94.5
Production Rate (ml/min)	73.4	40.93	40.89	92.9	76.4
Efficiency	22.6 %	11.2 %	10.5 %	30.3%	16.8 %

Table 10: Acid Test Comparisons

Table 11:Hydroxide Test Comparisons

	Monel	SS Plate	Monel	SS Plate
Separator	Plexiglas	Plexiglas	Plexiglas	Plexiglas
Concentration	5% KOH	5% KOH	5% NaOH	5% NaOH
Voltage (V)	8.9	8.6	7.9	7.9
Volume (L)	20	20	19	19
Power (W)	80.1	77.4	71.1	71.1
Production Rate (ml/min)	35.5	101.2	34.13	24
Efficiency	9.2 %	27.2 %	10 %	7 %

Table 11: Hydroxide Test Comparisons

Table 12: Top 3 Test Comparisons

	SS Plate	SS Plate	SS Plate
Separator	Plexiglas	Nafion	Nafion
Concentration	5% KOH	1% H_2SO_4	0.5% H_2SO_4
Voltage (V)	8.6	7	10.5
Volume (L)	20	20	20
Power (W)	77.4	63	94.5
Production Rate (ml/min)	101.2	92.9	76.4
Efficiency	27.2 %	30.3 %	16.8 %

Table 12: Top 3 Test Comparisons

Failed Experiments

Titanium and Aluminum Tests

The tests that used titanium and aluminum as electrodes showed that these materials are not suitable for electrodes. When power was supplied to the cell, the current draw decreased very quickly at a specific voltage. In reality, the resistance of the plates was increasing as time went on. After further research on this phenomenon, it was concluded that an oxide layer was being formed over one of the plates which drove the resistance up, not allowing any current to flow. Thus, neither titanium or aluminum plates yielded any hydrogen production and are unsuitable for an electrolysis application.

Figure 18 demonstrates the effects of electrolysis on titanium. The discoloration was either due to the reaction of titanium with sulfuric acid or the oxidation effects. No further analysis was conducted on titanium due to its oxidation effects.

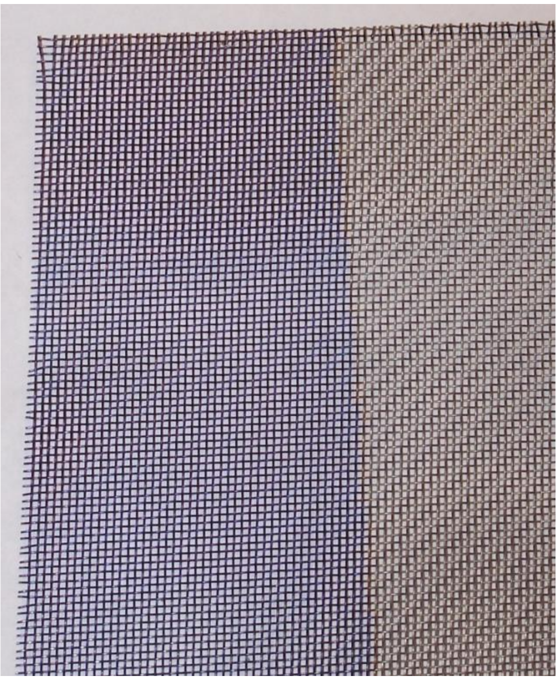


Figure 18: Titanium Effects

Analysis of Results

Statistical Analysis

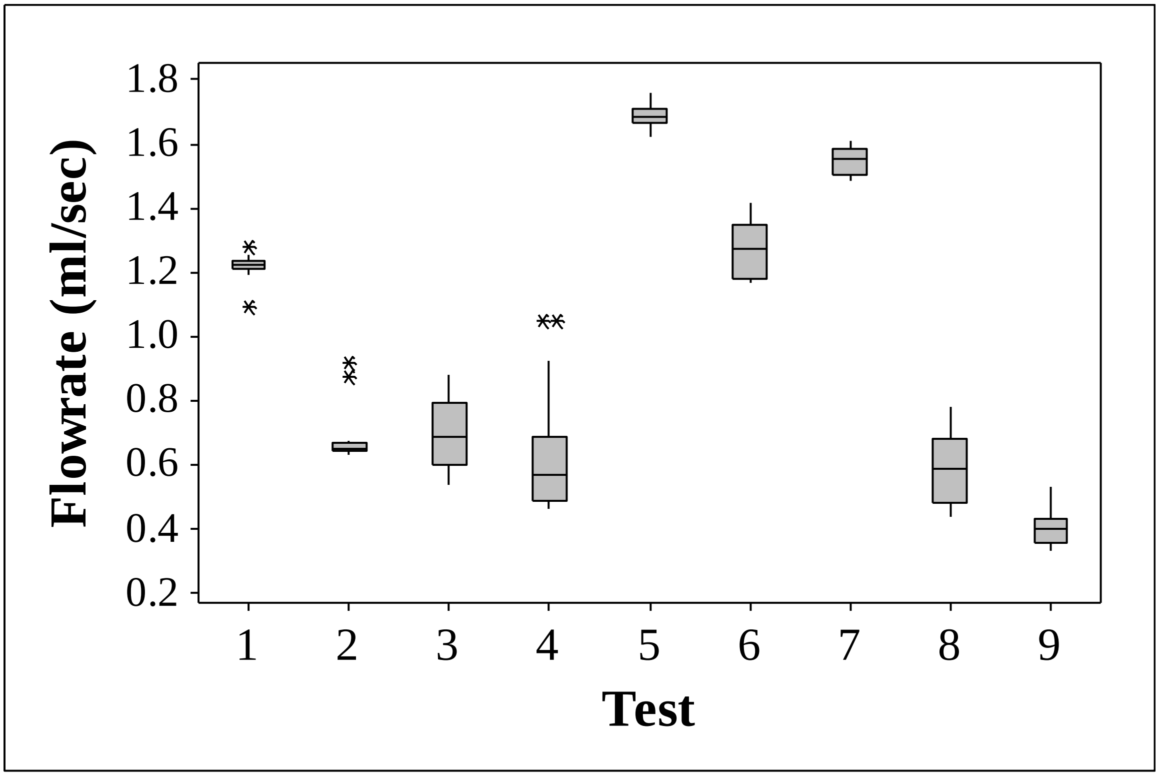


Figure 19:Boxplot of Flow rate (ml/sec)

Table 13: Key to Statistical Analyses

Test #	Test
1	SS Plate-5% H2SO4
2	SS Weave-5%H2SO4
3	SS Mesh-5% H2SO4
4	Monel-5% KOH
5	SS Plate-5% KOH
6	Nafion-0.5% H2SO4
7	Nafion-1% H2SO4
8	Monel-5% NaOH
9	SS Plate-5% NaOH

Table 14: Test Number Mean Ranking of Flowrate (High to Low)

5, 7	Statistically Similar
1, 6	
3, 4, 8	
2	Not Statistically Similar
9	

According to Table 14, the two combinations of the stainless steel plate/5% KOH electrolyte solution *and* Nafion separator/1% H2SO4 solution/stainless steel plate produced statistically similar results, but were statistically better hydrogen producers than all other electrolyzer material combinations.

Hydrogen Purity Gas Chromatograph Results

The final test was to determine the hydrogen purity of the gas produced from the best producing combination. To do this analysis, we sought the expertise of a graduate student that was proficient in analyzing gas samples with a gas chromatograph. The process involved gathering samples from the cell in gas tight syringes with a sample volume of 100 micro millimeters and then injecting them into a gas chromatograph machine to analyze the gas. The gas chromatograph would then test for H_2, O_2, N_2, CO_2, Methane and possible hydrocarbons in the gas mixture. These gas analysis samples were taken at two different stages of the production. The first was taken after about five min of production and the second was taken after an hour of production. Two sample points were taken to infer how quick the transition from an air hydrogen mixture to pure hydrogen gas took place. In addition, it was taken to insure that the seal created between the hydrogen and oxygen side was gas tight. Theoretically, the air-hydrogen mixture gas should have been displaced in approx 43 min based on the open volume of the cell and the hydrogen production rate. We knew this would not be the case because the production gas would be a continual mixture of hydrogen and air. Consequently, we took a sample after one hour for comparison. Figure 20 below displays the gas chromatograph results.

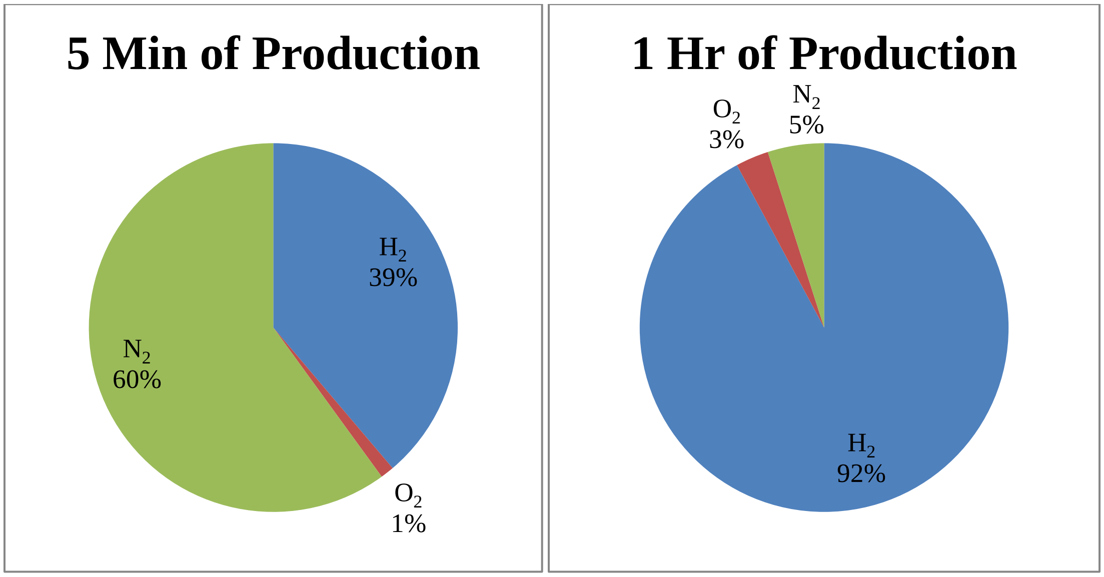


Figure 20: Comparison of GC Results

It can be concluded after these tests that the hydrogen gas produced was becoming very pure. After an hour, it was already above 90%. In addition, a portion of the percentage of O_2 and N_2 can be attributed to sample error meaning that the hydrogen purity was most likely higher. It can also be concluded that the gas seal worked effectively. The slight increase in the oxygen percentage could be attributed to a small leak, but compared to the hydrogen percentage it is very low. This low of a percentage was acceptable because of the nature of the tests we were conducting. The seal was continually being broken and restored between tests making it very difficult to create a completely gas tight seal every time.

Current Density

Current Density refers to the actual amount of electrical current that is flowing through the effective area of an electrode. In the case of an electrolytic cell, this is considered the "wetted area" of the one electrode. It was determined through literature reviews that there is an optimal current density desired for an electrolytic cell, as to maximize the cell efficiency. It was found that a current density of 1.29-3.87 Amps/in^2 was ideal according to a study by the National Renewable Energy Library which is recorded in appendix F. The most efficient prototype test that the team conducted was operating at a current density of .04 Amps/square inches. By decreasing the effective plate area, or by increasing the current, the optimum efficiency as related to current density could have been achieved. Optimal current density is also a way that a cell can be sized or scaled for individual applications. In each application, the specific provided current could be matched with an appropriately sized electrolysis scale as to match the optimal current density.

Conductance

Detailed analysis was also conducted on the conductance and specific conductance of the electrode and electrolyte combinations. The conductance of the cell was backed out of our experimental results. It was found by finding the overall resistance of the cell and then subtracting the resistance of the electrodes which was almost negligible. Specific conductance (C) is an important parameter in sizing an electrolysis cell. It is a measurement of the conductance of a cell multiplied by the cell constant (K), the ratio of electrode spacing (L) to electrode surface area (A). Equation 2 outlines the specific conductance equation.

$$C = G * \frac{L}{A}$$

Equation 2: Specific Conductance

Where
C=specific conductance
G= conductance in Siemens
L=length between electrodes
A= surface area of the electrodes

Table 15: Specific Conductance Comparison

	SS Plate	SS Plate	SS Plate
Separator	Plexiglas	Nafion	Nafion
Concentration	5% KOH	1% H_2SO_4	0.5% H_2SO_4
Production Rate (ml/min)	101.2	92.9	76.4
Efficiency	27.2 %	30.3 %	16.8 %
Conductance (Siemens)	1.145	1.294	0.861
Specific Conductance (µS/cm)	14,000	2874	1912
Cell Constant (L/A)	0.01	0.002	0.002

Table 15 outlines the specific conductance of our top three producers. The only concrete data than can be concluded from the conductance and specific conductance results it that it is a constant balance to keep the conductance of the solution high and the cell constant low. During analysis of the results, the group found more literature outlining optimum specific conductivity ranges. The table below, taken from the Cole-Palmer Technical Library (2009), demonstrates their theoretical optimum ranges for different cell constants.

Table 16: Optimum Specific Conductivity

Cell Constant (K)or (L/A)	Optimum Specific Conductivity Range (µS/cm)
0.1	0.5 to 400
1	10 to 2,000
10	1,000 to 200,00

It is obvious from the above tables that the prototype cell was outside of the optimum range according to Cole-Palmer. This table was included to demonstrate the balancing effect of electrolyte concentration, electrode separation, and electrode surface error. In addition, this table would be useful in scaling future designs.

Recommendations and Improvements

Material

It can be concluded after our tests, that by far the best material selection for electrodes would be stainless steel. It was evident in all of our tests no matter what the electrolyte that the stainless steel production was the highest. It was believed that this material was the best because it’s current density and overall resistance. The mesh and weave both had higher resistance which decreased the cells overall efficiency. The same was true for the monel mesh.

SPE Separator

The separator tests proved to be very beneficial. As stated earlier, the Nafion separator did not perform as an electrolyte because it did not come in direct contact with the electrodes. However, it worked amazingly as a separator. A Nafion separator with only a small concentration of electrolyte (<1%) produced more hydrogen than the best combination of any electrode with an electrolyte concentration around 5%. The down side to the Nafion separator was it has not been fully tested. It’s durability over time as well as its stability in an electrolyte solution is still unknown. However, it appears as though this separator will boost the production of any electrolysis cell. The question on its viability will be is the increase in production worth the initial cost.

Electrolyte

The only definite conclusion that can be made about the electrolytes is that the sodium hydroxide electrolyte had the smallest production rates by far. This result was surprising considering that its overall conductance was relatively high compared to the other combinations. It can also be concluded that the sulfuric acid electrolyte was the most consistent overall the electrodes tests. In comparison, the potassium hydroxide proved to have the highest production in combination with stainless steel, but also had very low production in combination with the monel electrode. The most concrete conclusion that can be made is that the productivity of the electrolyte solution is directly dependent on the electrode used in combination.

Scaling Approximations

Another consideration in the improvements of this electrolysis cell was how it would operate at different power inputs. The following table demonstrates based off a theoretical efficiency what it should theoretically produce using a stainless steel electrode and potassium hydroxide electrolyte. The theoretical efficiency was found by dividing the experimental production by the theoretical production found last semester using the Gibbs free energy necessary to separate hydrogen from a water molecule. The theoretical efficiency for stainless steel and KOH was found to be 38%.

Table 17: Power Input Scaling

Power Input (W)	H_2 Production Theoretical (ml/min)	H_2 Production Prediction (ml/min)
77	261	101
100	338	130
200	676	261
500	1690	652

Household Application

The first step in developing a typical household application was to determine the average amount of electrical energy that an American household consumes. This data was found on the Energy Information Administration's website, which contains the official energy statistics from the U.S. government. The data used in this example application was taken from the average consumption, physical units per household document contained on this website. Furthermore, the specific energy consumption data was then narrowed down to the West South Central data to better represent the target market in Oklahoma and Texas.

The total energy consumed by an average household in the West South Central Region of the country was approximately 7,678 kWh with approximately 1,354 kWh attributed to refrigeration usage and approximately 6,328 kWh attributed to other energy usage (EIA 2005). This data was then broken down into the average instantaneous energy usage of a household. After this value was found, many assumptions had to be made.

The first assumption that had to be made was how much of this energy was used during the night time hours when hydrogen production and storage would be most probable.

We assumed that the average night would be eight hours long and would only consist of the refrigeration energy usage along with approximately half of the other energy usage category. These assumptions brought down the total energy usage of a typical household over an eight hour night to 2.72 kWh.

The second assumption that was made was how many wind turbines would be used and at what load of their total rated power. We assumed that two 600 Watt wind turbines would be used and that they would operate at 100% of their max load. This load assumption was made on the basis that we wanted to be able to size the entire system on the maximum hydrogen production. These assumptions gave us a total value of 9.6 kWh of energy produced by the turbine throughout the night.

The next step was to subtract the energy usage amount of 2.72 kWh from the total wind turbine generated energy value of 9.6 kWh. Therefore, the total amount of excess energy available for hydrogen storage was 6.88 kWh. This amount of energy would allow for 12 of our best producing electrolysis cells operating at 77 W to be used to produce hydrogen. Consequently, the total amount of hydrogen produced over an eight hour night would approximately 0.048 kg. Using the Higher Heating Value of hydrogen, this value can then be converted into an energy equivalent of 1.9 kWh or 6,394 BTU of energy produced from the electrolysis cells.

In summary, a typical household in the west south central region of the United States using two 600 W turbines would be able to produce 1.9 kWh of energy equivalent from the hydrogen produced from our best electrolysis cell over an eight hour night.

Financial Analysis and Sustainability

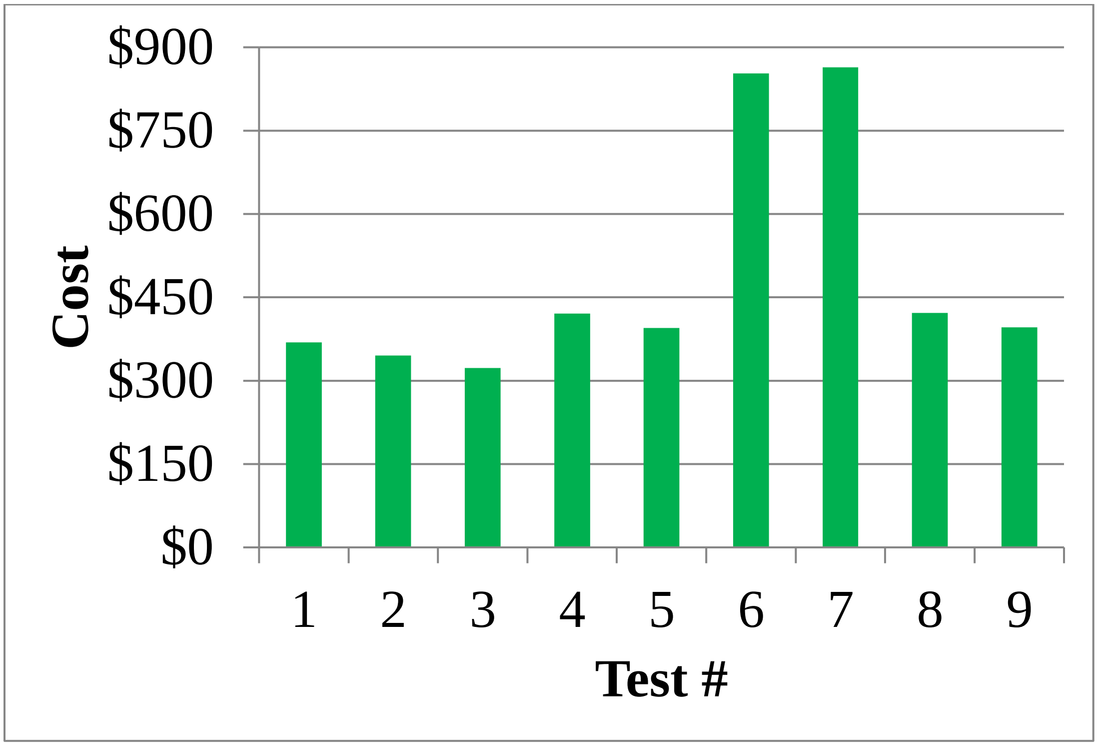


Figure 21: Material Cost Comparison

This figure shows the component material cost for each test. Figure 21 shows a substantial difference in cost from the least expensive to the most expensive altermative. Test number five was the cell which yielded the most hydrogen in our tests, with a component cost of $395.00. Test number seven was the most efficient cell as determined by our test producing the most hydrogen per the amount of energy required by the system, with a component cost of $864.00

The breakeven retail price for the (#1) electrolysis cell is $2475.00 (#1) being the most hydrogen-producing cell. The breakeven retail price for the (#2) cell, which produces slightly less hydrogen but was the most energy efficient is $2944.00. The breakeven cost for the full

Wind-to-Hydrogen system is $8,295 using the (#1) cell and $10,985 for the (#2) cell. The full breakdown of financials are included in the appendix.

Table 18: Total System Cost Estimate for Best Producer

Component	***Cost***
Wind Generator	$650
Smart Switch	$250
Electrolyzer	$395
Compressor	$5,000
Storage Device	$500
Generator/Fuel cell	$1,500
Total Cost	**$8,295**
Breakeven Cost	**$10,375**

Table 18 shows the estimate of the breakeven cost for the components of the entire system using the best hydrogen producing electrolysis cell. This cell has a stainless steel electrode plate and 5% Potassium Hydroxide solution. Further breakdown of the financials for this system are included in the appendix.

Table 19: Total System Cost Estimate for Most Efficient Producer

Total System Cost Estimate	
Component	*Cost*
Wind Generator	$650
Smart Switch	$250

Electrolyzer	$864
Compressor	$5,000
Storage Device	$500
Generator/Fuel Cell	$1,500
Total Cost	**$8,905**
Breakeven Cost	**$10,985**

Table 19 is the estimate of the breakeven cost for the components of the entire system using the most efficient hydrogen electrolysis cell. This cell has a stainless steel electrode plate and with a Solid Polymer Electrolyte (SPE)-Nafion and a 1% Sulfuric Acid solution. Further breakdown of the financials for this system are included in the appendix.

Industry Analysis

Economic conditions affecting the industry

With continued rise and volatility of the cost of electric generation fuel sources, a need for a new type of electric source for home and small businesses is needed. Also, with a new Presidential administration and Congress putting increased emphasis and funding sources in place for green technologies, a hydrogen electrolysis energy source continues to be viable.

Early adopters are those persons willing to take a risk for a new technology. These first adopters are people who can afford the best and most up-to-date alternative power source. They are the same people that had the first gas-electric hybrids and will be the ones who will have the first all electric cars, as well. Additionally, they will want to “get off of the grid.” Early adopters feel it is their responsibility to reduce their carbon footprint. Additional prospects would be those that have beach homes, specifically. This simply is because of the propensity of winds near the ocean, and the beach homes are often inhabited by persons who fit the above qualifications. The final possible prospect would be companies and/or individuals who have remote locations that need power. These could be a natural gas pumping station or remote hunting cabin.

The question continues to arise: Are renewable energy sources viable and sustainable? The industry continues to answer this question with a resounding yes, as the American populous increasingly becomes aware of the impact that fossil fuel-burning cars and coal-fired generation plant have on the environment. Many national advertising campaigns currently push the benefits and cost savings of alternative power sources and homegrown energy. The two main entities are T. Boone Pickens and BP formerly British Petroleum, a world leader in all forms of energy.

Industry definition, size and growth

In the United States, hydrogen production is included in the Hydroelectric and Renewable Power Generation Industry. According to an IBISWorld Industry Report, this industry consists of firms that operate hydroelectric and renewable-powered electricity generating facilities. Along with the most abundant hydroelectricity, geothermal energy, solar energy, and wind power, industry operators may also produce small amounts of electricity using other power sources, including hydrogen.

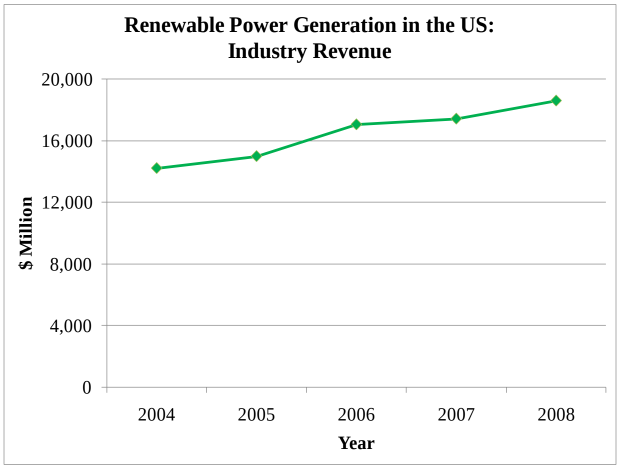


Figure 22: Renewable Power Generation in the United States: Industry Revenue in Millions of Dollars

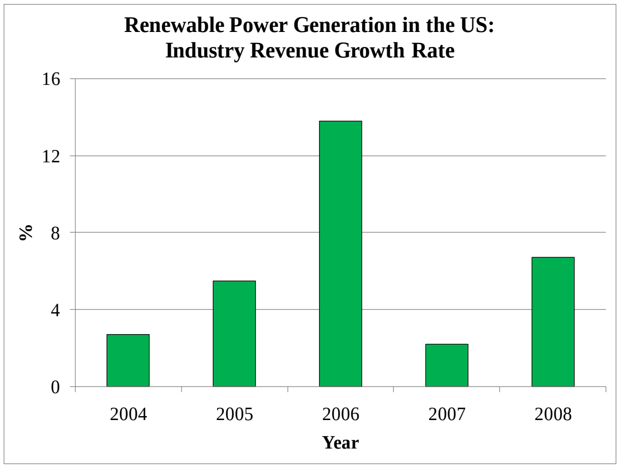


Figure 23: Renewable Power Generation in the United States: Industry Revenue Growth Rate

Figure 22 and Figure 23 show key statistics of the renewable power generation industry. Figure 1 shows steady revenue growth for all sectors from 2004 to 2008. Figure 23 shows the industry revenue growth rate of all renewable energy from 2004 to 2008. Although a decline in growth rate occurred in 2007, growth increased in 2008. Most importantly, the growth rate continues to stay positive in this sector. The increased growth rate in 2008 could be due to increase fuel prices in the same year, which suggests that the renewable energy sector is dependent on the price and availability of nonrenewables.

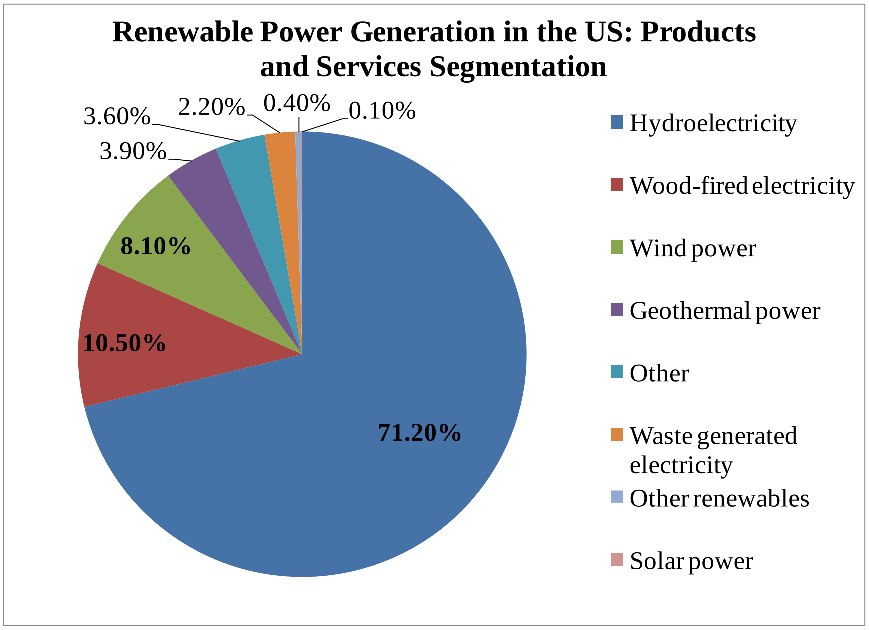


Figure 24: Renewable Power Generation in the United States: Products and Services Segmentation

Percentages of renewable power generation products and services are shown in Figure 24. Hydroelectricity produces the greatest percentage of renewable energy in the United States primarily because it has been around the longest. Although relatively new, wind energy makes up more than 8% of the renewable power generation sector and is “expanding strongly.” Hydrogen is included in the “Other” section, which makes up 3.6% of all renewable power generation. This section also includes “batteries, used tires, non-biogenic municipal solid waste, chemicals, pitch, purchased steam and sulfur.” According to IBISWorld (2008), “the Energy Policy Act of 1992 opened up the electricity generating industry so that any business could generate electricity and sell it on a wholesale basis. Independent power producers account for about 6.5% of this industry’s production, up from just over 2% in the late 1990s.” This provides evidence of potential market demand for a small-scale hydrogen electrolyzer. Small businesses, and even individuals, can utilize hydrogen as a renewable energy storage source to save and/or earn money. Figure 25 also shows the opportunities available in the hydrogen industry. It is a relatively untapped renewable energy field with major potential.

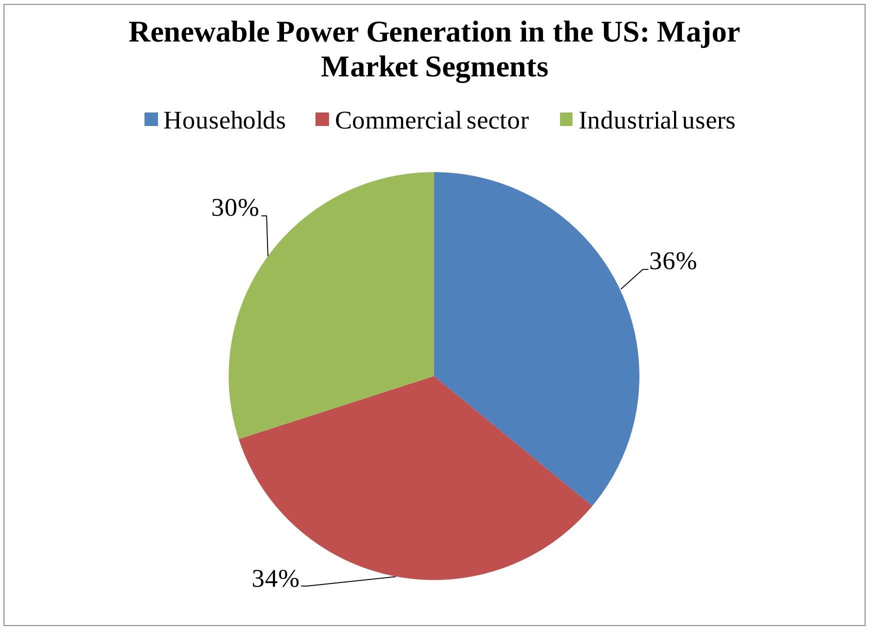


Figure 25: Renewable Power Generation in the United States: Major Market Segments

A Power Solutions Hydrogen Electorlysis Cell has been designed for small-scale home and office use. Figure 25 shows the major market segments of the renewable energy industry. While these segments are almost evenly split, the household segment still provides the largest market, followed closely by the commercial sector. These are ideal market conditions for a small-scale hydrogen electrolysis system.

The National Renewable Energy Laboratory (NREL) developed a Wind Deployment System (WinDS) for future energy projections. "The WinDS model is a multiregional, multitime-period, Geographic Information System, and linear programming model, designed to address the principle market issues related to the penetration of wind energy into the electric sector over the next 50 years" (Short et.al, 2005). Figure 26 shows hydrogen production from wind in 2050. The map shows the areas with the most hydrogen production from wind as being near a reasonable wind resource and a significant population center. Also, hydrogen production from wind is significant in areas with significant wind resources such as the north-central United States and the Midwest.

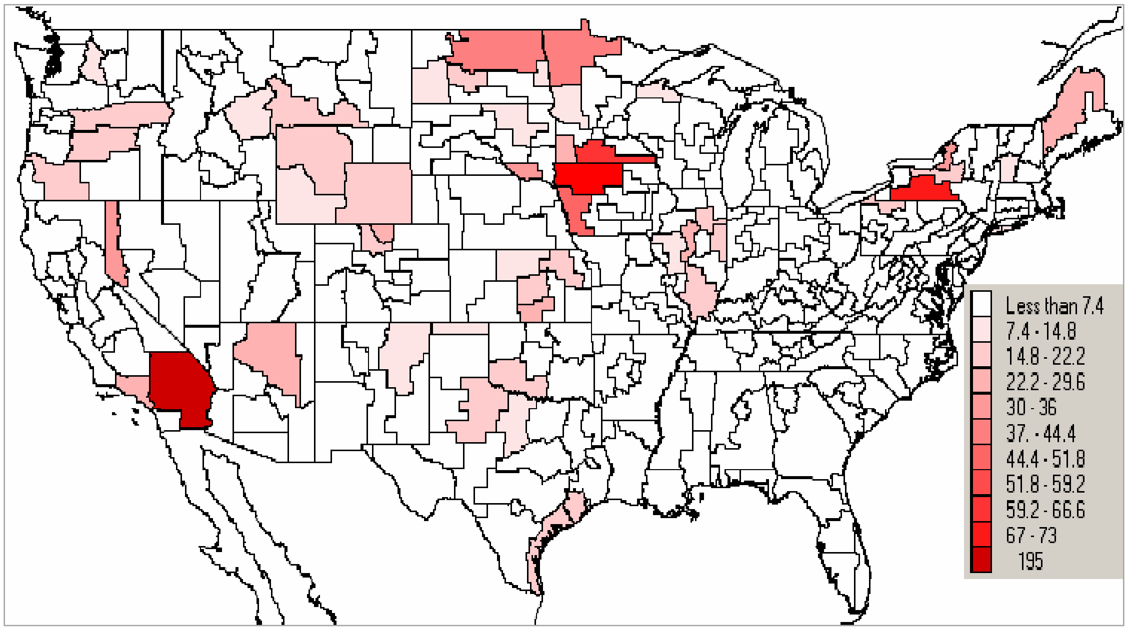


Figure 26: Annual H2 Production from Wind in 2050 (kilo tons)

The study by the NREL also analyzed the viability of different hydrogen production pathways. As Figure 27 shows, by the year 2050 approximately 28 GW of distributed electrolyzers are projected to produce hydrogen. An additional 25 GW of wind energy will be transported to the distributed electolyzers because it is more economical to transport electricity than hydrogen.

The study also shows by 2030 hydrogen will be provided with distributive electrolyzers and at wind sites for use as a transportation fuel.

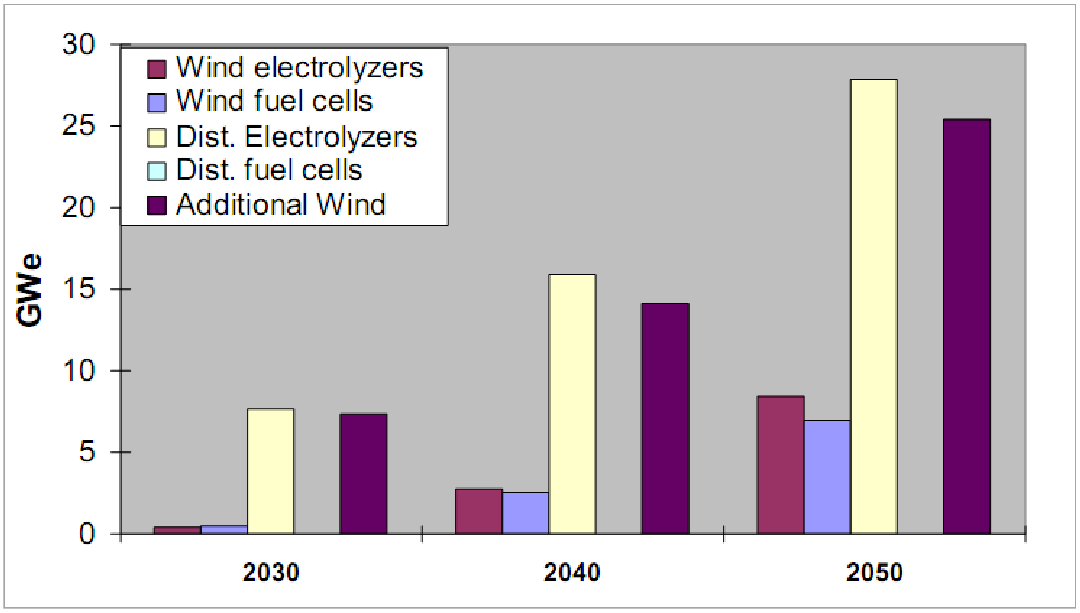


Figure 27: Hydrogen Technology Capacity

The growth of the market will rely heavily on marketing activities more than any other function considering it is a relatively new technology with a market that is untested. A considerable number of people and organizations engage in hydrogen production, but none are really doing it on a broad consumer-based scale. However, the company absolutely believes that this is will be a part of the overall reduction on fossil fuels dependence. This industry, although in its infancy, is positioned to grow over the next several years and beyond, heavily due to people's desire to reduce their use of fossil fuels and reduce their environmental footprint.

Government regulations/Industry standards

Regulations and standards have been investigated and include, but are not limited to:

- UL Subject 2264B: Gaseous Hydrogen Production—Water Reaction;
- UL Subject 2264A: Gaseous Hydrogen--Electrolysis Technology;

- ISO TC197 Working Group 8/ISO 22734: Hydrogen Generation using Electrolysis Process;
- NFPA 55: Standard for Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, Equipment and Tanks
    - Chapter 10: Gaseous Hydrogen Systems; and
- NFPA 2: Hydrogen Technologies.

Relevant trade publications

Many publications and trade organizations promote hydrogen but most are hobby or industrial hydrogen producers. A great number of people are engaged in garage hydrogen production and/or large scale production by multinational corporations. Some of the more outstanding publications/organizations are the International Association for Hydrogen Energy (http://www.iahe.org/) and the American Hydrogen Association (http://www.clean-air.org/).

Customers/Buyers

New product success is recognized shortly after its introduction. Early in the marketing process, shortly after a product's introduction into a market, it is important to analyze how a new product is performing. "There are two principal consumer groups in the marketplace: those who are eager to try a product with unknowns – early adopters, and those who prefer to wait until others have tried the product first – later adopters" (Wilke and Sorvillo, 2004). The customer group most likely interested in new hydrogen technology is the early adopters. According to The Nielsen Company, early adopters are the customer group best used to analyze the success of a new product and present valuable knowledge relating to customer acceptance (Wilke and

Sorvillo, 2004). Additional buyer prospects could be homeowners near beaches and/or boat and yacht owners. This is because of the propensity of winds near the ocean, and the beach homes often are inhabited by persons who fit the above qualifications. The final potential buyers are companies and/or individuals who have remote locations that need power. These include, but are not limited to, natural gas pumping stations and/or remote hunting cabins. Although early adopters are important for product inception, they are not the key to product success. Specific consumer segments for the product are merely speculation and will need further, extensive research.

Business-to-Business Buyers

Several potential business customers have been identified. These customers are businesses that currently manufacture small-scale, residential-sized wind turbines. The proposed companies are currently not using hydrogen for energy storage. The potential companies are Abundant Renewable Energy, LLC, Newberg, Oregon; Southwest Windpower in Flagstaff, Arizona; Bergey WindPower Company, Norman, Oklahoma. Currently, Bergey uses a “hybrid” system that uses the wind power directly to where power is needed and a diesel generator to provide power at times when there is no wind. However, this diesel generator is expensive, and the electrolyzer option provides an alternative not dependent upon diesel prices and would be cleaner. Prairie Turbines is a company that provides parts and instructions for constructing a 5500 Watt homebuilt wind turbine generator. Other potential business-to-business customers include solar cell producers, automobile and boat manufacturers, and the aerospace industry.

Current and potential market size

No current market is in place for the type of wind-to-hydrogen system proposed. Because of the small-scale size of the product, it has been differentiated from competitors in the wind energy industry. The potential market size would be small with the introduction of the product but could grow to be large with increased efficiency and economic viability. When dealing with any alternative energy, an important aspect is customer acceptance and trust. New technology in the energy industry is often more expensive and less reliable than systems previously on the market. After being more readily used, cost typically is reduced and reliability increases, resulting in increased trust in the technology and an opportunity for market growth (Tietenberg and Lewis, 2009).

The American Wind Energy Association expects an 18 to 20 percent market growth by 2010. Foreign markets also are ensured because U.S. standards require all U.S.-built wind turbines be compatible with the International Electrotechnical Commission (American Wind Energy Association, 2008).

Since September 2008, more than 1,300 megawatts of new wind energy has been installed. In 2007, 5,249 megawatts on wind energy were installed. This is a 45 percent increase from previous years. This also invested more than $9 million into the economy. According to the American Wind Energy Association, 17 domestic wind turbine and wind turbine component manufacturing facilities have opened since the beginning of 2008. Another 19 also have been announced. This is expected to create 9,000 job openings at the manufacturing facilities.

One concern with depending on wind energy is the consistency of wind available. The American Wind Energy Association has predicted the top 20 states that are expected to produce the most wind energy in kilowatts (See Table 1).

Table 20: Top 20 Wind Energy Producing States

1. North Dakota	6. Nebraska	11. Colorado	16. Illinois
2. Texas	7. Wyoming	12. New Mexico	17. California
3. Kansas	8. Oklahoma	13. Idaho	18. Wisconsin
4. South Dakota	9. Minnesota	14. Michigan	19. Maine
5. Montana	10. Iowa	15. New York	20. Missouri

Source: American Wind Energy Association, 2008

Oklahoma's wind energy potential is primarily in the western part of the state and in the panhandle. The Oklahoma Wind Power Initiative has calculated the wind potential across the state. This is shown in the figure below.

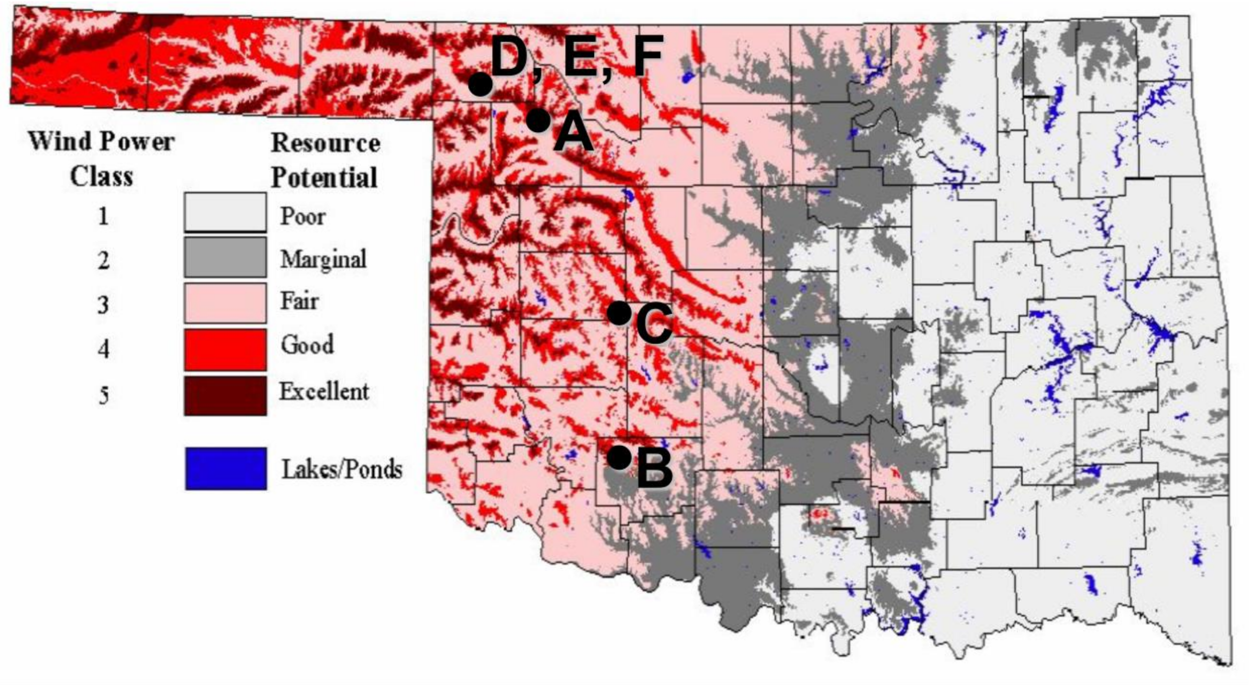


Figure 28: Oklahoma's Wind Resources

Consumer Trends and Motivation

Potential customers of new hydrogen technology learn about new products at tradeshows and through the press. Hydrogen energy products make great news stories about technology and energy. With renewable energy emerging as a major issue in the world, “advertising” through news articles and press releases will help reach our potential customers and increase knowledge and awareness of new hydrogen technology.

New technology, financial benefits, and positive environmental impacts motivate potential customers to buy new hydrogen energy products. Innovative technologies are important to the target market because they learn about the emerging topics and issues facing the United States and the world as well as what people are doing to address these issues. They also are motivated by safe environmental practices and the idea of being self-sufficient.

Most city and state governments give rebates for using a renewable resource such as wind energy. This should help people finance this type of wind turbine, making it more affordable and available to a larger consumer base. However, the federal wind energy production tax credit will cover 30% of system cost and is set to expire December 31, 2016 (American Wind Energy Association).

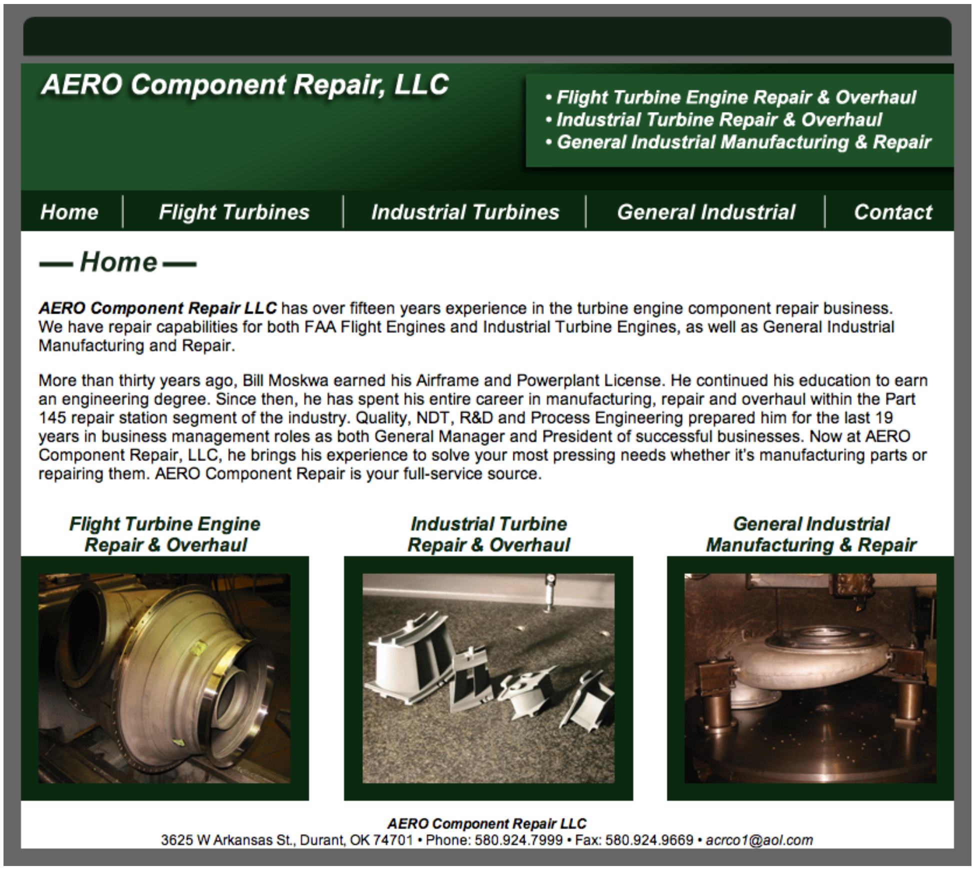
Potential customers of the product read national news and magazines targeted at business, technology, and the environment. They strive to remain educated on the topics facing the country and knowledgeable on the development of new technologies.

Media and Communications Plan

The media and communications plan is a key aspect to the success of the product. Integrated marketing communications is the goal for all aspect of communications. With integration across all media, effective communication can be achieved. This plan outlines the key components of communications in the development of the Power Solutions electrolyzer.

AERO Component Repair LLC

- Web site – A Web site, www.aerocomponentrepair.com, was created for AERO Component Repair LLC to promote the business' general manufacturing and repair capabilities, as well as diversifying its potential market segments. The Web site will help establish a positive reputation for the company and aide in the implementation of the electrolyzer into the market. Figure 28 illustrates the homepage.



AERO Component Repair, LLC

- Flight Turbine Engine Repair & Overhaul
- Industrial Turbine Repair & Overhaul
- General Industrial Manufacturing & Repair

— Home —

AERO Component Repair LLC has over fifteen years experience in the turbine engine component repair business. We have repair capabilities for both FAA Flight Engines and Industrial Turbine Engines, as well as General Industrial Manufacturing and Repair.

More than thirty years ago, Bill Moskwa earned his Airframe and Powerplant License. He continued his education to earn an engineering degree. Since then, he has spent his entire career in manufacturing, repair and overhaul within the Part 145 repair station segment of the industry. Quality, NDT, R&D and Process Engineering prepared him for the last 19 years in business management roles as both General Manager and President of successful businesses. Now at AERO Component Repair, LLC, he brings his experience to solve your most pressing needs whether it's manufacturing parts or repairing them. AERO Component Repair is your full-service source.

Flight Turbine Engine Repair & Overhaul

Industrial Turbine Repair & Overhaul

General Industrial Manufacturing & Repair

AERO Component Repair LLC
3625 W Arkansas St., Durant, OK 74701 • Phone: 580.924.7999 • Fax: 580.924.9669 • *acrco1@aol.com*

Figure 29: AERO Component Repair Homepage

- Press release – A press release was written to promote the new product and to highlight the renewable energy efforts of AERO Component Repair LLC. It will be sent to newspapers across Oklahoma, Texas and Kansas.
- Business-to-business technical flier – A flier has been created to promote the electrolyzer to potential businesses interested in using or marketing our product.
- Print materials – Several promotional materials were produced including updated business cards, letterhead, and an informational pamphlet with various inserts highlighting the business’ capabilities.

- Logo creation – A digital version of the existing logo was designed to accompany the new print materials.

Figure 30: AERO Logo

Printing costs for promotional materials

Printing costs were estimated by Print Net Marketing in Durant, Okla. The following table, Table (22), shows the estimated costs of printing a small folder to hold informational sheets.

Quantity	Production Time	500	1,000
Curved right pocket	4 – 5 days	$1,875	$2,250
Standard right pocket	15 – 20 days	$1,400	$1,750

Table 21: Promotional Costs

Printing 1,000 business cards on 14# paper, full color, with a glossy finish will cost approximately $72.

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Appendix A: Work Breakdown Structure

Work Breakdown Structure

WBS 1		*WBS 2*		*WBS 3*		*WBS 4*
1. Electrolysis Cell		1. Electrolysis Cell		1. Electrolysis Cell		1. Electrolysis Cell
		1.1 Container		1.1 Container		1.1 Container
		1.2 DC Power Source		1.1.1 Base		1.1.1 Base
		1.3 Internal Components		1.1.2 Top		1.1.1.1 Plexi-glass
		1.4 Bubbler/anti flash back				1.1.1.2 Plastic
		1. 5 External Components		1.2 DC Power Source		1.1.2 Top
				1.2.1. 12-24 volt Source		1.1.2.1 Gas Plumbing
						1.1.2.2 Fluid Plumbing/Inlet
				1.3 Internal Components		1.1.2.3 Electrode Fasteners
				1.3.1 Instrumentation and Controls		1.1.2.4 Electric Bus
				1.3.2 Diaphram/Separator/PEM		1.2 DC Power
				1.3.3 Electrodes		1.2.1. 12-24 volt Source
				1.3.4 Electrolyte		1.3 Internal Components
						1.3.1 Instrumentation and Controls
				1.4 Bubbler		1.3.1.1 Inlet/Outlet Control Valves
				1.4.1 Plexi-glass Container		1.3.1.2 Electric Voltage and Current
				1.4.2 Flexible Hose		1.3.1.3 Water Level Gage
						1.3.2 Diaphram/Separator/PEM
				1.5 External Components		1.3.2.1 Asbestos
				1.5.1 Gas Dryer		1.3.2.2 Nickel screen
				1.5.2 Oxygen Vent		1.3.2.3 Potassium titanate
				1.5.3 Water Purifyer		1.3.2.4 Fiberglass
						1.3.2.5 Other Composties
						1.3.2.6 SPE
						1.3.3 Electrodes
						1.3.3.1 Stainless Steel
						1.3.3.2 Platinum Plating
						1.3.3.3 Nickel Plating
						1.3.3.4 Wire Mesh
						1.3.3.5 Flat Plates
						1.3.3.6 Copper
						1.3.3.7 Multiple Plates
						1.3.4 Electrolyte
						1.3.4.1 NaCl
						1.3.4.2 NaOH
						1.3.4.3 H_2SO_4
						1.3.4.4 Solid Polymer Electrolyte (SPE)
						1.4 Bubbler
						1.4.1 Plexi-glass Container
						1.4.2 Flexible Hose
						1.5 External Components
						1.5.1 Gas Dryer
						1.5.2 Water Purifyer
						1.5.2.1 Deionization
						1.5.2.2 Carbon Filtration
						1.5.2.3 Micro-porous Filtration

Appendix B: Technical Research and Design

Pre-Design Considerations

Electrolysis: Overview

Figure 24 demonstrates the basic electrolysis process. Inputs consist of energy in the form of electricity, a conductive electrolyte and purified water. Electricity is applied to the system through electrodes (a type of conductive metal). Next, electricity is conducted through the system via the electrolyte to the water and the energy splits the bond holding hydrogen and oxygen together. Consequently, hydrogen and oxygen are generated as the outputs. In some cases, depending on the electrolyte and electrode, waste may be generated.

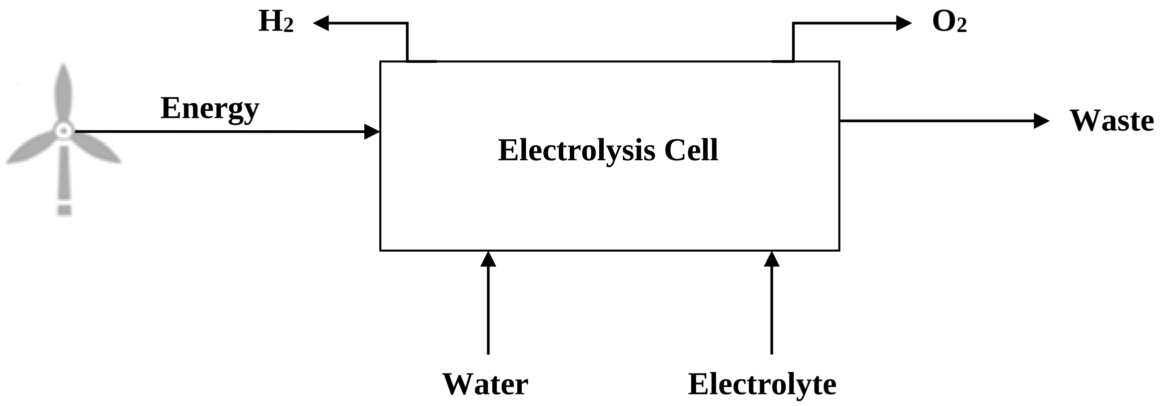

Figure 31: Electrolysis Overview

Electrolysis: Components

The first step in modeling the system was building a basic electrolyzer, and through experimentation, components, materials, and arrangement that provided the most cost-efficient design were found. The following components are necessary to build an electroylzer and included in each description is a list of materials for that component.

Container

A container to house the entire system was necessary. This container needed to be non-conducting, have high chemical resistance, easy machinability, and good insulation. A non-conducting container is the most important characteristic of the container because of the safety involved with electricity and water. The chemical resistance of the container is dependent upon the electrolyte selected. It is also important to determine the machinability of the container because, in mass production, the simplest form is the least expensive to manufacture. In addition, good insulation is an important factor because it is known that the electrolysis process becomes more efficient with increased temperature. The following materials were determined to fulfill these needs in the experimental phase: plastic, plexiglass, and glass.

Separator / Diaphragm

A separator was necessary to avoid intermixing of the solutes, which prevents undesirable secondary reactions. It consists of a porous diaphragm that an electrolyte solution can pass through, but it is impermeable to gas and prevents the electrodes from touching each other. The type of diaphragm also depends upon the type of system built. A tank type system requires a separator that allows the ions to pass through. This characteristic allows the cost of a tank type to stay low and makes more materials available for use as a separator. On the other hand, a filter-press type requires a diaphragm that must allow for the passage of ions so that the entire system is able to conduct electricity. This type of diaphragm is necessary to safely separate the hydrogen and oxygen generated. However, directly increases the cost of the system.

Materials for a tank-type separator include Ryton, glass, plexiglass and fiberglass. Materials for a filter-press type would include asbestos, Niafon, and other SPE materials.

Electrolyte

The electrolyte diffused within water conducts the electricity throughout the entire solution. Usually, the concentration is between 25% and 35%, depending on chemical used. The following materials would fulfill this need in the experimental phase: KOH, NaOH. H_2SO_4 NaCl, Proton Exchange Membrane (PEM), or Solid Polymer Electrolyte (SPE)

Electrodes

Electrodes are catalysts that conduct electricity into the solution and provide a surface area for the reaction between the catalyst and the electrolyte to occur. Electrodes are dependent upon the selection of electrolyte and should be selected based on their electrical conductance and corrosion resistance. The following materials would fulfill this need in an experimental phase: nickel, nickel-plated steel, platinum, steel, and copper.

Water Purification Device

Purity of water significantly increases electrolysis process efficiency. Many types of commercial filters can serve the purpose of water filtration for basic experimental purposes. The following water flitration techniques would fulfill this need in an experimental phase: deionization, carbon filtration, micro-porous filtration, and ultra-filtration.

Electrolysis: Important Parameters

Operating Temperatures

Operating temperatures affect the electrolysis cell, in that, as the temperature of the cell increases less voltage is required to split the molecules (Casper, 1978). However, this effect occurs only with fairly large temperature differences and would require the heat addition to come from another power source or an excellent type of insulation.

Operating Pressures

The newest technologies of hydrogen electrolyzers look at the effects of pressure on the system. Systems are being tested at very high pressure to see how the change in pressure affects the efficiency of the process. As the pressure increases the voltage necessary also increases but at the added benefit of higher efficiencies (Casper, 1978).

Cooling System

Depending on the size of the system, different types of cooling mechanisms are needed to remove the excess heat that is generated throughout the process. Methods for cooling the system include circulating the electrolyte, circulating water, and circulating the water through a heat exchanger (Casper, 1978).

Gas Removal Type Systems

Depending on the design, a type of separator is necessary to separate the hydrogen gas and electrolyte from the exit stream. This process is dictated by the type of electrolyte used. A dryer is also necessary because the gas is produced from a cell saturated with water vapor (Casper, 1978).

Methods for Increasing Efficiency

To produce the most efficient system, the highest current density as well as the highest voltage efficiency must be attained. These two parameters are limited by high resistances in the electrolyte, changes in voltage of the electrodes due to the concentration of polarization, and the voltage gradient due to slow reactions at the electrode (Casper, 1978). Three ways to increase efficiency and avoid these problems include maximizing the real to apparent surface area of the electrodes to reduce activation over-potential, increasing the operation temperature to reduce activation and ohmic over-potential losses, and reducing the thickness between the electrodes to decrease the ohmic drop (Casper, 1978).

Electrolysis: Current Types

Competitor analysis shows a wide range of companies that offer electrolyzers. The electrolyzers currently available range from units used for automobiles to industrial-sized electrolyzers. However, a market seems to exist for smaller electrolyzers similar to the size of this project. The main difference in most competitors' commercially available electrolyzers is that they do not have a membrane within their electrolyzer to separate the hydrogen and oxygen gas. Instead, their exiting gas is a mixture of hydrogen and oxygen, which is not desirable for this project because of the safety concerns. The size and type of electrolyzer also affects the price.

The majority of current commercial electrolyzers are designed for industry use. These industrial electroylzers are expensive and well out of the range of the application of this project. Table 2 outlines the commercially available industrial electrolyzers along with a reference for further information. Experiental electrolyzers are more in the range of the application of this project, but are not in high demand. Table 23 outlines the experimental electrolyzers along with their current market prices.

Table 22: Industrial Electrolyzer

Industrial- Price > $250,000				
Manufacturer	**Technology**	**Capacity (kg/ day)**	**Location**	**Ref**
AccaGen SA	Alkaline,Acid, and PEM	215.7	Switzerland	www.accagen.com
GHW	Unkown	1078.6	Germany	www.ghw-mbh.de/english
Manufacturer	**Technology**	**Capacity (kg/ day)**	**Location**	**Ref**
Hydrogenics	PEM and Alkaline	129.4	Canada	www.hydrogenics.com/onsite
Industrie Haunte Technologies SA	Alkaline	1639.4	Switzerland	www.iht.ch/technologie/electrolysis
Giner	PEM	11.8	Massachusetts, USA	www.ginerinc.com
Treadwell Coporation	PEM	22	Connecticutm USA	www.electrolysers.com/

Table 23: Experimental Electrolyzers

Commercial/ Experimental				
Manufacturer	**Technology**	**Capacity (cc/m)**	**Water Type**	**Cost**
Chrysalis® II Hydrogen Generator HPNM Series (No Maintenance)	SPE/ Batch Type	100	Deionized	$ 6,850.00
	SPE/ Batch Type	160	Deionized	$ 7,321.00
	SPE/ Batch Type	250	Deionized	$ 8,031.00
	SPE/ Batch Type	500	Deionized	$ 10,395.00
Chrysalis® II Hydrogen Generator SEPG	SPE/ Batch Type	100	Deionized	$ 5,431.00
	SPE/ Batch Type	160	Deionized	$ 5,904.00
	SPE/ Batch Type	250	Deionized	$ 6,967.00
	SPE/ Batch Type	500	Deionized	$ 9,095.00
Location: Kyle, TX; Reference: www.mathesontrigas.com				

Wind

The main energy source to drive the electrolysis process in this project comes from wind turbines. Wind turbines for this application should be small and low cost to target residential use. Since, the focus of this project is on the electrolysis process, a stock wind turbine is going to be selected to provide the electricity. Consequently, research was done to determine possible wind turbines for this application.

Table 24 provides a comparison of the four wind turbines that could be used in this application. These four turbines were selected on price and power output. Further technical specifications for each wind turbine can be found in the fall design report.

Table 24: Comparison of Wind Turbines

	Air X	XL. 1	Windmax-H5 500w	Windmax-H9 900w
Rated Power (watts)	400	1000	485	775
Rated Wind Speed	28 mph	25 mph	26 mph	28 mph
Power @ 25 mph (watts)	240	600	N/A	N/A
Blade Diameter in.	46 in	98.4 in	N/A	N/A
Dimensions L x W x H	27 x 15 x 9		N/A	N/A
Retailer	Southwest Windpower	Bergey	Amazon	Amazon
Retail Price	$595	$2,150	$475	$899

Based on this research, the 500 watt wind turbine from Windmax (Windmax-H5) best fits this project's application. The specifications for the Windmax-H5 are listed in Table 25 as well as the wind speed vs. power curve for the unit (See Figure 25).

Table 25: Technical Specifications of WindMax-H5

Model	WINDMAX-H5
Wheel diameter	4.6 Feet (1.4 Meters)
Blade material	Glass-fiber, strengthened nylon
Number of Blades	3
Speed-limitation mechanism	Electromagnetic speed limitation and blade over-speed braking
Start-up speed	2.3 m/s or 5.1 mph
Cut-in speed	3 m/s or 6.7 mph
Survival speed	60 m/s or 134 mph
Rated speed	26 mph
Rated power（W）	485W @ 13 m/s or 29 mph, 450W @ 26 mph
Max power (W)	600W
Rated voltage（v）	DC12v
Alternator	3 phases PMA
Recommended Tower height（m）	Fits 2.125" steel pipe, 1.5" or 2" steel pipe can be used with modifications 8-12m(according to different project)
Weight of system（LB）	40

(Source: www.magnet4less.com)

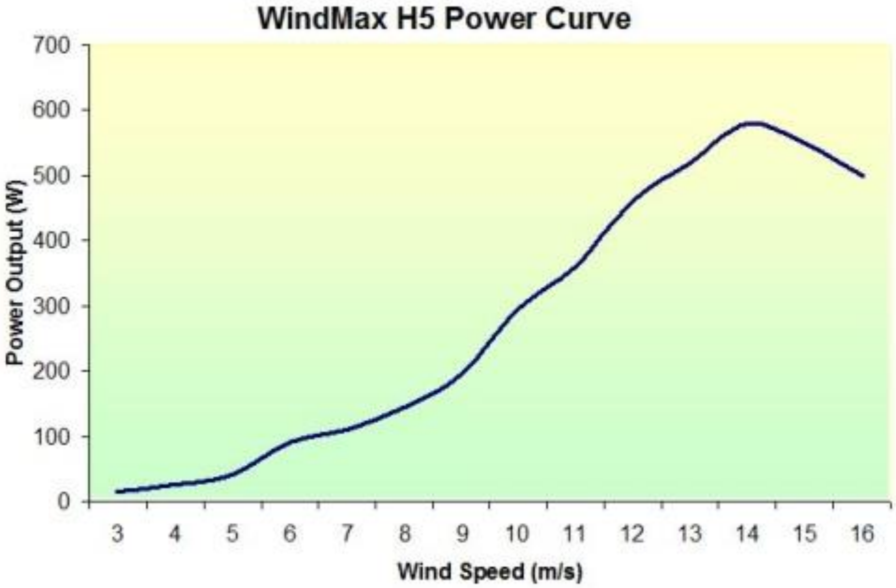

Figure 32: WindMax H5 Power Curve

(Source: www.magnet4less.com)

Storage

Compressing hydrogen requires attention to cost, space and safety. The extremely low density of the gas makes it difficult to store enough of it to do meaningful amounts of work without having to result to buying expensive or large pressurized tanks. At this point, three different methods for storing hydrogen exist: compressed hydrogen gas, cryogenic compressed hydrogen, and compressed hydrogen in the presence of a hydride.

Compressing hydrogen in a gas form requires the least amount of energy input, but it also does not create a very dense form of hydrogen. Commercial tanks are currently available in a wide range of shapes and volumes that store hydrogen up to 10,000 psi. Quantum Technologies produces a hydrogen storage tank that is designed to hold gas at 10,000 psi. These tanks are typically comprised of three layers. The inner most layer is made of a high molecular weight polymer that serves as a gas permeation barrier. The second layer is the load bearing layer. It is composed of a carbon fiber/epoxy resin composite shell. Outside of this carbon fiber shell is a layer that is used for impact and damage resistance. Compressed hydrogen gas pressure vessels are the most basic types of containers for storing hydrogen. Some individuals use old propane tanks that have been cleaned and pressure tested. These tanks work well but are normally only rated up to 200-250 psi. High pressure tanks such as the ones produced by Quantum Technologies cost more but can store the same amount of hydrogen as larger tanks due to the increased pressure of the hydrogen. This is good, but a cost/benefit analysis would need to be performed for each situation to determine if the increased cost is worth the extra area they free up in each location. The cheaper alternative, propane tanks, can be acquired for as little as $500 for a 250-gallon tank. The downside of using propane-type tanks is that it would require much higher tank volume to store the same amount of hydrogen as in a smaller, higher pressure tank.

The second form of storing hydrogen is within cryogenically cooled and compressed hydrogen tanks. These tanks can take extremely high pressures (10000+ psi) and are extremely well insulated. Cryogenically cooled compressed hydrogen can reach a much higher density than that of just compressed gas. Because of this, more hydrogen can be stored in the same volume container. Unfortunately, the energy required to cool and compress the hydrogen to a sufficient temperature to reach a near liquid form (77 K, -321 °F) is far too great to make this form of storage economical.

The last option for storing hydrogen requires utilizing some form of hydride. The hydride form of storing hydrogen is based on the fact that some metallic alloys can absorb and hold large amounts of hydrogen by bonding with the hydrogen molecules. Tests show that some hydrides can store up to 6.5 times the amount of hydrogen for a given volume of hydrogen gas that is compressed to 2850 psi. This sounds promising, but drawbacks do exist. High pressure hydride systems require special high pressure compressors to “charge” them. Compressors for these systems are expensive and the tanks can be large and heavy. Though hydride systems show hope for future hydrogen storage systems, their current price tag would cause this option be less cost effective.

Overall, it seems that compressing hydrogen gas in tanks such as propane tanks or high-pressure vessels would be the most economical way to store hydrogen.

Quantitative Analysis

Quantitative analysis of the electroylzer was difficult to complete in the design phase because of the numerous variables in the system and the unknown reaction rate at the electrode surface. Currently, the parameters of electroylzers are discovered during the experimental phase. A theoretical flowrate can be determined, but it was a high estimate due to the inefficiencies that are added to the system in actual design. These inefficiencies cannot be calculated due to the dependency of one parameter on another. The following calculations were made assuming 100% efficiency and were used for comparison with the experimental results.

Balance Equation

Anode:

$$H_2O = 4\,H^+ + 4e + O_2 \quad E^o\,(25^oC) = 1.23\text{ V}$$

Cathode:

$$4\,H_2O + 4\,e = 2\,H_2 + 4\,OH^- \quad E^o\,(25^oC) = 0.00\text{V}$$

Net Reaction:

$$2H_2O \rightarrow 2H_2 + O_2 \quad E^o\,(25^oC) = 1.23\text{ V}$$

The ideal overall voltage required to separate hydrogen and oxygen from H_2O was 1.23 V. This ideal voltage was the standard electrode potential at standard temperature and pressure. It was important to note that the following equations used this ideal voltage to calculate the ideal production of hydrogen during electrolysis.

Theoretical Flowrate

To determine, theoretically, what the hydrogen production rate was at 100% efficiency, the Gibbs free energy of the reaction was found. To simplify this calculation, some assumptions were made. The assumptions used in this calculation include the reaction taking place at standard temperature and pressure (STP), ideal gas, 100% of the voltage was used, 100% of the water was separated, and no internal resistance occurred. This calculation was solely theoretical, and the actual production rate should be lower due to the inefficiencies in the system.

$$\Delta G = -nFE$$

Where the electron coefficient (n) is 2, Faraday's constant (F) is 96,485 C/mol, and the cell voltage (E) was 1.229 J/C, which was the known value for the voltage potential to separate hydrogen and oxygen from H_20 from the Nernst equation.

$$\Delta G = (2)*(1.229\ J/C)*(96485 C/mol) = \mathbf{237{,}160\ J/mol} \text{ to separate } H_20$$

The next step in determining the ideal production of hydrogen was to find the volume of gas in one mole of H_20 at STP. This value was found by using the ideal gas law.

$$\frac{V}{n} = \frac{RT}{P}$$

At 25^{o}C and 101.325 Pa

$$\frac{V}{n} = \frac{\left(8.314\frac{J}{kmol}\right)(298.15K)}{(101.325\frac{N}{m^2})} = 24.466\frac{m^3}{mol} = \mathbf{24,466}\frac{\boldsymbol{cm^3}}{\boldsymbol{mol}}$$

The next step was to determine the amount energy needed to dissociate a cubic centimeter.

$$\frac{\Delta G}{V} = \frac{237{,}160\frac{J}{mol}}{24{,}466\frac{cm^3}{mol}} = 9.69\, J/cm^3$$

Now that the theoretical amount of energy needed to dissociate one mole of H_20 was found, the amount of power that will be applied to the system was determined. First, the production at 500W, which is the lower end power output of small wind turbines, was analyzed.

$$\frac{\frac{500J}{sec}}{9.69\frac{J}{cm^3}} = 51.6\, cm^3 gas/\sec = 3096\, cm^3 gas\ /\, min$$

This last value calculated was for the entire amount of gas that could be generated. To determine the appropriate amount of hydrogen gas to oxygen ratio, the ideal gas law must be applied again. It was proven earlier that an ideal gas at STP has a volume of 24, 466 cm^3 per mole, which is equivalent to 24.4 L. Thus, the breakdown in percent volume of the dissociation of water was 1 mole, or 24.4 L, of H_2 and 0.5 mole, or 12.2L, of O_2 with the total volume being 36.6 L; therefore, 2/3 of the product was H_2 and 1/3 of the product was O_2. Applying this knowledge to the calculation of gas generated per min, the system would theoretically generate:

H_2 = 2,064 cm^3 per min

O_2 = 1,032 cm^3per min

Again, this calculation assumed 100% of the turbine's power is applied to the electroyzer. It was known from the Nerst equation that, theoretically, only 1.23 V of energy are needed to dissociate H_20; therefore, in this assumption it is implied that 407 amps are applied to the electrolysis process. Clearly, this assumption was not applicable in a real situation because of the amount of current supplied to the system as well as the amount of heat that would be generated.

More realistically, the unit operates at 1.5 V, which provides enough voltage for over potential and resistance within the cell. The current desired is then as large as possible for increased efficiency but limited by safety and the size of wire needed to carry the current. It was assumed that 40 amps will be possible because the typical electric household oven runs on 40 amps. The following calculations assume that 1.5 V will be necessary for the dissociation of H_20 and that 40 amps will be applied to the system thus only utilizing 60 watts of the available 500 watts generated from the turbine. More electrolysis cells could be added to utilize the available excess power.

$$\Delta G = 289{,}455 \text{ J/ mol}$$

$$\Delta G/V = 11.83 \text{ J/cm}^3$$

$$\frac{\frac{60J}{sec}}{11.83\,\frac{J}{cm^3}} = 5.07\ cm^3 gas/\mathrm{sec} = 304\ cm^3 gas\ /\ min$$

Therefore:

H_2 = 203 cm^3 per min

O_2 = 101 cm^3per min

Temperature Effects

Temperature has a large impact on the efficiency of the system. In fact, in an electrolysis process, finding the ideal operating temperature is a balancing act. The higher the temperature, the more efficient the system operates; however, at STP the water must be kept from boiling. The process becomes more efficient because increasing the operating temperature lowers the voltage necessary to dissociate water. A large part of the experimentation phase of this project dealt with operating the unit at the ideal temperature. To quantify the effects of the increase in temperature, the following equation from *Electrochemistry* by Carl Hamann was used.

$$\frac{\delta Ecell}{\delta T} = -0.85\, mv/k$$

Therefore, if the operating temperature can be increased by 20^{o}C then the voltage applied to the system will be reduced by 0.02 volts, which can slowly increase overall efficiency. Figure 26 demonstrates the temperature effects at high operating temperatures.

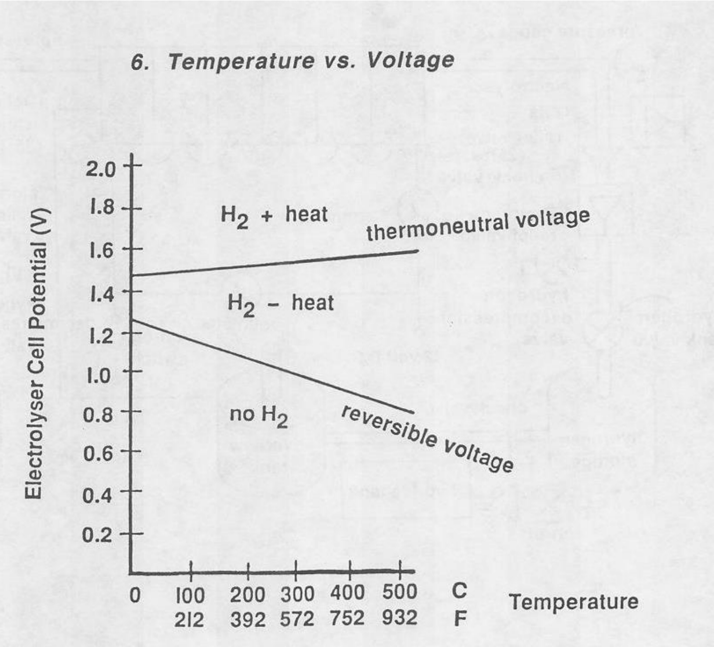

Figure 33: Temperature Effects

Taken from <u>Fuel from Water</u> (Peavey, 1998)

If the process stays between the reversible voltage and the thermoneutral voltage, the voltage necessary to dissociate H_20 can be reduced, consequently, increasing the efficiency of the process (Figure 9). The reversible voltage is the lower limit or the minimum voltage necessary for the reaction to take place and the thermoneutral voltage is the upper limit, or threshold, where the process generates heat instead of absorbing it. However, Figure 33 outlines a process at operating temperatures well above the temperatures expected in this project's application, but the same effects can be expected on a smaller scale.

Patents

4, 144, 161 – Electrolytic Diaphragm Cell

Author: Louis Bourgeois
Year: 1979
Type: Filter Press Design
Electrodes: Cathode - Steel Lattice and Anode - Graphite or Titanium
Electrolyte: Sodium Chloride Brine

This patent refers to an electrolysis system with a valve to monitor the electrolyte percolation rate through the diaphragm so that it remains proportional to the electrolyzing current density. The reasoning behind this system is to avoid premature swelling of the diaphragm of the electrolyte cell and thus increase efficiency. This function is achieved by using a float in the vessel connected with the valve in the gas outlet-pipe that progressively closes as it rises and opens the valve as it moves downward in response to electrolytic height variations. Drawings are available of this system as well as the entire patent in the fall design report.

4, 395, 230 – Method and Apparatus for Splitting Water Molecules

Author: Henry K. Puharich
Year: 1983
Type: New Design
Electrolyte: Seawater

This patent refers to a thermodynamic model designed to produce hydrogen gas and oxygen gas from ordinary water molecules or seawater at normal temperatures and pressures. It is based on the two basic bond angles of the water molecule. This design attempts to shift the bond angles from 104^o to the 109^{o}28' tetrahedral geometrical configuration. To accomplish this process, a function generator produces a complex signal and sends it into a thermodynamic device that shatters the water molecule by resonance into its component molecules. Drawings are available of this system as well as the entire patent in the fall design report.

7, 326, 329 Commercial Production of Hydrogen from Water

Author: Rodolfo Antonio M. Gomez
Year: 2008
Type: Tank Diaphragm-less Design
Electrolyte: 28% Potassium Hydroxide
Operating Pressure: 40 bars
Operating Temperature: 150^{0}C

This patent is for a large-scale commercial electrolyzer that produces hydrogen through electrolysis using a diaphragm-less electrolytic cell. The key to this diaphragm-less process is by separating the anode and the cathode and using a type of solution electrode. The type of solution electrode is not defined in the patent. This design also replaces the typical regenerative pump with a microwave unit. The only idea of this patent that would pertain to the application desired by this project would be the diaphragm free design, but overall the patent is vague and only provides ideas without application. Drawings are available of this system as well as the entire patent in the fall design report.

7, 393, 440 Hydrogen Generation Systems

Author: Debabrata Ghosh
Year: 2008
Type: Tank-type Design
Electrodes: Cathode- Aluminum and Anode- Magnesium
Electrolyte: NaCl

This particular patent is for a tank-type design that can be used both as an electrochemical process and an electrolytic process. The novel ideas in this invention include a polarity reversing system and pressure sensor switch to prevent the hydrogen pressure from becoming too high. The cathode and anode are arranged in a cylindrical fashion, minimizing the distance between the two electrodes with an electrical insulating layer between them. This patent also includes experimental data, which was beneficial in the design phase of this project. The experiments include polarization curve of anode and cathode, comparison of electrode materials vs. hydrogen production, effect of ohimic resistance, temperature effects, electrode spacing, corrosion characteristics, and the effect of the electrolyte concentration Drawings are available of this system as well as the entire patent in the fall design report.

Appendix C: Engineering Drawings

Appendix D: Detailed Experimental Results

Overview

The data listed below outlines the actual test data that was recorded during testing. The test listed describes the volume that we recorded the production rate. Most tests were recorded timing the production to 10 ml, however, the test that had slower production rates had to be timed to 1ml for better accuracy. All time trials listed were recorded in seconds and timed using a common stop watch. The coverage value is a representation of the height that the electrolyte was covering the electrode.

Test #1

Material	**SS Plate**	
Electrolyte	**5% H_2SO_4**	
Test	10 ml	
Depth	14 7/8	in
Voltage	7.5	V
Current	9	A
Coverage	9 3/8	
Time:		
1	8.09	
2	7.8	
3	8	
4	8	
5	8	
6	7.94	
7	8.27	
8	8.26	
9	8.14	
10	8.3	
11	8.26	
12	8.22	
13	8.2	
14	8.22	
15	8.21	
16	8.11	
17	8.22	
18	8.09	
19	8.35	
20	8.09	
21	8.1	
22	8.27	
23	9.11	

24	8.22	
25	8.09	
26	8.13	
27	8.14	
AVG	**8.18**	
Avg. Flowrate	**1.22**	**ml/sec**
	73.36	**ml/min**

Test #2

Material	**SS Weeve**	
Electrolyte	**5% H2SO4**	
Test	10 ml	
Depth	14 7/8	in
Voltage	9	V
Current	9	A
Coverage	9 3/8	
Time:		
1	15.16	
2	10.87	
3	15.38	
4	15.45	
5	14.84	
6	11.45	
7	15.82	
8	15.64	
9	15.53	
10	15.26	
11	15.42	
12	15.26	
AVG	**14.67**	
Avg. Flowrate	**0.68**	**ml/sec**
	40.89	**ml/min**

Test #3

Material	**SS Mesh**	
Electrolyte	**5% H2SO4**	
Test	**1 ml**	
Depth	14 7/8	in
Voltage	8.48	V
Current	9	A
coverage	9 3/8	
Time:		
1	1.18	
2	1.86	
3	1.41	
4	1.31	
5	1.28	
6	1.61	
7	1.5	
8	1.63	
9	1.75	
10	1.13	
AVG	**1.47**	
Avg. Flowrate	**0.68**	**ml/sec**
	40.93	**ml/min**

Test #4

Material	**Monel**	
Electrolyte	**5% KOH**	
Test	**1ml**	
Depth	14 3/8	in
Voltage	8.9	V
Current	9	A
Coverage	8 7/8	
Time:		
1	1.43	
2	0.95	
3	1.81	

4	0.95	
5	1.62	
6	1.92	
7	1.71	
8	1.96	
9	1.6	
10	1.84	
11	2.07	
12	1.28	
13	2.08	
14	2.08	
15	2.14	
16	1.5	
17	1.6	
18	2	
19	2.15	
20	1.08	
AVG	**1.69**	
Avg. Flowrate	**0.59**	**ml/sec**
	35.53	**ml/min**

Test #5

Material	**SS Plate**	
Electrolyte	**5% KOH**	
Test	**10 ml**	
Depth	14 3/8	in
Voltage	8.6	V
Current	9	A
Coverage	8 7/8	
Time:		
1	6.16	
2	5.9	
3	6.02	
4	6	
5	5.67	
6	5.84	
7	5.99	
8	5.93	
9	5.88	
10	5.8	

11	6	
AVG	**5.93**	
Avg. Flowrate	**1.69**	**ml/sec**
	101.24	**ml/min**

Test #6

Material	**SS Plate**	
Electrolyte	**0.5% H2SO4**	
Seperator	**Nafion**	
Test	**10 ml**	
Depth	14 7/8	in
Voltage	10.5	V
Current	9	A
Coverage	9 3/8	
Time:		
1	8.46	
2	8.57	
3	8.46	
4	8.4	
5	7.89	
6	7.83	
7	7.59	
8	7.05	
9	7.42	
10	7.5	
11	7.22	
AVG	**7.85**	
Avg. Flowrate	**1.27**	**ml/sec**
	76.40	**ml/min**

Test #7

Material	**SS Plate**	
Electrolyte	**1% H2SO4**	
Seperator	**Nafion**	
Test	**10ml**	
Depth	14 7/8	in
Voltage	7	V

Current	9	A
Coverage	9 3/8	
Time:		
1	6.68	
2	6.64	
3	6.72	
4	6.45	
5	6.55	
6	6.36	
7	6.39	
8	6.2	
9	6.33	
10	6.24	
AVG	**6.46**	
Avg. Flowrate	**1.55**	**ml/sec**
	92.94	**ml/min**

Test #8

Material	**Monel**	
Electrolyte	**5% NaOH**	
Test	**1ml**	
Depth	14 1/8	in
Voltage	7.9	V
Current	9	A
Coverage	8 5/8	
Time:		
1	1.5	
2	1.7	
3	2.25	
4	2.01	
5	1.89	
6	1.69	
7	1.28	
8	1.39	
9	1.61	
10	2.26	
AVG	**1.76**	

Avg. Flowrate	**0.57**	**ml/sec**
	34.13	**ml/min**

Test #9

Material	**SS Plate**	
Electrolyte	**5% NaOH**	
Test	**1ml**	
Depth	14 1/8	in
Voltage	7.9	V
Current	9	A
Coverage	8 5/8	
Time:		
1	2.78	
2	2.31	
3	2.39	
4	1.87	
5	2.53	
6	2.64	
7	2.79	
8	2.25	
9	3.02	
10	2.42	
AVG	**2.50**	
Avg. Flowrate	**0.40**	**ml/sec**
	24.00	**ml/min**

Appendix E: Safety

Safety Consultants SOP Guidelines

To: Team AERO Component

Subject: Recommended Guidelines for System Safety

From: Valentine Ezugha & Brett Noakes (Cowboy Safety)

Date: March 8, 2009

Team AERO Component

The following information has been developed on the requirements/needs that have been expressed by the Team. It consists of safety procedures, PPE, emanate and unforeseen dangers by your teams system.

With these guidelines, Cowboy Safety is not responsible for any matters/issues that may arrive that has not been expressed by your team. For example, changes that have not been brought to our attention will not be included in the guidelines. If any dangers arrive from those changes these guidelines will not absorb the responsibility of the consequences or any consequences.

Sincerely,

Valentine Ezugha

Brett Noakes

Experimental Safety

Test 1

Safety Issues with Test 1 are handling of materials.

Components of Test 1

- Hydrogen Sulfate/Sulfuric Acid
- Plexiglas
  - Container
  - Separator
- Stainless Steel Plate
  - Electrode Material
- PVC
  - Misc. Plumbing
- Titanium Mesh
  - Electrode material

PPE

When handling the chemical (Sulfuric Acid) use the following PPE:

- **Eyes:** Wear chemical splash goggles and face shield.
- **Skin:** Wear neoprene gloves, apron, and/or clothing. Viton gloves are recommended.
- **Clothing:** Wear appropriate protective clothing to prevent skin exposure.
- **Respirators:** Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Handling

The chemicals should be handled in the matter below:

- Wash thoroughly after handling. Remove contaminated clothing and wash before reuse.
- Do not allow water to get into the container because of violent reaction. Do not get in eyes, on skin, or on clothing.
- Keep container tightly closed. Discard contaminated shoes. Use only with
- Adequate ventilation. Do not breathe spray or mist. Do not use with metal spatula or other metal items. Inform laundry personnel of contaminant's hazards

Concluding

Any other physical or chemical considerations that are of concern will be located in Appendix A.

Test 2

Safety Issues of Test 2 are handling of materials. Anytime that the chemicals are interchanged, touched or moved, the following guidelines should be considered:

Components of Test 2

- Plexiglas
    - Container
    - Separator
- Nickel plated Copper
    - Electrode
- Potassium Hydroxide
    - Electrolyte
- PVC
    - Misc. Plumbing
- Aluminum Plate
    - Electrode

PPE:

- **Eyes:** Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166
- **Skin:** Wear appropriate protective clothing to prevent skin exposure
- **Respirators:** A respiratory protection program that meets OSHA's CFR 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant respirator use.

Handling:

- Wash thoroughly after handling
- Do not allow water to get into the container because of violent reaction
- Do not breathe dust, mist, or vapor
- Do not get in eyes, on skin, or on clothing
- Keep container tightly closed

Concluding

Any other physical or chemical considerations that are of concern will be located in Appendix C.

Test 3

Safety Issues of Test 3 are handling of materials. Anytime that the chemicals are interchanged, touched or moved, the following guidelines should be considered:

Components of Test 3

- Plexiglas
    - Container
    - Separator
- Nickel plated Copper
    - Electrode
- Sodium Hydroxide
    - Electrolyte
- PVC
    - Misc. Plumbing
- Aluminum Plate
    - Electrode

PPE:

- **Eyes:** Wear chemical splash goggles.
- **Skin:** Wear appropriate protective gloves to prevent skin exposure.
- **Clothing:** Wear appropriate protective clothing to prevent skin exposure.
- **Respirators:** A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant respirator use.

Handling:

- Wash thoroughly after handling. Do not allow water to get into the container because of violent reaction.
- Minimize dust generation and accumulation. Do not get in eyes, on skin, or on clothing.
- Keep container tightly closed. Avoid ingestion and inhalation. Discard contaminated shoes.
- Use only with adequate ventilation.

Concluding

Any other physical or chemical considerations that are of concern will be located in Appendix B.

Addressed Chemicals

Sodium Hydroxide

- **Personal Respirators (NIOSH Approved):**
  If the exposure limit is exceeded and engineering controls are not feasible, a half face piece particulate respirator (NIOSH type N95 or better filters) may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest.. A full-face piece particulate respirator (NIOSH type N100 filters) may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full-face piece positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

(Source: http://www.jtbaker.com/msds/englishhtml/s4034.htm this is an online MSDS)

Guidelines for sodium hydroxide solutions, 30-70%:

- RECOMMENDED (resistance to breakthrough longer than 8 hours): Butyl rubber; natural rubber, neoprene, nitrile rubber, polyethylene, polyvinyl chloride, Teflon(TM), Viton(TM), Saranex(TM), 4H(TM), Barricade(TM), CPF 3(TM), Responder(TM), Trellchem HPS(TM), Tychem 10000(TM).
- NOT RECOMMENDED for use (resistance to breakthrough less than 1 hour): Polyvinyl alcohol.

Guidelines for sodium hydroxide, saturated solution:

- RECOMMENDED (resistance to breakthrough longer than 8 hours): Polyethylene, Saranex(TM).
-

Guidelines for sodium hydroxide, above 70%:

- RECOMMENDED (resistance to breakthrough longer than 8 hours): Neoprene, polyvinyl chloride, Barricade(TM).
- There is evidence that this material can cause serious skin injury (e.g., corrosion or absorption hazard).
- Recommendations are NOT valid for very thin natural rubber, neoprene, nitrile and pvc gloves (0.3 mm or less).
- Recommendations are valid for permeation rates reaching 0.1 µg/cm^2/min or 1 mg/m^2/min and over. Resistance of specific materials can vary from product to product. Breakthrough times are obtained under conditions of continuous contact, generally at

room temperature. Evaluate resistance under conditions of use and maintain clothing carefully.

- Reference: Forsberg, K., et al. Quick selection guide to chemical protective clothing. 3rd edition. Van Nostrand Reinhold, 1997.
- EYEs: Chemical safety goggles. A face shield may also be necessary.

(Source: http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/sodium_hydroxide/personal_sod.html)

Potassium Hydroxide

- **Skin Protection:**
  Rubber or neoprene gloves and additional protection including impervious boots, apron, or coveralls, as needed in areas of unusual exposure.
- **Eye Protection:**
  Use chemical safety goggles and/or a full face shield where splashing is possible. Maintain eye wash fountain and quick-drench facilities in work area.

(Source: http://www.jtbaker.com/msds/englishhtml/p5884.htm online MSDS.)

- **Personal Respirators (NIOSH Approved):**
  If the exposure limit is exceeded and engineering controls are not feasible, a half face piece particulate respirator (NIOSH type N95 or better filters) may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest.. A full-face piece particulate respirator (NIOSH type N100 filters) may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full-face piece positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

(Source: http://www.jtbaker.com/msds/englishhtml/s4034.htm this is an online MSDS)

Hydrogen Sulfate/Sulfuric Acid

- **Personal Respirators (NIOSH Approved):**
  For conditions of use where exposure to dust or mist is apparent and engineering controls are not feasible, a particulate respirator (NIOSH type N95 or better filters) may be worn.

If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full-face positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

(Source: http://www.jtbaker.com/msds/englishhtml/p5543.htm Online MSDS)

- **HAND PROTECTION:** Wear butyl rubber, Saranex™, Barricade™, or Chemrel™ for routine industrial use. Use triple gloves for spill response, as stated in Section 6 (Accidental Release Measures) of this MSDS. If necessary, refer to U.S. OSHA 29 CFR 1910.138.

(Source: http://alemis.us.airliquide.com/ChemSafe/MSDS/Image/128395_1.PDF Online MSDS)

- **BODY PROTECTION:** Use body protection appropriate for task. Full-body chemical protective clothing is recommended for emergency response procedures. If a hazard of injury to the feet exists due to falling objects, rolling objects, where objects may pierce the soles of the feet or where employee's feet may be exposed to electrical hazards, use foot protection, as described in U.S. OSHA 29 CFR 1910.136.

(Source: http://alemis.us.airliquide.com/ChemSafe/MSDS/Image/128395_1.PDF Online MSDS)

- **EYE PROTECTION:** Splash goggles or safety glasses. If necessary, refer to U.S. OSHA 29 CFR 1910.133 or appropriate Canadian Standards.

(Source: http://alemis.us.airliquide.com/ChemSafe/MSDS/Image/128395_1.PDF Online MSDS)

Additional Safety Concerns

- Syringes – Considering that the syringes are not being used for biological sampling, there will not be any disposal concerns (HAZWOP).
  - The syringes should be kept in a solid secure container when not in use.
- Disposal of all chemical substances, are presented in Appendix A
- First Aid Measures can be found on the attached MSDS sheets provided by Team AERO.
- An IDLH atmosphere will not be reached, if the use of a well functioning fume hood, as was indicated by TEAM AERO, is used. Therefore, respiratory protection is not required/needed.

Emergency Numbers: from Oklahoma State University

(Source: http://ehs.okstate.edu/hazcom/manual/hc-phone.htm)

STATE & NATIONAL AGENCIES

CHEMTREC

1-800-262-8200

NATIONAL RESPONSE CENTER (NRC)

1-800-424-8802

ENVIRONMENTAL PROTECTION AGENCY (EPA) REGION VI

Allied Bank Tower
1445 Ross Avenue, Suite 1200
Dallas, Tx 75202-2733
(214) 665-6444 or (800) 887-6063

EPA Region 6 Emergency Response Center, Environmental Emergencies
1-866-372-7745

OKLAHOMA POISON CONTROL CENTER

1-800-222-1222 or 1-405-271-5062

NATIONAL PESTICIDE TELECOMMUNICATIONS NETWORK

(PESTICIDE POISONING)
1-800-858-7378

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

State Office: 1-800-522-0206
Local Office:
217 W. 5th St., #4
Stillwater, OK 74075
(405) 372-7387
Robert Huber, Environmental Specialist Supv.

OKLAHOMA HIGHWAY PATROL (OKC)

(405) 682-4343

OKLAHOMA DEPARTMENT OF TRANSPORTATION (ODOT)

Traffic Advisories 1-405-521-6000

STATE AGENCY DIRECTORY

1-405-521-2011

OKLAHOMA STATE UNIVERSITY--- (EMERGENCY 911)

ENVIRONMENTAL HEALTH & SAFETY

120 Physical Plant Services Building
(405) 744-7241
Floyd Cobb, Director, OSU Fire Marshal
Stephen Boles, Coordinator, Hazard Communication
Greg Fox, Coordinator, Environmental Hazards
Greg Hogan, Coordinator, Safety Training

CAMPUS POLICE DEPARTMENT

104 USDA Building
(405) 744-6523 [Emergency 911]
Mike Robinson, Director

COMMUNICATION SERVICES

(405) 744-6260
Gary Shutt, Director

STUDENT HEALTH CENTER

University Health Services/Clinic
(405) 744-7013
(405) 744-7026

PHYSICAL PLANT ACTION DESK

Physical Plant Services Building
(405) 744-7154

BIOLOGICAL SAFETY OFFICER

205 Cordell North
(405) 744-3203
(405) 880-4407 (Cell)
Trenna Blagden, Biological Safety Officer

205 Cordell North
(405) 744-3376
(405) 269-5366 (Cell)
Jennifer Nangle, Assistant Biological Safety Officer

RADIATION SAFETY OFFICER

226 Cordell North
(405) 744-8721
(405) 714-8040 (Cell)
Daniel Van Gent, Radiation Safety Officer

224 Cordell North
(405) 744-7890
(405) 714-8041 (Cell)
Jim Tucker, Radiation Safety Specialist

OFFICE OF UNIVERSITY RESEARCH COMPLIANCE

219 Cordell North
(405) 744-1676
(405) 612-9932 (Cell)
Dr. Steven O'Geary, Director

CITY OF STILLWATER--- (EMERGENCY 911)

STILLWATER FIRE DEPARTMENT

Headquarters Station
1506 S. Main Street
(405) 372-0498
Marion Blackwell, Chief

Fire Station #2
600 W. University Ave.
(405) 372-4767

STILLWATER POLICE DEPARTMENT

723 S. Lewis Ave.
(405) 372-4171
Norman McNickle, Chief

EMERGENCY COORDINATION & COMMUNICATION

723 S. Lewis Ave.
(405) 372-7484
Kirk Mittlestet, Director

ENVIRONMENTAL & SAFETY SERVICES

901 S. Lowry Ave.
(405) 377-0456
(405) 747-8099
Robert Fulton, Director

STILLWATER MEDICAL CENTER

1323 W. 6th Street
(405) 372-1480

Safety Consultant's Hazard Analysis

Preliminary Hazard Analysis Introduction

The following table (Table 28-32) lists possible hazards associated with project. This list was developed using a Source- Mechanism- Target analysis and list possible hazards and outcomes associated with those hazards. The column heading labeled Damage is split in to four areas of damage:

- Physical: This would include any hazard that could cause physical damage to the system or its components.
- Fire/ Explosion: This would include any hazard that could result in a fire or explosion of some sort.
- Injury: Hazards with this designation would result in the potential injury or death of the user and other parties present at the time of the hazard.

- Failure: this designation would include any hazard that would result in the failure of the system causing it not to work as designed.

In the recommendation column you will find preliminary recommendations on how reduce or eliminate the hazards. Through further analysis we might come up with a better recommendation at which time you will be notified. Some of these recommendations may result in the use of alarm devices to alert the user of a potential problem. These to will need more in-depth analysis to determine what the most effective alert device is for the specific hazard.

Table 26 – Possible Hazards Associated with Experiment

	Damage				
Hazard Description **Source – Mechanism – Target** **Analysis**	**Physical**	**Fire / Explosion**	**Injury**	**Failure**	**Recommendations**
Plexiglas container failures due to pressure build up form chemical reaction.	**X**	**X**	**X**	**X**	Install a pressure release device
KOH Electrolyte Corrosive, Possible Spill could eat through container or cause chemical burns to user.	**X**		**X**	**X**	Use only small quantities in approved containers while wearing appropriate Personal Protective Equipment.
NAOH Electrolyte Corrosive, Possible Spill could eat through container or cause chemical burns to user.	**X**		**X**	**X**	Use only small quantities in approved containers while wearing appropriate Personal Protective Equipment.
H2SO4 Electrolyte Corrosive, Possible Spill could eat through container or cause chemical burns to user.	**X**		**X**	**X**	Use only small quantities in approved containers while wearing appropriate Personal Protective Equipment.

NaCL Electrolyte Corrosive, Possible Spill could eat through container or cause chemical burns to user.	X		X	X	Use only small quantities in approved containers while wearing appropriate Personal Protective Equipment.
Proton Exchange Membrane could fail do to chemical reaction or tear from rough handling allowing oxygen and hydrogen to mix building up pressure with in the system with a volatile gas mixture.	X	X	X	X	Handle the Proton Exchange Membrane using proper technique and follow manufacturers' guidelines for acceptable use with other chemicals.

	Damage				
Hazard Description **Source – Mechanism – Target** **Analysis**	**Physical**	**Fire / Explosion**	**Injury**	**Failure**	**Recommendations**
Solid Polymer Electrolyte could fail do to chemical reaction or tear from rough handling allowing oxygen and hydrogen to mix building up pressure with in the system with a volatile gas	X	X	X	X	Handle the Proton Exchange Membrane using proper technique and follow manufacturers' guidelines for acceptable use with other chemicals

mixture.					
PVC can become brittle with temperature changes this could lead to possible cracking, and loose fittings, which could lead to flammable gas leaks, which could find an ignition source.	X	X	X	X	Try to keep the system at a constant temperature. Check all fittings and piping for cracks or leaks before use. Minimize accidental ignition sources in the area of operation.
Dririte used to remove water from the hydrogen gas could become excessively wet and clog resulting in access pressure build up on the hydrogen side of the cell.	X	X	X	X	Change the Dririte regularly to allow gas to move through it as unrestricted as possible.
Sealant used to make the Plexiglas container airtight could react with the electrolyte solution and fail causing leaks.	X			X	Test sealant before used in construction to make sure that it will not degrade when in contact with all chemicals in use.
Flammable gas ignited by accident and flashing into the system causing an explosion.	X	X	X	X	Consider the use of a commercial flame arrester or other suitable method of preventing a flash back into the system. Eliminate accidental ignitions sources in the area.

Table 27. Continuation of Possible Hazards Associated with Experiment

	Damage				
Hazard Description **Source – Mechanism – Target** **Analysis**	**Physical**	**Fire / Explosion**	**Injury**	**Failure**	**Recommendations**
Nickel electrodes could deteriorate due to chemical reaction with electrolyte solution leading to system failure.	**X**			**X**	Research which electrolyte solutions are compatible with this type of electrode.
Nickel-plated steel electrodes could deteriorate due to chemical reaction with electrolyte solution leading to system failure.	**X**			**X**	Research which electrolyte solutions are compatible with this type of electrode.
Platinum electrodes could deteriorate due to chemical reaction with electrolyte solution leading to system failure.	**X**			**X**	Research which electrolyte solutions are compatible with this type of electrode.
Stainless steel electrodes could deteriorate due to chemical reaction with electrolyte solution leading to system failure.	**X**			**X**	Research which electrolyte solutions are compatible with this type of electrode.

Copper electrodes could deteriorate due to chemical reaction with electrolyte solution leading to system failure.	**x**			**x**	Research which electrolyte solutions are compatible with this type of electrode.
Electrodes could arc inside the system-causing ignition to hydrogen inside container.	**x**	**x**	**x**	**x**	Be sure electrode divider is intact with no gaps that might allow an arc to pass from one electrode to another. Always remove power source when replacing electrodes.

Table 28 - Continuation of Possible Hazards Associated with Experiment

	Damage				
Hazard Description **Source – Mechanism – Target** **Analysis**	**Physical**	**Fire / Explosion**	**Injury**	**Failure**	**Recommendations**
Filter could fail allowing contaminates in to the system which might lead to an unplanned chemical reaction resulting in failure of system or reduction in system efficiency.				**X**	Be sure to change filter at regular intervals to minimize the risk of contaminates entering the system.
Spill during disposal of filters, and electrolytes that come in contact with user could lead to burns.			**X**		Follow manufacture recommendations on proper disposal and Personal Protective Equipment required.
NaCl could produce chlorine gas in an adverse chemical reaction that could lead to inhalation hazards.			**X**		If actually using NaCl and this probable risk need to get gas meters to help identify an IDLH atmosphere.
Electrical input could exceed the required 10 Amps during normal operation resulting	**X**	**X**	**X**	**X**	Use of a power regulator to limit the electricity that enters the system to the desired levels.

in excess heat in the system and an increased shock hazard.					
Electrical input could exceed the required 5 Volts during normal operation resulting in excess heat in the system and an increased shock hazard.	**X**	**X**	**X**	**X**	Use of a power regulator to limit the electricity that enters the system to the desired levels.
Temperature rises unexpectedly do to system malfunction resulting in boil over and excess pressure buildup and spontaneous ignition of flammable gas.	**X**	**X**	**X**	**X**	The use of a temperature regulation device and pressure relief device should be used to keep system with in safe operating parameters.

Table 29 - Continuation of Possible Hazards Associated with Experiment

	Damage				
Hazard Description **Source – Mechanism – Target** **Analysis**	**Physical**	**Fire / Explosion**	**Injury**	**Failure**	**Recommendations**
Improper disposal of used products could lead to burns, fires, and environmental issues.		X	X		Consider the need for trained personnel to dispose of used products.
Excessive hydrogen gas storage ignited by an unexpected ignition source.	X	X	X	X	Keep storage of gas in a separate building away from all possible ignition sources in grounded containers.
Excessive oxygen gas storage ignited by an unexpected ignition source.	X	X	X	X	Keep storage of gas in a separate building away from all possible ignition sources in grounded containers.
Improper chemical handling that leads to chemical burns on user.			X		Recommend the proper Personal Protective Equipment and proper handling techniques needed to handle all chemicals used by the system.

Table 30 - Continuation of Possible Hazards Associated with Experiment

	Damage				
Hazard Description **Source – Mechanism – Target** **Analysis**	**Physical**	**Fire / Explosion**	**Injury**	**Failure**	**Recommendations**
Flammable gases ignite from an unexpected ignition source.	**X**	**X**	**X**	**X**	Eliminate all possible ignitions sources from the area of operation.
Flammable gas ignited from static electricity build up in the area.	**X**	**X**	**X**	**X**	The system should be grounded to prevent static electricity.

CODES AND STANDARDS

The following Tables, 33-35, are lists of codes and standards that might apply to the current project. In some instances the code or standard may not apply but be used for information and the development of the project. As the project progresses the list will shorten and become more specific to the project. This list of codes and standards may be added to and reduces as the final project becomes better defined.

Table 31 - Codes

Standard or Code	Comments	Source
Work item: ISO 22734-1 Hydrogen generators using water electrolysis process — Part 1: Industrial and commercial applications	This Standard pertains to commercial units but may have some good information that applies to a unit designed for home use.	http://www.hpath.org/codes-and-standards.asp
Work item: ISO 22734-2 Hydrogen generators using water electrolysis process — Part 2: Residential applications	This Standard pertains to residential units.	http://www.hpath.org/codes-and-standards.asp
Work item ISO 14687-2 Hydrogen Fuel — Product Specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles	Standard applies to the Proton exchange membrane for use in vehicles but may have valued info that applies to residential units.	http://www.hpath.org/codes-and-standards.asp
NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals	Not applicable if stored chemicals is less than 1 gallon or 4 litters.	http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=45
NFPA 53: Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched	May be applicable because there is the potential for oxygen-enriched atmospheres with this process.	http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=53

Atmospheres		
NFPA 55: Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks	If system goes to production will have to follow do to the storage of Hydrogen and Oxygen.	http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=55
NFPA 68: Standard on Explosion Protection by Deflagration Venting	Might apply to the area in which the system is stored.	http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=68
NFPA 69: Standard on Explosion Prevention Systems	Might apply to the area in which the system is stored.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp

Table 32 - Continuation of Codes

Standard or Code	Comments	Source
NFPA 70: National Electrical Code®	Since electricity is needed for the process might apply.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
NFPA 77:Recommended Practice on Static Electricity	Would apply because static electricity is an ignition source.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
NFPA 91: Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids	Might apply due to the gases produced in process.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
NFPA 110: Standard for Emergency and Standby Power Systems	Depends on the intended use of system.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
NFPA 306: Standard for the Control of Gas Hazards on Vessels	Might need to be followed if used on a boat.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
NFPA 329: Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases	Might apply due to the gases produced in process.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp
NFPA 853: Standard for the Installation of Stationary Fuel Cell Power Systems	Might apply because this is a type of fuel cell.	http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp

1910.103 - Hydrogen. OSHA	Applies to the distribution of hydrogen.	http://www.osha.gov/pls/oshaweb/owares.do_search
1910.269 - Electric Power Generation, Transmission, and Distribution. OSHA	Has section pertaining to hydrogen systems.	http://www.osha.gov/pls/oshaweb/owares.do_search
ISO 15330:1999 Fasteners -- Preloading test for the detection of hydrogen embrittlement -- Parallel bearing surface method	This sounded like it might be something to look in to.	http://www.nssn.org/search/IntelSearch.aspx

Table 33 - Continuation of Codes

Standard or Code	Comments	Source
ISO/DIS 16110-2 Hydrogen generators using fuel processing technologies -- Part 2: Procedures to determine efficiency	This would help to determine efficiency.	http://www.nssn.org/search/IntelSearch.aspx
ANSI/CSA America FC 1-2004 Stationary Fuel Cell Power Systems	Might apply	http://www.nssn.org/search/IntelSearch.aspx
BSR/CSA FC 6-200x Hydrogen Generators Using Fuel Processing Technologies (DRAFT STANDARD)	Might apply	http://www.nssn.org/search/IntelSearch.aspx
BSR/CSA HG13-200x Hosing and Fittings for Hydrogen Gas Appliances (DRAFT STANDARD)	Will help with selecting hoses and fitting for the hydrogen side of the system.	http://www.nssn.org/search/IntelSearch.aspx
IEEE Std 463-2006 IEEE Standard for Electrical Safety Practices in Electrolytic Cell Line Working Zones	Could help with electrical components of the cell.	http://www.nssn.org/search/IntelSearch.aspx
SEMI C58-0305 Specifications and Guidelines for	Might have good information in dealing with	http://www.nssn.org/search/IntelSearch.aspx

Hydrogen	hydrogen.	
UL 2264B (Ed. 1) Hydrogen generators using water reaction	Might apply	http://www.nssn.org/search/IntelSearch.aspx
UL 404 (Ed. 7) Standard for Gauges, Indicating Pressure, for Compressed Gas Service	Might have good information on pressure gauges.	http://www.nssn.org/search/IntelSearch.aspx

CONCLUSION

The preceding codes, standards and analysis are all important elements in the project. Some may be highly important and others may become, after further analysis, negligible. Recommendations and more distinctive codes and standards will be developed from this analysis at a further date.

Appendix F: NREL Wind to Hydrogen Project Report

.

Appendix G: Detailed Financial Analysis

Appendix G1: Breakeven Analysis for Best Producing Cell

Appendix G2: Breakeven Analysis for Most Efficient Cell

Appendix G3: Breakeven Analysis for Best Producing System

Appendix G4: Breakeven Analysis for Most Efficient System

Power Solutions

Oklahoma State University
Multi-Disciplinary Senior Design Project
Engineering-Business-Communications

Team Members


Candice Blackwell
Agricultural Communications


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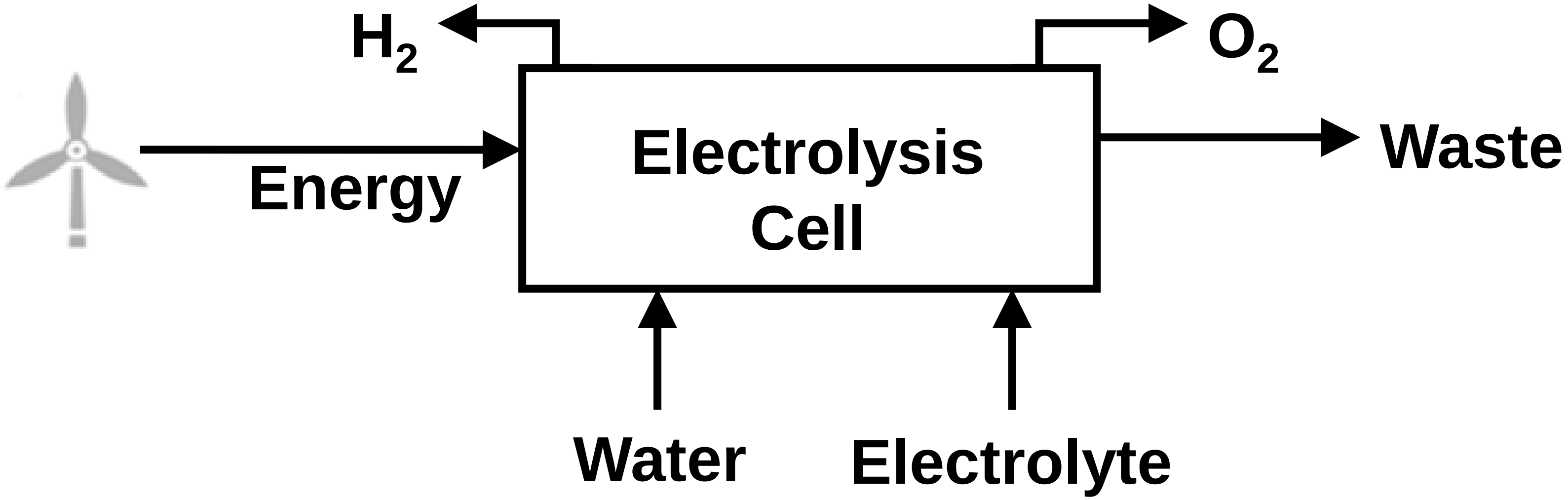
Problem Statement

With ever-changing energy costs, fossil fuels polluting the environment and few viable alternative energy sources available, an affordable wind to hydrogen energy product is needed. Exploring the possible integration of wind to hydrogen through electrolysis will provide homeowners and businesses the ability to produce and store clean energy.

Electrolyzer Components


H_2

O_2

Energy

Electrolysis Cell

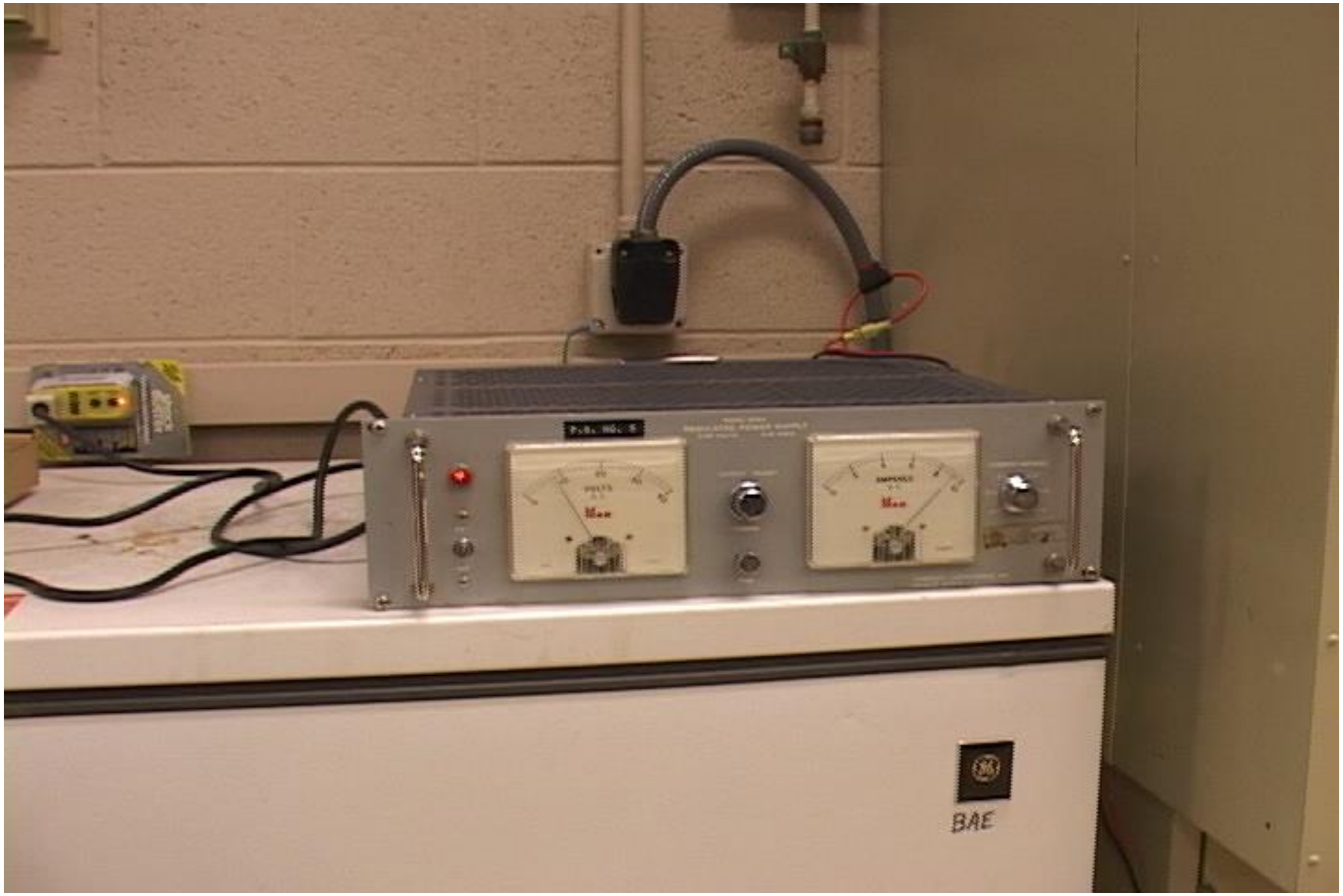
Waste

Water

Electrolyte

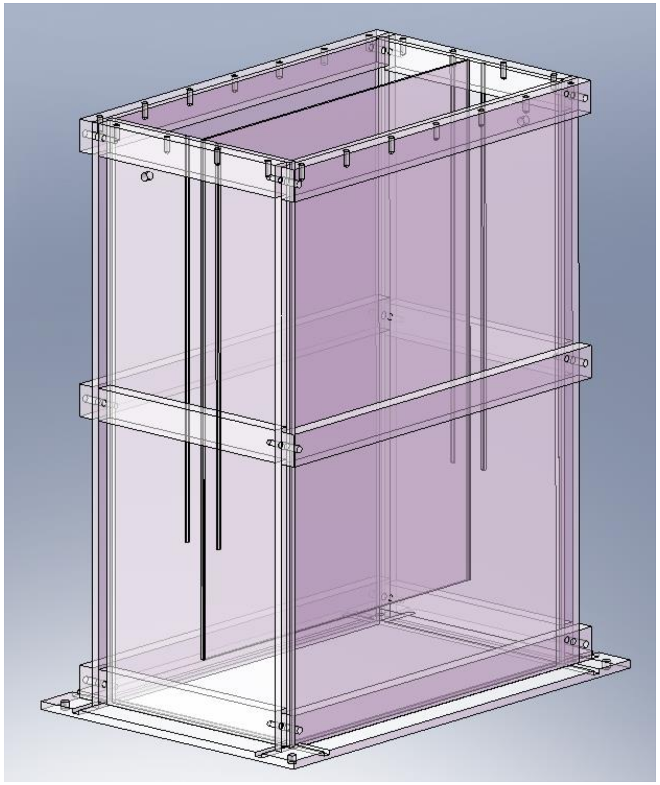
- Water
- Power Source
- Electrolyte
- Electrodes
- Separator
- Plumbing for Hydrogen and Oxygen
- Waste Stream

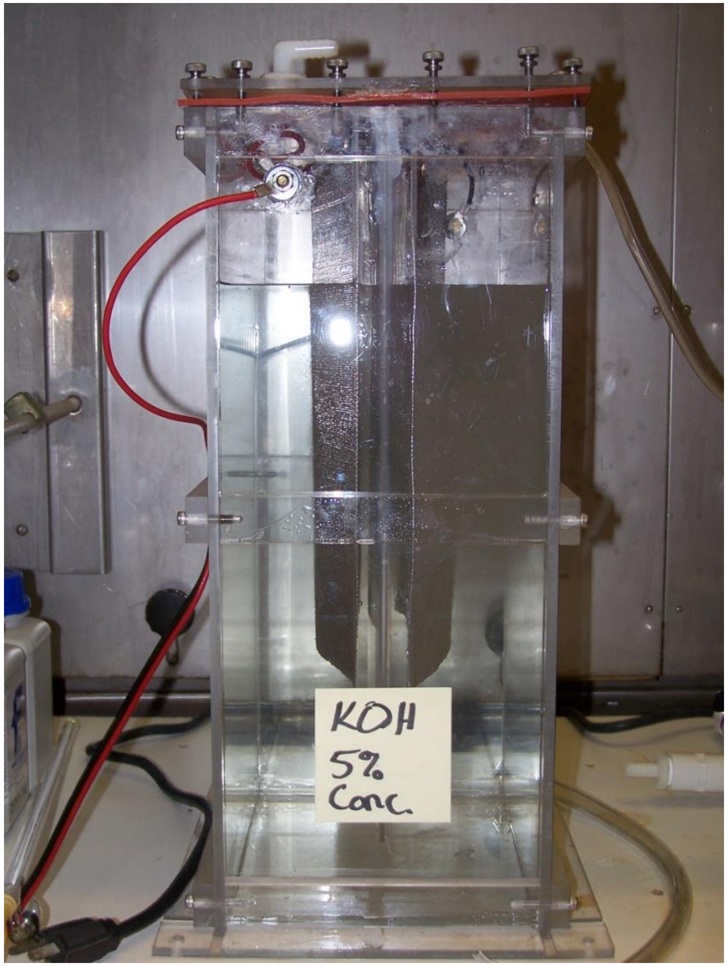
Electrolysis Process



Prototype Cell

- 12 X 7 X 18
- ¼ inch Plexiglas





Overview of Prototype Testing

- Surface Area Test
- Electrode/Electrolyte Test
- SPE Test

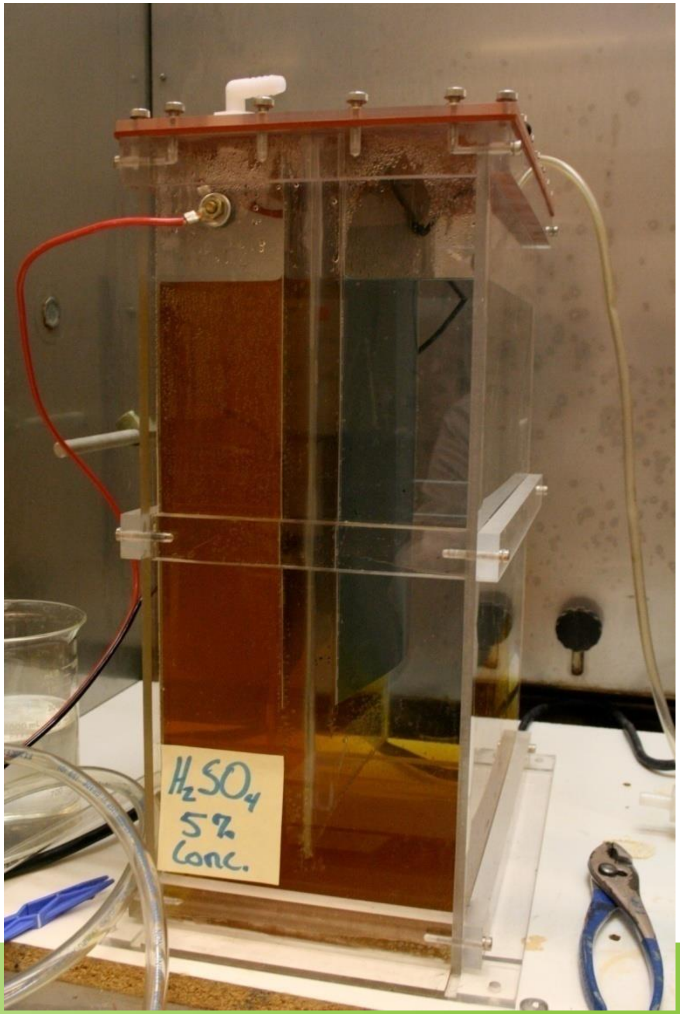
Surface Area Test

- Three Types of 316 Stainless Steel
  - Mesh
  - Woven Wire Cloth
  - Plate
- 5% Sulfuric Acid Electrolyte
- Plexiglas Separator
- Constant 9 Amps
- Used Bubble Flow Meter

Surface Area Test Observations

- Sulfuric acid discolored quickly
  - Only on oxygen side

- Good production rates
- Easily mixed



Surface Area Test Results

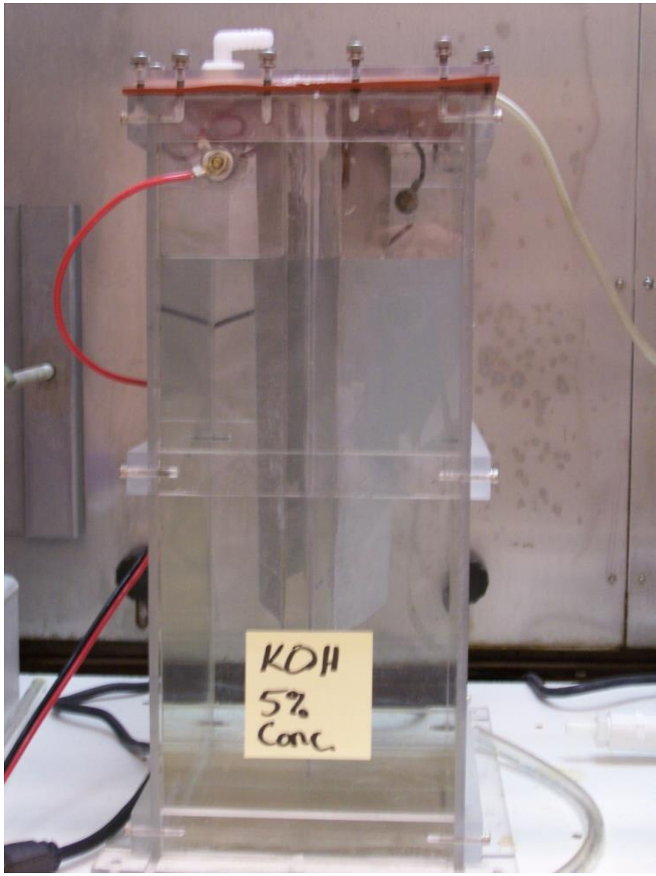
	SS Plate	**SS Mesh**	**SS Weave**
Separator	Plexiglas	Plexiglas	Plexiglas
Concentration	5%	5%	5%
Voltage (V)	7.5	8.5	9
Power (W)	67.5	76.5	81
Production Rate (ml/min)	**73.4**	**40.9**	**40.9**
Efficiency	**22.6 %**	**11.2 %**	**10.5 %**
Surface Area (in$^{2)}$	288	246	660

Electrode and Electrolyte Tests

- Sulfuric Acid (H_2SO_4)
  - Stainless Steel sheet
  - Titanium mesh
  - Aluminum sheet
- Potassium Hydroxide (KOH) / Sodium Hydroxide (NaOH)
  - Nickel plated copper mesh (monel)
  - Aluminum sheet
  - Stainless Steel sheet

Electrode and Electrolyte Test Observations

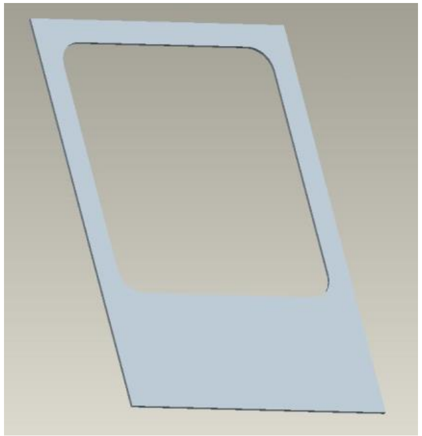
- KOH and NaOH did not discolor
- Hydrogen side became cloudy during production but cleared when disconnected
- KOH performed better than NaOH



Electrode and Electrolyte Test Results

	Monel	SS Plate	Monel	SS Plate	SS Plate
Separator	Plexiglas	Plexiglas	Plexiglas	Plexiglas	Plexiglas
Concentration	5% KOH	5% KOH	5% NaOH	5% NaOH	5% H_2SO_4
Voltage (V)	8.9	8.6	7.9	7.9	7.5
Volume (L)	20	20	19	19	20
Power (W)	80.1	77.4	71.1	71.1	67.5
Production Rate (ml/min)	**35.5**	**101.2**	**34.13**	**24**	**73.4**
Efficiency	**9.2 %**	**27.2 %**	**10 %**	**7 %**	**22.6 %**

Solid Polymer Electrolyte Test

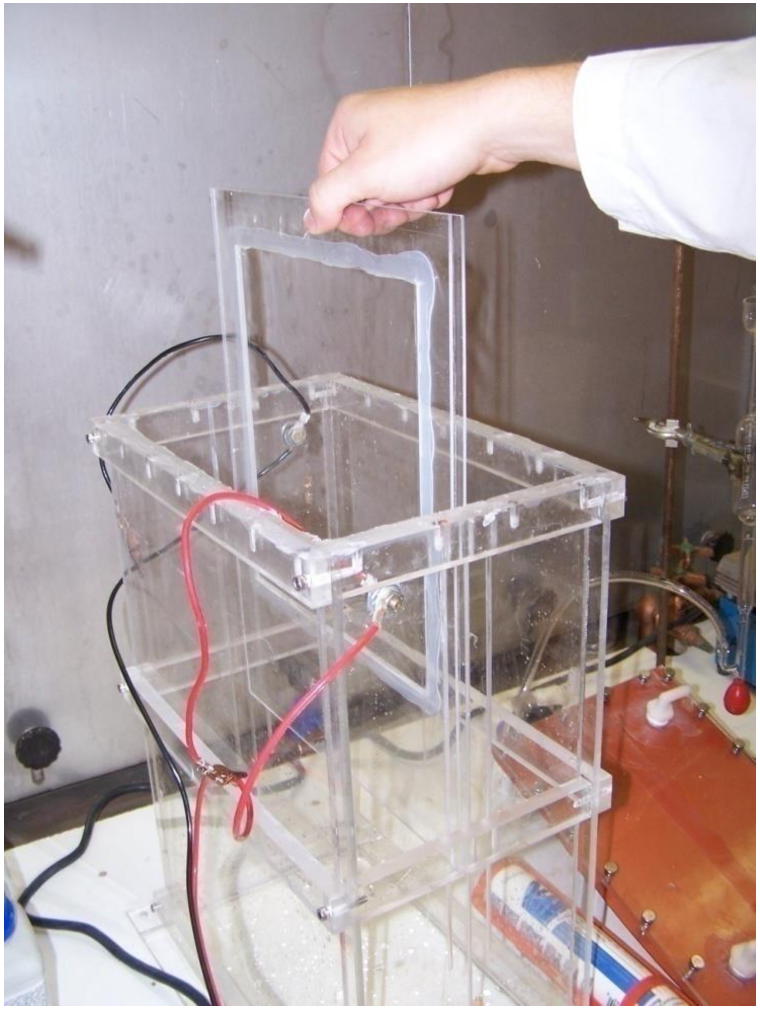


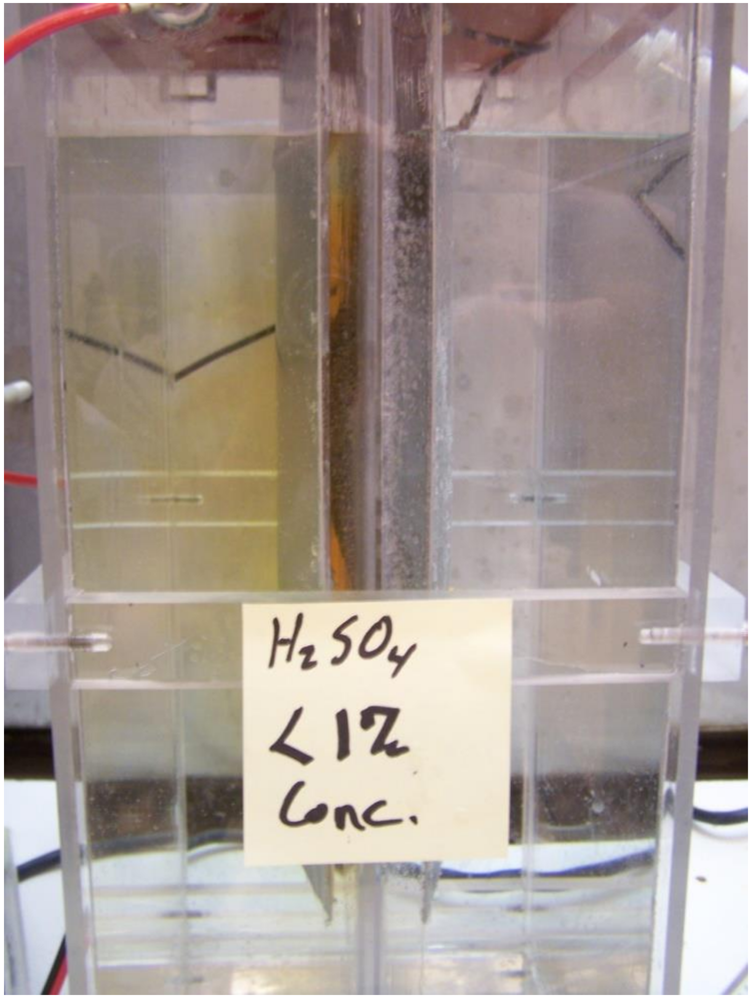
- Combines two functions
  - – Gas separation
  - – Electrolyte
- Not supposed to require any liquid electrolyte
- Several unknowns

Solid Polymer Electrolyte Test Observations

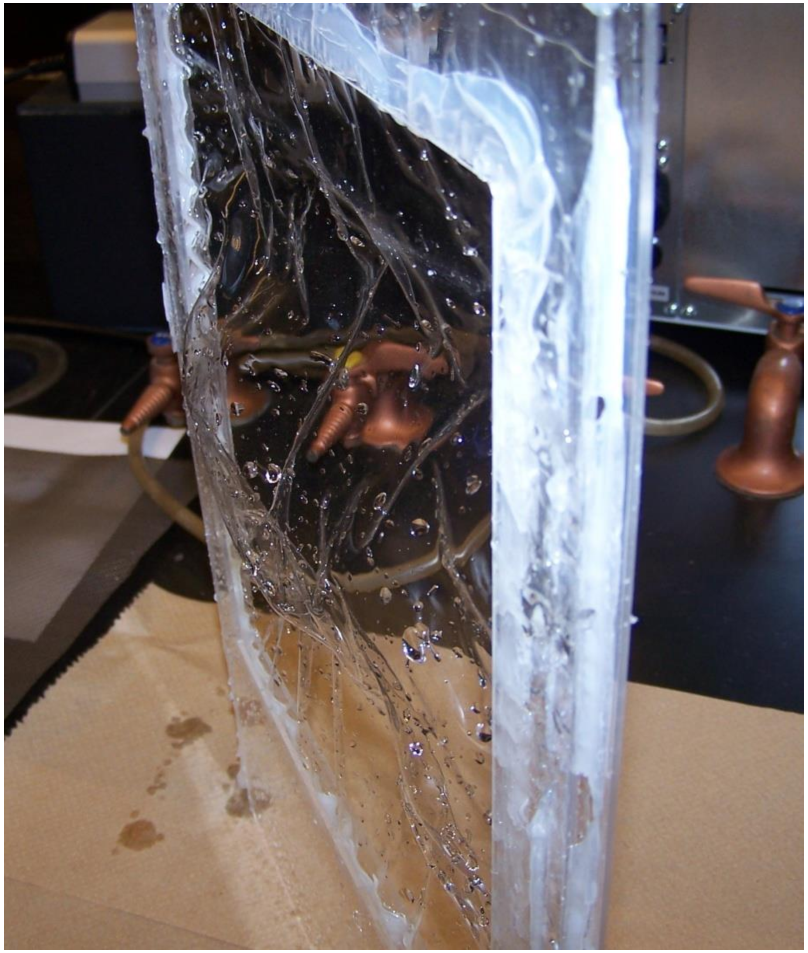
- SPE sheet became distorted within the cell
- Did not conduct current with distilled water
  - – Added a .5% and 1% solution of H_2SO
  - – Good production and efficiency with liquid electrolyte
- Needs more research to be used commercially

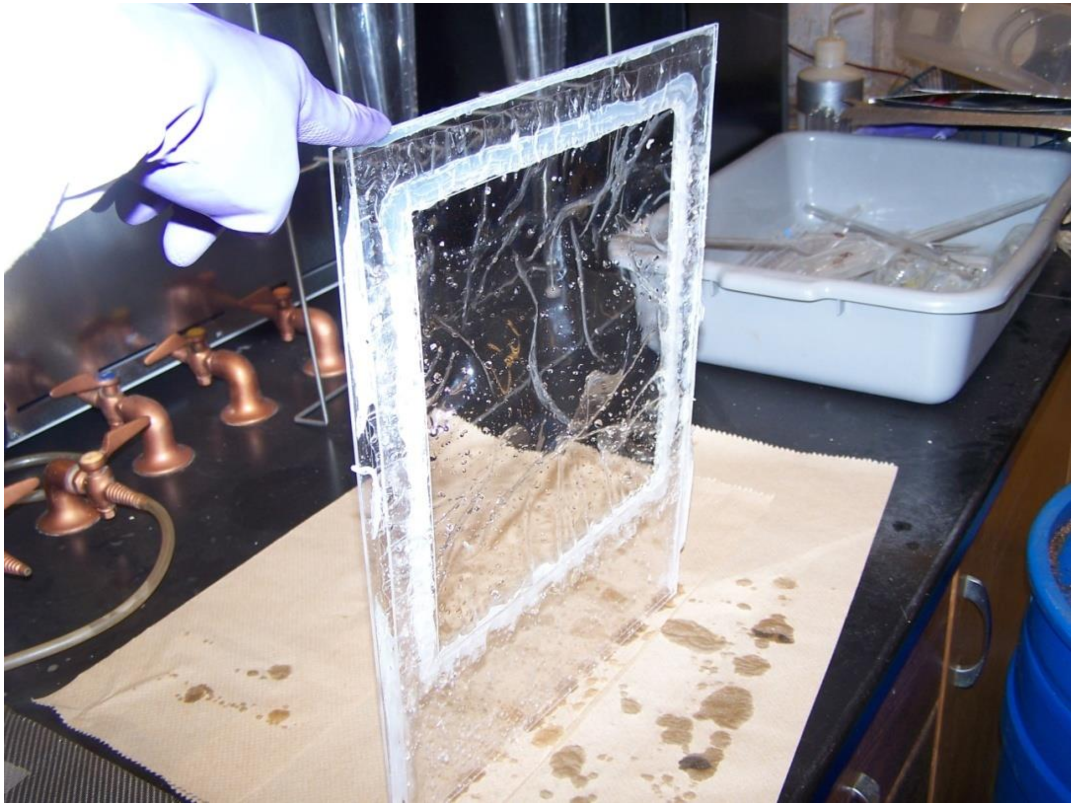
Observations





Observations





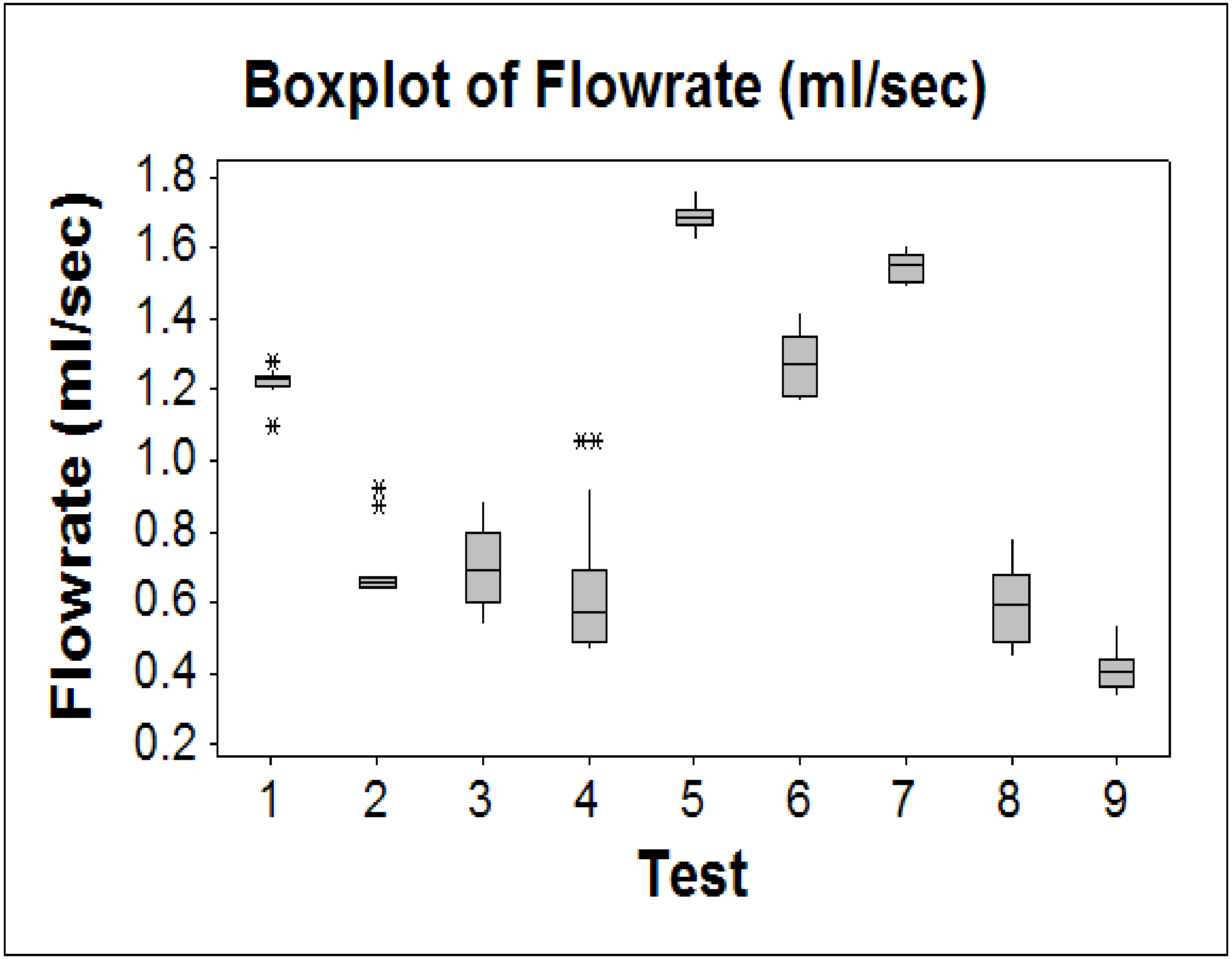
Solid Polymer Electrolyte Test Results

	SS Plate	**SS Plate**
Separator	Nafion	Nafion
Concentration	1%	0.5%
Voltage (V)	7	10.5
Power (W)	63	94.5
Production Rate (ml/min)	**92.9**	**76.4**
Efficiency	**30.3%**	**16.8 %**

Best Producer Comparison

	SS Plate	**SS Plate**	**SS Plate**
Separator	Plexiglas	Nafion	Nafion
Concentration	5% KOH	1% H_2SO_4	0.5% H_2SO_4
Voltage (V)	8.6	7	10.5
Volume (L)	20	20	20
Power (W)	77.4	63	94.5
Production Rate (ml/min)	**101.2**	**92.9**	**76.4**
Efficiency	**27.2 %**	**30.3 %**	**16.8 %**

Statistical Analysis



Test #	Test
1	SS Plate-5% H2SO4
2	SS Weave-5%H2SO4
3	SS Mesh-5% H2SO4
4	Monel-5% KOH
5	SS Plate-5% KOH
6	Nafion-0.5% H2SO4
7	Nafion-1% H2SO4
8	Monel-5% NaOH
9	SS Plate-5% NaOH

Current Density, Specific Cunductance & Scalability

- Optimal current density is ~1.29-3.87 A/in^2
  - – Highest producer density in testing was ~.04 A/in^2
- Conductance depends on electrolyte concentration
- Cell size can be based on supplied current and the desired current density

Conclusions & Recommendations

- Experiments show that S.S. Plate and KOH electrolyte had highest production
- SPE worked well with electrolyte, but has unknowns
  - Longevity, function, distortion
- Many variables affect efficiency
  - Current Density, Conductance, Surface Area
- Changing variables alter efficiency

Economic Analysis

Electrolysis Cell Estimate	
Component	*Cost*
Container	$90
Electrode Material	$72
Electrolyte	$48
Water Deionizer	$100
Misc. Plumbing	$60
Methylene Chloride/Solvent	$25
Total Component Cost	**$395**
Breakeven Cost	

Electrolysis Cell Estimate	
Component	*Cost*
Container	$90
Electrode Material	$72
Separator (SPE)	$495
Water Deionizer	$100
Misc. Plumbing	$60
Electrolyte	$22
Methylene Chloride/Solvent	$25
Total Component Cost	**$864**
Breakeven Cost	

Economic Analysis

Total System Cost Estimate	
Component	*Cost*
Wind Generator	$650
Smart Switch	$250
Electrolyzer	$395
Compressor	$5,000
Storage Device	$500
Generator/Fuel cell	$1,500
Total Cost	**$8,295**
Breakeven Cost	

Total System Cost Estimate	
Component	*Cost*
Wind Generator	$650
Smart Switch	$250
Electrolyzer	$864
Compressor	$5,000
Storage Device	$500
Generator/Fuel Cell	$1,500
Total Cost	**$8,905**
Breakeven Cost	

Potential Customers

- Single Family Homes
- Remote Sites
  - Communication towers
  - Natural gas pumping station
- Small Businesses
- Farms
  - Shops
  - Wells

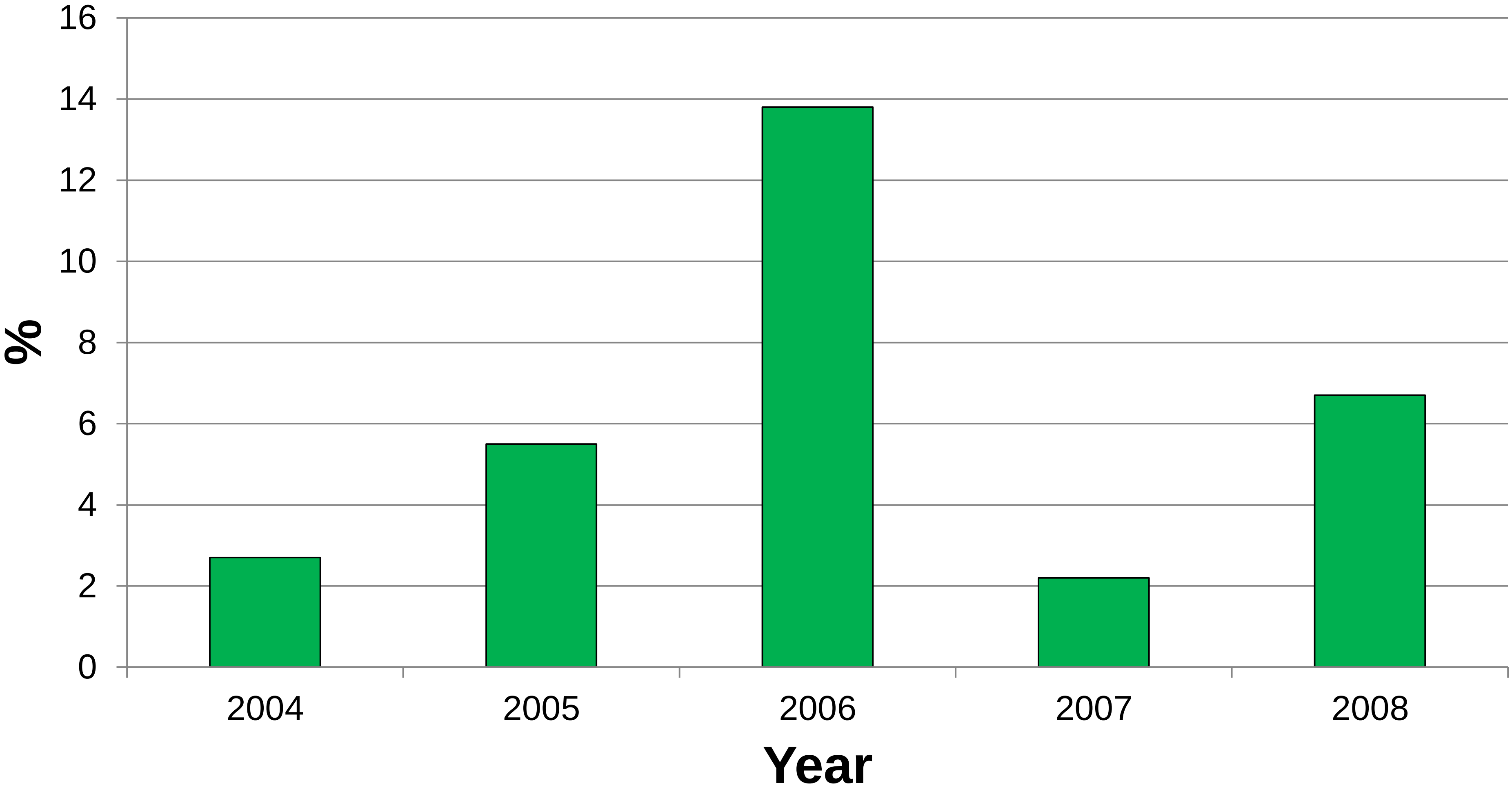
Green Budget

$6,000,000,000

Source: Title 24 of the American Recovery and Reinvestment Act (ARRA) of 2009

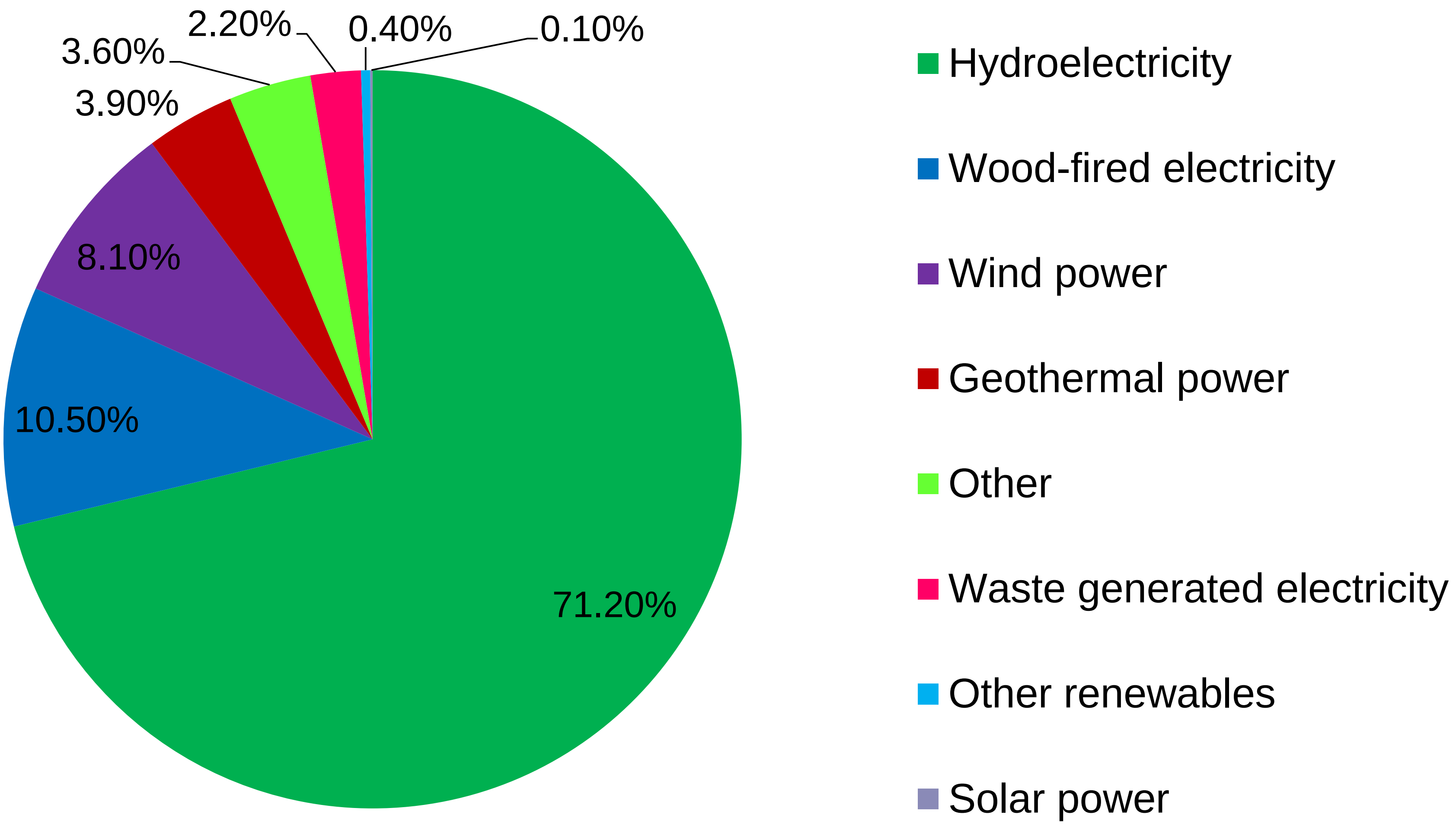
- Renewable Energy Grants
- Encourage Innovative Technologies

Renewable Power Generation in the U.S.: Industry Revenue Growth Rate



22111c - Hydroelectric & Renewable Power Generation in the US - Industry Report
Source: http://www.ibisworld.com/industry/default.aspx?indid=1912

Hydroelectric & Renewable Power Generation in the U.S.: Products and Services Segmentation



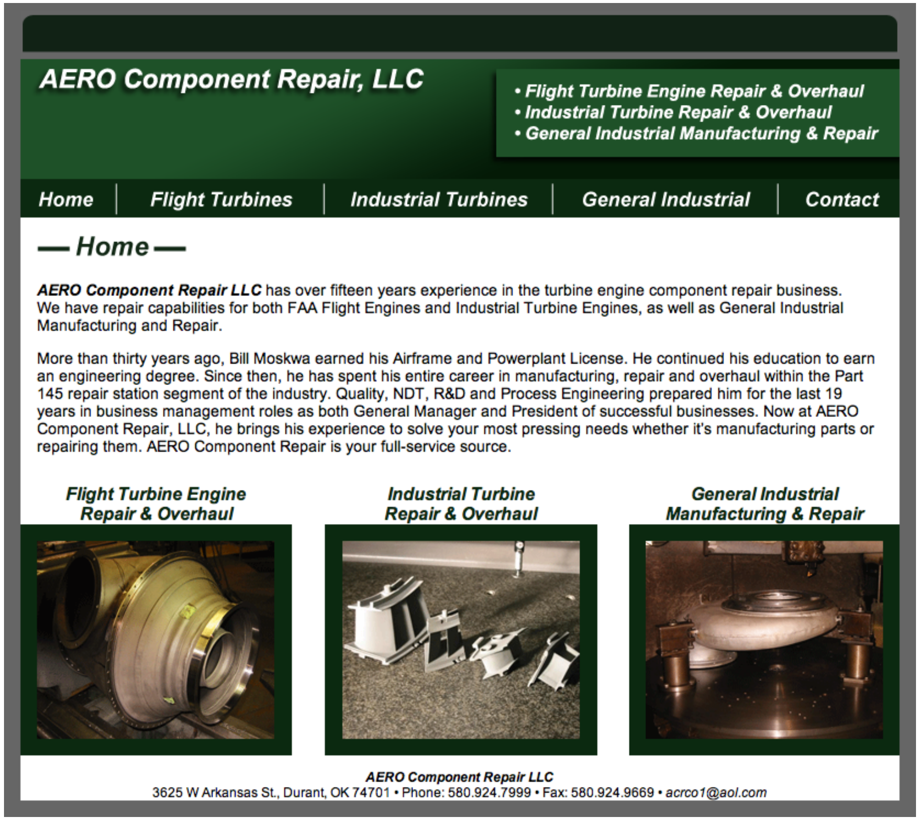
22111c - Hydroelectric & Renewable Power Generation in the US - Industry Report
Source: http://www.ibisworld.com/industry/default.aspx?indid=1912

Consumer Tax Credits

- Tax credit at 30% of component cost
  - Residential wind system
  - Residential fuel cell

Marketing Plan for AERO Component Repair, LLC

- Web site
- Logo design
- Brochures
- Business cards
- Letterhead



AERO Component Repair, LLC

- Flight Turbine Engine Repair & Overhaul
- Industrial Turbine Repair & Overhaul
- General Industrial Manufacturing & Repair

— Home —

AERO Component Repair LLC has over fifteen years experience in the turbine engine component repair business. We have repair capabilities for both FAA Flight Engines and Industrial Turbine Engines, as well as General Industrial Manufacturing and Repair.

More than thirty years ago, Bill Moskwa earned his Airframe and Powerplant License. He continued his education to earn an engineering degree. Since then, he has spent his entire career in manufacturing, repair and overhaul within the Part 145 repair station segment of the industry. Quality, NDT, R&D and Process Engineering prepared him for the last 19 years in business management roles as both General Manager and President of successful businesses. Now at AERO Component Repair, LLC, he brings his experience to solve your most pressing needs whether it's manufacturing parts or repairing them. AERO Component Repair is your full-service source.

Flight Turbine Engine Repair & Overhaul

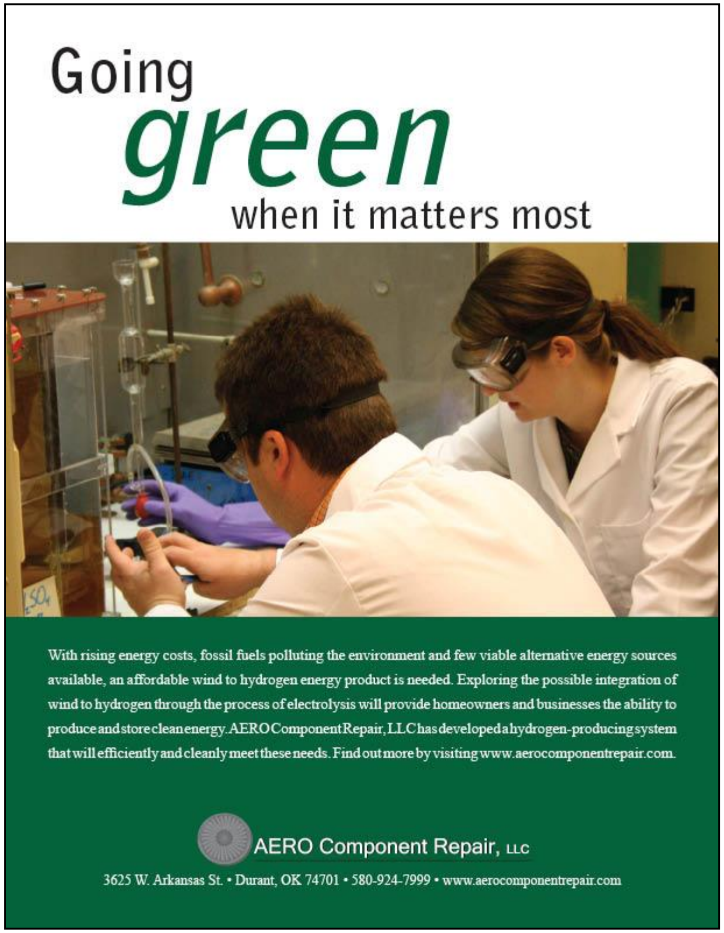
Industrial Turbine Repair & Overhaul

General Industrial Manufacturing & Repair

AERO Component Repair LLC
3625 W Arkansas St., Durant, OK 74701 • Phone: 580.924.7999 • Fax: 580.924.9669 • *acrco1@aol.com*

Marketing the Electrolyzer

- Press release
- Advertisements
- Technical inserts



With rising energy costs, fossil fuels polluting the environment and few viable alternative energy sources available, an affordable wind to hydrogen energy product is needed. Exploring the possible integration of wind to hydrogen through the process of electrolysis will provide homeowners and businesses the ability to produce and store clean energy. AERO Component Repair, LLC has developed a hydrogen-producing system that will efficiently and cleanly meet these needs. Find out more by visiting www.aerocomponentrepair.com.

AERO Component Repair, LLC

3625 W. Arkansas St. • Durant, OK 74701 • 580-924-7999 • www.aerocomponentrepair.com

Conclusion

- Experiments show that S.S. Plate and KOH electrolyte had highest production
- SPE worked well with electrolyte, but has unknowns
- SS Plate/KOH electrolysis cell was the most cost effective alternative
- With renewed emphasis and incentives, this technology will continue to be viable

Acknowledgments

Mr. Bill Moskwa
- Sponsor

Kay Watson
Shea Pilgreen
Dr. Glenn Brown
Dr. Scott Frazier
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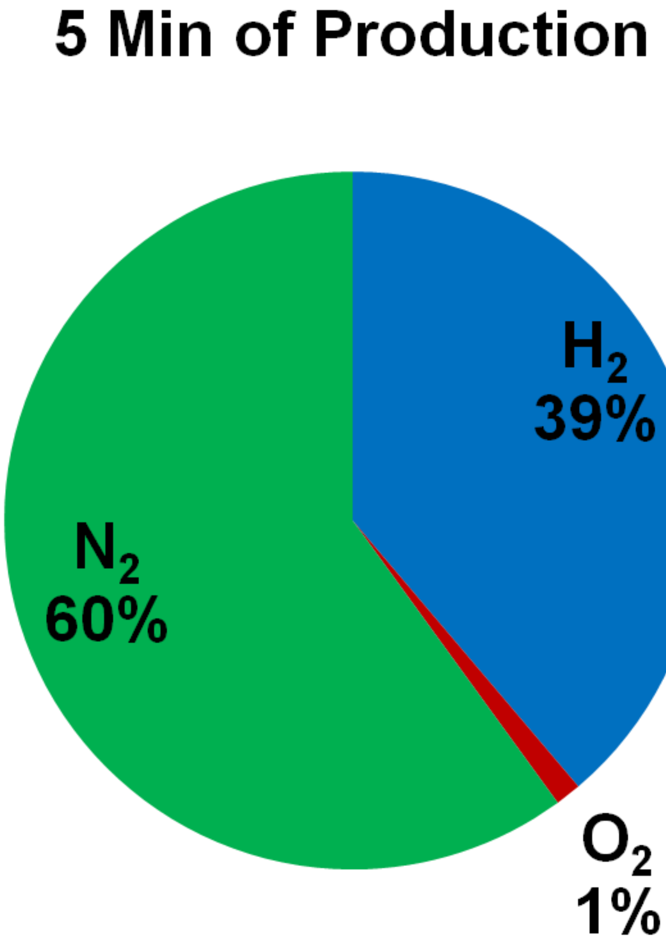
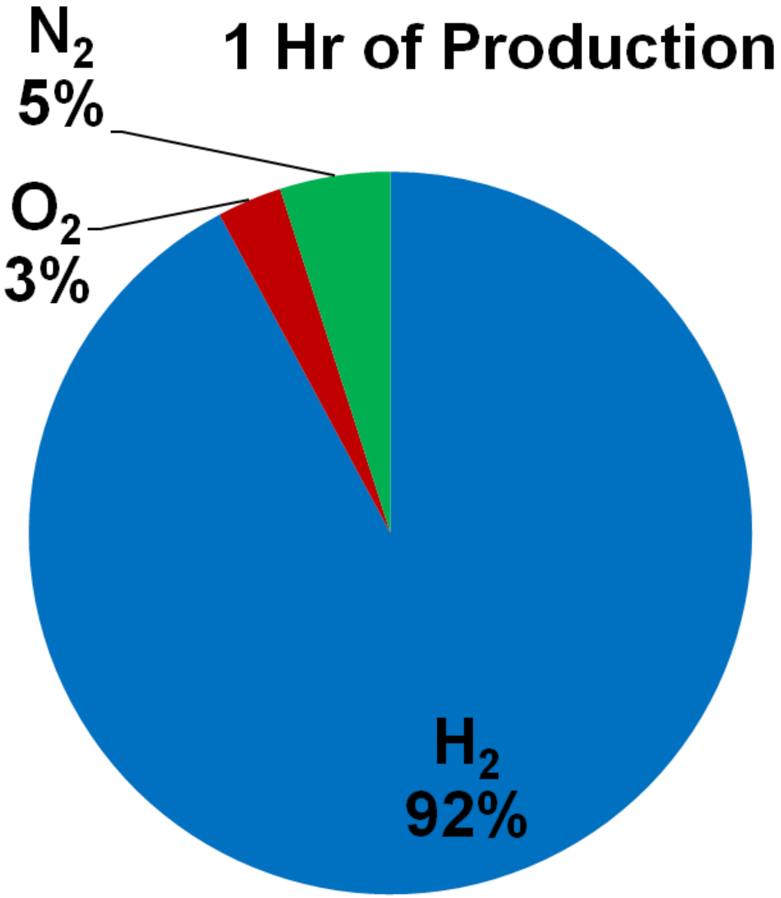
Dr. Dan Storm

Mr. Wayne Kiner
Mr. Robert Harrington
Mr. Mike Veldman
Dr. Paul Weckler
Dr. Rodney Holcomb
Dr. Dan Tilley
Dr. Cindy Blackwell
Dr. Shelly Sitton
Dr. Ron Delahoussaye

Gas Analysis





Household Application

Average Household Usage 2005 (West South Central Region)				
	Refrig	*Refrigerators & 1/2 Other	Total	
Modified Night Usage	0.8	1.9	**2.7**	kW-h
Turbine	1200	W		
Max Load @ 8 hrs	9.6	kWh		
		Turbine - Usage	6.9	kW-h
		Instanteous	0.9	kW
			859.6	W
		At 77 W	11	Cells
		Production Rate	0.0005	kg/h
		Total Production per cell	0.0043	kg/h
		Overall Total Production	0.0480	kg
		Energy Produced From Cells	**1.9**	**kWh**
			6393.6	**BTU**

Power Solutions

Oklahoma State University
Multi-Disciplinary Senior Design Project
Engineering-Business-Communications

Team Members

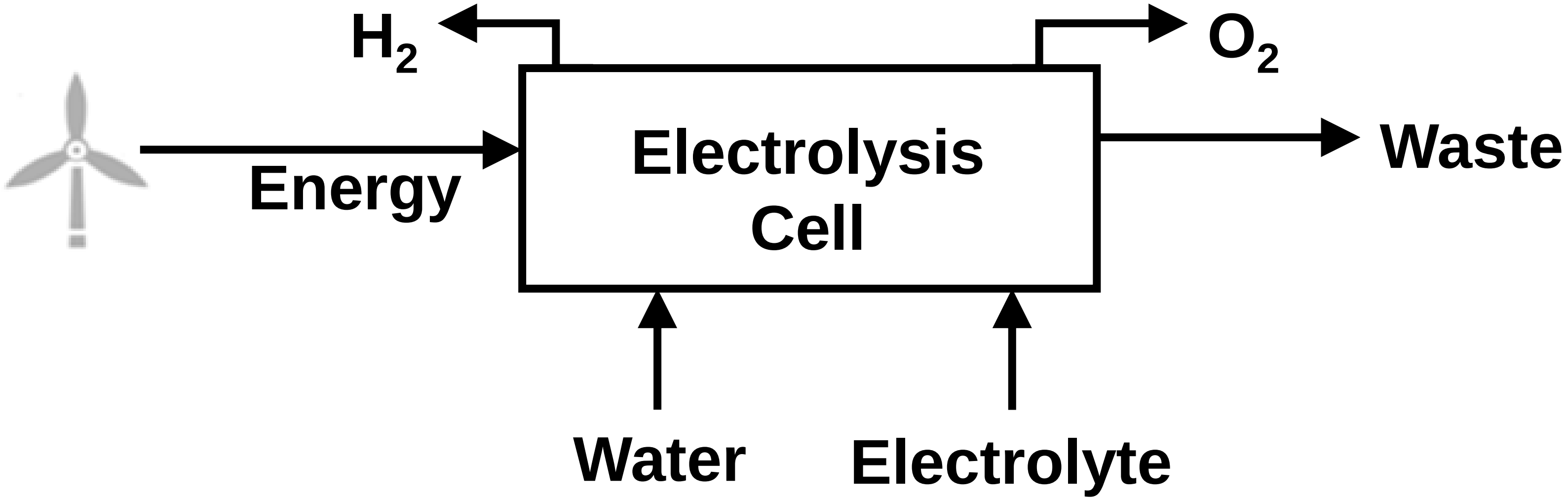
Client

- Mr. Bill Moskwa
- AERO Component Repair, LLC
- Durant, OK

Problem Statement

With ever-changing energy costs, fossil fuels polluting the environment and few viable alternative energy sources available, an affordable wind to hydrogen energy product is needed. Exploring the possible integration of wind to hydrogen through electrolysis will provide homeowners and businesses the ability to produce and store clean energy.

Electrolyzer Components



- Water
- Power Source
- Electrolyte
- Electrodes
- Separator
- Plumbing for Hydrogen and Oxygen
- Waste Stream

Prototype Testing

- Surface Area Test
  - Plate
  - Mesh
  - Dutch Weave Wire Cloth
- Electrode and Electrolyte Test
- Solid Polymer Electrolyte (SPE) Test

Cost Effective and Efficient

- Final recommendation will be based on
  - Benefit/Cost Analysis of each test
  - Efficiency
  - Amount and purity of hydrogen produced

Communications Plan

- Picture of website

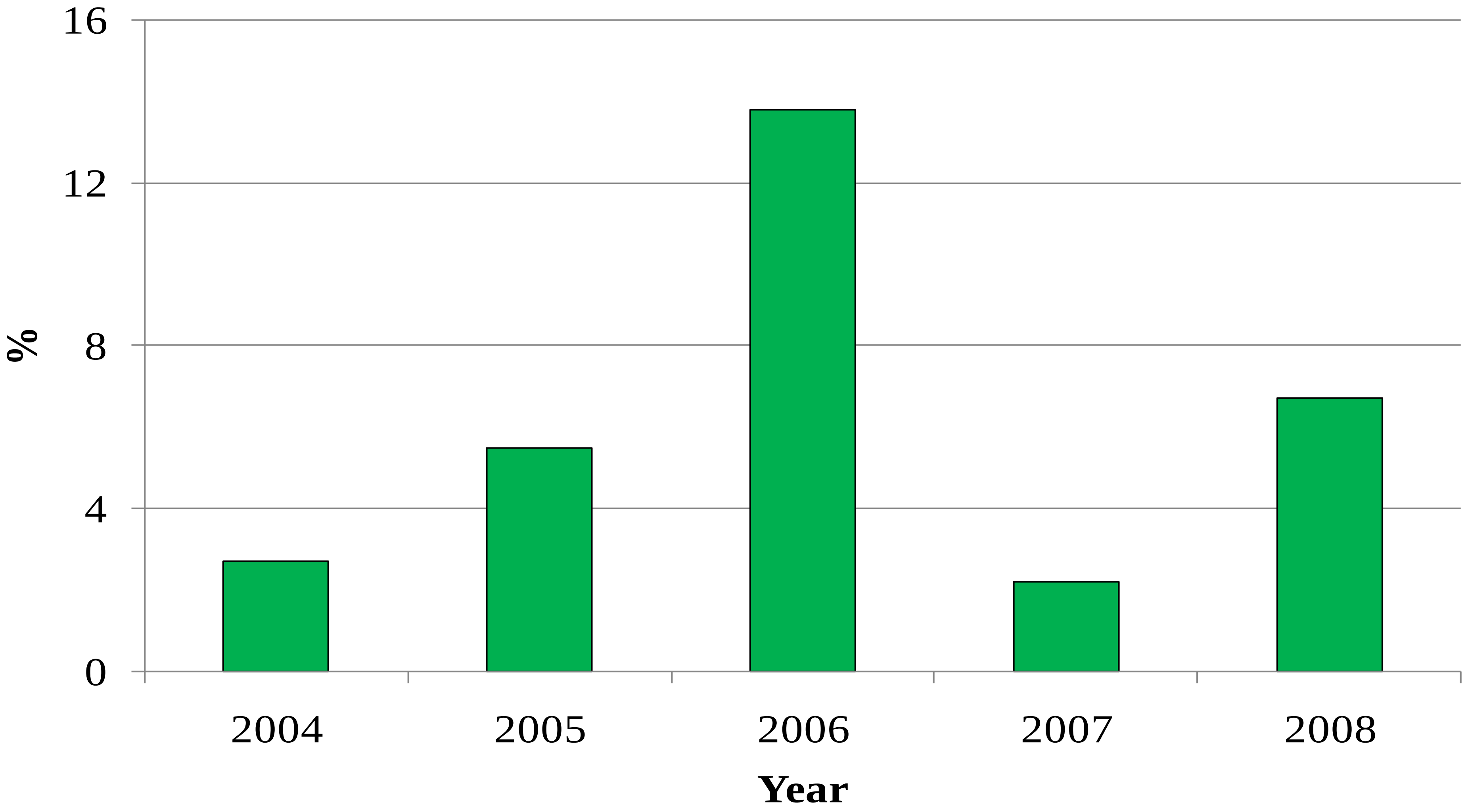
Communications Plan

- Blog

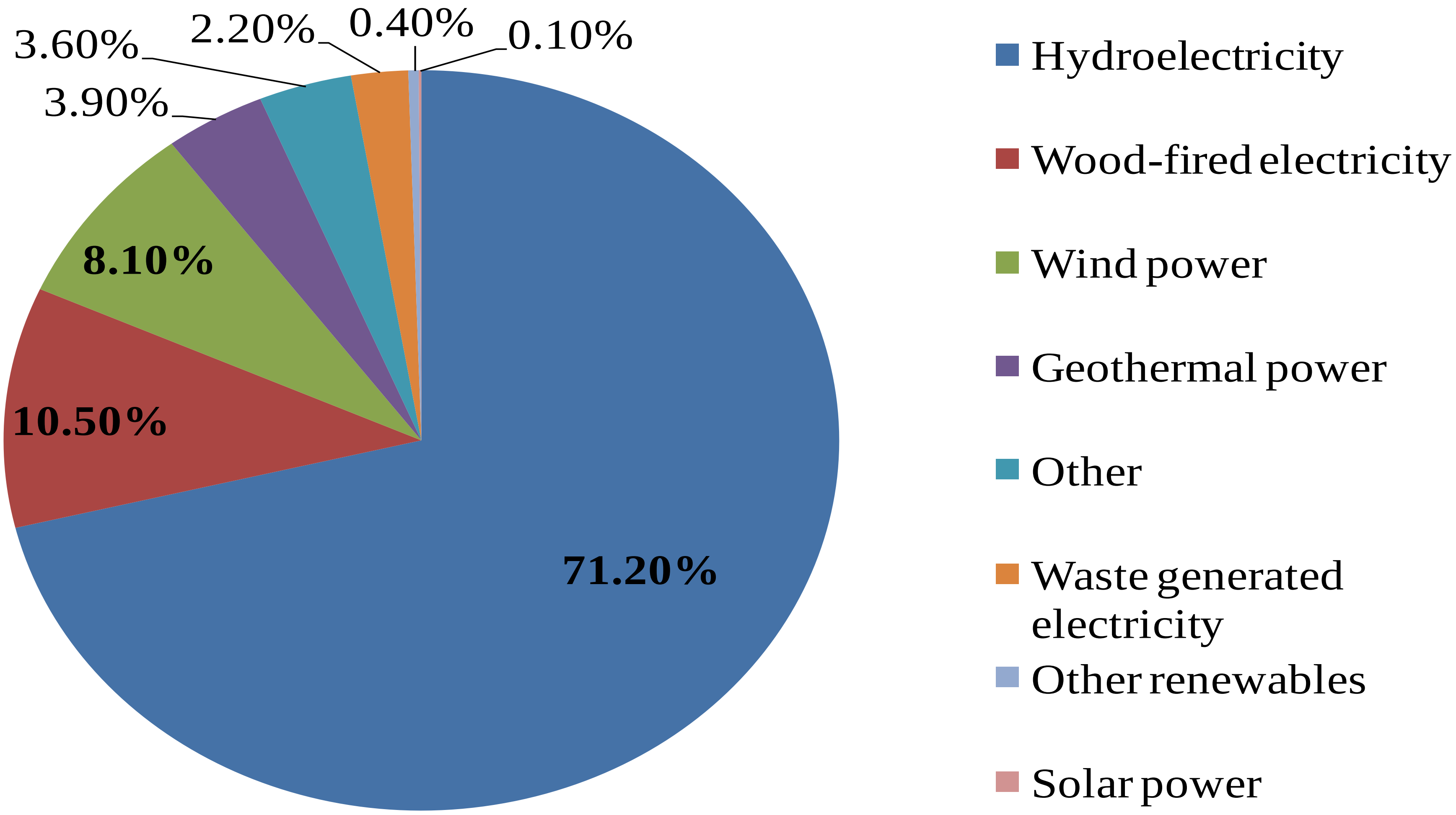
Marketing Plan for AERO Component Repair, LLC

- Web site
- Logo design
- Brochures
- Business cards
- Letterhead

Renewable Power Generation in the US: Industry Revenue Growth Rate



Renewable Power Generation in the US: Products and Services Segmentation



Economic Analysis

Total System Cost Estimate	
Component	*Cost*
Wind Generator	$475.00
Smart Switch	$250.00
Electrolyzer	$155.00
Compressor	$5,000.00
Storage Device	$500.00
Generator/Fuel cell	$1,500.00
Total Cost	**$7,880.00**

Most Expensive Prototype Electrolyzer	
Component	*Cost*
Container	$75.00
Electrode Material	$236.00
Separator (SPE)	$400.00
Misc. Plumbing	$25.00
Total Cost	**$736.00**

Potential Customers

- Business-to-consumer
  - Early adopters
  - Specific consumer segments unknown
  - Market demand requires further research

Potential Customers

- Business-to-business
  - – Hydrogen engines
    - Hydrogen Engine Center, Inc.
  - – Wind Turbines
    - Small turbines for residential, farm and commercial/industrial use
  - – Communication facilities
    - Cell phone towers

Green Budget

$6,000,000,000

- Green Jobs
- New Green Technology

Task List

Gantt Chart

Conclusion

- A Series of tests should yield an optimum combination of materials.
- Market research has been conducted and marketing campaigns are in the works.
- Industry analysis supports the electrolyzer market