Preliminary Design:

Renewable Energies Based Hydrogen Production

Presented To:

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Preliminary Design: Renewable Energy Based Hydrogen Production

Summary of the Renewable Energy Based Hydrogen Production Project

The purpose of this project is to design a hydrogen-gas production facility that uses the available water and renewable energy resources located behind the Northern Arizona University (NAU) College of Engineering & Technology (CET) building. The following are the requirements stated in proposal to Dr. Acker.

- Use of existing renewable energy as the energy supply to produce hydrogen gas
- Hydrogen must be stored in a manner available to fuel a hydrogen racecar
- Use available rainwater (utilizing available rooftops) supplemented, if necessary, with CET tap water

Deliverables for the Renewable Energy Based Hydrogen Production Project

H2 Generation proposes to provide two deliverables in the solution to the renewable energy based hydrogen production problem. The first deliverable will be the specification of the design layout for the production facility. The second deliverable will be to construct a proof of concept demonstration model.

Design Philosophy and Schedule of Upcoming Important Dates

The design philosophy incorporated by H2 Generation is to break down the large-scale design of a hydrogen generation station into manageable components for individual analysis. H2 Generation team has created and updated a schedule entailing deliverable dates and milestones aiming for the completion of the project (See Appendix 1). Listed here is a summary of upcoming dates.

- Receive edited Preliminary Full Scale Design Deliverable 2/13/03
- Design Review 3/11/03-3/13/03.
- Capstone Design Conference 4/25/03.

Feasibility of the Renewable Energy Based Hydrogen Production Project

H2 Generation has found the design of a renewable energy based hydrogen production facility at the NAU CET "Solar Shack" to be feasible. The table below summarizes the renewable energy and water collection calculations (See Table 1 below). For comprehensive calculations, see Appendix 2 and Appendix 3. The next step in determining feasibility for the project is to determine the mileage a hydrogen-powered vehicle could travel with the given amount of hydrogen producible. The table below summarizes the predicted mileage a vehicle could travel based on energy colleted and water collected.

Source	Amount Collected	H2 Produced Estimat	Mileage Traveled
Rainwater	8177.55 gallons/year	40,242,012 liters H_2*	35851 miles*
Electricity	14761 kWh/year	1,968,133 liters H_2*	1753 miles*

Table 1: Energy and Rainwater Limitations. *For calculations see Appendix 5.

The table above shows that electricity is the limiting factor. The rough mileage that a vehicle may travel on the possible hydrogen produced is 1753 miles. In order to produce more hydrogen electricity must be supplemented to equal the amount producible by water collected or a more efficient energy usage must be accomplished.

Preliminary Design Layout of Hydrogen Production Plant

The preliminary design for the hydrogen production plant includes the specification of the individual components illustrated in the Layout of Major System Components (See Appendix X). The specified components are listed in the table below (See Table 2 below).

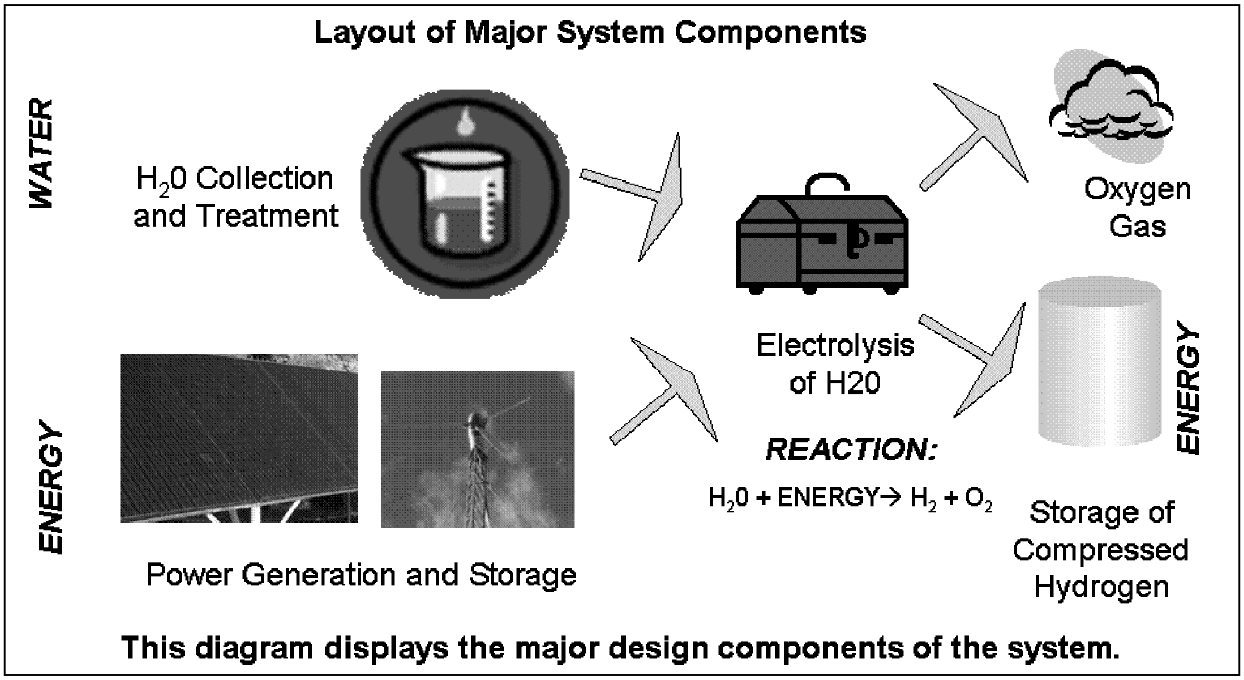

Figure 1: System Component Layout

Summary of PV Cell Calculations

The preliminary photovoltaic cell calculations consist of analyzing NAU's existing PV cell systems located at NAU's Solar Shack in Flagstaff, AZ. NAU's existing PV cell systems are made up of solar shingles lining the roof of the Solar Shack and a 45 degree angle (south facing) array. Data was collect including: area of the solar shingles lining the roof, angle of the roof's pitch, the area of the 45 degree array, and verification of the 45 degree angle.

The resource of NREL's website, http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/, provided 30 years of daily average insolation data (insolation in terms of kwh/m^2/day) for each month according to a specific location and desired angle of the PV cell array (the Solar Shack's roof was assumed to be flat plate). Combining the collected data with NREL's information, average kwh/day (a day in each month) and kwh/month was found. A "shading factor" was applied to the annual kwh production value. See Appendix 2 for exact values.

Summary of Wind Power Calculations

The preliminary wind power calculations consist of analyzing the 1.5kw Bergey wind turbine located at NAU's Solar Shack in Flagstaff, AZ. Western Regional Climate Center's website, http://www.wrcc.dri.edu/htmlfiles/westwind.final.html, provided monthly average wind speeds. Using Betz's equation (Power = C_p*.5*rho*u^3*A; refer to calculations for variable meaning and value) average joules produced/hour for each month was found. From that, kwh/month could be found, totaling to an annual kwh production value. See Appendix 2 for exact values.

Summary of the Total Power Produced by Wind Turbine and PV Cells

The total power produced by the wind turbine and the PV cells combines the power outcomes from the wind turbine and PV cells. The combination includes monthly PV cell power with shading factor, monthly wind production power, and an annual grand total power. See Appendix 2 for exact values.

Summary of the Preliminary Rooftop Water Collection Analysis

The preliminary rooftop water collection calculations consist of analyzing NAU's existing Solar Shack and rainfall in Flagstaff, AZ. University of Utah's website, http://www.met.utah.edu/jhorel/html/wx/climate/normrain.html, was used to find average monthly rainfall in Flagstaff, AZ. Collected data included the area of the Solar Shack roof. This area was then geometrically manipulated into a flat roof. A flat roof is desired because can represent a cubic rainfall depiction for volume calculation. The volume calculations were found for each month and annually. See Appendix 3 for exact values.

Design of Water Storage and Purification System

At this point using distilled water for the electrolyzer is necessary. Still to be determined is whether the water should be stored in the distilled state, or the initially filtered state. The initial filter will consist of a gravity filter that removes large impurities from the water. Storage of the water will take place in off the shelf drums, illustrated in Figure 4 below (Emergency Preparedness Center 2003), designed to store drinking water. There are two options for distilling the water. The first is to solar-distil the water using a "solar still" such as the "Rainmaker" illustrated in Figure 2 below (Sol Aqua 2003), and the second is to use an electrical distiller in Figure 3 below (Renewed Health Supply 2003). Table 2, below, summarizes the major aspects of each component.

Component Breakdown for Water Storage and Purification System

Figure 2: "The Rainmaker" Solar Water Distiller

Figure 3: Polar Bear Model 26-M Water Distiller

Figure 4: Water Storage Barrels

Component	Production Rate	Power Drawn	Initial Cost
Rainmaker	~1.5 gal/day summer	N/A	$398 dollars each
Model 26-M	8 gal/day	1.2 kW	$615 dollars
55 Gallon Storage Barrel	N/A	N/A	$69.95 each

Table 2: Summary of Water Storage Components

The advantage of using the "Rainmaker is the lack of power draw that will help conserve battery power, but if it is found that we have excess power, the electric distiller will be a good investment due to its higher and predictable production rate. With inexpensive water drums, the water can be stored pre-distilled or distilled.

Hydrogen Generation Analysis:

In the first phase of the project it was decided by the client to use electrolysis as the means for hydrogen production. In further research of hydrogen electrolysis, we found a simple system which includes a solid polymer electrolyte (SPE). The function of the SPE is to eliminate the use of caustic solutions that are typically mixed with water in electrolyzer usage. The function of a caustic solution or the SPE are to add a resistance to water so electrons can move more freely when separating the hydrogen and oxygen of the water molecule. The benefit of not needing to mix external solutions to act as an electrolyte (using the SPE) reduces the cost of producing hydrogen. Another benefit of SPE is the electrolyzer life cycle is increased due to the absence of corrosion on the cathode and anode caused by caustic solutions.

Additional benefits of the SPE include the following:

- Certified Safety: National Fire Protection Agency, and (OSHA-1910.103)
- Hydrogen produced to six sigma purification: 99.9999%
- Allowable output pressure ranging from 0 to 90 psi
- Hydrogen purity detection shutoff system

The SPE electrolyzer is available to produce at many different production rates. To analyze the energy efficiency we compared the energy per unit volume of hydrogen produced to the energy usage of the electrolyzer. The table below shows the production rate of each SPE electrolyzer system compared to electrolyzer power usage (watts).

Electrolyzer	Watts	L / h	h/L	Cost
A9090	480	5.4	0.185185185	$ 4,135.00
AB9100	480	9.6	0.104166667	$ 5,320.00
B9200	600	15	0.066666667	
B9400	600	30	0.033333333	
B9800	600	72	0.013888889	

Table 3: Electrolyzer power usage vs. hydrogen volume output

We used a molecular volume ratio for water in order to quantify the amount of hydrogen produced per unit of water. The molecular weight of water (a combination of two hydrogen atoms and one oxygen atom) was used to find a mass ratio of hydrogen to oxygen. It was found that 11.11% of the weight of water is hydrogen. The monthly energy of hydrogen stored was compared to the monthly energy used to produce it. The table below shows the monthly calculations and the amount of water in liters for each month.

Month	Inches of rainfall	meters of rainfall	volume of water (m^3)	volume of water (gal)	H2Gal At 25% Evaporation	H2 m^3 At 25% Evaporation	m^3*D = Kg	Kg * 11.1% = H2 mass	H2 mass / Dh = V V = m^3	m^3*1000 Liters
	website	inches * 0.0254	roof area * meters of rainfall	m^3 * 264.172						
January	2.040	0.052	3.693	975.568	731.676	2.769	2766.624	307.372	3415.24	3415243.02
February	2.090	0.053	3.783	999.479	749.609	2.837	2834.433	314.905	3498.95	3498949.95
March	2.550	0.065	4.616	1219.460	914.595	3.462	3458.279	384.215	4269.05	4269053.77
April	1.480	0.038	2.679	707.765	530.824	2.009	2007.158	222.995	2477.73	2477725.33
May	0.720	0.018	1.303	344.318	258.239	0.977	976.455	108.484	1205.38	1205379.89
June	0.400	0.010	0.724	191.288	143.466	0.543	542.475	60.269	669.66	669655.49
July	2.780	0.071	5.033	1329.450	997.088	3.774	3770.203	418.870	4654.11	4654105.68
August	2.750	0.070	4.978	1315.104	986.328	3.733	3729.517	414.349	4603.88	4603881.52
September	2.030	0.052	3.675	970.786	728.089	2.756	2753.062	305.865	3398.50	3398501.63
October	1.610	0.041	2.915	769.933	577.450	2.186	2183.463	242.583	2695.36	2695363.36
November	1.950	0.050	3.530	932.528	699.396	2.647	2644.567	293.811	3264.57	3264570.53
December	2.400	0.061	4.345	1147.727	860.795	3.258	3254.851	361.614	4017.93	4017932.96
annual	22.800	0.579	41.274	10903.404	8177.553	30.952	30921.086	3435.333	38170.36	38170363.13

Table 4: Electrolyzer Production

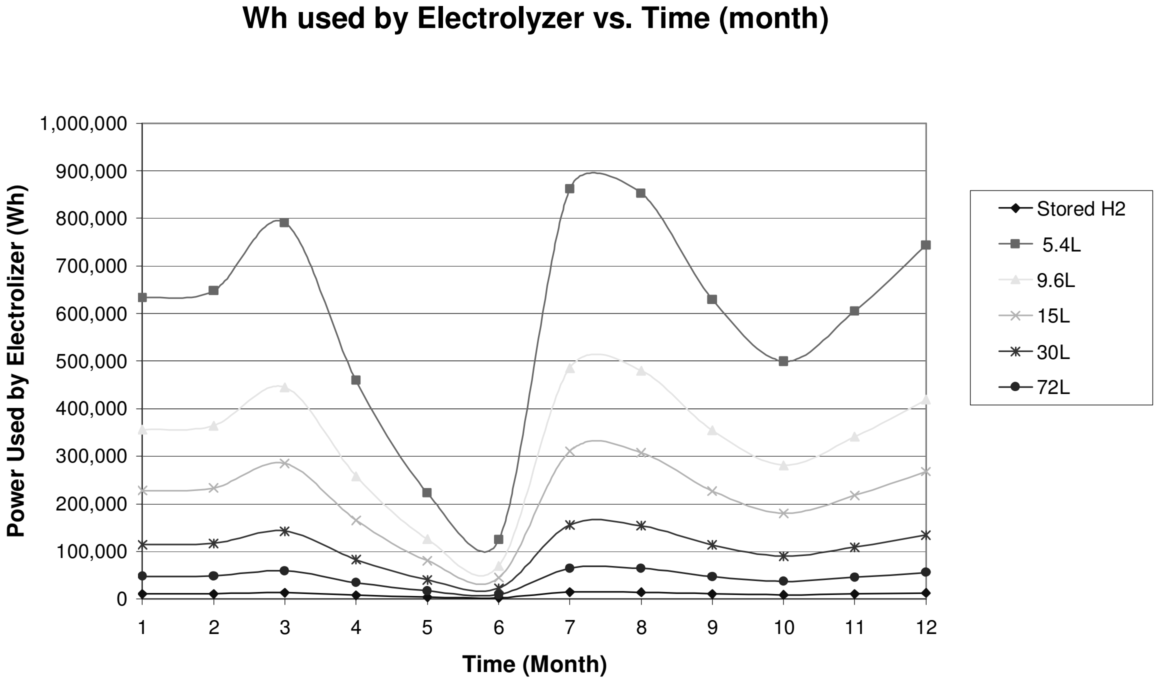

Figure 5: Power used by Electrolyzer vs. Time

Hydrogen Storage

The hydrogen storage system will consist of three main components:

- Low pressure propane tank
- Hydrogen gas compressor
- High pressure compressed gas cylinder

Because the electrolyzer and compressor will run at different volumetric rates, it is necessary to place a buffer tank between them. A 100 gallon propane tank will serve this purpose. The electrolyzer will pressurize hydrogen to about 90 psi in the propane tank. When this propane tank is full, the compressor will compress the hydrogen gas into a high pressure compressed gas cylinder.

Component Name	Capacity of Use	Power Used	Cost
Propane Tank	1200 gallons H2 STP	none	unknown
Compressor	unknown	unknown	unknown
Compressed Gas Cylinder	2040 gallons H2 STP	none	$140.25

Table 5: Necessary Components

Price quotes for compressed gas cylinders from two companies have been obtained:

Model	Capacity	Service	Price	
		Pressure	Cyl-Tec	Kaplan
220CF	2040 gallons H2 STP	2015 psi	$147.50	$140.25
250CF	2290 gallons H2 STP	2265 psi	$147.50	$168.00
300CF	2745 gallons H2 STP	2400 psi	$173.00	$175.00
435CF	4725 gallons H2 STP	4500 psi	$314.00	not available

Table 6: Price quotes for storage tanks (Cyl-Tech 2003, Kaplan Industries 2003).

Safety Research for Hydrogen Production Plant

Safety research is ongoing in the design of the hydrogen production plant. Listed below are some valuable statistics on safe levels of hydrogen in various situations (Pyle 1997 page 16, Pyle 1998 page 47):

- Flammable when volume of hydrogen in air is between 4 and 75 %
- Explosive when volume of hydrogen in air is between 18.2 and 58.9 %
- Flammable when volume of hydrogen in oxygen is between 14.7 and 93.9 %
- Explosive when volume of hydrogen in oxygen is between 15 and 90 %
- Industrial safety standards for purity: 99.5% pure hydrogen
- Research Grade hydrogen: 99.9% pure hydrogen
- Ultra high purity hydrogen: 99.9999% pure hydrogen

Appendix 1: Updated Team Schedule

Appendix 2: Renewable Energy Analysis

Appendix 3: Rainwater Collection Analysis

Appendix 4: Electrolyzer and Hydrogen Analysis

Appendix 5: Hydrogen Usage Analysis