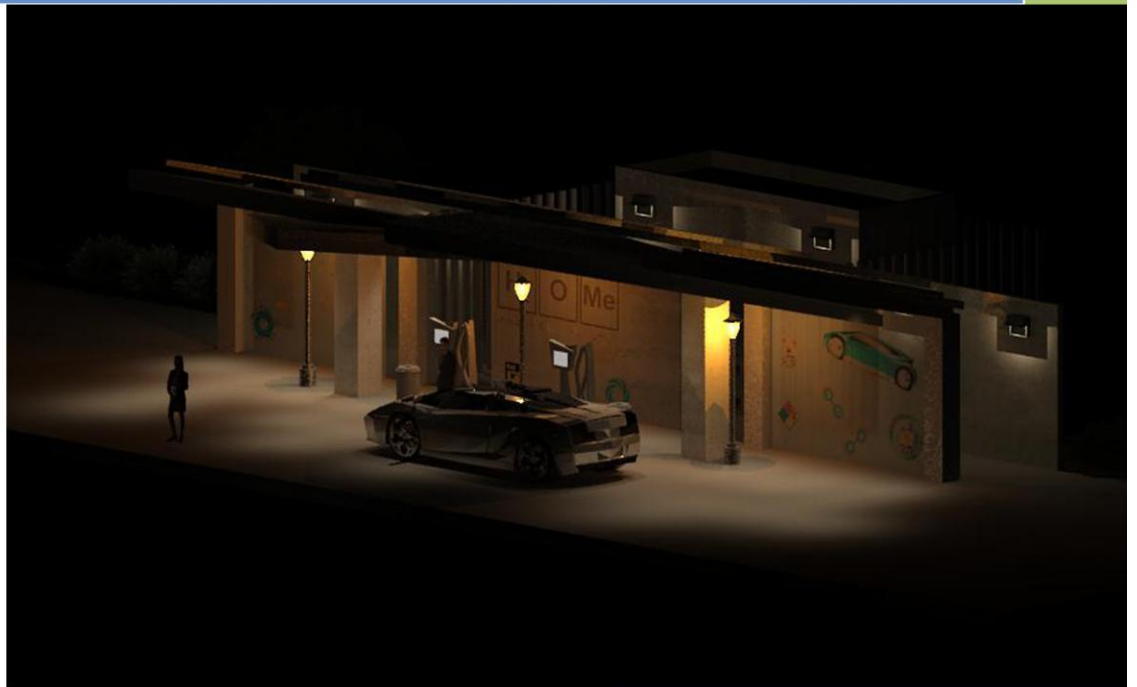


2011

Hydrogen Home Fueling Station



California State University Los Angeles

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3.1 Residential Hydrogen Fueling System Design Executive Summary

The residential hydrogen fueling station is conveniently located in the city of Santa Monica in close proximity of the “hydrogen highway”, Interstate 405 (CA). The edifice is a 5-story residential building that is strategically placed in the bustling part of the city; it consists of an apartment complex above and a market place, retail shops, eateries and station’s hydrogen education center, H₂OMe: Center for Sustainable Education, on the 1st floor. The residential building provides “free” hydrogen fuel as an incentive to attract tenants.

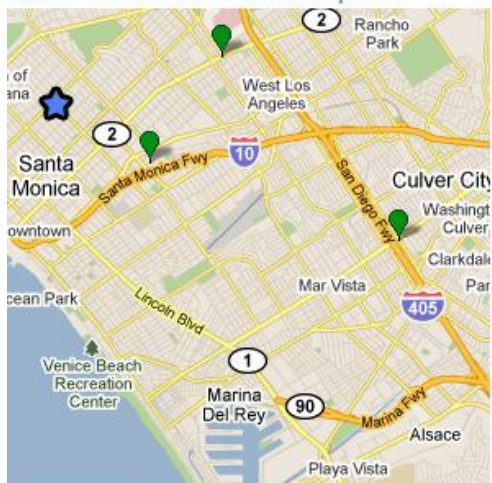
The hydrogen refueling station is situated behind the building where shop parking is located. The hydrogen production site follows all codes and safety standards. There is a total of 40 fuel cell vehicles and a storage capacity of 60kg. Hydrogen is produced through electrolysis via solar electricity. Hydrogen is compressed and stored for vehicle refueling.

H₂OMe: Center for Sustainable Education, is strategically placed in the 1st floor as a storefront where it will attract the general public as they converge at these fine venues. The integration of the education center and local shops allow a seamless acceptance into the community. H₂OMe will serve as a catalyst to deploy hydrogen education to the general public but also generate income to pay the cost of rent and maintenance of the hydrogen station. The safety of customers and the community is paramount to the acceptance of emerging hydrogen technologies. Regulations and codes regarding safety of handling, storage and dispensing are described in detail. Through the usage of passive and active components listed in detail, sets of possible scenarios are described along with means of lowering potential catastrophic outcomes.

An environmental impact analysis will address the hydrogen home fueling station’s CO₂ emissions.

A detailed economic business analysis will determine the cost effectiveness of this residential refueling station. It will include cost of major components and available funding.

Hydrogen Station Map in California California Fuel Cell Partnership 2010



Open (20) H₂OMe: Center for Sustainable Education

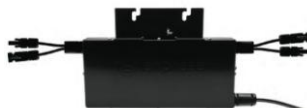
3.1.2 Hydrogen Production

Solar- 200 kW Solar Power System

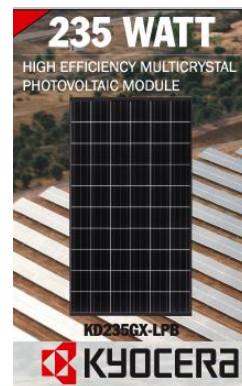
Lease **

The hydrogen home fueling system will produce hydrogen through electrolysis via solar. The station is with a 200kW. The location of the community is based in Santa Monica, CA with Los Angeles Department of Water & Power (LADWP) as the utility company.

[e] ENPHASE MICROINVERTER D380



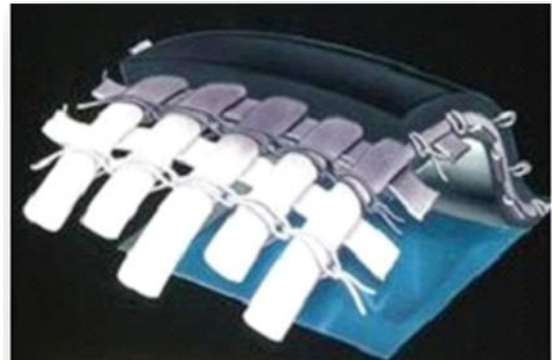
The components of the system consist of 638 Kyocera 235 Watt high efficiency multicrystal pv module (KD235GX-LPB) and 319 Enphase Microinverter D380. Microinverter improves



energy harvest, increases reliability and dramatically simplifies design, installation and management of solar power systems.

Rainwater Harvesting (Primary Hydrogen Production)

We will harvest rainwater by channeling and redirecting the rainfall from the rooftop, through a stream of pipes and filtered into an Original Rainwater Pillow storage system. This unique storage pillow is made with a reinforced polymer alloy that is used by military and fire department. These are a few characteristics of this strong durable material:



- Ultra violet radiation inhibitors are incorporated in the manufacturing process of the polymers to provide excellent ultra violet radiation resistance.
- The breaking strength of our material is 550 lbs per inch, which means a one-inch strip of it can hold 550 lbs.
- Seams are radio frequency welded, which means that we use electromagnetic energy to heat and bond materials together under pressure, ensuring strong, leak-proof seams. Each pillow is pressure tested before shipping.
- It is severe-weather tolerant, able to sustain extreme temperatures, ranging from -30 to +160 Fahrenheit.
- Easily repairable with heat or cold bonding. (Rainwater Collection Solutions, Inc)



The Original Rainwater Pillow will rest in the underground parking structure. Its enclosure is a 100ft x 100ft x 6ft unit. It is equipped with water filtering system, pumping system and overflow outlets to prevent flooding. Once the rainwater has been de-ionized it will be pumped to the electrolyser with a pressure of 25psi with rate of 10-12 gallons of water per minute (Rainwater Collection Solutions, Inc). This sustainable approach of supplemental hydrogen production is a simple solution to remedy

run-off rainfall that may lead to flooding and pollution into our beaches. Water harvested locally as opposed to utility water that travels thousands of miles to get to its destination has environmental benefits of reducing CO₂ emissions; replenish our aqua firms and alleviating drought.

December 2010. Supplemental Rainwater Hydrogen Production Analysis

According to Weather Underground, the total rain in December 2010 in the City of Santa Monica was 23 inches. The possible hydrogen production from rainwater harvesting is calculated below.

•Calculating Water Collection
$RainWater_{gal} = (rainfall[in]) \left(\frac{0.623gal}{ft^2 \cdot in} \right) (RoofTopArea [ft^2])$
$SantaMonica_{RainWater(gal)} = (23in) \left(\frac{0.623gal}{ft^2 \cdot in} \right) (15,557ft^2) = 222,916gal \text{ RainWater} * 90\%$

We assume water loss from rainwater rushing towards storage is 10%, so we collect about 90% of that water, a total 200,624gal. Our electrolyser produces 40kg of hydrogen utilizing 96gal of water. Below are the formulas used to calculate the supplemental hydrogen production.

••Calculating Hydrogen Production
$\text{Aggregate } H_2 \text{ Production} = \text{RainWaterCollected}(gal) \frac{\text{Yield}_{production}(kg)}{\text{Water}_{consumed}(gal)}$
$H_2\text{Production} = \frac{200,624(gal)[40H_2(kg)]}{96(gal)} = 80,249.6(kg) \text{ of Hydrogen}$
•••Calculating Yearly Hydrogen Production
$H_2\text{Yearly}_{production} = H_2\text{Aggregate } H_2O \text{ Production}_{H_2} \left(\frac{1day}{40kg} \right) \left(\frac{1year}{365day} \right)$
$H_2\text{Yearly}_{production} = 80,249.6(kg) \left(\frac{1day}{40kg} \right) \left(\frac{1year}{365day} \right) \approx 5.5\text{years}$

This numbers indicate that in the month of December we can potentially produce 40kg of hydrogen for the next 5.5 years or we have the option to utilize the storage rainwater for landscape irrigation or toilet grey water.

Hydrogen Production Process

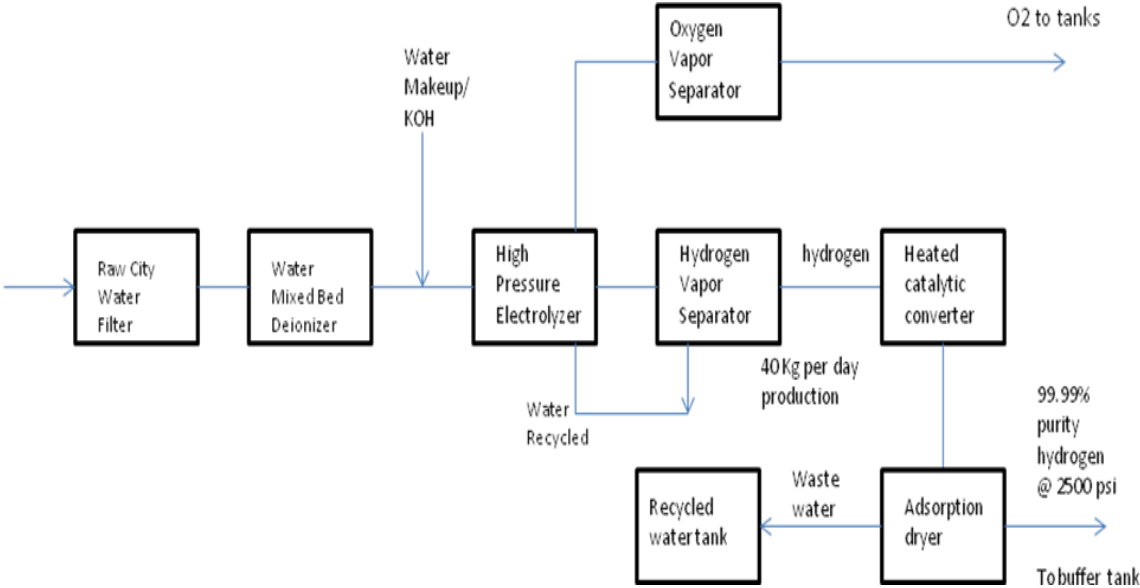


Figure 3.1.2: Hydrogen Production Process

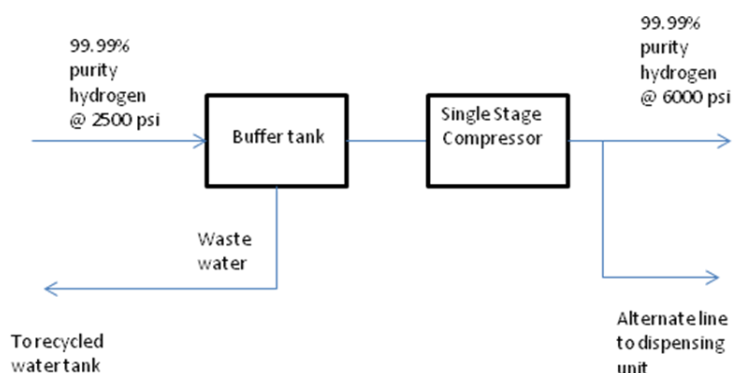
Electrolysis is our hydrogen residential fueling station’s method of hydrogen production. The water utilized will come from the city water supply and a supplemental source from our rainwater harvesting when available. It will be filtered through a mixed bed deionizer and will be mixed with potassium oxide to a 28% solution before going into the electrolyser. Once the gasses are released, the oxygen is sent through an oxygen vapor separator and captured in oxygen tanks to be sold. The hydrogen continues through the system, flowing within a hydrogen vapor separator, then to a catalytic converter which will recombine any oxygen left in the mostly hydrogen gas mixture to create water vapor. Then the gas is passed through an adsorption dryer to condense out the remaining water vapor from the hydrogen to give us ultra pure hydrogen gas. Any water in the system that must be drained out is reused for irrigation. Although it may greatly decrease the life of the filters, it will ensure that very little water is wasted. Our system uses 4 Avalence Hydrofiller 175 electrolyser units, each producing 10 kg of hydrogen per day for a total of 40 kg hydrogen production per day. The electrolyser use 1 gallon of water per hour, totaling 96 gallons per day and require a power input of 26 kW per unit for a total of 104 kW. The Avalence Hydrofiller’s electrolyser have the advantage of having a high outlet gas pressure (2500 psi) and only require single stage compression to reach our target of 6000 psi storage. The electricity used to power the electrolyser will come indirectly from our 200 kW grid tied solar panel array. This way we are using renewable energy while it is daylight, but our system can still function at night.

Company	Avalence
Electrolyser	Hydrofiller 175
Rated Hydrogen Output	10.0 kg/day
Rated Input Power	26 kW
Typical AC Voltages	480 V AC
Water Usage (at 100% Power)	1.0 gph (4.5 I/hr)
Maximum Delivery Pressure	Up to 2500 psig (175 bar)
Treated Gas Purity	99.99%
Acceptable Duty Cycle	0 to 100% (24*7)
Electrolyte	Water with 28% KOH by Weight
Weight	8,000 lbs/3,700kg
Dimensions (L x W x H)	8 ½ x 4 ½ x 10 ½ ft

Table 3.1.2: Electrolyser Specifications

3.1.3 Hydrogen Compression

Figure 3.1.3: Hydrogen Compression
 To compress the hydrogen gas up to 6000 psi for storage, we selected a C06-03-5250LX single stage hydraulic piston compressor from Hydropac. We chose a single stage



compressor rather than a multi-stage compressor because we are using a high-pressure electrolyser that releases hydrogen at 2500 psi. Multi-stage compression systems are commonly used so that the gas being compressed does not heat to extreme temperatures that may damage the equipment that it is flowing through and consequently decrease the energy density of the hydrogen. However, since the pressure of the hydrogen is already relatively high coming out of the electrolyser, it will take significantly less energy to compress the hydrogen to the target pressure than other low pressure electrolysis systems, which means less heat. We also included an after-cooler unit to cool down the hydrogen after the compression process and a flow controller that allows for manual control of the hydrogen flow from 10% to 100% to minimize losses to the pressure relief valves. The compressor will be located behind the refueling station.

Company	Hydropac
Compressor	C06-05-5200LX-H2
Discharge Pressure	6000 psig
Range of Inlet Pressure	800-6000 psig
Capacity with H2 at min inlet	5.8 scfm
Capacity with H2 at max inlet	52 scfm
Motor Power	5 hp

Table 3.1.3: Compressor Specifications

3.1.4 Hydrogen Storage

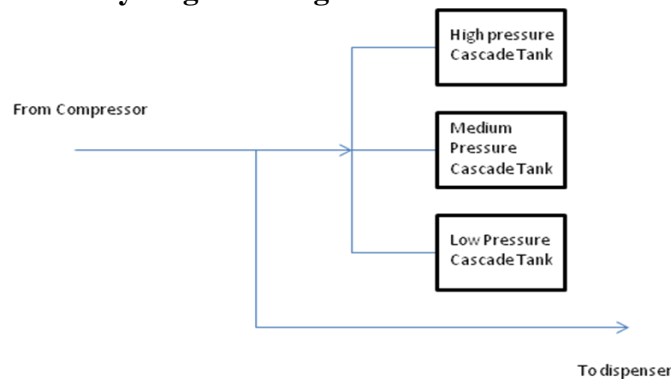


Figure 3.1.4 : Hydrogen Storage

The Hydrogen storage method is 3 bank storage cascade. We chose the cascade storage method to optimize the use of pressure differentials and can fill the fuel cell vehicles quickly and effectively. Cascaded storage banks are a common technique for storing compressed natural gas to later refuel CNG vehicles. Our storage vessels will be located behind the hydrogen station in open air. We will use 3 cascade vessels each rated at

7500 psi that will feed the dispensers passively. There will be a high, medium and low-pressure tank to feed each dispenser. First the low-pressure cascade vessel will fill the vehicle tanks up to 3500 psi. Next, the medium pressure cascade vessel will fill the vehicle tanks up to 4500 psi and the high-pressure cascade vessel will fill the vehicle tanks to 5000 psi. The tanks are composite wrapped aluminum core tanks from Structural Composites Industries. Each storage tank will hold 20 kg of hydrogen for a total storage capacity of 60 kg.

Company	Structural Composites
Storage Tank	SCI Model ALT 1015
Working Pressure	7500 psi
Minimum Burst Pressure	25500 psi
Empty Weight	516 lbs
Operating Temperature Range	-60°F to 140°F
Dimensions(L x D)	10 x 1 ½ ft

Table 3.1.4: Storage Tank Specifications

3.1.5 Hydrogen Dispensing

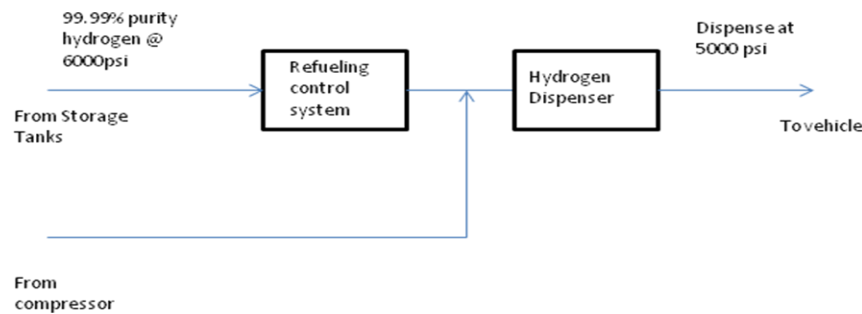


Figure 3.1.5: Hydrogen Dispensing

The Hydrogen dispensers will be visible to the hydrogen community. We will utilize two dispensers for the Hydrogen Community Apartment complex. FTI International Group Incorporation manufactures the dispensers, which is located in Ontario, Canada. The dispensing units, high profile cabinets with single delivery hose, side mounted nozzle, delivery pressure will be at 350 bar (5,000 psi) with a maximum flow rate of 20 kilograms per minute. The dispenser is integrated with wireless communications support for direct communications with the vehicle during the fill, card reader/receipt printer which will be in use by the people of the community center to have access to the hydrogen station fueling system, and/or with RFID which will be faster to identify members of the hydrogen community to provide a faster and more convenient way of refueling their hydrogen cars. To accommodate the usage of the Hydrogen Community, the first dispenser will be located in front of the Hydrogen Educational Center and the other units will be placed at the back of the apartment complex. Our first dispenser will attract people to learn about the hydrogen stations.

Company	FTI
Configuration	High profile cabinet with single delivery hose, side mounted nozzle
Filling Pressure	350bar
Maximum Working Pressure	447bar
Maximum Flow Rate	Up to 20 kg/minute
Operating Temperature Ranges	4° F to +160° F
Electrical Requirements	120 VAC, 60 Hz, 3A/ or 220 volts, 50 Hz, 3A
Weight	650 lbs
Dimensions (W x D x H)	33 x 22 x 92 in

Table 3.1.5: Dispenser Specifications

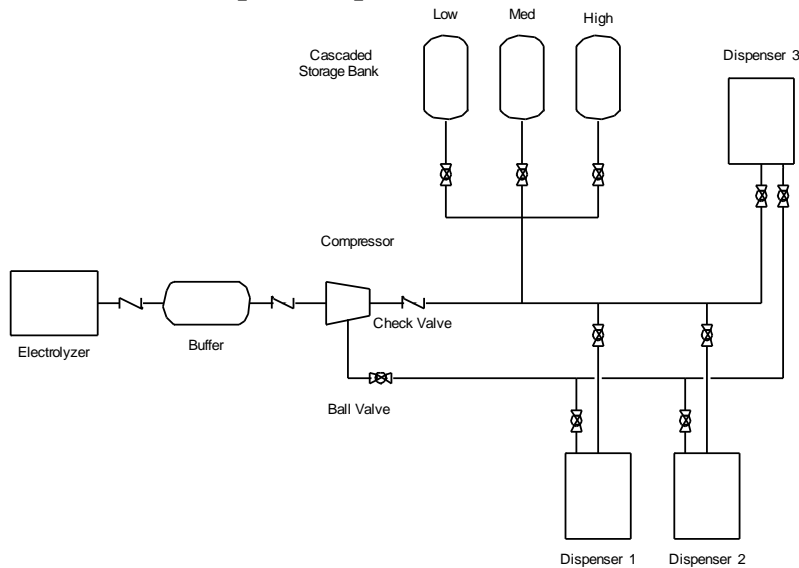


Figure 3.1.6: Hydrogen Process Flow Diagram

Figure 3.1.6 shows the flow process of our refueling station. Hydrogen coming from the electrolyser will fill a buffer tank. From the buffer tank, hydrogen will go into a compressor that ramps the pressure from 2500 psi to 6000 psi. The pressurized hydrogen will then flow into each tank in the cascade storage bank till they are all filled to 6000 psi. Each dispenser can then pull hydrogen from each of the cascade storage tanks in sequence from low to high pressure. The filling process is controlled automatically by a refueling control system that will open and close the appropriate valves as needed. Our system also includes an alternate line going from the compressor to each of the dispensers to help boost pressure in case the pressure in the storage tanks drops too low from constant refueling.

3.2 Safety Analysis

There are numerous components involved in ensuring a safe hydrogen station environment. It is vital for this design to promote a positive outlook on hydrogen. To ensure and secure public safety, hydrogen flame detectors will be placed at the station to detect hydrogen's unique invisible flame and alarm when leakage is detected. A video camera will be integrated with the flame detectors



Figure 3.2.1

Hydrogen Flame



Figure 3.2.2

Hydrogen Gas Detector

to have surveillance on a perimeter, figures 3.2.1 and 3.2.2 respectively. The alarm will notify the operator of the station. Furthermore, an automated monitoring system will shut off the power supply to all hydrogen storage, compression, and dispensing equipment. It will also close valves between the compressor and main storage supply, storage tanks, and dispensing equipment.

Appropriate signage around the hydrogen station will provide safety precautions for the general public. Our venting system will allow

hydrogen exit into open environments and away from people. Proper gating and enclosure walls will prevent people interference with equipment. The industrialized water produced by the electrolyser will be used for irrigation on the station’s premises. Four portable fire extinguisher rated at 20-B:C will be located within 50 feet of our dispensing area. In case of a fire were to erupt, a sprinkler system will be used at the dispensing, compressor, and storage location. Strict signage, barriers, and monitoring equipment will prevent any mishaps to the general public but also demonstrate our commitment to safety.

3.2.2 Codes

The National Fire Protection Agency is the leader in researching, and is the authoritative resource of codes and standards that help prevent fire related mishaps. They work with many organizations such as the International Fire Code (IFC), Department of Transportation (DOT), Compressed Gas Association (CGA) and American Society of Mechanical Engineers. This project deals with a volatile gas therefore codes are used in the construction, operation and maintenance of the hydrogen refueling station. The station and satellite education center will strictly follow the codes and standards set by the NFPA.

Erection of the station will rely heavily on the codes and standards set forth by the NFPA. Focal point of component design will depend on NFPA 52 Vehicular Gaseous Fuel Systems Code 2010 Edition; Chapter 5.2.1, all components utilized within the system is listed or approved by the DOT, and ASME.

Ultimately the preservation of safety relies heavily on the pristine integrity of the refueling stations components. Maintenance of the station will also be conducted in a similar fashion using guidelines set by the NFPA. When dealing with safety, NFPA 52 Systems Code chapter 7 subsection 7.3 entails system testing procedures within the entire fueling system. A more specific example is in Chapter 7.3.2 that states; the complete assembly shall be tested with either helium or hydrogen at full pressure. Chapter 7.4 has detailed instructions on what methods should be followed when faults within the system are found and also what the proper procedures are to be taken when repairs or replacements are to be made. An example of such code is Chapter 7.4.2; all damaged lines shall be replaced and not repaired.

SEVERITY (S)		
DESCRIPTOR	NUMERIC RATING	DEFINITION
Catastrophic	4	Failure causes complete loss and or potential injury.
Critical	3	Major damage to the system and possible injury.
Marginal	2	Will most likely not cause damage or injury.
Negligible	1	Partial failure, but will not be extensive or cause injury.
OCCURRENCES (O)		
DESCRIPTOR	NUMERIC RATING	DEFINITION
Frequent	6	Likely to occur frequently.
Probable	5	Likely to occur several times in usage over 1 year
Occasional	4	Likely to occur sometime in the usage over one year.
Remote	3	Unlikely to occur but possible
Improbable	2	So unlikely that occurrence may not be experienced
Incredible	1	Virtually impossible.
DETECTION (D)		
DESCRIPTOR	NUMERIC RATING	DEFINITION
Very Low	5	Cannot detect a device failure.
Low	4	Not likely to detect device failure.
Moderate	3	May have detectable failure.
High	2	Will likely have detectable failure.
Very High	1	Will definitely have detectable failure.
RISK RESULT (S x O x D =RPN)		
0-19	Acceptance Range	
19-47	As Low As Reasonably Predicted	
47-125	Not Acceptable	

Table 3.2.1

3.2.3 Failure Mode Effect Analysis

Effective use in passive and active devices and proper training with staff and end user is critical. There are many potential failures that could arise from within the process of production, storage and dispensing. Valves, hoses, and piping must be checked for leaks as well as the reliability of the detection devices implemented on site on a timely basis. The website H2incidents.org provided a sample of real world anomalies reported within the field of hydrogen production, dispensing, and research in a database format. With a seemingly endless array of possible failures it was decided to designate a common point of failure from each of the major operations the station. The *table 3.2.1* depicts the failure mode analysis weight each incident could potentially be given. Severity, occurrence, and detection are key factors in acknowledging and sorting mishaps from disasters. Components of the production consist of an electrolyser and complementary devices such as a water system to feed the necessary amount to keep up with production. Storage involves the pressurized vessel, its connecting valve, and surrounding area and dispensing involves the dispenser, hose, and peripherals. Piping is given its own category because it is within itself an underlying subsystem that requires attention aside from all components.

The electrolyser has the greatest potential to cause damage because of the hydrogen it produces. As observed on H2incidents.org; electrolyser will fail primarily because of internal leakage and faulty or non-existing hydrogen detection system. As illustrated in *table 3.2.2*, such risk for an electrolyser disaster is relatively high and will be addressed through continuous inspection of piping and valves within the electrolyser and implementation of hydrogen detectors. Storage vessels will most likely fail at the valve; fire or explosion prevention will rely heavily on routine inspection of the valve through leak test and hydrogen sensors. The major hazard in dispensing is decided to be human error related; a driver might drive away with the hose still attached. As a preventive measure, the dispensing unit will be electronically equipped with an emergency shut off valve. Since dispensing unit is located outdoors, leaked hydrogen will easily vent out into the atmosphere due to its light molecular composition and greatly reduce any grave incident. Although this is a system that can be easily overlooked, piping cannot be ignored because it has a high potential risk. Piping should be inspected using methods prescribed by the NFPA.

Process/ Major Components	Potential Failure Mode	Potential Effects Failure	of Severity	Potential Causes	Occurrence	Process Controls Prevention	Process Controls Detection	Detection	RPN
Production	Electrolyser	Fire Explosion	4	Leak within the electrolyser.	4	Inspection of connection valves and piping within the electrolyser.	Continuous Hydrogen Sniffer with shut off capability.	3	48
Storage	Valve leakage.	Fire Explosion Possible Injury	4	Valve leak. Improper location of detection devices.	4	Inspection of valve every 6 months.	Hydrogen sniffer and purging system.	3	48
Dispensing	Refueling hose leak.	Fire Explosion Possible Injury	4	Hose either rips through heavy usage or is pulled away from accidental drive away.	5	Hoses should be examined daily for signs of external damage. High-use fueling hoses should be replaced every six months.	Emergency shut off valve, pressure and hydrogen sensors.	5	100
Piping	Piping leak.	Explosion throughout the entire piping.	4	Piping corrosion and lack of detection devices	5	Inspection daily.	Installing hydrogen sniffer.	4	80

Table 3.2.2

3.3Economic/Business Plan Analysis

Solar lease programs require little or no up-front cash to participate as well as the possibility of passing on the operations and maintenance (O&M) responsibilities to a qualified installer. Instead of purchasing a PV system, the end user enters into a contract with the owner of the PV system and agrees to make monthly lease payments over a set period of time while consuming the electricity generated. If the local utility has a net-metering policy, the end user will receive credit for any excess electricity sent back to the grid. The combination of a lower monthly utility bill and a monthly lease payment will be less than the utility bills that the end user has been paying prior to installing the system.

The annual electric bill before solar is assessed at \$12,000 per year with an annual bill escalation of 5 percent per year. The annual bill savings after solar has been installed is assessed at \$33,808.

	Before Solar	After Solar	Bill Savings
Jan	\$898	-\$1,092	\$1,990
Feb	\$880	-\$1,562	\$2,442
Mar	\$855	-\$1,716	\$2,571
Apr	\$901	-\$2,023	\$2,923
May	\$882	-\$2,013	\$2,895
Jun	\$1,209	-\$2,385	\$3,594
Jul	\$1,269	-\$2,499	\$3,767
Aug	\$1,286	-\$2,528	\$3,814
Sep	\$1,223	-\$2,022	\$3,245
Oct	\$886	-\$1,563	\$2,449
Nov	\$835	-\$1,315	\$2,150
Dec	\$878	-\$1,089	\$1,967
Total	\$12,002	-\$21,807	\$33,808

The system cost is projected at \$1,600,000 with federal/state/local tax credit of \$480,000 the net cost of the system is reduced to \$1,120,000. This cost is based on solar PV industry standards of \$8/Watt. Cumulative lifetime savings is expected of \$1,613,547 over 25 years. The investment on return is 3.7%.

3.3.1 Hydrogen Station Cost

The table below is an itemized capitol cost for hydrogen station's equipment and installation cost. The residential refueling station will cost approximately 1.5 million dollars.

Avalence HydroFiller Residential Hydrogen Fueling Station			
Construction of Fueling Site	Cost \$ 000	Comments	Manufacturer
Concrete Flatwork	25	Fueling Island paving	
Structural Concrete	20	Building and Canopy Supports	
Retaining Walls	20	100 LF of average 8' height w walls	
Membrane Waterproofing/Perimeter Drainage	10	Site surface drainage to street	
Building Signs, Safety Signs and Graphics	10	Includes 30 safety signs	
External Lighting	30	Canopy and Site lighting	
Subtotal	115		
On-Site Electrolysis Based Hydrogen Generator			
Electrolyser- 4 ea	1,200	40 kg/Day Hydrofiller 1.2 mil	Avalence
H2 Gas Chillers and Aftercoolers	1	Hydropac	Hydropac
Water Filtration and Treatment	15	10 gpm capacity	
Compressor	22	6000 psi, input 800-6000	Hydropac
High Pressure Storage- 3 ea	24	3 vessels @ 20 kg @ 7500 psi	Structural Composites
350 BAR Dispenser with Hose/Nozzle	30	includes card reader and meter/nozzle	FTI
Flow Controller	2	Regulate pressure and flow	Hydropac
Alarm and Monitoring System	15	(5) flame detectors and video cameras	Det-Tronics
Alarm and Monitoring Mounting	5	Mounted in Utility Room	
Subtotal	1,314		
Tax			
Sales Tax- 9.75%	70	Tax on equipment and material	
Subtotal	70		
System Cost	\$1,499		
ESTIMATED TOTAL COST	\$1,499	Operations and Maintenance included in capital costs	

Using National Renewable Energy Laboratory’s (NREL) H2A Hydrogen Production Cash Flow Analysis Tool V2.1, we were able to calculate the cost of hydrogen production at our site. We

H2a Analysis Results

COST RESULTS

Specific Item Cost Calculation		
Cost Component	Cost Contribution (\$/kg)	Percentage of H2 Cost
Capital Costs	\$2.22	75.8%
Decommissioning Costs	\$0.24	8.1%
Fixed O&M	\$0.47	16.1%
Feedstock Costs	\$0.00	0.0%
Other Raw Material Costs	\$0.00	0.0%
Byproduct Credits	\$0.00	0.0%
Other Variable Costs (including utilities)	\$0.00	0.0%
Total	\$2.93	

have allocated over \$100 million federal and local funding to pay for the capitol cost of the station. Funding will come from California Energy Commission, Proposition 84, Motor Vehicle Registration Fee and others (see Appendix: Funding). We estimate to get 1% of total federal and local funding and that is equivalent to approximately \$1 million in the span of 10 years. That is approximately \$100,000 per year to fund our station infrastructure and capitol support. The system was designed with

minimal returns and cash flow. This is a not-for-profit operation; the landowner provides affordable hydrogen fuel for tenants. The real cost of hydrogen is included in the cost of the housing unit. The meager cost of hydrogen makes living at this residential complex very appealing. At \$2.93/kg of hydrogen makes this alternative very cost competitive to fossil fuels. A full tank on a fuel cell vehicle (4kg) will approximately cost \$12 to fill.

According to California Energy Almanac, the price of gasoline for the 2010 4th quarter was \$3.492 for premium fuel.

Vehicle Fuel Type	Gasoline	Hydrogen
Mileage	32.6 miles/gal	44 miles/kg
Daily Commute	35 miles	35 miles
Annual Mileage	12,000 miles	12,000 miles
Cost of Fuel	\$3.492/gal	\$2.93/kg
Calculating Total Fuel/Year $Total_{annual(gal)} = \left(\frac{annual_{mileage}}{miles/fuel_{unit}} \right)$	$Total_{annual(gal)} = \left(\frac{12,000miles}{32.6miles/gal} \right)$	$Total_{annual(kg)} = \left(\frac{12,000miles}{44miles/kg} \right)$
Total Fuel/Year	368.10 gal	272.72kg
Cost of Total Fuel/Year $Annual_{cost(\$)} = (Annual_{Fuel})(Fuel_{cost})$	(368.10 gal)(\$3.492/gal)= \$1285.40	(272.72kg)(\$2.93/kg)= \$799.70

From federal funding the team was able to reduce cost of hydrogen to \$2.93 per kilogram. This makes it very appealing to the automotive consumer because it is economically feasible and its low environmental impact.

•Electrolyser Hydrogen Production Rate

The specifications of the electrolyser are listed below. The following table and formulas convey the cost of water from utilities.

Electrolyser Consumption	Daily	Month (30days)	Year (12months)
Water Consumed	96 gal	2,880 gal	34,560gal
Hydrogen Produced	40kg	1,200kg	14,400kg

•Calculating Water Usage Cost

$Monthly_{cost} = HCF * TierCost$	$WaterUsage_{month} = \frac{2,880gal}{748.5gal} = 3.8HCF$
1Hundred Cubic Foot (HCF) = 748.5gallons	

We have calculated that on an average monthly basis we consume about 2,880 gallons of water. The City of Santa Monica has a tier system in which the resident is billed. Their rate is based on Hundred Cubic Feet (HCF) which 1HCF is equivalent to 748.5 gallons. We divide our total gallons of water consumed in the month (2,880gal) by 748.5gallons and a product of 3.8HCF.

Santa Monica Water Rates	
Rate/HCF	Range of Use
1 st Tier - \$2.01	0-14 HCF
2 nd Tier - \$3.02	15-40HCF
3 rd Tier – \$4.52	41-148HCF
4 th Tier – \$7.06	149+HCF

Above table is a list of Santa Monica water rates. We multiply our water usage by the range of use to get our monthly cost.

$Monthly_{cost} = HCF(TierCost)$
$Monthly_{cost} = 3.8HCF(\$2.01) = \$7.64$
$Yearly_{cost} = \$7.64/month(12months) = \$91.67/year$

The water bill is relatively low but the energy production is most sustainable when harvesting rainwater instead of water that has traveled thousands of miles to get to its destination.

3.3.2 Potential Market Growth

Worldwide, there is a push for hydrogen highways and clusters. In the U.S., California is leading with its long history of energy efficiency and pollution reduction policies and its Global Warming Solutions Act of 2006, AB32, which mandates major cuts in greenhouse gas emissions.

According to the U.S. Fuel Economy website, there are both benefits and challenges to adopting FCVs. The benefits include: reduction of greenhouse gas emissions, air pollutants, and dependency on foreign oil. The challenges that must be tackled for FCVs to successfully compete in the market include: size, weight, and expense of onboard hydrogen storage; the cost of FCVs, which are more expensive than conventional gasoline, diesel, and hybrid vehicles; fuel cell durability and reliability deficiencies; competition; safety; public acceptance; and the need for new fuel infrastructure (U.S. Fuel Economy, 2010). One of the problems with the push for hydrogen fuel infrastructure is the chicken and egg issue. Car manufacturers can't quickly push forward without the refueling infrastructure. However, infrastructure isn't feasible without adequate demand. Residential refueling stations/appliances can lower the capital costs and speed deployment by eliminating the need for transporting the hydrogen gas. Incorporating the

residential refueling station into mixed-use apartment or condo complex can make the system more affordable through cost sharing among the residents after application of incentives. Another major factor besides technology and cost is public acceptance. The Technology Acceptance Model describes the necessary ingredients for the adoption of technological change: perceived value and ease of use. Ely, from the field of human performance technology, found that it might be more productive to examine “facilitative conditions” rather than focus on resistance to change (Surry & Ely, 2007). These facilitative conditions are “dissatisfaction with the status quo, knowledge and skills exist, availability of resources, availability of time, rewards and/or incentives exist, participation [involving participants in decisions], commitment, and leadership (Surry & Ely).” Although the mixed-use housing approach isn’t for everyone, it does have the potential to address some of the public needs for acceptance of HRAs. For example, the apartment or condo complex deployment of onsite hydrogen production simplifies the transition to a hydrogen fuel by providing the required maintenance and training through existent building engineer staff.

Other factors that will influence market growth are economies of scale, which will speed up due to the recent adoption of specialty markets (e.g., forklifts shift to fuel cell technology). The EV charger will spur market growth as the consumer expects the convenience of home refueling, which will cause FCV manufacturers to offer HRA through strategic partnerships. Honda has demonstrated its intent through its solar prototype located in Torrance. Honda’s market research showed that the “ability to refuel a vehicle at home ranks third among the values consumers see of owning an electric vehicle“(Infogreen, 2010). If the Department of Energy’s support and goals as reported to Congress in their January 2009 report remain consistent, the Oak Ridge National Laboratory scenario of 2.5 million vehicles by be achieved by 2020 with residential hydrogen refueling stations a large part of that growth (DOE Report to Congress, 2009).

The Environmental Information Agency reports that there will be a shift in non OPEC production of crude oil production due to lack of resources. As seen on chart 3.3.1, the EIA the United States is estimated to lower production by 2035. This could potentially lead to an increase in gasoline prices and a shift in energy policies. According to the EIA the, “Real prices (in 2009 dollars) for motor gasoline and diesel in the *AEO2011* Reference case increase from \$2.35 and \$2.44 per gallon, respectively, in 2009 to \$3.69 and \$3.89 per gallon in 2035, lower than in the *AEO2010* Reference case. Annual average diesel prices are higher than gasoline prices throughout the projection because of stronger growth in demand for diesel than for motor gasoline.”

The chart 3.3.2 also provided by the EIA depicts a relatively wide margin of error when forecasting cost per barrel. This wide deviation can signify gas price increase dramatically above the reference case. An unstable gasoline fuel market will give more leeway to home refueling station because it can offer a steady price of hydrogen with little potential influence from external entities.

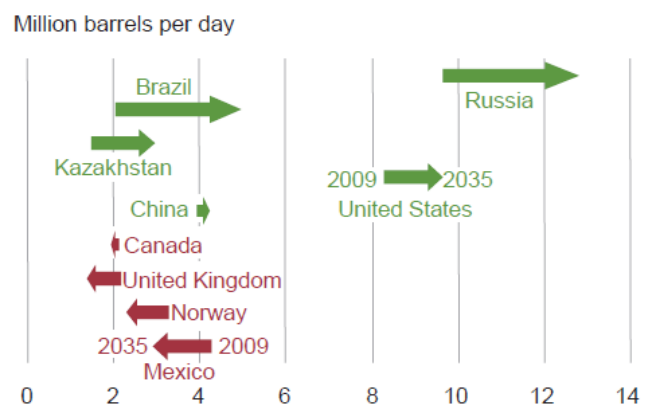


Chart 3.3.1

The DOE is making great strides in increasing the adoption of alternative fuels. There was over 100 million dollars of federal and local funding uncovered for alternative fuels and energy projects. This station design uses 1 percent of the funding found to help aid its successful deployment. Using all funding could increase the potential number of home stations to one hundred similar existing sites within a relatively short time span. In total over 400 hydrogen home refueling implementations that can all be erected in parallel. Without the cost of hydrogen mirroring current cost of gasoline it is safe to assume that in economic terms the transition to the design will be relatively welcomed.

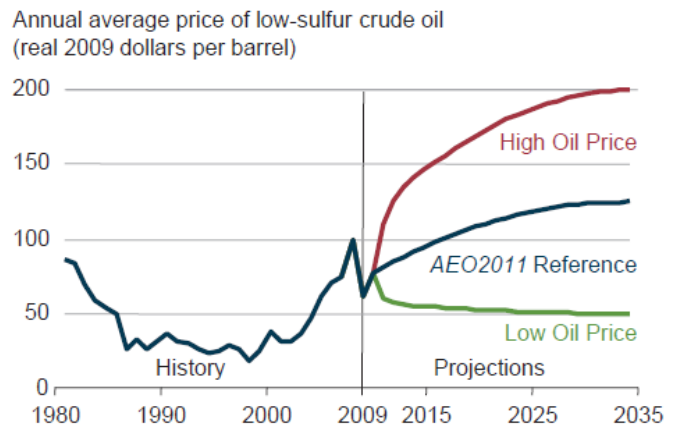


Chart 3.3.2

Without the cost of hydrogen mirroring current cost of gasoline it is safe to assume that in economic terms the transition to the design will be relatively welcomed.

3.4 Environmental Analysis

The adoption of fossil fuels by humanity can be traced back to rudimentary beginnings of this country's transportation sector. Unfortunately advancement to a cleaner alternative has not been extensively implemented since. Aside from the added benefit of having a refueling unit within arm's reach of habitation the design of the station design has number of impacts that will affect the environment in a positive and negative bias. The system is designed with electrolysis as production method of hydrogen instead of the cheaper dirty method of gas reformation. Electrolysis produces no local CO₂ emissions but does require a relatively large amount of electric power to function. The electrolyser has a limited potential life span of 10 years and must be maintenance regularly. With electrolysis emissions of CO₂ production is shifted onto the entity that produces the energy required; the grid. A 200kWh photovoltaic system will be implemented at the premise to offset the large amount of electric power needed to run the electrolyser and compressor and un used portions of the power will be funneled into the grid and credits will be deducted at night time. The solar system it is estimated to produce 335,613 kWh of electricity/year which is equivalent to eliminating 317,703 lbs of CO₂ pollution over the first year. Offsetting power consumption from the grid by usage of photovoltaic panels requires a large amount of surface area and can only be used on average 6 hours per day and is only about 13%-17% efficient. Water for usage in the production will come from the harvesting of rainwater. When not in use the 200,624 gallons of water harvested per year will be used for irrigation and or grey water.

3.4.1 Well to Wheel Energy and Emissions Analysis

There must be an understanding before continuation of any calculations that local emissions at the site of production will be zero. The production of CO₂ will be calculated using information based on the EIA website's report for the generation of electricity in California. As shown in table 3.4.1 California produces a majority of its power through natural gas burning. Utilizing natural gas to fuel power generation produces a relatively smaller amount of CO₂ per kilowatt hour produced this is true because of California's strict air pollution policy enforcing agency; California Air Resource Board.

Net Electricity Generation: September 2010 (Energy Information Administration)		
	California	Share of U.S.
Total Net Electricity Generation	18,237 thousand MWh	5.30%
Petroleum-Fired	4 thousand MWh	0.20%
Natural Gas-Fired	9,716 thousand MWh	10.50%
Coal-Fired	178 thousand MWh	0.10%
Nuclear	3,237 thousand MWh	4.70%
Hydroelectric	2,665 thousand MWh	15.80%
Other Renewable Sources	2,196 thousand MWh	16.70%

Table 3.4.1

The design is based on an electrolyser that generates 40 kilograms of hydrogen and a compressor that will continuously.

Therefore, the amount of energy required to produce one kilogram of hydrogen by the electrolyser is about 75kWh, and the compressor uses 9kWh. Total power required per one day of usage is the most important amount.

1. Amount of Energy per Kg of Hydrogen Produced per day 75
[kWh/Kg *Kwh/Kg*]
- a. Compressor kWh/day 216 kWh
2. Amount of H₂[Kg] produced per day 40 Kg
3. Total Amount of kWh per day
[1*2]+1a → [75 [kWh/Kg *Kwh/Kg*] * 40 Kg]+216 kWh → 3216 kWh

Assume that the electrolyser will run continuously and that 6 hours of solar power will be available every day and the excess power generated will be fed back to the grid for later use.

4. Total Amount of kWh of excess kWh produced by PV
[PV OUTPUT-SYSTEM REQ] → [6hr*200kWh – 6hr*134kWh → 396kWh]
- 4a. Total Amount of kWh from the grid for 18 hr. (offset of 6 hr. process by solar)
[3*0.75] → [3216kWh*0.75] → 2412 kWh
- 4b. [(4a)-(4)] → 2016kWh

The EIA states that California's total production of electricity by CO₂ Emitting Technology is 54.3% which is a sum of production of electricity by natural gas; 53.3%, and production of electricity by Coal; 1%.

5. Percent of Energy from Grid using CO₂ emitting technology 54.3%
 53.3%[N.G.]+1%[COAL] 54.3%

6. Total Amount of kWh using power grid

$$[5*4b] \rightarrow [54.3\% * 2016\text{kWh}] = \rightarrow 1094.688 \text{ kWh}$$

The EIA also states that per 1 kWh natural gas emissions are 553.88 g of CO₂ and coal emissions are 990g of CO₂. This will be implemented in finding the respective amounts each fuel generates per day.

7. Total Mass of Daily CO₂ Emissions

$$[\text{Natural Gas Emissions}] + [\text{Coal Emissions}] = \text{Total Emissions}$$

$$\left[\left(\frac{553.88 \text{ g CO}_2}{\text{kWh}} \right) * (1083.733 \text{ kWh}) \right] + \left[\left(\frac{990 \text{ g CO}_2}{\text{kWh}} \right) * (10.95 \text{ kWh}) \right] = 611095 \text{ g}$$

$$[600258 + 10837] = \rightarrow 611.095 \text{ Kg}$$

The final step is to divide the number of total mass of CO₂ created on a daily basis by the amount of kilograms produced.

$$8. \left[\frac{7}{2} \right] \rightarrow \left[\frac{\text{TOTAL MASS OF CO}_2}{\text{Amount Of H}_2[\text{Kg}] \text{ per day}} \right] = \rightarrow \left[\frac{611.095 \text{ Kg}}{40 \left(\frac{\text{Kg}}{\text{day}} \right)} \right] = \rightarrow 15.277 \left[\frac{\text{Kg CO}_2}{\text{H}_2[\text{Kg}] \text{ produced}} \right]$$

$$9. \left[\frac{8}{\frac{44 \text{ miles}}{\text{H}_2} \text{ Kg}} \right] \rightarrow \left[\frac{\frac{\text{Kg CO}_2}{\text{H}_2 \text{ Kg}}}{\frac{\text{miles}}{\text{H}_2 \text{ Kg}}} \right] \rightarrow \left[\frac{15.277 \frac{\text{Kg CO}_2}{\text{H}_2 \text{ Kg}}}{\frac{44 \text{ miles}}{\text{H}_2 \text{ Kg}}} \right] = \rightarrow 347.21 \text{ g CO}_2 / \text{mile}$$

The resulting emission per kilogram generated by the refueling station design is 347.21 g CO₂ per mile. It is only about 18% less CO₂ than the 422 g per mile generated by the traditional internal combustion engine technology. The consensus is somewhat an unbalanced comparison because there is a comparison of a final end product versus the process it takes to create the final product. If compared to the amount of CO₂ released by the process of creating, and delivery of gasoline the comparison would be much greater distinction. Hydrogen technology would clearly reduce the amount of CO₂ emissions. While water and power requirements are sufficient to for refueling process functionality, improvements in photovoltaic efficiencies would greatly increase the design's independence from fossil fuels.

3.5 Marketing and Education Plan

H₂OMe: Center for Sustainable Education (H₂OMe: CSE) is our solution of integrating hydrogen education to the general public. Hydrogen education is no longer separate from the community but sewn into the fabric of our daily routine. H₂OMe: CSE is strategically placed on the 1st floor of a 5-story modern apartment complex, with various retail boutiques, market place and eateries. The overwhelming foot traffic will reduce the need for printed



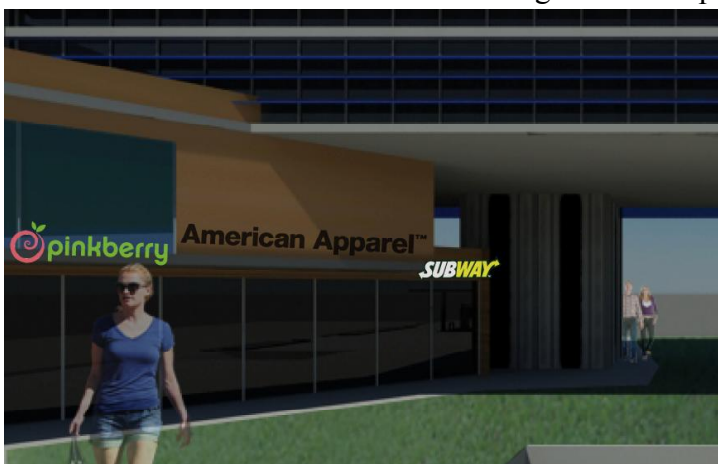
propaganda and will heavily rely on digital media and social networks for advertising.

The H₂OMe: CSE storefront is covered in glass with illustrations of simple chemistry; hydrogen molecules extracted from water's molecular structure through electrolysis via solar. The "green" hydrogen powers the grid and homes via fuel cells and is gaseous fuel for hydrogen fuel cell vehicles. The simplicity of the storefront diagrams is very appealing to the general public.

H₂OMe: CSE functions as a catalyst to educate and raise awareness of the benefits of hydrogen as an alternative fuel source. H₂OMe: CSE will host "green" technology tours, seminars, film screenings, panels and various events that bring attention of sustainable living and technologies.



The interior layout of the H₂OMe: CSE serves as an educational walkthrough that is appropriate for all ages. It will focus on various simulations and demonstrations of hydrogen production and power generation and other renewable energy technologies. A mini power production model will simulate hydrogen production through electrolysis via solar. The simulation is as follows: an electrolyser membrane joins 2-glass cylinders vertically on both sides of the electrolyser. The electrolyser is stimulated by an electric current; hydrogen and oxygen gas-bubble forms in the de-ionized water. The hydrogen and oxygen fuel travel through glass piping into the fuel cell's appropriated catalyst, anode and cathode. The fuel cell will utilize the oxygen and hydrogen to generate electricity that spins an electric motor that propels a model fuel cell vehicle. The backdrop of the simulation model will contain exploded diagrams of system's major components that will exemplify and summaries their inner workings. This simulation will coincide with our on-site residential hydrogen refueling station in that it will harvest rainwater for supplemental hydrogen production. The reason for harvesting rainwater is demonstrate a sustainable solution for run-off water that causes street flooding and ocean pollution, plus it's a renewable source. In



addition, other simulations and demonstrations on the tour include; ease of use in dispensing hydrogen to the vehicle; a computer simulation of a vehicle's efficiency between using hydrogen fuel (a chemical/electrical process) and using gasoline (a combustion mechanical motion); and overall safety features of the system. Furthermore, inviting local agencies, city officials, and community organizations to several "Open House" events will solidify support

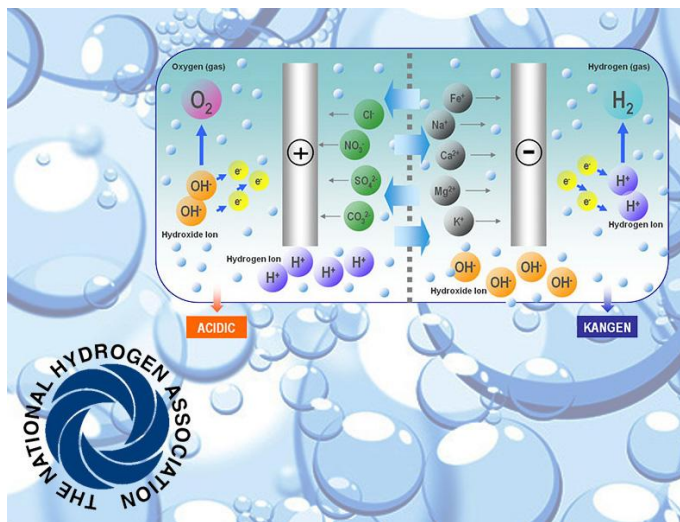
when highlighting the importance of being independent from foreign oil; which helps to both

preserve the environment and stimulate the local economy. In addition, creating partnerships with city agency such as the City of Santa Monica's Office of Sustainability and Environment to promote sustainable living and green technology. Partnerships benefit both parties because mission is accomplished with ease. City agency can provide the funding necessary to promote the education we foster. These partnerships solidify our commitment to the community and environment and further appeal to the general public. This will further advocate public support and acceptance by bridging hydrogen technology with life's everyday conveniences.

The screening area will feature film documentaries, seminars and panels that bring attention to environmental degradation and discuss possible environmental solutions. Share people's triumphant struggles as they defend and protect their environment. In addition, it will hold public hearings on current environmental state propositions to educate and discuss both sides of the possible legislation with proper mediation.

Below is a sample education event that focuses on hydrogen safety and technology. These exhibits consist of various parameters that will help fathom the complexities of hydrogen.

Hydrogen: Sustainable Living Exhibit consists of interactive illustrations and demonstrations that promote inquisitive research to catalyze hydrogen knowledge. The topics bring attention to the benefits of "green" hydrogen as a vital role in our society; a means for clean energy in transportation, utilities and residential/ commercial sector. A hydrogen molecular diagram is showcased on the wall that describes its universal abundance, efficiency and energy content in various technologies.



In addition, the exhibit will also illustrate the safety standards implemented and practiced by the production site such as emergency shut off valves, pressure relief valves and hydrogen leak/ flame detectors to promote and demonstrate the austere hydrogen safety requirements that will bring peace of mind and technological acceptance to the general public.

H₂OME: CSE will ally with celebrities that have similar beliefs about the environment to spread hydrogen consciousness and promote the education center. The celebrities will embrace the services we provide; environmental education and "green" hydrogen production, to push the hydrogen acceptance agenda upon the public. This will help alleviate general public's doubts and inhibitions of hydrogen and green technology. Furthermore, All events are open to the public and accommodate public transportation, carpool, bicycling, and walking. Our location is designated where public transportation is conveniently accessible.

A strategic marketing/sales team will offer single or multi-residential hydrogen refueling station to homeowners that are interested in hydrogen home fueling. The marketing/sales team will serve as a broker to hydrogen residential fueling companies and not deal with financing or construction aspect of the project. The sales personnel will inform the potential customer of the major components of the hydrogen home fueling system and size up a system for their residency. The customer has 2 options of hydrogen, through electrolysis, home fueling station to choose

from. The 1st hydrogen fueling station is the base level system that offers utilities energy feedstock, electricity and water from utilities. The 2nd hydrogen home fueling station is a sustainable approach. It will utilize solar and harvest rainwater to produce hydrogen. Either option is a custom system that fits their budget and needs. This feasible income provides the capital for the hydrogen equipment maintenance, staff and storefront overhead expenses. Flyer depicts integration of human life and hydrogen fuel as an inseparable entity.

Cost Analysis on Marketing and Educational Plan

Radio Advertisements	
Recording a 30 second radio Advertisement	\$100
Buying Airtime from Radio Station	\$500
Mailed Materials	
Print Manufacturer	\$200
Newspaper / Print Media Advertisement	
Cost for Advertisement Space	\$100/month
Internet	
Web Master / Host Service	\$500
Social Networks	
Facebook©/Myspace©	\$0
Graphic Communications	
Graphic Designer	\$2000
Education Center	
Rainwater Harvesting	
Education Storefront Rent	\$3000/month
Total	



H₂O Me:
SUSTAINABLE LIVING

Hydrogen the fuel for life.











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Deionization

Lenntech 12/6/2010

<http://www.lenntech.com/applications/process/demineralised/deionised-demineralised-water.htm>

Dave Mauterer 12/6/2010

Email & talking on the phone

Reverse Osmosis

Lenntech 12/6/2010

<http://www.lenntech.com/library/reverse-osmosis/whatisro.htm>

Hydrogen Compression

Hydro-Pac Inc 12/19/2010

<http://www.hydropac.com/HTML/hydrogen-compressor.html>

Hydrogen Dispensing

Kraus International 12/23/2010

<http://www.krausglobal.com/hydrogen-dispenser.php>

Cascade Storage Bank

Gas Technology Institute 12/29/2010

<http://www.interenergysoftware.com/PDF/CasManual.pdf>

Check Valves

Spirax Sarco 1/2/2011

<http://www.spiraxsarco.com/resources/steam-engineering-tutorials/pipeline-ancillaries/check-valves.asp>

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U.S. Department of Energy Energy Efficiency and Renewable Energy

http://www.fueleconomy.gov/feg/fcv_challenges.shtml

Appendix

Funding and Incentives for hydrogen refueling infrastructure, water and education projects

Program	Agency	Funding (either total funding or individual grants, credits, or rebates)
Clean Cities (part of the Office of Energy Efficiency and Renewable Energy's Vehicle Technologies Program)	U.S. Department of Energy (SEPs)	States apply for these grants, which is implemented through a network of volunteer coalitions to develop public/private partnerships and to promote alternative fuels and advanced vehicles among other initiatives.
Loan Guarantee Program	U.S. Department of Energy (DOE) (Reference 42 U.S. Code 16513)	Improved Energy Technology Loan guarantees for up to 100% of the amount of the loan.
Alternative and Renewable Fuel and Vehicle Technology Program	The California Energy Commission (Reference Senate Bill 1340, 2010; California Code of Regulations, Title 13, Chapter 8.1; and California Health and Safety Code 44270-44274.7)	Grants and loans are available for projects that produce alternative fuels, expand fuel infrastructure/stations; expand infrastructure connected with transportation corridors; and conduct public education and promotion among other initiatives.
Motor Vehicle Registration Fee Program	The Air Resources Board (ARB) through local air districts (Reference Health and Safety Code 44220 (b))	Alternative Fuel Vehicle (AFV) and Fueling Infrastructure Grants Statewide, the program provides approximately \$60 million for funding various projects including supporting infrastructure needed for emission reductions.
Advanced Transportation Financing	The California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA) (Reference Senate Bill 71, 2010, and California Public Resources Code 26000-26017)	The program provides financing and incentives in the form of sales and use tax exclusions.
South Coast Air Quality Management District's Clean Fuels Program	The South Coast Air Quality Management	Technology Advancement Funding has approximately \$10 million available funding annually (with expected cost-share from other project partners and stakeholders). Selected projects result from both specific RFPs and unsolicited proposals.
2011-2012 Investment Plan for the Alternative and Renewable Fuel and Vehicle Technology Program	California Energy Commission The statute, subsequently amended by AB 109 (Nuñez, Chapter 313, Statutes of 2008),	The Energy Commission has an annual program budget of approximately \$100 million to support projects that “develop and deploy alternative and renewable fuels and advanced transportation technologies to help meet the State's goals for reducing greenhouse gas emissions and petroleum

		dependence in the transportation sector.” The 2010-2011 Investment Plan allocated \$13M for the Alternative and Renewable Fuel and Vehicle Technology Program http://www.energy.ca.gov/2009-ALT-1/index.html
Recovery Act – Energy Efficiency and Conservation Block Grant Program	U.S. Department of Energy EERE (Intergovernmental Program)	Recovery Act – Energy Efficiency and Conservation Block Grants \$250,00 Total funding for the EECBG Program under the Recovery Act totals = \$3.2B <ul style="list-style-type: none"> • \$2.7 billion will be awarded through formula grants. • Funding Opportunity Announcement (FOA) for allocation of approximately \$454 million through competitive grants. • Use of Funds includes transportation programs to conserve energy and support renewable fuel infrastructure.
Prop 84	Department of Conservation	The Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006 (Proposition 84) Santa Monica Sustainable community Funding Prop 84, \$280,000. http://bondaccountability.resources.ca.gov/p84.aspx
Prop 50	State Water Resources Control Board	Chapter 5 Clean Water and Water Quality (Gross Funding total: \$100,000) Chapter 8 Integrated Regional Water Management (\$280,000)
Green Building Incentives	City of Santa Monica	Building permit fee waiver for solar projects Expediting permitting for green buildings
Residential Energy Tax Credits	IRS	30% Tax Credit, no limitations

Budgetary restraints have impacted the availability of some of the solar rebates at this time.