Hydrogen City

Group 5 – Knights of the Curved Table

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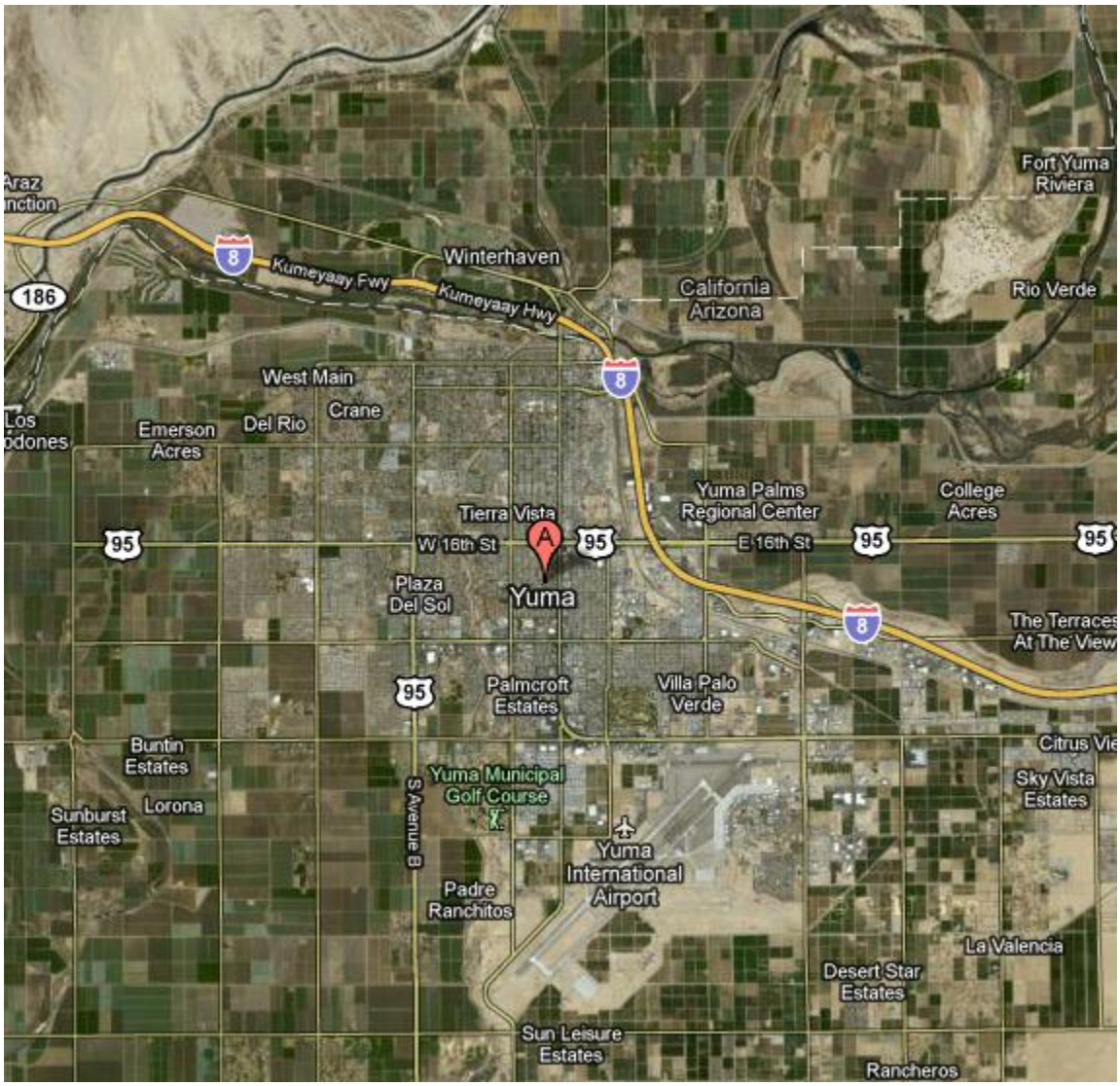
Introduction:

- Problem Statement – Our task is to create a concept design for a sustainable hydrogen fuel station that will eventually replace current liquid gasoline stations for a given city. The station must provide enough H_2 and HCNG (Hydrogen/Compressed Natural Gas combination) to meet all the demands of a city.
- Design Criteria – Our concept design must meet all the fuel needs of our chosen city, as it will completely replace the current predominant fuel source. The concept must have a method for gathering methane, producing hydrogen, producing HCNG, and providing all the energy to power the station and its various processes. The station must be completely self sustaining, ridding our dependence on fossil fuels to power our stations and vehicles. In order to provide the amount of energy we need, various forms of renewable energy will have to be utilized. We must also incorporate all common amenities provided by current station. Other considerations are the safety and environmental impact of our station. We are assuming for this project that there is an established market for vehicles that use H_2 and HCNG. We are also able to choose our own city where our design will be located.
- City – The city where our design will be incorporated is Yuma, AZ. It has a population of approximately 91000 people (2008, www.visityuma.com). Historically, Yuma is one of the sunniest locations in the US, wind speeds average ~11 mph, and the Colorado River runs right along the cities borders. All of these factors make it prime location to take

advantage of various forms of renewable energy like solar, wind, and hydropower. The South Yuma landfill is located approximately 30 minutes outside the city and can serve as a resource for methane. Below is a satellite image of the city.



Demand Analysis:

- Upon analysis of vehicle throughput of similar stations already in place, we determined that for a relatively small station approximately a 200 car/day throughput was an accurate estimate for each station. This number is also backed up by a study done by Pike research which states that a station would only be cost effective if it provided for that amount of

cars per day. Using registered vehicle numbers compiled by the Bureau of Transportation Statistics, we've determined that approximately 40% of vehicles will require HCNG as a fuel. Currently, hydrogen and HCNG powered vehicles are projected to need 3-5 kg per fill-up on average. Assuming all other vehicles that don't use HCNG require hydrogen, our station will have to provide 360-600 kg of hydrogen fuel (120 vehicles x 3 or 5) and 240 – 400kg of HCNG (80 vehicles x 3 or 5) daily, per station. For the total number of stations needed, we assumed that each person fills their vehicle once per week. This translates to serving 1400 vehicles per week per station. Although the actual average number of people per vehicle is around 1.6, we rounded up to 2 people per vehicle so we weren't accounting for partial people. With a population of 91000 people and estimating 2 people per vehicle, 45500 vehicles must be served per week. Therefore, 45500 vehicles/week divided by 1400 vehicles/station/week means that to provide for the entire city, 32 stations will be required.

- When choosing our city, our group focused primarily on the availability of natural energy resources. In order to make the station as sustainable and as cost efficient as possible, we wanted to consider all forms of renewable energy. Also, as long as landfills are necessary, they should be capped (enclosed) so that methane can be captured for use. Not only will this benefit whatever industry that chooses to harness the methane, but it will also prevent it from being released into the atmosphere. As a general rule of thumb, it's advisable to use public transportation or car-pool whenever possible. Less vehicles on the road; less fuel must be provided. Another option for future vehicles is photolysis. Using Photoelectrochemical cells (similar to PV cells), sunlight can be used to split water into hydrogen and oxygen. Theoretically if this system were to be installed directly onto

vehicles, the only fuel needed to power a car would be water. The splitting could be done onboard the vehicle to provide hydrogen to the fuel cell, although this technology is currently highly experimental.

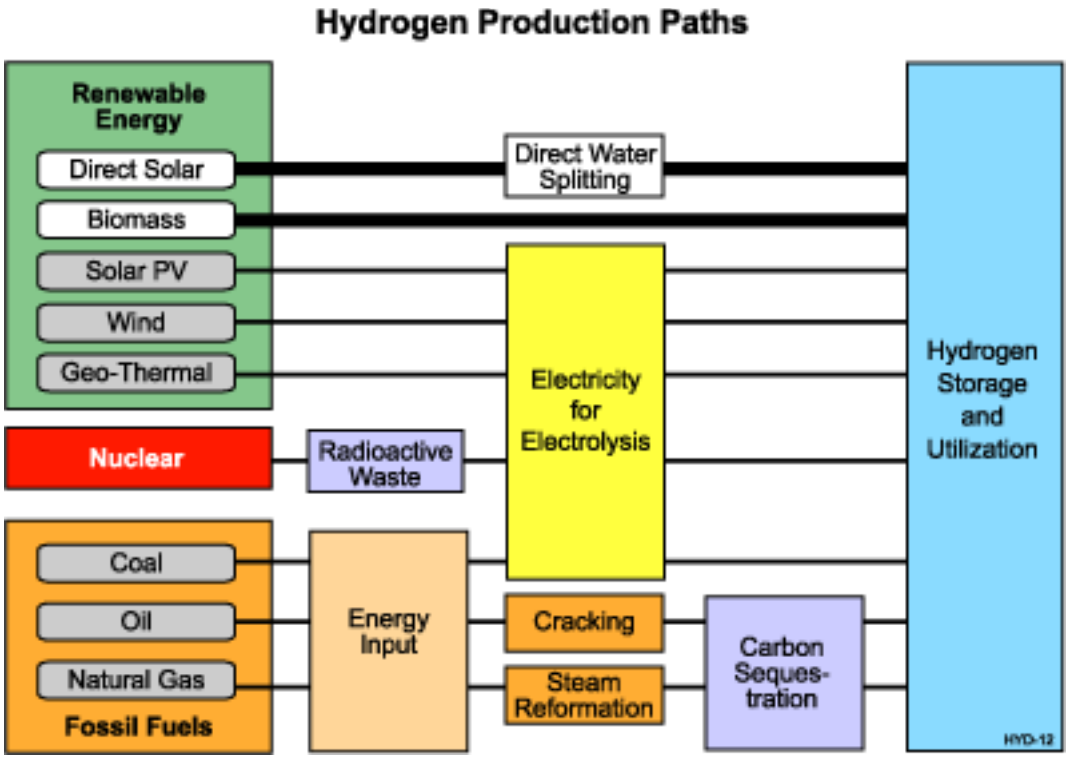
- Travel patterns likely vary between seasons. More people likely use vehicles in the winter as oppose to biking or walking in the summer months. To account for this variation, all of our calculations from here on forward will be on the maximum end of the spectrum, IE providing the maximum amount of hydrogen and HCNG per day.

Sources for Introduction:

http://www.cea.fr/var/cea/storage/static/gb/library/Clefs50/pdf/047a048luzzi-gb.pdf

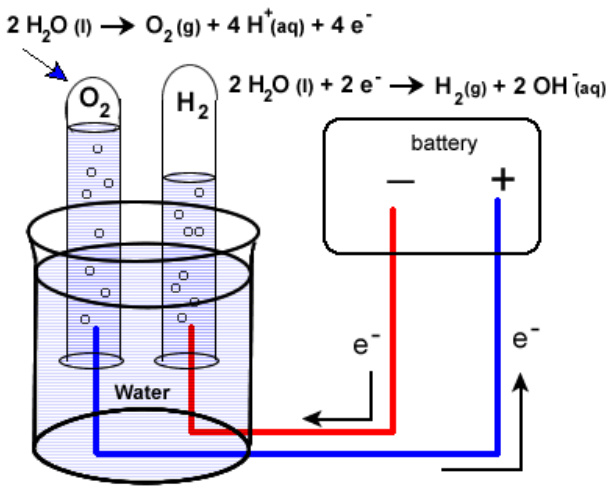
www.pikeresearch.com

Preliminary Concept Design:



Hydrogen Production Methods

I. Electrolysis



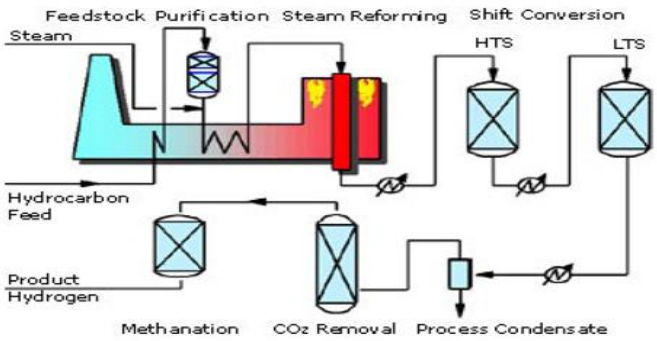
- Electrolysis convert water into hydrogen and oxygen using a electric current. This process is beneficial since the only **waste product is oxygen.**

- 50-79 kWh is needed to produce 1kg of hydrogen

  So since we need 680kg of hydrogen a day the calculations come out as fallows

  50kWh x 680kg = **34,000kWh** a day to produce hydrogen for our station using electrolysis.

II. Steam Methane Reforming



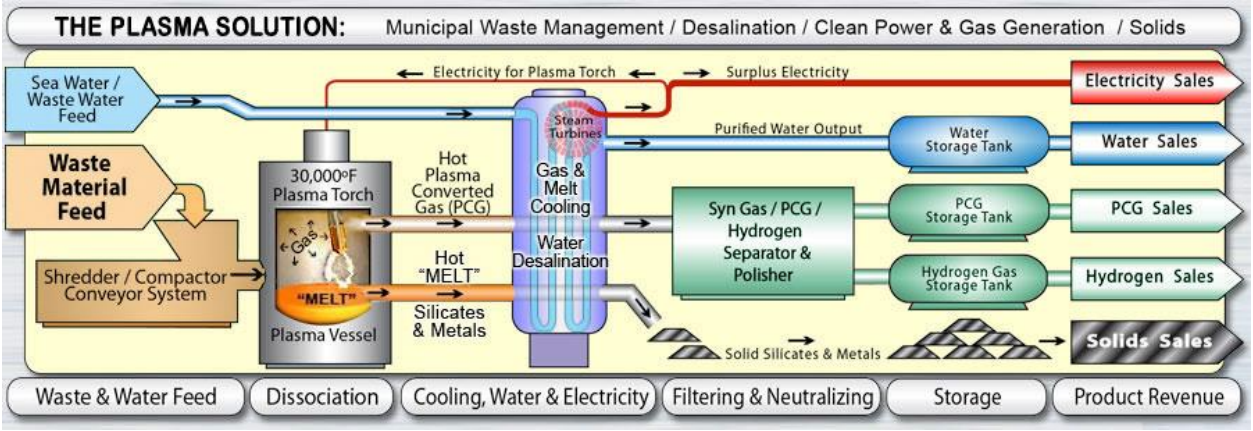
- Steam methane reforming converts a hydrocarbon like methane into hydrogen through use of super heated steam. This process yields a **waste product of carbon dioxide**.

- 2-2.5kWh is needed to produce one cubic meter of hydrogen

  Since we need 680kg of hydrogen a day this can be converted into 7560.04 cubic meters of hydrogen the calculations are.

  2kWh x 7560.04 cubic meters = **15120.08 kWh** a day to produce hydrogen for our station using steam methane reforming.

III. Plasma Reforming



- Plasma reforming uses a hydrocarbon like methane input and converts it into hydrogen by use of a high temperature plasma torch. The only **waste product is compressed carbon.**

- .1-.2kWh is needed to produce one cubic meter of hydrogen.

We know that we need 7560.04 cubic meters of hydrogen a day so the calculations are .1kWh x 7560.04 cubic meters = **756 kWh** to produce hydrogen for our station using plasma reforming, on the low end.

Selection Matrix:

When choosing which method of hydrogen production would be best for our design electricity usage was the biggest factor. Since we need to make the station sustainable we would need to be able to produce the energy by renewable means. Based on this factor plasma reforming was by far the best. Next we looked at waste product we didn't want our station producing carbon dioxide or monoxide since these are considered green house gases. This factor eliminated steam methane reforming for us. Our other biggest concern was safety but after reviewing each process we determined that they were all inherently safe and that no matter what we picked nobody

would be put in any type of danger. *After our analysis we determined that Plasma Reforming was the best option currently available for sustainable hydrogen production.*

Sources for Plasma Reformation:

http://www.theplasmasolution.com/

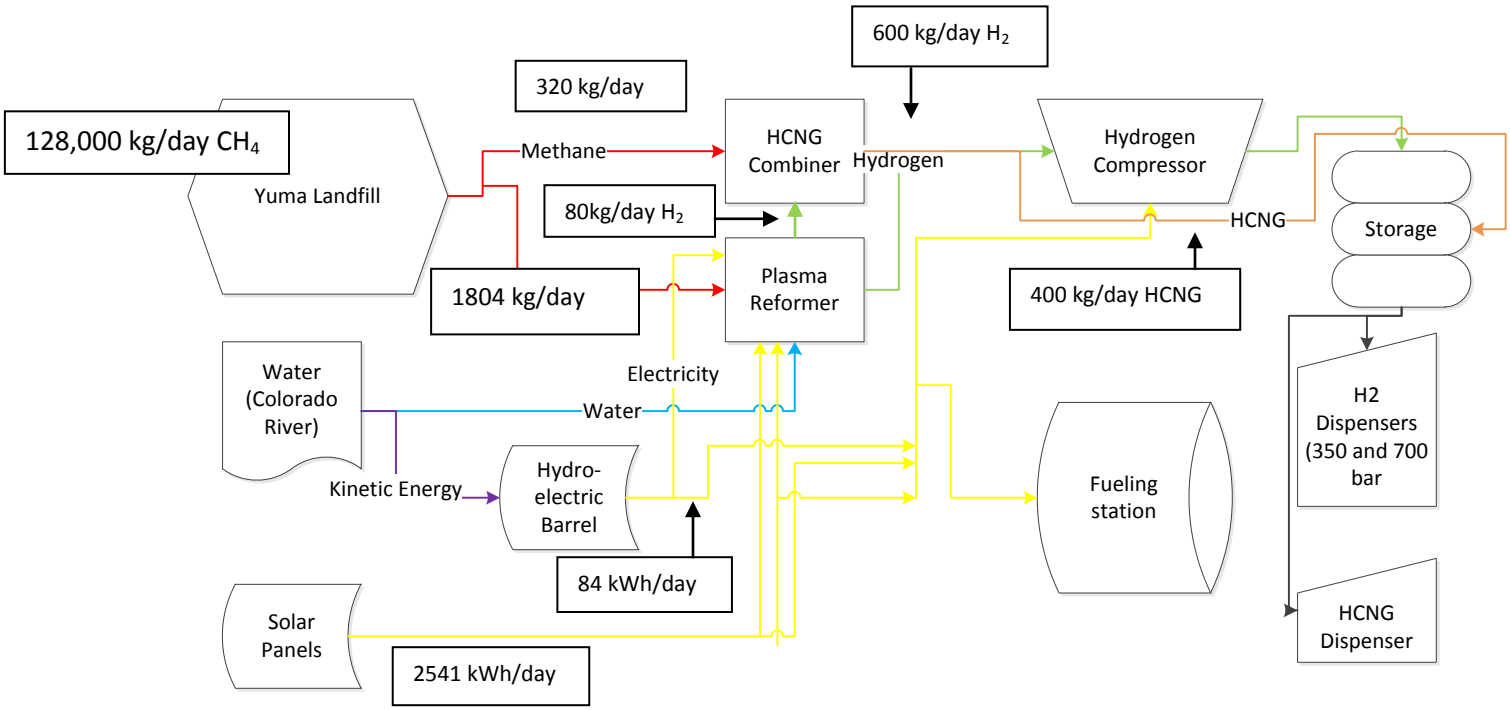
http://www.making-hydrogen.com/steam-reforming-hydrogen.html

http://www.saskschools.ca/curr_content/chem30_05/6_redox/redox3_3.htm

http://books.google.com/books?id=p30j25f-7kkC&pg=PA43&lpg=PA43&dq=efficiency+of+plasma+reformer&source=bl&ots=znBAmz2v- o&sig=0nVGjP212ZdhCvOMXJQMTJKprd0&hl=en&ei=_pqsTdOhMov2gAexpOTzBQ&sa=X&oi=book_result&ct=result&resnum=2&ved=0CCAQ6AEwAQ#v=onepage&q=efficiency%20of%20plasma%20reformer&f=false

http://www.fsec.ucf.edu/en/consumer/hydrogen/basics/production.htm

<u>Station Concept Description:</u> All numbers are on a per day – per station basis system, except for the amount of methane collected from the landfill.



- Our final design concept for Yuma, AZ is based on using several renewable energy resources and a landfill to provide all the necessary resources. Below is a breakdown of all the resources and calculations to determine energy cost.

1. **Methane Production and Use:** Our design utilizes methane captured from the South Yuma landfill located outside the city. The capacity of the landfill is 2.5 million cubic meters by volume and 2.6 million Mg by mass. Therefore the density of the landfill is 1.04 Mg/m^3. In order to use the methane collection calculations, this number must be

converted into lbs/yd^3. After converting, this number is approximately 1750 lbs/yd^3. To determine the methane collection by volume the following equation is used:

The ratio of 1750/1200 is a correction due to the fact that this equation was derived from a landfill that had a density of 1200 lbs/yd^3. After converting the volume of our landfill to foot-acres and plugging into the equation, it was determined that our landfill would provide 6,650,000 ft^3/day. Converting this number to kg/day yields 128,000 kg/day of methane provided. As you can see from the system schematic, each station needs 320 kg collected per day for HCNG, assuming a mixture of 20% hydrogen, 80% methane, and 400kg HCNG needed per day. We calculated the amount of methane needed to produce our hydrogen using the following molecular equation for methane reformation:

In other words, for every mole of methane consumed, 3 moles of hydrogen gas are produced. We know that we need 600 kg/day of H_2 for hydrogen fuel and 80 kg/day of H_2 for HCNG fuel, so 680 kg/day total. Using the molecular weights of hydrogen and our known amount of hydrogen needed, we can use the following equation to determine the amount of methane needed:

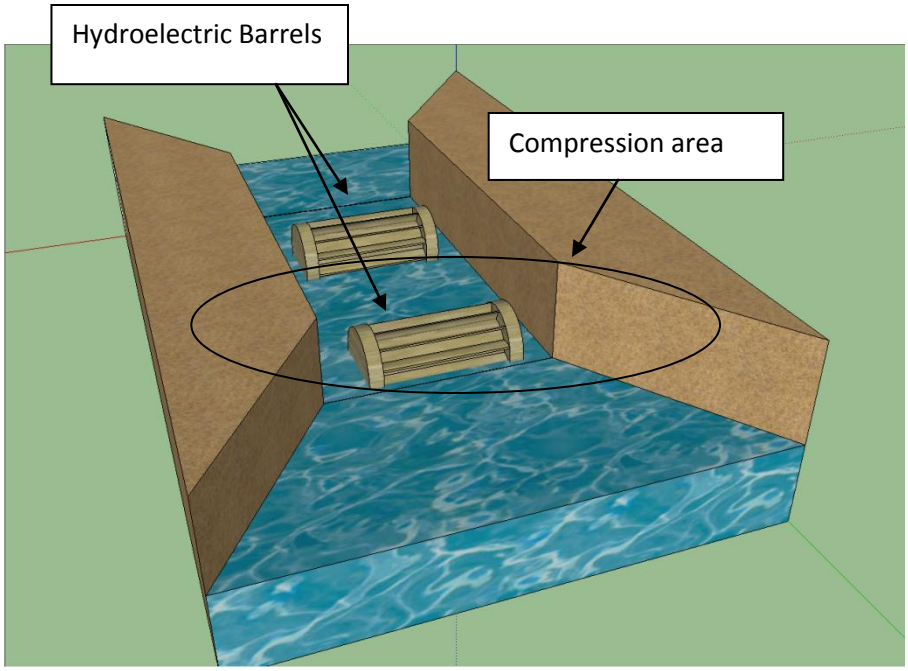
In total, each station requires 320 kg/day + 1804 kg/day = 2124 kg/day/station. Divide the total amount of methane collected per day by the methane needed for each station and we are able to provide for (128,000kg/day)/(2124kg/day/station) = ~60.3 stations. As you can see, our landfill is capable of providing for almost double the amount of proposed stations. However, even

though our landfill is capped, collecting the methane may not be a 100% efficient process. Also this is assuming the landfill is filled to capacity which is unlikely.

2. **To Produce and Compress Hydrogen:** Using our chosen method of producing hydrogen, plasma reformation, we need 1500 kWh to produce the required amount of hydrogen per station. This is an over-estimate, assuming it always takes .2 kWh/m^3 to produce hydrogen using this process. After the hydrogen is produced, it travels to either the HCNG combiner or to storage tanks. In order to compress the hydrogen to 700 bar and 350 bar, we must provide 1.36 kWh/kg and 1.05 kWh/kg, respectively. If we are to provide equal amounts of the two pressures, 300 kg of each must be compressed. The energy required to compress hydrogen to 700 bar is then 300 kg x 1.36 kWh/kg = 408 kWh, and for 350 bar it is 300 kg x 1.05 kWh/kg = 315 kWh. In conclusion, in order to produce and compress the amount of hydrogen required, we need to provide 2223 kWh.
3. **Energy Costs for the Station:** According to a study done by the University of Victoria, the energy required to run the station is as follows–
    - Dispenser**:** 2 kWh per dispenser
    - Exterior Lighting: 1 kWh
    - Interior Lighting and Services: 1 kW

    Assuming 24 hour operation of the station, the lighting and services would require 48 kWh/day of energy. If the average fill up time for a car is 5 minutes, then the pumps will operate for a total of 1000 minutes per day, or 16.7 hrs. Therefore the pumps will require an energy input of 200.9 kWh/day, bringing the total to operate the station to 248.9 kWh/day per station. *The total amount of energy required per station per day is 2471.9 kWh.*

4. **Providing the Energy:** Our station utilizes 2 forms of renewable energy, solar and hydroelectric. The form of hydroelectric power we are using is a developing technology known as a Hydroelectric Barrel. These are a developing technology but are highly feasible. Essentially, the Hydroelectric Barrel is a water wheel which uses the kinetic energy to turn a generator. The system is light, and easy to transport and install. Its environmental impact is also minimal, as it simply sits on top of the water and has a fairly small foot print. The output of one barrel can be as high as 3.5 kW for the 2 meter diameter model; however this requires a water flow speed of 5.5 mile per hour. Due to the cities proximity to the Colorado River, the river is the perfect installation point for the barrels. If in the event the water speed is not high enough at that point, our team has designed a simple system that could increase the rate of water flow. Basic fluid physics says that if you decrease the area of water flow, but volume remains constant, the pressure, and therefore velocity, through the area will be greater. A simple example of this principle is holding your thumb to the end of a running water hose. The barrels are also suspended freely, meaning they can adjust to a rise in water level, and can virtually be placed in any area with running water. A 3-d representation of this proposal is shown below.



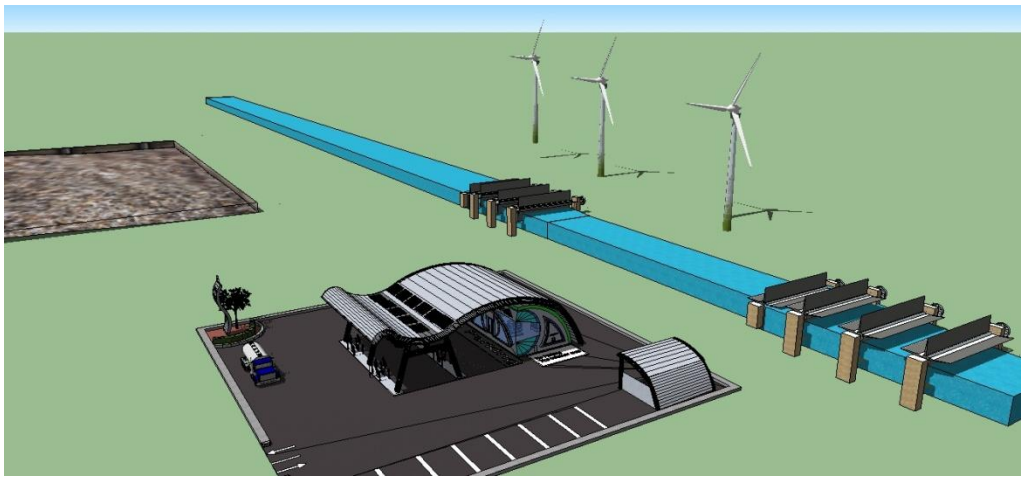
The simple but effective design will allow us to increase the energy output of the barrels significantly. Also, the physical alteration of the river doesn't have to span the entire width of the river and could only take up a small section, again minimizing the environmental impact. With 1 barrel per station operating at 3.5 kW running for 24 hours per day, each station would receive 84 kWh per day.

The next source of power we considered was solar. Yuma is annually listed as one of the sunniest locations in the continental United States, so harnessing solar power was a given. However, we wanted each station to be self sufficient, without having to rely on a large PV array field or a distributed PV system. For this reason, many PV systems wouldn't meet our needs for providing enough power while keeping the station footprint at a minimum. Our final solution was to use the HD16-21 concentrated solar system. This system uses mirrors to reflect light onto a receiver plate to maximize the energy captured by the sun. This system runs optimally at 21 kW, and if it's possible for the system to

receive 11 hours of sunlight per day, each panel could produce 231 kWh. To fill our remaining need for energy we would need 11 panels for a total of 2541 kWh/day per station. In summary:

As you can see, we actually produce more power than we need, and the Hydroelectric barrel could be dismissed altogether. However this shows the versatility of our system, and how it can be adapted to any sort of environment to produce the best results for a minimum amount of money.

We also examined wind power which was also a very feasible option, and could easily be considered for another location. Since our design requires every station to be self-sufficient this would require a wind turbine at every station, and while they produce plenty of power, they can be an eye-sore for some consumers. The figure below demonstrates the use of all of our systems working together in our final concept.



Sources for Concept:

http://www.h2fuelstation.com/documents/H2_Station_Design_Final.pdf

http://www.hydro-electric-barrel.com/index.html

http://hdsolar.com/pages/technology/hd16.htm

http://www.hydrogen.energy.gov/pdfs/9013_energy_requirements_for_hydrogen_gas_comprcompre.pdf

Economics:

•Station Cost

CAPITAL COST ESTIMATION GUIDE			
EDSGN 100 Spring Semester 2011 Fueling H2 City Project			
All costs are for representative purposes only			
Filling System Installed Costs			
(including piping, instrumentation, and ancillary components)			
		Inputs:	
Number of people in city		91000	people
Average miles driven per person		13500	miles/person/year
Miles driven per kg of H_2		60	miles/kg H_2
Number of stations		32	
Number of pumps, 350 bar		2	
Number of pumps, 700 bar		2	
Number of HCNG dispensers		2	
Area of station		1673	m^2
Hours pumping per day		16	hours
Labor rate, $		10	$/hr
		Outputs:	
Total private vehicle miles driven by all people		1,228,500,000	miles driven/year
H_2 used per mile		0.0167	kg H_2/mile
H_2 used per year, all people		20,475,000	kg/year

H_2 used per day, all people		56096	kg/day
H_2 used per day, per person		0.62	kg/day/person
H_2 working storage capacity		1753	kg
Flow rate H_2		1.826	kg/min
HCNG used for entire city		400	kg/day
HCNG flow rate		0.417	kg/min
HCNG working capacity		12.500	kg
H_2 Fueling station costs			
H2 compressor system, 350 bar	180000	$ 258,332	
H2 storage system, 350 bar	38000	$ 3,357,780	
H2 dispenser system, 350 bar	5000	$ 10,000	
H2 compressor system, 700 bar	260000	$ 373,146	
Cooling block/chiller system, 700 bar	90000	$ 129,166	
H2 dispenser system, 700 bar	60000	$ 120,000	
CNG compressor, 250 bar	80000	$ 47,311	
CNG storage system, 250 bar	28000	$ 127,439	
HCNG blend system	30000	$ 17,742	
HCNG dispenser	50000	$ 100,000	
Balance of Plant	210000	$ 210,000	
Other Costs			
Land, purchased and developed	50	$ 83,650	
Buildings, finished and furnished	3000	$ 5,019,000	
Onsite H2 production (all methods)	9500	$ 0	
Per station	Total=	$ 9,853,567	
Total investment (First cost)		$ 315	Millions
Sales			
Volume of H2 sales		56096	kg/day
Volume of H2 sales (Number of units sold annually)		20475000	kg/yr
Volume of HCNG sales		400	kg/day
Volume of HCNG sales (Number of units sold annually)		146000	kg/yr
Salaries		$ 160	$/day
Salaries (PV Annual Cost)		$ 58,400	$/yr

From this chart we take our station cost of **$9,853,567**

•Sustainability Cost

Hydro electric power supply-
Hydro Electric Barrel
1500-3000 British pounds for 2 meter version
so $2477.85- $4955.70 cost prediction from Mike Lowery

$4955.70 x 1 barrels = $4955.70 Total

Solar panel energy-
$50,000 per panel estimate x 11 panels = $550,000 Total

Plasma reformer-
$4,090,000 per reformer x 1 reformer = $4,090,000

Total sustainable cost per station = $4,644,955.70

•Total Stations cost :
$4,644,955.70 + $9,853,567 = **$14,498,522.70 per station**

Start Up Costs

$14.5 million x 32 stations = **$464 million**

Operating Costs

- Methane needed per day 94,839.60 m^3 x $.247/$m^3$ = $23,925.40 per day x 365 days a year = **$8,732,771 a year for methane***

- Salaries
  from chart above $58,400 per year/station x 32 stations = **$1,868,800 a year in salaries**

$8,732,771 + 1,868,800 = **$10.6 million a year**

Customer Cost / Profit

Hydrogen cost / kg	Approximate fill up cost	Profit per station / year	10 Year Profit
$5.50	$27.50	$12,000	3.84 million
$7.10	$35.50	$520,000	166.4 million
$10.00**	$50.00	$1,450,000	464 million

***Note:** This number was determined assuming that we would only collect the necessary amount of methane to provide for our stations.
****Note:** As hydrogen fueling stations become more prevalent demand for hydrogen fuel will increase and price to fill up your vehicle could become comparable to gasoline fill ups if necessary for profit.

www.advancepower.net

Conclusion:

As our calculations show, we have analyzed and developed a sustainable fueling system for the entire city of Yuma, Arizona. Not only is our design highly accurate and efficient but it also has the possibility to be reproduced large scale anywhere in the world. The three options for producing electricity for our system include hydro-electric water barrels, a wind turbine, and solar panels located on top of our stations. Through use of hydro, solar and wind power options, our stations are able to produce all of the energy they need to operate. These systems can be interchanged to produce the needed energy for our station. Design options range from using all three in combination, to using only solar to power the whole station. In this way, if the environment lacks wind speed or a flowing water source, it will still be able to utilize our design concept.

The key feature to our design is our plasma reformer which produces all of the hydrogen that our systems need onsite. Not only is this system cost efficient, but it is also environmentally friendly in the waste it produces. Under current conditions the plasma reformer is the best solution for producing hydrogen available. It is over ten times more efficient than other methods like steam methane reformation and electrolysis. Plasma reformation also opens the door to possibilities of power generated from steam generators located in its core. Once this technology is developed, the whole reformer will be able to power itself and part of the electrical needs of

the station, while creating clean water that can be recycled through the processes or distributed among local populations. The small size of the reformer also allows for maximum flexibility. The source of methane that will provide the city with hydrogen comes from a large capped landfill located right outside of the city. This design aspect will be easily reproduced around the country considering most large cities have at least one landfill in proximity. By capping each landfill, twice as much methane can be collected yielding higher amounts of hydrogen being produced. Also, capping landfills will prevent greenhouses gases from being released into the environment as most landfills currently do.

The completely sustainable and recreate-able design of our project are the biggest selling points, however, it will still bring in high profits. The station can sell hydrogen at very competitive prices while still turning a profit. To maximize profits though, hydrogen can be sold at price comparable to a gasoline fill up. By using this method investors could turn a profit of around 464 million dollars in just ten years. That is a hundred percent profit over a ten year period. This means that it won’t be hard to find investors in our design. By having a renewable process for creating hydrogen, we can decrease dependence on fossil fuels and by utilizing this concept all over the world; we can make all transportation systems completely sustainable and renewable.