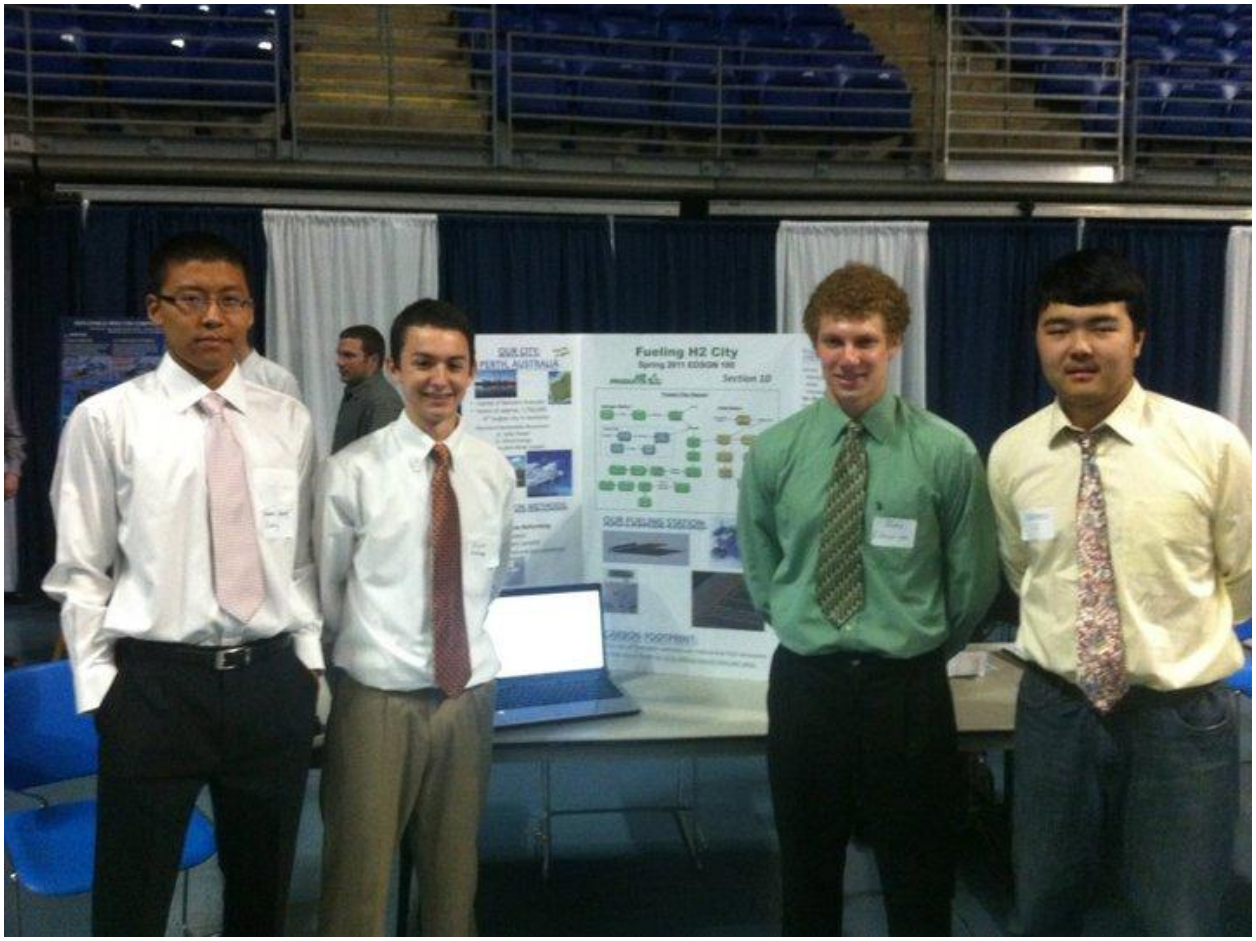
Fueling H_2 City

E-Design 100



Section 10

Group 6

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I Introduction:

The goal of this design project was to convert the transportation system of a city that relies on conventional fossil fuels to one that can be supplied with Hydrogen and HCNG. We were to select a real city and based on economic, geographic, and demographic factors, design a hydrogen and HCNG fueling system incorporating methods of production, transportation, and distribution. The project must have realistic real-world applications, as well as being economically feasible.

Mission Statement:
Our fueling system will utilize hydrogen produced from renewable resources to fuel the city of Perth, Western Australia, and in doing so create a transportation system that is more sustainable, environmentally friendly, and set an example for the world that green energy is the path to a healthy future.

Design Criteria:
Our fuel stations must supply hydrogen at both 350 Bar and 700 Bar, as well as hydrogen/natural gas blends containing up to 30% hydrogen at 250 Bar. Our system must have enough distribution capability to supply the fuel needs of the entire city, with the assumption that hydrogen fuel cell and HCNG vehicles are available.

Our City:
The city we selected for our design project was the city of Perth, Australia. This city of 1,750,000 people and 2,079.5 sq miles is located in southwest Australia. It is the capital city of Western Australia and acts as the economic and political center of the region. There is a high potential for the use of renewable resources due to the high solar exposure, significant wind energy, and coastal water sources. Perth was also chosen because of its progressive attitude toward green energy and the government's support of green initiatives. Australia's close political and financial ties to the United States also allow for the potential of foreign investment and technology.

II Demand Analysis

<u>The following is the demand of HCNG and H_2 fuel of Perth:</u>

Total number of buses in Perth: 122

We estimate that half the busses will operate on H_2 and half on HCNG

H_2 fuel buses: 61

HCNG fuel buses: 61

We assume both H_2 fuel bus and HCNG fuel bus: 30kg fuel/day (1 tank/day)

So, for buses, H_2 demand=30kg/day * 61=1,800kg/day

HCNG demand=1,800kg/day

By producing this amount of HCNG and H_2, 1,260kg CH_4/day and 2,340kg H_2/day

Small cars that need H_2 fuel: 831,250

We assume the need of small car: 0.17kg H_2/day *car

So, for small cars, H_2 demand=0.17kg /day/one * 831,250=145,000kg/day

So, the future Perth needs 147,340kg H_2/day and 1,260kg CH_4/day

The following is data for fuel use and distance driven by vehicles in Perth:
Consumption of automotive gasoline in Australia: 1.92×10^{10} liters per year

- Western Australia accounts for 34% of this total
- Perth contains 76% of the population of Western Australia
- 1 liter = 0.26417 gallons

1.92×10^{10} gal x .34 x .76 x 0.26417gallons/liter = 1.31×10^{9} gallons of gasoline

1.31×10^{9} gal x 8.8kg CO_2/gal x 1 metric ton/1000kg = 15.09 million metric tons CO_2 per year in Perth (using gasoline)

Average CO_2 emissions: 222.4g/km (2008 Australia)

15.09 million metric tons CO_2 x 1km/.2224kg = 6.785×10^{10} km driven per year

Transportation Recommendations:
In order to further reduce fuel consumption, we recommend that Perth encourages use of public transportation and practices such as car-pooling, biking, and even walking if the distance is reasonable.

Seasonal Variations:
Statistics have shown that fuel consumption is higher in the summer due to the increase in driving by citizens. Luckily, this rise in fuel demand matches the time period when solar intensity is the greatest, allowing a higher rate of hydrogen production to meet the demand.
We also considered the possibility of utilizing alternative resources to boost hydrogen production when environmental conditions do not provide enough energy, such as low solar intensity during the winter or in bad weather.

III Concept Development

Potential Concepts:

1) **Steam Methane Reformation**

Steam reforming of natural gas or syngas, sometimes referred to as steam methane reforming (SMR), is the most common method of producing commercial bulk hydrogen, as well as the hydrogen used in the industrial synthesis

of ammonia. It is also the least expensive method. At high temperatures (700 – 1100 °C) and in the presence of a metal-based catalyst (nickel), steam reacts with methane to yield carbon monoxide and hydrogen. These two reactions are reversible in nature.

$CH_4 + H_2O \rightarrow CO + 3\ H_2$

Additional hydrogen can be recovered by a lower-temperature gas-shift reaction with the carbon monoxide produced. The reaction is summarized by:

$CO + H_2O \rightarrow CO_2 + H_2$

The first reaction is strongly endothermic (consumes heat), the second reaction is mildly exothermic (produces heat).The United States produces nine million tons of hydrogen per year, mostly with steam reforming of natural gas. The worldwide ammonia production, using hydrogen derived from steam reforming, was 109 million metric tons in 2004. This SMR process is quite different from and not to be confused with catalytic reforming of naphtha, an oil refinery process that also produces significant amounts of hydrogen along with high octane gasoline. The efficiency of the process is approximately 65% to 75%.

This option is attractive because it is the most used method and has a relatively high efficiency.

2) Hydrolysis (Water Electrolysis)

Another method of producing hydrogen is by passing an electrical current through water molecules, causing their molecular bonds to be broken and producing H_2 and O_2.

In the water at the negatively charged cathode, a reduction reaction takes place, with electrons (e^-) from the cathode being given to hydrogen captions to form hydrogen gas (the half reaction balanced with acid):

Reduction at cathode: $2\ H^+\ (aq) + 2e^- \rightarrow H_2\ (g)$

At the positively charged anode, an oxidation reaction occurs, generating oxygen gas and giving electrons to the anode to complete the circuit:

Anode (oxidation): $2\ H_2O\ (l) \rightarrow O_2\ (g) + 4\ H^+\ (aq) + 4e^-$

The same half reactions can also be balanced with base as listed below. Not all half reactions must be balanced with acid or base. Many do like the oxidation or reduction of water listed here. To add half reactions they must both be balanced with either acid or base.

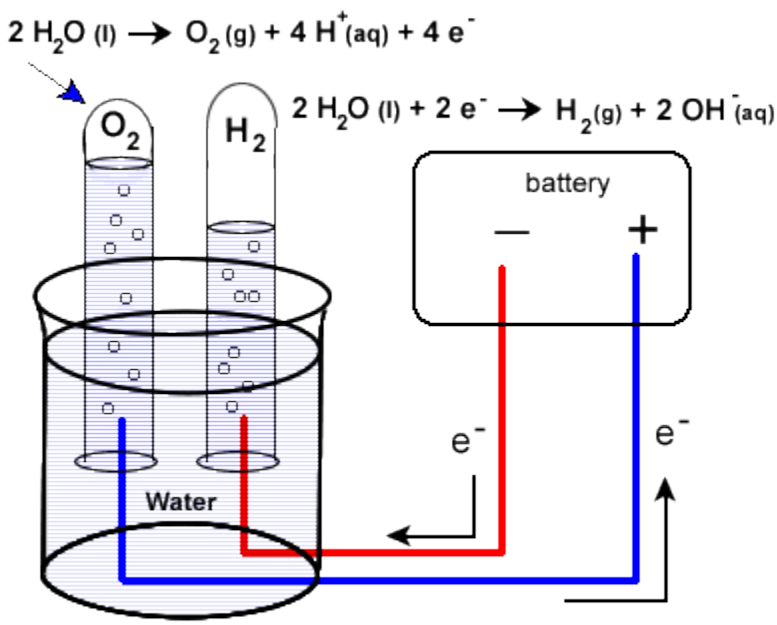
Cathode (reduction): $2\ H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2\ OH^-(aq)$

Anode (oxidation): $4\ OH^-\ (aq) \rightarrow O_2\ (g) + 2\ H_2O\ (l) + 4\ e^-$

Combining either half reaction pair yields the same overall decomposition of water into oxygen and hydrogen:

Overall reaction: $2\ H_2O\ (l) \rightarrow 2\ H_2\ (g) + O_2\ (g)$

The number of hydrogen molecules produced is thus twice the number of oxygen molecules. Assuming equal temperature and pressure for both gases, the produced hydrogen gas has therefore twice the volume of the produced oxygen gas. The number of electrons pushed through the water is twice the number of generated hydrogen molecules and four times the number of generated oxygen molecules.



3) Gasification

The gasification process is similar to that of steam methane reforming; in fact SMR is a particular branch of gasification. The general process of gasification involves reacting any carbon-containing material with controlled amounts of steam and oxygen at high temperatures, producing a syngas that can itself be used as a fuel source or further refined into pure hydrogen.

We decided against this process because of the higher emission levels relative to SMR and easily available supplies of methane.

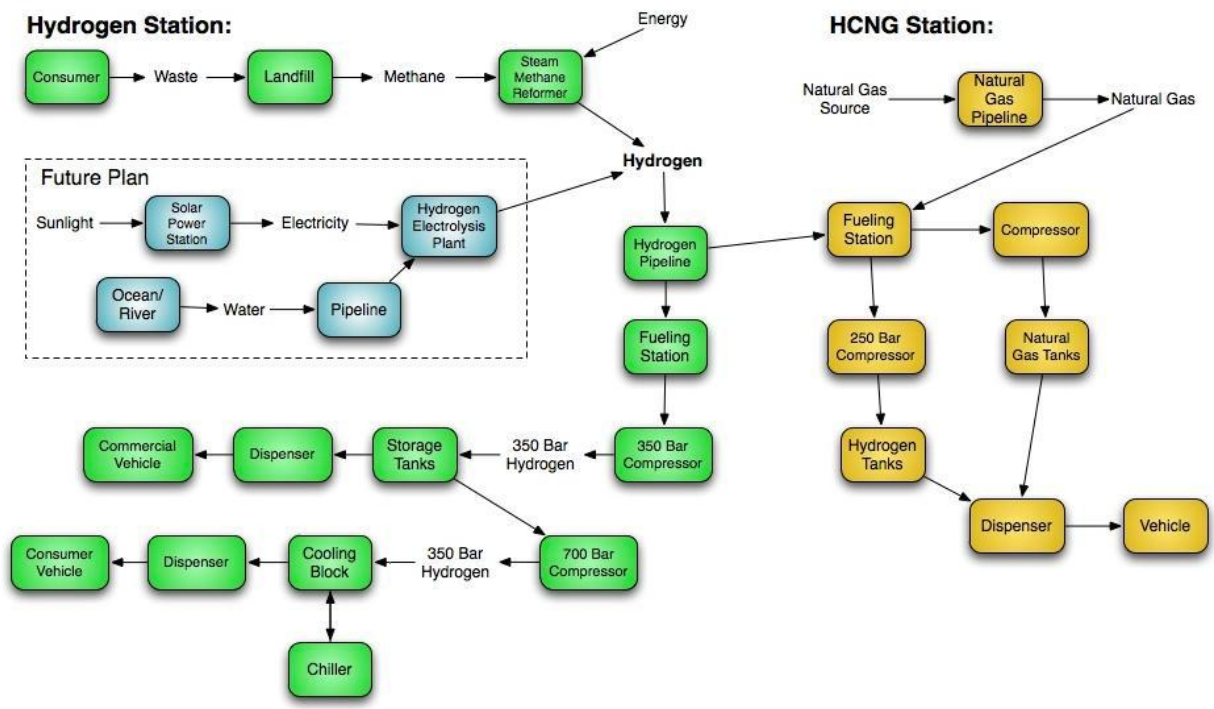
4) High-temperature Splitting

This process is a variation of water electrolysis that involves using water that is at significantly higher temperatures. This allows for a more efficient process because much of the initial heat is converted directly into chemical energy, requiring less electrical energy to be applied. This process is almost always used in conjunction with a nuclear heat source to produce the high-temperature water required.

This last detail is the reason we decided not to utilize this method because there is no nuclear heat source available to us.

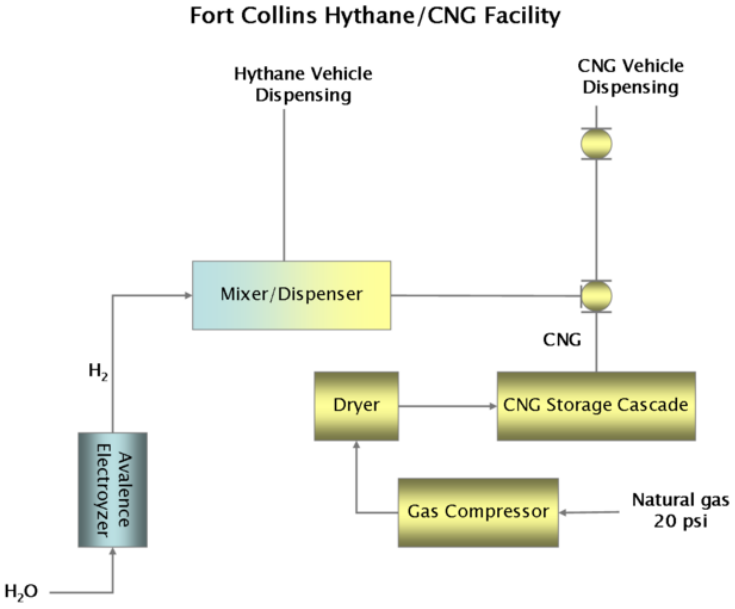
IV Detailed Concept Description

Process Flow Diagram:



The design for our H_2/HCNG fueling system will begin by using methane gathered from the nearby Tamala Park landfill to produce hydrogen via Steam Methane Reforming. This hydrogen will then be transported from the production facility in a gaseous form through a pipeline to the city of Perth, where the pipeline will then split into multiple smaller pipelines that will transport the hydrogen directly to each fueling station.

Once the H_2 reaches the individual fueling stations, it will be compressed to 350 Bar and stored in high-pressure tanks beneath the station. Some of the H_2 will then be further compressed to 700 Bar, chilled, and then stored in high-pressure tanks beneath the station. The hydrogen can then be drawn from the tanks to the individual dispensing pumps and distributed to the consumer through the dispensing nozzles.
In the case of separate mass-transit stations, which operate largely on HCNG, there is an additional natural gas pipeline which provides the natural gas for the HCNG blend. This is transported from Dampier, Australia via the Dampier to Bunbury Natural Gas Pipeline (DBNGP), which has a capacity of 785 TJ/day, easily enough to sustain our fuel system's needs.

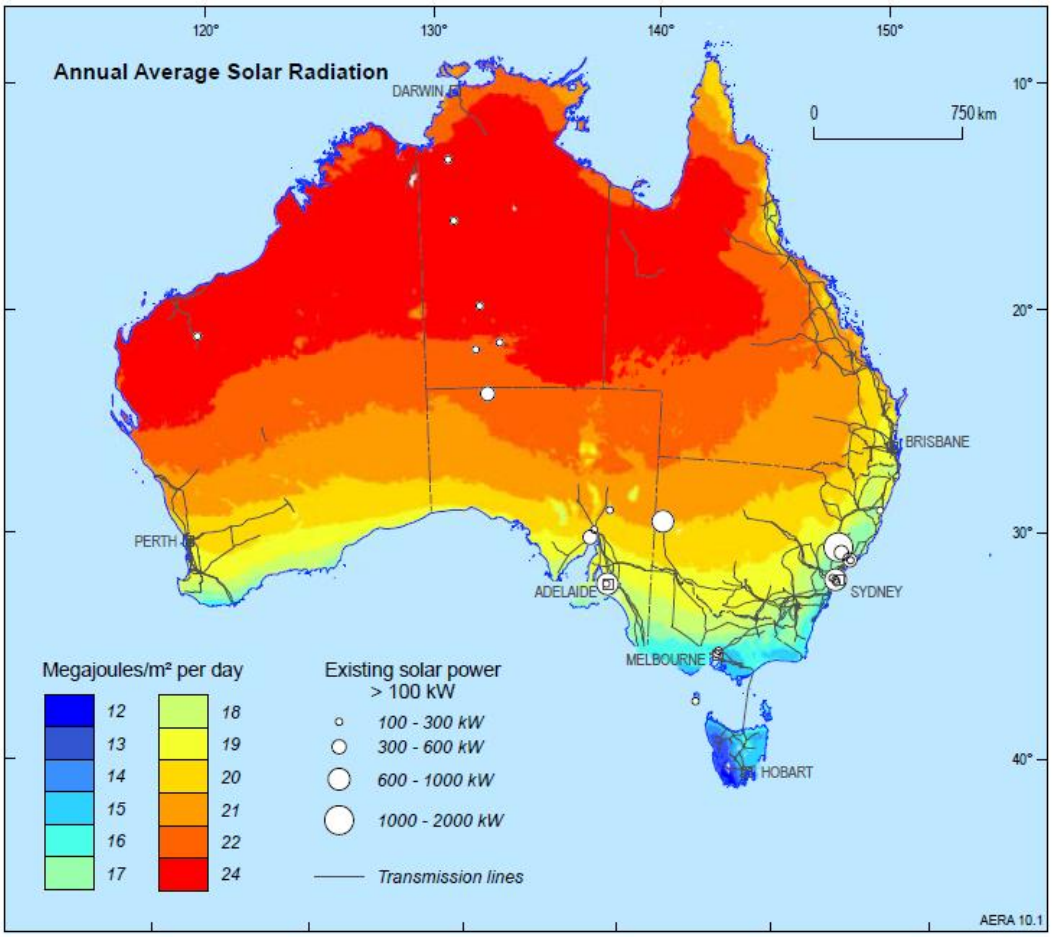


Tamala Park:
Tamala Park is also Western Australia's largest landfill Waste-to-Energy operation. Tamala Park is located approximately 31 kilometers north of Perth, in the City of Maneroo; the site comprises an area of 250 hectares; Last year (2010), some 280,000 tons of waste was sent to landfill at Tamala Park; the landfill should reach maximum capacity by 2020.

Long-term Goals:
The long-term goals of our fuel system are to convert from using steam methane reforming to hydrogen production via water electrolysis, which is a 100% "green"

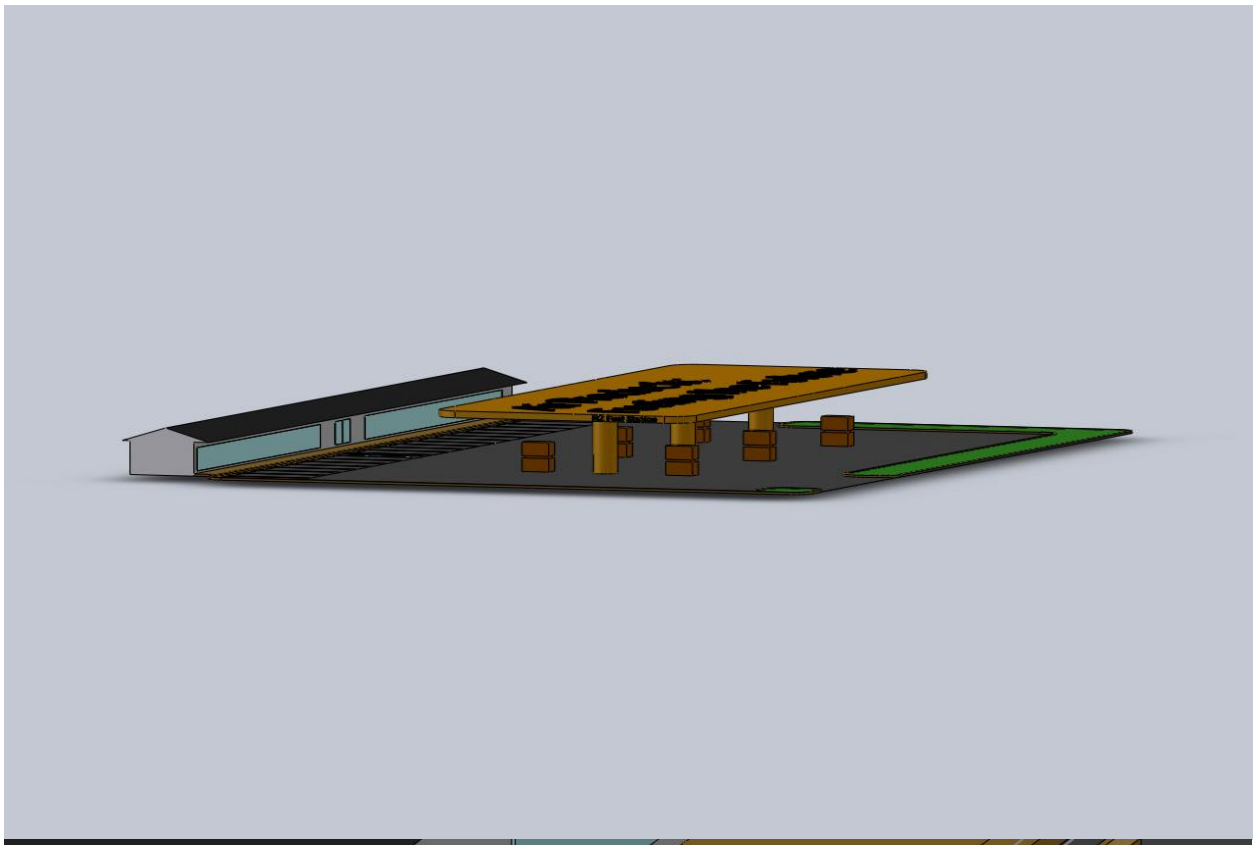
process. We plan to reinvest the revenue we receive from our hydrogen distribution via SMR into producing power plants that utilize solar cells and wind turbines to take advantage of the significant renewable resources of the region. The solar plant will be located in Carnarvon, located north of Perth due to the higher solar potential of this region.

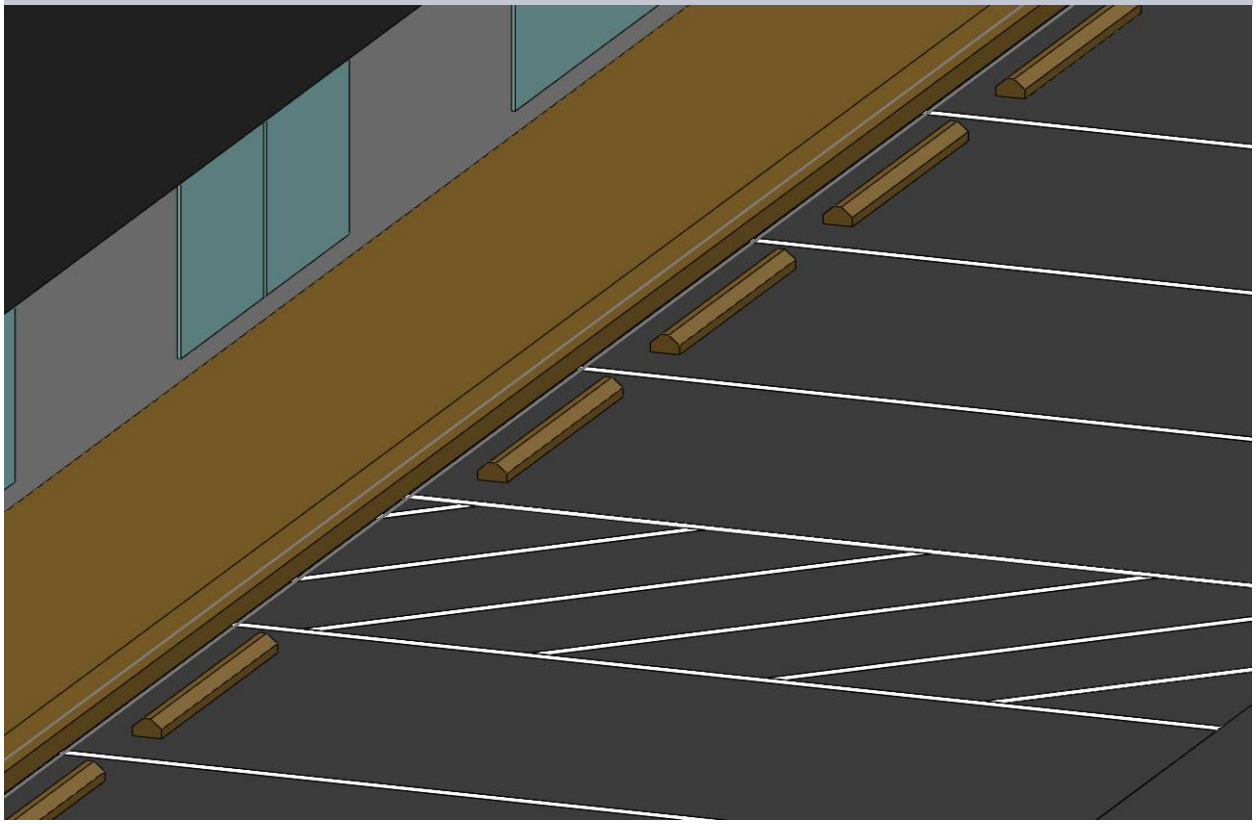
- Illustration of average solar radition



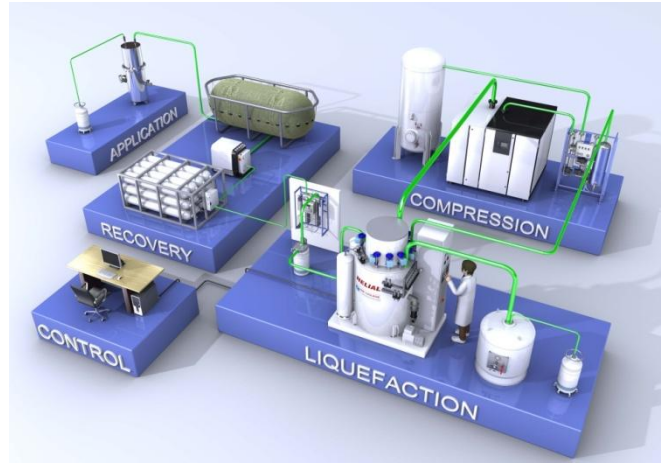
- Solar Panels similar to those that will be located in Carnarvon

CAD Model of our Fuel Station:





Economics:



Total hydrogen cost analysis in ten years

Discount rate	5.00%
First Cost	$90,000,000
Annual Cost	$303,200,000
Number of units sold annually	$62,050,000
Cost per Unit	$6.50

Year	First Cost	Annual Cost	Annual Income per Unit	comulative cost	cumulative income	payback
0	$200,000,000	$303,200,000	$403,325,000	$503,200,000	$403,325,000	($99,875,000)
1		$288,761,905	$384,119,048	$791,961,905	$787,444,048	($4,517,857)
2		$275,011,338	$365,827,664	$1,066,973,243	$1,153,271,712	$86,298,469
3		$261,915,560	$348,407,299	$1,328,888,803	$1,501,679,011	$172,790,209
4		$249,443,390	$331,816,476	$1,578,332,193	$1,833,495,487	$255,163,294
5		$237,565,134	$316,015,691	$1,815,897,327	$2,149,511,178	$333,613,852
6		$226,252,508	$300,967,325	$2,042,149,835	$2,450,478,503	$408,328,668
7		$215,478,579	$286,635,547	$2,257,628,414	$2,737,114,051	$479,485,636
8		$205,217,695	$272,986,236	$2,462,846,109	$3,010,100,286	$547,254,178
9		$195,445,423	$259,986,891	$2,658,291,532	$3,270,087,177	$611,795,645
10		$186,138,498	$247,606,563	$2,844,430,031	$3,517,693,740	$673,263,710
NPV	$200,000,000	$2,644,430,031	$3,517,693,740			
Profit %			23.7%			

The total cost is divided into two parts, fixed cost and annual cost. Fixed cost is the spending at beginning of 10 years; annual cost is like operating cost by using energy, repairing the machine.

In building hydrogen fueling system of Perth, the fixed cost includes the cost of solar panel, the building fueling station and delivery pipeline.:

Pipeline: The delivery length for the pipeline and truck is shown as a function of the number of refueling station.

$L_{pipeline}=\beta*N_{station}^{\gamma}$ (β=2.43,γ=0.4909)

=13.8km≈15km

Pipeline construction cost include installation and right-of-way cost about $600,000/km in urban area and pipeline material cost, about $20M.

Station: the cost of construction for a station is about $2M, in Perth, the estimated number of station is about 35, so the total cost for station is $70M.

Solar panel: we assume the production will occur in future, so the panel will become the most important in production. All the electricity for hydrogen electrolysis, compression, running of the shop will come from panel. The estimated cost of solar panel is about $110M.

So the total fixed cost at the beginning is about $200,000,000.

In building hydrogen fueling system of Perth, the annual cost includes the cost of producing hydrogen, storage cost, delivery cost.

The production of hydrogen: from information, the common method producing hydrogen is $4/kg, the demand of hydrogen in Perth is about 170000kg/day, the cost of producing hydrogen in a year is about $294M

Storage: we decide to store the hydrogen in both pipeline and underground, the total cost is about $2.5M.

Delivery cost: By using pipeline to deliver the hydrogen, the cost of compression and repairing the machine is about 7M/yr.

So the total annual cost per year is about $300,000,000/yr

The cumulative cost in first year is $300M+$200M=$500M, by using the model above (assuming the average discount rate in ten years is 5% in ten years) we got the total money cost in ten years is about $2800M. If we set the price at $6.5/kg, the company cannot make money until the third year. And the total benefit rate is about %6.5 in 10 years.

Number of hydrogen stations

First, find the amount of demand of hydrogen in the city of Perth by using the formula: Hydrogen Demand Density in Perth (kg H2/day/km2) = Population Density (324people/km2) x Vehicle Ownership (4/7LDV/person) x Market Penetration Rate (100%, because we assume all the cars use hydrogen fueling) x Fuel Use (0.17kg H2/day/vehicle)=31.47kg H2/day/km2.

Calculate the amount of hydrogen a station can store:
Fueling station capacity: number of car to be fueled=1000cars
H2 Production provide from each fueling station=1000cars x 5kg of H2=5000kg.

Aggregate hydrogen demand equals Hydrogen Demand Density in Perth x the area of Perth=170,000 Kg H2/dayThe number of fueling station =Aggregate hydrogen demand/H2 Production provide from each fueling station=34

So Perth will need nearly 35 hydrogen fueling stations.

Summary:

Initial Costs = $200,000,000
Annual Costs = $303,200,000
Annual Income = $403,325,000
Projected 10 Year Results:

- $3,517,693,740 Gross
- Profit Return = 23.7%
- Fuel Price = $6.50/kg

Safety

Primary Concerns:

1) Vehicle Safety
   - Strict regulations on tank design prevent leaks, ruptures, unintended ignitions
   - H_2 very light and diffuses quickly if leaked into the atmosphere, making it difficult to create conditions susceptible to explosive ignition, unlike a gasoline leak which tends to pool and emit a dense cloud of fumes

2) Transportation Safety
   - Gaseous hydrogen pipelines
     -in 2004, there were already 900 miles of pipelines in US and 930 in Europe
     -Similar in cost to CNG
   - Since hydrogen particles are very tiny, equipment needs to have improved seal technology in order to prevent leaks
   - H_2 is a highly reactive and therefore the pipelines must be made out of a corrosion resistant material
   - Fiber-reinforced polymer pipelines have been tested and proven as an effective solution

3) Fuel Station Safety
   - Storage tanks similar to those at gasoline stations but with different specifications and regulations
   - Slightly different procedure but the general process is very similar to traditional gasoline fueling
   - With the integration of multiple sensors and valves, the fueling process can be safely regulated and controlled with no greater risk to the consumer

There have been numerous studies and tests on the feasibility and safety of hydrogen as an energy source. Although hydrogen has properties different from gasoline, some which are beneficial, harmful, or just different, these studies prove that it is a substance which can be just as same, if not safer, than gasoline if the proper safety precautions are taken

V Conclusion

Design Summary:
In the short-term, our fueling system will distribute hydrogen and HCNG produced via SMR utilizing methane produced at the nearby Tamala Park landfill. This

hydrogen will be transported via pipelines to the distribution centers located throughout the city.
Our long-term objective is to create a 100% “green” system by producing our hydrogen through water electrolysis utilizing the substantial renewable resources located in the region.
The advantages of this design are that the initial and short-term costs are relatively low compared to alternative designs for hydrogen production and in the long-run the system is extremely sustainable and environmentally friendly, providing an effective and affordable hydrogen fueling system to the city of Perth.

Sustainability Considerations:
There are many things that can be done to make a transportation system more sustainable and converting to hydrogen is a good start. Some other possibilities are building roads and the vehicles themselves out of sustainable and renewable materials, designing a more efficient road system, greater utilization of public transportation, and many more. The possibilities are almost limitless; we just have to take the time to find them and invest the money to implement them.

Lessons Learned:
We learned a variety of things from doing this project. We learned that sometimes it takes a while to find what you’re looking for on the internet, Prezi is significantly more time-consuming than Powerpoint, converting lots of numbers gives you a headache, and that the turf at Beaver Stadium is really, really soft.