

First Annual University Student Hydrogen Design Contest:
Hydrogen Fueling Station

University of Missouri – Rolla Proposal

Submitted
by:

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Competition Presented by:
National Hydrogen Association, U.S. Department of Energy and ChevronTexaco

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Executive Summary

In 1870, Jules Verne described in “Mysterious Island” a world that would derive from water “an inexhaustible source of heat and light”. Now in 2004, Jules Verne’s island has become a reality. Utilizing an ancient technology, wind, there are now the means to generate a pollution free energy source. Coupled with the principle of electrolysis, the ability to generate an efficient medium is available for energy transfer. Off-site wind potential in western Missouri is higher than the station’s proposed location. In doing so, the environmental detriment has been minimized. The “island” as envisioned utilizes cutting edge technology to produce hydrogen efficiently and safely. A mixture of off-site wind and conventional energy sources was selected.

The design incorporates two electrolysis and storage units, affording redundancy and flexibility. By utilizing a smart card system, improper fueling will be eliminated. This technology removes part of the human element in the refueling process thus making it inherently safer. Finally, the station is designed for easy adaptation to changing market conditions and vehicle design; such as decreased fueling time, increased hydrogen demand and increased vehicle storage capacity.

1. Technical Analysis

1.1. General Design

The hydrogen fueling station design for the University of Missouri – Rolla will consist of two 45 Nm³/hr electrolysis units, two 105 kg storage units, and two dual pressure dispensers, which will exceed the requirement of 150 kg/day. This was chosen in order to meet four design constraints placed on the station. The fueling station constraints require the ability to fuel 50 cars per day at 3 kg/car, to meet a peak load of 20 kg/hr, for both dispensers to operate simultaneously, and to achieve zero downtime for either dispenser. Moreover, this system was chosen for redundancy of each unit, simplifying parts storage and maintenance training. There exists the possibility through traffic flows one dispenser may be utilized more than the other. To address this concern, the two dispensers will be interconnected through a manifold such that both will be able to draw from either cascade storage unit in order to maintain filling requirements.

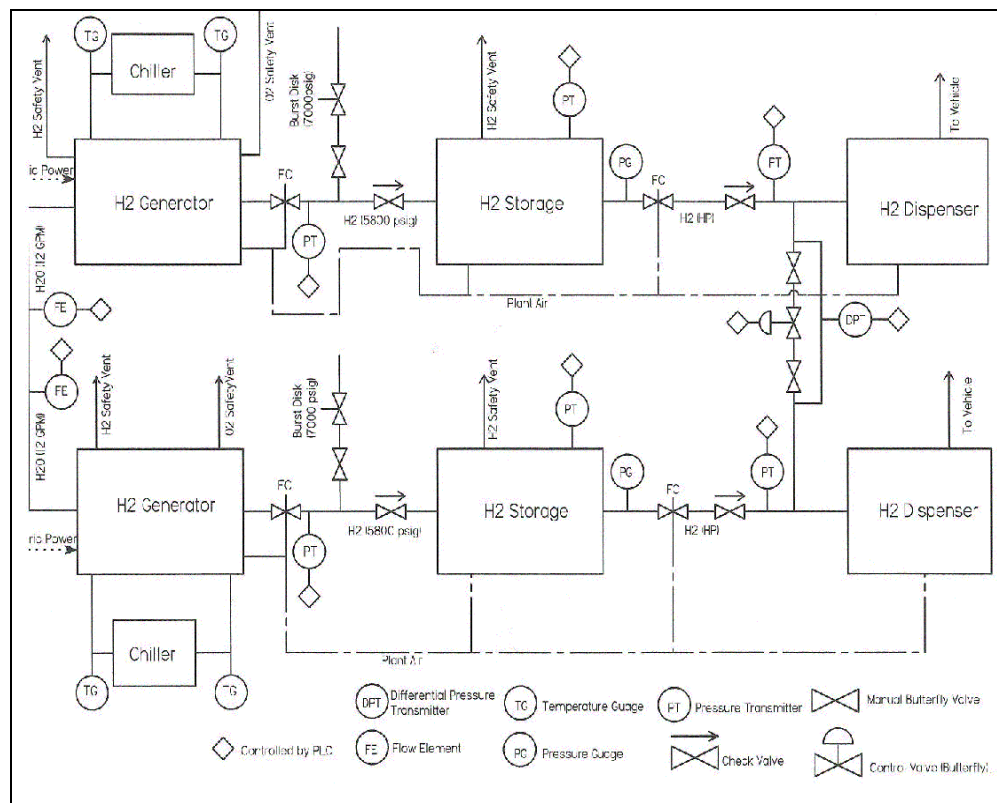


Diagram 1.1 PID Proposed Design

1.1.1. Electrolyser

Dual HESf-45 Stuart Electrolysers will consume approximately 24 gal/hr of water to produce 192 kg/day of hydrogen at industrial grade purity (99.997 %). Water supplying the electrolysis units will first pass through a filter to ensure high purity.

Filtering prevents deposits from forming on the electrolysis stacks and consequently preserves system integrity. Hydrogen will be produced during the electrolysis process at a pressure of 360 psig. The hydrogen will then go through a four stage diaphragm compressor to boost pressure to 5800 psig. The HESf-45 systems were selected in order to meet the design specification of 150 kg/day.

1.1.2. Storage System

The storage system will consist of three storage banks in a cascaded configuration. The first bank will provide the initial filling of the vehicle's tank until it equalizes the pressure between the two tanks. At this point the second bank begins charging the vehicle with the third bank following suit until the vehicle's tank reaches capacity. The storage system will have a factory installed venting system in order to prevent over pressurizing of the storage tanks. In addition to the safety venting of the storage systems, additional burst disks are designed to rupture if the pressure reaches 8000 psig. These burst disks will be installed inline between the compressors and the storage units for safely releasing the hydrogen to atmosphere if electrical systems fail. The burst disks will release the hydrogen from piping out of the ground to dispense the hydrogen from a height of 14 feet to prevent customer interference or harm. The burst disks will also be enclosed in the system security perimeter.

1.1.3. Fuel Dispenser

Each fuel dispenser will have two nozzles in place, one for slow fill at 3800 psig and the other at 5000 psig. A flow limiter is also present to meet current advisories set forth by the California Fuel Cell Partnership. The flow limiter is set at 0.23 kg/min which allows a fueling time of 13 minutes per vehicle. The design will be equipped with two fuel dispensers to meet the anticipated peak demand of 20 kg/hr. The dispenser will have safe-guards in place to detect proper connection between the vehicle and the nozzle in order for safe dispensing of fuel. A point-of-sale display for payment options will be installed along with a smart card reader. The smart card will be able to provide the necessary fueling data including historical fueling, security and payment information. In order to keep up with industry standards, provisions will be in place to remove the slow fill option and replace it with a hose assembly and vehicle interface to allow filling up to 10,000 psig.

1.1.4. Control System

1.1.4.1. Cascading Storage Control

A control system is necessary to manage the operation of the three banks within each of the two storage units. This control comes standard from Stuart Energy to accompany the storage units. This system was simulated using the Gas Technology Institute CASCADE compressor/storage refueling station demonstration program. This third party computer program was used to independently verify the performance of the cascade unit and the control system. The provided control system was modeled and found to sufficiently meet all four design constraints.

1.1.4.2. Manifold Control

A control system will need to be incorporated to monitor flow from the cascade units to the dispensers and maintain fully functioning dispensers. Ideally, dispenser *A* will draw hydrogen from cascade system *A*, while dispenser *B* draws product from cascade system *B*. However, if dispenser *A* is over-utilized, cascade system *A* will become depleted before cascade *B*. At this point the control system will switch the supply of dispenser *A* to cascade *B*. This cascade will then supply dispenser *A* and *B* until cascade *A* is filled to the same pressure as cascade *B*. Once this happens, the control system will close the control valves such that each dispenser is drawing product from its primary cascade unit. This system will recognize and react to depletion of either cascade *A* or *B*.

1.1.4.3. Safety Systems Control

Safety will not be compromised for any reason. This system incorporates many safety measures as stated in the Safety Analysis section of this report. To ensure that all the safety systems work properly in the event a system failure all safety valves will mechanically close to fail-close position. In addition, the dispenser must be disabled without a proper connection with the vehicle interface established. Pressures must be monitored to detect over pressurization of storage tanks or a decrease/increase in pressure when fuel is not being dispensed. If over pressurization is detected, the compressor will shut down and an alarm will be sent to operators to indicate a system fault. A decrease in pressure when fuel is not being dispensed indicates a loss of hydrogen containment and will cause all valves to close, and an alarm signal to be given. Any unexpected rapid variance in pressure will send an alarm, as well as shut down the system.

1.1.5. Piping

As specified by Stuart Energy, piping shall be 0.5 inches internal diameter pipe made of 306 stainless steel.

1.2. Conceptualizations

1.2.1. Case 1. Two Separate Electrolyser Systems

The current system shown below satisfies the constraints of the design on the fueling station. This concept yields the lowest capital cost as well as the lowest operating cost.

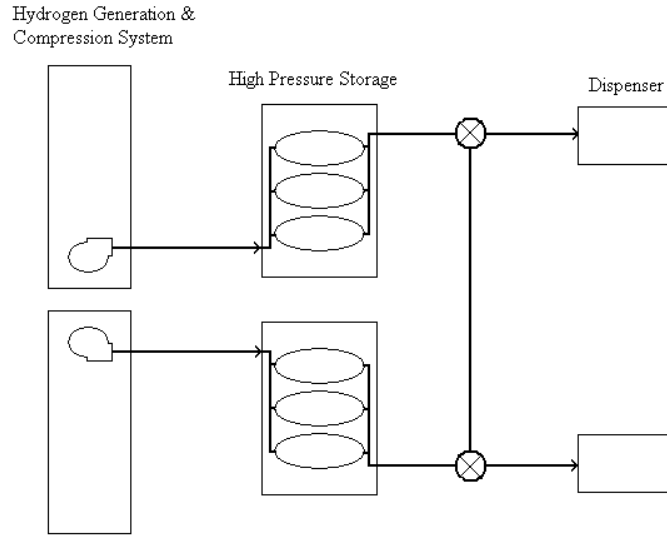


Diagram 1.2 Case 1: Two Separate Electrolyser Systems

1.2.2. Case 2. Two separate Electrolyser systems utilizing bulk storage tank and two booster compressors

The system shown below involves two electrolysis units and incorporates a bulk storage tank and two booster compressors. Advantages would be complete redundancy in that a bulk storage tank will allow hydrogen from both electrolyser units to flow into bulk storage. Hydrogen then flows through the dual compressors and into the Stuart Storage systems. Disadvantages would be a much higher capital cost in buying a bulk storage tank and two additional compressors, as well as higher operating costs.

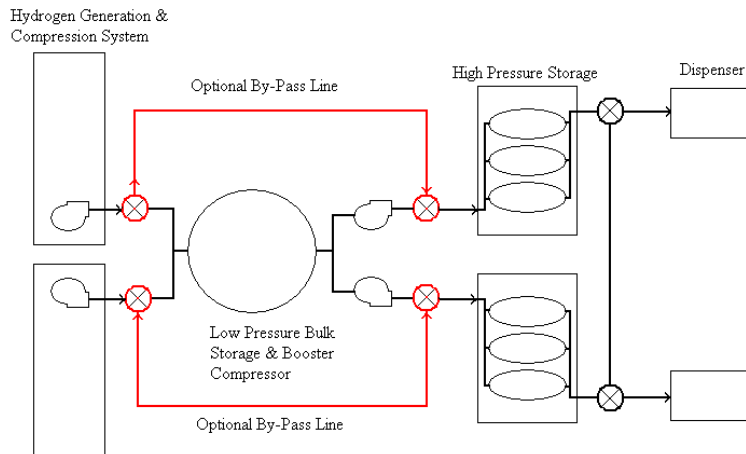


Diagram 1.3 Case 1: Bulk Storage with Two Small Booster Compressors

1.2.3. Case 3. Two separate electrolyser systems utilizing a bulk storage tank and one additional booster compressor

This case uses two electrolyser systems which compress hydrogen into one bulk storage system. From the bulk storage, the hydrogen is boosted to 5800 psig from one 75 hp compressor into dual storage systems. The advantage is that the system is completely redundant. The disadvantages are high operating and capital costs.

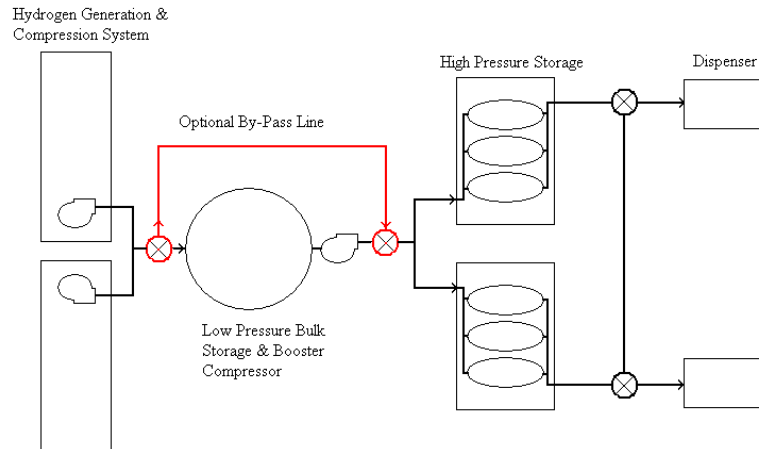


Diagram 1.4 Case 2: Bulk Storage with One Large Booster Compressor

1.2.4. Method for Choosing the Best Case

The three cases were ranked on the following performance criteria: capital cost, operating and maintenance costs, and redundancy. A weighted value was assigned to each of the performance criterion based corresponding to anticipated effect on the success of the fuel station. The least important design criterion carries the least weight and therefore is given a multiplier of one. Moreover, each case was ranked based on its standing within each of the performance criterion. The weighted value of each of the performance criteria was multiplied by the associate rank of each case. Next, the values for each case were added together with the lowest number corresponding to the most desirable case.

W = weight

n = rank

i = metric

$$\text{sum} = \sum_{i=1}^3 W_i n_i$$

	Capital Cost	Operating Cost	Redundancy	Sum
Weighted Value	2	3	1	n/a
Case 1* rank	1	1	3	8
Case 2** rank	3	2	1	13
Case 3*** rank	2	3	1	14
*uses no bulk storage				
**uses bulk storage with two 30 hp auxiliary compressors				
***uses bulk storage with one 75 hp auxiliary compressor				

Table 1.1: Performance Metrics

The electrolysis units, cascaded storage tanks and dispenser are common among the three cases. Cases two and three had added capital costs with the addition of bulk storage tanks and booster compressors, rendering case one the most favorable option.

In concern to operating and maintenance costs, additional power and service would be necessary for cases two and three. Case three utilizes one additional compressor operating at 75 horsepower, while case two uses two additional compressors operating at 30 horsepower each. Case one uses no auxiliary compression units, yielding cheaper operating costs and less maintenance for each subsequent case.

Case two and three are completely redundant systems, allowing operation for several days given the failure of any one piece of equipment. Case one allows one additional day of operation at full capacity in the event that one piece of equipment fails.

Based on the above analysis, case one was found to be the most desirable equipment configuration and therefore has been chosen for the final design. The only performance criterion in which this system was not ranked most beneficial was redundancy; however, this case has sufficient redundancy. If one electrolyser is inoperable for maintenance or failure, this station will be able to run at nearly full capacity, refueling 39 vehicles for the first day and 26 vehicles each subsequent day.

1.3. Green Power Generation

1.3.1. Wind Power

The feasibility of wind power was studied for the location here in Rolla, Missouri. The first option looked at was including on-site power generation through a 1000 kilowatt turbine on top of a 100 meter tower. The height of the tower was determined after examining wind data maps for the anticipated location of the hydrogen fuel station. Capital cost for this option was highly prohibitive at 1.5 million dollars for the tower and the generator combined. This cost could not be recovered during the anticipated life of the system, projected at 25 years. The 100 meter height would also be in violation of planning and zoning ordinances for the city of Rolla with modest chance of a variance being granted. Another mode of supplying wind power through the usage of two smaller capacity wind turbines to was explored. The commercially available turbines were 10 meters in height and produced a mere 0.16 kW. Initial thoughts were that the turbines would be able to power a small HOGEN 20 electrolysis unit provided

by Proton; however, further investigation determined that it would take over a month to refuel a single vehicle.

1.3.2. Solar Power

Providing energy to the hydrogen production units by photovoltaic cells was also investigated. This concept was dismissed due to the small amount of power produced per photovoltaic cell. For example, with a solar panel with tracking mounts only produces 158 W. Another disadvantage of the solar panels would be the daily maintenance cost of the batteries associated with storing the electricity produced.

1.3.3. Purchase Green Power

The power for the final concept of the hydrogen fuel station will be purchased from the grid. This is justified by purchasing green power supplied as stated in the Environmental Analysis.

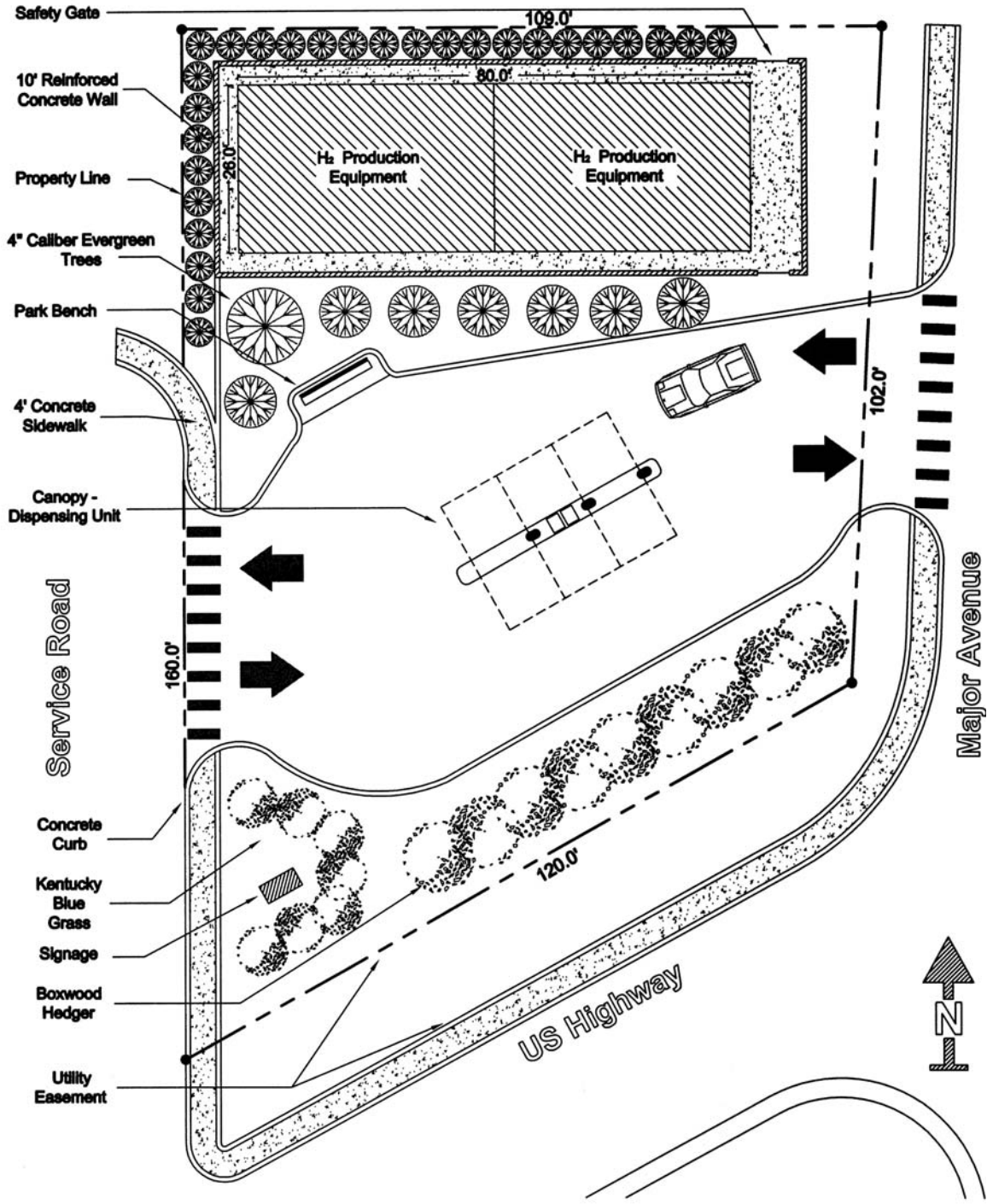
1.4. Expandability

The final design may be modified to fit changing market demands. One scenario is that demand for hydrogen will increase above the current demand of 150 kg/day. The combined electrolysis units are capable of producing 192 kg/day. This extra hydrogen production of 42 kg/day would correspond to the ability to fuel 14 additional vehicles at the current refueling pressure. Another scenario is that hydrogen fuel cell vehicles will advance and be equipped with 10,000 psig tanks. This is anticipated to occur within the life of the station. In response to this change, the hydrogen storage pressure would need to be increased to 10,800 psig, which is below the existing cascade tank system rating of 12,000 psig. In addition two booster compressors would be needed. Productivity of the station can be improved by decreasing the fueling time. This can be accomplished with a simple adjustment of the flow limiter setting at the dispenser.

1.5. Architecture

1.5.1. Site Design

The site proposed for the station is at the corner of a US highway and a major avenue. The H₂ production equipment will be located at the farthest point that could be managed to maximize safety. Production equipment for the station will be enclosed by a 10 ft tall concrete (fire resistant) wall located 5 ft from the boundary line. There will fire-resistant doors in the wall to allow maintenance personnel access to a 3 ft (perimeter) work area. Also, there will be trees surrounding the enclosure to add and aesthetic touch. In the southwest corner of the enclosure there will be a park bench surrounded by flora to encourage the thought that this station is environmentally friendly. About 15-20 feet from the park bench will be the pumps themselves. These will be covered by a decorative canopy that spans about 20 ft in width and 30 ft in length. All hydrogen-bearing things have been kept back as far away from traffic and pedestrians as possible. The closest object in the station to outside public access is the sign, and that will be located approximately 10 ft from the sidewalk (4ft wide, on the south and east sides), and 5 ft from the city's 17 ft easement on the south side.



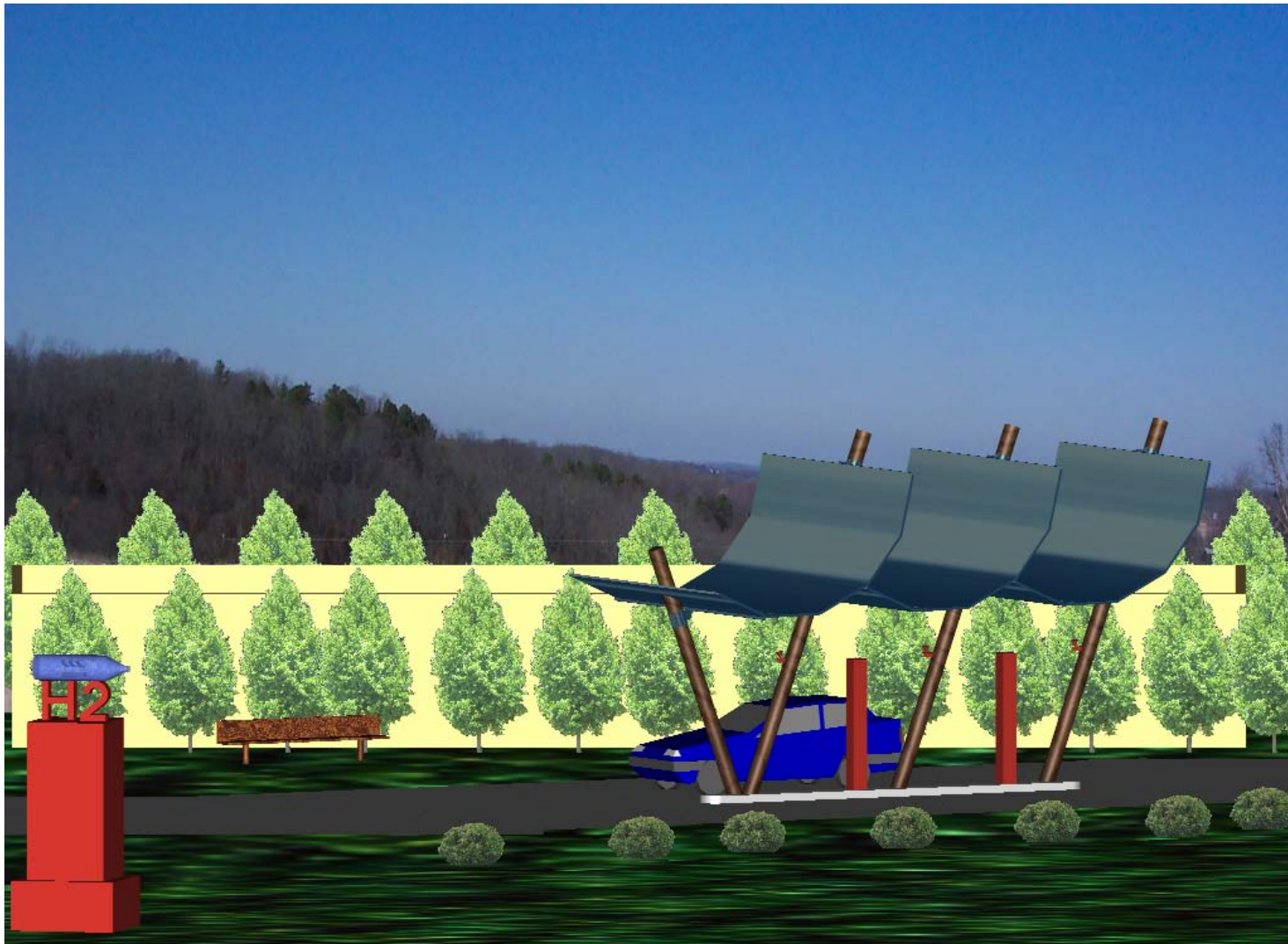
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SITE PLAN



Diagram 1.5 Site Plan



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Perspective Image

Drawing 1.1 Artist Rendition of Site

2. Safety Analysis

2.1. Fire Codes and Standards

2.1.1. Legal Definitions

This section will define our station as an Automotive Unattended Self-Service Station as according to the International Fire Code (2001).

2.1.2. Automotive Service Station

That portion of property where flammable or combustible liquids or gases used as motor fuels are stored and dispensed from fixed equipment into the fuel tanks of motor vehicles.

2.1.3. Attended Self-service Stations

Attended self-service stations shall comply with Sections 2204.2.1 through 2204.2.5. Attended self-service stations shall have at least one qualified attendant on duty while the station is open for business. The attendant's primary function shall be to supervise, observe and control the dispensing of fuel. The attendant shall prevent the dispensing of fuel into containers that do not comply with Section 2204.4.1, control sources of ignition, give immediate attention to accidental spills or releases, and be prepared to use fire extinguishers.

Since this station will not have an attendant we must qualify for extra, Unattended Service Station Codes.

2.2. Design Response to Codes and Standards

2.2.1. Dispenser Labeling

NO SMOKING, IGNITION OFF, and the exact Location of Emergency shutoff switch will be clearly marked on the canopy columns. Also, the following emergency procedure sign will be posted:

IN CASE OF FIRE OR RELEASE
1. USE EMERGENCY PUMP SHUTOFF
2. REPORT THE ACCIDENT!
FIRE DEPARTMENT TELEPHONE NO. _____
FACILITY ADDRESS _____

This station will have a non-pay phone that can easily reach the local fire department.

2.2.2. Storage Tanks and Production Facilities

Our storage tanks must be outside the range of any flammable objects, or other reactant chemicals. According to NFPA 50A our hydrogen production/storage containers must be at least 5 ft from the from anything else (pumps, public sidewalks, etc), assuming that there is a wall constructed of a material with a fire resistance rating of 2 hours or greater. The storage system must be also located no less than 5 feet below electrical lines, and cannot be located below piping containing hazardous materials at any height.

These tanks must be labeled, so that they can be easily identified by anyone. Any piping must also be constructed so that ice and moisture will not form on or in the pipes.

2.2.3. Pressure Relief Devices

Pressure relief devices must be equipped on every storage tank, and positioned so that when pressure is released it is in a safe direction, and will not damage any walls, personnel, or the container itself.

2.3. Failure Modes

2.3.1. Identifying Failure Modes

When considering the possible failure modes for the hydrogen fueling station, the following eight failure modes were identified:

1. Fire and combustion of hydrogen
2. Customer error/misuse of equipment
3. Collision by vehicle
4. Equipment failure
5. Natural disasters
6. Power outage
7. Pipe/fitting failure
8. Over pressurizing tanks

These eight failure modes are listed in order of decreasing Risk Priority Number (RPN) from a Failure Mode Effects Analysis (FMEA). The eight potential failure modes were identified and then given a score based on severity, occurrence and ability to detect. The modes were scored from 10-1 with 10 indicating the highest severity, most frequent occurrence and absolute uncertainty in detection. A score of 1 is given to failure modes with no severity, remote occurrence and almost certain ability to detect. The RPN is the product of the values of these three criteria. The following tables show criteria along with corresponding scores.

Severity

<i>Criteria</i>	<i>Score</i>
Hazardous without warning	10
Hazardous with warning	9
Very High	8
High	7
Moderate	6
Low	5
Very Low	4
Minor	3
Very Minor	2
None	1

Table 2.1

Ability to Detect

<i>Detection Capability</i>	<i>Score</i>
Absolute Uncertainty	10
Very Remote	9
Remote	8
Very Low	7
Low	6
Moderate	5
Moderately High	4
High	3
Very High	2
Almost Certain	1

Table 2.2

Occurrence

<i>Criteria</i>	<i>Frequency</i>	<i>Score</i>
Very High	1 in 2	10
Very High	1 in 3	9
High	1 in 8	8
High	1 in 20	7
Moderate	1 in 80	6
Moderate	1 in 400	5
Moderate	1 in 2000	4
Low	1 in 15000	3
Low	1 in 150000	2
Remote	1 in 1500000	1

Table 2.3

$$RPN = Severity \times Occurrence \times Detection$$

The following table shows the values given for each of the factors mentioned above:

		Severity	Occurrence	Ability to detect	RPN
1	Fire and combustion of hydrogen	10	7	9	630
2	Customer error	7	6	10	420
3	Collision by vehicle	7	3	10	210
4	Equipment failure	6	4	3	72
5	Natural disasters	9	4	2	72
6	Power outage	6	6	1	36
7	Pipe/fitting failure	7	1	5	35
8	Over pressurizing tanks	8	1	3	24

Table 2.4: FMEA

To explain how the values were determined, fire and combustion of hydrogen will be given as an example. This failure mode is hazardous without warning scoring a 10 for severity. One in every thirteen fueling stations experiences some kind of fire every year. This high frequency of occurrence scores a 7. Since fires usually come without warning, the ability to detect was identified as “very remote” and scores 9. Finally, the three values were multiplied to give the RPN of 630. After performing FMEA for the failure modes, each was addressed and preventive measures were taken in the design.

2.3.2. Fire and Combustion of Hydrogen

Hydrogen is a flammable gas which is colorless, odorless, tasteless, and nontoxic. It is the lightest gas, having a specific gravity of 0.0695. Hydrogen burns in the air with a pale blue, almost invisible flame. At atmospheric pressure, the ignition temperature of hydrogen-air mixtures has been reported by the US Bureau of Mines to be as low as 932° (500°C). The flammable limits of Hydrogen-air mixture depend on pressure, temperature, and water vapor-content. At atmospheric pressure the flammability range is approximately 4 – 74% by volume of hydrogen in air. While hydrogen is technically non-toxic, it can be lethal if it displaces the normal 21% of oxygen in a confined area.

The flammability range of hydrogen in normal conditions is very extreme and should be regarded as a great risk if any source of flame is introduced. Customers of the station could be seriously injured or even killed by a hydrogen flame. According to nfpf.org, between 1994 and 1998 7,400 fires and explosions per year occurred at public service stations. Many preventive measures for the hydrogen fueling station will resemble those rules of a conventional gasoline fueling station as mentioned above. Static electricity has been identified as a possible cause of fire at the dispenser, and this will be addressed with a grounding safety system. Infrared sensors will cause the dispenser to fault out in the event that there is a flame within the perimeter of the dispensers.

2.3.3. Customer Error/misuse of Equipment

Human error is an important issue to address when taking into account safety. Human actions are unpredictable and every possible fault should be considered. One possibility is that a customer may fail to properly connect the dispenser nozzle to their vehicle and attempt to begin fueling. A measure that has been taken to mitigate risk in the design of this fuel station is a sensor that will not allow fueling in the event of an improper connection. A customer may also drive off without disconnecting the nozzle. To cope with this action, the hydrogen dispenser is equipped with breakaway nozzles. In addition, the hydrogen dispensers will be equipped with smart cards that are read by a smart card reader to begin fueling. As the nozzle is attached and the dispenser is activated, a computer receives fueling and billing information, calculates the amount of fuel needed to fill the tank and shuts off when it is full.

2.3.4. Collision by Vehicle

Vehicle accidents take place everyday. Operator error could lead to a vehicle impacting hydrogen dispensers or hydrogen production equipment. The damage sustained by the station could cause loss of containment allowing hydrogen to flow freely into the surroundings. As hydrogen escapes at high pressures, it will become entrained with air and highly explosive. It is however, very light and will disperse quite quickly. In order to mitigate the risk of vehicles colliding with hydrogen dispensers and production equipment, a concrete wall has been designed around possible impact locations (See site layout). It is unlikely that a vehicle would ever impact the equipment given the wall; but if this event were to occur, the equipment is equipped with redundant valves that would fail closed immediately and not allow hydrogen to escape. Most probable impact location would be at the dispensers. Dispensers are equipped with shear valves to allow minimal, if any, product exposure if involved in a vehicle collision.

2.3.5. Natural Disaster

Natural disasters can be devastating. Tornadoes can rip apart whole towns, earthquakes level entire cities, and torrential downpours cause widespread flooding. While earthquakes are not likely in the Ozark Region, all of the piping for the station will be mounted in a way that will allow some movement without causing pipe rupture or fitting failure. Tornadoes are more prevalent and the equipment and structures are designed to withstand such an event. The sail like canopy may not survive a direct hit from a tornado, but all the supports and the equipment enclosure will sufficiently protect from the forces of a tornado. Flooding is not a problem due to the station being located on top of a hill overlooking the beautiful Ozark Mountain greenery. The last natural disaster identified as causing a great threat is lightning. Lightning will strike at the highest point, which is the main support for the canopy. Lightning rods and sufficient grounding will prevent the likelihood of a fire caused by lightning.

2.3.6. Power Outage

In the event of a power outage, all electrical systems would be rendered inoperable. Certain mechanical safeguards would be in place to ensure that neither transport, nor venting would occur. Valves, that would be fail-close, would be in place to lock close if no electrical signal is sent to the solenoid valve, which would not allow air into the valve to actuate it. These valves will be in place between the electrolyser and the storage unit,

as well as between the storage unit and the fuel dispensers. These valves will only be operated in event of a power failure, as they will always be open if the system is operating according to design parameters and power is supplied to the solenoid valves.

2.3.7. Equipment Failure

To mitigate safety risks, it is important that each piece of equipment is operating in the safe pressure and temperature range. All equipment is complete with pressure and temperature sensors, which shut down the equipment when an abnormality occurs. This lowers the possibility a catastrophic failure will occur. Another safety measure is the placement of fail-closed valves placed upstream and downstream of each piece of equipment. If a failure occurs, causing large change in pressure, this will not propagate throughout the remainder of the system. The valves are controlled electrically by the safety control system as well as mechanically fail-closed.

2.3.8. Piping / fitting Failure

Hydrogen is an excellent fuel for several reasons, it is non-toxic, non-corrosive and non-carcinogenic, and therefore it doesn't have any adverse effects on the environment in case of a leak. In the event that the pipes or fittings of the hydrogen system fail, a control system is required to cope with the failure by sensing the sudden change in pressure and then shutting the system down.

The pipes to be used are made of stainless steel, which is a non-corrosive material. Most failures in pipes occur in regions of mild mechanical damage. Following the damage, ambient-temperature strain aging, which promotes sensitivity to hydrogen stress cracking takes place in the mechanically damaged region, in a surface layer of the pipe wall which has been subjected to a critical level of strain. The time period for this step would be on the order of several years so maintenance checks on the pipes will be in conducted to prevent such a leak. The pipes will be physically available for maintenance at the hydrogen system and gates will be utilized from the system to the dispenser unit so the pipes are easily accessible in case of damage.

2.3.9. Over Pressurization of Tanks

Tanks could rupture and cause total system failure if they become over pressurized. For this reason safety measures have been incorporated into the design to mitigate the risk of an excessive pressure being reached. First of all, the storage tanks specified are rated for a safety factor of over 2. Tanks are equipped with rupture disks on vent pipes rising to a safe location from property lines, structures, other equipment and customer location. A control system as described in the Technical Design summary will cause alarm signals and shut down compressors before over pressurizing becomes an issue.

3. Economic Analysis

3.1 Introduction

Unlike a conventional gasoline station, the hydrogen fueling station is a stand-alone station. It can produce fuel on site, while a traditional station is more like a distribution point for fuel. One disadvantage of the hydrogen station will be the larger investment costs due to the initial expense of the production unit and the cost for new technology. However, most of the costs will be front loaded capital costs, such as the costs for the equipment, building, and land. Since the material used in the production of hydrogen is water and electricity, the operating costs and cost of materials along the project time line will be smaller than the costs incurred at a conventional gas station.

The economic analysis of the project will be performed in detail, including taxes, depreciation of the equipment, operating expenses, and maintenance costs. The financial analysis will be done annually for the 10-year time frame. The hydrogen selling price will be determined based on the results from the cash flow analysis using the Internal Rate of Return (IRR) approach. Furthermore, the selling price will be used in benchmarking the cost per mile of vehicle travel for both the conventional vehicle using gasoline and the fuel cell vehicle using hydrogen.

3.2 Cost

The cost of the hydrogen fueling station project can be classified into three main categories: infrastructure and construction costs, equipment costs, and operating and maintenance costs. The first two categories are fixed costs, while the last category includes variable costs. All costs in this analysis are in U.S. dollars.

3.2.1 Infrastructure and Construction

Infrastructure and Construction costs include all costs of buildings, site preparation of foundations, utility installation, building material, land, etc. The approximate cost for this project is \$440,000. Land costs are estimated by a local real estate agency in Rolla, MO at the rate of \$12 per square foot. This project assumes a five percent annual increase in land prices.

3.2.2 Equipment

Equipment costs include the cost of equipment, shipping, installation, and tariffs. This project is only comprised of the hydrogen system. The list of equipment and associated costs are shown in Table 3.1.

For this project the hydrogen production system is provided by Stuart Energy System Corporation in Canada. Canada is one of the countries under the North America Free Trade Agreement (NAFTA). However, tariffs for producers of gas or water gas generators is free for general rates of duty based on the United States International Trade Commission (Harmonized Tariff Schedule of the United States, 2004, section XVI, pages 84-5). Although the project is planned for construction in 2006, this analysis assumes the same zero percent tariff rate for year 2006. Since the government continues to show incentives for green energy, it is felt that there will be no tariff for importing the hydrogen production system into the near future.

Item	Description	Qty	Price (each)
1	Hydrogen System*		
1.1	HESf-45 Hydrogen Generator Module Subsystems: compression system, deoxo-dryer, closed-loop cooling system, mixed beds demineraliser system, instrument air compressor, and ventilation	2	\$525,000
1.2	Storage System Module	2	\$125,000
1.3	Dispenser System Module	2	\$100,000
1.4	Interconnecting Materials and Peripherals	2	\$25,000
1.5	Engineering Document	1	\$50,000
1.6	Commissioning and Operator Training	1	\$20,000
2	Controller System	1	\$7,410
3	Installation and Shipping Costs	1	\$244,112
	Total Price		\$1,871,522

* Hydrogen system cost obtained from Stuart Energy Corporation (<http://www.stuartenergy.com>).

Note: Assume 15 percent for installation and shipping cost.

Table 3.1: The Equipment List and Cost

3.2.3 Operation and Maintenance

Operational and Maintenance costs to run the hydrogen fueling station include the cost of electricity, water, and maintenance.

The water consumption rate is 12 liters per one kilogram of production hydrogen. This station produces 150 kg of hydrogen per day. The approximate water consumption per year is 164,250 gallons (11.25x150x365/3.75). The month rate for water in the Rolla area is \$2 per thousand gallons plus \$6 per active meter. There are also sewer costs associated with water consumption. In Rolla, the month rate is \$2.2 for each 1,000 gallons of water. The approximate water and sewer cost per year becomes:

$$\text{Water and Sewer cost} = [(164.25 \times \$2) + (\$6 \times 12)] + (164.25 \times \$2.2) = \$761.85 \quad (\text{Eq. 3.1})$$

Electricity costs are associated with two components: the hydrogen system and the building. The electricity price is comprised of two parts: the energy charge and the demand charge. The energy charge is calculated from all kWh of energy used, while the demand charge is computed from all kW of demand.

For the hydrogen system, the electricity consumption rate is 57.6 kWh per one kilogram of production hydrogen. The approximate annual electricity usage is 3,153,600 kWh. The peak load is 432 kW. Then annual electricity cost is

$$\text{Energy charge} + \text{Demand charge} = (5.18 \text{ cent/kWh} \times 3153600 \text{ kWh}) + (432 \times \$6.34 \times 12) = \$196,223.04 \quad (\text{Eq. 3.2})$$

Maintenance costs are associated with two components: the hydrogen system and the building. Since the fueling process will be fully automated, there is no need to have any employees present at the station for normal operation. The cost of personnel for safety

and system maintenance, which include engineers and technicians, will be accounted for as part of the maintenance cost for this analysis. The costs information is shown below.

Item	Description	Electrical Cost (per year)*	Water & Sewer Cost (per year)*	Maintenance Cost (per year)
1	Hydrogen System	\$ 196,223.04	\$ 761.85	\$ 30,000
2	Building	\$ 466.45	N/A	\$ 5,000

- Data based on Rolla Municipal Utilities

Table 3.2: Operating and Maintenance Cost

3.2.4 Sources of Energy

A study of possible renewable energies for the Missouri area was considered. An analysis of wind power and solar power is outlined below:

Wind power: Most of the area in Missouri is classified as class two for wind based on a Missouri wind map from the U.S. Department of Energy. As a result, wind speed in Missouri is quite low and not suitable for commercial use. Typically, suitable wind classes for commercial use need to have a wind class greater than two to be economically efficient.

Solar power: Even though Missouri has sunshine most of the year, solar power was still calculated to be unsuitable. The current market price of solar panels is expensive and not justified when compared to the relatively inexpensive electric grid power available in the Missouri area. However, this type of power is suitable for remote sites that do not have access to the electrical grid.

The decision regarding the source of energy for this project is based on both an economic and environmental point of view. The cost comparisons between wind, solar, and the electrical grid are shown in Table 3.3. This table shows that the price per kW of solar power is much more expensive than wind power cost. However, the efficiency of the wind turbine is low (less than 15 percent) due to low wind speed in the Missouri area. As an alternative to generating wind power on site, there is also the option of buying wind power from neighboring areas. Boone Electric Cooperative offers green power at the normal electric rate plus \$2 per 100 kWh. When comparing costs per kWh between wind (both with investments in wind turbines and utilizing the buying option) and the electrical grid power, the analysis shows that the electrical grid is cheaper, even when peak load charges are considered for the electric grid power. From an economic perspective, the electrical grid power is the best alternative. On the other hand, using grid power will cause environmental effects due to the production of electricity. Therefore, the decision has made to use 50% of the required power from power grid, and another 50% from buying green power. This will provide a suitable balance between economic efficiency and environmental considerations.

Description	Wind Power			Electrical Grid Power		Solar Power ^{##}
	At 70 meters [*]	At 100 meters [*]	Buy ^{**}	RMU Summer [#]	RMU Winter [#]	
Price (per kW)	\$1,300	\$1,456	-	-	-	\$4,666
Total Power ⁺	858,480	1,427,880	-	-	-	-
Cost per kWh	\$0.17	\$0.11	\$0.07	\$0.05	\$0.04	-

* Data based on Lorax Energy Systems, LLC

** Data from Boone Electric Cooperative

Data based on Rolla Municipal Utilities (RMU) historical data

Data based on Fords MTM LLC

+ kWh per year

Table 3.3: Cost Comparison between Energy Sources

3.3 Internal Rate of Return Analysis (IRR)

The Internal Rate of Return (IRR) is defined as the discount rate that equates the present value of a project's expected cash inflows to the present value of the project's expected costs.

$$PV(\text{Inflows}) = PV(\text{Investment costs}) \quad (\text{Eq. 3.3})$$

The current cost analysis utilizes an after-tax IRR of 10 percent for a 10-year analysis to find the appropriate hydrogen selling price. In order to analyze the IRR, numerous variables, such as depreciation, expected income, sale tax, income tax, and inflation play important roles.

Depreciation is a reduction in the value of fixed or capital assets through use, damage, weathering, or obsolescence. Depreciation can be estimated using a number of methods. The Modified Accelerated Cost Recovery System (MACRS) consists of two depreciation systems - the General Depreciation System (GDS) and the Alternative Depreciation System (ADS). The GDS system utilizing a 200% declining balance depreciation method is applied for this project. Each type of equipment in Table 3.1 is classified as a 7-year MACRS property class asset. The building is classified as a 15-year MACRS asset.

Income for the station will come solely from selling hydrogen to customers. The total annual income will equal the sales volume per year multiplied by the selling price as shown in Equations 3.4 and 3.5. The selling price (parameter P below) is derived from the IRR analysis. This analysis is based on the minimum requirements of the station.

$$\text{Annual sale volume} = 3 \text{ kg/car} \times 50 \text{ car/day} \times 365 \text{ day/year} = 54,750 \text{ kg} \quad (\text{Eq. 3.4})$$

$$\text{Total annual income} = 54,750 \text{ kg} \times \$ P / \text{kg} = \$54,750(P) \quad (\text{Eq. 3.5})$$

Sales taxes include the taxes imposed on product sales, usually at the retail level. These expenses will be added to the price of the product. Sales taxes will be used in the analysis as an additional cost for a customer who is purchasing a specific amount of hydrogen at the current selling price. The hydrogen fuel price plus sales taxes will be used to compare with the given cost per mile of the gasoline fuel car. Sales taxes for the local Rolla Missouri area are 7.60%.

Income taxes are taxes on pretax income (taxable income) of an organization in the course of regular business. The definition of taxable income is given in Equation 3.6, where gross income represent the gross profits from operations. There are two types of income taxes, i.e. federal income taxes and state income taxes. Federal income taxes are taxed at different rates depending on the organization's level of taxable income. The rate table shown in Table 3.4 gives the federal

income taxes as of the year 2000. It is assumed that this rate will stay constant from the beginning to the end of the project. Missouri state income taxes are currently 6.25% of net taxable income that is earned in the state. The state of Missouri also allows 50% of federal income tax payments to be deducted before computing taxable income. For the tax analysis, a combined 39% federal and state tax rate burden is used to account for the federal rate, state rate, and appropriate deductions.

$$\text{Taxable income} = \text{gross income} - \text{expenses (except capital expenditures)} - \text{depreciation} \quad (\text{Eq. 3.6})$$

If taxable income is		The tax is :	
over	but not over	of the amount over	
\$ -	\$ 50,000.00	15%	\$ -
\$ 50,000.00	\$ 75,000.00	7,500 + 25%	\$ 50,000.00
\$ 75,000.00	\$ 100,000.00	13,750 + 34%	\$ 75,000.00
\$ 100,000.00	\$ 335,000.00	22,250 + 39%	\$ 100,000.00
\$ 335,000.00	\$ 10,000,000.00	113,900 + 34%	\$ 335,000.00
\$ 10,000,000.00	\$ 15,000,000.00	3,400,000 + 35%	\$ 10,000,000.00
\$ 15,000,000.00	\$ 18,333,333.00	5,150,000 + 38%	\$ 15,000,000.00
\$ 18,333,333.00	6,416,667 + 35%	\$ 18,333,333.00

Table 3.4: 2000 Federal Income Taxes Rate

Source: Financial Management: Theory and Practice, 10th edition, Bringham and Ehrhardt

CPI-U YEAR	Percent Change	
	DEC-DEC	AVG-AVG
1994	2.7	2.6
1995	2.5	2.8
1996	3.3	3
1997	1.7	2.3
1998	1.6	1.6
1999	2.7	2.2
2000	3.4	3.4
2001	1.6	2.8
2002	2.4	1.6
2003	1.9	2.3
Average	2.38	2.46

Table 3.5: 10-year CPI Data

Inflation: Since the economic analysis will be conducted over an extended time period, inflation needs to be considered in the analysis. The previous 10-year percentage change average of the Consumer Price Index (CPI) for all products is used to adjusted prices over the 10 year project period. The CPI information is shown in Table 3.5. These numbers are from the U.S. Department of Labor’s Bureau of Labor Statistics (<http://www.bls.gov/cpi/home.htm#data>). The calculated value used in this analysis is a 2.46% increase in price per year.

In order to calculate the price per unit of hydrogen, the real value of income that meets the 10% per year IRR requirement has to be estimated. The calculation approach that is used is shown in the following equations. The calculation details and result are shown in the Appendix 3-1.

$$\text{PV(Investment)} = \text{PV(Income After Tax)} \quad (\text{Eq. 3.7})$$

$$\text{PV(Expense + Capital)} = \text{PV (Income – Tax)} \quad (\text{Eq. 3.8})$$

$$\text{Tax} = (39\%) \times (\text{Income} - \text{Expense} - \text{Depreciation}) \quad (\text{Eq. 3.9})$$

$$\text{PV(Income)} = \frac{(0.61)\text{Expense} + \text{Capital} - (0.39)\text{Depreciation}}{(0.61)} \quad (\text{Eq. 3.10})$$

3.4 Comparison

From the IRR analysis, the hydrogen price (including sales tax) is \$9.27 per kilogram. The comparison between the cost of travel per mile between conventional gasoline and the hydrogen fuel cell vehicle will be investigated. This cost per kilogram will be translated into cost per mile by using the given consumption rate of 60 miles travel distance per one kilogram of hydrogen, resulting in \$ 0.15 per mile for the hydrogen fuel vehicle.

3.5 Sensitivity Analysis

The sensitivity analysis is conducted for variations in three factors: equipment capital cost, power consumption of hydrogen production, and hydrogen consumption by the vehicle. Each factor will be varied $\pm 30\%$ while holding the other two factors constant. The cost of per mile of the hydrogen fuel cell vehicle will be examined for each scenario. The results are shown in table 3.6 and plotted in figure 3.2.

Parameter	Cost per Mile with						
	Valued at						
	-30%	-20%	-10%	Original	+10%	+20%	+30%
Equipment Capital Cost	\$ 0.133	\$ 0.140	\$ 0.147	\$ 0.155	\$ 0.162	\$ 0.169	\$ 0.176
Production Operating Cost	\$ 0.141	\$ 0.146	\$ 0.150	\$ 0.155	\$ 0.159	\$ 0.163	\$ 0.168
Vehicle Consumption Rate	\$ 0.221	\$ 0.193	\$ 0.172	\$ 0.155	\$ 0.140	\$ 0.129	\$ 0.119

Table 3.6: Cost per Mile Sensitivity Analysis

Examining Figure 3.1 below, the consumption rate has the steepest sloped line, indicating that it has the most sensitivity to changes in the original value. In other words, the consumption rate of the hydrogen fuel cell vehicle has the largest effect on the cost per mile of the vehicle. By improving the vehicle efficiency by 30%, the cost per mile of the vehicle will decrease by 23%. The cost per mile is less sensitive to changes in the equipment and operating costs, illustrating the economic robustness of the design.

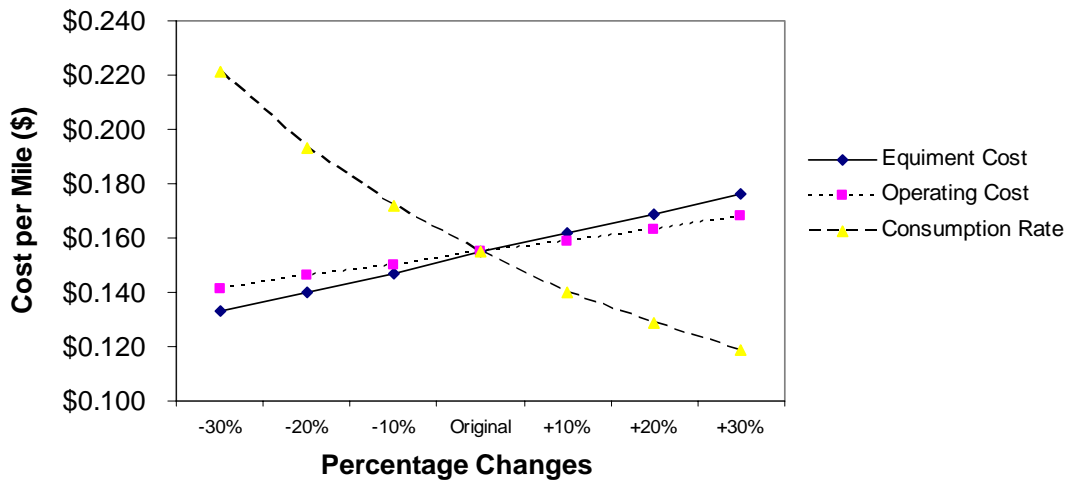


Figure 3.1: Cost per Mile Sensitivity Analysis

3.6 Conclusion

Although the current costs of using a hydrogen fuel vehicle is still higher than a conventional gasoline vehicle, the costs must be considered in conjunction with the environmental advantages of hydrogen fuel use. Since the availability of fossil fuels is expected to decrease in the future, resulting in price increases for traditional fuels, the costs of hydrogen production should decrease as technological advances make hydrogen fuel more cost efficient.

4. Environmental Analysis

4.1 Well-to-tank Analysis

The well-to-tank analysis shows the total emissions that involve the processes from generating the raw materials, transferring them to the service station, and depositing it in the fuel pump. Table 4.1 shows the well-to-tank emissions for a conventional gasoline vehicle and a H₂ fuel cell vehicle. When 18,178 grams CO₂/mmBtu is converted to grams CO₂/gallon gasoline produced the CO₂ emissions for the production of gasoline becomes 2,619 grams CO₂/gallon gasoline. When 149,354 grams CO₂/mmBtu is converted to grams CO₂/kg H₂ the CO₂ emission for the production of H₂ becomes 21,930 grams CO₂/kg H₂. The grams CO₂/gallon gasoline is less than the grams CO₂/kg H₂ because the energy that produces the H₂ is generated with coal which produces a high amount of CO₂ emissions. The inputs for the program along with any assumptions that were used to generate the well-to-tank and well-to-wheels analysis along with the equations used to convert grams/mmBtu to grams CO₂/kg H₂ or grams CO₂/gallon gasoline follow the well-to-wheels analysis.

	Conventional Gasoline	FCV: GH2, Electrolysis
Total Energy WTP	241,528	2,205,417
Efficiency	80.5%	31.2%
Fossil Fuels	237,393	1,243,929
Petroleum	109,064	54,246
CO2	18,178	149,354
CH4	109.120	248.184
N2O	0.303	2.836
GHGs	20,563	155,445
VOC: Total	16.220	10.771
CO: Total	14.849	34.924
NOx: Total	41.513	144.035
PM10: Total	3.334	18.864
SOx: Total	22.421	203.459
VOC: Urban	5.632	0.631
CO: Urban	4.149	5.878
NOx: Urban	8.840	12.836
PM10: Urban	1.502	1.567
SOx: Urban	9.250	11.424

Table 4.1 Btu or grams per mmBtu of fuel available at fuel station pumps

4.2 Well-to-wheels Analysis

The well-to-wheel analysis shows the emissions in grams/mile that is produced from the feedstock, fuel, and vehicle operation. The well-to-wheels analyses for the fuel cell vehicle (FCV) and the gasoline vehicle are shown in Table 4.2. In these analyses it is assumed that the FCV gets 60 mile/kg H₂ and the conventional gasoline vehicle gets 27.5 mpg. When compared, the feedstock emissions of CO₂ in a H₂ FCV are much greater than the feedstock CO₂ emissions for the gasoline vehicle. However in the vehicle operation, the H₂ FCV produces no CO₂ emissions whereas the conventional gasoline vehicle produces 318 grams

CO₂/mile. In order to estimate the well-to-wheels emissions savings for one year by replacing 50 conventional gasoline vehicles with 50 H₂ FCV we will assume an annual driving distance of 12,000 miles. At this distance the 50 conventional gasoline vehicles will produce 236,400kg CO₂/year whereas the 50 H₂ FCV will produce 165,000kg CO₂/year. This will result in a net well-to-wheels savings of 71,400kg CO₂/year.

FCV: GH2, Electrolysis	FCV: GH2, Electrolysis			Gasoline Vehicle: CG		
	Btu/mile or grams/mile			Btu/mile or grams/mile		
	Item	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel
Total Energy	4,066	0	1,843	177	838	4,200
Fossil Fuels	2,293	0	1,040	170	827	4,200
Petroleum	100	0	45	53	405	4,128
CO2	275	0	0	17	59	318
CH4	0.458	0.000	0.000	0.382	0.076	0.084
N2O	0.005	0.000	0.000	0.000	0.001	0.028
GHGs	287	0	0	25	61	328
VOC: Total	0.020	0.000	0.000	0.013	0.055	0.207
CO: Total	0.064	0.000	0.000	0.033	0.029	5.517
NOx: Total	0.266	0.000	0.000	0.091	0.083	0.275
PM10: Total	0.035	0.000	0.021	0.003	0.011	0.033
SOx: Total	0.375	0.000	0.000	0.019	0.075	0.069
VOC: Urban	0.001	0.000	0.000	0.001	0.023	0.207
CO: Urban	0.011	0.000	0.000	0.002	0.016	5.517
NOx: Urban	0.024	0.000	0.000	0.002	0.035	0.275
PM10: Urban	0.003	0.000	0.021	0.000	0.006	0.033
SOx: Urban	0.021	0.000	0.000	0.001	0.038	0.069

Table 4.2 Well-to-Wheel Comparison

Inputted Data:

Hydrogen FCV

Electricity	
Items	Assumptions
Residual Oil Utility Boiler Efficiency, Current (%)	35.0%
Residual Oil Utility Boiler Efficiency, Future (%)	35.0%
NG Utility Boiler Efficiency, Current (%)	34.0%
NG Utility Boiler Efficiency, Future (%)	35.0%
NG Simple Cycle Turbine Efficiency, Current (%)	34.0%
NG Simple Cycle Turbine Efficiency, Future (%)	35.0%
NG Combined Cycle Turbine Efficiency (%)	55.0%
Coal Utility Boiler Efficiency, Current (%)	32.0%
Coal Utility Boiler Efficiency, Future (%)	35.5%
Advanced Coal Technology for Power Generation (%)	41.5%
Electricity Transmission and Distribution Loss (%)	8.0%
Hydrogen	
Items	Efficiency
Electrolysis Production Efficiency: Refueling Station (%)	55.0%
Refueling Station Electric Compressor Efficiency: H2 via Electrolysis (%)	94.0%

Table 4.3 Hydrogen Fuel Production Assumptions

Items	Gasoline Car	Diesel Car
Gasoline Equivalent MPG	27.5	33.2
Exhaust VOC	0.062	0.049
Evaporative VOC	0.063	0
CO	2.759	2.759
NOx	0.036	0.063
Exhaust PM10	0.01	0.01
Brake and Tire Wearing PM10	0.021	0.021
CH4	0.065	0.011
N2O	0.028	0.016

Table 4.4: Baseline Vehicles Comparison

Items	Hydrogen Fuel-Cell Vehicle
Gasoline Equivalent MPG	222.4%
Exhaust VOC	0.0%
Evaporative VOC	0.0%
CO	0.0%
NOx	0.0%
Exhaust PM10	0.0%
Brake and Tire Wearing PM10	100.0%
CH4	0.0%
N2O	0.0%

Table 4.5: MPG and Emission Ratios: FCV/GV

Electricity	
Pathway Options	
NG CC Turbine for NG Plants (%):	30
Advanced Technology Share: Advanced Coal Technology for Coal Plants (%):	20
Marginal Generation Mix	
Residual Oil (%):	1
Natural Gas (%):	14.1
Coal (%):	16.9
Nuclear Power (%):	18
Others (%):	50
Average Generation Mix	
Residual Oil (%):	1
Natural Gas (%):	14.9
Coal (%):	53.8
Nuclear Power (%):	18
Others (%):	12.3
Hydrogen	
Vehicle Technology	
Fuel-Cell Vehicle	
Pathway Options	
Type of Hydrogen:	Gaseous
Hydrogen produced in:	Refueling Station from Electrolysis Utility System Electricity
Electrolysis Electricity Generation for Hydrogen:	Utility System Electricity

Table 4.6 Pathway Selections

*Baseline vehicle comparisons are the same for both technologies so it is not displayed again for the conventional gasoline vehicle.

Conventional Gasoline Vehicle:

Petroleum	
Items	Assumptions
Crude Recovery Efficiency (%)	97.7%
CG Refining Efficiency (%)	85.5%
Electricity	
Items	Assumptions
Residual Oil Utility Boiler Efficiency, Current (%)	35.0%
Residual Oil Utility Boiler Efficiency, Future (%)	35.0%
NG Utility Boiler Efficiency, Current (%)	34.0%
NG Utility Boiler Efficiency, Future (%)	35.0%
NG Simple Cycle Turbine Efficiency, Current (%)	34.0%
NG Simple Cycle Turbine Efficiency, Future (%)	35.0%
NG Combined Cycle Turbine Efficiency (%)	55.0%
Coal Utility Boiler Efficiency, Current (%)	32.0%
Coal Utility Boiler Efficiency, Future (%)	35.5%
Advanced Coal Technology for Power Generation (%)	41.5%
Electricity Transmission and Distribution Loss (%)	8.0%

Table 4.7: Gasoline Fuel Production Assumptions

Fuel/Feedstock	Feedstock	Transmission	Transportation	Transportation	Transportation	Transportation	Distribution
	NG	Pipeline	Ocean Tanker	Barge	Pipeline	Rail	Truck
Petroleum							
CG	Mode Share		20.0%	4.0%	73.0%	7.0%	100.0%
	Distance		1,700	520	400	800	30
Ocean Tanker							
Items	Ocean Tanker Size (tons)						
Crude Oil	1,143,000						
Gasoline	150,000						

Table 4.8: Fuel Transportation Assumptions

Conventional Gasoline	
Vehicle Technology	
Spark Ignition Engine	
Pathway Options	
Conventional Gasoline O2 Content (%):	0.4
Conventional Gasoline Sulfur Level (ppm):	340
Conventional Gasoline Oxygenate:	Methyl Tertiary Butyl Ether
Electricity	
Pathway Options	
NG CC Turbine for NG Plants (%):	20
Advanced Technology Share: Advanced Coal Technology for Coal Plants (%):	5
Marginal Generation Mix	
Residual Oil (%):	1
Natural Gas (%):	14.9
Coal (%):	16.1
Nuclear Power (%):	18
Others (%):	50
Average Generation Mix	
Residual Oil (%):	1
Natural Gas (%):	14.9
Coal (%):	53.8
Nuclear Power (%):	18
Others (%):	12.3

Table 4.9: Pathway Selections

The gasoline equivalent mpg in Table 5 is calculated for a FCV that gets 60 mile/kg H₂ and a conventional gasoline vehicle that gets 27.5 mpg.

This calculation was performed the following way:

1 kg H₂ = 424 standard cubic feet (scf) / (416 scf/ gallons gasoline equivalent (gge)) = 1.109 gge.

Thus, 60 miles/kg H₂ = 60 * 1.1019 = 61.15 miles/gge.

Thus, 61.15 miles/gge/ 27.5 mpg gasoline = 2.224 = 222.4%

The calculations for the g CO₂/kg H₂ or /gallon gasoline were made the following way:

(149,354g CO₂/mmBtu)*(0.1141mmBtu/gge)*(1.019gge/kg H₂) = 21,930 g CO₂/kg H₂

(18,178g CO₂/mmBtu)* (0.1141mmBtu/gge) = 2,619g CO₂/gallon gasoline

5. Public Awareness/Marketing and Education Plan

Rolla has unique characteristics that require a complicated marketing strategy for a high-tech product. The town has two sides: on the one hand it is a rural environment where townspeople have a limited technical background; on the other hand, it is the home of the University Of Missouri-Rolla, where extensive research is done and nationally known faculty members and future engineers reside. A successful marketing approach for the hydrogen fueling station would have to communicate our message via a strong image that the target market would appreciate and respect. The public awareness campaign will encompass the whole community as a means of spreading the message to a wider audience.

According to the US Census 2000, the population of Rolla is 16,367. Roughly 9% of the population is in the 10-18 year old range; 20% is in the 18-24 range; and 28% is in the 24-60 range.

The target market for the hydrogen fueling station will be the 24-60 year old age demographic since these individuals are most likely to afford and have the desire to purchase a fuel cell-powered vehicle (FCPV). This group of approximately 6000 people contains the UMR faculty members, but the vast majority of these are townspeople who are not very well educated on the workings of a hydrogen car. The marketing and education plan will be focused on this group.

The 18-23 year old range represents mostly college students who do not have the resources to purchase a FCPV, but show much interest in the new technology. However, most of these people are not expected to live in Rolla once they graduate and begin to acquire the purchasing power. The marketing plan will not exclude this group to promote the awareness of the station, but the focus of our marketing efforts will still be on those who permanently reside in the Rolla area.

The 10-18 year old range represents the current youth who will not be a part of the buyer's market for a few years. UMR's team anticipate they will be more involved in the next five years, as that is when these individuals will have the necessary purchasing power to afford a FCPV. At this point this group needs to be educated as to the safety and benefits of hydrogen as an energy source. Our goal is to attract the attention and interest of the upcoming generation to the hydrogen fuel technology.

Taking account that Rolla is a rural area and the lifestyle of the target market has many pastoral aspects, a strong image to associate with the hydrogen fuel technology will be "purity" in terms of its ecological friendliness. Using this image as the theme, the technological aspects will be expressed. Once their attention is gained through association of hydrogen energy with something they value, the impacts of the technology will be strongly emphasized. The most likely questions to arise from the target market will center on how their lives will change due to this new technology. The marketing team must readily be able to respond to doubts on issues such as cost per mile, mileage capacity of the vehicle, and safety of the overall technology. In each of these areas, the advantages of hydrogen over gasoline will be emphasized.

Phase one of the marketing campaign will entail announcing the new technology to UMR faculty members. These announcements will be conducted via email and brochures that contain brief information about hydrogen fuel technology and the hydrogen fuel station to be constructed in Rolla. Due to their technical knowledge, they will be asked to volunteer to help enhance public awareness of this concept.

Phase two will start with advertisements to local press and media, stressing the “purity” image. An example of this one-page advertisement is attached to this report. The goal is to dispel any fears that hydrogen technology will have an adverse effect on the environment. From there, UMR’s team will mail brochures (similar to those distributed to the faculty members) to every household within the Rolla city limits.

In Phase three, UMR’s team will organize seminars aiming at educating the public. These seminars will take place at one of the local hotels and will be announced through mailings to the households. Faculty members who agreed to participate during Phase one of these initiatives will give presentations to townspeople in which they seek to dispel the major myths and concerns regarding hydrogen technology. Topics will include: the environmental benefits of hydrogen in contrast to gasoline; the future scarcity of oil; the inevitable necessity of alternative energy resources; the wide availability and easy production of hydrogen fuel; and facts regarding driving and refueling a vehicle that will seek to educate the public as to the improvements hydrogen technology will bring. UMR’s team will make direct comparisons of the hydrogen vehicle to gasoline vehicles in terms of price, performance, and fuel economy.

Phase four will be targeted to the 10-18 year old age group. Seminars will be held at every local middle and high school. These seminars will be given by the hydrogen fueling station student design group members so as to create a friendlier environment. The topics will include the environmental benefits, information on the vehicles, and on the station itself.

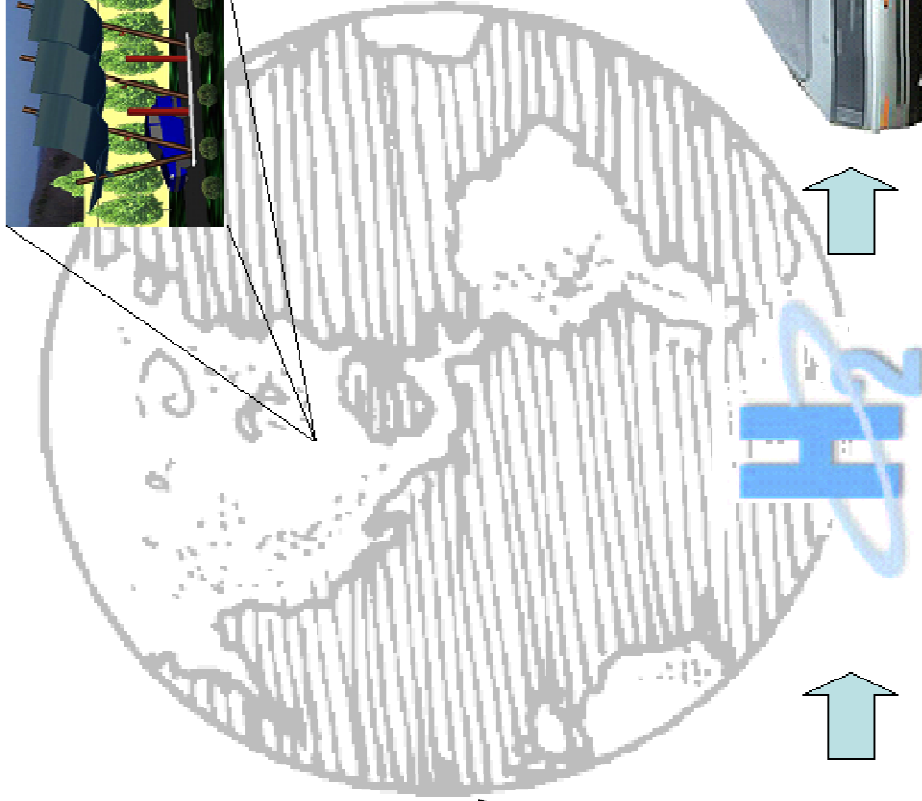
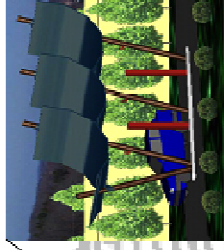
In addition, two large bulletin board displays will be rented on Interstate 44 to advertise the hydrogen fueling station. While the hydrogen fueling station is being built, banners displaying pictures of the finished station will cover the construction site. Also, the marketing team will be present at important local events (St. Pat’s, Homecoming, etc...) to answer any questions and distribute brochures.

The overall public awareness/marketing strategy for the hydrogen fueling station will be a campaign that will run throughout the year 2005 and address the whole community, with a central focus on the aforementioned target market. UMR’s team anticipates that marketing efforts will cost approximately \$20,000 (see Appendix for detailed cost breakdown). When the station opens in 2006, the Rolla community will have the required knowledge of the technology and the benefits of its use.

Missouri Hydrogen Fueling Station

Experience the future of automotive innovation

- Why Hydrogen Fuel?
 - Safer than Gasoline
 - Odorless and Colorless
 - Affordable
 - Environmentally Friendly



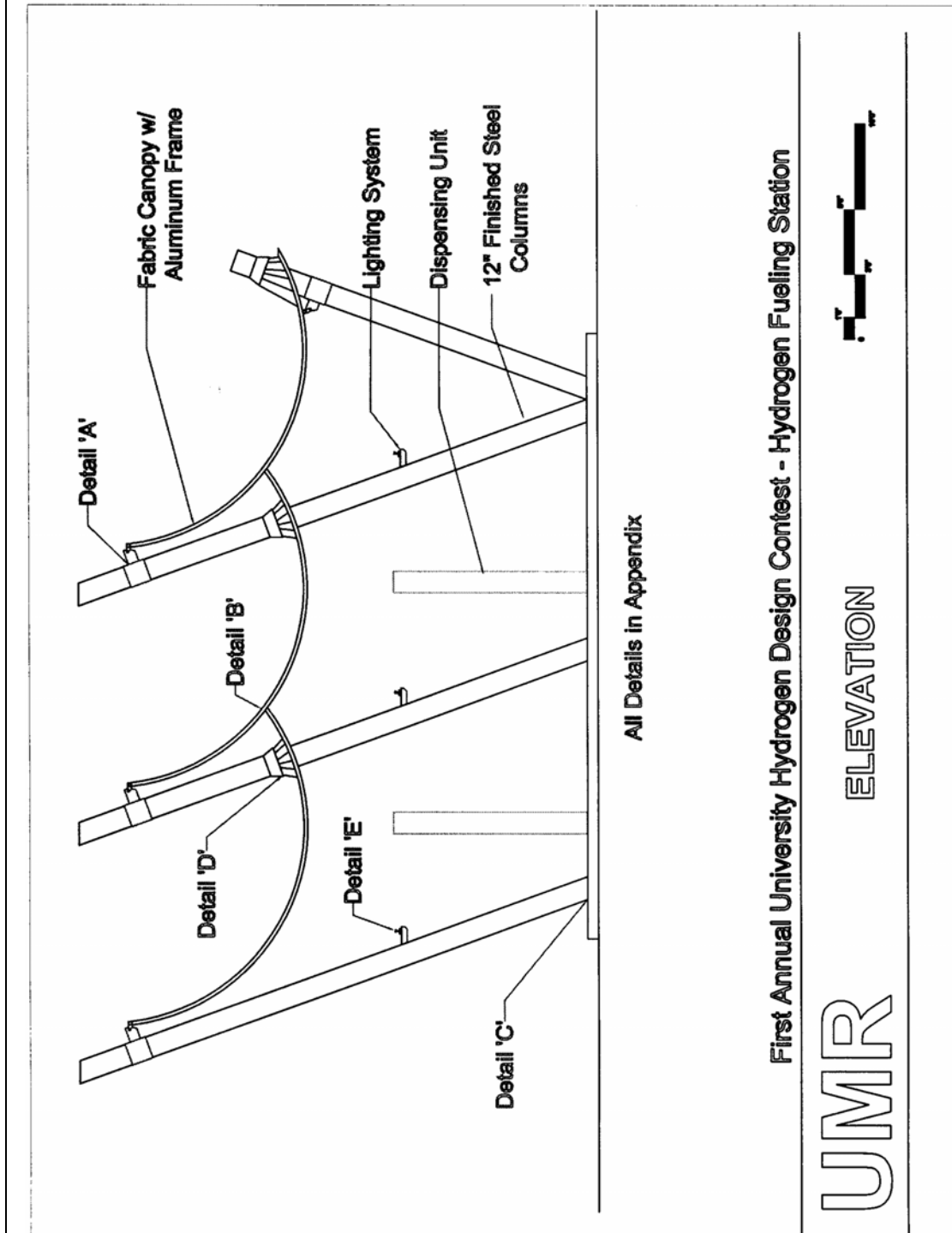
6. References

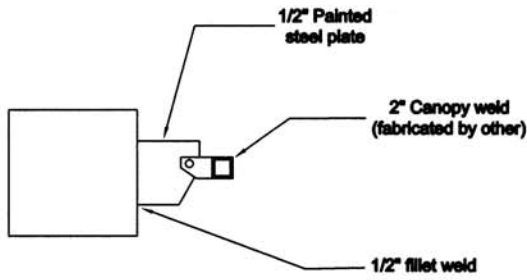
1) U.S. Department of Energy, One S. Wacker, Suite 2380, Chicago IL 60606
<http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/properties.html>

The well-to-tank and well-to-wheel analysis data was generated through GREET 1.6. GREET 1.6 is copyrighted by the University of Chicago. The following data is different from the standard input data in GREET 1.6:

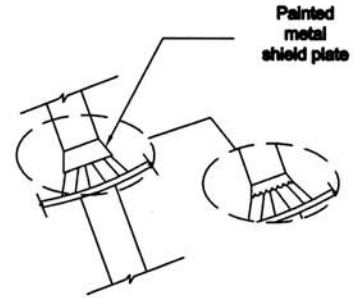
1. Electrolysis Production Efficiency: Refueling Station (%)
 2. Gasoline Equivalent MPG (27.5 mpg and 222.4%)
 3. Marginal Generation Mix (Electricity and Conventional Gasoline)
- 2) California Fuel Cell Partnership, 3300 Industrial Blvd.Suite 1000,West Sacramento, CA 95691
- 3) General Motors http://media.gm.com/news/releases/030210_hydrogen.html
- 4) Proton Energy Systems, 10 Technology Drive, Wallingford CT 06492
- 5) Stuart Energy Systems Corporation, 5101 Orbitor Drive, Mississauga, Ontario L4W 4V1 Canada
- 6) National Fire Protection Agency, 1 Batterymarch Park, Quincy, MA 02169-7471
- 7) International Code Council 5203 Leesburg Pike, Suite 600; Falls Church, VA 22041
- 8) City of Rolla Missouri 200 N. Main Street, Rolla , MO 65401
- 9) GTI, 1700 South Mount Prospect Road,Des Plaines, IL 60018-1804

7. Appendix

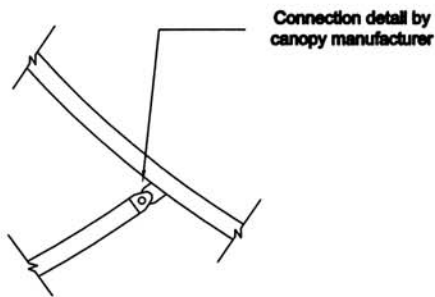




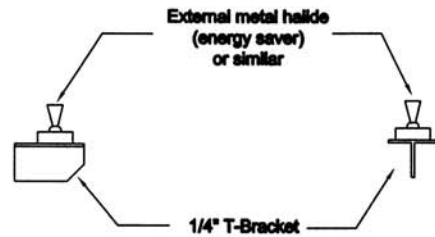
A CANOPY TO COLUMN CONNECTION
SCALE: NTS



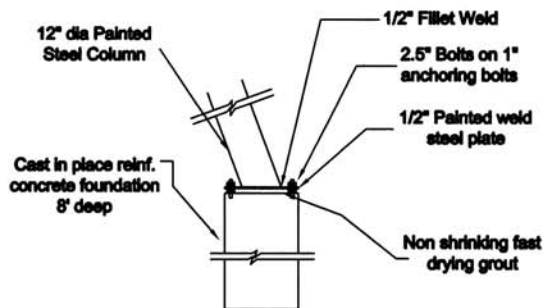
D CANOPY TO COLUMN CONNECTION
SCALE: NTS



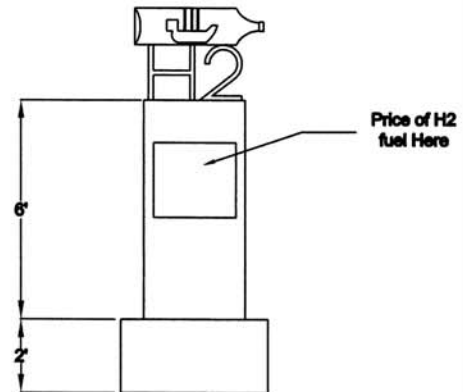
B CANOPY TO CANOPY CONNECTION
SCALE: NTS



E LIGHT FIXTURE
SCALE: NTS



C COLUMN TO FOUNDATION CONNECTION
SCALE: NTS



SIGNAGE
SCALE: NTS

First Annual University Hydrogen Design - Contest Hydrogen Fueling Station

UMR

DETAILS

10-year Cash Flow Analysis

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cash Flow Analysis											
Equipments											
Price and Installation	\$ 1,863,000.00										
Maintenance Cost	\$ 30,000.00	\$ 30,736.00	\$ 30,736.00	\$ 31,494.15	\$ 32,268.91	\$ 33,062.73	\$ 33,876.07	\$ 34,709.42	\$ 35,563.27	\$ 36,438.13	\$ 37,334.51
Operating Cost	\$ 196,984.89	\$ 201,830.72	\$ 206,795.75	\$ 211,882.93	\$ 217,095.25	\$ 222,435.79	\$ 227,907.71	\$ 233,514.24	\$ 239,268.69	\$ 245,144.46	
Life Time	15 Years										
Depreciation with MACRS											
Depreciation per year	\$ 266,222.70	\$ 456,248.70	\$ 325,838.70	\$ 232,868.70	\$ 232,868.70	\$ 166,365.90	\$ 166,179.60	\$ 166,365.90	\$ 83,089.80	\$ -	\$ -
Infrastructure											
Land Cost	\$ 174,800.00										
Construction and Material cost	\$ 440,000.00										
Maintenance	\$ 5,000.00	\$ 5,123.00	\$ 5,249.03	\$ 5,378.15	\$ 5,510.45	\$ 5,646.01	\$ 5,784.90	\$ 5,927.21	\$ 6,073.02	\$ 6,222.42	
Operating	\$ 466.45	\$ 477.92	\$ 489.68	\$ 501.73	\$ 514.07	\$ 526.72	\$ 539.67	\$ 552.95	\$ 566.55	\$ 580.49	
Depreciation with MACRS											
Depreciation per year	\$ 22,000.00	\$ 41,800.00	\$ 37,620.00	\$ 33,880.00	\$ 30,492.00	\$ 27,412.00	\$ 25,960.00	\$ 25,960.00	\$ 26,004.00	\$ 26,004.00	\$ 25,960.00
Other Expense*	\$ 50,000.00	\$ 51,230.00	\$ 52,490.26	\$ 53,781.52	\$ 55,104.54	\$ 56,460.12	\$ 57,849.03	\$ 59,272.12	\$ 60,730.21	\$ 62,224.18	
Total Capital Cost	\$ 2,312,925.20										
Total Expense	\$ 282,451.34	\$ 289,399.64	\$ 296,518.87	\$ 303,813.24	\$ 311,287.04	\$ 318,944.71	\$ 326,790.75	\$ 334,829.80	\$ 343,086.61	\$ 351,506.05	
Total Depreciation per year	\$ 288,222.70	\$ 498,048.70	\$ 363,458.70	\$ 266,568.70	\$ 266,568.70	\$ 196,857.90	\$ 193,591.60	\$ 192,325.90	\$ 109,049.80	\$ 26,004.00	\$ 25,960.00
IRR Analysis											
Present value of capital cost	\$ 2,312,925.20										
Present value of expense	\$ 256,773.95	\$ 239,173.26	\$ 222,779.02	\$ 207,508.53	\$ 193,284.76	\$ 180,035.97	\$ 167,696.32	\$ 156,200.57	\$ 145,493.73	\$ 136,520.80	
Total	\$ 1,904,465.91										
Present value of depreciation	\$ 262,020.64	\$ 411,610.50	\$ 273,071.90	\$ 182,070.01	\$ 122,233.27	\$ 109,277.41	\$ 98,693.60	\$ 50,872.54	\$ 11,028.23	\$ 10,008.70	
Total	\$ 1,530,866.79										
Present value of income	\$ 4,717,382.88										
Total Unit Sale in 10 years	547500	Kg									
Real value of price	\$ 8.62	per Kg									
Real price with sales tax	\$ 9.27	per Kg									
Hydrogen Fuel Cell Consumption	60	mile per Kg of Hydrogen									
Cost per mile for H2 Vehicle	\$ 0.15	per mile									
Information											
Inflation Rate	2.46%	per year									
Tax Rate	39%	This is the estimation tax rate including both federal and state incomes taxes									
Federal	34%	The income is in this rate bracket									
State	6.25%	with 50% of federal tax deductible									
Sales Taxes	7.60%	for Rolla area									