

THE UNIVERSITY of TENNESSEE at
CHATTANOOGA
COLLEGE of ENGINEERING
and COMPUTER SCIENCE

Spring 2009

Hydrogen Fueling Station

ENME 450

Final Technical Report

UTC 2009 Fueling Team Members:

Scott Bareham, Nathan Hooker, Marie Labrie, Ryan Mullis, Trevor Owens, John Ozbeck, Preston Payne,
Jeremy Pou, Jason Price

04/14/2009



Executive Summary

The purpose of this project is to design a hydrogen fueling station (HFS) for the University of Tennessee Chattanooga. The need to decrease our dependence on foreign oil and reduce the emission of greenhouse gases has led numerous institutions and government agencies to explore the use of hydrogen as an alternative fuel source. If successful this will be the first station of its kind in the Chattanooga area and will afford the University the opportunity to acquire data that may lead to revolutionizing the transportation world as it is viewed today.

Decisions regarding the design and construction of the HFS must conform to all rules and regulations governing the construction of a facility that will produce and store potentially hazardous gas. Safety considerations will be integral to all design ideas and decisions will measure this element of the project. This is in order to maintain a safe environment for both those that operate and those who visit the HFS.

Several production methods have been considered. Coal gasification and high temperature electrolysis are not feasible within the scope of this project. These two methods still need to be developed in order to improve efficiency and reduce cost. Electrolysis and gas reformation are the two production methods that are viable for the project. Due to budget constraints and small scale production requirements, electrolysis is more suitable for this design.

Once the production method was selected, individual components of the station were assessed. These components include a water purification unit, an electrolyzer, a compressor, storage tanks as well as leak detection devices. When choosing components, it is important to ensure that the components are compatible with each other. For example, it is important to verify the water purification unit can provide enough de-ionized water to the electrolyzer; this will ensure that the electrolyzer will operate efficiently. Component selection is an integral part of the design process.

Table of Contents

Introduction	4
Problem Statement	5
Background on Hydrogen Production Methods	5
-Nuclear	5
-Gasification	6
-Electrolysis	6
-Gas Reformation	7
Economic Analysis	7
Competitive Analysis	10
Decision Making	14
Technical Design	15
-Energy Analysis	15
-Process Flow Diagram	16
-Water Purification	17
-PEM Electrolysis	17
-Compressors	17
-Hydrogen Storage	18
-Dispensing	20
-Leak Detection	22
-Site Location	23
Value Engineering & Analysis	28
Testing Requirements & Procedures	32
Safety & Standards	33
-General Design	33
-Equipment	34
-Barrier Walls	34
-Weather Protection	35
-On Site Production	35
-Hydrogen Safety	35
Budget Analysis	36
Environmental Issues	38
Conclusion & Future Work	40
References	42
Appendices	44

Introduction

Numerous factors have influenced the increase in oil prices through out the world, with current prices being higher than ever before. Military actions in the Middle East along with severe weather phenomena have caused oil prices to skyrocket over the last ten years. While the cost of oil has increased, so has the nation's consumption [1]. In 2007 the United States imported nearly 55% of the oil it consumed. According to the Department of Energy (DOE) this amount is expected to increase to nearly 57% by the year 2025 [2]. This has led academic and government leaders to examine alternate energy sources that are both abundant and environmentally friendly.

In 2003 President Bush proposed the Hydrogen Fuel Initiative. The Initiative's goal is to develop hydrogen production technologies and commercialize a hydrogen fuel infrastructure in order to resolve America's concern about the nation's energy supply. The initiative has also made it financially possible for institutions, such as UTC, to participate in this research through numerous grants and proposals [3].

Hydrogen is the most abundant element in the universe and its potential as a fuel has been chronicled for decades. During the combustion process the major waste product is water vapor. However, elemental hydrogen does not exist in nature by itself. Any potential use as a fuel requires energy to break it free from its more readily available compounds. Water is one of the most widely available hydrogen carriers. Hydrocarbons such as coal, methane and biomass are other potential sources of hydrogen [4].

There are already more than seventy hydrogen fueling stations throughout North America with nearly all of them located in the United States. Most of these stations are operated by private organizations and universities with the goal of obtaining data to justify the conversion to a hydrogen economy [5]. Several automobile manufacturers, such as Ford, GM, and BMW to name a few, have pledged support for the conversion and have begun designing vehicles to make use of this new fuel source [6].

Problem Statement

The client for this project has tasked the Hydrogen Fueling Station team with determining the economic feasibility and design of a fueling station capable of producing two kilograms of hydrogen gas a day and the means by which to store a total of ten kilograms. The station must also have the capability to deliver the stored hydrogen to a vehicle.

The hydrogen supplied from this station is presently planned to support testing of a fuel cell bus operating on a closed loop within campus. A second goal will be to supply the Hydrogen Vehicle Conversion (HVC) team with fuel for its purposes as well.

Background Information

The hydrogen fuel station will consist of four major components. These include production, storage, dispensing and compression (Figure 1).

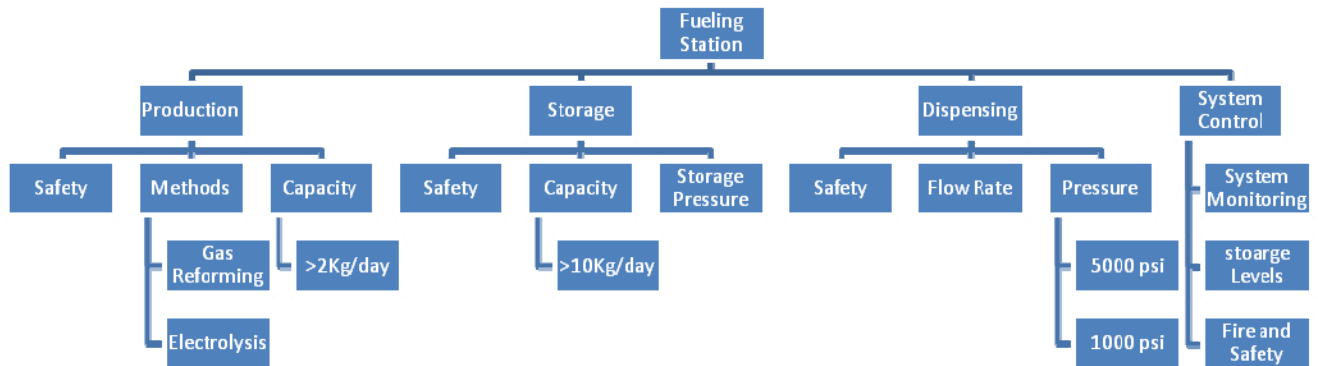


Figure 1: Work Breakdown Structure

Hydrogen generation from Nuclear energy

Nuclear technology could be used to supply high temperature heat to a heat exchanger for hydrogen production. The use of nuclear energy as the heat source of a large scale hydrogen production operation would significantly reduce carbon emissions compared with current methods of natural-gas-fired steam reforming operations. Hydrogen production from nuclear energy would also provide flexibility commercially since nuclear power plants are also capable of co-generating electricity along with hydrogen production. These plants are effective in reducing the consumption of fossil fuels and the emission of greenhouse gases.

High temperature electrolysis has the potential to produce hydrogen with an overall system efficiency of 45-55% [8], this is without fossil fuel consumption, and greenhouse gases. The only trade off will be the disposal of nuclear waste. Five MW of energy from a nuclear unit can produce approximately 140 kilograms of hydrogen per hour.

Coal Gasification

Coal is an abundant and inexpensive domestic resource. The US has a larger coal reserve than any other country in the world, roughly a 245 year supply based on current consumption [10]. Coal accounts for approximately 50% of the electricity produced in the US today. This electricity is acquired from a coal combustion process, which releases carbon dioxide and other emissions. The cost of hydrogen production at a central gasification plant devoted to hydrogen production is estimated to be \$1.03/kg of hydrogen at the plant gate with carbon dioxide sequestration [7].

A challenge facing this process is dealing with the large scale CO₂ sequestration. An integral coal gasification plant with carbon capture sequestration (CCS) has not yet been adequately demonstrated [9].

Electrolysis

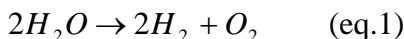
Electrolysis is the passage of an electric current through an electrolyte with subsequent migration of positively and negatively charged ions to the negative and positive electrodes.

One of the greatest advantages to electrolysis is that it can produce hydrogen from the most abundant natural resource on earth: H₂O. This clean and efficient process also has minimal impact to the environment, because the only by-product to electrolysis is oxygen.

Electrolysis has been used for many years to produce hydrogen. An important issue with electrolysis is the ratio of hydrogen production to power consumption. Electrolyzers are available in a wide range of production capacities. The electrolyzer generates hydrogen at low pressures ([200psi). This in turn requires the use of compressors and moderate sized storage tanks in order to supply H₂ at the desired pressure.

There are currently two types of commercially available electrolyzers: the alkaline electrolyzer, which uses potassium hydroxide (KOH) as its electrolyte, and the proton exchange membrane

(PEM) electrolyzer which uses a solid state polymer electrolyte. Regardless of the method employed, the electrolytic reaction can be summarized as:

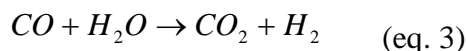


Natural Gas Reformation

Steam methane reforming is a process in which natural gas is used to produce hydrogen gas. First, the natural gas is treated with hydrogen to remove sulfur. The sulfur stream bi-product is scrubbed and then released into the atmosphere. Then the natural gas is mixed with high temperature steam (700-1000°C) at 3-25 bars of pressure over a nickel-alumina catalyst. The reaction produces hydrogen gas and carbon monoxide [11].



A water-gas shift reaction follows. The carbon monoxide and more steam then react in two stages. First, a high temperature shift occurs at approximately 350°C. A low temperature shift follows at approximately 190-200°C. In this process, the carbon monoxide and steam produce carbon dioxide and more hydrogen.



Finally, in the pressure-swing adsorption, CO₂ and impurities are removed and discarded appropriately [11].

Economic Analysis

The stability of the U.S. economy is the primary reason for the need to use hydrogen as an energy source. Switching to an energy source that does not need to be imported would improve availability and security. Two different hydrogen production methods were evaluated for use at the UTC fueling station. The different methods were natural gas reformation and electrolysis.

There are several advantages associated with natural gas reformation. First, the reformation process is 56% efficient and could produce hydrogen for \$3.00 per kg [11]. Second, pipelines used for transportation of methane are already in place. Third, the technology used in natural gas

reformation is already widely in use. Ninety-five percent of the hydrogen produced in the US is produced using natural gas reformation [12]. Natural gas also has a high H to C ratio, which means that there will be less carbon dioxide emitted per kg of hydrogen produced.

Natural gas reformation does have its drawbacks. For one, natural gas is not renewable. The US is currently importing 15% of their natural gas through pipelines from Canada and Mexico, and as Liquid Natural Gas (LNG) from Egypt, Nigeria, Trinidad and other countries [13]. Natural gas doesn't solve the dependence issue, it simply displaces it. Another issue is that natural gas reformation still emits 12 kg of CO₂ per kg of H₂ produced. Also, natural gas losses to the atmosphere are detrimental. Natural gas has a warming potential of 23. That means it contributes to the greenhouse effect 23 times more than CO₂. Natural gas reformation currently operates near the theoretical limit; therefore there is not much room for improvement [11].

Electrolysis is a production method that can be cost-effective, especially when renewable energy is used. With the exception of hydroelectric power, renewable energy sources account for less than one percent of the electricity generated in the U.S. When renewable energy is not available the electricity needed to power the electrolyzer will have to be purchased. An electrolyzer with an efficiency of 75% can produce hydrogen for \$4.24 per kilogram of hydrogen. This cost is based on an electrolyzer being powered by electricity costing 8 cents per kilowatt hour. When compared to gasoline, one kilogram of hydrogen has the energy equivalency of 1 gallon of gasoline [5]. As the price of gas continues to rise, hydrogen production from electrolysis will become cheaper than buying gasoline. Also, technologies relating to electrolysis are continually improving which will cause the cost of production to drop in the future.

In order for hydrogen to be an economically viable option, the cost to the consumer must be equal or preferably less than that of gasoline. A gallon of gasoline contains roughly the same amount of energy as a kilogram of hydrogen. A typical internal combustion engine (ICE) gets about 27 miles per gallon of gasoline. When hydrogen is used in an ICE, fuel efficiency drops to

24 miles per kilogram. The price equivalence of a kilogram of hydrogen and a gallon of gasoline can be calculated using a ratio of the mpkg and mpg.

$$\frac{mpg_{H_2ICE}}{mpg_{gasICE}} * \frac{\$}{gal_{gas}} = \frac{\$}{kg_{H_2}}$$

This equation is represented graphically in Figure 2

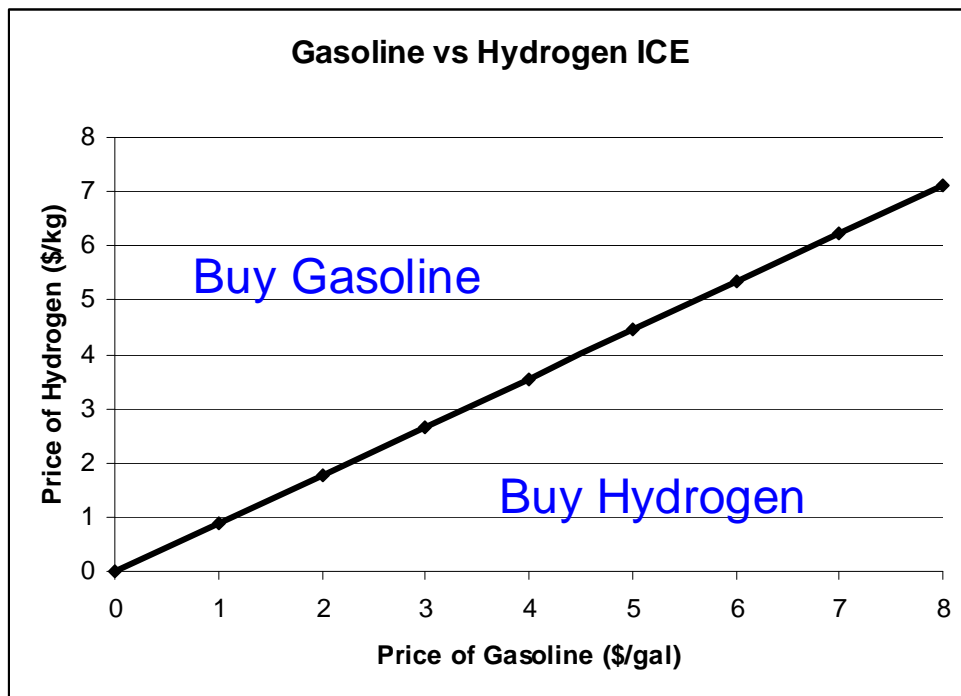


Figure 2: Gasoline vs. Hydrogen ICE

Ultimately, the hydrogen produced by the station would be used in fuel cell (FC) vehicles. The average fuel cell vehicle is expected to get about 65 miles per kilogram. This would give hydrogen a significant advantage over gasoline ICE which only gets 27 mpg. The price equivalence is shown graphically in Figure 3.

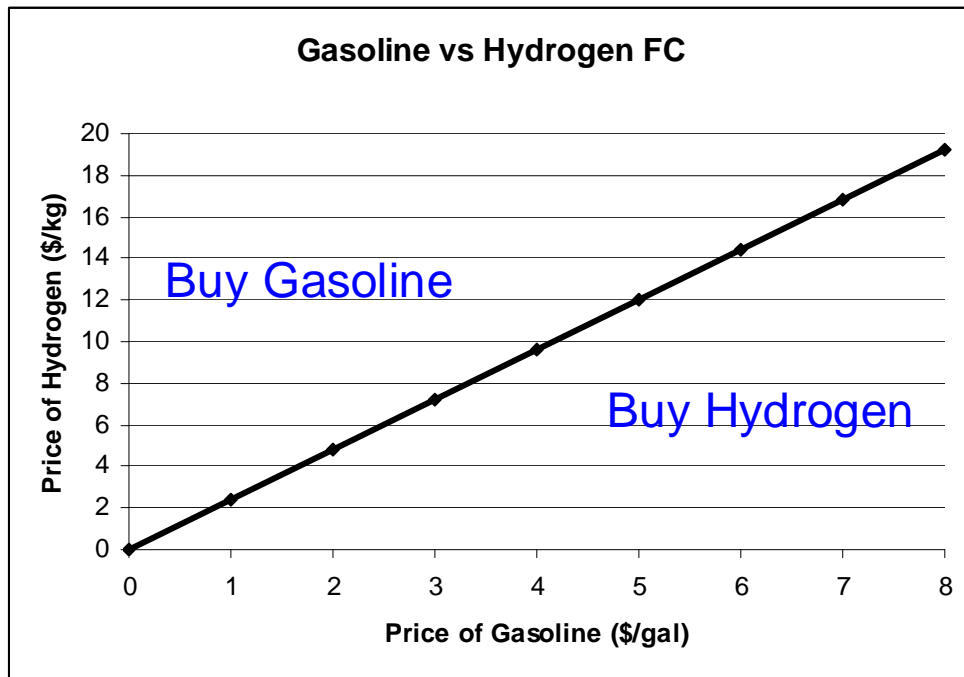


Figure 3: Gasoline vs. Hydrogen FC

Using Figures 2 and 3, consumers can determine whether it is more economical to buy hydrogen or gasoline.

Competitive Analysis

The competitive analysis for the hydrogen fueling station was divided into two categories. The first was the key assets that the team has available to use in designing the station. The second was a list of outside factors that could influence the success of the project. First to be discussed was the key assets.

People, intellectual property, cash, real estate, and personnel skills were emphasized when determining the key assets of the hydrogen fueling station team. The first of these assets was a lap top computer loaded with all required software needed to perform economic and pressure analyses. The second asset was the availability of the test track. This facility will allow the hydrogen dispensing station to be collocated with the test vehicle. The third asset available was the diverse skills of the team itself. The team consisted of five mechanical, two electrical, and two chemical engineering students. The inclusion of the different disciplines provided a wide

basis of skills needed to solve all of the problems associated with constructing this station. Along with the general skills possessed by the students, one team member is a certified machinist; also, several of the students are CAD certified. In addition, several team members are competent in Solid Works, and one is competent in Inventor software which is also design software. And last, but not least, one team member has passed the FE.

Along with these key assets, there were six categories of outside factors that could have affected the success of this project.

The categories of outside factors included: external and internal constraints, customers, suppliers, partners, competition, and technology.

The first of the six categories of external factors to be discussed was constraints. Constraints were either external or internal in nature. The first external constraint that affected this project was that the project was dependent upon the cost of petroleum. The price of gasoline and natural gas directly affect the need for an alternate fuel source such as hydrogen. If their price was to drop drastically, the funds for this project may be diverted to different projects. Second, the price of electricity with respect to natural gas affected which design was chosen and what production method was to be used. The third external factor was the fact that the Saturn Vue's design was not finalized. This resulted in the need to make assumptions about pressurization requirements. Also, the vehicle was not street legal weighed heavily in the decision to locate the fueling station at the test track. The final external restraint was that the project was for research only. This fact dictated it would address a very small market with highly restricted customer requirements. Also, this restricted market made it difficult to obtain information from vendors. The team believed it would be unethical to misrepresent themselves when communicating with vendors about the availability of funds and the scope of the project in the effort to request information about the products and prices of the needed components of the station. Also, much of the required information was proprietary in nature which made it difficult to obtain information from the vendors. External constraints were not the only type that affected this project. Internal constraints also affected it.

The first internal constraint was the small budget. Only approximately \$60,000.00 was available. This was known to be not enough to fund the entire project. The lack of funds resulted in the prioritization and selection of which elements were to be purchased now and

which were to be purchased later. A second internal constraint was the limited timeline in which the team had to complete the project. The design must be completed by the end of the term which only gave the team 16 weeks to complete it. The last internal constraint was the lack of a civil engineering student in the team. This resulted in much more effort expended by the other students to evaluate the tasks that would be accomplished by a civil engineering student.

The second category of outside factors that affected the project was the customer. The primary customer for this project was the Saturn Vue team. The fueling station was to be constructed to support the requirements of that team. Also, Dr. Bailey and Dr. Kazemsky were customers for the project. Not only were they to rate the performance of the team, but also would serve as the final approving/disproving agents. In selecting the customers, emphasis was placed on industry, geography, demographics, market status, and the project's lifecycle. First, this was a research project that was to support one specific vehicle. This narrowed the market considerably. As for geography, there was no existing hydrogen fueling stations in the Chattanooga area. This meant there was no local competition, but also meant there was no source of lessons learned to draw upon. Third, the demographics for this market was limited to collegiate America. This fact eliminated major corporations as customers. As for market status, using hydrogen as a fuel for automobiles was an emerging market. California was leading the nation in the use of hydrogen, but as a nation, more and more emphasis is being placed on alternative fuels. Market projections show that by 2030, hybrid automobiles will be the most widely class of automobile used in America, and by the year 2050, hydrogen powered automobiles will dominate the market.

The third external influence on the competitive analysis was that of the supplier. For a supplier to be deemed qualified, it had to charge a competitive price for the needed products. Also a warranty and/or maintenance plan must be included. The company must also use a price control system to ensure it would remain competitive in the future. Also, the supplier must provide all needed fittings and hardware that is specific to the equipment. And last but not least, the company must provide good customer relation after the sale. Too many companies ignore their customers after the sale.

For the water purification unit, Teledyne and Aqua-Solutions both were determined acceptable. Avalence and Teledyne, and Proton were acceptable for the electrolyzer. For the multi-stage compressor, Hydro-Pac and Pressure Products Industries were determined to be viable suppliers.

Only North Shore responded to inquiries for the Cascade storage system. Also only FTI responded to inquiries of the dispenser.

The fourth category of external influence was partners. Due to the limited scope of this project, the normal parameters of marketing, distribution network, installation channel, and manufacturing facility were not emphasized for this analysis. Instead, partners were chosen due to their direct influence on this project. The partners of the hydrogen fueling station were UTC at Knoxville who were a possible source of information and funding, Middle Tennessee State University who demonstrated an existing hydrogen fueling station, and TVA who provided the test track and other logistical support.

The fifth category of external influence was competition. A competitor's production capability, products, services, strength, and degree of threat to current project were the primary considerations for this category. The competitors were deemed to be other universities and private corporations that were both vying for limited grants and federal aid. No information was available as to which universities or companies were competing for the funds

The sixth and final category of external influence was technology. Dependency on parallel technological developments, exposure to breakthrough technology, and laws pertaining to carbon cap and greenhouse gasses were emphasized when determining how technology could affect this project. Parallel and breakthrough technologies include any advances in ethanol power vehicles, improvements in battery power used for electric vehicles, advances in electrolyzer design and efficiency, and advances in hydrogen storage efficiency could all affect the design of the fueling station. As for legal matters, hydrogen production results in oxygen being infused with moisture. This may be addressed in the greenhouse gas laws in the future. There were existing patents that could affect the project. The first was 6810925 which addressed Hydrogen Fueling Station. The second is 6755225 which addressed the Transportable Hydrogen Refueling Station. The third was 7360563 which targeted a System and Method for Refueling a Hydrogen Vessel. The fourth and last patent was 6182717 which provided a Process for Filling Hydrogen into a Hydrogen Storage Tank in Automobile.

Decision Making

Decision making criteria is essential in any design process. Keeping the scope of the project within guidelines is also important. In order to analyze production and storage for this project, a model called, “source to pump analysis” was established. Stated differently, the analysis will include everything from the production of hydrogen to its storage and delivery. There are six key criteria to this model. The first criteria is start up cost. The second and third are fossil fuel use and total energy use. Operating efficiency is the fourth criteria. Greenhouse gas emissions and safety are the final two criteria used in our decision making process.

Start up cost is the first and arguably most important criteria for deciding on a viable design. This primary cost is the limiting factor in the production and storage method selection. The initial investment must be justified for commitment to the project or it will be cancelled.

The use of fossil fuels is the second factor on our list of design criteria. A focus for this project is to decrease the dependence on foreign fossil fuels. Oil was eliminated as a production method for this very reason. Although natural gas reformation uses methane, a fossil fuel, technology is in place to efficiently produce hydrogen using this method. Also, the needed infrastructure, including gas pipes are currently in place making this a viable option. Coal gasification, while a viable method of producing hydrogen, is not economically feasible for production on a small scale.

Total energy use is also a major concern. This falls under the category of operating cost. It is critical to consider the amount of energy needed to produce 2kg of hydrogen per day. Also, a major concern is the amount of energy required to compress hydrogen to the needed pressure for storage and dispensing.

Operating efficiency is next on the list of criteria. Even if a production method is within the initial budget and its fossil fuel use is acceptable, its operating efficiency must be adequate. Operational and maintenance costs must be low when compared to the resulting income as well.

Regardless of the decisions made on previous criteria, the option chosen must adhere to all applicable safety codes and standards. Safety will not be sacrificed to lower production or maintenance costs.

Technical Design:

Energy Analysis

The energy balance of a hydrogen production facility is a critical step in the design process. It reveals energy gains and consumption throughout the entire process. After ruling out various production methods such as coal gasification and natural gas reformation, PEM electrolysis was selected as the desired production method. The first step in an energy balance is to conduct a materials and a mass flow balance. The goal is to determine how much water must be used to produce the 2kg of H₂ stipulated in the design objectives. Once a material balance has been determined, the amount of energy required can be calculated.

A material balance revealed the need for 1000 moles (4.7 gallons) of water to theoretically produce 2 kg of H₂. Electrolyzer has an efficiency of 90% when converting water to H₂, thus the electrolyzer requires 5.2 gallons of water to produce 2 kg of H₂. Using 2260 kJ/kg as the heat of vaporization of water, calculations show that 45 MJ is required to vaporize 5.2 gallons of water in the purification process. This value assumes water is subsequently condensed without added energy expenditure.

Electrolyzer efficiency is the next step in the energy analysis of the production process. Efficiency is defined as the energy contained in a kg of H₂, 39 kWh, divided by the energy used by the electrolyzer to create 1 kg of H₂. Three major Electrolyzer manufacturers' average energy usage is 65kWh per kg of H₂. By dividing 39 by 65, an efficiency of 60% is obtained. Thus, to create 2kg of H₂, with a Higher Heating Value (HHV) of 284MJ, 473MJ must be used.

There are also energy losses associated with compressing the H₂ to 6000 psig+.

A chart of energy losses due to compression (See Appendix 3) reveals that a multi stage compressor that achieves 6000 psi+ will also have an energy loss of approximately 10%. With a HHV of 284MJ, 2kg of H₂ would require 28MJ of energy to meet the compression requirements.

An assumption that no hydrogen leakage occurs during any stage of production was made. With this assumption in place the energy usages for each step in the production line can be summed together. Thus, 545MJ was required to produce and store the required 2kg of hydrogen. Overall production efficiency was calculated to be 52%.

Process Flow Diagram

A Process and Instrumentation drawing describes the interconnections of a particular process as well as the equipment and the instrumentation used to control the process (See Fig. 4).

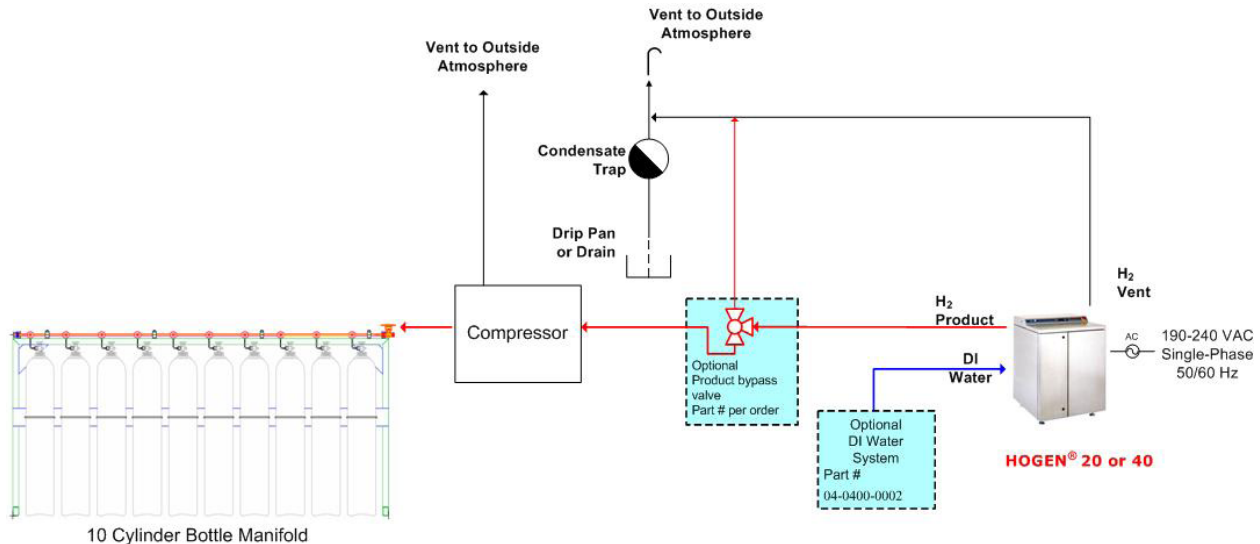


Figure 4: Process Diagram

The P & I D provided for the hydrogen fueling station will provide the team with helpful insight into the individual and sometimes intricate components of the fueling station. This particular Process Diagram is designed for two independent methods for acquiring hydrogen. The first of which is to purchase the hydrogen from a private vendor. This purchased hydrogen will be provided at 2000 psig and will be stored in a low pressure storage unit. The other option is to make the hydrogen on site. This process will be done with the use of a Hogen-40 electrolyzer. A direct water feed will go into a water purification unit and deionizer. This process removes all impurities and removes ions from the water. Next the purified water will move into the electrolyzer where the water molecules will be separated into hydrogen gas and oxygen gas. The oxygen gas can be expelled into the atmosphere or bottled and stored for future use. After the hydrogen is separated from the water it can then be stored in the same low pressure storage unit as previously discussed.

After the low pressure unit is filled, the gas can then be further compressed to its upper storage pressure of 5000 psig. This process is done by a high pressure diaphragm type compressor. Once the high pressure compression process is complete the hydrogen is then stored into the multi tank cascading storage system. The cascading system is a very unique system for

distributing the hydrogen efficiently. Eleven electronic valves cycle the 10 tanks independently in order to efficiently distribute the 4.6kg of hydrogen at its required pressure of 5000psia.

Water Purification:

This station will require a water purification unit. Ions in tap water could cause irreparable damage to the proton exchange membrane contained within the electrolyzer. There are several ways to obtain purified water. The two most common methods are distillation and reverse osmosis. Reverse osmosis is considered the most economical way to purify water. It removes 95-99% of contaminants contained in the water. In the reverse osmosis process, solutions with different concentrations of contaminants are separated by a semi-permeable membrane. Pressure is applied to the more concentrated side to counteract osmotic pressure. Due to the pressure, pure water flows out of the concentrated solution through the membrane and into its storage tank [18].

On-site PEM Electrolysis:

Electrolyzers that utilize a PEM contain a solid-state ion conducting membrane that replaces the liquid electrolyte used in alkaline electrolyzers. The energy inputs to the PEM electrolyzers are comparable to those required by alkaline electrolyzers. But because these units can operate at higher efficiencies, the cost of producing hydrogen is lower. PEM electrolysis is free of toxic materials that can spill or leak and as a result are considered to be a safer alternative than alkaline electrolyzers. While PEM electrolyzers can have a high capital cost, this cost is recouped due to the minimal maintenance costs over their life cycle. Manufacturers typically warrant the key component of the electrolyzers for the life of the unit.

Compressors

Due to budget constraints, a reciprocating compressor is suggested for this particular application due to its lower cost in comparison to diaphragm style compressors. Reciprocating compressors are categorized as single, multi stage, and hybrid cycles.

Single stage compressors provide an efficient means for moving large amounts of gas when high inlet pressures are available.

The multi-stage compressors increase hydrogen gas from inlet pressures as low as 100 psi to exit pressures as high as 15,000 psi. These units are used to fill storage tanks much like the type that will be used in the HFS team's station. They can be sized to match the flow of hydrogen gas produced by a reformer or electrolyzer. The multi-stage compressor is widely accepted as an economic and reliable component for the compression of hydrogen.

Hybrid compressors combine features of the multi-stage as well as the single stage units. When inlet pressures are low, hybrid compressors behave like a conventional multi-stage unit and will increase inlet gas pressures. When high inlet pressures are obtainable, hybrid machines behave as a single stage compressor and take advantage of the higher capacity that is possible with the higher inlet pressures.

Hydrogen Storage:

There are numerous methods for storing hydrogen. It can be stored in a liquid state, under high pressure, or through the use of metal hydrides. Storing hydrogen in liquid form allows a larger amount of hydrogen to be stored in a smaller space than either the use of high pressure or metal hydrides. Storage in liquid form requires cryogenic storage. A cryogenic tank consists of inner and outer shells with a vacuum separating them. This vacuum helps prevent heat infiltration from the outside of the tank. This is important because liquid hydrogen must be stored below its vaporization temperature of -259°C . The extremely low temperature makes this method expensive to employ.

Another method for hydrogen storage is the use of metal hydrides. In this method of storage, hydrogen molecules bond with metal hydride molecules. The metal hydride compound used for hydrogen storage usually consists of sodium, lithium or calcium. Heat is needed to extract the hydrogen from the metal hydride compounds, the heat from a PEM fuel cell can be harnessed for this task. One problem with metal hydride storage is that it can only be stored in small quantities and has slow intake and outtake kinetic properties. This is a concern when selecting a method for hydrogen storage, especially with respect to discharge time.

The last storage method researched is high pressure gas storage. This method stores gaseous hydrogen at a high pressure in a high pressure vessel. The normal pressure range for storing gaseous hydrogen is between 5,000 and 10,000 psi. High pressure hydrogen storage methods are

more economically feasible for a small scale refueling stations than the two previous methods. Another advantage of this method is that its charge and discharge times are shorter than other methods. One important factor in determining the charge time is the flow rate of the compressor. The storage tanks are capable of receiving the hydrogen as quickly as the compressor can compress it. A cascade dispensing system is employed with the storage of high pressure gaseous hydrogen. A cascading storage system consists of two or more compressed gas cylinders that are linked in series. For example, a three stage cascading system can be used to store hydrogen at 7,000 psig. The three cylinders in the cascade system would be used to pressurize an empty storage vessel. To accomplish this, the first storage vessel's valve is opened allowing the cascade tank and the tank being filled to equalize in pressure. Both tanks would then have 3,500 psig of hydrogen stored. Next, the valve on the second cylinder in the cascade system would be opened resulting in 7,000 psig to be dispensed into the receiving tank. An example of this process is shown below in Table 1.

Table 1: Pressure Dispersement

	Cascade Fueling System	Automobile Tank
Stage 1	7000 psig	0 psig
	3500 psig	3500 psig
Stage 2	7000 psig	3500 psig
	5250 psig	5250 psig
Stage 3	7000 psig	5250 psig
	6562.5 psig	6562.5 psig

To determine the number of tanks required, the volume of hydrogen at 7,000 psig must be determined. This was accomplished by using a modified ideal gas law.

$$v = \frac{ZRT}{p} \quad (\text{eq. 4})$$

The partial pressure of hydrogen is 186 psig. The storage containers will store the hydrogen at 7,000 psig. Because the storage pressure is much greater than the partial pressure of hydrogen, it is not considered an ideal gas. This means that a modified version of the ideal gas law must be used to determine the volume of the hydrogen. The problem with the difference in pressures is solved by introducing the compressibility factor (Z) into the ideal gas equation. Z is determined using the Nelson-Obert Generalized Compressibility Chart. Below are the calculations used to determine the volume of hydrogen at 7,000 psig, a mass of 10 kg, 296 K, and an ideal gas constant of 4.124 kJ/kg*K. The following equation is used to determine the ratio between the critical and actual pressures. This ratio is used on the Nelson-Obert Chart.

$$P_r = \frac{P}{P_{cr}} = \frac{7000 \text{ psi}}{188.1 \text{ psi}} = 37.21 \quad (\text{eq. 5})$$

Using this value and the generalized compressibility chart the value of the compressibility factor Z was determined to be 1.4. The modified ideal gas equation was then employed to solve for the volume of hydrogen stored in the three tank cascade system. The complete computation follows:

$$Z = \frac{Pv}{RT} \quad \longrightarrow \quad v = \frac{ZRT}{P} \quad \longrightarrow \quad v = \frac{1.4 * 4.124 \frac{KJ}{Kg * K} * 296K}{48Mpa} \quad \longrightarrow$$

$$v = 0.036 \frac{m^3}{Kg} \quad \longrightarrow \quad 0.036 \frac{m^3}{Kg} * 10Kg = 0.36m^3$$

These formulas may be used to determine the number of tanks needed in this project's cascading storage system.

Dispensing

All hydrogen fueling stations must have a dispensing system to control the flow of hydrogen from the station storage tanks to the vehicle storage tank. Stations that dispense compressed natural gas have found that consumers prefer dispensing systems that are similar to current gasoline/diesel dispensing systems in appearance and operation. In addition, the dispensing nozzle that provides interface between the dispenser and the vehicle must be standardized and thereby compatible with all types of vehicles that will utilize this station for fueling. Standard

codes such as NFPA 52 dictate the nozzle rating and thus the final delivery pressure of the dispenser.

The dispensing system will consist of a single unit comprised of the following components:

- Metal dispenser housing (cabinet)
- Leak detection system
- Fill nozzle
- High pressure flexible supply hose
- Flow meter
- User interface and control panel (touch pad and/or LCD)
- Replaceable hydrogen filter
- Break away connection assembly
- Priority sequence panel for implementing a fill algorithm from station cascade storage tanks
- Control system for implementing fill algorithm to account for ambient temperature and heat of compression effects

The specifications for a 350 bar, slow-fill, single hose hydrogen dispenser is a flow meter and display unit like those shown in Table 2. A picture of a dispensing unit is shown in Figure 5.

Table 2: Specification for a hydrogen dispensing unit. Source: Fueling Technologies Inc.

GENERAL SPECIFICATIONS	
Configuration	Single Hose, 1 Inlet, Side Mounted Nozzle
Maximum working pressure	447 Bar
Maximum flow rate	20 Kg/min
Dimensions	33" W x 22" D x 92" H
Weight	650lbs
Operating Temperature Range	-20° C to 60° C
Electrical Requirements	120 VAC, 3A, 60Hz
External 2 or 3 Bank cascading control output:	Two 110VAC output terminals.
Design codes and standards:	NEC for Class 1 Division 2 Group B ASME B31.3



Figure 5: Photograph of a hydrogen dispensing unit.

Source: Fueling Technologies Incorporated

Leak Detection:

Hydrogen gas leak detection is critical to the safety of the workers, safety response personnel, and customers of the hydrogen fueling station. Being the smallest element in the universe hydrogen is able to pass through many materials and small openings, thus making it extremely dangerous to produce, store, and dispense. Many leaks resulting from small openings are too small for conventional leak test equipment that uses nitrogen [21]. The flammability range of hydrogen is very wide with a lower limit of 4 percent. For this reason, detector devices must be capable of detecting amounts of hydrogen down to one percent concentration levels. Two categories of sensors are required. One is a stationary type, which is in continual operation and must be located in any confined space where hydrogen leaks could occur or where hydrogen gas could accumulate; such as the ceiling or air ducts. The second type is a hand-held wand, which is used for daily and/or periodic inspections by the station superintendant.

Five types of sensors were researched. Catalytic bead sensors use two beads connected to a Wheatstone bridge. One bead is coated to act as the catalyst and the other is passive. When hydrogen gas is present, a difference in resistance between the two beads causes a change in current flow through the galvanometer. This variation of signal then results in the galvanometer

outputting a signal to a warning device. The catalytic bead sensor was not chosen because it does not react only to hydrogen. This could result in false alarms.

A second type of sensor is an electro-chemical sensor. This operates on the principle that when hydrogen gas passes over the chemically sensitive electrolyte, a reversible chemical reaction occurs. This reaction generates a current proportional to the gas concentration. When there is no longer gas present, the electrolyte returns to its original state. This type of sensor was not chosen because it is not hydrogen specific.

A third type to be considered is the hydrogen field-effect transistor. This sensor uses palladium as its gate material. The presence of hydrogen gas causes small changes in the palladium, which produces large changes in the current-voltage characteristic of the transistor. The transistor then outputs a signal to a warning system. This type of sensor meets the requirements of safety parameters.

A fourth type was the solid state sensor. This sensor uses semiconducting oxides to detect the amount of oxygen in the air. The presence of hydrogen reduces the amount of oxygen and results in the sensor sending a signal to a warning indicator.

The final type researched was the resistive palladium alloy. This sensor utilizes the ability of palladium to dissolve more than six hundred times its volume in hydrogen. The amount dissolved proportionally changes the resistivity of the metal and results in the sensor sending a signal to a warning indicator.

The selected hand-held wand sensor is a solid state sensor. It meets and/or exceeds all safety requirements pertaining to hydrogen detection. The stationary sensor selected is a hybrid between solid state and palladium sensors. It uses palladium to detect leaks, but uses the solid state electronics to operate.

Site Location:

Four possible sites were considered for the hydrogen station location. The University of Tennessee at Chattanooga Advanced Vehicle Testing Facility (UTC AVTF) (Figures 6 & 6.1) located off Amnicola near highway 153 was selected as a prime location, since both the shuttle bus as well as the Saturn Vue will be tested there. The site also has a large building already on

site that can accommodate the HFS in its entirety. The AVTF is also an isolated location, so in the event of an accident, spills, and/or fires could be contained with minimal threat to the public.



Figure 6: UTC AVTF



Figure 6.1: UTC AVTF

The Carta Bus Depot located on Market Street next to the Chattanooga Choo Choo (Figure 5) is another possible location for the HFS. This site allows easy access for shuttle buses should the Carta bus line decide to convert their busses to run on hydrogen. The close proximity to the public and other combustible materials may increase facility costs in regards to ISO and NFPA

location standards. The major draw back to this location is its inaccessibility to the AVTF, were the shuttle bus and Saturn Vue will be tested.



Figure 7: Carta Bus Depot

The UTC SIM Center (Figure 7) is another possibility for the fueling station. The building located behind the SIM center would be a great location due to its close proximity to UTC. This facility also has a solid state fuel cell in place, which means UTC has experience in meeting all local fire codes and safety requirements pertaining to hydrogen production and storage.



Figure 8: UTC SIM Center

UTC Parking Services (Figure 9) is the last location to be looked at. This location provides a great opportunity for UTC's engineering department. Being across from the engineering math and computer science building (EMCS) visitors and guests of the engineering department could simply walk over and visit the facility. This would provide great opportunities for individuals and businesses that fund programs such as UTC's interdisciplinary design projects.



Figure 9: UTC Parking Services

The optimal location for the hydrogen fueling station was determined by using the decision matrix in figure 10. Each of the four prospected locations was graded against the six traits that are important aspects for the location of the fueling station. The UTC Advanced Vehicle Testing Facility showed an overwhelming advantage over the other three locations. This is greatly due to the Saturn Vue, which will use the hydrogen produced by the fueling station to perform road test at the UTC AVTF.

Table 3: Location Matrix

TRAIT	WEIGHT FACTOR	LOCATIONS			
		UTC AVTF	SIM CENTER	BUS DEPOT	UTC PARKING FACILITY
Solar Energy Availability	5	5	0	0	0
Restrictions of Saturn Vue	50	50	0	0	0
Secure Area	10	10	9	5	7
Accessibility from Campus	5	0	5	0	5
Explosion Hazard	10	10	0	0	5
Controlled Testing Environment	20	20	0	0	0
TOTAL	100	95	14	5	17

Within the UTC AVTF there are four locations that are projected for the fueling station. Figure 11 is a CAD rendering of the test track facility, this figure depicts the four locations that are prospects for the fueling station location within the UTC AVTF.

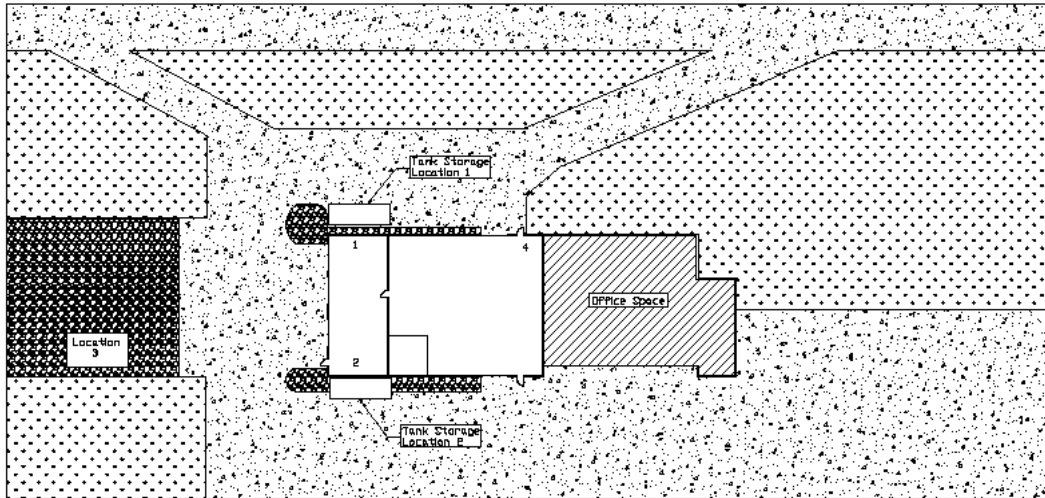


Figure 11: Test Track Drawing

A decision matrix was drafted to determine the optimal location within the UTC AVTF. Location 1 and 2 are in the same bay and offer superior ventilation. Both location 1 and 2 have available electric power. Location 3 is located outside of the building in a fenced in gravel lot. This location will require that a building with a concrete pad be built. Location 3 has electric power available but it has no water hook up. Location 4 is a location within the main bay of the existing building. This location has available electric power and water. The only draw back to location 4 is that there are two bay doors and walk through door in this corner of the building; this will cause problems with locating the electrolyzer and water purification.

Table 4: AVTF Location Metrics

TRAIT	WEIGHT FACTOR	LOCATIONS			
		1	2	3	4
Volume of Air for Ventilation	10	10	8	10	10
Indoor Location for Electrolyzer	20	20	20	5	20
Ease of Fueling Test Vehicle	20	20	16	16	20
Safety/Prohibit Unauthorized Entry	20	20	20	8	10
Proximity to Solar Panels	10	10	10	0	4
Access to Water and Electricity	20	15	20	8	20
TOTAL	100	95	94	47	84

Conclusions drawn from the decision matrix led the team to choose location 1 within the UTC AVTF. Location 1 is located in an area with more than adequate ventilation to meet the safety requirements of gaseous hydrogen along with the fact that all necessary water and electric sources are readily available. All 4 locations meet the site preparation requirements for installation of a Hogen 40 electrolyzer which requires that a concert slab be installed such that the floor is no more than 2 degrees from level. Upon arrival if the client decides that a more suitable location within the AVTF is found, some minor modifications will be necessary to assure a trouble free installation. Most notable of which are rerouting of water and electrical sources to the electrolyzer.

Value Analysis

At some point during the design phase, it is beneficial to perform a value analysis, or value engineering (VE) study, on individual components to determine if cost can be reduced or if quality can be improved. To determine if any improvements could made in this regard, the HFS team performed a rudimentary value analysis for the major components of the refueling station. The first step was to make a list of functions performed by the refueling station. Next, this list was broken down into basic functions and secondary functions. Basic functions define the reason for the product or design. In this case, the principle reason for the hydrogen refueling station is to make and dispense hydrogen for vehicle use. Secondary functions are typically the methods by which these basic functions are brought to fruition, or those functions that support

the basic functions. Again, in the case of the hydrogen refueling station, secondary functions might include regulating hydrogen flow or detecting leaks. Table 5 shows a succinct, but not comprehensive, list of functions performed by the hydrogen refueling station.

Table 5: Function Analysis for Refueling Station

Function#	Verb	Noun	Basic	Secondary
1	compress	hydrogen	X	
2	generate	hydrogen	X	
3	regulate	flow		X
4	prevent	leaks		X
5	transfer	hydrogen		X
6	warns	user		X
7	filter	water		X
8	contain	hydrogen		X
9	allow	flow		X
10	measure	flow		X
11	fill	tanks		X
12	supply	hydrogen	X	X
13	supply	water		X
14	increase	convenience		X
15	control	flow		X

Once the basic and secondary functions were delineated, a cost-function matrix was created for the components related to the basic functions only. The cost-function matrix for the components that perform basic functions is shown in Table 6. The components making up the secondary functions were considered to have little overall impact on product price and quality. This is true since most of these components - which consist mostly of piping, control valves, pressure regulators, pressure relief devices, and fittings - have single vendors, comprise a very small portion of overall cost, and meet or exceed current industry standards for safety and performance.

Table 6: Cost-Function Matrix for Major Components

Components	Cost (in \$1000)	Compress Hydrogen		Generate Hydrogen		Supply Hydrogen			
		%	Cost	%	Cost	%	Cost		
Hydrogen Refueling Station									
Electrolyzer	79			100%	79				
Compressor	95	100%	95						
Storage Tanks	19	33%	6.3	33%	6.3	33%	6.3		
Dispensing System	48					100%	48		
Total Function Cost	241	42%	101.3	35%	85.3	23%	54.3		

From Table 6, it can be seen that the biggest impact on value could be achieved with respect to the generation and compression functions of the station design. As a result, the HFS team only studied these two components in detail.

For hydrogen generation, three different methods were considered for the final design. While potentially less expensive up front, the steam methane reformers and alkaline electrolyzers held hidden costs that diminished their value in the design. With respect to the former, the unstable price of natural gas held great potential for vast operating cost swings. With respect to the latter, frequent maintenance and hazardous chemical monitoring/handling presented increased operating costs and lowered reliability. So, the HFS team determined that a PEM electrolyzer, while more expensive up front, lowered operating costs and increased reliability, therefore substantiating its superior value.

For the compression function, two types of compressors were considered. Quotes for a reciprocating piston type and for a three-diaphragm type compressor were obtained. While the diaphragm type compressors are four times the cost of a comparable piston type, issues with reliability and with product contamination must be considered in an effort to establish a relative value. The piston type compressors are noted for their relative unreliability and for contamination of the hydrogen stream with hydraulic fluid. On the other hand, for pure hydrogen production, the diaphragm type compressors are preferred for ensuring a contaminant free hydrogen stream. When considering potential costs that could result from impure hydrogen

delivered to a customer, especially with a fuel cell vehicle, it was determined that a diaphragm type compressor held superior value over the piston type. A further note is that the diaphragm type compressors are better suited to the small scale hydrogen production of PEM electrolyzer chosen for the design. That is to say, the electrolyzer chosen had an impact on the final choice of a compressor. It is worthy to also note that using a diaphragm type compressor precludes the necessity of a buffer tank, which would have been required if a piston type compressor had been chosen.

Finally, the value analysis performed for this project was rudimentary due to the absence of a complete, concise, and definite final design. Final drawings showing elaborate detail and indicating every single component for an actual design were not part of the scope of this project. However, the principles of value analysis were helpful in determining not only major components, but also in looking at alternative designs. For instance, it was considered feasible from the beginning of the project that a suitable alternative to onsite production might be a portable tube trailer delivered to the refueling station site. While a dispensing system would still be required, a tube trailer would negate the need for the generation and compression function. Other studies have indicated that this is the lowest cost option for refueling a small fleet of vehicles [16]. However, the tube trailer option does not lend itself to refueling large vehicle fleets or to showing the viability and reliability of distributed hydrogen generation, which is considered to be a necessary part of the hydrogen economy. For hydrogen to be a suitable alternative to current transportation fuels, it must be available at every street corner, as gasoline is currently. The most cost effective option for prevalent hydrogen refueling facilities is local, distributed generation and compression.

Testing Requirements and Procedures

Several assumptions were made over the course of the semester to estimate the amount of energy required to produce and compress the required amounts of hydrogen needed. Once installed the system efficiency can be determined using installed electrical meters. Lead times from the vendor prevent the Spring 2009 team from being able to perform the analysis at this time.

At the UTC Hydrogen Fueling Station, safety has the highest priority. This means that any action that can present an unsafe situation is prohibited. The dangers associated with hydrogen are very real and must be considered at all times. First, it is important to understand what these dangers are. Hydrogen is a flammable and explosive gas. It requires a very low amount of energy to ignite (one tenth the amount of energy required to ignite gasoline) and it burns with an invisible flame. What all this means is that extra care must be taken to eliminate any possibility of a fire. Hydrogen, like all gases can displace oxygen and cause asphyxiation. This event is unlikely, however it must be considered when inside the building. If a hydrogen leak is detected inside, safe practice is to open the doors and windows and exit the building and let a trained individual handle the equipment.

The number one cause of accidents is human error. Therefore, in order to eliminate accidents we must eliminate human error. Individuals that are onsite must look for and abide by all posted signs. Following these signs will reduce the risk of a fire or any other accident. There is no smoking allowed near any of the fueling station equipment. You must remember that hydrogen molecules are very small and can easily leak out into the air. When arriving onsite one must not assume conditions are safe. The first thing that should be done is stop and look around to make sure there are no unsafe conditions. Remember it is all individuals' responsibility to practice safe behavior in order to keep any accident from occurring.

The UTC Hydrogen Fueling Station is not designed for public use. This means it should not be operated by anyone other than an individual who has been trained to operate this equipment. No one shall touch the equipment or fuel a vehicle without first being properly trained on the UTC Hydrogen Fueling Station. Before fueling a vehicle, read and follow the Fueling Checklist and Procedure that is located in the appendix 5.

Safety and Standards

In order to maintain the safety of those who use the University's fueling station, it is of paramount importance that all applicable rules and regulations are adhered to. These rules and regulations may be based on criteria set forth by national government agencies such as the Department of Occupational Safety and Health (DOSH) as well as state and local permitting agencies. Many organizations have recently added amendments specific to the topic of hydrogen gas used as a fuel source that is distributed to the general public [17].

There are several organizations that have rules or regulations pertinent to different aspects of the projects completion. These organizations are listed below as related to the step in construction that they are applicable to [17].

General Design

International Fire Code (International Code Council)

35- Flammable Gases

2209.1 -General

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages

7.3 -Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Fuel Systems Code

9.3 -System Siting

14.2 -Facility Design

NFPA 55, Use and handling of compressed gases and cryogenic fluids

7.1.6 Separation from Hazardous Conditions

An example of the NFPA 55 10.4.4 Indoor Hydrogen System Location is outlined below:

Hydrogen systems of less than 3500 scf (99m³) and greater than the MAQ, where located inside buildings shall be located in the building so the system will be as follows:

- 1) In a ventilated area in accordance with the provisions of section 6.16
- 2) Separated from incompatible materials in accordance with the provisions of 7.1.6.1.
- 3) 25 ft (7.6m) from open flames and other sources of ignition.
- 4) 50 ft (15m) from intakes of ventilation, air-condition equipment, and air compressors.
 - a. The distance is permitted to be reduced to 10 ft (3m) where the room or area is protected by a listed detection system as per article 500.7 (K) of NFPA70, National Electrical Code, and the detection system shall shut down the fuel supply in the event of a leak that results in a concentrations that exceeds 25 % of the LFL.
 - b. Isolation values used to isolate the fuel supply shall be of a fail-safe design.
- 5) 50 ft (15m) from other flammable gas storage.
- 6) Protected against damage in accordance with the provisions of 7.1.6.6

Equipment

International Fire Code (International Code Council)

2209.2 Equipment

NFPA 52, Vehicular Fuel Systems Code

9.2 General System Requirements

Barrier Walls

International Fire Code (International Code Council)

2209.3.1.1 Barrier Wall Construction – Gaseous Hydrogen

NFPA 55, Standard for Storage, Compressed Gases and Cryogenic Liquids

8.6.2.1 Fire Barriers

8.6.3.1 Fire Barriers

Weather Protection

International Fire Code (International Code Council)

2209.3.2.2 Weather Protection

2704.13 Weather Protection

On Site Production

International Fire Code (International Code Council)

2209.3.1 Separation from Outdoor Exposure Hazards

International Fire Code (International Code Council)

703.1 General Requirements

NFPA 52

5.2 Systems Approvals

Hydrogen Safety

Hydrogen is an odorless, colorless and tasteless gas 15 times lighter than oxygen. A hydrogen leak in an open air fueling station poses a low threat to those around it. In enclosed spaces, high concentrations of hydrogen may be reached quickly should a leak develop. The high concentration of hydrogen could cause a deficiency of oxygen possibly resulting in individuals exposed to the hydrogen experiencing “headaches, ringing ears, dizziness, drowsiness, unconsciousness, nausea, vomiting and the depression of all the senses. The skin of the victim may have a blue color. Under some circumstances death may occur. Hydrogen is not expected to cause mutagenicity, embryotoxicity, teratogenicity or reproductive toxicity. Pre-existing respiratory conditions may be aggravated by overexposure to hydrogen.” [16]. Still, the chance of a hydrogen leak in a properly designed and maintained system is small. Despite the relatively low molecular size of hydrogen compared to other fuels, properly mated metal-to-metal seals (flared or compression joints) are considered sufficient.

Hydrogen has the widest range of flammable concentrations in air among all common gaseous fuels. Hydrogen's lower and upper concentration limits, 4% and 75% by volume, give it a large range of flammable volumes. Other properties of the gas such as its high buoyancy and high diffusivity tend to cause a decrease in the ignition potential over time. Hydrogen also has a low auto ignition temperature, which can cause ignition by heating or spark. The minimum spark energy required is approximately one tenth of that required by gasoline, and like gasoline exposure to weak sparks, hot surfaces or open flame is sufficient to ignite hydrogen. Even a small leak could be very hazardous because a despite having a higher flame temperature than hydrocarbon fires, such as natural gas, coal, or petroleum derivatives, it burns nearly invisible. "The energy of an explosion of hydrogen, expressed in kg of TNT per kg fuel is 24, compared to 11 for methane and 10 for gasoline." [17] [18]

Continuous exposure to hydrogen also causes embrittlement in some steels, this may cause cracks in pipes, welds, and metal gaskets. In general stainless steel has better embrittlement resistance properties than other steels and aluminum and its alloys are considered better than stainless steels, providing the gas is dry. [17]

Budget Analysis

Economic analysis is a major constituent of the final design phase. As the design goes from concept to realization an economic assessment must accompany. The analysis examines capital costs and operating costs providing a total annual cost of the Hydrogen Production facility. This cost figure divided by the yearly production of hydrogen gives a cost per kilogram for the system.

Capital costs consist of equipment purchases, training as well as site preparation and set up. The total capital cost of \$214,000.00 is established from a bid from Proton Energy, a copy of bid is located in appendix. The bid includes a fueling nozzle, a fueling tank and a HP tank consisting of 10 DOT3AA6000 Cylinders. Next on the bid list is a water purifier by Aqua Solutions which will feed into the Hogen 40 electrolyzer which has a 2.27 kg per day production capacity. The hydrogen will be carried to diaphragm compressor capable of compressing hydrogen up to 6000psi. A calibration kit and diagnostic software are also included in the bid. Ordinarily site

purchase fees would be located in the capital cost sections, but this facility has the advantage of a free site location.

In order to assess capital costs into the cost per kilogram of hydrogen produced the capital costs must be annualized. For the sake of this analysis an interest rate of 8% is assumed and a payback period of ten years was chosen. The formula for annualizing present worth is found below.

$$A = P \left(\frac{i(1+i)^n}{(1+i)^n - 1} \right)$$

$$A = 220,414 \left(\frac{0.08(1+0.08)^{10}}{(1+0.08)^{10} - 1} \right)$$

$$A = \$38,274.26$$

In the above formula, *A* is annualized worth over the payback period, *n*. The interest rate, *i*, is then plugged into the equation. In the economic analysis of the Hydrogen Production facility \$220,414.00 was used as a capital cost which includes training and set up. A pay back of ten years was chosen and an interest rate of 8% assumed providing a figure of \$38,274.26.

The next step in the economic analysis is to establish operating costs. Once a bid had been obtained with a component list utility duties could be established. The Aqua Source water purifier uses 0.94 liter per hour. 24 hour operation time is assumed with no downtime for maintenance. The total water use per month is 24ft³ establishing a water rate of \$0.20/ft³. This is added to a ¾” meter fee which costs \$18.28 per month for a total water bill of \$23.08 per month. A ¾’ meter was chosen because it is same size as inlet diameter of water purifier.

Electricity needs are the next step in establishing operating costs. The Hogen 40 electrolyzer uses 169kWh to produce the 2.27kg it make during 24 hour operation. Multiplying this energy usage by a \$0.09/kWh residential utility rate gives a daily cost of \$15.58. A compressor duty of 8kWh per day is assumed based on interpretation of Chart EA1 located in appendix.

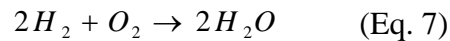
The total operating costs per year are calculated to be \$6,248.00. This is added to the annualized capital cost for a total yearly cost \$44,500. Divide this by the yearly production rate, excluding

downtime for maintenance, of 828 kg of hydrogen gives a cost of \$53.77 per kilogram of hydrogen. If capital costs are ignored a rate of \$8.00 per kilogram is found. Or, if capital costs are set to \$2,000.00 cost stay below \$9.00 per kilogram of hydrogen produced.

Environmental Issues

One of the benefits of hydrogen fuel is the reduction of greenhouse emissions. Greenhouse gases trap heat waves that are reflected by the earth and contribute to global warming. Greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxides, ozone and CFC's [2].

Hydrogen as a fuel produces virtually no emissions. When pure hydrogen is fed into a fuel cell vehicle, the only by-product is water vapor.



In a combustion engine, small amounts of nitrogen oxides can be produced as well due to the high temperature of the reaction.

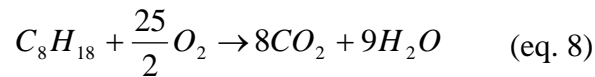
Comparing the performance of hydrogen and gasoline can be problematic because hydrogen is a gas at room temperature. For this reason, comparisons are often made based on energy equivalence. A gallon of gasoline and a kilogram of hydrogen both contain approximately 120 mega Joules of energy [15]. When used in a fuel cell, hydrogen is 2.4 times more efficient than gasoline when used in an internal combustion engine. The average internal combustion engine car gets approximately 27 miles to the gallon. A hydrogen fuel cell vehicle gets approximately 65 miles per kilogram [7].

While carbon dioxide is not directly produced by hydrogen vehicles, some carbon dioxide is emitted in the production of the hydrogen. The values in Table 7 do not take into account any carbon capture or sequestration.

Table 7: Carbon Dioxide Emissions for Various Hydrogen Production Methods

Production Method	kg CO ₂ /kg H ₂
Coal Gasification	19
Natural Gas Reforming	17.6
Electrolysis - Non Renewable Power Source	12
Electrolysis - Renewable Power Source	0

In order to determine the amount of carbon dioxide emitted by today's internal combustion engine, it is assumed that gasoline is mostly octane and that complete combustion occurs. The combustion equation is as follows:



Using this equation, the amount of carbon dioxide emitted per gallon of gasoline can be calculated.

$$1 \text{ gal}_{gas} * \left(\frac{2.661 \text{ kg}_{gas}}{\text{gal}_{gas}}\right) * \left(\frac{\text{kmol}_{gas}}{114 \text{ kg}_{gas}}\right) * \left(\frac{8 \text{ kmol}_{CO_2}}{\text{kmol}_{gas}}\right) * \left(\frac{44 \text{ kg}_{CO_2}}{\text{kmol}_{CO_2}}\right) = 8.2 \text{ kg}_{CO_2} \quad (\text{eq. 9})$$

The amount of carbon dioxide emitted from a gasoline engine may seem to be less than that emitted in the production of hydrogen, but it is important to remember that hydrogen is more efficient than gasoline. Also, when carbon capture methods are used in the production of hydrogen, the values seen in Table 3 can be drastically reduced. The ideal production method would be electrolysis using renewable energy sources because it would completely eliminate carbon dioxide emissions.

From stoichiometric analysis, the amount of water vapor emitted from a kilogram of hydrogen fuel can be calculated.

$$1 \text{ kg}_{H_2} * \left(\frac{\text{kmol}_{H_2}}{2 \text{ kg}_{H_2}}\right) * \left(\frac{2 \text{ kmol}_{H_2O}}{2 \text{ kmol}_{H_2}}\right) * \left(\frac{18 \text{ kg}_{H_2O}}{\text{kmol}_{H_2O}}\right) = 9 \text{ kg}_{H_2O} \quad (\text{eq. 10})$$

In an internal combustion engine, the water vapor emitted can be calculated as follows:

$$1 \text{ gal}_{gas} * \left(\frac{2.661 \text{ kg}_{gas}}{\text{gal}_{gas}} \right) * \left(\frac{\text{kmol}_{gas}}{114 \text{ kg}_{gas}} \right) * \left(\frac{9 \text{ kmol}_{H_2O}}{\text{kmol}_{gas}} \right) * \left(\frac{18 \text{ kg}_{H_2O}}{\text{kmol}_{H_2O}} \right) = 3.8 \text{ kg}_{H_2O}$$

(eq. 11)

It is important to remember that hydrogen is more efficient than gasoline; therefore, the amount of water emitted by both is approximately equivalent on a per mile basis.

Also important to consider is that hydrogen leaked to the atmosphere is detrimental to the environment. It is estimated that approximately 10-20% of all hydrogen produced for transportation will be leaked at some point during production, storage or distribution [14]. This is an environmental hazard because of hydrogen's wide flammability range and low ignition temperature. The hydrogen and air mixture can be easily ignited. Alternatively, the hydrogen can rise up to the upper atmosphere where it will get oxidized into water. This would cause a cooling effect, which could have an impact on ozone chemistry [14].

Conclusions & Future Work

The Hydrogen Fueling Station Team's objective is to build a station that is capable of producing 2 kg of hydrogen a day while storing 10 kg. The team has evaluated four production methods and selected electrolysis. Individual components were researched and requests for information were sent to several vendors.

Proton Energy Inc. supplied the Fueling station team with a quote that provided all necessary equipment to meet the required production and storage criteria. In conjunction with this quote the team further researched available methods for delivery from the storage tanks to the vehicle. A high pressure fuel line from Dynatec Ind. and a fueling nozzle from WEH Enterprise were selected. Lead times for the aforementioned components prevent initial system analysis to be performed at this time. Delivery and installation of the equipment will be the first step by UTC to help further understand both the benefits and potential shortcomings of using hydrogen as an alternative fuel source in the United States.

More research and testing will need to be performed in subsequent semesters to obtain quantitative analysis of the proposed design. The cost of current technology prevents widespread market saturation at this time. However, as more data is collected the technology will become both more abundant and economically feasible.

References

1. "Daily Fuel Gauge Report." AAA's Media Site for Retail Gas Prices. 14 Oct. 2008. AAA. 14 Oct. 2008 <http://www.fuelgaugereport.com/tnavg.asp>.
2. "Petroleum Basic Statistics." Energy Information Administration. Sept. 2008. U.S. Department of Energy. 14 Oct. 2008 <http://www.eia.doe.gov/basics/quickoil.html>.
3. "President's Hydrogen Fuel Initiative: A Clean and Secure Energy Future." U.S. Department of Energy Hydrogen Program. 2003. U.S. Department of Energy. 14 Oct. 2008 http://www.hydrogen.energy.gov/presidents_initiative.html.
4. "Hydrogen and Fuel Cells Research." National Renewable Energy Laboratory: Science and Technology. 2 Sept. 2008. NREL. 14 Oct. 2008 <http://www.nrel.gov/hydrogen/>.
5. "Hydrogen Fueling Station Database." National Hydrogen Association: General Information. 14 Oct. 2008. NHA. 14 Oct. 2008 <http://www.hydrogenassociation.org/general/fuelingsearch.asp>.
6. "Hydrogen Road Tour '08." 31 States in 18 Cities in 13 Days. 2008. U.S. Department of Transportation (US DOT). 14 Oct. 2008 <http://hydrogenroadtour08.dot.gov/>.
7. National Research Council (U.S.). "Hydrogen Production Technologies." The Hydrogen Economy : Opportunities, Barriers, and R&D Needs. New York: National Academies P, 2004. 91-105.
8. Besenbruch, G.E. "HIGH EFFICIENCY GENERATION OF HYDROGEN." OECD/NEA, Information Exchange Meeting on the Nuclear Production of Hydrogen, 2 Oct. 2000, Paris, France. 14 Oct. 2008 <http://web.gat.com/pubs-ext/misconf00/a23510.pdf>.
9. "Gasification Technology R&D." U.S. Department of Energy. 10 Sept. 2008. U.S. Department of Energy. 14 Oct. 2008 <http://fossil.energy.gov/programs/powersystems/gasification/index.html>.
10. Canine, Craig. "How to Clean Coal." OnEarth. Fall 2005. Natural Resources Defense Council. 14 Oct. 2008 <http://www.nrdc.org/onearth/05fal/coal1.asp>.
11. Hydrogen Production " Steam Methane Reforming (SMR)." HYDROGEN FACT SHEET. New York State Energy Research and Development Authority. 14 Oct. 2008 <http://www.getenergysmart.org/files/hydrogeneducation/6hydrogenproductionsteammethanereforming.pdf>.
12. "Today's Hydrogen Production Industry." U.S. Department of Energy Hydrogen Production Technology. 28 Oct. 2005. U.S. Department of Energy. 14 Oct. 2008 <http://www.fossil.energy.gov/programs/fuels/hydrogen/currenttechnology.html>.
13. A Look At Some Of The More Promising Alternative Fuels." 2005. Natural Gas Liquid. 14 Oct. 2008 <http://www.naturalgasliquid.com/>.

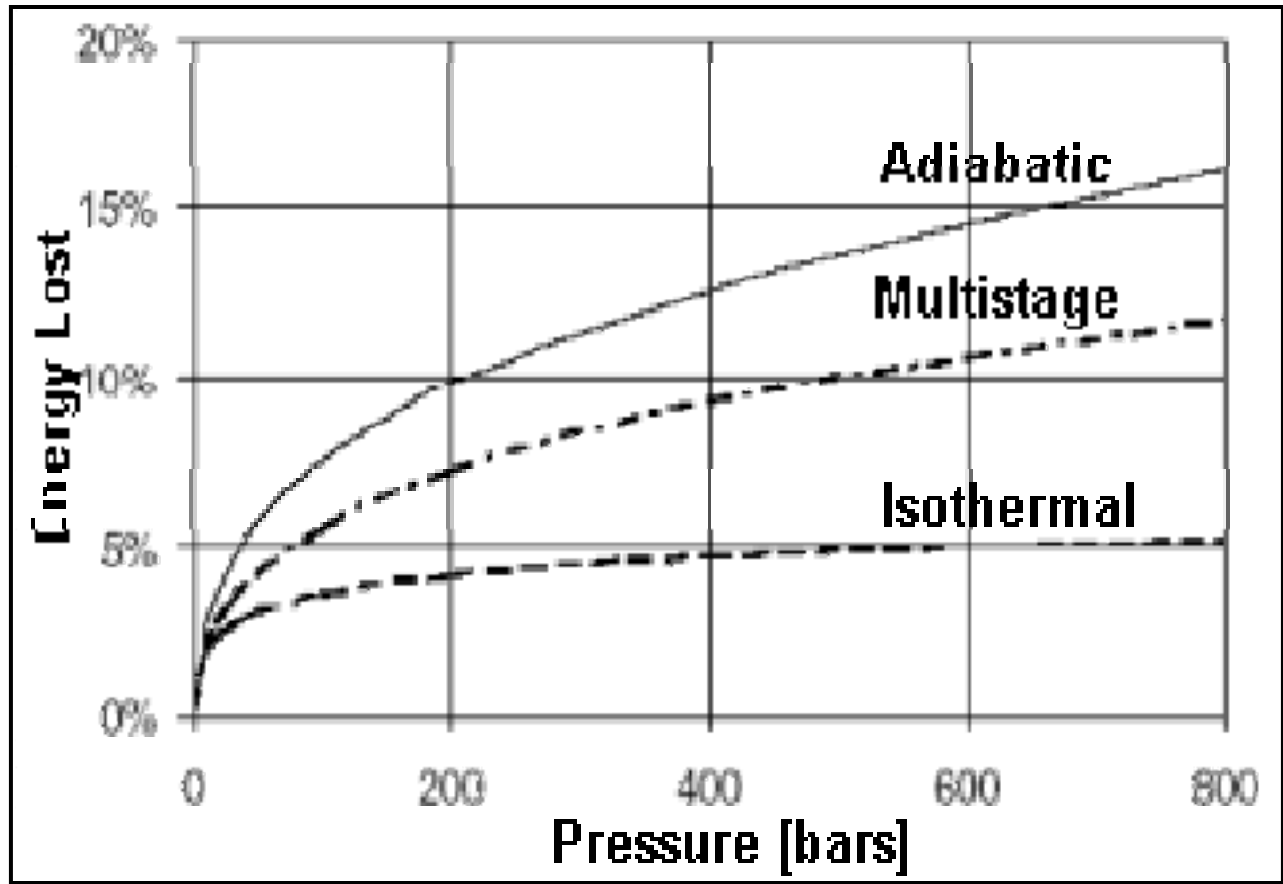
References (cont)

14. Tracey, Tromp K. "Potential Environmental Impacts of a Hydrogen Economy on the Stratosphere." Science Magazine.
<http://www.sciencemag.org/cgi/content/full/300/5626/1740>.
15. "Lower and Higher Heating Values of Fuels." Hydrogen Analysis Resource Center. Mar. 2006. US Department of Energy. 14 Oct. 2008
http://hydrogen.pnl.gov/cocoon/morf/hydrogen/site_specific/fuel_heating_calculator?can_print=false.
16. Weinert, Jonathan. A Near-Term Economic Analysis of Hydrogen Fueling Stations. Tech. no. UCD-ITS-RR-05-04. University of California - Davis, Institute for Transportation Studies, 2005.
17. Lenntech. "Hydrogen-H." Chemical properties of hydrogen - Health effects of hydrogen - Environmental effects of hydrogen. 2008. Lenntech Water treatment & air purification Holding B.V. Sept.-Oct. 2008 <<http://http://www.lenntech.com/periodic-chart-elements/h-en.htm>>.
18. Praxair Material Safety Data Sheet. Tech.No. P-4604-G. Material Safety, Praxair Technology Inc. Praxair Technology Inc. 1-10.
19. National Renewable Energy Laboratory, "Technology Brief: Analysis of Current-Day Commercial Electrolyzers," NREL/FS-560-36705, September 2004.
20. U.S. Department of Energy Multi-Year Research, Development, and Demonstration Plan, Section 3.1.4.2.4 "Hydrogen Generation by Water Electrolysis Barriers."
21. Standard temperature and pressure (STP) is 0C & 1 atm; Normal temperature and pressure (NTP) is 20 C & 1 atm; At NTP 1 mole of ideal gas volume = 22.4L or 0.0224Nm³, 1 mole of H₂ = 2 g of H₂, 1 Nm³ of H₂ = 0.0892kg.
22. "H₂ Safety Best Practices" H₂ Best Practices, Pacific Northwest National Laboratory and Los Alamos National Laboratory, September 2008
http://h2bestpractices.org/storage/compressed_gas/fittings_and_joints/
23. "Fuel Cell Sensors and Overview," HIL Tech Development Limited, March 2005
http://www.hiltechdevelopments.com/images/uploads/fuel_sensors.pdf
24. "Hydrogen Safety," Hydrogen Association, Fact Sheet Series Number 1.008, No Date Given. http://www.hydrogenassociation.org/general/factSheet_safety.pdf

Appendix 1: Project Time

ID		Task Name	Duration	Start	Finish	Predecessors
1	✓	Research Methods for H2 Production	7 days	Mon 9/8/08	Wed 9/17/08	
2	✓	Develop Preliminary Work Breakdown Structure	14 days	Mon 9/8/08	Tue 9/30/08	
4		Prepare Design Criteria Statement (Fueling System Requirements)	3 days	Mon 9/8/08	Wed 9/10/08	
3	✓	Finalize Project Definition Statement	2 days	Tue 9/23/08	Wed 9/24/08	
9	✓	Prepare and Submit Midterm Project Report	4 days	Tue 9/23/08	Tue 9/30/08	
6	✓	Verify with Hydrogen Vehicle Team the on-vehicle tank size and pressure	2 days	Thu 9/25/08	Mon 9/29/08	
5	✓	Finalize and Submit Work Breakdown Structure	2 days	Tue 9/30/08	Wed 10/1/08	
7		Develop brainstorm list of design options (any possibilities - justify refusal of any option)	2 days	Tue 9/30/08	Wed 10/1/08	
16		Finalize Project Schedule and Preliminary Budget	4 days	Thu 10/2/08	Thu 10/9/08	
8		Finalize On-Site Hydrogen Production Method - based on economic analysis - look especially at capital costs	2 days	Tue 10/7/08	Wed 10/8/08	
10		Determine List of Optional Station Features to be considered	3 days	Tue 10/14/08	Thu 10/16/08	
11		Determine contingency conditions, if any, for station (support tanker refueling if primary production is offline) - economic analysis	3 days	Tue 10/14/08	Thu 10/16/08	
12		Determine any station design flexibility features (multiple pressure refueling) - cost benefit	3 days	Tue 10/14/08	Thu 10/16/08	
13		Determine if station should supply power back to grid - complete economic analysis (cost benefit)	3 days	Tue 10/14/08	Thu 10/16/08	
14		Determine if solar arrays should be used to supply power to station - complete economic analysis (cost benefit)	3 days	Tue 10/14/08	Thu 10/16/08	
15		Determine necessary security measures/weather protection if any for station (fence, restricted access)	7 days	Tue 10/14/08	Mon 10/27/08	
17		Prepare Draft Preliminary Design (should include preliminary process flow and description of equipment)	10 days	Tue 10/21/08	Wed 11/5/08	
39		Prepare preliminary major component layout	3 days	Tue 10/21/08	Thu 10/23/08	
28		Prepare and Submit End of Term Final Report (should include final preliminary design)	14 days	Thu 10/23/08	Tue 11/18/08	
18		Determine any necessary infrastructure requirements (water, sewer, power)	2 days	Mon 11/3/08	Tue 11/4/08	
44		Decide on Storage Method Design (made up of components or purchase complete storage system from vendor)	7 days	Tue 10/28/08	Thu 11/6/08	
19		Develop Specifications and Cost Estimates for Station Components	14 days	Mon 11/2/09	Tue 2/3/09	
20		Develop Specifications and Cost Estimates for Power Rectifier (AC to DC converter)	7 days	Mon 11/2/09	Wed 1/21/09	
21		Develop Specifications and Cost Estimates for H2 Generation Equipment	7 days	Mon 11/2/09	Wed 1/21/09	
22		Develop Specifications and Cost Estimates for Compression Devices	7 days	Mon 11/2/09	Wed 1/21/09	
23		Develop Specifications and Cost Estimates for Dispensing System	7 days	Mon 11/2/09	Wed 1/21/09	
24		Develop Specifications and Cost Estimates for Balance of Plant Components (Piping, wiring, fence, etc.)	14 days	Mon 11/2/09	Tue 2/3/09	
25		Develop Specifications and Cost Estimates for Chiller (used for temperature regulation of Electrolyzer and Compressor)	7 days	Mon 11/2/09	Wed 1/21/09	
26		Develop Specifications and Cost Estimates for Storage Systems	7 days	Mon 11/2/09	Wed 1/21/09	
41		Determine all setback requirements for station (local state codes)	7 days	Mon 11/2/09	Wed 1/21/09	
42		Perform site selection process - justify refusal and selection of any site	14 days	Mon 11/2/09	Tue 2/3/09	
29		Develop Specifications and Cost Estimates for all Safety Features to be implemented	14 days	Wed 1/21/09	Thu 2/12/09	
30		Safety analysis for fueling station (applicable codes and standards)	14 days	Wed 1/21/09	Thu 2/12/09	
31		Summarize potential failure modes - perform FMEA analysis	14 days	Wed 1/21/09	Thu 2/12/09	
32		Describe required safety features in station along with justifications (barriers, leak/combustion detectors)	14 days	Wed 1/21/09	Thu 2/12/09	
36		Determine annual operating and maintenance cost estimate	7 days	Tue 1/27/09	Thu 2/5/09	
38		Develop power usage requirements for station	7 days	Tue 1/27/09	Thu 2/5/09	
40		Prepare Final process flow diagram	7 days	Tue 1/27/09	Thu 2/5/09	
27		Develop Specifications and Cost Estimates for Site Development	7 days	Tue 2/3/09	Thu 2/12/09	
33		Determine capital cost estimate	14 days	Tue 2/3/09	Wed 2/25/09	
34		Prepare final cost estimate for all major components	14 days	Tue 2/3/09	Wed 2/25/09	
35		Prepare final cost estimates and bill of materials for all ancillary components (wiring, pipe, fence, concrete, shelters, etc.)	14 days	Tue 2/3/09	Wed 2/25/09	
37		Create environmental impact statement (from well to wheel and well to pump) - with comparison to gasoline benchmark	14 days	Tue 2/3/09	Wed 2/25/09	
43		Prepare and Submit End of Project Final Report - with Recommendations and Final Design	21 days	Tue 2/24/09	Tue 3/31/09	

Appendix 2: Compressor Efficiency



Appendix 3: Major Component List and Cost

Component	Specification	Supplier	Qty	Unit Price	Total Price	Running Total
Fueling Nozzle	CW290 Type 3 Class B Fueling Nozzle	WEH	1	\$391.11	\$391.11	\$391.11
Fueling Hose	Filling and Vent Hose 9/16"-18 THRD (Filling Hose) 7/16"-20 THRD (Vent Hose)	Dynatech	1	\$946.20	\$946.20	\$1,337.31
HP Tank	DOT 3AA6000 Cylinders- 6000psi, 37.4L Volume	Proton Energy	10	\$1,355.00	\$13,550.00	\$14,887.31
Linear Manifold	10 Cylinder Linear Manifold 6000 PSI Working Pressure	Proton Energy	1	\$19,030.00	\$19,030.00	\$33,917.31
Compressor	Diaphragm Type Hydrogen Compressor, 6000 PSI Matched for Integration to Hogen S Electrolyzer	Proton Energy	1	\$94,899.00	\$94,899.00	\$128,816.31
Fire Suppression	Fire Extinguishers Dry Foam	n/a	2	\$0.00	\$0.00	\$128,816.31
Electrolyzer	Hogen 40 Elctrolyzer w/ Dryer Production Rate 40 SCFH Optional D/C input	Proton Energy	1	\$79,128.00	\$79,128.00	\$207,944.31
Water Purifier	Aqua Solutions RO Water Treatment 12 L Storage Tank Purification Rate 8 LPH	Proton Energy	1	\$6,101.00	\$6,101.00	\$214,045.31
Calibration Kit	17 L Pure Hydrogen for Calibration	Proton Energy	1	\$735.00	\$735.00	\$214,780.31
Diagnostic Software	V285 Windows Diagnostic Software Data Logging of System Parameters Monitor System Operation	Proton Energy	1	\$0.00	\$0.00	\$214,780.31
Cascade Software	Cascade Version 3.1.3 Windows 2000/XP Analyze Cascade System Performance	Inter Energy	1	\$186.00	\$186.00	\$214,966.31

Appendix 4: Fueling Checklist and Procedure

Fueling Checklist & Procedure

STEP	ACTION
1.	Turn off vehicle engine.
2.	Put the vehicle in park or engage the emergency brake.
3.	Make sure no sources of ignition are present e.g. match, lighter, or cigarette.
4.	Discharge any static build-up before coming in contact with the fueling nozzle or any part of the fueling station.
5.	Inspect the fueling nozzle and hose for any damage or corrosion. If damage, corrosion, or anything that could affect equipment performance is discovered, fix or replace before using equipment.
6.	Check pressure on storage tanks to ensure pressure is not greater than the design pressure (over pressurized).
7.	Remove dust cap from vehicle's fuel tank and inspect for any damage, and clean/remove any dirt or debris if needed.
8.	Make sure fueling nozzle is properly and securely connected to vehicle's fuel tank to prevent any leakage.
9.	Begin fueling process. Open valve slowly to prevent rapid expansion of hydrogen gas.
10.	Do not re-enter vehicle while fueling is in progress. If entering the vehicle is necessary, discharge static build-up before coming in contact with fueling nozzle or station.
11.	If a hydrogen leak is detected during the fueling process, shutoff gas supply. Check to make sure the fueling nozzle is properly attached to the fuel tank. Inspect the fueling nozzle and hose for possible source of leakage. If no damage is found in the nozzle or hose, properly attach fueling nozzle to fuel tank and restart the fueling process while following all previous steps. If leak still exists, shutoff hydrogen supply and do not restart fueling until source of leak is found and fixed.
12.	When the fueling process is complete shutoff gas supply, remove fueling nozzle from fuel tank and return to designated location, and close the vehicle's fuel tank before starting the engine

Appendix 5: Outline Drawing and Bill of Material for Design

Mark	Quantity Req'd	Description
AA	1 EACH	WATER PURIFIER, REVERSE OSMOSIS AND DEIONIZED WATER TYPE, 110/120VAC, 60HZ, AQUA SOLUTIONS TYPE 04-0400-0002
AB	1 EACH	ELECTROLYZER, HYDROGEN, PEM TYPE, HOGEN 40 SERIES, TYPE S4021A1A000, 40SCFH PRODUCTION RATE, COMPLETE WITH CELL STACK, POWER SUPPLY, HEAT EXCHANGER, AND INTERNAL DRYER, INCLUDES OPERATING MANUALS AND MAINTENANCE TOOLS
AC	1 EACH	COMPRESSOR, DIAPHRAGM, THREE LAYER DIAPHRAGM, INCLUDES RELAY LOGIC CONFIGURED FOR USE WITH HOGEN 40 ELECTROLYZER
AD	1 EACH	MANIFOLD, DISTRIBUTION, FOR FILLING STEEL CYLINDERS, PROTON ENERGY TYPE CYL001
AE	10 EACH	STORAGE TANKS, 1KG HYDROGEN CAPACITY AT 6000PSI MAX PRESSURE, DOT 3AA6000 TYPE, STEEL
AF	3 EACH	VALVE, BALL, MANUAL, SWAGELOK TYPE SS-43GS4
AG	3 EACH	VALVE, CHECK, SWAGELOK TYPE SS-CHS4-5
AH	2 EACH	GAUGE, PRESSURE, SWAGELOK TYPE PGI-63C-PG300
AI	1 EACH	VALVE, BALL, MANUAL, SWAGELOK TYPE SS-H83PS8
AJ	3 EACH	VALVE, RELIEF, PROPORTIONAL, SWAGELOK TYPE SS-RL3M4-S4
AK	2 EACH	VALVE, RELIEF, FOR VEHICLE DISPENSING SYSTEM, BAUER TYPE VAL-0154
AL	500 FEET	TUBING, STAINLESS STEEL, 1/2", SWAGELOK TYPE 2507-T8-S-065-20
AM	100 FEET	TUBING, STAINLESS STEEL, 1/4", SWAGELOK TYPE 2507-T4-S-035-20
AN	10 EACH	TEE, STAINLESS STEEL, FOR 1/2" TUBE, SWAGELOK TYPE SS-400-3-4
AO	1 EACH	SWITCHING DEVICE, EMERGENCY PUSH STOP, SQUARE D TYPE ZB5AS834
AP	40 FEET	PIPE, STAINLESS STEEL, VENTING, 18 GAUGE, 3"
AQ	1 EACH	SWITCHING DEVICE, DUAL PUSH BUTTON CONTROL, SQUARE D TYPE 9001BG201
AR	1 EACH	NOZZLE, FUELING, SAE J514, WEH GAS TECHNOLOGY TYPE TK16
AS	1 EACH	HOSE, STAINLESS STEEL, FOR HYDROGEN DISPENSING, FUELING TECHNOLOGIES TYPE B567
AT	2 EACH	SENSORS, HYDROGEN DETECTION (TO BE SPECIFIED)
AU	50 FEET	CONDUIT, FLEXIBLE NON-METALLIC, 3/4", WATERTIGHT
AV	6 EACH	MALE CONNECTORS, FOR 3/4" FLEXIBLE WATERTIGHT
AW	100 FEET	CONTROL WIRE, SINGLE CONDUCTOR, #12 AWG, TYPE
AX	100 FEET	CONTROL WIRE, SINGLE CONDUCTOR, #18 AWG, TYPE
AZ	1 EACH	WARNING ALARM, SPECO TECHNOLOGIES TYPE SA15RP
BA	1 EACH	LIGHT STROBE, SPECO TECHNOLOGIES TYPE SFA12
BB	1 EACH	VALVE, BALL, 3 WAY, 1/4" CPI, STAINLESS STEEL, FOR MANUAL BYPASS TO VENT, PROTON ENERGY TYPE 02-2504-0008
BC	1 EACH	SURGE MODULE, UNDER/OVER VOLTAGE, PROTON ENERGY S-SERIES TYPE, CAT# KT-1000-0032

