HYFLOW

Hydrogen Power Park Design Proposal

for the

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Executive Summary

A call for proposals by DOE (US Department of Energy) and NHA (National Hydrogen Association) was sent out to design a hydrogen power park. The hydrogen power park is a concept for a distributed system to serve both hydrogen and electrical demands in a not-too-distant future. Hydrogen being the central carrier of energy, permeating the entire plant's operation, this facility fits well with visions of a blooming hydrogen economy. Hyflow Systems is pleased to present the design for such a concept.

The concept's underlying themes include modularity and environmental-friendliness. The system is dependent upon only a few factors, and thus is easily transplantable to different locations. Only relative sizings of components need be changed. The environmentally friendliness is emphasized with our rooftop mounted wind turbines. The wind turbine is the key source of energy, and being both renewable and environmentally benign, it has much more intrinsic value than traditional methods of electricity and hydrogen production. The concept of rooftop mounting is to make greater use of the available resources in an urban setting. It is in urban areas where hydrogen demands will be greatest, and this addresses that. Furthermore, the idea is that by generating power for a fraction of the building's electrical loads, it will pave the way for future self-sustaining office buildings or skyscrapers.

The design features multi-level energy storage and complimentary operation. The variability of wind energy is mitigated by energy storage, including a long-term storage and a short-term storage system. The short-term system, simply a flywheel, serves to smooth out transient behavior, such as sudden gusts of wind, or spikes in voltage or current levels. The long-term system involves balancing the output power and hydrogen levels by supplying the deficit during times of low wind, and storing the surplus during times of excess wind. This is achieved through an electrolyzer, fuel cell stacks, and a hydrogen storage tank. Additional hydrogen production support is provided by a steam-methane reformer. The operational level of the reformer, which provides the power park's only source of greenhouse gas emissions, is inversely proportional to the availability of wind resources.

The hydrogen power park facility itself runs on a DC bus, further emphasizing the modularity aspect. This bus allows for ease of control and operation. In addition, it allows the grid to view the facility as one unit, rather than a conglomeration of separate components. The interconnection with the grid is achieved via a bidirectional AC/DC power converter.

Although the system may be integrated anywhere with the available energy resources, the Hyflow Systems Hydrogen Power Park is to be located in Bellevue, Washington, which is in one of the regions with strongest support of renewable energy. As a secondary project the location of Honolulu, Hawaii is also considered.

The system is designed to generate 100 kW of electricity and 50 kg of hydrogen per day at station opening in 2010. Hydrogen production is increased to 250 kg per day by 2020.

Data Table

Starting year of operation	2010
Daily H_2 capacity	2010: 50 kg, 2020: 250 kg
Peak hourly capacity	30 kg
Refueling time	Approx. 4 min
Hydrogen cost	$9.866/kg
Capital investment	$1.598 million
Electrical power generation	100 kW
Percentage of load support	~5-10% for Skyline Tower
Mode of generation	Wind and H_2-based fuel cell
Reduction of CO_2 / day	1,761,107 grams

Figure 1. Proposed concept

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Figure 2. Proposed concept

1 TECHNICAL DESIGN

1.1 Hydrogen Power Park Overview

The National Hydrogen Association (NHA) and the United States Department of Energy (US DOE) is requesting proposals for "the design of a hydrogen power park to produce hydrogen and hydrogen-fueled electrical power to serve light duty hydrogen fuel cell vehicles and various electrical loads." A design for such a facility by the University of Washington's design team is presented herein.

This power park meets the two main objectives; namely, the production of hydrogen to serve fuel cell vehicles, and the generation of electricity through means of hydrogen. Rather than creating a whole set of infrastructure to meet our needs, we seek to merge with existing infrastructure. The infrastructure for a hydrogen economy must arise as a product of the current fossil fuel infrastructure, not as an entirely different project altogether. Thus, a systems approach is taken, and we are creating an entirely modular system which may be transplanted to different suitable locations, with changing only the relative sizing of the components. In the future, the highest hydrogen demands – at least for re-fueling purposes – will invariably be in heavy urban locations. To make novel use of space, we seek to integrate our system into a skyscraper or tall office building. Structural and safety concerns are analyzed in depth and well mitigated, so such a hybrid system (electricity and hydrogen co-generation) may very well herald a hydrogen economy reality. All the various components of the system are located on a footprint less than 21,000 ft^2, serving 10 vehicles at 5 kg H_2/vehicle per day at the station opening.

A second focus of the design is an environmental one. Hydrogen may only be denoted as a "clean" fuel when the process of producing that hydrogen is relatively clean. Therefore, we use renewable energy, specifically wind energy, as the basis of our system. The skyscraper will support multiple vertical-axis wind turbines, effectively capturing wind energy which would be otherwise wasted. The stochastic nature of this energy resource forces us to design and make use of a multi-level energy storage system [1]. This storage system is based conveniently on hydrogen, allowing us to effortlessly operate the electrical and hydrogen sides of the system in an integrated manner.

1.2 Park Location

Wind resource availability influences the hydrogen power park quite a bit. As wind is the predominant driving force behind our system, the lack of wind will drive the value of our power park down, and reduces profitability. However, the utility of integrating our power park into a skyscraper or office building is highlighted, as wind speeds are greater at higher altitudes, due to wind shearing [2]. In the densest urban areas, turbulence is also an issue. Generally speaking, the taller a skyscraper is relative to its neighbors, the less pronounced the effect. The hydrogen power park is proposed to be located in Bellevue, Washington. The skyscraper, or in this case, a tall office building to be integrated with is the Skyline Tower. It is the tallest building in the immediate vicinity, and is one of the more active areas of the greater Seattle area.

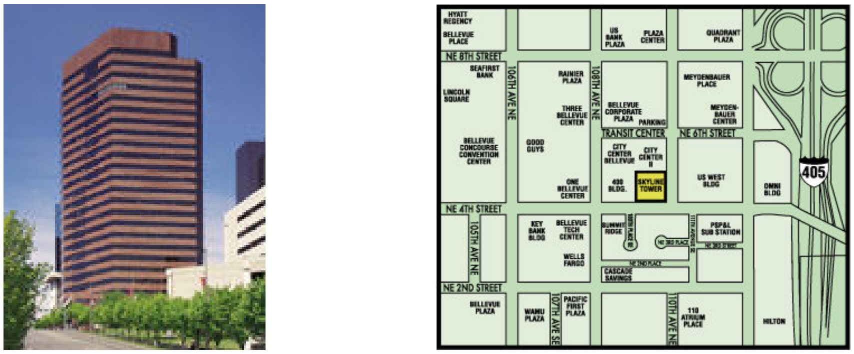


Figure 3. Skyline tower and location

It should be again emphasized that our facility may be integrated anywhere. Bellevue, Washington serves as a concrete model to present the effectiveness of our system. This location is proposed due to the relatively open-mindedness of the community's attitude towards renewable and clean energy. A clean, alternative method of electricity generation – wind, coupled with the promise of a 100% environment-friendly fuel – hydrogen, should be accepted with minimal opposition. It is also projected to require less educational efforts than communities in other parts of the country might otherwise need. Furthermore, the area's grid power offers zero greenhouse gas (GHG) emissions. As a perfectly viable alternative, Honolulu, Hawaii will also be analyzed in various ways.

1.3 Overview of Components

The main components for power conversion include wind turbines and a fuel cell, as well as a high-power bidirectional AC/DC power electronics converter. The components for hydrogen production include an electrolyzer and a steam-methane reformer. Hydrogen, which is used in both processes, is stored in specialized, state-of-the-art tank storage systems. A flywheel is also used to absorb any short-term imbalances within the system. There also exists an internal water cycle, in which much of the water is reused and recycled within the system itself. The operating processes, which are discussed in detail in sections 1.6, 1.7, and 1.10, are summarized with the following figure:

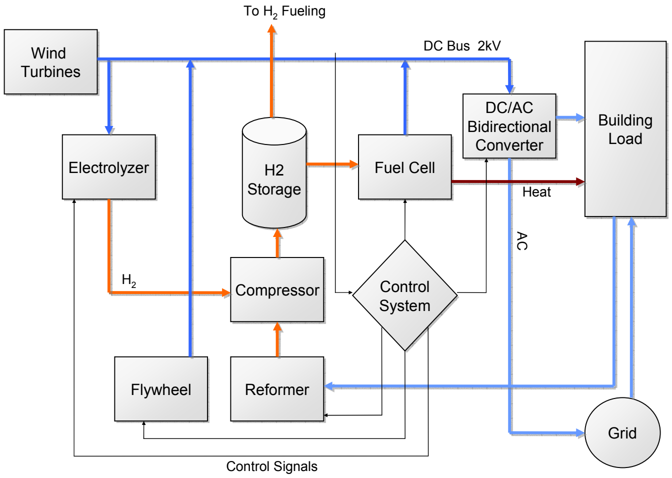
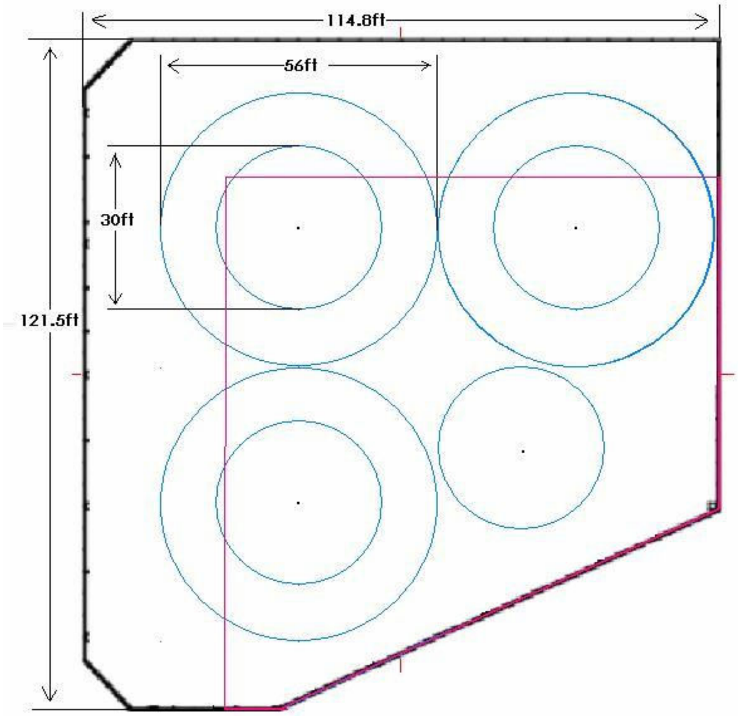


Figure 4. Schematic overview of hydrogen power park system

1.4 Power Park Site Plan and Layout



The 56ft circles represent the distance needed for anchoring the supportive cables.

The 30ft circles represent the swept area of the wind turbine's blades.

Red line outlines the boundries of the elevated roof area

Figure 5. Rooftop layout

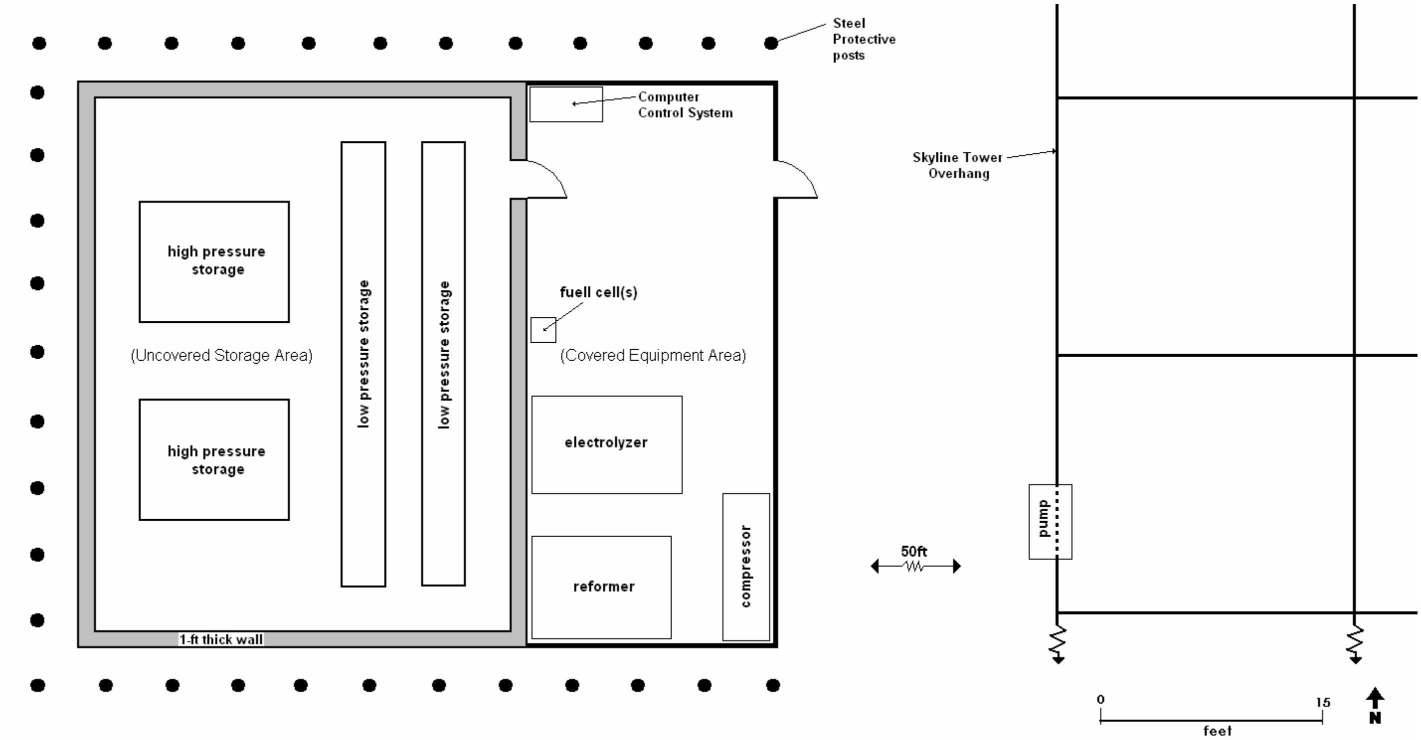


Figure 6. Ground-level layout

1.5 Hydrogen and Electrical Process Schematics

For the hydrogen process schematic, which refers to vehicle re-fueling and shows all major equipment and flow paths, please refer to the appendix, **section 6B**. For the electrical process schematic, which depicts power production and distribution components, as well as major controls, please refer to the appendix, **section 6C**. The following sections will discuss the processes captured in these schematics. It should be also noted that sizings for components are derived based on mathematical analysis. A summary of the methodology used may also be found in the appendix, **section 6D**.

1.6 Hydrogen Fuel Production

1.6.1 Overview of hydrogen system

The power park simultaneously serves the role of a hydrogen fueling station. It has the capacity of delivering 50 kg hydrogen gas per day, with a peak demand of 30 kg per hour (6 vehicles at 5 kg/vehicle) at the station opening in 2010. The daily capacity will be increased to 150 kg/day by 2015 and 250 kg/day by 2020.

As shown in Figure 2, hydrogen is produced via two pathways, the electrolyzer and the steam-methane reformer. The electrolyzer is designed to absorb excess power coming off of the DC bus (section 1.6), while the reformer is added to meet the hydrogen requirements. The hydrogen requirements are twofold. One, the refueling requirements of the fueling station imposes a constant demand. Two, supplemental power required during times of low wind, which is a necessity inherent to our system, is provided by the fuel cell and also requires a certain quantity of hydrogen. The latter is directly related to wind availability. The two purposes for hydrogen production within the power park are mutual, and therefore both use one integrated storage system. For Bellevue, wind resources are about average, and a relatively large amount of hydrogen is required to support the 100 kW load. For Honolulu, however, wind resources are plentiful, thereby eliminating the need for reformers altogether.

1.6.2 Electrolysis and steam-methane reforming

Teledyne Energy Systems' Titan EC-750 electrolyzes feedwater to produce hydrogen at up to 99.9998% purity at 115 psig [9]. It also requires the input of pressurized inert gas at 60 to 100 psig, with a consumption of 1.6 Nm^3 for startup. The inert instrumental gas input must be of around 85 to 250 psig, with a consumption rate of 1.2 Nm^3/h. Nitrogen gas is used as the inert gas and is acquired from local suppliers. GeoTech's Renegade Gas Compressor Model TG-550H then compress the argon gas to 100 psig [8]. The Renegade TG-500H compressor has a tank capacity of 18 gallons, which provides for sufficient buffered storage of compressed argon gas.

The H_2-Gen's HGM 2000 steam reformer is the other source of hydrogen [3]. It is designed to deliver 2,000 scfh (52.8 Nm^3/h) of hydrogen at up to 200 psig and a purity of up to 99.999%. It operates at 469 V, 3-phase, 60 Hz AC, and is thus separated electrically from our system. It takes in typical North American Pipeline Grade natural gas: 1,500 scfh (39.6 Nm^3/h), 85% methane by volume, and less than 100 ppmv of sulfur and aromatic hydrocarbons content [3]. The natural gas, which is already flowing through the building, is simply provided by Puget Sound Energy. Water below 95°F is used to cool the reformer, with an optional air cooler. In the reformer, steamed de-ionized water then mixes with natural gas.

1.6.3 Storage

Storage will invariably be a key component in our system. The system is designed to operate with a low pressure system cascaded with a high pressure system. They are inter-connected, however, and thus overall act as one large storage system. Winds typically exhibit seasonal behavior, thus relatively large quantities of hydrogen are stored. Calculations show that for the Bellevue site, approximately 10,000 Nm^3 of H_2 (900 kg) is needed for supplemental power during periods of low winds. This large storage demands the use of metal hydrides to store hydrogen. Metal hydrides take advantage of the high density of metals to store hydrogen, making storage more effective than most compressed gas storage and even liquefied gas. Ninety Texaco Ovonic Hydrogen Systems LLC's Bulk Storage Systems are used, each capable of storing 10 kg [5]. Hydrogen is stored by utilizing the metal's tendency to be oxidized, taking advantage of the high densities of metals to store hydrogen. The addition of heat easily removes the hydrogen, with an outlet pressure of 500psig.

As needed, some of this outlet hydrogen will be directed to a fuel cell, while the others will be compressed (section 1.5.4) and dispensed as discussed in Section 1.5.4 and 1.5.5 respectively. The compressed high-pressure hydrogen is stored in four tanks provided by CP Industries' Seamless Pressure Vessels, capable of storing gas up to 7,770 psig [4]. They are capable of holding about 227 Nm^3 of hydrogen each, which is only capable of refueling one car. These four tanks will be cascaded together in one bank to ensure fuel is always available. One of the tanks' pressure dynamics for a refuel is shown below, with the calculations based on the Redlich Kwong equation of state:

Table 1. High pressure storage dynamics

Pressure (psig)	V (m^3/mol)	V (m^3/kg)	Density (kg/m^3)	Refuel
7,770	6.325E-5	0.03137	31.87	-
5,341	8.378E-5	0.04156	24.06	1

The tank pressure will be monitored such that when one tank reaches the critical pressure of 5,341 psig, the system will switch to another filled tank to refuel the cars. The control system will randomly chooses between tanks with pressures of 7,700 psig and connect with the dispenser. Meanwhile, the compressor will compress more hydrogen into the used tanks. This cascaded, buffered system allows for quick and directs refueling, while ensuring hydrogen fuel to the next customer.

1.6.4 Compression

The outlet hydrogen pressure from the metal hydride storage is 500 psig. Hydrogen is then compressed to 7,770 psig by Hydro-Pac Inc.'s Gas Compressor [6]. This particular compressor consists of both a hydraulic system and a gas system. A metal diaphragm isolates components between these two systems. It has a maximum discharge pressure of 12,000 psig at a rate of 30-40 kg hydrogen/hr, and requires an energy input of 4 kW. This rate ensures that the compressor can keep up with fueling demands. The compressor comes with an integrated system of check valves to ensure the machine operates at the optimal conditions rather autonomously.

1.6.5 Delivery

Hydrogen is delivered through one hydrogen dispenser: model CH350A provided by General Hydrogen [7]. The semi-automatic module consists of a hydrogen hose and nozzle, with an integrated automatic safety system. The nozzles dispense the hydrogen at pressures up to 6,250 psig. It has separate electrical and gas enclosures in compliance with standard codes described in IEC 60079. It requires a power input of 110 V, 15 A, so it may be directly connected to the AC system. The average filling rate of the CH350A module is around 4 minutes, allowing it to effortlessly meet 30kg/hr peak refueling demands.

The fueling station is located on ground level, and is easily accessible from the street via a drive-thru. Customers will refuel their vehicles exactly in the same manner as in a typical gasoline refueling station, thereby required little adaptation on their parts. The pressure differential between the buffered storage and the car tank allows for passive and quick fueling process. A summary showing the pressure and state of hydrogen gas at each of the components of the fueling process is shown below.

Table 2. Operating pressures of hydrogen equipment

Equipment	State	Pressure (psig)
HGM-2000/EC-750	Gas	100-200
Ovonic Bulk Storage (inlet/outlet)	Metal-H	100/500
Hydro-Pac Gas Compressor (inlet/outlet)	Gas	500/7,770
Buffered Storage	Gas	7,770/5341
Car Tank	Gas	5,000

1.7 Electrical Power Production

1.7.1 Overview of power system

The main input energy source is wind power. Wind, however, is inherently quite variable, and to counteract a portion of that effect, we provide a multi-level storage system. The flywheel balances short-term fluctuations, and an electrolyzer absorbs power during excess wind speeds, and stores it in hydrogen form. This contributes to the main storage which may serve either the hydrogen or the electrical load. During periods of low wind speeds, however, a fuel cell supplies supplementary power to the load, drawing from the hydrogen available in reserve. The load is simply the skyscraper we are integrating into (Skyline Tower). Furthermore, the presence of the reformer allows the system to keep pace with the hydrogen demand, from both a power generation and a hydrogen fueling perspective. Please refer to the system diagram in the appendix, section 6C. This provides complimentary methods for the production of power and hydrogen, able to operate in a balanced and synergistic manner.

1.7.2 Electrical infrastructure and interconnection interfaces

The core of the electrical system is a 2 kV DC bus extending from the wind turbines on the rooftop to the remaining equipment in the basement, a distance of approximately 1000ft. In the basement are: electrolyzer, fuel cells, flywheel, reformer, and the power converter. The effects of each component are listed in Table 2 below.

Table 3. Electrical function of principle system components

Component	Electrical Function
Wind turbines	Source
Electrolyzer	Load
Fuel Cell	Source
Flywheel	Compensates for short-term power fluctuations
AC/DC Power Converter	Grid interface with voltage control function

The decision of a DC bus is centered on the fact that many devices operate in DC, such as the fuel cell, as well as better power management. Specifically, the wind turbines, which have AC/DC conversion integrated by the manufacturer, and fuel cells both output power in DC form. Although using AC turbines would have been possible, it would have resulted in a variable-frequency AC bus, and thus a more complex system. The quantity of 2 kV was chosen because a lower voltage would create larger currents and thus greater losses, while a higher voltage could create insulation cost problems.

1.7.3 Description of major components

The wind turbines we are utilizing are the WindStor 100 kW vertical-axis turbines [13]. Sensitivity at low wind speeds, coupled with its relatively small size, makes it ideal for our rooftop-mounted application. Vertical-axis turbines will allow us to mount multiple turbines in a small area. For Skyline Tower, four turbines are required. Structural implications of this are discussed in section 1.11.

The electrolyzer, as mentioned in the hydrogen fuel production section, is used to convert excess power as storable energy – hydrogen. The fuel cell, the size of which (see Appendix D) is achieved by stacking 34 of the Asia Pacific Fuel Cell Technology's 36-cell 3 kW PEM fuel cell, will then supplement the wind turbines in times of low wind, to achieve the desired requirement of 100 kW. One cell stack is 150 cm^2 in area. The fuel cell is favored other means of generating electricity from hydrogen, even with its relatively low efficiency, due to its clean nature.

A 10 kWh flywheel is incorporated onto the DC bus. This is the short-term storage portion of the mentioned multi-level storage system. It is essentially the first line of defense against voltage fluctuations on the DC bus. This size of flywheel may be able to support the entire electrical output requirement for approximately 2 minutes, which is long enough for all load/source balancing and absorption of transients.

The power converters utilized are custom solutions provided by Siemens. Small converters interface the DC bus with the wind turbines, fuel cells, and electrolyzer, but the interface to the grid of the electrical system is the AC/DC bidirectional converter. The standard power converter design for our application is a Voltage Sourced Converter (VSC), which controls its power flow by measuring the DC voltage and adjusting a PWM signal accordingly. For our ratings application, IGBTs are the most ideal. A transformer is also placed between the utility and the switches. The transformer's electrical decoupling permits the necessary DC offset between the two sides (DC bus and AC grid). Because these power converters must connect to normal 3-phase utility lines, they are assumed to contain such a transformer. The minimum rating for this converter is 2kV, 360A.

1.7.4 Harmonics considerations and protection equipment

According to IEEE Std. 519-1992, harmonics in any line cause increased ohmic losses, corona, and voltage stresses (e.g. in insulation). Our converters built by Siemens exhibit harmonic distortion levels of around 5% Total Harmonic Distortion (THD). According to a cable capacity vs THD graph, these harmonics derate the AC cable by less than 1% of its rated current capacity, and thus pose no problem. Our system employs three types of protection: over/under-voltage, over-current, and lightning.

Voltages outside of 2kV can occur if power generation and load are imbalanced. One of the jobs the AC/DC power converter takes on is to control this voltage. With regards to over-current, DC circuit breakers limit the amount of current through each device. We considered both passive bimetallic AC breakers and active breakers. The bimetallic breakers can not handle the voltage requirements, so insulated-gate bipolar transistor (IGBT) based, active breakers are used. Some of these breakers are capable of detecting surge currents based on current change measurements, and thus open before full surge currents occur. The circuit breaker is placed in series in the line with the correct polarity, where the intrinsic diode opposes the current flow. Should a DC fault occur, the IGBT will open and the current will cease. If the breaker were absent, there would be no way of preventing current from flowing from the AC input through the converter IGBTs and into ground. Such would be detrimental, essentially destroying the electrical equipment.

1.8 Efficiency

The efficiency of the system is dependent upon factors such as wind availability and load. During a period where wind power is at a maximum, the manner of power generation is direct, and essentially the only losses incur through the power converter and cables. During minimum wind power and higher load output, however, system efficiency is lowered due to the generation of electricity via the fuel cell, thus the pathway to electricity is roundabout. The wind turbines output about 100 kW max, and therefore beyond this point, the fuel cell also kicks in.

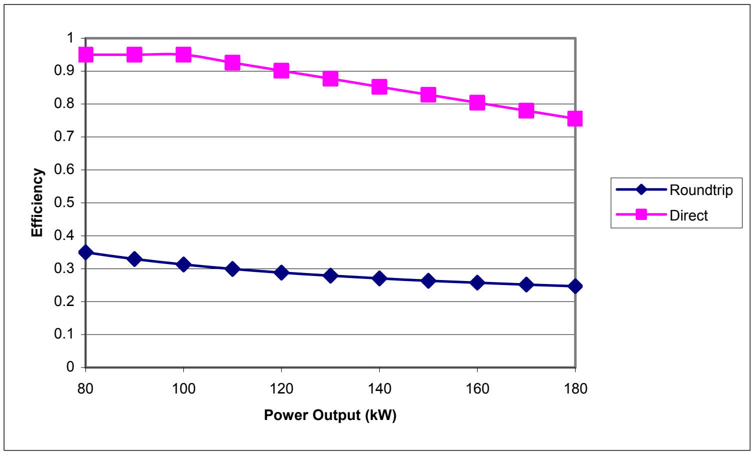


Figure 7. Net efficiency vs load

1.9 Electrical and Heat Load Served

The electrical load served will be the building to which the hydrogen power park is integrated into. The facility is designed to output a constant 100 kW to the building. Although the system will respond to transient fluctuations, it will not follow the load curve to a certain percentage. The reasoning behind this is that the power park is a support facility, not a power plant. The PEM fuel cell (operating at 40 – 70 °C) and the reformer are interconnected with the natural gas pipelines and heating, and is able to provide a small amount of heating. It fluctuates dramatically with usage, however, and the output will only be an extremely small fraction of the building's load.

1.10 Control System

There is a hierarchal programmable computer control system which oversees the operation of all the components and the entire plant. The control system delegates the relative operation of complimentary components in an efficient manner. The short-term storage (flywheel) is the first in line to deal with fluctuations. Once the control system detects levels above or below a certain threshold, it will trigger the electrolyzer and fuel cell, respectively. In addition, the control system will allow the necessary amount of natural gas into the reformer to keep pace, but not overshoot, the hydrogen demand. It has two major roles: to balance output power at 100 kW with help of wind speed monitoring, and to channel enough power and/or natural gas to the electrolyzer and reformer for the necessary hydrogen production rate. It should be noted that the wind turbines have power trackers for maximum power output. Figure 6 displays the relative operation of several components for a simulated period from 11/2003 to 10/2004.

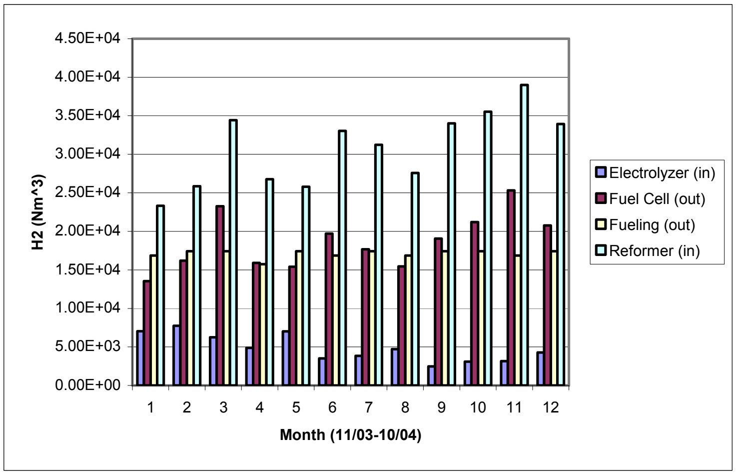


Figure 8. Relative H_2 production and usage

Extensive computer simulation was performed on this system. The ideas of multi-level storage as well as dynamic DC bus voltage control are incorporated. Simulations were run in MATLAB and Simulink, and results reveal that component sizings as well as operation are valid. A figure of the overall model is in the appendix, section 6D. Each box represents a component, and contains the dynamic behavior models and control processes of each. Electric power dynamics as well as hydrogen tank levels were simulated. The following is a simulation result of tank capacity, and validates the sizing of the storage system.

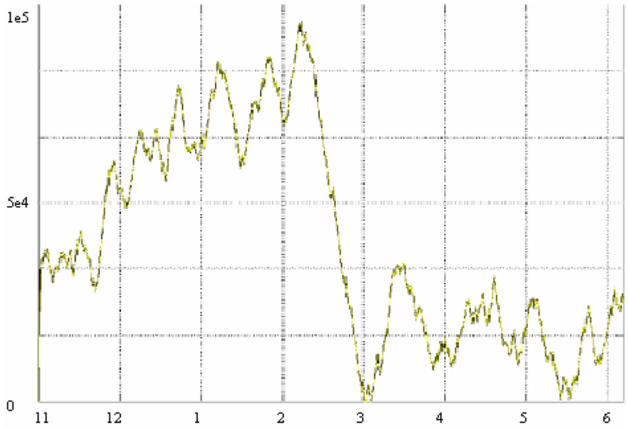


Figure 9. H_2 level over hypothetical period of 11/03 – 6/04

1.11 Structural Analysis and Design

The Skyline Tower was the primary candidate for installation of the four vertical axis wind turbines (VWT's) for many reasons, including that it was built less than 25 years ago (signifying more-current building standards, and less structural decay due to time and better-designed materials were available during construction), it is not too tall (causing excess imposed moments on the structure), and it has a fairly wide base (better enabling it to handle increased moments on the structure). The Skyline tower also met the roof space needed to install four turbines, since the blades must have enough clearance (30ft each) and the supportive cabling must have enough room to be secured soundly as was designed by Dermond Inc.

Before the installation of the turbines, the roof will need structural reinforcement, as it was not specifically designed to handle the loads from the turbine systems. This reinforcement would tie vital spots into the core supportive structure (the elevator shafts) of the tower. The project is quite feasible and would not negatively affect other areas of the building [11, 12].

Structural load analysis on the Skyline Tower shows that it is a suitable candidate for the appending of four VWT's by Dermond Inc. The analysis indicated that the magnitudes of additional force and moment imposed on the structure by the turbines (3.5% and 5.8%, respectively) would be fairly minor relative to the *minimum* design loads, and these calculated estimates would be significantly reduced after factoring in the other design loads and assuming that the structure is slightly designed above those minimal required design loads. This could indicate the imposed relative forces and moments are smaller by a factor of two or more.

The vibrations due to the addition of the turbines would be minimal due to the turbine spinning about a vertical axis (as opposed to horizontal-axis wind turbines) and the slow rotational speed of the VWT's. This design also extremely cuts down on the noise produced by the turbine.

The walled hydrogen storage area was also of major design importance. The walls had to be able to withstand attack and be a working firewall in the case of an emergency. This prompted the design that the walls of the structure would be reinforced concrete design with No.7 rebar. To provide even further protection in the case that a large vehicle were directed towards the tanks, steel pipes were sunk into the ground at 3ft intervals surrounding the perimeter and then filled with cement. The combination of wall and poles should provide adequate general safety to the structure.

In all of the structural design and analysis, HyFlow's main focus has been to ensure and maintain the safety and effectiveness of its systems, as is shown.

Figure 10. Perspective renderings at different angles

2 SAFETY ANALYSIS

2.1 Codes and Standards

Because our electrical system employs high voltages and currents, safety is a paramount concern. The codes pertaining to our system are mostly in the 2002 National Electrical Code (NEC), also known as the National Fire Protection Association (NFPA) Code 70. Most fire codes are listed under the NFPA codes. Most of the following codes are all taken into consideration and rigorously applied to our design [9, 10].

Table 4. Electrical codes

Code	Code Title
NEC Article 240	Overcurrent Protection
NEC Article 250.122	Size of Equipment Grounding Conductors
NEC Article 250, Section VIII	Direct-Current Systems
NEC Article 310	Conductors for General Wiring
NEC Article 692	Fuel Cell Systems
NEC Article 725, Section II	Class 1 Circuits

Table 5. Fire codes

Code	Code Title
NFPA 50A	Gaseous Hydrogen Systems at Consumer Sites
NFPA Section 911	Explosion Control
NFPA Chapter 22	Motor Fuel-Dispensing Facilities and Repair Garages
NFPA Chapter 23	High-Piled Combustible Storage
NFPA Chapter 27	Hazardous Materials – General Provisions
NFPA Chapter 30	Compressed Gases
NFPA Chapter 38	Liquefied Petroleum Gases (for general combustible gas provisions)

2.2 Power Park Safety Overview

The Power Park safety concerns can be divided into three categories: electrical, fire, and structural. To address as many safety issues as possible, the hydrogen power park is designed around as many existing electrical, fire, and building codes as possible, with an integrated safety system to mitigate potential hazards.

2.2.1 *Electrical system hazard controls*

Our electrical system is designed around the codes listed in section 2.1. The primary concerns of any electrical system are avoiding overvoltage and overcurrent situations, because of their propensity to cause damage. Overcurrent protection is provided by circuit breakers (either AC or DC, depending on the situation). The DC circuit breakers also provide overvoltage protection via voltage change sensing, isolating system components from a destructive power feed.

In the event of a lightning strike on the building roof, there is theoretically the potential for a large hydrogen explosion. More specifically, this potential comes from the fact that the wind turbines are wired directly into the DC bus, which runs straight into the outside facility. To minimize the chance of an electrical spark igniting hydrogen fumes, class 1 wiring will be employed in the rooms housing the hydrogen system. This corresponds to the respective NFPA 50A codes.

2.2.2 *Hydrogen system hazard controls*

A safety control system specifically for the hydrogen system is integrated into the power park. A control system will monitor the pressure, temperature, and flow rates in all the components. Once extreme values are detected, the control system will automatically take the appropriate measures. For example, if the pressures in the tanks are approaching critical thresholds, the control system will halt hydrogen production and compression regardless. Furthermore, the pipe pressures are monitored as well, to prevent any pipe bursting.

As another preventive measure, only qualified technicians can access the hydrogen storage area to prevent unauthorized access. The system components' performance will be evaluated and replaced periodically, ensuring optimal conditions.

Since hydrogen burns in an invisible flame, flame detectors and sprinkler systems will be placed in rooms containing any hydrogen system components. In case of a hydrogen leak, the control system will automatically shut off the valves connecting to the tank. Even when combustion occurs, the hydrogen storage tank is contained within two-hour fire masonry walls, effectively isolating it from other hydrogen components and the rest of the building. An extensive ventilation system is integrated into building to ensure rapid clearage of accumulated gas in case of a leak [17].

2.3 Failure Modes

While many types of failure are possible, and almost every has potential to cause a catastrophe, certain failures will be more probable than others. The following failure modes with the highest probabilities will be analyzed.

Table 6. Most probable failure modes

Failure	Cause	Effect	Prevention & Control	Probability
Gradual hydrogen leakage	Equipment failure; connection failure	Possibility of fire or explosions; health risks	Periodic maintenance; real time monitoring; automatic shutdown and ventilation of H2	High
Sudden loss of hydrogen	Structural failure (earthquake, building collapse, etc.); equipment failure	Possibility of fire or explosions;	Sprinkler system activation; building evacuation	Medium
Ignition of hydrogen gas	Human error; any type of spark; tank burst	Fire or explosion	Heightened security and authorization; physical isolation; flame detection and sprinkler system	Medium
Overcurrent / undercurrent	Internal short; equipment failure; operational error	Overheating; destruction of cables and wiring; possible fire	Monitoring; circuit breakers	Low
Overvoltage / surge	Equipment (e.g., power converter) failure; lightning	Further equipment failure; insulation fatigue or destruction	Surge arrestors; built-in protection on equipment; dc breakers	Low

The most probable failure mode is the leakage of hydrogen gas at connecting pipes and valves. To prevent this from occurring, the pipes will be closely monitored and replaced periodically. Pressure and flow rate gauges will monitor and record conditions inside these components over time. Component performance will be evaluated based on the trends established by the recordings. From these data, gradual leakage at a specific pipe could be detected. The connecting valves will be closed to shut off the pipe, so that the worn pipe or valve can be replaced or repaired.

2.4 Structural Safety Issues

Four turbines are placed on the roof in our design. To maintain a safe environment, steel reinforcing is used to tie the roof more soundly to the supportive structure of the tower. This minimizes the risk of any structural system not being able to support the loads from the turbines.

In addition to bracing, we have located the towers as close to the center of the structure as possible in the case of an unforeseen structural failure; in doing so, this minimizes the possibility of the turbine being able to fall from the roof area. Using cables and a steel base plate to secure the structures ensures that if one system were to fail, the others would be able to support the rest of the load until repairs could be made. This adds extra security in the case of an attack on the structure.

The stress on the building was taken into primary consideration and estimated very conservatively. The extensive analysis indicates that the building has stayed within estimated acceptable levels and that the loading on the building is likely significantly less of a relative percentage than estimated. Vibration and structure motion will be small due to the vertical-axis turbine design and low rotational turbine speeds [17].

Safe storage design is also essential, especially due to our culture’s youthful experience of working with large amounts of stored and accessed hydrogen. This is why outdoor open-air storage is the design of choice at this time. By locating the hydrogen storage tanks in an outdoor location, over 50ft away from any buildings, we have not only maintained safety codes, but have provided the customer with a sound storage solution. The storage facility is encased in a one-foot thick reinforced concrete wall that is topped with coiled barbed-wire to dissuade unwanted access and surrounded with concrete-filled steel pipes to add protection against any vehicular accidents or attacks. Furthermore, the wall also acts as a 5+ hour firewall.

The equipment shed adjacent to the walled storage facility houses all of the machinery required to produce and manage the hydrogen, and to protect those assets the building is equipped with smoke detectors, a hydrogen detection system and a pre-action deluge foam-water sprinkler system in case of a fire [14]. Due to the tendency of escaped hydrogen to rise and build up in high areas, the room is also equipped with a ventilation system that provides air on the north side of the building and exhausts air out of the southern side of the building through vents located on the ceiling above the machinery – this will remove any lose hydrogen gas before it can build up.

In addition, the equipment shed will have secured electronic keypad doors (both to the shed and to the walled facility), surveillance system, and alarm. Only authorized personnel will possess the ability to enter the secured facilities. The facilities will be continuously monitored, and in the case of a dire emergency, the entire system will be automatically shut down.

3 ECONOMIC ANALYSIS

The essence of Hyflow's business plan revolves around a partnership with the building which we are integrating with. Details of this partnership are incorporated into the economic analysis. The economic analysis is dependent of two core sections. The first section describes the calculation of hydrogen selling price. The second division describes cost associated with the formation of the hydrogen park and the estimated cost of continuation.

3.1 Cost of Hydrogen

The price is set at $9.866/kg or $.164/mile, with certain assumptions of average consumption, for example the consumption of 5 kg H_2 per vehicle. It is takes into account an ongoing inflation rate of 2% a year. Hyflow can serve a maximum of 10 cars a day for the first 5 years starting in 2010 when the facility first goes into business. In 2015, the company will expand by purchasing an additional reformer, so that a maximum of 30 cars per day are servable until 2020. In the year 2020, the production of hydrogen will increase again by acquiring another reformer, so that 50 customers can be served per day.

The price is based on the cash discount of a ten year operation. At year end, earnings of that year will be discounted at 10%. By the end of the ten years, the accumulation of the discounted cash flow will be equal to the initial capital investment. Although the price for the purposes of analysis remains set at $9.866, the price can and will fluctuate to meet the demands of the market or to further increase profits of the business.

3.2 Other Costs

Reasons to have a joint business include advantages for both partners. Hyflow will benefit by having access to the skyscraper and a certain percentage of the adjoining area for hydrogen production. The partner benefits by having greater space availability, reduction of utility fees, reduced advertisement, and has an influx of customers from Hyflow. Supplemental profits include selling extra production of electricity to local utilities, Seattle City Light at the 2004 green-energy price of $.0512 per kWh, as compared to the purchase price of $.0491 per kWh [21]. Additional profits can be generated by cooperating with food related businesses such as mini marts or fast food, if such expansions were possible.

3.3 Capital Investment

The capital cost is reflected upon the required equipment. To aid in the initial investment process, sponsorship would be ideal. This would help us achieve our goals quicker and easier, while at the same time, we would be a symbol of the sponsorships upheld values. A public image of renewable and clean energy will be an asset to any company, in particular oil companies. Vulcan, Inc., founded by Paul Allen, is based in the greater Seattle area, and is an active supporter of renewable energy. They have funded similar projects in the past, and are expressing interest towards Hyflow. Such a sponsorship would provide a great springboard for Hyflow's launch, but sponsorship estimates have not yet been determined, and thus will be disregarded for this analysis. In that situation, a large portion of the initial capital investment would be provided by the sponsor, and the remaining cost would be provided by the owner.

3.4 Operating Costs

The factors analyzed in the operating costs include: cost to produce electricity and hydrogen, repairs and maintenance, wages, salaries, benefits, insurance expense, marketing and advertising expense, and miscellaneous expense.

A chief expense in the production of hydrogen is water. Both the electrolyzer and the reformer require feedwater input [8, 35]. There are two ways to mitigate the associated cost. First, a large reservoir of waste water from the fuel cell will store water for later use. Second, there would be a rainwater collection system, which would be extremely simple to install. Combined, an estimated $2000 is saved annually, based on weather data provided by NOAA.

Repairs and maintenance costs are calculated by the given maintenance rates as shown in the table along with yearly increasing inflation.

As for human compensation, Hyflow will need no more than two main employees to operate the machines and daily activities with an estimated wage of $40,000 a year. Additional works may be hired as needed. Other costs include insurance expense, marketing and advertising expense, and miscellaneous expense, all of which are estimated from United States census of 1996. Insurance is assumed to be 15% with 2% yearly inflation increases [19].

3.5 Cash Flow Analysis

An analysis of annual net income, revenue, depreciation, discounted cash flow, and internal rate of return of 10% for years 2010 to 2020 is summarized in the tables below.

Table 7. Capital investment

Component	Cost (thousands of dollars)
Hydrogen Storage	62.5
AC/DC Power Converter	160.0
Central Programmable Controller	50.0
Dispenser	58.3
Sensors and Valves	21.3
Misc. Electrical Equipment	20.0
Compressor (Hydro-Pac E04-0842)	71.0
PEM Fuel Cell	60.0
Reformer	335.0
Electrolyzer	440.0
Wind Turbines	320.0
TOTAL	**1598.1**

Table 8. Operating and maintenance costs

Source	Cost (thousands of dollars)
Utilities expenses	
Water (Seattle area)	0.5
Electricity (Seattle area)	6.5
Natural Gas (Seattle area)	1.0
Utilities Total	**8.0**

Maintenance costs	
Reformer maintenance (0.3%)	0.9
Storage maintenance (1%)	0.6
Compressor maintenance	1.0
Dispenser maintenance (10%)	5.8
Electrolyzer maintenance (4%)	17.6
Wind turbine maintenance (2%)	6.4
Maintenance Total	**32.4**

A discounted cash flow analysis from the operating periods of 2010 to 2020 is given by table 9 and 10. Note: all values are given in thousands of US dollars.

Table 9. Discounted cash flow analysis from 2009 to 2014

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Sales Revenue						
Hydrogen	0.0	180.1	183.7	187.3	191.1	194.9
Electricity	0.0	50.9	51.9	53.0	54.0	55.1
Total Sale	0.0	231.0	235.6	240.3	245.1	250.0
Cost of Goods Sold	0.0	8.0	8.2	8.3	8.5	8.7
Hydrogen	0.0	7.3	7.4	7.6	7.7	7.9
Electricity	0.0	0.7	0.7	0.7	0.7	0.8
Gross Margin	0.0	223.0	227.4	232.0	236.6	241.3
Operating Expenses						
Repairs & Maintenance	0.0	32.4	33.0	33.7	34.3	35.0
Wages, Salaries, Benefits	0.0	125.0	127.5	130.1	132.7	135.3
Insurance Expense	0.0	3.9	4.0	4.1	4.1	4.2
Marketing and Advertising	0.0	10.0	10.2	10.4	10.6	10.8
Miscellaneous Expense	0.0	18.0	18.4	18.7	19.1	19.5
Operating Expenses	0.0	189.3	193.0	196.9	200.8	204.9
Operating Income	0.0	33.7	34.4	35.1	35.8	36.5
Capital Investment	-1598.1	0.0	0.0	0.0	0.0	0.0
Other Revenue and Expense						
Income Before Taxes	1598.1	33.7	34.4	35.1	35.8	36.5
Income After Taxes	1598.1	28.6	29.2	29.8	30.4	31.0
Depreciation	0.0	16.2	16.5	16.9	17.2	17.5
Cash Flows	1598.1	28.6	29.2	29.8	30.4	31.0
Discounted Cash Flows (10%)	0.0	25.8	26.3	26.8	27.4	27.9
Tax Internal Rate of Return	0.0	2.9	2.9	3.0	3.0	3.1
Net Income	0.0	5.7	5.8	6.0	6.1	6.2

Table 10. Discounted cash flow analysis from 2015 to 2020

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Sales Revenue						
Hydrogen	540.2	551.0	562.0	573.2	584.7	900.3
Electricity	56.2	57.3	58.5	59.6	60.8	62.0
Total Sale	596.4	608.3	620.5	632.9	645.5	962.3
Cost of Goods Sold	8.8	9.0	9.2	9.4	9.6	9.8
Hydrogen	8.1	8.2	8.4	8.6	8.7	8.9
Electricity	0.8	0.8	0.8	0.8	0.8	0.9
Gross Margin	587.5	599.3	611.3	623.5	636.0	952.6
Operating Expenses						
Repairs & Maintenance	35.7	36.4	37.2	37.9	38.7	39.4
Wages, Salaries, Benefits	138.0	140.8	143.6	146.5	149.4	152.4
Insurance Expense	4.3	4.4	4.5	4.6	4.7	4.8
Marketing and Advertising	11.0	11.3	11.5	11.7	12.0	12.2
Miscellaneous Expense	19.9	20.3	20.7	21.1	21.5	21.9
Operating Expenses	209.0	213.1	217.4	221.7	226.2	230.7
Operating Income	378.6	386.1	393.9	401.7	409.8	721.9
Capital Investment	-369.9	0.0	0.0	0.0	0.0	-408.4
Other Revenue and Expense						
Income Before Taxes	8.7	386.1	393.9	401.7	409.8	313.5
Income After Taxes	7.4	328.2	334.8	341.5	348.3	266.5
Depreciation	48.6	49.6	50.6	51.6	52.6	81.0
Cash Flows	7.4	328.2	334.8	341.5	348.3	266.5
Discounted Cash Flows (10%)	6.7	295.4	301.3	307.3	313.5	239.8
Tax Internal Rate of Return	0.7	32.8	33.5	34.1	34.8	26.6
Net Income	1.5	65.6	67.0	68.3	69.7	53.3
Net Income After Ten Years						**355.1**

Thus, the HyFlow hydrogen power park will be an economically viable business. It must be kept in mind that sponsorship would further enhance the business operation remarkably. The intrinsic worth of renewable and clean energy is tremendously great, and not only will people be willing to pay more to get it, the benefits such a facility provides will over time pay for itself.

4 ENVIRONMENTAL ANALYSIS

4.1 Introduction

A fundamental goal in the production of our hydrogen power park (HPP) is to reduce the amount of green house gases emitted. Greenhouses gases, especially carbon dioxide (CO_2), are a commonly accepted contributor to global warming, a leading concern among environmentalists. In what follows, we present an analysis on the environmental impact of our HPP and its contribution to the reduction of CO_2. In section 3.1, we present the methodology that we use for the impact assessment. In sections 3.2 and 3.3 we implement the methodology and perform CO_2 impact analyses. In section 3.5 we add additional considerations about the quality of the environmental design of the project. We conclude in 3.6.

4.2 Methodology

Our environmental impact assessment is centered on three steps: site selection, subsystem analysis, and overall systems analysis. As appropriate sites for this analysis, we have selected both the areas of Seattle, Washington and Honolulu, Hawaii. There are two reasons behind these choices. First, Honolulu is an excellent location for the installation of renewable wind and solar energy conversion systems with favorable wind speeds and solar radiation. In the Seattle area and the city of Bellevue, wind speeds and solar radiation are much lower on average. However, electric power is here largely provided by hydroelectric power plants with zero emissions while in Honolulu most existing electric power generation is obtained through combustion of fossil fuels. Thus, in the Seattle area with its clean record in electric power generation and lower wind speeds and solar radiation, it will be a challenge to beat an already enviable environmental record. In Honolulu, the opposite is true and our system is expected to lead to dramatic improvements. It is this observation to that led us to consider both Seattle and Honolulu as this allows us to cover a wide spectrum of local situations.

Following this site selection, we have performed two subsystem evaluations. The first evaluation is concerned with the environmental impact of the electric power generation. We find out the composition of the electric power generation, i.e. the percentages of the different resources that are used to produce electric power. We use this information to calculate how many grams of CO2 are emitted per kWh electric energy for different power systems. We distinguish between Seattle City Light [31], the Hawaiian Electric Company [28]. We do then the same for our HPP locations in Seattle and Honolulu. We assume an average load of 2400 kWh per day and calculate the CO_2 that is produced per day by multiplying the value obtained for emissions per kWh by 2400.

The second subsystem calculation concerns the environmental impact of the transportation side. Here we compare the emissions of cars fueled with our hydrogen with cars that are equipped with a combustion engine. We consider both the source to tank and tank to wheels impacts. We assume that 3100 miles are driven per day for all the cars we provide fuel to base on our 50 kg hydrogen supply per day. We also obtain the emissions of CO_2 per day for transportation.

We obtain the total emissions per day by summing up the contributions from power generation and transportation. The comparisons of the HPP system emissions with the current situations in Seattle and Honolulu give us a good insight into the environmental impact.

4.3 Subsystem CO_2 Impact Evaluation

4.3.1 Electric power generation

In the table below, the emissions based on current grid compositions are shown for Seattle City Light and Hawaiian Electric Company. For each resource we take the CO_2 emissions and then multiply by its percentage share. These percentage contributions are then summed up to get the average grams of CO_2 emissions per kWh for each of the two power systems. Since we consider a load of 2400 kWh, the daily emissions are then obtained by multiplying by 2400, as already stated in section 3.2.

Table 11. Emissions due to power generation based on current grid compositions

	Seattle City Light	**Hawaiian Electric Company**
Composition	90.2 % hydro 5.3 % natural gas* 2.6 % nuclear 0.6 % coal 0.2 % other	78 % petroleum 15 % coal 6 % non-hydro renewables <1 % hydro
Grams CO_2 / kWh	0	839.15
Grams CO_2 / day	0	2,013,960

*it should be noted that this is natural gas used in a co-generation project, of which all the carbon dioxide emissions are completely mitigated.

With our HPPs we are able to provide the electric power exclusively through renewable sources. This is reflected in the table below.

Table 12. Emissions due to power generation based on HPP

	HPP Seattle	**HPP Honolulu**
Composition	100 % wind power	100 % wind and solar power
Grams CO_2 / kWh	0	0
Grams CO_2 / day	0	0

4.3.2 Transportation

For cars using conventional combustion engines, we found emissions for source to tank and tank to wheels emissions in [25]. The values are given in the table below. For the fuel car that obtains hydrogen at our HPPs, we get zero emissions for the tank to wheels path. The emissions for the source to tank path depend on the location of the HPP. In Honolulu we can generate the hydrogen based on renewable power conversion and get zero emissions for source to tank.

Table 13. Emissions due to transportation

	Combustion Engine Car	Fuel Cell Car Powered by HPP Seattle	Fuel Cell Car Powered by HPP Honolulu
Source to Tank Emissions	7,951 g CO_2 / gallon	10,621 g CO_2 / kg H_2	0
Tank to Wheels Emissions	8,316 g CO_2 / gallon	0	0
Source to Wheels Emissions	16,267 g CO_2 / gallon	10,621 g CO_2 / kg H_2	0
Average Miles / unit	22 miles / gallon	62 miles / kg	62 miles / kg
Grams CO_2 / mile	739.41	171.31	0
Grams CO_2 / day	2,292,168	531,061	0

In Seattle we need the reformer to generate hydrogen for transportation purposes. For the reformer, which is described in the technical section of this report and depicted below, we assumed one mole of CO_2 for every mole of methane used in the reaction to calculate the number of moles of methane needed to produce the necessary amount of hydrogen. This gives us the source to tank emissions.

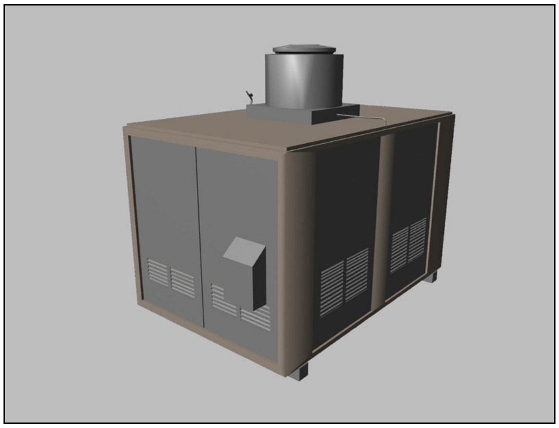


Figure 11. Reformer used in HPP Seattle

The source to wheels emissions are found by summing up the source to tank and tank to wheels contributions. Using the given average miles per unit, the grams CO_2 per mile are calculated. With the assumption of 3100 miles per day driven as discussed in section 3.1, we obtain the emitted grams of CO_2 per day.

4.4 Overall CO_2 Impact Evaluation

We insert the results from section 3.3 for respectively power generation and transportation into the first two rows of the table below. We assume that cars have predominantly conventional combustion engines in both Seattle and Honolulu. By summing up the contributions from power generation and transportation, we obtain the total emissions given in the last row. The bar chart shows the results in graphical form.

Table 14. Total emissions due to power generation and transportation

	Seattle Today	HPP in Seattle	Honolulu Today	HPP in Honolulu
Power Generation Grams CO_2 / day	0	0	2,013,960	0
Transportation Grams CO_2 / day	2,292,168	531,061	2,292,168	0
Total Grams CO_2 / day	2,292,168	531,061	4,306,128	0

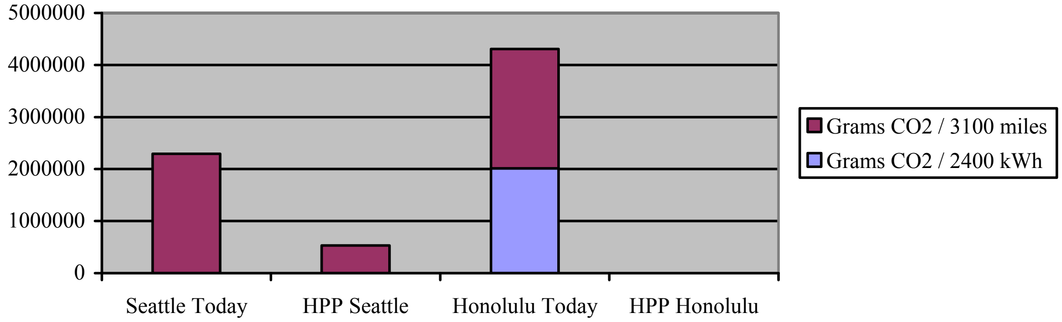


Figure 12. Difference of emissions in certain different locations

Comparing the total grams of CO_2 per day for the situations in Seattle and Honolulu as of today and for the HPPs installed shows that the savings in CO_2 emissions for only one HPP installed is substantial (of course, adding more HPPs multiplies these savings):

Grams CO_2 / day saved in Seattle: 1,761,107.
Grams CO_2 / day saved in Honolulu: 4,306,128.

4.5 Complimentary Considerations

Our power park is largely run off of components from other companies, such as the fuel cells and reformers. To ensure integrity of our final product, we choose tier 1 suppliers that share our goals towards sustainability. Should more efficient technologies or better methods of developing hydrogen be developed, we can easily replace any part of our system because of the modularity of our design. This cuts down on construction costs, as well as environmental consequences, especially since renovation in such an urban area is not easy.

4.6 Conclusions

The Intergovernmental Panel on Climate Change recommends immediate reductions of carbon dioxide emissions into the atmosphere to the tune of half of the total current emissions in the next 100 years in order to avoid many of the effects of global warming [29]. Changing the mechanisms present in our power generation and current transportation system is the first step towards creating a more sustainable, secure future. Based on the savings of CO_2 emissions that we have calculated, we believe that our HPPs can strongly contribute to this step.

5 MARKETING / EDUCATION

5.1 Introduction

The ability of our hydrogen power park to be profitable and to sustain itself relies heavily upon the public's perception of our system. The public's opinion of our hydrogen power park in turn is a function of four main factors: the dissatisfaction with today's energy and transportation systems and the environment, environmental benefits of our system, safety of our system, and sustainability of our system.

5.2 Objectives

In order to be effective, our public awareness campaign must accomplish several key goals:

1) To educate the public about the problem of global warming and how today's energy and transportation systems contribute to it, as well as various other environmental problems.
2) To convince the public that hydrogen fuel cells running on hydrogen made from clean, renewable energy provide the basis for a better system.
3) To allay fears about using hydrogen technology.
4) To notify the public about our company, our location, and how we operate.

The immediate target of our ads will be the local driving populations in our hydrogen park cities. While most people will not have hydrogen fuel cell cars when these parks open, all drivers are potential customers. Our ads will need to be general enough and brief enough where they will hold the interest of most drivers, however they still need to be educational enough to build support for our power park.

5.3 Implementation

The format of our advertising and education will take several forms. Each of our objectives will take place through a variety of forms of ads and information. Our ads will run over the period of the ten years, of a total cost of roughly $10,000.

5.3.1 Considering the flaws of today's energy and transportation systems

One of the main implementations of advertising goals is to provide an interactive education system in each fueling station. We will provide various pamphlets, educational brochures, and other forms of information to not only educate about global warming, but to educate people about the flaws of today's systems. Ideally, a partnership with a supportive nongovernmental organization or a progressive fossil fuel company would allow us to put these brochures in gas stations or other public places. Our consideration of the flaws of today's systems will be heavily focused on global warming, and contribution of today's systems to it through the emission of greenhouse gases. To do this, we must convince the public that global warming is a problem, since much of the public is still uneducated about the topic. We will focus on the impacts of global warming, and then provide various solutions, including the role of hydrogen.

5.3.2 *Making the case for hydrogen*

Once we have offered an analysis of the problems with today's energy and transportation systems and the environment, we can lay out how hydrogen based energy and transportation systems based on clean, renewable resources, address these issues. We will show how our hydrogen power parks reduce carbon emissions. This will be done at the on-site educational center and will hold a small place in our ads. Even though it is impossible to provide extensive education in brief ads, especially given the highly technical nature of the material, we will make general statements about the efficacy of the system in dealing with various issues. An important aspect of convincing the public that the hydrogen economy is a better system is in demonstrating that it does not imply a fundamental lifestyle change. Many ecologists argue for the movement away from mass transportation and a meaningful change in the way the typical American lives their lives. While this is a noble idea, it is unrealistic because it asks people to change their fundamental views on the roles of the consumer, businesses, and consumption. This type of change is beyond the scope of our project and may not be desirable. We will avoid infringing on the fundamental need for people to be mobile, but instead will focus on bettering the mechanisms by which they can become mobile.

5.3.3 *Allaying fears*

Allaying public fears is another objective that requires extensive education, which is largely technically based. While it is easy to claim that our system is safe and well designed, public doubt does not go away easily. Highlighting our main safety precautions and features will be more effective than giving a complete technical overview of the system. However, much of the burden of educating the public about the realities of the safety of the system falls upon the car companies, since consumers will have more interaction with the cars than the power park. By partnering with the car companies in their efforts to educate the public, we can help them make a more convincing case for hydrogen based cars and also make our point to a more appropriate audience.

5.3.4 *Building awareness about our company*

Our attempts to build awareness will be through partnerships with fossil fuel companies, car companies, and through our ads. Being able to use the names of large fossil fuel companies as sponsors will help establish credibility for our company and spread our name through their resources. Establishing partnerships with car companies that make fuel cell based cars will be useful, especially in providing new car customers with information about the nearest hydrogen fueling stations. Finally, our ads will each contain information about where to find our hydrogen power parks.

5.4 Conclusion

Our marketing and education will approach the issue of public awareness using education centers in each of our fueling stations, ads, and partnerships. We will focus on targeting current and future customers, with education about the flaws of today's energy and transportation systems, the advantages of our system, safety information, and the location of our power parks.

THE CHOICE IS
CLEAR

CHOOSE HYDROGEN FUEL FOR A
CLEANER TOMORROW

Conventional combustion engines run off of petroleum, which contributes to global warming, degrades air quality, creates foreign dependence, and is not a sustainable resource. On the other hand, hydrogen power made from renewable resources creates no pollution, can be made almost anywhere, and is completely sustainable.

- Alex Zheng, HyFlow
Environmental Specialist

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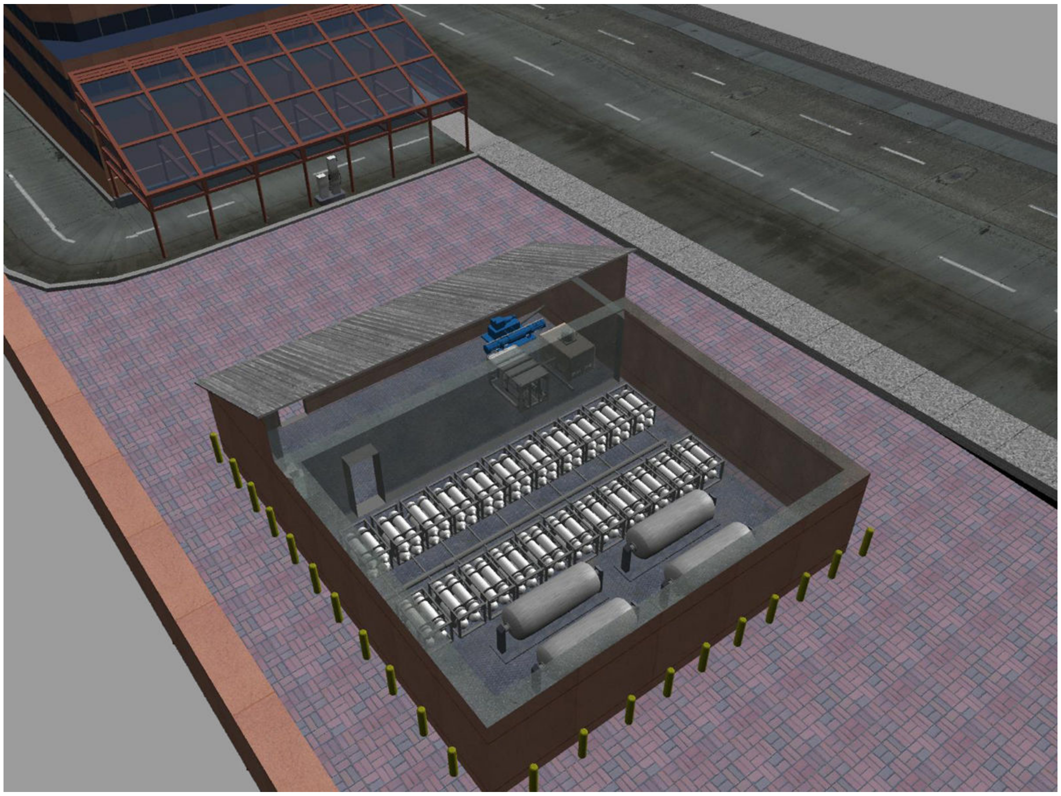
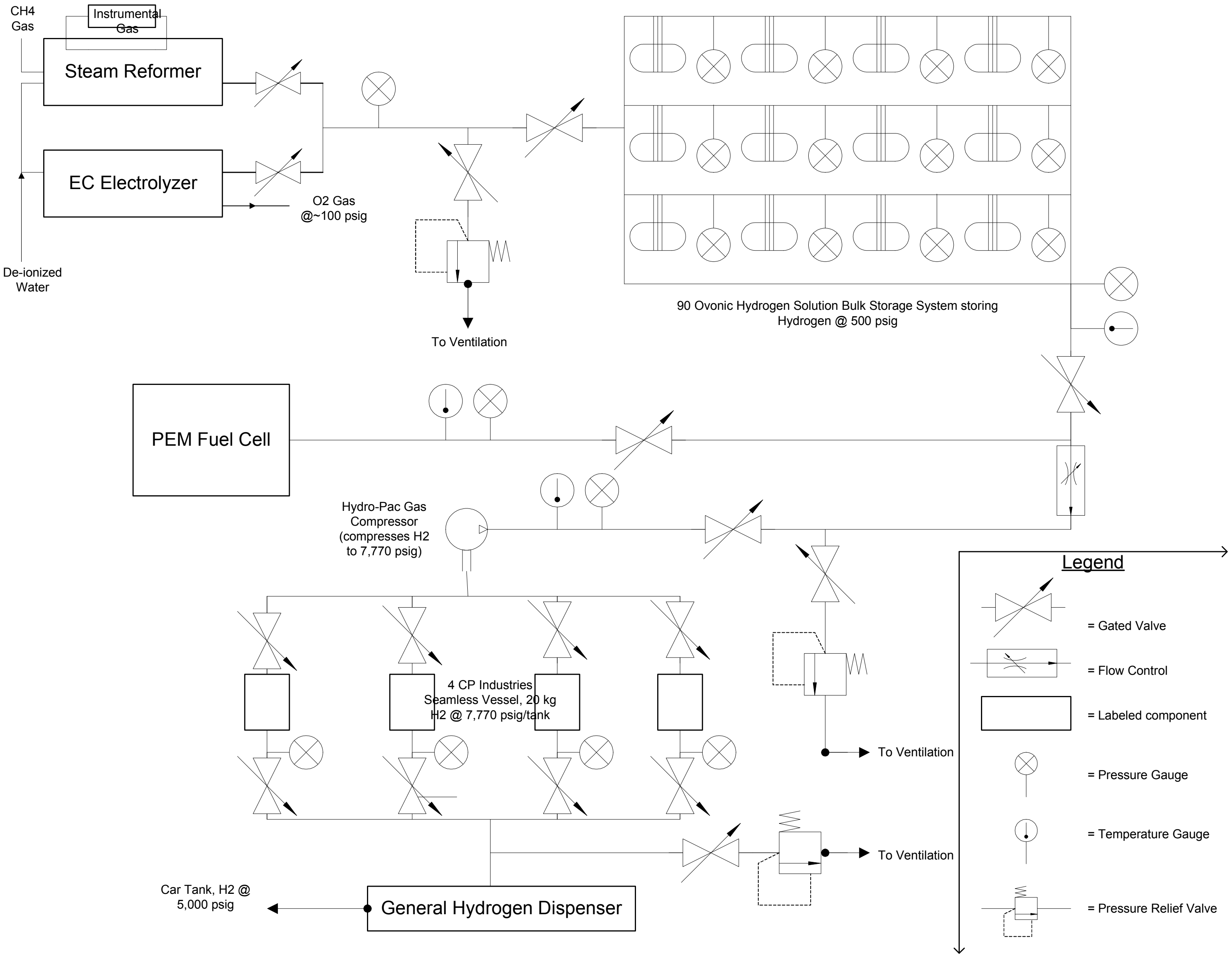
6 APPENDIX

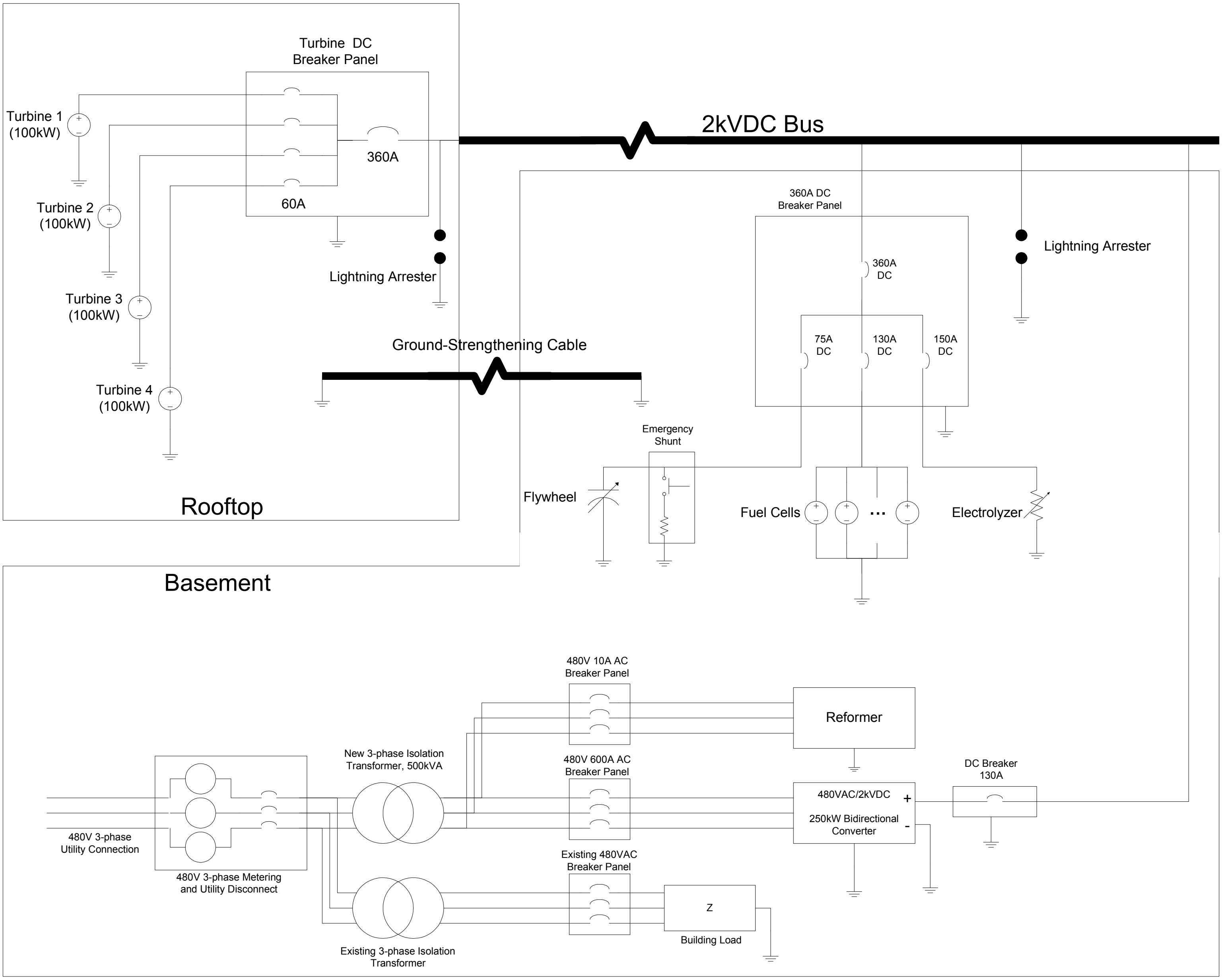
6A Additional Drawings and Renderings



6B Hydrogen Process Schematic



6C Electrical Process Schematic



6D Sizing and Simulation

The sizing of our system depends on many factors, and an analytical approach is taken. The following algorithm summarizes the methodology used.

Steps for sizing system

1. Determine the maximum load requirement $\max\{P_{load}\}$. Size fuel cell such that this may be met by fuel cell alone.
2. Determine greatest excess input power $\max\{P_{wind} - P_{load}\}$. Size electrolyzer such that this excess power is utilized.
3. Maximize wind turbine(s) power generation capability. This will be limited by cost, structural feasibility, and space.
4. Find total kWh of excess energy produced over one year during times of high wind speeds. Determine the amount of hydrogen produced via the electrolyzer with this excess.
5. Find total kWh of deficit energy needed over one year during times of low wind speeds. Determine the necessary amount of hydrogen needed for the fuel cell to generate this energy.
6. If (4) – (5) > 0, the power supplied to the load and/or the utility grid, P_{load}, may be increased. Otherwise, a reformer is necessary to supply the extra demand of hydrogen. Find average reformer production rate needed to meet this requirement. Size the reformer such that this in addition to hydrogen fueling requirements is met.
7. Find maximum period of either extended hydrogen tank dispensing, or filling. Determine the net quantity of hydrogen grossed over this period. To accommodate either case, size hydrogen storage tank to this quantity.
8. Maximum power flow out of system is simply the power generation requirement, P_{load}.
9. Maximum power flow into the system is the necessary amount of power to operate the electrolyzer, which supplies the fuel cell with enough hydrogen to maintain output power production, in a worst case scenario (e.g., no wind and unexpectedly low quantities of hydrogen in storage).

As mentioned in previous sections, extensive simulations were performed. The following figure is the overall high-level model in Simulink.

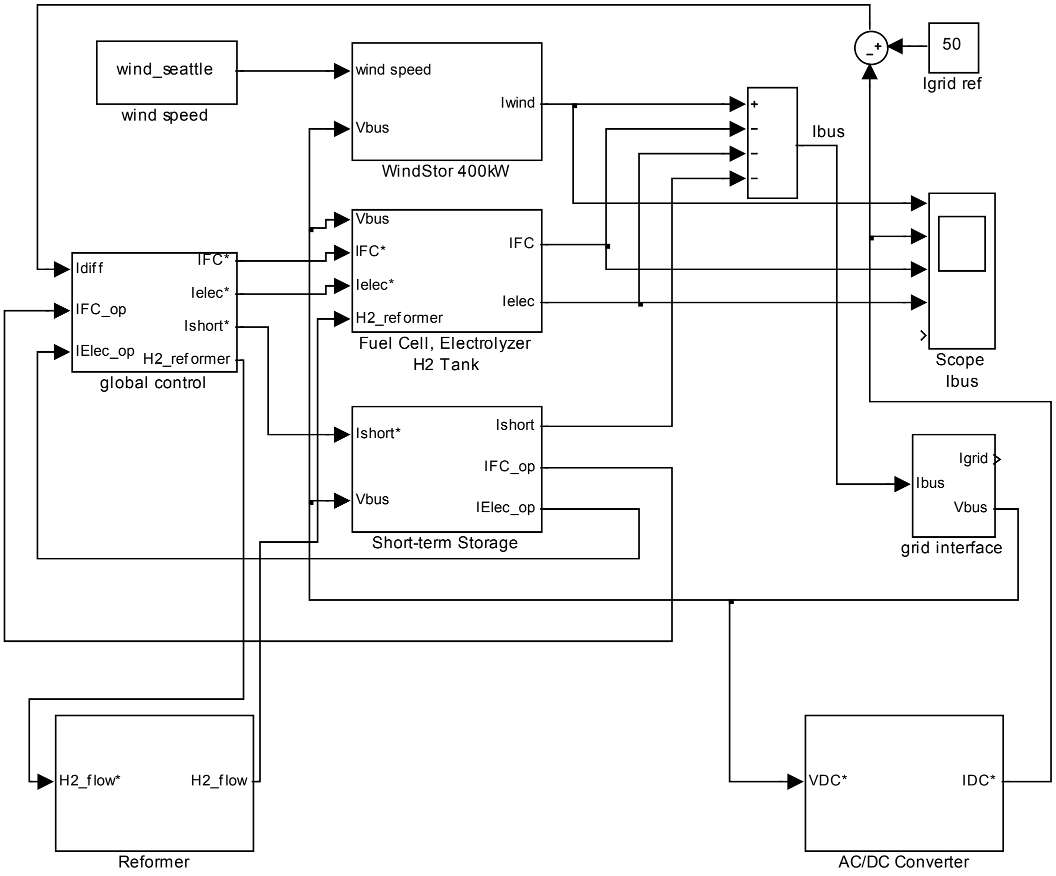


Figure 13. Simulink model of system

City of Bellevue
Post Office Box 90012 • Bellevue, Washington • 98009 9012

Dear Mr. Reed

I have reviewed your recently submitted set of pre-plan documents for the installation of the Hydrogen generation facility and fueling station at Skyline Tower. Your drawings along with our recent pre-plan meetings provide a clear concise overview of the project.

At this time the project appears to meet current International Fire Code (2003 edition) requirements as well as NFPA guidelines. Therefore the Bellevue Fire Department has approved the installation of the facility in concept.

Additional plans must be submitted for specific review and developmental permits required for the installation of an early warning alarm system, fire suppression system, mechanical permit for all piping installations, building permit for structural components, electrical work and of course a Fire Department permit for the storage and use of hazardous materials.

Conceptual pre-plan reviews do not in any way authorize you or any company to commence construction of this project without the written consent through the plan review process of the Bellevue Fire Department or any other City of Bellevue developmental system.

Please feel free to contact me at you convenience for any additional information or questions at 425-452-2925.

Sincerely,

R Tuininga
Lead Fire Prevention Officer
Bellevue Fire Department

"The Bellevue Fire Department exists to assist the public in the protection of life and property by minimizing the impact of fire, medical emergencies, and potential disasters or uncontrolled events that affect the community and environment."

Bellevue Fire Department • 766 Bellevue Way SE • Bellevue, Washington 98004
Phone: [425] 452-6892 • Fax: [425] 452-5287

7 REFERENCES

[1] Strunz, K.; Brock, E. K.: Hybrid plant of renewable stochastic source and multi-level storage for emission-free deterministic power generation. Proceedings of the CIGRE/IEEE PES International Symposium of Electric Power Delivery Systems, Montreal, Canada, October 2003.

[2] Plate, E.J., Kiefer, H., Wacker, J., "Wind and Urban Climates", American Meteorlogical Association, http://ams.confex.com/ams/pdfpapers/80813.pdf

[2] Carr, Greg. "H2Gen Hydrogen Generator", H2Gen Innovations, Inc. 2004.

[3] Cielinski, Jim. CP Industries. January 10, 2005.

[4] Chao, Ben. Texaco Ovonic Hydrogen Solution. January 11, 2005.

[5] Connelly, Thomas J. Hydro-Pac Inc. Proposal E04-0842. December 16, 2004.

[6] Garandza, Karin. General Hydrogen. January 10, 2005.

[7] "Renegade Pro Series Gas Compressors", GeoTech Environmental Equipment Inc. May 2004.

[8] "Teledyne Titan EC Generator Series, Hydrogen/Oxygen Gas Systems", Teledyne Energy Systems Inc., Teledyne Technologies Company. June 6, 2002.

[9] Building and Fire Code: Uniform Fire code, 2003.

[10] International Building Code, 2003

[11] Structural Design Analysis: American Society of Civil Engineers: Minimum Design Loads for Buildings and Other Structures (ASCE 7-02).

[12] Structural Design Advising: Dr. Marc Eberhard, Civil Engineering Professor, University of Washington

[13] Turbines: Dermond Wind Turbine, by Dermond Inc. a McKenzie Bay Company. http://mckenziebay.com/

[14] Sprinkler system: http://www.victaulic.com/content/victaulicfoamfireprotectionsystem.asp

[15] Floor Plan: http://www.unicoprop.com/downloads/skyline.pdf

[16] Tower Shot – used for measurements for ground layout and design http://terraserver.microsoft.com/image.aspx?T=4&S=8&Z=10&X=11211&Y=105474&W=2&qs=%7cbellevue%7cwashington%7c

[17] Ventilation system: http://www.phoenixcontrols.com/solutions.html#Hospital

[18] Bureau of Labor Statistics. Table: Seattle-Tacoma-Bremerton. Jan 2004. http://www.bls.gov/ncs/ocs/sp/ncbl0655.txt

[19] Sissine, Fred. CRS Issue Brief for Congress: IB10041: Renewable Energy: Tax Credit, Budget, and Electricity Restructuring Issues. National Library for the Environment. March 9, 2001. http://www.ncseonline.org/NLE/CRSreports/energy/eng-54.cfm?&CFID=18262172&CFTOKEN=11702964

[20] Puget Sound Energy. Total of General Gas Price - Gas: Commercial and General Service. Washington: Puget Sound Energy. http://www.pse.com/account/pdfs/gas_summary_prices_2004_11_01b.pdf

[21] City of Seattle. Medium General Service, City. Washington: City of Seattle. http://www.seattle.gov/light/accounts/rates/ac5_erps11.htm

[22] Brooks, Alec, N. "Perspectives on Fuel Cell and Battery Electric Vehicles." AC Propulsion. December 5th, 2002.

[23] California Fuel Cell Partnership. "California Fuel Cell Partnership". http://www.fuelcellpartnership.org/aboutus.html

[24] Department of Energy. "CO2 Emissions Report." Carbon Dioxide Emissions from the Generation of Electric Power in the United States. http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html

[25] Department of Energy. "Office of Fossil Energy Home Page". Office of Fossil Energy. http://www.fossil.energy.gov/

[26] European Union. "Environment". Activities of the European Union. http://europa.eu.int/pol/env/index_en.htm .

[27] Green Car Congress. "Fuel Cells". Green Car Congress – Technologies, issues and policies for sustainable mobility. http://www.greencarcongress.com/fuel_cells/

[28] Hawaiian Electric Company, Inc. "Renewable Energy for Hawaii" Hawaiian Electric Company, Inc. http://www.heco.com/CDA/default/0,1999,TCID%253D1%2526EmbedCID%253D0%2526CCID%253D0%2526LCID%253D4578%2526CTYP%253DARTC,00.html

[29] Intergovernmental Panel on Climate Change. "Climate Change 2001". IPCC Third Assessment Report – Climate Change 2001. http://www.ipcc.ch/

[30] Rocky Mountain Institute. "Energy Library". Rocky Mountain Institute. http://www.rmi.org/sitepages/pid171.php#20H2Myths

[31] Seattle City Light. "Fingertip Facts" Seattle city Light Customer Information. 2002 Guide. http://www.cityofseattle.net/light/aboutus/customerguide/#PowSup

[32] Seattle City Light. "Global Warming" Seattle City Light Conservation. http://www.cityofseattle.net/light/conserve/globalwarming/

[33] Spath, Pamela L. and Mann, Margaret K. "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming." February 2001. National Renewable Energy Laboratory.

[34] Teller, Ph, P. and Germain, A. "A comparative LCA of different proton exchange membrane fuel cells (PEMFC) and a microturbine for combined production of heat and electricity". 2000. Industrial Chemistry department, University of Liège, Belgium.

[35] Carr, Greg. "*H2Gen Hydrogen Generator*". H2Gen Innovations, Inc.