H2U Waterloo Student Design Proposal 07/08

Presented by: Ryan Hsu
Jamie David
Ashan Garusinghe
Slavi Grozev
Lan Kang
Sayjel Patel
Ryda Peung
Rajdeep Solanki
Arthur Yip

Advisor: Dr. Michael Fowler

Executive Summary

Sustainable development is a global issue with environmental, social, economic, and political aspects. Pollution, climate change, oil dependence, and economic instability are all consequences of the exploitation of non-renewable energy sources. Hydrogen offers itself as a stable and abundant energy carrier, with the potential to power cell phones, laptops, automobiles, homes, infrastructures and even airplanes in the future.

This report outlines a redesign of the Columbia Metropolitan Airport (CAE), proposed by the H2U Waterloo Design Team. The redesign consists of the integration of hydrogen applications to reduce air and noise pollution, mechanical inefficiencies, energy waste, and dependence on oil-based fuels at the airport. The heart of the proposal is the installation of a hydrogen refuelling station on airport premises, that will generate its own hydrogen via electrolysis to meet the airport's and public's projected hydrogen fuel demands for the next five years.

The redesign includes a new Green Limousine service to serve hundreds of passengers commuting to and from the airport and downtown Columbia on a daily basis. The limousine fleet will initially be composed of three Honda FCX Claritys, fuel cell cars that offer zero emissions from the tailpipe, and almost noiseless operation. The use of the three FCX Claritys instead of regular gasoline vehicles will divert approximately 82 tons of CO_2 from the atmosphere per year. In addition, it is proposed that 15 of the airport's internal service vehicles be retrofitted with hydrogen fuel injection systems to bring about a reduction of pollutant emissions for each vehicle of up to 50%. With a cleaner burn, these vehicles are guaranteed to experience at least an 8% increase in mileage and improved engine performance. It is also proposed that one of the airport's diesel Ground Power Units (GPU) be replaced with a hydrogen fuel cell power generator. Since these produce no emissions at the source, their utilization would therefore divert approximately 3.5 tons of CO_2 per year.

Safety is a paramount concern in today's airports, and to address this concern, a Failure Mode and Effect Analysis (FMEA) was conducted. The FMEA examined the risk involved with each of the hydrogen systems proposed in the redesign. The top four failure modes identified by the FMEA are human error, terrorism/vandalism, external fire, and equipment failure. From the analysis, it was determined that the components of the design proposal are extremely safe and secure, with all risks mitigated with satisfactory safety measures.

The implementation of the redesign will cost an initial investment of US$ 2.75 million in 2009. For the first year, the redesign will have an annual cost of $162,830 (excluding the initial investment). However, with expected increases in Green Limousine users, public hydrogen fuel sales, and cost savings from the various units, the annual cost will reduce to $3,030 by 2013, and is projected to generate income in further years.

In order to promote the CAE's hydrogen redesign and to encourage support for hydrogen applications in general, a public education and awareness program is also proposed. The program will focus on teaching airport commuters and school children about the benefits of hydrogen and hydrogen technologies, and how they are safe. It will consist of an exhibit in the airport, which will highlight the elements of its hydrogen redesign, hydrogen awareness events in local elementary and high schools, and a Green Limousine advertising campaign.

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APU	Auxiliary power unit
Barg	Bar gauge
CAE	Columbia Metropolitan Airport
CO	Carbon monoxide
CO_2	Carbon dioxide
FAA	Federal Aviation Administration
FMEA	Failure mode and effect analysis
GPU	Ground power unit
H2U	Hydrogen-2-U
HC	Hydrocarbons
HFI	Hydrogen fuel injection
HGS	Hydrogen generating system
ICE	Internal combustion engine
LCA	Life cycle analysis
Mpg	Miles per gallon
NCMH	Normal cubic metres per hour
NHA	National Hydrogen Association
NO_x	Nitrogen oxides
PM	Particulate matter
Ppm	Parts per million
Psig	Pounds per square inch gauge
TNT	Trinitrotoluene
TSA	Transportation Safety Administration
Vol %	Volume percent
ZEV	Zero emission vehicle

1 Introduction to the Design

Today's airports face difficult challenges in reducing the environmental impact they have on the world. Aside from financial hardships and stringent airport regulations, airports have to constantly deal with other vital issues such as air quality, noise reduction, water pollution, international security, and internal operations [1].

The H2U Waterloo Design Team proposes the implementation of hydrogen technologies and applications at the Columbia Metropolitan Airport (CAE) to bring a solution to these outstanding issues. The proposal is designed to modernize the airport by integrating hydrogen technologies in a way that does not impede on current airport activities, all the while addressing pollution and energy concerns, maintaining reliability and airport security, and providing the foundation for a future hydrogen economy.

This proposal aims to further the recognition of the Columbia Metropolitan Airport as one of the most innovative and prospective international airports in the USA. By accepting this proposal, the CAE will be credited for being one of the first North American airports to implement hydrogen technologies as a means for diverting harmful air emissions attributed to climate change, reducing the world's oil dependence, and leading the way to a hydrogen future in South Carolina, by providing critical infrastructure and improving public awareness.

The report will consist of five distinct sections and is organized as follows: technical design, environmental analysis, safety analysis, marketing analysis, and economic analysis. The technical design portion will focus on the proposed hydrogen refuelling station and the hydrogen applications to be implemented at the CAE. The second section presents the environmental study done to project the environmental benefits of the new design. The third section will discuss the safety aspect and provide an overview of the major failure modes of the proposed redesign. The fourth section outlines the marketing and education strategy proposed to create awareness and promote support for hydrogen applications and technologies to encourage the public to generate support for the development of a hydrogen economy. Finally, the last section presents an overview of the economic evaluation of the proposed project with a breakdown of the capital and operating costs.

1.1 Technical Specifications for Hydrogen Refuelling Station

Several crucial factors drove the inclusion of a hydrogen refuelling station in the design proposal. The CAE has the potential to become a significant user of hydrogen fuel, and a leader in the advancement of the hydrogen economy by building critical hydrogen infrastructure in Columbia. The "Greater Columbia Fuel Cell Challenge," a project similar to Hydrogen Student Contest has already completed two phases [2] that are leading the city towards a hydrogen village, and the H2U Waterloo Design Proposal aims to satisfy the hydrogen requirement at the airport while also providing a community outreach program. The proposed refuelling station is the basis of this outreach, creating a foundation for future hydrogen-related applications in the area.

To handle the expected growth in demand for hydrogen, the refuelling station was designed to meet the following requirements. The design of the station must be concerned with the safe operation of the generation and dispensing of hydrogen using currently available technologies with minimal impact on current local operations. The station must be flexible and adaptable in order to minimize operating costs, and allow for expansion to keep up with future demand. These specifications enable the refuelling station to be open for future growth, while remaining self-sufficient and sustainable, both physically and financially. This will allow the public to access the station and allow the fuelling station to be operated as a business, facilitating the growth of the hydrogen economy in the area.

The following section discusses the fuel supply model, technical design, and component justification of the hydrogen refuelling station.

1.1.1 Fuelling Supply Model

Based on recent hydrogen demand models, the number of hydrogen applications is expected to increase steadily until the year 2025 (2). The refuelling station is designed to meet these projected demands for the next 5 years of both the airport and the public. According to the proposed design, daily fuelling requirements of the airport will be as follows:

Table 1.1: Daily Fuel Requirements

Vehicle	Route	Fuel Consumption	Daily H_2 Fuel Requirement
Honda FCX – Limo 1	6 x 14 miles = 84 miles	240 miles / 3.75 kg H_2 [1]	1.32 kg
Honda FCX – Limo 2	6 x 14 miles = 84 miles	240 miles / 3.75 kg H_2 [1]	1.32 kg
Honda FCX – Limo 3	6 x 14 miles = 84 miles	240 miles / 3.75 kg H_2 [1]	1.32 kg
Hydrogen Fuel Cell Ground Power Unit	N/A	15 kg / 3.79 hr [2]	24 kg
Internal Service Vehicles	Various	N/A [3]	N/A
Public Hydrogen Vehicles [4]	Various	3 kg / tank	3 kg / customer × 25 customers = 75 kg
		Total:	102.96 kg

1. Conservative fuel consumption rates were used to account for idling time and city driving. Limousine mileage based upon a 240 mile range for a full tank.
2. Assuming operation of 6 hours a day at full capacity.
3. Internal service vehicles being retro-fitted with Hy-Drive hydrogen fuel injection systems will generate their own hydrogen, and will not require refilling at the station.
4. Projected demand of hydrogen by the public in the area by 2013 is 25 customers / day.

1.1.2 Site Location

The refuelling station is to be located at the intersection of Air Commerce Drive and Air Commerce Drive, less than a kilometre from the airport. This location was chosen with safety as the primary consideration. The site is sufficiently far away from any densely populated area, yet easily accessible by the public, as well as to the airport. The proximity to the airport allows for the expansion of a hydrogen pipeline into the airport in the future, while the convenient public access leaves the station open for quick refuelling by commercial tanker trucks that wish to distribute the hydrogen to off-site locations. Moreover, it is conveniently placed by a major road to meet the future hydrogen demand of the public, without creating extra traffic congestion at the airport.

The proposed lot is 1,255 m^2 (13,500 ft^2) in size and is situated next to the maintenance shop, which is the current fuel point for the airport. Since it will be situated near the airport's current fuel point, several resources provided by the maintenance shop can be shared and many of the safety features and considerations for a fuelling station are already in place.

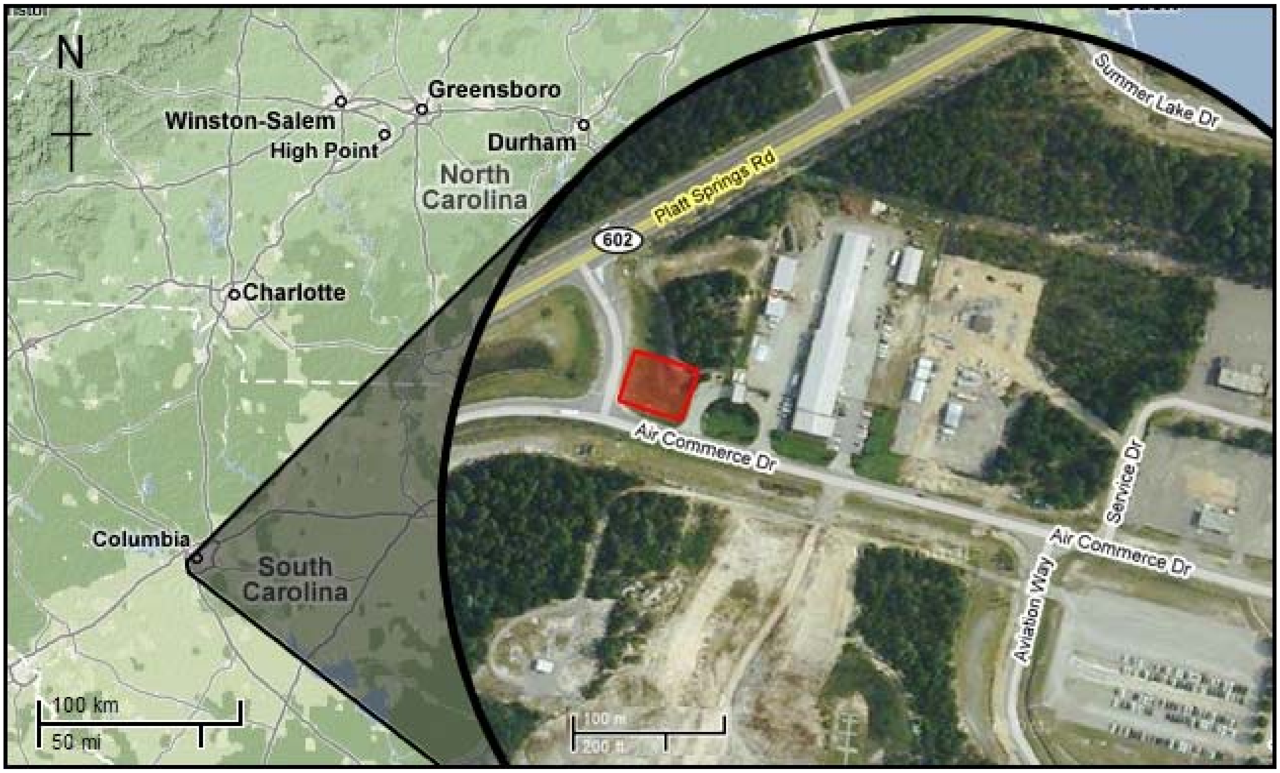

Figure 1.1: Proposed Refuelling Station Lot Location

1.1.3 Station Layout and Design

There are several different modules comprised in a refuelling station, all of which are packaged separately. However, they can be easily integrated together to serve their purpose as a refuelling terminal. Four different modules are required for electrolysis, compression, storage and dispensing. [3]. These are described in the sections below.

The H2U Waterloo design proposes the use of Hydrogenics equipment for the refuelling station. Hydrogenics is a global provider of hydrogen and fuel cell systems. Together, the HySTAT-A generator, compression, storage, and dispenser module are combined, alongside purification packages, to produce the necessary quantity and quality of hydrogen fuel [4].

All units will be housed in Alucobond enclosures, making them versatile and resistant to weathering [4]. For safety purposes, the electrolysis, compression and storage modules will be kept separate from the dispenser, within a chain-link fence, to reduce confusion and minimize unnecessary interaction with the hydrogen-producing equipment. The dispenser will be accessible to the public for those capable of taking advantage of the hydrogen fuel.

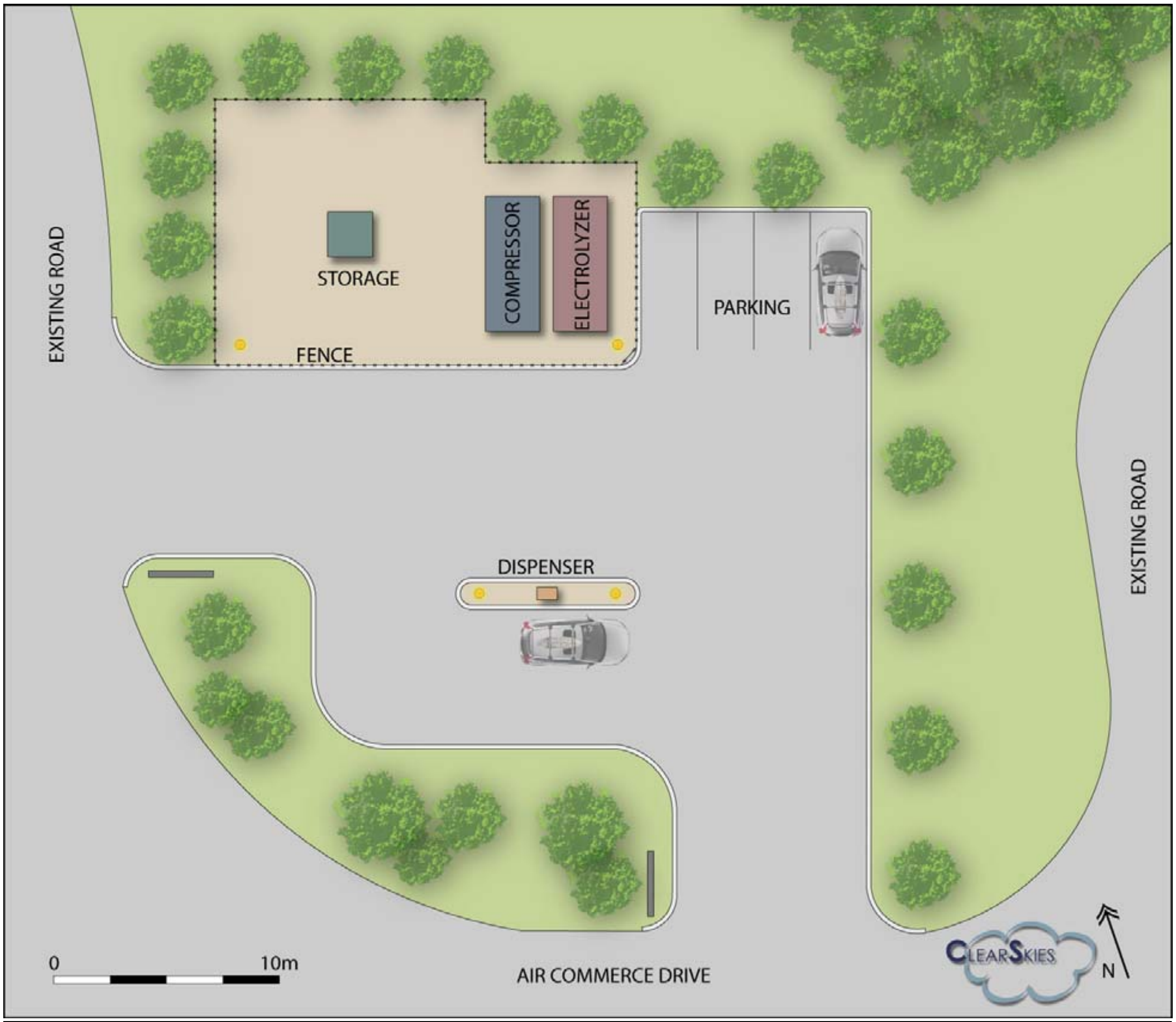

Figure 1.2: Proposed Refuelling Station Site Layout

1.1.4 Refuelling Station Component Modules

1.1.4.1 Electrolyser Modules

To benefit from cheaper rates of electricity, the hydrogen production units will run continuously during off-peak hours, producing and storing enough hydrogen to allow the dispenser modules to operate 24 hours a day. The Hydrogenics' HySTAT-A electrolyser will be capable of producing 90 NCMH (7.55 kg of H_2 / hr) [(5)]. There are typically 14 hours designated as off-peak usage of electricity, for every 24 hour period [(6)]. This setup allows for 105.7 kg of compressed H_2 to be generated daily, with a maximum of 181.2 kg of H_2 if on-peak generation is considered.

The HySTAT-A uses IMET technology, a pressurized alkaline-based electrolyser that delivers high-purity hydrogen at 25 barg before compression or purification of the gas. This gas is delivered to the compressor for more compact storage held at higher pressure [(4)].

This production allows for the hydrogen requirements for the proposed design applications to be met with excess amounts available to be sold to the public. The H2U Waterloo Design Team has also opted for high purity packages installed on the electrolysers to allow hydrogen to be used in any application, rather than excluding applications requiring high purity hydrogen, e.g. fuel cells, local industries.

Table 1.2: HySTAT-A Purity Specifications

Component	Concentration Without Purification Packages	Concentration With Purification Packages
Nitrogen	12 ppm	2 ppm
Oxygen	5 ppm	< 1 ppm
Water	5 ppm	< 1 ppm
Hydrocarbon	< 1 ppm	< 1 ppm
CO_2/CO	< 1 ppm	< 1 ppm
Max Impurities	< 23 ppm	< 5 ppm
Purity Level	> 99.9977 %	> 99.9995 %

[4]

In order to ensure that the refuelling station is capable of handling surges in demand, the criteria of 20 kg dispensed H_2 per hour was used. Thus, it was determined that 12.5 kg of accessible hydrogen should be available in storage, at any time, so that this demand can be met with hydrogen production off the grid, as required.

Other benefits of the HySTAT-A include:

- Maintenance free; pump-less electrolyte circulation
- Variable hydrogen production to adapt to airport/customer requirements
- Safe and reliable; meets applicable international codes and standards
- Convenient and easy to use – rated for outdoors with remote monitoring [4]

1.1.4.2 Compression Modules

Following hydrogen generation and purification, the compression module uses a diaphragm type pump to compress the gas from 25 barg to 430 barg. The compression pump is vital in creating the high pressures necessary to maintain the head pressure between storage and the fuel tank of the vehicle [4]. The diaphragm type compressor is selected for several reasons, namely: superior life cycle costs, flexible capacity range, high reliability, and the capability to generate higher purity levels of hydrogen, so that the gas does not come into contact with any lubricants.

The compression unit is contained with the electrolysis module to minimize footprint, and both are kept secured from public access. Pressure, temperature, and hydrogen sensors are located before and after the compression cycle, to ensure proper handling and operation of the fuelling station.

1.1.4.3 Storage Modules

Compressed hydrogen is to be kept inside hydrogen storage tanks rated for up to 450 barg of pressure. These tanks are based on Type III Carbon-wrapped aluminum tanks and are designed for pressures well above operating limits [7]. Pressure relief devices are vital in such a design to allow small amounts of hydrogen to escape if pressures obtained get too high.

Pressure readings will be used to determine hydrogen inventories and will set the criteria for generator operation. The storage modules will be operated using a cascade configuration controlled by Hydrogenics proprietary software, which is preferable for intermittent fast-fill vehicle fuelling. Benefits of using cascade storage options also include minimizing the need for large hydrogen storage and to allow for scalable dispensing pressures [4].

Along with the electrolysis and compression unit, the hydrogen storage modules are kept away from public access with a chain-link fence, and are placed in a well-lit area for security reasons.

1.1.4.4 Fuel Dispenser Modules

The experience of using a HySTAT fuel dispenser module is much like a conventional gasoline dispenser. The customers interact with the user-friendly interface on the dispenser to select a filling pressure and attach the hose to the vehicle's refuelling receptacle. The system and software within the module completes the rest of the process to inject pure hydrogen gas into the vehicle and detect when the tank is full. The customer then replaces the nozzle back unto the dispensing unit and drives away.

The fuelling modules selected will dispense hydrogen up to a pressure of 350 barg. Customers will require a unique swipe card to gain access to the devices. A fast-fill option was selected for the modules, so that a typical fuel cell vehicle will be able to fill up in as little as 2-3 minutes [4]. Flow metering, data display, and data capturing will all be available to users to allow for easy and user friendly operation.

The safety aspects of the dispensers were also analysed. Similar to a gasoline dispenser, the hydrogen dispenser units have built-in safety features in their design. For instance, nozzles have been designed specifically for hydrogen, with built-in "Capture Vent" technology, which mitigates hydrogen release when the nozzle is connected or disconnected from the vehicle, and incorporates the standard break-away feature, to ensure minimal damage in case customers accidentally drive-off with the hose still connected to the vehicle [4].

Figure 1.3: Clear Skies – 3-D Model of Proposed Refuelling Station in SC, Columbia

1.2 Green Limousines

The H2U Waterloo Student Design Team proposes the operation of a limousine service, based at the Columbia Metropolitan Airport. The idea of a limousine service has already been implemented in several airports around the world. With heavy adoption and promotion, these limousines can help mitigate air pollution by providing a clean alternative transportation choice, to and from the airport. The limousines will also support themselves economically with passenger revenues. The following section outlines the details and requirements of implementing this service.

1.2.1 Customer Model & Customer Requirements

The airport currently reports that, on average, 100 – 125 people use ground transportation to and from the airport, on a daily basis. Most of these individuals either choose to rent vehicles, or are picked up or dropped off by relatives or peers [(8)]. It is proposed to have the limousine service operate simultaneously with currently operating shuttles, taxis, rental car services, and other public transportation. The proposal assumes that the limousine service will attract 15% of the passengers commuting to and from the airport.

Luggage can be stored in the rear section of the vehicle but mainly should be stored in the trunk of the vehicle to address safety and hazard concerns. Currently, there is no provision for handicapped passengers.

1.2.2 Vehicle Support Logistics and General Considerations

The limousines will be stationed at the airport parking lot, with priority parking. The proximity to the proposed refuelling station makes it ideal for fast refilling operations. This location also allows for the greatest convenience for airport passengers to board a limousine and travel away from the airport. Upon initial implementation, the limousine service will only operate as a drop-off service, carrying passengers from the airport to selected stops in downtown Columbia. With only three limousines initially in service, the limited range is designed to allow for shorter wait times and maximized service. It is predicted that with proper marketing and appeal, the popularity of the service will grow. Depending on the rate of this growth and demand for pick-ups and delivery, the airport can consider how it will choose to expand this fleet, or broaden the range of service area for these limousines.

1.2.3 Promotion of the Service

Promotion for the limousine service will derive from inside the airport terminals. Marketing booths will be set up in high traffic areas in the airport to educate the public on hydrogen safety and raise awareness of the available limousine service. The Marketing Section strategizes on how to promote the vehicles inside the airport. The limousines will be used to increase public awareness of the CAE's efforts to found a hydrogen economy. Their exteriors will be uniquely painted with the image and slogan of the H2U Marketing poster to promote the CAE's hydrogen redesign and support for hydrogen technologies in general. The operation of these vehicles through high population areas will allow them to serve as optimal advertising vehicles outside of the airport.

1.2.4 Vehicle Selection - Honda FCX Clarity

The Green Limousine service's initial fleet will compose of three Honda FCX Claritys, Honda's new concept hydrogen fuel cell car. The FCX Clarity is made available by Honda to select industries willing to prosper in the hydrogen economy. These cars will be leased from Honda at a very affordable price. Using a hybrid fuel-cell electric powertrain, these vehicles highlight hydrogen's greatest advantage - zero emissions at the source [(9)].

There are a number of environmental and financial reasons why the Honda FCX Clarity was chosen. The car produces no emissions, minimal vibrations, almost no noise, and is extremely energy-efficient [(10)]. The FCX Clarity is a Zero Emissions Vehicle (ZEV), using hydrogen fuel cell technology. An electric powertrain minimizes the number of moving parts, resulting in minimized noise pollution. The ZEV will also have a regenerative braking system that transforms breaking energy into electrical energy for the car greatly increasing its efficiency [(10)]. The car will be leased for $ 600 / month as advertised by Honda, which is relatively inexpensive for the benefits it offers.

1.3 Internal Service Vehicles Retrofit

The Columbia Metropolitan Airport utilizes a variety of internal service vehicles serving different purposes. Mobile transportation is the largest contribution to airborne emissions such as carbon dioxide and nitrogen oxide emissions. Fortunately, hydrogen is ready to assist in the mitigation of pollutants in automotive systems.

With recent developments in technology, hydrogen can be utilized as a fuel additive to create positive results in the aspects of energy efficiency and environmental improvement. The following section details the use of a Hydrogen Fuel Injection (HFI) system to be installed on selected internal service vehicles to take advantage of what they have to offer.

1.3.1 Vehicles

Several airport vehicles were selected for hydrogen assisted retrofitting. An analysis was done on the average gas mileage, annual fuel cost, annual carbon emissions, and air pollution score of all the vehicles. From the analysis, the most inefficient vehicles, from the energy use and pollution perspective were chosen. The selected vehicles and their analysis results are summarized in Table 1.3. A complete list of maintenance and service vehicles used in the airport was not provided to the design team; therefore, these vehicles were not included in the analysis. On the other hand, given that maintenance vehicles are often diesel-powered and significant contributors to airport air emissions, it can be assumed that many of these vehicles would be suitable for hydrogen retrofitting as well. The airport should consider the inclusion of baggage tugs, belt loaders, mobile stair units, and de-icing trucks, when the data is available.

The study done looked at how much fuel, on average, the selected vehicles consume on an annual basis, assuming 45% of the driving was done around the city and 55% along highways. The average annual kilometres driven were assumed to be consistent between the different vehicles. Based on the average gas mileage and annual vehicle range, the average annual cost of fuelling the vehicle was calculated based on average fuel prices of $3.10/gallon and $3.41/gallon for gasoline and diesel respectively [11]. Studies were also done based on how much carbon, in tons, the vehicles generated per year, given its engine type, gas mileage, and vehicles range. In addition, an air pollution score was assigned based on a scale of 0-10, with 10 being the best and 0 being the worst.

Table 1.3: Selected Vehicles for Hydrogen Assisted Retrofit

	Average Miles per Gallon (mpg)	**Average Annual Fuel Cost (US$)**	**Carbon Footprint (tons/yr of CO_2)**	**Air Pollution Score (0-10)**
Fire Department Vehicles				
3x 1500 Gallon Crash Diesel Trucks	--	--	--	--
1x Rescue Truck	--	--	--	--
1x Rapid Intervention Vehicle	--	--	--	--
1x Engine	--	--	--	--
1x Trailblazer	--	--	--	--
Average	15	3320	13.1	1
Airport Police Department Vehicles				
1x Chevrolet Trail Blazer	17	2906	11.4	5
1x GMC K5 Blazer	16	3102	12.2	2
1x Ford Explorer	16	3102	12.2	2
Administration Vehicles				
3x Ford Explorers	16	3102	12.2	2
1x Honda Pilot	17	2734	10.8	6
1x Chrysler Town and Country Minivan	19	2446	9.6	6

(11)

The retro-fitting of these vehicles will involve the installation of Hy-Drive hydrogen fuel injection systems. These systems are meant to increase fuel efficiency, decrease emissions, and improve overall engine performance.

1.3.2 Hy-Drive Hydrogen Fuel Injection and Hydrogen Generation Systems

Hy-Drive Technologies Ltd. is a world leader in on-board hydrogen fuel injection and Hydrogen Generation Systems (HGS). The company specializes in the manufacturing of a hydrogen generating system which supplies hydrogen on-demand to automotive engines. The unit operates by simple electrolysis by utilizing electrical energy supplied by the battery. The end result becomes a more complete combustion process, leading to reduced maintenance costs and a significant reduction in emissions (13).

1.3.3 Benefits

1.3.3.1 Emissions Reduction

It has been known for decades that injecting hydrogen as an additive to gasoline or diesel fuel will result in reduced emissions during the combustion process. The injection of hydrogen allows for a more complete combustion process inside an internal combustion engine due to its higher flame speed and unique combustion properties. This allows for higher performance from the vehicle engine, and reduction in unwanted particulate from an incomplete burn (14). A 50 % cut of unwanted emissions can be obtained with as little as 1-2% by mass of hydrogen gas blended with conventional fuel (14) (15) (16). While it is true that a fuel cell vehicle running on pure hydrogen fuel is able to produce zero emissions during operation, a fuel cell car does not utilize hydrogen effectively to reduce harmful greenhouse gases.

The hydrogen leverage factor is a measure of the ratio between the percent emissions reduction versus the percent hydrogen energy of the fuel. It is represented by the following equation:

$$\text{Leverage Factor} = \frac{\text{Percent Emissions Reduction}}{\text{Percent Hydrogen Energy}}$$

By this definition, a fuel cell vehicle has a leverage factor of 1 (15). It is not uncommon to see vehicles with a leverage factor greater than 35 when using a Hy-Drive HGS (14) (16).

1.3.3.2 Less Maintenance

With a cleaner burn being experienced in the engine, vehicles operating with the Hy-Drive unit are less prone to engine problems and maintenance issues. The HGS is programmed to operate its first 500 hours of operation in what is called the performance mode. During this period the unit is dedicated to injecting hydrogen to remove soot, excess lubricant and unwanted particulate trapped in the engine. After these 500 hours, the engine is much cleaner than before. Although difficult to price, cost savings are expected due to the reduced maintenance required and a longer vehicle service life.

1.3.3.3 Improved Mileage

A more complete burn means that more energy is harvested by the fuel. Hydrogen blended in with fuel creates more ignition points for combustion. Hydrogen gas also has a faster flame speed creating a more rapid and complete burn. These specific characteristics allow Hy-Drive to guarantee an 8% increase in mileage [18]. The improved mileage and better performance correlate to fewer expenses on diesel or gasoline, and a more efficient energy system than a typical internal combustion engine (ICE).

1.3.3.4 Reduced Cost

With increased vehicle usage, a typical Hy-Drive unit quickly pays for itself by fuel and maintenance savings. On top of that, by leveraging the hydrogen use to reduce significant amounts of greenhouse gases, and prolonging the life of already owned vehicles, the cost to lease or own a Hy-Drive unit is easily justified. Typical fleet owners experience paybacks of the unit within 2 to 3 years and continue to operate the unit for years after the stated service life[18].

With the newly introduced Case Study Initiative promoted by Hy-Drive, there is an even greater financial incentive to pursue with the installation of these units. Section 5 discusses the economics of this program in greater detail to justify the cost of each Hy-Drive unit.

1.3.4 Installation

For the proposed application, select service vehicles operated by the airport will receive Hy-Drive's Heavy Transport System. Although these units are commonly targeted towards diesel powered fleets, they provide the same benefits to commercially available gasoline vehicles. By carefully selecting the appropriate vehicles to be retrofitted with the device, an optimum level of reduced emissions and cost benefit can be obtained.

1.3.5 Maintenance & Operation

There is very little knowledge required to maintain and operate a Hy-Drive unit. Once installed, the hydrogen generator system is put into action upon turning the engine on. The generator produces hydrogen continuously on-demand and feeds the hydrogen directly into the engine as a mixture with the fuel. The only maintenance procedure required by the driver is replenishing the cell with distilled water when the liquid level reaches a low point. This refill procedure is done with little knowledge of how the unit actually operates and can be done by reading the instructions printed on the lid of the unit. A typical refilling varies between 3 to 5 minutes and requires nothing more than distilled water and a fill tube. After a fill procedure has been completed, the unit is able to operate again immediately, and does not need to be refilled for approximately another 80 hours of operation [18].

1.4Ground Power Unit Replacement

1.4.1 Existing GPUs

Each airport has an arsenal of Ground Power Units (GPU) available at a number of locations. The main purpose of a GPU is to supply grounded airplanes with electricity so aviation fuel can be saved. Although, Auxiliary Power Units (APU) are also available on larger airplanes, GPUs are still more commonly used because of the high investment cost for APUs. The GPUs fuelled by diesel, similar to the ones used at the Columbia Metropolitan Airport, generally produce high levels of NO_x, CO_2, CO, and other harmful air emissions due to the inefficient combustion of the fuel [2]. Since the airport presently operates 8 GPUs, it would be greatly beneficial if these units were all modified or replaced to minimize the amount of pollution they generate [19]. This design proposes the replacement of the airport's GPUs with hydrogen powered units.

1.4.2 Hydrogen Fuel Cell Generators

The proposed alternative generators operate using a hydrogen fuel cell; thereby eliminating the generator's dependence on any type of petroleum-based fuels. The hydrogen powered generators offer immense reductions in air pollutant emissions. The only product released by these generators to the atmosphere is steam. The units also improve on energy efficiency, because the energy output over input of hydrogen fuelled generators are much greater than that of the diesel ones [20]. This can be seen in the assessment done in the Environmental Analysis section of the proposal. The only slight drawback in installing these alternative units is the high capital cost associated with hydrogen fuel cell generators.

Considering that only $3 million is in the project budget allowance, only one of the eight GPUs in the airport can be replaced, because of the aforementioned high capital costs. The GPU to be replaced will be the oldest or the most ineffective model currently owned by the airport, in order to maximize the emissions reduction and energy savings the new generator can offer. When there is more capital available for hydrogen applications at the airport in the future, the remaining GPUs used shall also be considered for replacement.

1.4.3 Hydrogenics HyPM HD 65 Model

The model chosen to replace one of the airport's diesel generators is the Hydrogenics HyPM HD 65 model. This unit is already commercially available and has been proven to be in compliance with Federal safety standards. It has a maximum output of 65 kW and is being used for a variety of industry applications, from replacing internal combustion engines to powering forklifts. At full load, the efficiency of the unit is rated at 55% [20]. The unit comes in several modules, which contain all the required parts for it to function as a generator.

On a full tank, the hydrogen generator can operate for up to 8 hours. Thus, it will need to be refuelled approximately once a day. For safe and convenient refuelling, a full tank's worth of hydrogen will be brought to the unit each day using a compressed gas cylinder. The compressed gas cylinder will be transported to and from the generator and the proposed hydrogen refuelling station using a cart which will be bought separately and has already been incorporated into the new GPU's system design.

2 Safety Analysis

Public safety and security are paramount concerns for any airport. After the 9/11 attacks in the United States of America, safety and security systems have been heavily scrutinized to ensure similar natured events are not repeated, so that the public's mind is put to ease. It is also known that operating a business in North America in a safe and secure manner reduces long-term costs and is a key factor in creating a harmonious and successful company. This section of the report is dedicated to addressing the issues surrounding safety and security in the proposed design.

2.1 Hydrogen Specific Concerns

Like many of today's prominently used fuels, there are several concerns and risks associated with the use of hydrogen as a fuel. Numerous studies have been conducted to examine these issues, and while it was determined that hydrogen poses a different set of risks than gasoline and natural gas, these different risks can be addressed for the safe utilization of hydrogen. Many tests also concluded that hydrogen can be used just as safely as gasoline (21). The light and buoyant properties of hydrogen make it difficult to create high enough concentrations for combustion, whereas gasoline leaks tend to build up and pool (21).

There are several valid concerns dealing with hydrogen use listed below. This is by no means an exhaustive list of concerns, but merely a sample of the issues and how they can be addressed in the H2U Waterloo Design Proposal.

2.1.1 Compressed Gases

Hydrogen is energy-dense by weight compared to other fuels; however, unlike the crude-based fuels, it is not energy-dense by volume (2). Thus, the typical storage solution for hydrogen is to store it at high pressures in compressed cylinder tanks. These tanks can store hydrogen at 450 barg; therefore, releasing this pressure in an uncontrolled environment can cause severe damage. Thus, any storage tanks for compressed gases will contain redundant pressure relief valves and be located in open areas to ensure gas pressures are controlled.

2.1.2 Pooling of Hydrogen Leakage

Hydrogen is very light by nature. When released into air, it tends to float and dissipate upwards. In confined spaces, it is crucial to have air circulation to remove any pooled hydrogen in sufficient amounts to cause an undesired explosion.

2.1.3 Less Energy Required than Gasoline to Combust

The amount of energy needed to ignite hydrogen is comparable to natural gas but is one-tenth the energy needed to ignite gasoline. To cause an explosion, three elements must be present: 1) sufficient levels of fuel, 2) an oxidizer and 3) an ignition source (5). The prevention of explosions should begin by assessing the local environments to determine what possible conditions may exist in the environment to determine if additional safety checks are warranted.

Hydrogen is not very different from other high-energy content fuels such as gasoline, natural gas, propane, or methane that are used every day. Safe handling of such a fuel depends on the knowledge of its particular physical, chemical, and thermal properties, and considerations of safe ways to accommodate those properties.

Table 2.1: Fuel Property Comparison with Hydrogen, Natural Gas and Gasoline

Characteristic Property	Hydrogen	Natural Gas	Gasoline
Lower heating value (kJ/g)	120	50	44.5
Self-ignition temperature (°C)	585	540	228-501
Flame temperature (°C)	2,045	1,875	2,200
Flammability limits in air (vol %)	4-75	5.3-15	1.0-7.6
Minimum ignition energy in air (μJ)	20	290	240
Detonability limits in air (vol %)	18-59	6.3-13.5	1.1-3.3
Theoretical explosive energy (kg TNT/m^3 gas)	2.02	7.03	44.22
Diffusion coefficient in air (cm^2/s)	0.61	0.16	0.05

(21)

2.2 Codes and Regulations

The H2U Waterloo Student Design Proposal will meet all applicable safety requirements for the design, construction and operation of the various systems and facilities that make up the integrated project.

The safety codes and regulations that apply to the proposed systems related to the production, storage, and operation of these hydrogen technologies are still in their infancy. As the hydrogen infrastructure in the USA and across the globe expands, these codes will mature. As for now, safety inspections and approvals are seen on a case-by-case basis by the embodied authority depending on the type of application and whether the system is fixed or mobile [5].

The Transportation Safety Authority (TSA), Federal Aviation Administration (FAA), and National Hydrogen Association (NHA) are the major governing boards responsible for the safety approval and regulation of operation of the proposal. With the combined expertise of all organizations, a better knowledge of hydrogen safety can be developed for best practices and future regulations.

2.3 Failure Mode and Effect Analysis

A Failure Mode and Effect Analysis (FMEA) was conducted to identify the risks involved with each hydrogen system in the proposed design. It was also used to determine the safety checks in place or preventative measures necessary for risk mitigation. The level of risk is determined numerically by calculating the risk priority score based on three criteria – frequency of occurrence, degree of severity and chance of detection or prevention. Table A.1 in Appendix A shows the results of the FMEA which was used to determine the highest risk failure modes, while Table A.2 shows the evaluation criteria and scale used to score the three criteria.

2.4 Major Failure Modes

The top four failure modes identified by the FMEA are 1) human error, 2) terrorism or deliberate vandalism, 3) external fire and 4) equipment failure. These risk priority scores amount to 405, 100, 90 and 54, respectively. These specific failure modes are discussed below and analyzed to show that inherent design features and appropriate safety checks are used to mitigate potential hazards.

2.4.1 Human Error

Human error is one of the highest relative risks associated with this project. This is a result of all the design components involving some degree of manual operation, whether it is maintenance, refuelling, or direct operation. Hydrogen cars were identified as the highest risk of failure due to human error as it is operated outside of the airport and is more interactive with the public. The probability of a vehicular accident occurring and the degree of severity is relatively high, while the chance of detection is low. This resulted in a higher risk score for operating hydrogen limousines. This risk is mitigated by a combination of inherent design features and proper driver training. Integrated design features such as isolated high voltage system, fuel cell system box and hydrogen tanks, will prevent a flash fire inside the car cabin during a collision.

2.4.2 Terrorism or Deliberate Vandalism

The United States is at a “High” threat level for all domestic and international flights due to recent acts of terrorism [22]. A hydrogen infrastructure at the airport is an added risk as it is a convenient target for terrorists due to hydrogen’s ignitable nature. The probability of a terrorist attack on the hydrogen infrastructure including the storage tank and the refuelling station is low; however, the severity is high and the chance of detection is rated as low. This mode of failure is mitigated using an “all-hazards” approach [23]. The main action is to analyze and enhance security measures such as concrete barriers and monitored fences at high-risk facilities (hydrogen tank and refuelling station). Moreover, a coordinated emergency response system with airport fire and police, and regional fire, police, and health facilities will be implemented.

2.4.3 External Fire

An external fire has the potential to cause an explosion or elevated temperatures and pressures in any hydrogen system. The possibility of its occurrence is low while its detection is high; hence, the priority risk is relatively lower than the previous two failure modes. However, the severity of this failure mode is relatively high; therefore, an appropriate response for mitigation is required. The damage from an external fire is reduced by a pre-planned and exercised execution strategy with automatic inclusion of the fire department. Preventative measures must be taken to reduce the possible ignition sources in the vicinity of the hydrogen systems. Physical barriers, fencing, and adequate signage will be used to protect these systems from avoidable risks.

2.4.4 Equipment Failure

With all operating equipment, it is probable that equipment could fail and result in burst or damage to other equipment, or cause bodily harm. Preventative measures are required in order to mitigate these risks. Routine maintenance checks, redundant control sensors, adequate design plans and certified emergency procedures are all necessary. Shut-down systems and backup modes should be implemented to prevent being caught off-guard in a severe situation.

Though, some of these concerns are not hydrogen specific, and most are major failure modes found commonly in any system design. The identification of the risks imposed by these hydrogen technologies and the design safety features in place to mitigate them are important to develop a safe and effective overall design.

3 Environmental Analysis

The request for proposal calls for designs and applications aimed specifically at reducing pollution generated at the Columbia Metropolitan Airport. Hence, the design is rooted in incorporating hydrogen technologies that promote the preservation of the environment. The main environmental considerations integrated in the design are the operation of environmentally friendly technologies, reduction of greenhouse gas emissions, compliance with international environmental regulations, and promotion of public health and safety.

3.1 Analysis Methods and Assumptions

To accurately estimate the environmental effect caused by the H2U Waterloo Student Design Team's proposal, several analysis methods were performed. For air pollution, comparison studies were performed by collecting data regarding the emissions of currently operated technologies and comparing them with the proposed design applications.

With the comparison studies, the annual CO_2 eq. diverted per year by switching from the old method to the new one, for each application, was summed to arrive at the total projected annual CO_2 eq. diverted per year for the entire design. This annual amount of CO_2 diverted is equivalent to the air pollution reduction brought about by the re-design. A similar comparison study was also done to determine the projected decrease in noise pollution. The indirect effect on the amount of water pollution produced by the airport was considered as well. Life Cycle Assessments (LCA) compared the overall changes in well-to-wheels efficiencies brought about by using hydrogen, compared to other conventional fuels shown in Appendix A.

3.2 Types of Pollution

3.2.1 Impact on Air Pollution

The following sections will discuss each application in the proposal and describe its ability to reduce harmful air emissions, particularly, NO_x, CO_2, CO, hydrocarbons (HC) and particulate matter (PM). These emissions are generally tied to the greenhouse effect and ozone depletion which are both precursors to climate instability.

3.2.1.1 Refuelling Station

Construction of a local refuelling station to generate hydrogen eliminates the need to purchase and transport hydrogen from an outside supplier. The impact of not constructing a local electrolysing station to supply the proposed hydrogen requirements in this proposal was considered.

In terms of air pollution reductions, emissions are reduced by not requiring transport vehicles to deliver or distribute the hydrogen supply. With on-demand generation of hydrogen and proper storage algorithms, hydrogen can be used adequately without the need of conforming to supplier delivery schedules. Such operations can lead to wasted hydrogen and in turn, a greater emission rate per kg of H_2.

In the best case scenario, electricity is generated through nuclear power or through renewable sources such as wind or solar power. By generating electricity where no carbon is burned into the atmosphere, it is possible to achieve a zero emission well-to-wheel cycle thereby reducing 100% of vehicular pollution. In reality, the electricity received off the grid is a combination of a variety of sources and is considered in the worst case scenario. Table 3.1 reveals these cases at a maximum production of hydrogen by the refuelling station. The test cases neglect transportation of hydrogen and consider only gaseous compressed hydrogen.

Table 3.1: Lifecycle CO_2 Generation for Different Hydrogen Production Methods

Hydrogen Production Method	kg of CO_2 Emitted / kg of H_2 Produced	CO_2 Projected Generation Based on Maximum H_2 Production (661,38 kg H_2/year)
Steam Methane Reformation (SMR)	8.9 (25)	588,628.2 kg CO_2
Coal Gasification	12.4 (25)	820,111.2 kg CO_2
Electrolysis using Nuclear Power [1]	0.05227 (26) (27)	3,457.033 kg CO_2
Electrolysis using Renewable Energy Source (i.e. Wind Power) [2]	0	0 kg CO_2

1. EMISSIONS ARE GENERATED DURING MINING AND TRANSPORTATION. EMISSIONS PRODUCED DURING PLANT CONSTRUCTION WERE NOT TAKEN INTO ACCOUNT.
2. WIND TURBINES DO NOT DIRECTLY GENERATE AIR POLLUTION, BUT THE PROCESS OF MAKING THEM AND TRANSPORTING THE ENERGY DOES WHICH WERE NOT TAKEN INTO ACCOUNT.

Based on the results from Table 3.1, and considering electricity from only nuclear sources, by using the proposed hydrogen generating system, the CAE will be able to divert up to 817 tons of CO_2 annually while operating at maximum capacity.

3.2.1.2 Limousine Service

It is estimated that on average 100 - 125 people per day utilize ground transportation when travelling to or from the Columbia Metropolitan Airport. Assuming that each person would normally arrive at or leave the airport in a conventional gasoline fuelled vehicle, an estimate of the daily air emissions by these vehicle users can be specified. By further claiming that roughly 15% of those individuals utilize the limousine service proposed to travel downtown from the airport, an attempt to quantify the reduced emissions in one year was made.

Table 3.2: Emissions at the Source Diverted per Year by One Green Limousine

Trip Distance (One way)	10 (miles)	**Average CO_2 Emissions by ICE**	0.4147 (kg CO_2/mile)
Frequency	18 (people/day)	**Average CO_2 Emission by Honda FCX Clarity**	0 (kg CO_2/mile)
Diverted CO_2 Emissions by One Limousine	27,245.79 (kg CO_2/year)		

The calculations made in Table 3.2 show that by the outlined projection, nearly 28,000 kg CO_2 will be diverted per vehicle per year. By accepting a fleet of three zero-emission-vehicles (ZEV) as limousines, the airport will be diverting nearly 82 tons of CO_2 per year.

3.2.1.3 Internal Service Vehicles Retrofit

Both simulations and experiments reported in the literature agree in that a significant fuel reduction is obtained from hydrogen addition. Besides the increase in engine efficiency due to the effect of hydrogen injection, harmful air emissions are significantly reduced including reductions in unburned hydrocarbons, nitrogen oxides, carbon monoxide, carbon soot and particulate matter. Carbon (in the form of soot), carbon monoxide, unburned hydrocarbons and nitrogen oxides are all heavy contributors to industrial produced smog which has adverse health implications especially on the respiratory system. Smog can inflame breathing passages and effects both adults and children with heart and lung conditions such as emphysema, asthma and bronchitis.

Many of the emissions produced by automotive vehicles are also contributors to the greenhouse effect. Carbon dioxide and nitrous oxide are typical examples of these greenhouse gases. The Hy-Drive unit produces varying effects upon different engines, however typical results seen specify 10- 20% reduction in NO_x with some cases reporting 50% reductions in NO_x emissions.

Below, in Table 3.3, two studies are shown with the results of the emission reductions of the Hy-Drive unit.

Table 3.3: Two Studies Reporting Emission Reductions with Hy-Drive HGS system

Study	SAE Report	CEE Analysis
Emissions Reductions	PM - 60% CO - 30% NO_x - 19 %	HC - 74.5% CO - 14.6% NO_x - 11.1% PM - 81.4 %

Although the HFI system is actually a promoter of CO_2 production inside the engine, by allowing for more complete combustion, the net overall effect is a reduction in spent carbon being released into the atmosphere. This is due to the reduction in inefficiencies seen coming out the exhaust gas and less fuel consumption in Hy-Drive fitted vehicles.

Hy-Drive's HFI system reduces harmful emissions, reduces fuel consumption and on top of that extends the service life of Hy-Drive installed vehicles. This can be seen as an environmental benefit. Vehicles will run for longer lifetimes before scrapping, producing less waste through the production and disposal of fewer replaced engines and vehicles.

As a rough estimate, nearly 1.86 tons of harmful emissions are diverted per vehicle per year using the HGS. This number was obtained by assuming a thirty percent reduction in emissions and operating a vehicle for only 2 hours a day. Hy-Drive reports that frequent drivers can divert as much as 16 tons of greenhouse gases per vehicle a year.

3.2.1.4 Ground Power Unit Replacement

GPUs are heavily relied upon to provide electrical power to grounded airplanes. By using a HyPM HD 65 as a GPU, there will be zero emissions at the source. Table 3.4 illustrates a comparison of the efficiencies and emissions between the HyPM HD 65 generator with an equivalent diesel generator.

Table 3.4: Diesel and Hydrogen Powered Generator Comparison

	Efficiency at Full Load (%)	Emissions (kg / hr)
Diesel GPU	40%	1.56 CO_2 + 0.042 NO_x
HyPM 65 GPU	55%	0
Savings	15%	1.56 CO_2 + 0.042 NO_x

At the CAE, GPUs are used on average for about 6 hours per day. By running an emission-less generator in place of a diesel generator, a significant amount of emissions are diverted, nearly 3,500 kg CO_2 per year.

3.2.2 Impact on Noise Pollution

3.2.2.1 Limousine Service

The Honda FCX Clarity uses a hybrid fuel cell-electric powertrain, and contains few moving parts compared to a conventional internal combustion engine. The FCX Clarity operates with minimal vibrations, and is virtually silent during idle operation.

While driving the FCX, there are some increases in noise, due to the wheels and drivetrain motion. There is a peak in noise levels heard from a FCX when cruising on the highway (70 mph) which reaches approximately 71 dB from 7.5 metres. This is comparable to a Ford Crown Victoria at similar driving conditions.

3.2.2.2 Ground Power Unit Replacement

Similar to the Honda FCX vehicles, the GPU is run by a fuel cell which is completely silent during operation. The generator selected, the HyPM HD 65 GPU produces minimal noise which is caused by a heat sink fan to moderate temperatures inside the fuel cell GPU. Compared to a diesel powered GPU with the same power rating, differences in noise level can be easily seen and are summarized in Table 3.5.

Table 3.5: Noise Levels Produced by Diesel and HyPM 65 GPU from 1 m

	Measured Noise Level at Full Load (dB)	**Distance Associated with Noise Measurement (m)**
Diesel GPU	85	1
HyPM HD 65 GPU	18	1

The significant reduction in noise levels will be appreciated by airport staff and workers while working with or near these power units. Working around loud sounds poses a potential health risk to the inner ear. By reducing the noise, a more healthy and enjoyable atmosphere is created.

3.2.3 Impact on Water Pollution

The Columbia Metropolitan Airport uses many diesel-powered vehicles. Though burning diesel does not directly affect water pollution, gasoline and lubricant leaks are a direct source of water contamination. As well the sulphur, nitrogen, and carbon compound emissions of these vehicles contribute to the formation of acid rain, which also significantly contributes to water pollution. Hence, a significant portion of the design is based on adopting the use of hydrogen vehicles in the airport and hydrogen retro-fitting existing vehicles. This is meant to greatly reduce the amount of gas leaks and air pollutant emissions that consequently cause water contamination.

4 Marketing and Business Plan

A good understanding of the benefits and safety measures of hydrogen applications is vital to their acceptance in the Columbia Metropolitan Airport. Fear and confusion are natural reactions to new technology. Hence, a public education and awareness program is necessary to mitigate concerns and promote acceptance of hydrogen technologies by helping the public understand how they are safe and beneficial to the environment.

4.1 Message

There are three key points to the message that the education program will be focused on. The goal is to address public concerns and to promote the benefits of hydrogen applications. The key points are:

1) Hydrogen technologies are safe
2) Hydrogen technologies can reduce pollution and inefficiencies
3) Hydrogen technologies are the way of the future

4.2 Audience

The main audience is the CAE travelers. These travelers come from all over the world. Thus, communicating the message to them will be most effective and beneficial. They will also be the most apprehensive towards hydrogen applications at the CAE. It is vital to communicate to them that hydrogen is innovative, safe, and beneficial.

The secondary audience will be elementary and high school children since they are the voice of the future. Educating them on the benefits of hydrogen early on will encourage them to develop hydrogen technologies and support sustainable development. Also, children can pass the hydrogen message on to others best because of their enthusiasm.

4.3 Marketing Strategy

4.3.1 Product

The “Green Limousines” will be the most advertised element to the public since this service will be available to the main audience of airport travelers. The educational program will also emphasize the safety measures and benefits provided by the hydrogen refuelling station, generator and retrofitted vehicles at the CAE to underscore how hydrogen technologies are safe and make the world a cleaner and better place.

4.3.2 Place

Within the airport, marketing will be centred at a main exhibit next to the ticketing or baggage area. The installation will comprise of three main stations, each focusing on a key point of the message. Each station will comprise of a video stand, an educational walkway, and a “personal tour guide”. The video stand will continuously play a short, entertaining, educational video on one of the key points. For example, the “Hydrogen Technology is Safe” booth will have a video highlighting the safety features in the airport’s hydrogen refuelling station, generator and retrofitted vehicles. The video stands at each station will each have a rack with 5 headsets that allow for audio to be toggled between different languages. The educational walkway will comprise of boards with educational posters, outlining the key point and illustrating it through pictures of the applications at the CAE. Finally, the “personal tour guide” will guide people through each station and answer any questions or concerns they may have about hydrogen and hydrogen technologies.

Aside from the main installation, booths will also be located beside stores, food shops, gates and other high traffic areas along the terminals. Each booth will comprise of a video stand playing the three videos on repeat, and a multi-language headset rack. Posters will also be placed throughout the CAE and a banner will be hung on its Northwest wall, facing the roads. Also, the main poster's image will be painted on the "Green Limousines".

Hydrogen talks will also be done at the elementary and high schools of Columbia in order to promote the key points of the hydrogen message among children and teenagers and show them how the CAE has implemented hydrogen technology and the pollution reductions, and energy and fuels savings. Educating the children on the benefits of hydrogen and how they are already safely used in local places will make them more supportive and less apprehensive to hydrogen and hydrogen technologies.

4.3.3 Promotion

The main poster for the program is meant to generate interest and promote a positive image for hydrogen. The slogan, "Clear Skies", denotes the safe and beautiful environment, and promising prospects offered by hydrogen applications. The visuals allude to the CAE and its investment in a better future through its hydrogen redesign.

The poster will be positioned all over the airport and its image will be on a banner that will be hung on the Northwest wall. As well, the same image will be painted on the "Green Limousines." Since they will be travelling throughout Columbia, this will allow for the most efficient way of promoting hydrogen technologies to CAE travellers. While in the "Green Limousines" they will also be provided with hydrogen brochures that will contain the same messages and pictures presented in the airport's main hydrogen exhibit to show how the CAE's hydrogen re-design is safe, beneficial and an investment in the future.

A massive media blitz is not planned. Since the main audience is airport commuters, it was decided that getting the message to them would be most effectively done through the stands and exhibit within the airport. It is also predicted that many South Carolina residents would not go out of their way to drive to the airport just to see hydrogen equipment. The best promotional point to the public is the story of the airport's hydrogen redesign, and the prospective improvement in efficiencies and reduction in pollution it will provide. This story can best be promoted by local media and news outlets. Thus, there will be a press release to notify them of the CAE's hydrogen re-design once all the applications and the main exhibit have been installed. This will encourage the media and news outlets to do a story on the CAE's hydrogen re-design. This strategy is meant to minimize unnecessary costs while maximizing the effect and reach of the program.

4.3.4 Price

The capital cost for the marketing and educational program will be approximately $88,450 with annual operating costs of $31,500 for equipment upkeep and salary for the marketing co-ordinator. This cost does not include the salaries for the exhibit "tour guides" and school talk speakers because they are to comprise of hydrogen advocator volunteers.

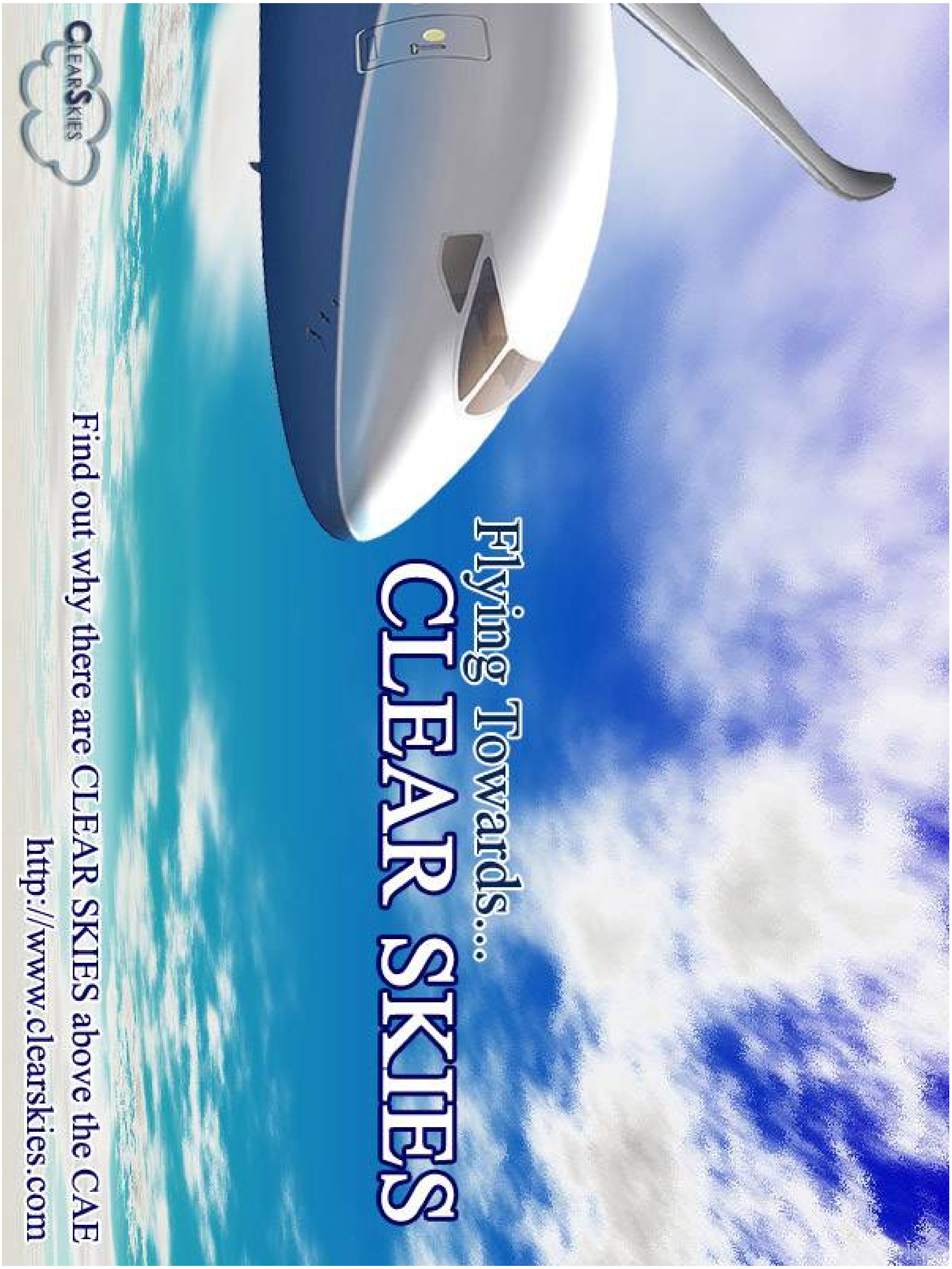

Figure 4.1: 1-Page Marketing Ad

5 Economic Analysis

5.1 Initial Investment

An initial investment of $2.75 million will be required in 2009 to implement the H2U Waterloo design plan. The main component of this initial investment is the full-scale electrolyser and refuelling station, built to serve various hydrogen-powered airport vehicles and public customers.

The cost estimate for the HySTAT-A refuelling station was provided by Hydrogenics to be $1.96 million and another $0.15 million for installation and construction [24].

The other major initial investment is the purchase of a heavy-duty Hydrogenics HyPM HD 65 fuel cell module to replace a conventional diesel-powered GPU.

A summary of the initial costs are displayed in Table 5.1.

Table 4.1: Initial Investment Schedule for Start-up in 2009

Initial Startup Costs	**(in US$)**
Hydrogen Infrastructure	
Hydrogenics HY-STAT A refuelling station[25]	
Electrolyser, tank, compressor, dispensers	1,955,500
Fencing, lighting, safety systems, security systems	160,000
Installation	145,000
Paving, clearing, approvals, administrative	75,000
Spare parts	35,000
GPU Replacement	
Hydrogenics HyPM 65 fuel cell power module[38]	279,000
Compressed tank / cart	4,000
Scrap revenue from diesel GPU	- 300
Hy-Drive unit installations (15 units)[37]	6,000
Limousine service licensing (3 vehicles)	6,000
Marketing	
Vehicle painting (3 vehicles)	30,000
Display exhibits (9 LCD screens, 45 headsets)	9,470
Display boards (12)	480
Video production (3 promotional videos)	36,000
Signage	10,000
Training	2,500
Total capital expenditures at start-up in 2009	**2,753,650**

5.2 Revenues and Expenses

The H2U Waterloo proposal is designed to sustain itself economically, as much as possible, by minimizing additional monthly expenses to the airport. The following sections detail the economic analysis associated with each hydrogen application. Table 5.2 is a statement of revenues and expenses for the refuelling station. Table A.3 to A.5 are listed in the Appendix with a breakdown of the economic revenues and expenses for the remaining hydrogen technologies.

5.2.1 Electrolyser and Refuelling Station

The electrolyser and refuelling station is the backbone of the H2U Waterloo design. It will generate hydrogen via electrolysis using off-peak electricity supplied by the South Carolina Electric & Gas (SCE&G) Company at a cost of $0.03168/kWh [6]. The hydrogen will be used to refuel the Green Limousine fleet, the fuel cell-powered GPU, and eventually, public customers.

The H2U Waterloo Design Team is confident that by 2009, fuel cell vehicles will be operated by members of the public community in Columbia, South Carolina, and that there will be a growing demand for hydrogen fuel. The refuelling station will be of significant value to the hydrogen sector near Columbia, South Carolina. The design expects to sell approximately 900 kg of hydrogen per month in 2009 at $5 per kg, generating $54,000 for that year. Hydrogen sales are expected to increase until 2013, when the refuelling station at the airport will be at maximum capacity, serving 2250 kg per month to public customers, while supporting airport vehicle fleets running on hydrogen.

Table 4.2: Statement of Revenues and Expenses for Refuelling Station, Year 2009 - 2013

Revenues	2009	2010	2011	2012	2013
Hydrogen sales to public[1]	54,000	64,800	81,000	102,600	135,000
Total Revenues	**54,000**	**64,800**	**81,000**	**102,600**	**135,000**
Expenses					
Regular maintenance (garbage, snow inspection)	6,000	6,000	6,000	6,000	6,000
Technical maintenance of equipment[25]	30,000	30,000	30,000	30,000	30,000
Electrical power demand charge[3]	9,504	9,504	9,504	9,504	9,504
Electrolysis cost for hydrogen for public sales[4]	22,239	26,687	33,359	42,255	55,598
Total Expenses	**61,743**	**66,191**	**72,863**	**81,759**	**95,102**
Net Income/Loss	**- 7,743**	**- 1,391**	**8,137**	**20,841**	**39,898**

1 Based on sales of 30 kg/day sales in 2009, steadily increasing to 75 kg/day, and $5/kg pricing.
2 Based on increased power demand of 180 kW * $4.40/kW, quoted by South Carolina Electric & Gas Company.
3 Based on 65 kWh to produce 1 kg of hydrogen with HySTAT A system, and $0.03168 / kWh for off-peak power.

5.2.2 Fleet of 3 Green Limousines

The H2U Waterloo Design Team proposal expects to lease 3 Honda FCX Claritys, for an advertised $600 per month from Honda. Honda will also include maintenance for the vehicles in the lease cost. Upon lease, it is expected that the CAE will apply for government green car rebates or similar funding initiatives.

To offset the leasing costs of the FCX Clarity vehicles, they will be aggressively marketed as the airport's Green Limousines to travellers coming through the Columbia Metropolitan Airport. It is projected that 15% of the 100 to 125 daily ground transportation users will ride the Green Limousines, averaging 14 miles per trip (round trip distance from airport to downtown). Pricing is established to be $15 for one person or $10 per person for multiple passenger trips. These pricings were determined by comparing competitors' rates [25].

The wages for the Green Limousine drivers were estimated to be $30,000 per year, totalling to $90,000 per year spent on the drivers for three limousines.

5.2.3 Fuel Cell-Powered GPU

The proposed fuel cell-powered GPU will generate savings in fuel costs due to the rapid increase in oil and gas prices. It is assumed that the cost of diesel will go up steadily by US$ 0.36 / gallon per year until 2013. By using electricity from SCE&G to produce hydrogen fuel, it is determined that operating a hydrogen GPU would be more cost-effective than a diesel GPU.

5.2.4 Hy-Drive Hydrogen Generating Systems

Hy-Drive units are hydrogen fuel injection units that provide cost savings in fuel and engine maintenance by increasing mileage and facilitating a cleaner burn. They can be leased for $349/month for 3 years [26]. They are guaranteed by Hy-Drive to increase the mileage of vehicles by 8% or more, leading to a 7.4% savings in fuel [18].

It is proposed that all 15 internal service vehicles be equipped with a Hy-Drive unit. However, with better data, Hy-Drive units would be installed only on vehicles more frequently used to result in higher profitability for each unit.

Hy-Drive Technologies Ltd. is currently promoting Hy-Drive's Case Study Initiative. The offer involves utilization of wireless Hy-Link technology to collect data of the vehicles installed with their HGS system. Data collected through Hy-Link includes vehicle emissions, fuel intake, driver mileage, and driving patterns both before and after the installation of the HFI system. The data is used to improve the performance of the Hy-Drive unit for the particular vehicle it is installed on. As a result, Hy-Drive will pay $CDN 500 a month for each qualified vehicle involved in the study. With this financial incentive, there is a potential savings for the CAE. With 15 vehicles selected for retrofit at $500 dollars a month, this brings about a potential savings of $CDN 7,500 a month or $CDN 90,000 a year to CAE if all vehicles are qualified to participate. By getting involved with Hy-Drive Case Study Initiative, not only will there be a financial incentive, but the airport will be assisting in the development of advanced hydrogen fuel injection technology.

5.2.5 Total Summary Revenues and Expenses for 5 Years

Table 4.3: Summary Statement of Revenue and Expenses for the Year 2009 - 2013

Revenues	**2009**	**2010**	**2011**	**2012**	**2013**
Sale of hydrogen to public	54,000	64,800	81,000	102,600	135,000
Taxi service fees	81,000	89,100	103,680	112,320	120,960
GPU cost savings	38,060	39,790	41,510	43,230	44,960
Hy-Drive cost savings	11,650	12,490	13,320	14,160	15,000
Total Revenues	**184,710**	**206,180**	**239,510**	**272,310**	**315,920**
Expenses					
Electricity for hydrogen production					
Sales to public	22,240	26,690	33,360	42,250	55,600
Green Limosine fleet consumption	2,160	2,380	2,590	2,810	3,030
Fuel cell-powered GPU consumption	11,120	11,120	11,120	11,120	11,120
Electricity cost subtotal	35,520	40,190	47,070	56,180	69,750
Leasing					
3 FCX Clarities (incl. maintenance)	21,600	21,600	21,600	21,600	21,600
15 Hy-Drive units	62,820	62,820	62,820	-	-
Leasing subtotal	84,420	84,420	84,420	21,600	21,600
Wages for Green Limosine drivers	90,000	90,000	90,000	90,000	90,000
Refuelling station expenses	39,500	39,500	39,500	39,500	39,500
Marketing expenses[1]	31,500	31,500	31,500	31,500	31,500
Miscellaneous expenses	66,600	66,600	66,600	66,600	66,600
Total Expenses	**347,540**	**352,210**	**359,090**	**305,380**	**318,950**
Net Income/Loss	**- 162,830**	**- 146,030**	**- 119,580**	**- 33,070**	**- 3,030**

1. Educational staff, and equipment upkeep.

For the first year, 2009, the H2U Waterloo design will run at a deficit of $162,830, (not including the initial investment). However, with expected increases in Green Limousine ridership, sales of hydrogen to the public, cost savings from the GPU and Hy-Drive units, the H2U Waterloo design will only cost the airport $3,030 in 2013, and will provide a sustainable income in further years.

It should be noted that insurance and depreciation costs were not evaluated into the economic analysis done because there was insufficient data available, when the proposal was drafted. The service lives, depreciation rates and insurance costs of the different hydrogen technologies were unknown for the proposed systems in the redesign. As well, all maintenance costs for the various hydrogen systems proposed were based on estimates instead exact quotes.

6 References

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A Appendix

Table A.1: Failure Mode Effect and Analysis on Proposed Design

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Equipment	**Mode of Failure**	**Cause of Failure**	**Effect of Failure**	**Frequency of Occurrence (1-10)**	**Degree of Severity (1-10)**	**Chance of Detection /Prevention (1-10)**	**Risk Priority (1-1000) [5] x [6] x [7]**	**Design Action**
Hydrogen Storage Tank	Hydrogen Release	Leaks from Damaged Tank, Tubing or Pipe	Hydrogen Ignition	3	4	2	24	Hydrogen Sensors, Routine Inspections
	Equipment Failure	Tank Rupture due to Issues with High Pressure Relief Valve	Hydrogen Ignition	3	4	1	12	Routine Relief Valve Inspections
	External Fire	Tank Rupture due to Fire or Hot Ambient Temperature	Hydrogen Ignition	1	4	8	32	Temperature Sensor and Sprinkler System
	Projectile of Hydrogen Cylinder	Improper Transportation of Cylinder	Injuries to Human or Damages to other Equipments	1	6	1	6	SOPs and Training
	Terrorism or Deliberate Vandalism	Lack of Security	Hydorgen Fire Leading to Human Injuries	1	10	10	**100**	Storage Tank is Protected by a Fence with Regular Monitoring
Hydrogen Cars	Human Error	Traffic Accident could cause Storage Tank to Break and Hydrogen to Ignite	Hydrogen Ignition Leading to Human Injuries or Damages to Surrounding Environment	5	9	9	**405**	Driver Training and Hydrogen Storage Tank is Designed to Withstand Collision
	Equipment Failure	Storage Tank Rupture due to Issues with High Pressure Relief Valve. could cause Hydrogen to Ignite in the Vehicle Engine	Injuries to Human or Damages to Surrounding Environment	3	9	2	**54**	Routine Relief Valve Inspections
	External Fire	Storage Tank Rupture due to Fire could cause Hydrogen to Ignite in the Vehicle Engine	Injuries to Human or Damages to Surrounding Environment	1	8	5	40	Hydrogen Storage Tank is Designed to Withstand Fire
	Hydrogen Inhalation	Leaks from Damaged Storage Tank into Bus	Difficulty Breathing because H_2 Displaces O_2	3	1	1	3	Hydrogen Sensor and Routine Inspections of the Tank
Hydrogen Internal Vehicles	Human Error	Accident could cause Storage Tank to Break and Hydrogen to Ignite	Flash Fire Leading to Employee Injuries	4	5	2	40	SOPs and Certification
	Human Error	Collision with an Aircraft cause Hydrogen to be Ignited and Fire will be Transferred to the Aircraft	Flash Fire, Aircraft damage, Civilian Injuries and/or Fatalities	1	10	1	10	SOPs and Certification
	Hydrogen Inhalation	Leak from a Damaged Hydrogen Tank on a Vehicle to Parking Hangar	Difficulty Breathing because H_2 Displaces O_2	3	4	1	12	Routine Inspections
Hydrogen Ground Power Unit	Hydrogen Release	Leak from the damaged tank	Hydrogen Ignition	3	4	2	24	Routine Inspections
Hydrogen Refueling Station	Frozen Pipes And Pipe Blockages	Moisture Accumulation	Pipe Damage And Possible Hydrogen Release	1	5	4	20	Install a sensor to monitor moisture content in the pipe after compression
	External Fire	Fire could cause Hydrogen to Ignite	Human Injuries and Damage to Public Property	2	9	5	**90**	Temperature Sensor and Sprinkler System

Table A.2: Scoring Data Criteria for FMEA

Column/Value	1	2	3	4	5	6	7	8	9	10
[5]. Frequency (per # years)	<2	4	6	8	10	12	14	16	18	>20
[6]. Severity for Airport/Customers	Minor Maintenance Work			Major Maintenance Work /Complains from Customer			Flight Delay /Injuries to Customers			Airport Shutdown /Evacuation /Fatality
[7]. Probability of Detection/Prevention	Certain				Possible					None

Table A.3: Statement of Revenues and Expenses for Hy-Drive Units, Year 2009 – 2013

	2009	2010	2011	2012	2013
Revenues					
Fuel (gasoline/diesel) costs saved[1]	8,649	9,486	10,323	11,160	11,997
Maintenance costs saved[2]	3,000	3,000	3,000	3,000	3,000
Total Revenues	**11,649**	**12,486**	**13,323**	**14,160**	**14,997**
Expenses					
Leasing and installation of 15 Hy-Drive units[3]	62,820	62,820	62,820	-	-
Total Expenses	**62,820**	**62,820**	**62,820**	**-**	**-**
Net Income/Loss	**- 51,171**	**- 50,334**	**- 49,497**	**14,160**	**14,997**

1. Based on Hy-Drive guaranteed 8% increase in mileage, and assumed diesel prices of $4/gal in 2009, steadily increasing to $4.8/gal in 2013.
2. Based on guaranteed $200/year savings per unit.
3. As quoted by Hy-Drive.

Table A.4: Statement of Revenues and Expenses for GPU, Year 2009 - 2013

	2009	2010	2011	2012	2013
Revenues					
Diesel costs saved[1]	34,464	36,187	37,910	39,634	41,357
Maintenance costs saved	3,600	3,600	3,600	3,600	3,600
Total Revenues	**38,064**	**39,787**	**41,510**	**43,234**	**44,957**
Expenses					
Maintenance costs	3,600	3,600	3,600	3,600	3,600
Electrolysis costs for hydrogen fuel[2]	11,120	11,120	11,120	11,120	11,120
Total Expenses	**14,720**	**14,720**	**14,720**	**14,720**	**14,720**
Net Income/Loss	**23,344**	**25,068**	**26,791**	**28,514**	**30,237**

1. Based on 718 gallons of diesel consumption/month, and assumed diesel prices of $4/gal in 2009, steadily increasing to $4.8/gal in 2013.
2. Based on 65 kWh of electricity to produce 1 kg of hydrogen with HySTAT A system, * $0.03168 / kWh for off-peak power.

Table A.5: Statement of Revenues and Expenses for Green Limousines, Year 2009 - 2013

	2009	2010	2011	2012	2013
Revenues					
Taxi service fees[1]	81,000	89,100	103,680	112,320	120,960
Total Revenues	**81,000**	**89,100**	**103,680**	**112,320**	**120,960**
Expenses					
FCX Clarities leasing and maintenance from Honda[2]	21,600	21,600	21,600	21,600	21,600
Insurance	63,000	63,000	63,000	63,000	63,000
Electrolysis costs for hydrogen fuel[3]	2,162	2,378	2,595	2,811	3,027
Wages for 3 drivers	90,000	90,000	90,000	90,000	90,000
Total Expenses	**176,762**	**176,978**	**177,195**	**177,411**	**177,627**
Net Income/Loss	**- 95,762**	**- 87,878**	**- 73,515**	**- 65,091**	**- 56,667**

1. Based on 5 trips/day/vehicle in 2009, steadily increasing to 7 trips/day/vehicle in 2013, and $15 per trip pricing.
2. As quoted by Honda website.
3. Based on 65 kWh of electricity to produce 1 kg of hydrogen with HySTAT A system, * $0.03168 / kWh for off-peak power.

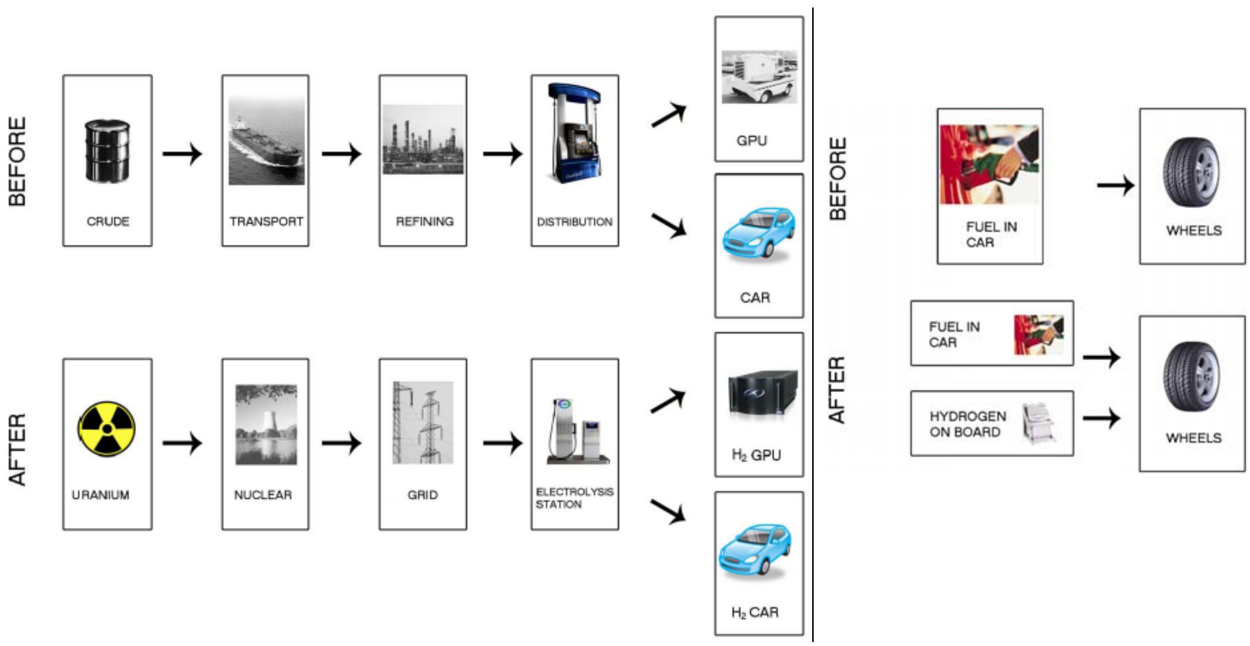

Figure A.1: Energy Flow Diagram Before and After Implementation of Proposed Design

RACEMASTER
AUTOMOTIVE
Service & Parts

February 18, 1998

To Whom It May Concern;

Re: 610 Hydrogen Generator on 1996 Dodge Ram 1500 V/8

From the beginning, in January 1997, the truck itself was only getting between 5-8 M.P.G. in the city and 15.29 M.P.G. on the highway. After 10,000 km on the truck, the mileage went up to 11.8 M.P.G. in the city and 18.92 M.P.G. on the highway. Since having the generator on and marking the difference, it was totally impressive. Not only did this generator cut back the pollutants in the truck to zero, the horsepower increase and throttle reponse were very noticable. As well, there is little to no residue in the tailpipe. I now have 20,000 km on the truck, and have made numerous trips on the highway and the truck is used daily for the business.

The fuel mileage now recorded is 15.96 M.P.G. in the city and 28.75 M.P.G. (average) on the highway. The mileage increase noted is 35.3% city, and 52.0% on the highway. If I may Also note, the pulling power and the passing power have also shown an increase with the generator on. With very little pressure on the gas pedal, an immediate response from the engine is noticed.

I am so impressed with this system, that I am planning on installing one on our race car, to reduce the emissions and, not to mention increase the horsepower.

Sincerely,

Rodney J. Cusiac
President

Figure A.2: Hy-Drive HGS Testimonial

Table A.6: H2U Waterloo Design Proposal Summary Data Sheet

Section		Description	Data
1.1	**Refuelling Station**		
1.1.1		Refuelling Station Location	Intersection of Airport Commerce Drive & Airport Commerce Drive in SC, Columbia
		Refuelling Station Lot Size	1,255 m^2
1.1.4.1		Hydrogen Production Method	Off-Grid Electrolysis
		Maximum Hydrogen Production (Off-Peak)	105.7 kg/day
		Maximum Hydrogen Production (With On-Peak)	181.2 kg/day
		Electricity Consumption	~ 65kWh/kg of H_2
		Hydrogen Purity	> 99.9995%
1.1.4.2		Storage Pressure of Hydrogen	430 barg
1.1.4.4		Dispensing Pressure of Hydrogen	350 barg
		Fill Time	2-3 minutes
1.2	**Green Limousines**		
1.2.1		Customer Model	18 people/day
1.2.4		Vehicle Model	Honda FCX Clarity
		Vehicle Type	H_2 FCV
		Fleet Volume	3
		Fuel Requirements	3x 1.32 kg/day = 4 kg/day
1.3	**Service Vehicles**		
1.3.1		# of Vehicles for Retrofit	15
1.3.2		On-Board HGS Manufacturer	Hy-Drive Technologies Ltd.
1.4	**GPU Replacement**		
		Replaced Unit	Diesel generator 65kW or equivalent
1.4.3		Hydrogen GPU Manufacturer	Hydrogenics Corporation
		Hydrogen GPU Model	HyPM HD 65
		Output Power Rating	65 kW
		Fuel Requirements	24 kg/day
3	**Environmental**		
3.2.1.1		CO_2 Diverted by Refuelling Station	up to 817 tons of CO_2/year
3.2.1.2		CO_2 Diverted by Limousines	82 tons CO_2/year
3.2.1.3		GHG Diverted by Hy-Drive Retrofit	27.9 tons GHG/year
3.2.1.4		CO_2 Diverted by GPU Replacement	3,500 kg CO_2/year
5	**Economics**		
5.1		Initial Capital Investment	$US 2,753,650.00
5.2		Electricity Costs	$US 0.03168/kWh
		Hydrogen Selling Price	$US 5.00/kg
		Net Income (2009)	- $US 162,830.00
		Net Income (2013)	- $US 3,030.00