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HYDROGEN APPLICATIONS FOR

LAMBERT- ST.LOUIS INTERNATIONAL AIRPORT

by

MATHEW THOMAS

A THESIS

Presented to the Faculty of the Graduate School of the

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

2009

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ABSTRACT

Today, major airports are facing challenges related to pollution, energy efficiency, and safety and security. Hydrogen and fuel cell technologies, regarded as one of the key energy solutions of the 21^{st} century are more energy efficient and reliable than conventional systems and have the potential to diminish these challenges. These technologies can also play a significant role in reducing the noise, air, and water pollution and enhancing energy security. This paper presents the design of a set of hydrogen technologies and systems that are commercially available and are ready for practical, real-world use.

The hydrogen applications selected for Lambert-St. Louis Airport include a hydrogen fueling station, back-up and auxiliary power systems, portable emergency power, light-duty vehicle applications, and a stand-alone system designed for public exposure to hydrogen technologies. Specifically, the selected back-up and auxiliary power systems will displace existing battery and diesel power systems with fuel cells. All hydrogen systems selected will comply with or exceed the existing safety codes and standards. The economic feasibility and environmental impacts of hydrogen applications at airport were studied. A marketing and educational plan was formulated to educate the airport staff and public and to alleviate any concerns regarding the introduction of hydrogen technologies at the airport. Consequently, increased safety and security, higher energy efficiency, reduction in pollution, and smaller impact during power interruptions achieved by using hydrogen technologies will benefit the airport.

ACKNOWLEDGMENTS

I am extremely grateful to my advisor Dr. John W. Sheffield for the encouragement and guidance and the extreme patience shown in completing this work. He has also given me sufficient freedom to explore avenues of research while correcting my course and guiding me at all times. I would like to thank the Mechanical and Aerospace Engineering Department at the Missouri University of Science and Technology for supporting this research.

I thank my committee members Dr. K. Chandrashekara and Dr. Scott Grasman, without whose help, this effort and its successful completion would not have been possible. I am grateful to the ME 261 team of Fall 2007 and to Fanny Valencia Juscamaita for their valuble help. Special thanks go to my friends Ravi Philip, Rana Gunarathnam, Robins Mathai, and Ryan Matthews who have stood by me at all times.

On a personal note, I thank my parents P.M. Thomas and Vimala Thomas, for the tremendous encouragement and support I have received throughout my life which has enabled me to face the challenges and achieve success.

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1. INTRODUCTION

Airports are among the markets with greatest opportunity for practical implementation of hydrogen technologies. In addition to the task of handling millions of travelers every day, today's airports face challenges related to air and water quality, noise pollution, energy efficiency, and safety and security [1]. The statistical information indicating the increase of delays and cancellations (and thus lost revenue) can be found in the Appendix B Figure 1-4. The primary objective of this paper is to identify, select, and design hydrogen technologies to address the challenges related to pollution, energy efficiency, and safety and security at Lambert-St. Louis International Airport (STL), Missouri. Even though technology selections were made for the St. Louis Airport, the key elements of the design are applicable to other airports around the world. All technologies that have been selected are either presently commercially available or will be commercially available such that this design will be possible to implement for practical, real-world use by 2009.

Hydrogen technologies when compared to conventional systems are more energy efficient, reliable and have fuel flexibility, energy security, scalability, light weight, and lower emissions. Specific hydrogen technologies were selected based on these benefits and include a fully integrated system for on-site hydrogen generation, compression, storage and distribution, as well as several niche roles for introducing hydrogen applications at STL. Specifically, these systems comprise of hydrogen generation from steam methane reformation and electrolysis, composite and steel storage tanks, hydrogen fuel cell applications for auxiliary power generation, portable emergency power, light-duty vehicle applications, and a stand-alone system designed for public exposure to hydrogen technologies. A hydrogen fuel cell system capable of providing back-up power to critical systems replacing some of the existing battery and diesel power systems was also recommended in the design. A hydrogen internal combustion engine (H2ICE) shuttle bus was selected to transport passengers from the terminal to the parking lot. This paper will discuss each of these applications in detail and will address its design, safety, economic and environmental impacts, as well as the marketing and educational plan for the hydrogen applications.

U.S Department of Energy Hydrogen Program acknowledges that safe practices in the production, storage, distribution, and use of hydrogen are essential components of a hydrogen economy [2]. According to the U.S. Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) and National Hydrogen Association (NHA) [3-4] “hydrogen is no more or less dangerous than other flammable fuels, including gasoline and natural gas.” During the design of hydrogen applications, safety analysis was performed to identify the major failure modes of each equipment, its effects, and the steps to mitigate them. General failure modes of the hydrogen system were also analyzed and potential damage and frequency were estimated.

Since hydrogen technologies have not reached mass production yet, the cost associated with them is huge when compared with the existing technologies. An economic analysis was performed to evaluate the economic impact of implementing hydrogen technologies at Lambert-St. Louis International Airport. A business plan encouraging partnership between different agencies to implement hydrogen technologies at St. Louis airport was also devised.

Hydrogen’s attractiveness as a fuel is due to the fact that it is not just a clean-fuel, but that it can be produced through renewable, energy-efficient means. In order to study the environmental effects hydrogen technologies at the airport an environmental analysis was performed. Public acceptance of hydrogen is one of the biggest challenges faced by hydrogen energy and technology leaders. To address the issue of public acceptance and build local support for STL’s use of hydrogen technologies, a well-placed education and marketing plan was developed. This includes educational plans for airport staff, passengers, and the public and will support the design and understanding of hydrogen technologies to reduce potential resistance, and raise awareness of the benefits of hydrogen.

As such, the paper has been divided into six distinct sections as follows: (i) the design, (ii) safety analysis, (iii) environmental analysis, (iv) economic analysis, (v) marketing and educational plan, and (vi) conclusions and recommendations.

2. THE DESIGN

One can find numerous applications for hydrogen technologies at airports. For example, Wee [5] illustrates the use of PEM fuel cell in different real-world systems including transportation, stationary, and portable applications. The challenge is to identify specific application for the airport depending upon its unique needs. The hydrogen applications selected for Lambert-St. Louis International Airport were based on the different hydrogen technologies that are currently deployed or that will be deployed at Missouri University of Science and Technology (Missouri S&T). These hydrogen technologies include Polymer Electrolyte Membrane (PEM) fuel cell, Hydrogen Internal Combustion Engine (H2ICE) shuttle bus, Proton Exchange Membrane electrolysis, Steam Methane Reformation (SMR), Pressure Swing Adsorption (PSA), composite and steel hydrogen storage tanks, 5000 psi hydrogen dispensing, etc. A Phosphoric Acid Fuel Cell (PAFC) was also selected for auxiliary power generation at the airport. All these hydrogen applications can be divided into several smaller, distinct areas as given below:

1. On-site hydrogen production
2. Back-up power generation providing up to 30 kW of back-up power
3. Auxiliary & energy savings power generation
4. Hydrogen powered vehicles
5. Portable /Mobile fuel cell
6. Technologies dedicated to public education

Hydrogen will be produced on-site hydrogen production via steam methane reformation and electrolysis and will be used to fuel the hydrogen powered vehicles as well as various fuel cell applications. Most of the fuel cell applications used in the design require only industrial grade hydrogen (99.95% pure) and are capable of using hydrogen from K cylinders that are commercially available. The daily production and consumption of hydrogen was estimated and is summarized in Table 2.1.

Table 2.1. Daily Hydrogen Production and Consumption at Airport

Application	H_2 Production	H_2 Usage	Hours Operated
SMR	15 kg	-	24 hrs
FuelGen® 12	12.94 kg	-	24 hrs
HOGEN® H 2M	4.31 kg	-	24 hrs
H2ICE shuttle bus	-	20 kg	8 hrs
Fuel cell vehicles	-	6 kg	12 hrs
Back-up power unit	-	varies	power outage
Plug Power Fuel Cell	-	4.31 kg	24 hrs

To facilitate a better systems understanding, the proposed hydrogen applications at STL have been summarized in Appendix C and are represented visually in Table 2.2.

Table 2.2. Hydrogen Applications - Lambert-St. Louis International Airport

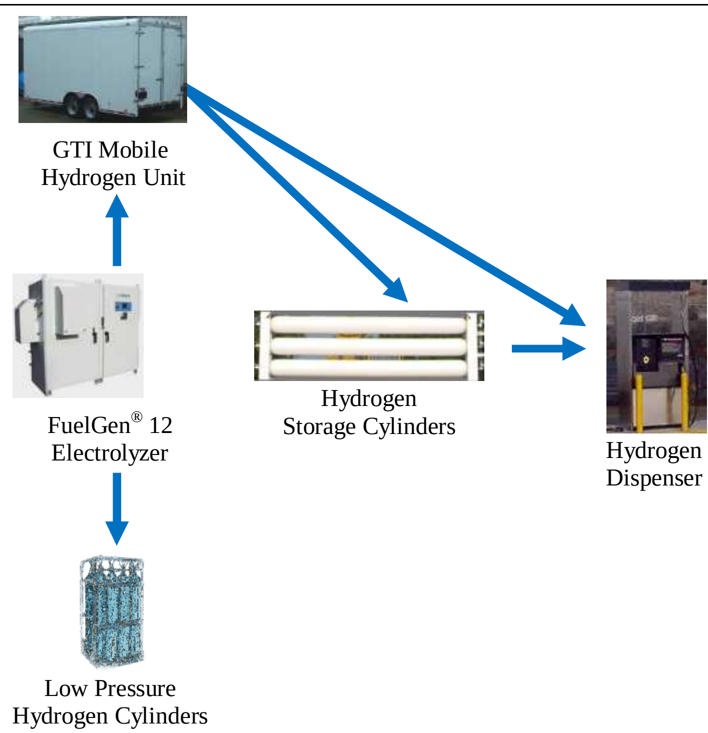
Applications	Equipments
Hydrogen Fueling Station	

Table 2.2.(cont.) Hydrogen Applications – Lambert-St. Louis International Airport

Back-up power eration	 Low Pressure Hydrogen Cylinders →  Altery Freedom Power ™ FCM-5 →  Server
Auxiliary & energy saving power generation	 Pure Cell® 200 →  Transformer
Hydrogen powered vehicle applications	 Lift truck  Ground Support equipment  Personal Transportation  Shuttle Bus  Scooter
Portable/Mobile power generation	 Low Pressure Hydrogen Cylinders →  FillPoint™ Hydrogen Canister Refilling Station →  Jadoo Power XRT™Extended Runtime Adapter
Technologies dedicated to public education	 HOGEN® H 2M Electrolyzer →  GenCore® Fuel Cell →  Computer

2.1. ON-SITE HYDROGEN PRODUCTION, STORAGE, AND FUELING

Hydrogen will be produced on-site via two leading hydrogen production technologies; (i) steam methane reformation and (ii) electrolysis. An integrated hydrogen fueling station will be purchased from Gas Technology Institute (GTI) and will comprise of a GTI designed Mobile Hydrogen Unit (MHU), external hydrogen storage tanks, and a dispenser. The MHU is a custom built trailer and will house a steam methane reformer, pressure swing adsorption system, compression system, composite storage tanks, and buffer tanks for natural gas and hydrogen. The unique design of the MHU will allow the hydrogen production and storage to be semi-mobile and can be moved easily or stored safely in case of an emergency or extreme weather conditions. Figure 2.1 shows the GTI designed MHU, external hydrogen supply tube trailer, external storage tanks, and the hydrogen dispenser located at E^3 Commons at Missouri S&T.

Figure 2.1. Missouri S&T Hydrogen Fueling Station at E^3 Commons

GTI's MHU shown in Figure 2.2 is capable of producing 15 kg of hydrogen per day through steam methane reformation of natural gas. Hydrogen from the reformer, after going through the hydrogen purification PSA system is fed into a buffer tank. The buffer tank supplies hydrogen to a two-stage hydrogen compressor (flow rate of 6 to 8 scfm) which compresses the hydrogen to 6250 psi. The compressed hydrogen will be stored inside the on-board composite tanks and the external ASME steel tanks. Both composite and external steel storage tanks are arranged in a three-bank cascade configuration and can hold up to 18 kg and 33 kg of hydrogen respectively.

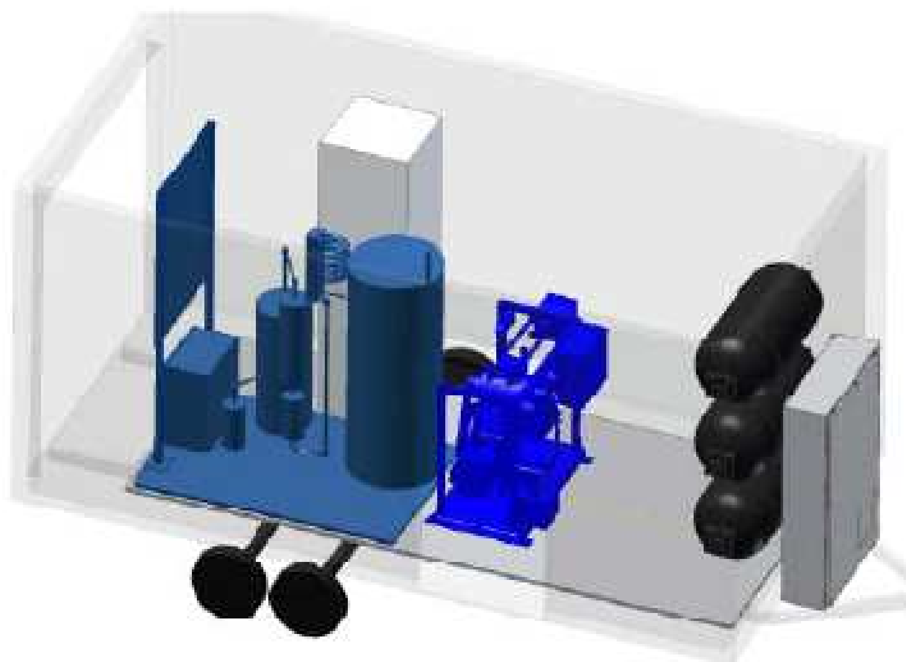


Figure 2.2. GTI's Mobile Hydrogen Unit (MHU) [6]

One of the greatest advantages of the MHU is that it can accept hydrogen (up to 10 kg per day when SMR is online and up to 25 kg when SMR is offline) from an external source such as a hydrogen tube trailer or an electrolyzer. This flexibility of the system will allow the scheduled maintenance of the steam methane reformer without interfering with the hydrogen fueling station operations.

Hydrogen will also be produced on-site via electrolysis using a FuelGen® 12 electrolyzer capable of producing 12.94 kg of hydrogen per day using proton exchange membrane technology. An external buffer tank specially designed for the electrolyzer equalizes pressure differences and provides the hydrogen gas flow from the electrolyzer to the buffer tank housed inside the mobile hydrogen unit. A separate hydrogen line from this buffer tank will be connected to a K cylinder refilling unit. This refilling unit will be used to fill hydrogen in the K cylinders and will supply hydrogen to the back-up power system discussed later in the section. Figure 2.3 illustrates the design and layout of the proposed hydrogen fueling station.

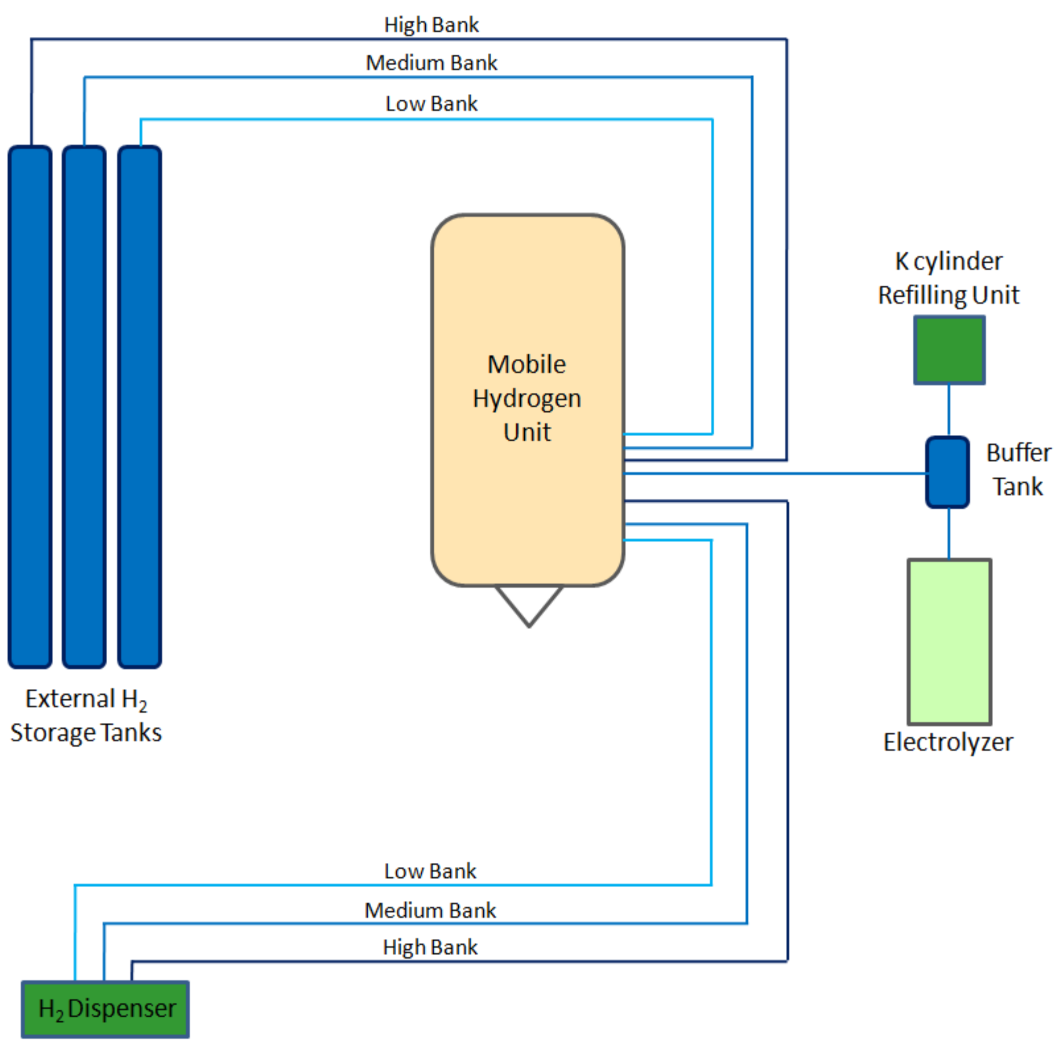


Figure 2.3. Proposed Hydrogen Fueling Station Design

Hydrogen dispensing will be based on GTI's patented Hydrofill™ technology and the dispenser will be able to dispense hydrogen at 5000 psi. This system meets all SAE hydrogen vehicle interface standards and doesn't require complex communication protocols, or intense training that other systems require [6].

The station will be capable of remote operation. Power controls and data acquisition systems will be included so that the station can be monitored, started, and stopped remotely, or it can be operated automatically to maintain pre-set pressure and hydrogen inventory [6]. The station will be used to fill both hydrogen internal combustion engine vehicles as well as fuel cell vehicles. The design recommends the hydrogen station to be built at one of the two Super Park parking lots as shown in Figure 2.4. Safety features of the hydrogen station and the associated equipments will be discussed in later section.

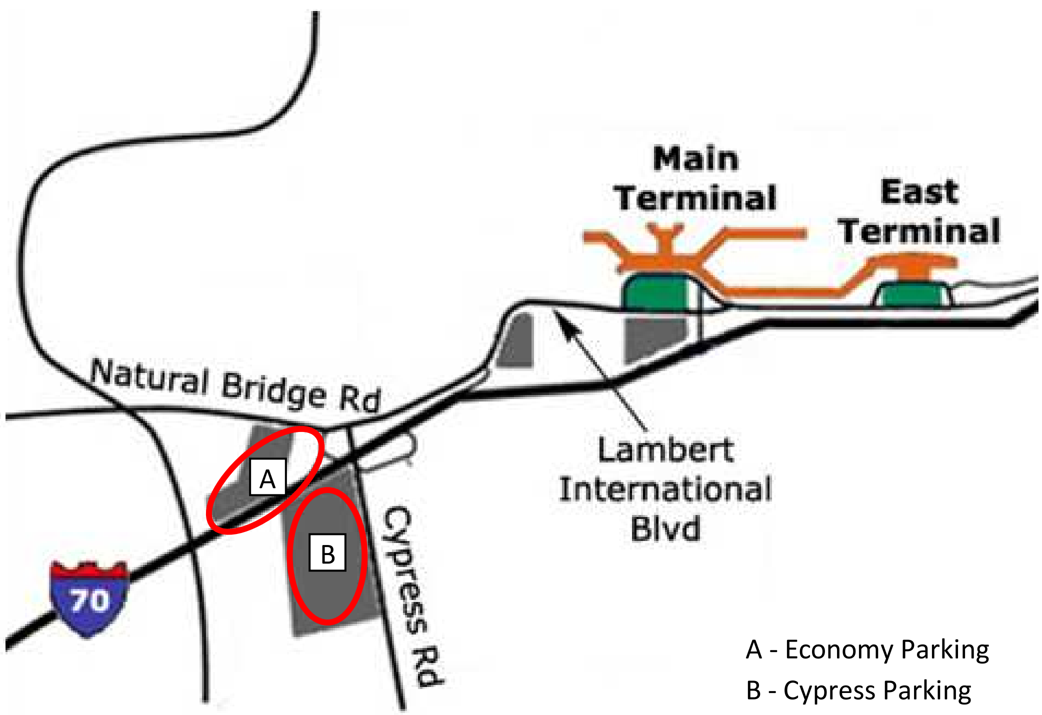


Figure 2.4 Proposed Location for Hydrogen Fueling Station

2.2. BACK-UP POWER GENERATION

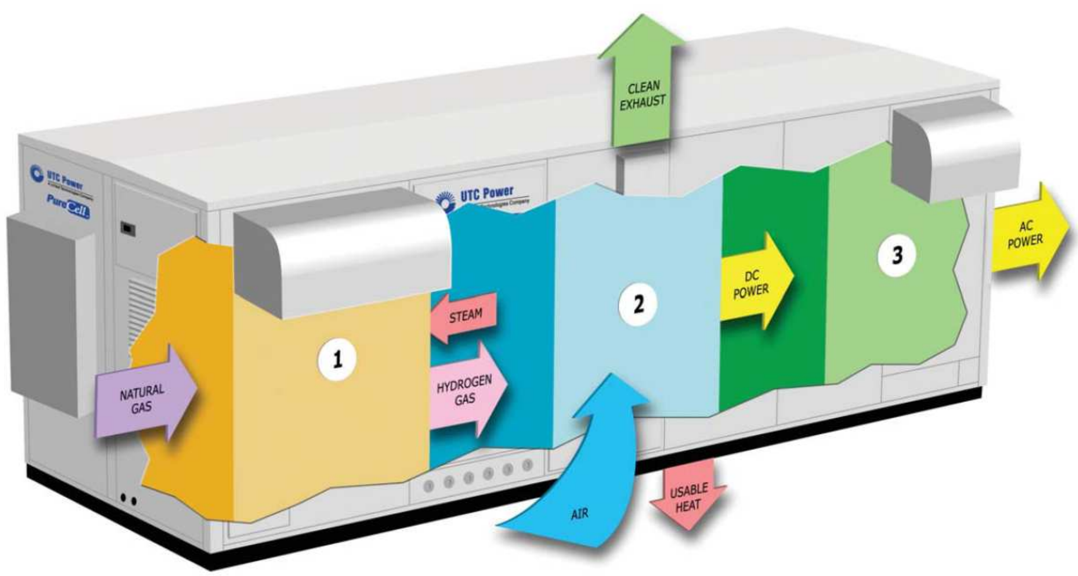
After analyzing flight operations at Lambert-St. Louis International Airport, it was observed that the power outages experienced by the airport significantly impact airport operations. To mitigate this critical weakness, the proposed design includes a 30 kW back-up power system furbished by Altergy Systems for uninterrupted power supply. The 30 kW system is a modular configuration of six Freedom Power™ FCM-5 fuel cell. Individually, these units are rated from 0-5000 W, with a 30 second overload capacity of 6250 W and rated net current of 0-100 A@48 VDC [7]. They will be fueled by the hydrogen K cylinders mentioned in the previous section and will consume 0.38 kg of hydrogen per hour while generating 5 kW. They are equipped with fuel leak sensors and remote communication and control ability. The system also includes a power distribution module (PDM) for administering the six FCM-5 units, a transient power module (TPM) for start-up and bridge power (downtime between a power failure and fuel cell warm-up time), and a power conversion module to convert DC power to AC power. The location of the system can either be located indoor or outdoor; if it is placed outdoor then it would need external conditioning. While this back-up power system could serve any number of different areas, the design suggests that the airport computer network be protected first. The dependability of the fuel cells and the back-up power unit in general will assure that the airport can perform its critical tasks and that no data will be lost in the event of a power outage. By utilizing this system, the Lambert-St. Louis International Airport will experience fewer critical outages ultimately preserving not only its flight schedule but also reducing effects throughout the country.

2.3. AUXILIARY AND ENERGY SAVINGS POWER GENERATION

To drive down energy costs and to lessen the load of the local utilities, auxiliary power generation system was selected. The proposed system comprises of a stationary Pure Cell® Model 200 PAFC system capable of producing 200 kW of power, and approximately 900,000 Btu/hr of heat for combined heat and power (CHP) applications [8]. According to Neef [9], the advantages of the stationary fuel cell systems compared to the competing condensing boilers or conventional heat and power plants consist of higher efficiencies and reduced emissions, but also of a contribution to decentralized electricity production and to stability of the electric grid.

The system can be operated in both grid-connected and grid independent modes depending on the power requirements of the airport. It can use either natural gas or anaerobic digester gas as fuel, which will be reformed with steam to generate hydrogen for the fuel cell stack. The DC power generated by the fuel cell stack is conditioned to provide AC power using a power conditioner inside the Pure Cell® Model 200. An illustration of how the fuel cell work can be found in Figure 2.5. The system can be configured to run at 400V at 50 Hz or 480V at 60 Hz. The footprint of the power module is 15' by 18', allowing a single unit to be installed in a variety of locations, or making the modular configuration of several units a realistic possibility.

Of the many advantages this offers, perhaps the most notable is that the system will be capable of running for long periods of time as long as a hydrogen fuel is readily available. During emergency situations, this equipment also acts as back-up or auxiliary power generation. With only a single unit, per unit specifications power assurance is in excess of 99.99%.



1 - Fuel Processor 2 - Fuel Cell Stack 3 - Power Conditioner

Figure 2.5 UTC Pure Cell® 200 Operation [10]

2.4. HYDROGEN POWERED VEHICLES

The transportation sector is the single largest consumer of petroleum in the United States, accounting for nearly two-thirds of its annual consumption. According to U.S. DOE's Hydrogen, Fuel Cells & Infrastructure Technologies Program, "a transportation system powered by hydrogen and fuel cells would significantly improve the national energy security and reduce emissions of harmful pollutants and greenhouse gases."[11]

Keeping this in mind, five specific hydrogen vehicles for unique operations was selected for Lambert-St. Louis International Airport. These vehicles will act as a part of the design's educational and marketing component and will introduce hydrogen technologies to both airport employees and passengers in highly visible applications. The selected hydrogen powered vehicles includes both internal combustion engine and fuel cell powered vehicles and are as follows: (i) Ford E-450 H2ICE shuttle bus, (ii) hydrogen powered lift truck, (iii) a fuel cell ground support equipment, (iv) a fuel cell scooter, and (v) a fuel cell personal transporter.

2.4.1. Ford Hydrogen Shuttle Bus. The most noticeable hydrogen powered vehicle included in the design is the Ford hydrogen internal combustion engine (H2ICE) shuttle bus. This vehicle, leased from Ford Motor Company will supplement the existing natural gas shuttle bus service and will be used to shuttle passengers between Lambert-St. Louis International Airport's main terminal, east terminal and Super Park parking lots. The proposed route found in Appendix E is approximately 6.5 miles and will take around 30 minutes for a round trip. This proposal has been constructed around an estimated eight to ten hours of operation per day.

The hydrogen shuttle bus is a retrofitted Ford E-450 that uses gaseous fuel injection system, modified ignition & electrical system, iridium dipped spark plugs, super charger, and intercooler [12]. Hydrogen is stored on-board in six storage tanks and can hold up to 29.4 kg of hydrogen at 5,075 psi. Hydrogen from these tanks is regulated to 70-80 psi before being injected into the engine. The shuttle bus also has a hydrogen management system which will be discussed in detail in the safety analysis section of the paper. The use of hydrogen in internal combustion engines should be seen as a bridging technology while fuel cell technology becomes economically viable and is further refined for transportation purposes. Since the vehicle is being leased, when sufficiently developed technology becomes commercially available, the airport may readily upgrade its environmentally friendly passenger transportation.

Missouri University of Science and Technology have been using two of these hydrogen shuttle buses (Figure 2.6) for more than a year (June 07 - Nov 08) for demonstration purposes and for shuttling students around campus. During this period, studies have shown the vehicle can easily travel at highway speeds and has a fuel economy of approximately 6 miles per kg of hydrogen.

Figure 2.6. Ford E-450 H2ICE

2.4.2. Hydrogen Fuel Cell Lift Truck. Hydrogen fuel cell lift truck is an excellent candidate for multi-shift indoor material handling operation. The advantages of this technology include zero emissions, reduced fueling times, elimination of space for charging stations, and extended run-time between fills. This is especially useful if the equipment is being used inside where ventilation is less than adequate.

Hydrogenics HyPM® Fuel Cell Power Pack (FCPP) shown in Figure 2.7 was selected to meet the specific requirement of a drop-in replacement for traditional battery power systems in lift trucks. It is an integrated electric hybrid power solution that includes a fuel cell, hydrogen storage tank, power electronics, system controls, thermal management system and an electrical storage device [13]. The details of the fuel cell lift trick can be found in the Table 2.3 given below.

Figure 2.7. HyPM® Fuel Cell Power Pack [13]

Table 2.3. Fuel Cell Lift Truck Features [13]

Vehicle Specification	
Forklift	Hyster E 55 Class 1 Electric Counterbalanced Lift Truck
Wheels	4
Tire Type	Cushion
Power Solution	
Product	Hydrogenics HyPM Fuel Cell Power Pack
Configuration	Fuel Cell Ultracapacitor Hybrid
Peak Power (10s)	27 kW
Fuel Cell Power Module	HyPM 12
Continuous Net Rated Power	12 kW
Electrical Storage	Ultracapacitors
Hydrogen Storage	1.6 kg @ 350 bar
	3.5 lb @ 5000 psi
Run-time	12 hours
Refueling time	< 5 minutes

Hydrogenics has already demonstrated the benefits of using the fuel cell lift trucks at General Motors (GM) of Canada's automotive assembly plant in Oshawa, and at FedEx Canada's logistics hub at the Toronto Pearson International Airport [13]. The fuel cell lift truck application at Lambert-St. Louis International Airport will use the Hyster Class 1 Electric Counterbalanced Lift truck identical to the one used at Oshawa and Toronto.

2.4.3. Hydrogen Fuel Cell Ground Support Equipment. The fuel cell power pack used in the Section 2.4.2 will also be used to power airport ground support equipment (GSE). The design will use John Deere's 6x4 Gator™ platform to deploy a fuel cell powered utility vehicle. This vehicle will be used in terminal for light cargo as well as passenger transport. In addition, the fuel cell powered Gators can provide external AC and DC power, enabling the fuel cell to act as generator that provides off-board power to operate tools, and other electrical equipment. Much like the fuel cell for the lift trucks detailed above, this will not only allow the vehicle to operate indoors emissions free, but will also boast a rapid refueling time when compared to existing battery systems. The details of the fuel cell lift trick are summarized in the Table 2.4 given below.

Table 2.4. Fuel Cell Ground Support Equipment Features [13]

Vehicle Specification	
Configuration	6x4 Gator™
Vehicle Weight	730 kg (1640 lb)
Maximum Speed	33 km/hr (21 miles/hr)
Power Solution	
Fuel Cell Power Module	HyPM 12
Continuous Net Rated Power	12 kW
Electrical Storage	Ultracapacitor pack
Hydrogen Storage	0.6 kg @ 350 bar
	1.3lb @ 5000 psi
Range	2-3 hours (normal drive cycle)

2.4.4. Hydrogen Fuel Cell Scooter. A hydrogen powered scooter designed by Asia Pacific Fuel Cell Technologies, Ltd (APFCT) was selected as an additional roaming advertisement for hydrogen technologies. The ZES IV.5, or Zero Emission Scooter IV.5 Generation, is a hydrogen fuel cell scooter that boasts a power plant producing 120 amps at 24V which allows it to reach a maximum level speed of just over 30 mph [14]. At a more tame speed of 18 mph, the scooter has a range of approximately 37 miles before refueling is necessary. The scooter's fuel supply is delivered via a metal hydride canister that can be simply exchanged for a new canister at refueling as seen in Figure 2.8. The scooter and fuel canister have a combined weight of 240 pounds, allowing the vehicle to operate nearly anywhere pedestrian traffic is possible.

Figure 2.8. ZES IV.5 Fuel Cell Scooter [14]

2.4.5. Hydrogen Fuel Cell Personal Transporter. The design selected a fuel cell personal transporter for the security officers at the airport. It will help tighten security with faster response and can increase extend of area under surveillance. The transporter is a modified Segway® Personal Transporter (PT) designed to run on hydrogen using fuel cells purchased from Jadoo Power Systems [15]. Hydrogen will be stored in hydrogen fuel canister and can be easily recharged using Jadoo's FillPoint™ refill station. These canisters can be replaced and recharged depending on the use of the personal transporter.

2.5. PORTABLE/MOBILE FUEL CELL.

Off- the grid portable power equipment are extensively used by first responders including fire fighters, emergency medical responders, and law enforcement. The design includes a hydrogen fuel cell power pack unit manufactured by Jadoo Power. The XRT™ Extended Runtime Adapter as seen in Figure 2.9 offers built-in 110 VAC and 12 VDC output jacks delivering 100W of continuous power [16] and will be used for both portable and remote power applications such as communications equipment for early response teams, small electric tool operation, or any other application that requires light, reliable portable electric power. Their advantages over conventional battery units are compact size, modularity, rapid refill time, consistent run-time, and no self-discharge giving the unit a very long shelf life.

Figure 2.9. Jadoo Power XRT™ Extended Runtime Adapter [16]

2.6. PUBLIC EDUCATION TECHNOLOGIES.

Public perception of hydrogen technologies was given high importance while designing hydrogen applications at the airport. In order to educate the public and to increase their acceptability towards hydrogen technology a public/passenger hydrogen education center was designed. It will educate and inform public about the hydrogen applications and also about the greater possibilities that can be realized through the use of hydrogen technologies. This center should be located in a high-traffic area of the airport to have maximum visibility.

This exhibit will be powered entirely by hydrogen produced through the exhibit itself. For this requirement, the design specifies a HOGEN® H2M electrolyzer, seen in

Figure 2.10. The H 2M employs a proton exchange membrane electrolysis technology and produces 4.31 kg of hydrogen per day at 218 psig (99.9995% purity) [17]. The hydrogen produced by this system will fuel a 5 kW Plug Power (GenCore® 5U120) hydrogen fuel cell which will power multiple computers as well as audio/visual equipment located within the exhibit. It should be noted the 5 kW fuel cell will not be run at full load, allowing expansion of the display at a later time.

Figure 2.10. HOGEN® H Series Electrolyzer [17]

2.7. OVERALL

The technologies selected for this design should not be seen as the end product of a hydrogen infrastructure at an airport. Instead, these systems have been designed to serve as a stepping stone to the introduction of larger hydrogen systems within an airport or similar facility. Technologies that were considered during the design but not selected have been summarized in Table 2.5.

Table 2.5 Other Possibilities at STL

Technologies not selected	Reasons for not using
Wind Turbine	Permitting issues
Solar Panel	High volume of batteries/ space constraints
Fuel cell cars, buses, wheelchairs, etc.	High cost

3. SAFETY ANALYSIS

Safety is the primary concern for any airport operations. H_2BestPractices.org, a collaboration of the Pacific Northwest National Laboratory and Los Alamos National Laboratory warns “A catastrophic failure in any hydrogen project could negatively impact the public's perception of hydrogen systems as viable, safe, and clean alternatives to conventional energy systems, and could reduce the ability of hydrogen technologies to obtain insurance, a necessary step in commercialization of any technology” [18]. As such, special care is needed to not only identify probable failure methods of hydrogen systems, but also to provide a design that mitigates this risk and provides a safe image to the public. This section will address the safety analysis of specific hydrogen equipments as well as different accident scenarios of PEM fuel cells (e.g., Gerbec et al. [19]) and other hydrogen systems used in the design. Codes and standards applicable to hydrogen equipments selected during the design have been summarized in Appendix F.

3.1. EQUIPMENT FAILURE MODES

Failure modes associated with different hydrogen application and methods to mitigate them have been summarized in the Table 3.1.

Table 3.1. Failure Mode Analysis

Equipment	**Potential failure mode(s)**	**Potential effects of failure**	**Safety features and failure control/ prevention**
Mobile Hydrogen Unit	Hydrogen leak	Fire and combustion of hydrogen , asphyxiation	a). H_2 leak detection system b). Ventilation c). Fire detection and suppression safety system d). Emergency shutdown devices e). PLC-based system control and remote monitoring system f). Electrical connections and panels compliant with National Electrical code

Table 3.1.(cont.) Failure Mode Analysis

Hydrogen storage tanks	Over pressurizing	Failure of tank	Pressure relief valves
Hydrogen fueling station	Hydrogen leak	Fire and combustion of hydrogen; other emergencies	Emergency shutdown devices located at different convenient locations
Altergy fuel cell	Hydrogen leak and fuel cell degradation	Fire and combustion of hydrogen; low power output	a). H_2 leak detection system b). Remote system and fuel monitoring
Pure Cell® 200 fuel cell	Hydrogen leak and fuel cell degradation	Fire and combustion of hydrogen	a). H_2 leak detection system b). Remote system and fuel monitoring
Ford hydrogen shuttle bus	Hydrogen leak and roadside emergency	Combustion / asphyxiation	a). H_2 sensors b). H_2 temperature & pressure sensor in tank valve c). H_2 fans in the storage compartment d). Audible alarm and light on dashboard if H_2 concentration > 2% e). Manual shut-off valve f). Battery disconnect g). Pressure relief valves and devices
Fuel cell lift truck & GSE	Hydrogen leak	Fire and combustion of hydrogen	Hydrogen sensor
Fuel cell scooter	Hydrogen leak	Fire and combustion of hydrogen	a). Uses metal hydride hydrogen storage b). Self limiting in gas release rate
HOGEN® H 2M electrolyzer	Hydrogen leak	Fire and combustion of hydrogen	a). On-board H_2 detection b). Automatic fault detection and system depressurization c). Emergency stop d). Remote alarm and shutdown
Plug Power electrolyzer	Hydrogen leak and fuel cell degradation	Fire and combustion of hydrogen; low power output	a). H_2 detection system b). Low fuel alarm c). Remote monitoring system

3.2. HYDROGEN SYSTEM FAILURE MODES

After considering possible failure modes of hydrogen equipments, general failure modes of the whole hydrogen system were identified and are as follows:

1) Fire and combustion of hydrogen
2) Human operator error or equipment misuse
3) Natural disaster
4) Hardware failure
5) Electrical Power outage

The failure modes above are listed in decreasing order of risk to the St. Louis airport. Each scenario was evaluated for both damage potential and frequency, and then scored appropriately (1-10, 10 being the most severe). The results of this analysis can be seen in Table 3.2.

Table 3.2. Risk Factor Analysis

Failure Mode	**Damage Potential**	**Frequency**	**Risk Factor**
Fire and Combustion	10	6	60
Operator Error	8	5	40
Natural Disaster	8	4	32
Hardware Failure	5	3	15
Power Outage	2	7	14

3.2.1. Fire and Combustion of Hydrogen. In 2007, fire killed more Americans than all natural disasters combined [20]. Furthermore, direct property loss due to fires was estimated at $14.6 billion [20]. Hydrogen being colorless and odorless is very difficult to detect; it is also highly flammable. Table 3.3 provides the flammability limit, explosion limits, and ignition energy of hydrogen compared to gasoline vapor and natural gas.

Table 3.3. Fuel Comparison Matrix [3-4]

Properties	Hydrogen	Gasoline	Natural Gas
Flammability limits (in air)	4-74%	1.4-7.6%	5.3-15%
Explosion limits (in air)	18.3-59%	1.1-3.3%	5.7-14%
Ignition energy (mJ)	0.02	0.20	0.29

It can be observed that hydrogen has a wide flammability and explosion limits. Hence, it is crucial that ignition sources be removed from any area where hydrogen is being processed or handled. To mitigate this risk, appropriate warning signs including "NO SMOKING, FLAMMABLE GAS, NO CELL PHONES, HYDROGEN DOESNOT HAVE A DISTINCTIVE ODOR" will be posted in areas where hydrogen equipments are present. Since static electricity discharges also pose a risk as an ignition source, all equipment will be equipped with an appropriate safety grounding system. At the hydrogen fueling station, infrared sensors will be installed to detect hydrogen flames.

Finally, measures will be taken to assure operators and the public that hydrogen is a safe fuel, despite its high range of combustibility. Scenarios such as those found from the fuel leak simulation of hydrogen and gasoline vehicle (see Figure 3.1) will be used to illustrate this idea. It can be observed that the traditional gasoline vehicle is completely destroyed. Remarkably, the maximum surface temperature measured on the hydrogen vehicle was 117^{o} Fahrenheit at the rear window glass [21]. Similar information will be disseminated at the public education facility at the airport.

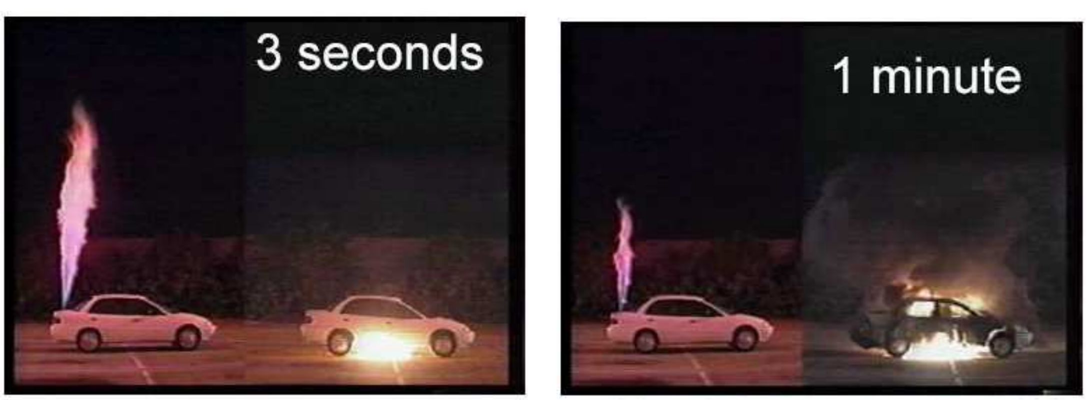


Figure 3.1: Fuel Leak Simulation of Hydrogen (left) and Gasoline (right) Vehicle [21]

3.2.2. Human Operator Error or Equipment Misuse. Human operators pose a risk to the overall integrity of the any system during its operation. Even trained operators make mistakes and can be forgetful. For this reason, the design calls for several safety checks to be installed, especially with regard to the hydrogen fueling station where hydrogen will be at high pressure (5000 psi). The system will be run using a smart card so that only trained users will be able to access the station. In the event that a driver pulls his/her vehicle away before nozzle disconnection, a break-away design such as those found at gasoline service stations will be used. Operator error also includes incidents such as a vehicle collision with hydrogen equipment. Due to the mobile nature equipment such as the hydrogen store and dispensing unit, mobile jersey barriers will be used to protect this equipment. These hollow plastic barriers can be filled with water to impede a vehicle's path, but are easy to relocate quickly and without the use of heavy equipment. The water can simply be drained from the barrier and the barrier carried to a new location.

All hydrogen production, compression and storage equipment at Missouri S&T hydrogen fueling station is located inside a fenced area to minimize physical damage and vandalism. Missouri S&T has also installed a security camera to monitor the activities at the hydrogen fueling station. Similar steps would be taken at Lambert-St. Louis International Airport to ensure the safety of public and equipments.

3.2.3. Natural Disaster. Natural disasters have the ability to annihilate any of man's creations. In St. Louis area, the greatest cause for concern is tornados and thunderstorms. Tornados can produce winds in excess of 100 miles per hour and are typically accompanied by torrential rain. The mobile nature of the MHU allows it to be moved to a higher elevation if a storm is expected. If necessary, the equipment could be taken off-site for the duration of the storm. The high winds should have little impact on the other aspects of the design due to their location inside or their relatively low profile. Localized flooding and flash flooding, while a threat to human life can be mitigated in the design phase of the project by avoiding construction in low-lying areas. All equipment exposed to the environment will be adequately protected from rain-water penetration.

3.2.4. Hardware Failure. Typically every system is prone to mechanical or hardware failure associated with time and usage. To prevent such failures, routine maintenance should be performed, especially to any surfaces with hydrogen exposure. Hydrogen embrittlement resistant piping, valves, and fittings will be selected. Any crack or scratch on a product interface surface should be closely monitored for any fatigue or corrosion effects causing the crack to open. If inspections reveal a critical crack or one outside of design tolerance, the airport maintenance personal will de-energize, follow lockout/tagout procedures, and then make appropriate repairs to the system.

It is also important that all temperatures and pressures be maintained at or below system specifications. The pressure sensors, temperature probes, and relief valves included in each system will ensure that the equipments operate within the safety limits and that the equipment will shut down safely in case of an event. Inspections for hydrogen leak at hydrogen piping and valves joints must be performed periodically as well as during installation of the equipment.

3.2.5. Electrical Power Outage. An electrical power outage at the airport would result in a loss of instrumentation and system control, possibly resulting in one of the failure methods above. Because of this, an electrical power outage is a risk to system integrity. To manage this risk, system specifications will require all product valves to fail closed to prevent unintentional release or processing of hydrogen gases. All systems will also be equipped with pressure relief valves that function without power requirements, allowing any critical pressure increase to be released safely and in a controlled manner during times of electrical power outage.

4. ECONOMIC/BUSINESS PLAN ANALYSIS

U.S. businesses lose $29 billion annually from computer failures due to power outages and lost productivity [22] and are quickly realizing that fuel cells may help prevent some of these losses. However, being a new technology, hydrogen technologies have a high cost associated with them. Lambert-St. Louis Airport will be encouraged to partner with multiple agencies/organizations to implement hydrogen technologies proposed in the design. As an example, the E^3 Commons site at Missouri S&T comprising of hydrogen fueling station, hydrogen research garage, and renewable energy transit depot has been funded by Defense Logistics Agency (DLA), Federal Transit Administration, and National University Transportation Centre (NUTC). St. Louis airport could solicit funds from different organizations to implement one or more hydrogen applications recommended in the design. A possible outcome of these could be a partnership between Federal Aviation Administration, St. Louis Airport Authority (SLAA), and Department of Energy.

The hydrogen technologies selected attempt to address several economic issues including showing fiscal viability through power cogeneration and moderating losses due to power outages through reliable back-up systems. The design incorporates leased equipment which will help to keep the initial outlay of assets down while also creating flexibility to change with emerging and improving hydrogen technologies. The business plan includes both capital investments in purchased equipment as well as lease agreements.

4.1. CAPITAL AND INSTALLATION COSTS

The initial capital investment for all operating equipment will be $3,250,000 with an additional $400,000 estimated for installation. Installation costs were estimated based on the cost involved in the installation of the E^3 Commons facility at Missouri S&T. It was assumed that the no extensive site preparation would be required and that utility connections are available on-site. Table 4.1 illustrates the cost break-down of proposed hydrogen application at Lambert-St. Louis International Airport.

Table 4.1. Capital Investment & Installation Cost Summary

Capital Costs			
Item	**Description**	**Quantity**	**Price**
1	**Hydrogen Cogeneration System**		
1.1	UTC Pure Cell® 200 - Incl. Installation	1	$1,100,000
2	**Hydrogen Fueling Station**		
2.1	MHU, storage, and dispenser	1	$1,100,000
2.2	Fuel Gen® 12 Electrolyzer	1	$275,000
2.3	Hydrogen K cylinder refilling unit	1	$25,000
2.4	Concrete pad, design, utility connections, fence, flame detection system , security cameras, etc.		$200,000
3	**Hydrogen Back-up Power System**		
3.1	Altergy Integrated Fuel Cell	1	$120,000
3.2	Transient Power Module	1	$30,000
3.3	Communications and Control Module	1	$15,000
3.4	Installation		$50,000
4	**Public Education Module**		
4.1	HOGEN® H 2M Electrolyzer	1	$140,000
4.2	Plug Power Fuel Cell	1	$20,000
4.3	Desired Peripherals		$25,000
4.4	Installation		$50,000
4.5	Marketing		$100,000
5	**Hydrogen Vehicles & Portable Power System**		$400,000
Total Capital Cost			**$3,650,000**

4.2. OPERATIONAL COSTS

Hydrogen technologies deployed at Lambert-St. Louis International Airport will have utility costs, maintenance cost, and other cost associated with its operation. The operational cost also includes the 30 month lease payment on the Ford H2ICE shuttle bus at $250,000 for 30 months [23]. Electricity and natural gas are supplied by Ameren UE. The energy charge for electricity is $0.024 per kWh during summer and $0.0212 per kWh during winter [24]. The electricity demand charge for summer and winter is $14.35 per kW and $6.52 per kW respectively [24]. The electricity cost is derived from operation of the two electrolyzers, and mobile hydrogen unit (approximately 50,000 kWh per month) producing hydrogen 24 hours a day. The average electricity cost per month for hydrogen generation is approximately $1,840. Natural gas is priced at $0.28 per Ccf for the first 7000 Ccf $0.18 for every Ccf thereafter [25]. It was estimated that the Pure Cell® 200 auxiliary power generator will require natural gas and the Steam Methane Reformer worth $3,350 and $650 respectively. The operating cost per year was calculated and has been tabulated in Table 4.2. Grid water used for cooling purposes and de-ionizer feedstock is assumed to be a negligible cost factor. The maintenance costs are assumed to be 5% of the total investment cost.

Table 4.2. Yearly Operating Costs

Item	**Cost**
Electricity	$22,000
Natural Gas	$48,000
Shuttle Bus	$140,000
Maintenance	$160,000
Total	**$370,000**

4.3. COST ALLEVIATION

The most important cost alleviation factor in the design is the Pure Cell® 200 fuel cell unit which produces 200 kW. This unit will be operational 24 hours a day and will save approximately $5,000 per month in electric bills. Other cost savings include fuel and maintenance cost savings for the hydrogen vehicles including H2ICE shuttle bus, fuel cell lift truck, ground support vehicle, and the fuel cell scooter. Keeping the airport up and running during power failures curtails losses due to flight delays and cancellations not only at STL, but at all connecting airports as well. The cost saving anticipated by the introduction of hydrogen technologies at the airport have be summarized in Table 4.3.

Table 4.3. Cost Savings

Item	Avg. monthly savings	Avg. yearly savings
Pure Cell® 200 fuel cell	$5,000	$60,000
Hydrogen vehicles	$3,000*	$30,000
Total	**$8,000**	**$96,000**

*Assuming gasoline costs $3 per gallon and the monthly rent and maintenance cost on the hydrogen vehicles to be saving to be $1000.

4.4. AIRPORT UP-TIME

The market for hydrogen fueled technologies is still emerging and hence, as with all new technologies, is still quite expensive. Currently it is not cost effective to simply replace existing fossil fueled technologies. According to the economic feasibility prediction of commercial fuel cell application by Ma et al. [26], the installation of 200 kW auxiliary power generation system will not result in direct monetary gain or profit. The selected hydrogen technologies will combat the 'high cost and profit' issue by solving critical problems such as airport down time due to power failure. The Altergy fuel cell computer back-up system along with the 200 kW auxiliary power generation system ensure that the airport experiences shorter down-time (and thus reduced loss of revenue) during power interruptions. The breakdown of flight schedules at one airport also affects every connecting airport leading to a serious loss in revenue, productivity and customer satisfaction. The airport currently employs multiple back-up power systems, but they are antiquated and unreliable. The value of technologies guaranteeing zero interruption and power generation to over 99.99% is virtually immeasurable when compared to the domino effect of loss created when an airport shuts down.

4.5. OVERALL

The Altergy integrated fuel cell/UPS and Pure Cell® power generator solve the critical issue of cancelled and delayed flights as a result of power interruption. The next measure promotes hydrogen technologies to the general public as well as the airport work force. The public education module as well as the multitude of hydrogen vehicles supplied to the airport will have myriad benefits as these hydrogen technologies become widely accepted. The hydrogen powered Ford shuttle bus, specifically, will provide a valuable customer service while enhancing the public image of the airport for supporting *green* technologies. And lastly, to provide some quantifiable economic viability, the cogeneration effort of the Pure Cell® will reduce electricity costs in between times of power interruption and lighten STL's grid load. Through these methods, achievements are made in finding a solution to a critical airport problem, increasing public awareness and approval of a new *green* fuel, and finding an economically sound means of cost savings, all with hydrogen.

5. ENVIRONMENTAL ANALYSIS

Hydrogen and fuel cell technologies provide a major opportunity to shift the carbon-based global energy economy to a clean, renewable, and sustainable economy based on hydrogen. According to Edwards et al. [27] hydrogen, with its energy storage capacity would be the potent link between sustainable energy technologies and a sustainable energy economy. But, in the United States, 95% of the hydrogen produced comes from steam methane reformation of natural gas which produces hydrogen and carbon dioxide as by-products. Hydrogen is also produced through electrolysis of water, but it is primarily dependent on grid power predominantly from coal powered power plants. Hence it is important to do an environmental analysis to study the impact of hydrogen production and its use at the airport. Environmental impact of using steam methane reformation and electrolysis to produce hydrogen on-site were examined along with comparison of combustion of traditional fossil fuels to burning hydrogen or using hydrogen in fuel cells, effect of displacing batteries with hydrogen fuel cells and finally, the differences in the noise level of the diesel generator with fuel cell system.

5.1. COMPARISON OF FOSSIL FUELS AND HYDROGEN

It has been estimated that about 50% of Americans live in areas levels of one or more air pollutants are high enough to affect public health and/or the environment [28]. Hydrogen being a clean-fuel has a potential to mitigate this problem and when used in a fuel cell to generate electricity that can power transportation, stationary, or portable applications while producing only pure water and heat as byproducts.

One aspect of the proposed design, the UTC Pure Cell® 200, is a strong example of how emissions can be drastically reduced through the use of hydrogen fuel cell technologies. Figure·5.1 is a generalization of the emissions generated during use of the Pure Cell® unit when compared to both the United States grid electric as well as a typical natural gas engine of comparable capacity. It can be seen from the Figure 5.1 that fuel cell technologies offer distinct advantages over fossil fuels, especially when considering environmental effects. Compared with traditional combustion powerplants, a single Pure

Cell® Model 200 system emits 17,000 pounds less acid rain and smog-causing pollutants into the environment every year and reduces carbon dioxide emissions by more than 1.5 million pounds per year [29].

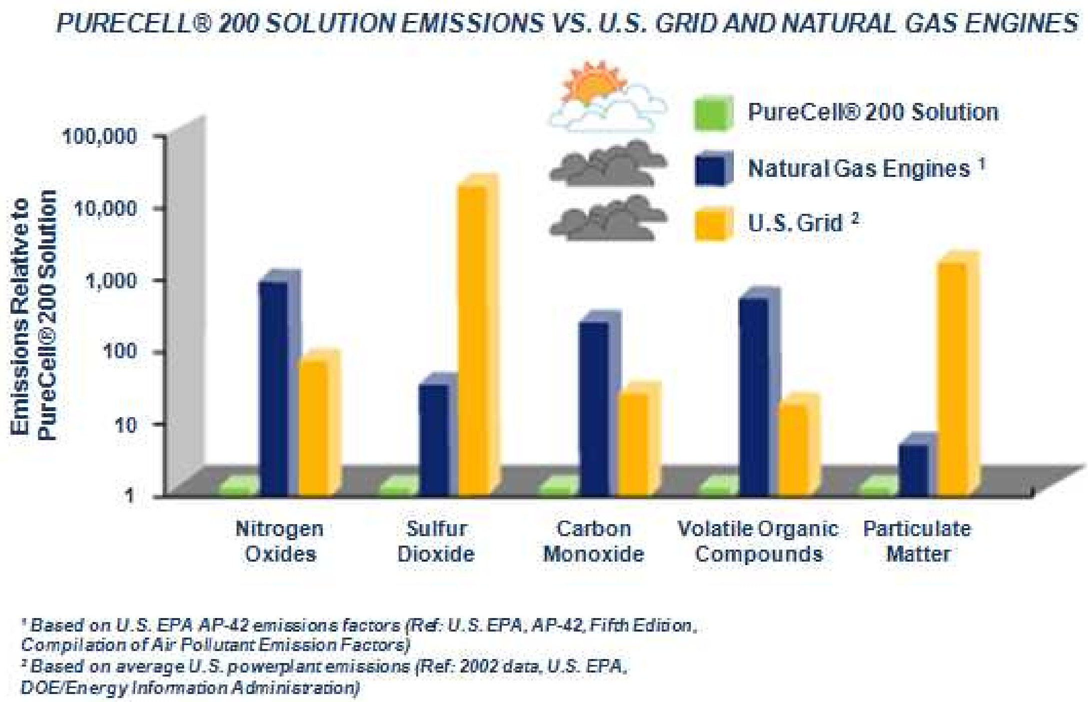


Figure 5.1. Fossil Fuel and Fuel Cell Comparisons [29]

Even though the auxiliary power generation system, hydrogen powered shuttle bus, hydrogen fuel cell lift truck, ground support equipment and public education center displace carbon dioxide, production of hydrogen from steam methane reformation and electrolysis using grid power produces carbon dioxide. The amount of CO_2 emitted and displaced using hydrogen technologies at the airport were estimated and are summarized in the Table 5.1. It was found out that the hydrogen application at the airport displaced 224,335 kg of CO_2 annually.

Table 5.1. Impact on CO_2 Emissions at STL

Application	CO_2 displaced (kg/year)	CO_2 added (kg/year)
Pure Cell® Model 200	675,000	-
Steam Methane Reformation	-	51,800
Electrolysis	-	462,000
Ford Shuttle Bus[1]	15,375	-
Fuel Cell Fork lift[2]	17,350	-
Fuel Cell GSE[2]	10,550	-
Public Education Center	19,850	
TOTAL	738,125	513,800

[1]Compared with natural gas vehicle
[2]Compared with electric vehicle

When traditional fossil fuels are burned, they release many compounds and fine particulate matter into the atmosphere. These off-gases include chemicals such as nitrogen oxides, sulfur compounds, carbon monoxide, and countless other molecules that can poison the air and eventually make their way into the water supply. However, when hydrogen is burned with oxygen, the by-product is clean, pure water vapor. To further gain from the clean burning of hydrogen fuels, the proposed design offers a Ford E-450 H2ICE shuttle bus which only produces water vapor and trace amounts of NO_x. To fully realize the environmental benefits of hydrogen, a well-to-wheel (WTW) analysis of the full fuel cycle was performed using the latest version (version 1.8b) of the GREET [30] software. The results obtained from the GREET [30] model are tabulated in Appendix D Table·1-4. Default estimates for 2008 were adopted during the simulation and hydrogen was assumed to be produced on-site via steam methane reformation. Since the design employs Ford E-450 H2ICE, it was compared with its possible alternatives. Following Table 5.2 compares the emissions generated during production and use of hydrogen, gasoline, and natural gas.

Table 5.2. Summary of Data Obtained from GREET [30] Analysis

	Total Energy	Coal	Natural Gas	Petroleum	GHGs
	Btu/mile	Btu/mile	Btu/mile	Btu/mile	g/mile
Gasoline	8,058	260	565	6,986	629
CNGV	7,858	334	7,402	52	536
Electric	5,171	3,234	1,033	234	449
H2ICE	10,080	836	8,976	94	694
H2FCV	6,342	526	5,648	59	435

From the table it can be seen that the fuel cell vehicle produces the least greenhouse gas (GHG) emissions and uses the less amount of energy and fossil fuel per mile. The total emissions of the hydrogen H2ICE and hydrogen fuel cell vehicle would have been lesser if renewable energy sources were used in the production of hydrogen.

5.2. REPLACING BATTERIES WITH FUEL CELLS

The Mercury-containing and Rechargeable Battery Management Act was passed in 1996 to phase out the use of mercury in batteries and to provide for the efficient and cost-effective collection and recycling or proper disposal of used nickel cadmium batteries, small sealed lead-acid batteries, and certain other batteries [31]. According to the United States EPA, battery recycling keeps heavy metals (the primary contaminant of all batteries) out of landfills and out of the air [32]. If left in landfills, it is possible for the heavy metals from batteries to seep into groundwater systems. In locations where trash is incinerated, the heavy metals may also be lifted into the atmosphere with the ash. Hence, batteries can be a source of both air and water pollution and poisoning.

Replacing a battery system with a fuel cell eliminates the source of these heavy metals in our environment. The proposed design has replaced several systems that are traditionally battery powered with hydrogen fuel cells. Of these applications, the largest is the electric power back-up system manufactured by Altergy Systems. Instead of using traditional battery back-up, the system utilizes stacked hydrogen fuel cells to provide back-up power. It should be noted, however, that a small number of batteries are necessary to maintain a workable transient response, as the fuel cells are not able to respond immediately.

Additional systems that have been retrofitted with a fuel cell to replace a battery include class 1 lift truck, scooter, ground support vehicle, personal transporter, and portable power packs. In all of these applications, the user will be utilizing not only a more environmentally friendly product, but also one with greater reliability and energy efficiency due to the implementation of a fuel cell.

5.3. GENERATOR NOISE POLLUTION COMPARISONS

While pollution is traditionally thought of as contaminants to our air, water, and soil, excessive noise is also considered a pollutant, especially in urban areas. In this respect, fuel cells and hydrogen energy offer yet another benefit over traditional systems. As an example, the Pure Cell® 200 will be compared to a Caterpillar diesel generator of comparable load rating. EPA recommends sound levels to prevent hearing loss with a reasonable margin of safety is below 70 dB_A (continuous exposure) [33]. At a distance of 50 feet, a Caterpillar generator equipped with a sound attuned enclosure has sound pressure levels of approximately 70 dB_A. But, the Pure Cell® 200 unit only produces sound pressure levels of 60 dB_A at a distance of 30 feet. If a low noise cooling module is purchased for the Pure Cell® 200 unit, the sound level is further reduced to 54 dB_A at 30 feet. Sound pressure levels of 55 dB_A outdoors is identified by EPA as noise level preventing activity interference and annoyance, emphasizing the quiet operation of the fuel cell unit[33].

6. MARKETING AND EDUCATION PLAN

The marketing and educational plan is one of the most important programs in order to achieve the success of appropriate use of hydrogen based applications. Programs for both the airport staff and the general public are detailed below.

6.1. EDUCATIONAL PLAN

An effective educational plan must consider many different methods of learning: linguistic, logical, spatial, musical, kinesthetic, as well as interpersonal and intrapersonal learners. Activities that will be employed in this design are listed in the following subsections.

6.1.1. Trained Airport Staff. The hydrogen safety training and education are going to be based on inputs from hydrogen experts, academic faculty and staff (Missouri S&T), energy leaders, and safety training providers to build support for understanding of hydrogen technologies. The first step in the process will be to adapt the attitude of the airport personnel to eliminate any resistance to change and to sensitize the topics of energy and security for the hydrogen systems. In the second part, time will be spent to explain all of the systems, mechanisms, controls, security, safety procedures, reporting of data, monitoring, and other additional tasks. Interactive workshops using a combination of several techniques will provide an experience of learning more profound and pragmatic than lecturing alone would. These workshops will be based on the PPP procedure (Presentation, Practice, and Production).

6.1.2. General Public/Travelers. The principal objective of the general public education is to explain the basics of hydrogen production, delivery, storage, and fuel cell technologies. Missouri S&T's team will organize seminars aimed at educating the public. In a case study of the approach to training, the instructor acts more as an assistant to the learning process of group, an advisor when required and a catalyst for learning, instead of lecturer or a trainer. The methodology of the educational part includes:

(i) Workshops which provide a stimulating learning environment will bring together people with a wide range of experience. In these workshops, the general public and travelers wary of new technologies may express concerns about safety and efficiency to allay public safety fears or reduce potential resistance. Topics will include: the environmental benefits of hydrogen in contrast to gasoline, the future scarcity of oil, the inevitable necessity of alternative energy resources, the wide availability and easy production of hydrogen fuel, and facts regarding driving and refueling a vehicle. These topics will seek to educate the public as to the improvements hydrogen technology will bring.

(ii) Interactive web pages. Communication skills and organization are as important as the technical knowledge of these topics. Adults learn best when they are involved in an active way: remembering 20% from what they hear, 40% of what they see, and 80% of what they discover for themselves. Therefore, this package is based on interactive teaching methods.

6.2. MARKETING PLAN

The designers of new airport facilities face a series of new challenges to achieve the balance between long term economic and environmentally sustainable development. These challenges include issues such as security, costs, passengers, communications, and also energy. For this reason, the recommendations of the Voluntary Airport Low Emission (VALE) Program of Federal Aviation Administration suggest the use of hydrogen as good practice at airports [34].

6.2.1. International Experiences. Different airports have diverse programs and solutions to face problems related to air pollution, security, energy, and passenger comfort. One example can be seen in the Munich International Airport, ranked 28th by total amount of passengers [35]. The sustainable promotion of hydrogen energy in this strategic master project shall help to demonstrate the application of hydrogen and prepare the ground for a wide operational spectrum in the future. For the first time in the world, the production and storage of hydrogen, as well as the fully automated fuelling of passenger busses and other vehicles, is being tested under the strict safety regulations of an international airport. In addition, the Illinois Clean Energy Community Foundation developed Illinois' first hydrogen fueling station powered by renewable sources. “The airport of the future will be clean, efficient and fuel independent" said Rockford Airport Director Bob O'Brien. "I'm excited that we'll be the first airport in the world to demonstrate that renewable solar and wind energies can be successfully integrated into the transportation sector."[36]. Also, the marketing team will be present at local events to present these experiences and other local experiences, answer any questions, and distribute brochures about this new technology. In addition, presentations will be made at the different events such as those organized by Airport Council International (ACI).

6.2.2. Publicity. The publicity program will start with advertisements for the general public and travelers. The goal will be to demonstrate the advantages of technologies where hydrogen fuel can help reduce greenhouse gases and diversify the world's energy supply, and that hydrogen safety, like any fuel, requires proper handling and safe system designs for production, storage, and usage.

Also, newsletters will be distributed to the entire community, including workers of the airport. The topics will include environmental benefits, information on the vehicles, and information on the station itself. Use of hydrogen technologies and fuel cell technology applications should include a detailed description of the fuel cell installations, how it will be publicly visible to demonstrate the practical use of fuel cells, and a data collection plan on system operation in different advertisement panels. It is suggested to use two large bulletin board displays to advertise the hydrogen fueling station to the widest audience. A preliminary example of a possible periodical advertisement for the new hydrogen systems at the airport can be found in Appendix A.

7. CONCLUSIONS AND RECOMMENDATIONS

Potential hydrogen applications that could be deployed at Lambert-St. Louis International Airport was identified, selected, designed, and analyzed. The proposed hydrogen technologies include back-up power fuel cell system for airport's critical computer network, fuel cell for auxiliary power generation, hydrogen fueling station, hydrogen powered vehicle applications, portable hydrogen fuel cell power packs, and hydrogen technologies for public education. These technologies or application have the potential to mitigate the critical challenges related to pollution, energy efficiency, safety and security. Safety analysis of the proposed hydrogen systems was performed and major failure modes were identified.

The environmental analysis demonstrated that hydrogen production pathway has a significant impact on the environment. Even though hydrogen applications at the airport will lower CO_2 emissions, priority should be given to hydrogen production using electrolysis from renewable and nuclear sources, as well as from fossil fuel-based systems with carbon sequestration rather than using steam methane reformation and electrolysis using grid power. The total initial cost of the design and the annual operating cost were estimated to be $3,650,000 and $376,000 respectively. However, the proposed design will solve critical problems and will reduce airport down time and thus loss of revenue. Through the utilization of hydrogen technologies, Lambert-St. Louis International Airport can not only improve process efficiencies, but can also help keep the world clean for future generations.

APPENDIX A

HYDROGEN APPLICATIONS AT AIRPORT - ADVERTISEMENT

Advertisement for Hydrogen Systems at STL

APPENDIX B

AIRLINE STATICS - BUREAU OF TRANSPORTATION STATISTICS

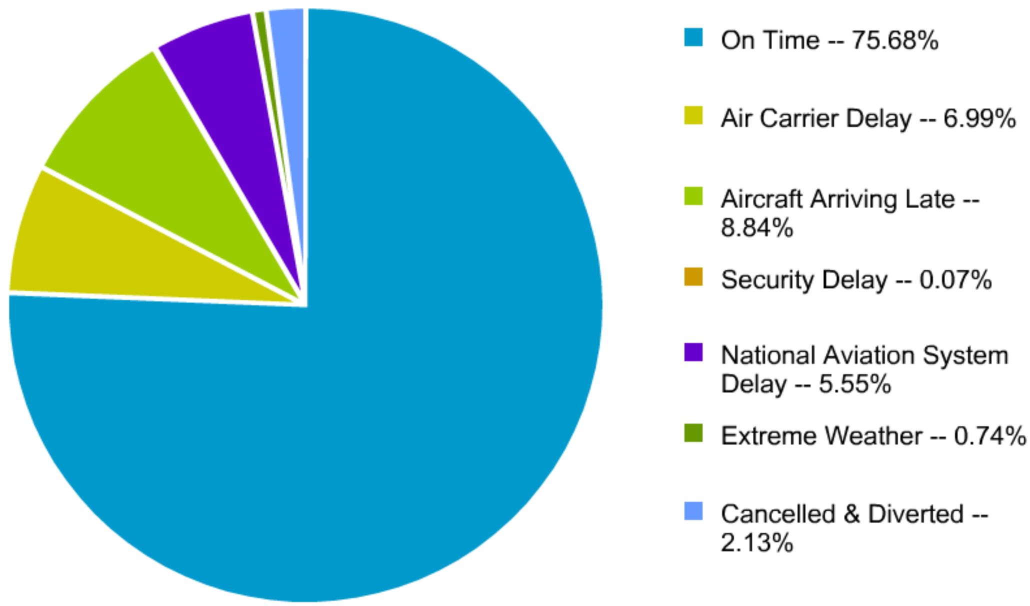


Figure 1. Flight Delays by Cause, STL (April 2007 - Sep 2008) [37]

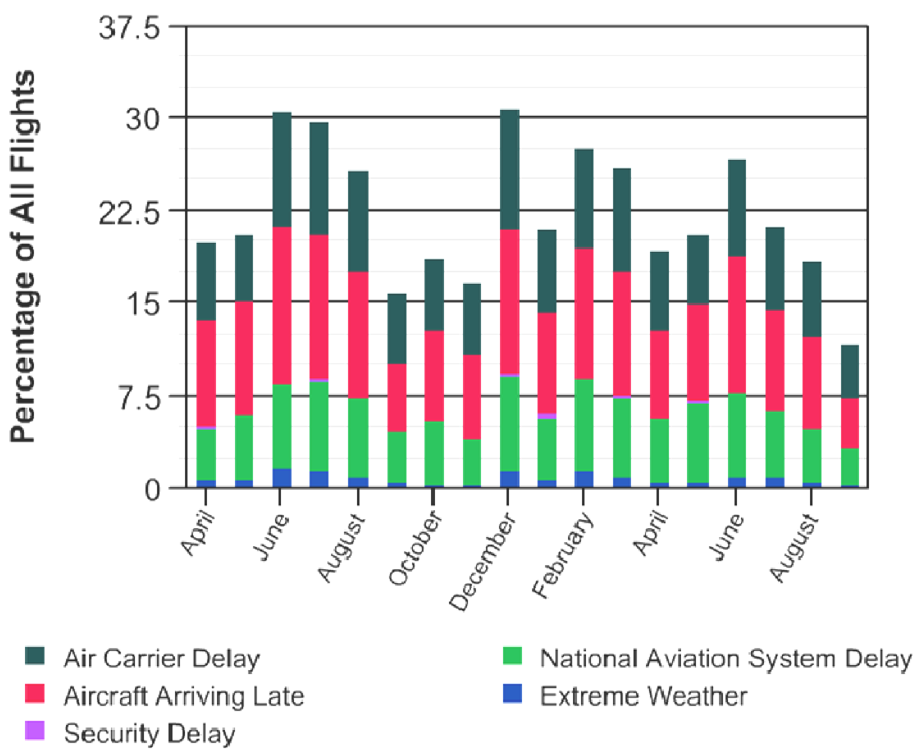


Figure 2. Flight Delay by Cause, STL (April 2007 - Sep 2008) [37]

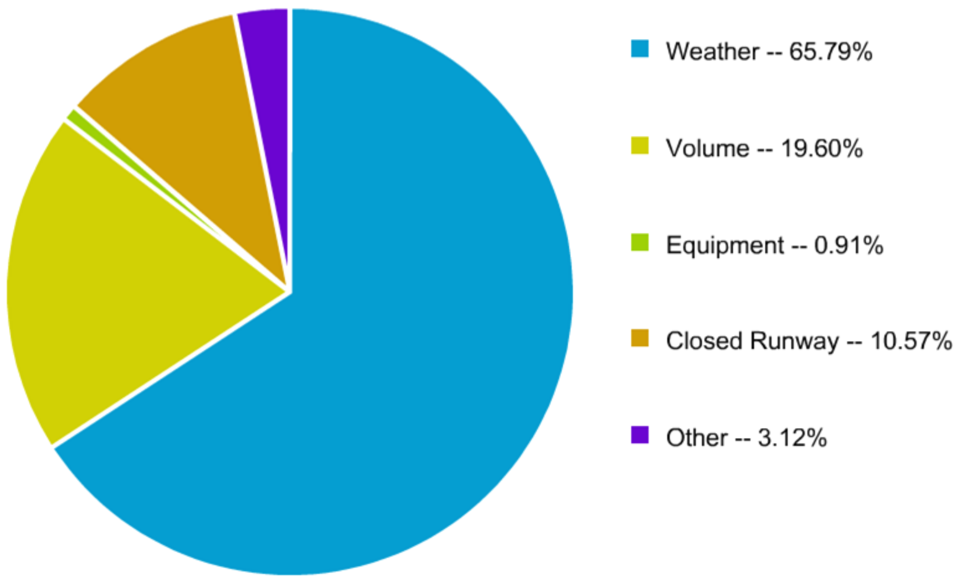


Figure 3. Causes of National Aviation Systems Delays, STL (April 2007 - Sep 2008) [37]

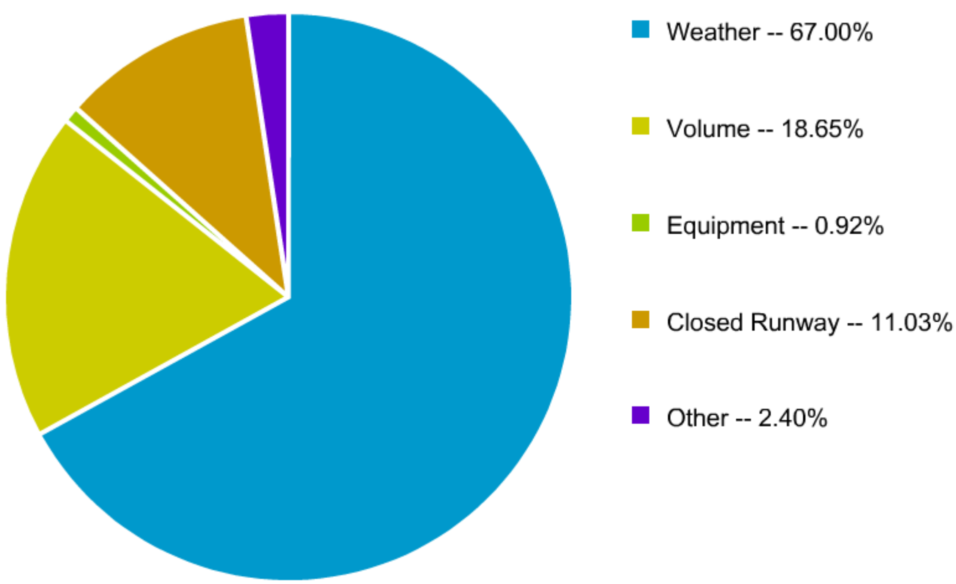


Figure 4. Causes of National Aviation Systems Delays, National
(April 2007 - Sep 2008) [37]

APPENDIX C

HYDROGEN EQUIPMENT MATRIX

Equipments & Vehicles used	Process / Fuel Cell	H_2 Production	Storage	Compression	Use
PureCell™ Model 200	SMR / PAFC	Intermediate	-	-	Auxiliary power
Low Pressure H_2 cylinders	-	-	0.463kg/cyl	2265 psig	H_2 storage
Mobile Hydrogen Unit (MHU)	SMR	15 kg/day	18 kg	6000 psig	H_2 production & storage
External H_2 Storage Tanks	-	-	33 kg	6000 psig	H_2 storage
GTI/Greenfield H_2 Dispenser	-	-	-	5000 psig	H_2 dispensing
FuelGen 12	PEM	12.94 kg/day	-	218 psig	H_2 s production
Altergy Freedom Power™ Backup	PEM	-	-	-	Backup power
Fuel cell lift truck	PEM	-	1.6kg	5075 psig	Fork lift
Ford H2ICE E-450 shuttle bus	H2IC Engine	-	29.4 kg	5000 psig	Shuttle bus
Fuel cell Ground Support Equipment	PEM	-	0.6 kg	5075 psig	Ground support vehicle
Fuel cell Personal Transporter	PEM	-	H_2 canisters	400 psig	Personal Transporter
HOGEN® H Series Electrolyzer	-	4.31 kg/day	-	218 psig	H_2 production
Plug Power Fuel Cell	PEM	-	-	-	Power supply
APFCT®H_2 canister refilling station	-	-	-	300 psig	H_2 canister refilling station
APFCT®H_2 canister	-	-	0.2 kg	300 psig	H_2 storage
APFCT®Fuel Cell Scooter	PEM	-	0.4 kg	300 psig	Scooter
Jadoo FillPoint™ H_2 refilling station	-	-	-	400 psig	H_2 canister refilling station
Jadoo XRT ™ power supply	PEM	-	6 H_2 canisters	400 psig	Power supply

APPENDIX D

GREET ANALYSIS

Data from GREET Analysis

Table 1. Gasoline Vehicle

Item	Btu/mile or grams/mile		
	Feedstock	Fuel	Vehicle Operation
Total Energy	321	1,255	6,482
Fossil Fuels	310	1,137	6,364
Coal	51	210	0
Natural Gas	181	384	0
Petroleum	79	543	6,364
CO2	21	87	498
CH4	0.599	0.101	0.020
N2O	0.001	0.006	0.012
GHGs	37	91	502
VOC: Total	0.023	0.154	0.254
CO: Total	0.043	0.049	4.944
NOx: Total	0.159	0.148	0.345
PM10: Total	0.013	0.057	0.033
PM2.5: Total	0.006	0.021	0.019
SOx: Total	0.056	0.102	0.008
VOC: Urban	0.004	0.097	0.158
CO: Urban	0.002	0.023	3.075
NOx: Urban	0.007	0.061	0.215
PM10: Urban	0.000	0.012	0.021
PM2.5: Urban	0.000	0.007	0.012
SOx: Urban	0.005	0.043	0.005

Table 2. Natural Gas Vehicle

Item	Btu/mile or grams/mile		
	Feedstock	Fuel	Vehicle Operation
Total Energy	530	505	6,823
Fossil Fuels	526	439	6,823
Coal	19	316	0
Natural Gas	478	101	6,823
Petroleum	29	23	0
CO2	37	42	405
CH4	1.628	0.056	0.205
N2O	0.001	0.001	0.012
GHGs	78	44	414
VOC: Total	0.041	0.004	0.184
CO: Total	0.058	0.011	4.548
NOx: Total	0.166	0.046	0.345
PM10: Total	0.007	0.056	0.033
PM2.5: Total	0.004	0.015	0.019
SOx: Total	0.081	0.102	0.002
VOC: Urban	0.001	0.000	0.114
CO: Urban	0.002	0.002	2.829
NOx: Urban	0.006	0.008	0.215
PM10: Urban	0.000	0.000	0.021
PM2.5: Urban	0.000	0.000	0.012
SOx: Urban	0.002	0.018	0.001

Table 3. H2ICE Vehicle

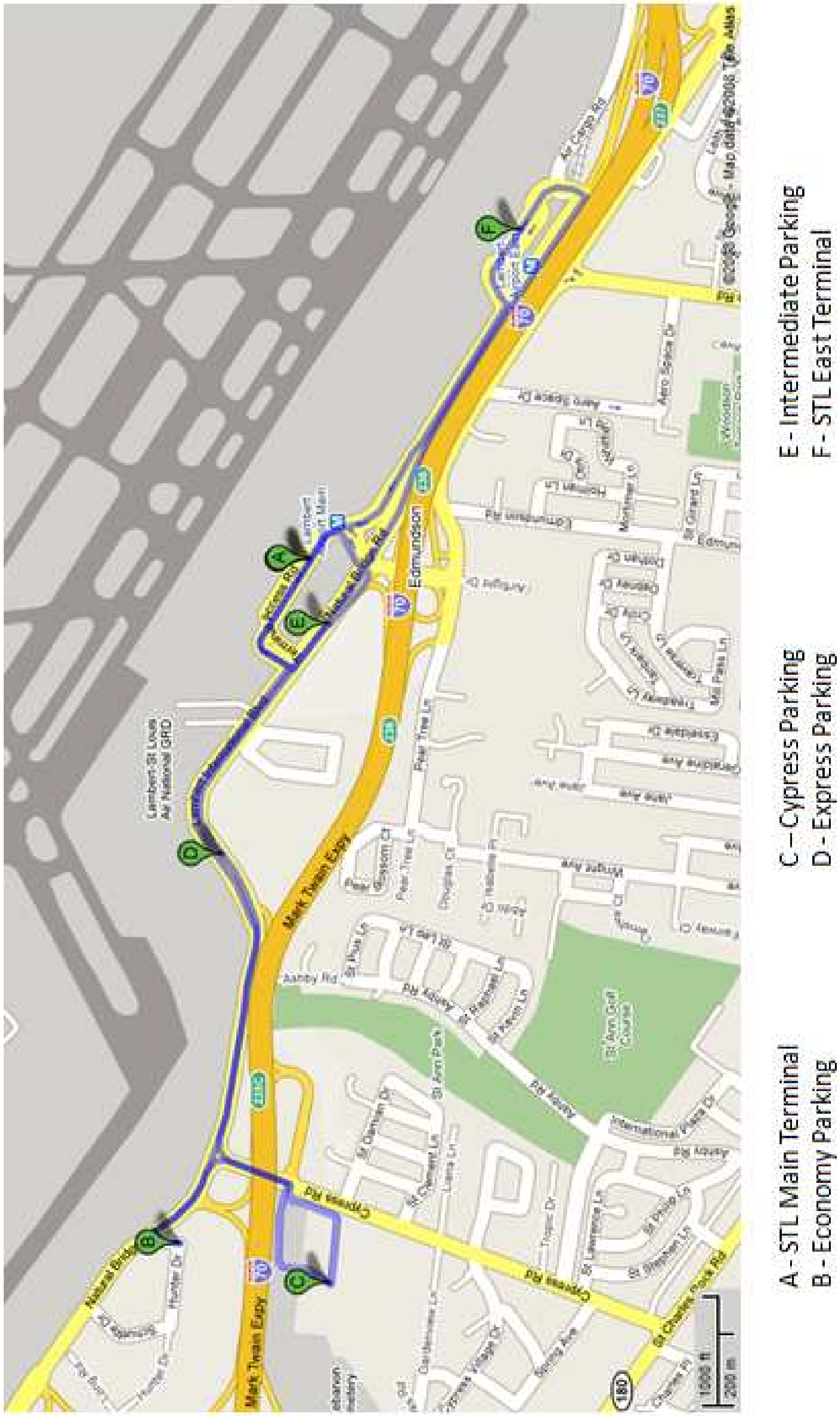
Item	Btu/mile or grams/mile		
	Feedstock	Fuel	Vehicle Operation
Total Energy	449	3,843	5,788
Fossil Fuels	446	3,673	5,788
Coal	16	820	0
Natural Gas	405	2,783	5,788
Petroleum	25	69	0
CO2	32	606	0
CH4	1.381	0.707	0.009
N2O	0.001	0.002	0.012
GHGs	66	624	4
VOC: Total	0.035	0.036	0.122
CO: Total	0.049	0.121	2.571
NOx: Total	0.140	0.283	0.345
PM10: Total	0.006	0.217	0.026
PM2.5: Total	0.003	0.110	0.013
SOx: Total	0.069	0.291	0.000
VOC: Urban	0.001	0.010	0.076
CO: Urban	0.002	0.057	1.599
NOx: Urban	0.005	0.098	0.215
PM10: Urban	0.000	0.050	0.016
PM2.5: Urban	0.000	0.050	0.008
SOx: Urban	0.002	0.047	0.000

Table 4. Hydrogen Fuel Cell Vehicle

Item	Btu/mile or grams/mile		
	Feedstock	Fuel	Vehicle Operation
Total Energy	283	2,418	3,642
Fossil Fuels	281	2,311	3,642
Coal	10	516	0
Natural Gas	255	1,751	3,642
Petroleum	16	43	0
CO2	20	381	0
CH4	0.869	0.445	0.000
N2O	0.000	0.002	0.000
GHGs	42	393	0
VOC: Total	0.022	0.023	0.000
CO: Total	0.031	0.076	0.000
NOx: Total	0.088	0.178	0.000
PM10: Total	0.003	0.137	0.021
PM2.5: Total	0.002	0.069	0.012
SOx: Total	0.043	0.183	0.000
VOC: Urban	0.001	0.006	0.000
CO: Urban	0.001	0.036	0.000
NOx: Urban	0.003	0.061	0.000
PM10: Urban	0.000	0.032	0.013
PM2.5: Urban	0.000	0.031	0.007
SOx: Urban	0.001	0.030	0.000

APPENDIX E

PROPOSED SHUTTLE BUS ROUTE



Proposed Shuttle Bus Route at Lambert-St. Louis International Airport [38]

APPENDIX F

CODES AND STANDARDS MATRIX

Codes and Standards [39]

Equipments & Vehicles used	**Codes & Standards**
PureCell® Model 200	CSA No. 5.99, UL 2264B, ISO 16110-1, ASME PTC 50, NFPA 70 Art 692, NFPA 110
Low Pressure Hydrogen cylinders	ASME BPVC
Altergy Freedom Power™ Backup	ASME PTC 50, CSA No. 33, UL 1741, NFPA 853,NFPA 70 Art 692, NFPA 110
Mobile Hydrogen Unit	CGA PS-26, CGA PS-2, ASME BPVC, NFPA 52
External Hydrogen Storage Cylinder	CGA PS-26, CGA PS-2, ASME BPVC, NFPA 52
Hydrogen Dispenser	NFPA 52, SAE J 2600
Fuel Cell Lift Truck	SAE J 2572, 2574, 2578, NFPA 52, SAE J 2600, SAE J 2719
Ford H2ICE E-450 shuttle bus	NFPA 52, SAE J 2600
Fuel cell Ground Support Vehicle	SAE J 2572, 2574, 2578, NFPA 52, SAE J 2600, SAE J 2719
HOGEN® H Series Electrolyzer	CSA No. 5.99, UL 2264B, ISO 16110-1
Altergy Freedom Power™ Fuel Cell	CSA FC 1, CSA No. 33, UL 1741, NFPA 853, NFPA 70 Art 692, NFPA 110
APFCT® Fuel Canister Refilling Station	CGA H-2, NFPA 52
APFCT® Fuel Canister	CGA H-2
APFCT® Fuel Cell Scooter	CGA H-2, CSA FC 3, SAE J 2572, 2574, 2578, NFPA 52, SAE J 2719
Jadoo FillPoint™ Refilling Station	CGA H-2, NFPA 52
Jadoo XRT™ Extended Runtime Adaptor	CGA H-2, CSA FC 3
Hydrogen Piping and Pipelines	ASME B31, CGA G 5.4, CGA 5.6
Hydrogen Vent Systems	CGA G-5.5
Hydrogen Fueling Station	ISO/PAS 15594
Installation & operation	OSHA: 29 CFR 1910.103
All equipments	NFPA 55

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VITA

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