Hydrogen Powered Fuel Cell/Battery Hybrid Scooter

Hydro Scooters

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…and Google for their awesomeness.

EXECUTIVE SUMMARY

In accordance with the request for proposal put forth, the following report describes our approach to convert a gasoline powered Vespa Granturismo 200 (GT200) scooter to run on hydrogen fuel. The product is planned to launch in the North American and European markets in May 2007.

The hydrogen scooter (dubbed the Vespa GT200**H**) is designed to perform similar to the gasoline version. To achieve this, a 500W fuel cell power module is incorporated along with a 3.7kWh 125V NiMH battery pack. The battery is charged by the fuel cell and powers an electric motor. The GT200H maintains the aesthetic appearance and Italian styling of the GT200. The scooter can be fueled at a high-pressure (6000psig) hydrogen gas fueling station in under 3 minutes (at a fueling rate of 85g/min or higher). The design incorporates solar panels to power the dashboard display. Nanotechnology has been exploited to enhance scooter performance and durability in several ways.

Safety is considered an essential part of the scooter's design. The normal operation of the scooter is ensured through compliance with regulating standards. Additionally, systematic assessments and risk mitigation strategies have been performed to minimize hazards and operability issues.

The marketing plan uses promotional and educational techniques to promote the GT200H and to communicate the benefits of hydrogen to the general public. Our team completed a detailed economic and business analysis of the fuel cell/battery hybrid scooter. This economic analysis addressed production and operational costs, revenue streams, the benefits of owning a hydrogen fuel cell scooter, and other economic and marketing issues. The GT200H will be priced at US $9,157 to yield a 5% internal rate of return over a 10-year period (2007 – 2017).

A thorough environmental emissions analysis was performed to compare the hydrogen scooter with the gasoline version. Energy input/output was performed for CO_2 emission.

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1.1 Overview

Hydrogen, the most abundant element in the universe, has great potential as an energy source. Unlike petroleum, it can be easily generated from renewable energy sources. It is also nonpolluting, and forms water as a harmless byproduct during use.

In retrofitting the Vespa Granturismo 200 to be fuelled by hydrogen, several technical aspects must be considered. The main goal is to maintain the performance envelope and range capacity offered by the gasoline version, while providing an acceptable level of safety. Moreover, the Vespa GT200 has stylized storage (such as the two-helmet storage underneath the seat) that will not be modified in any way.

HydroScooters' GT200H weighs 200kg and uses a fully integrated PEM power module that delivers 500W at 50% efficiency. The power module continually charges the scooter's NiMH batteries (125V, 3.7kWh, 30Ah) that in turn provide power, via the motor controller, to drive a 90% efficient 125V DC electric motor. The fuel cell shuts off automatically when the battery pack is fully charged. Fueling is done at a hydrogen fueling station into a 28L compressed hydrogen tank located in the belly of the scooter. From our power calculations (see section 1.9 below), this model allows the scooter to be driven for 200km in the city (30km/h) with a top speed of 100km/h. Table 1.1 below compares the characteristics of the GT200 versus GT200H.

	GT200H	**GT200**
Fuel	Hydrogen	Gasoline
Weight	200kg	140kg
Range	200km	200km
Acceleration (0 - 50km/h)	3.6 sec	5.0 sec
Top Speed	100km/h	120km/h
Noise	Very Quiet	Noisy
Emissions	Zero	High
Maintenance	Minimal	High
Operating costs	Very Low	High

Table 1.1 Comparison of GT200 vs. GT200H

Section 1.2 briefly discusses the outstanding design strategy employed by HydroScooters. Following sections briefly discuss the components and their integration into the scooter. Section 1.8 highlights some of tremendous advantages that could been obtained by incorporating nanotechnology in various components of the scooter. Section 1.9 briefly discusses directions for future improvements. Finally, the process flow diagram for scooter operation is appended to the end of the technical section.

1.2 Design Strategy

The hydrogen-powered GT200H employs a clever strategy and state of the art technology to deliver a product that is economically feasible, technically sound and operationally safe. At first glance designing a hydrogen-powered scooter that simultaneously satisfies all of these criteria seems impossible. The GT200's gasoline internal combustion engine delivers 15.4kW of power. A 10kW PEM fuel cell at the heart of a comparable hydrogen-powered scooter would alone cost $30,000 according to optimistic estimates.

The GT200H scales this major hurdle by incorporating a hybrid design, combining the best features of hydrogen fuel cells and battery technology. By employing the combination of a 500W fuel-cell and a 125V NiMH rechargeable battery, we have managed to scale the cost down to a manageable amount while providing comparable power.

1.3 Components

1.3.1 Power Module

Our design calls for a state-of-the-art proton exchange membrane (PEM) fuel cell module. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles [1]. Ballard Power Systems makes PEM modules suitable for mobile applications. For example, the Mark902 [2] power module is robust and features reliable operation and durable packaging. Alternatively, Protonex Tech. offers 500W power modules [3] for niche motor scooter applications. The scaled dimensions for such a power module are 250x400x520 mm.

1.3.2 Hydrogen Storage

Fueling is done at a hydrogen fueling station (up to 6000psig). Two main options are available for storing hydrogen onboard vehicles – compressed gas or solid-state storage such as metal hydrides.

Metal-hydrides, such as Mg_2NiH_4 and $LaNi_5H_6$ [4] reversibly adsorb and desorb large amounts of hydrogen. A storage tank using metal hydride may contain 100 times [5] more hydrogen than a conventional compressed gas cylinder. However, although metal hydrides are inherently safer and have the potential to be more efficient than gas or liquid storage, at this point, they are not economically viable. Adverse issues with metal hydride materials include cost, weight, uptake, release kinetics and thermal management during refueling. Metal hydride tanks are heavy and degrade scooter performance severely.

Compressed gas storage is more suitable for scooters. Our calculations indicate a 200km trip requires 250g of hydrogen that can be stored in a 28L tank at 1800psig. The tank can be filled in under 3 minutes at a fueling rate of 85 g/min or higher. A 25kg tank is offered by the FuelCellStore [6] (High Pressure Cylinder SP22017-1). A pressure regulator (CGA 350 fitting) [6] ensures that hydrogen is fed to the fuel cell stack in the power module at 1-2 bar. Additionally, Quantum Tech. [7] has recently developed a lightweight composite tank, the TriShield tank, for vehicular applications in collaboration with the US Dept. of Energy. Currently, however, the Trishield tank is not economically feasible, but we can expect that over the next few years' price reduction would enable us to incorporate it in our design.

1.3.3 Battery Pack

Four main types of battery choices are commercially viable for a scooter: Li-ion (Lithium ion), NiMH (Nickel metal hydride), NiCd (Nickel Cadmium) and SLA (sealed lead acid) [8]. The immediate advantage of Lithium battery chemistry is higher charge density. Li ions are small and mobile, and more readily stored than hydrogen. Thus a battery based on Li is smaller than one with hydrogen, such as a NiMH or NiCd, and with fewer volatile gases. However, they are not as durable as NiMH or NiCd designs and can be extremely dangerous if mistreated.

The NiMH battery has many significant advantages over other rechargeable technologies including cycle life, safety, and non-hazardous materials. A NiMH battery is similar to a NiCd battery but which does not contain expensive (and environmentally risky) cadmium or lead (Cadmium causes calcium loss in bones within hours of exposure [9] while lead is thought to cause brain damage in children). This is why NiMH batteries are sometimes called the most environmentally friendly battery type. They are used in hybrid vehicles such as the Toyota Prius, and electric vehicle development is underway. For these reasons, a NiMH battery pack solution is employed in the GT200H.

The "metal" in a NiMH battery is actually an intermetallic compound. Many different compounds have been developed for this application, but those in current use fall into two classes. The most common is AB_5 (e.g. $LaNi_5$), where A is a rare earth mixture and/or titanium and B is nickel, cobalt, manganese, and/or aluminum. Higher-capacity "multi-component" electrodes are based on AB_2 (e.g $TiNi_2$) compounds, where A is titanium and/or vanadium and B is zirconium or nickel, modified with chromium, cobalt, iron, and/or manganese [10].

A 3.7kWh, 30Ah capacity NiMH battery at 125V is ideal for the scooter. Such a battery pack is already being employed [11] by a hybrid electric scooter (Vectrix Maxi [12]) and is manufactured by Gold Peak Batteries of Hong Kong.

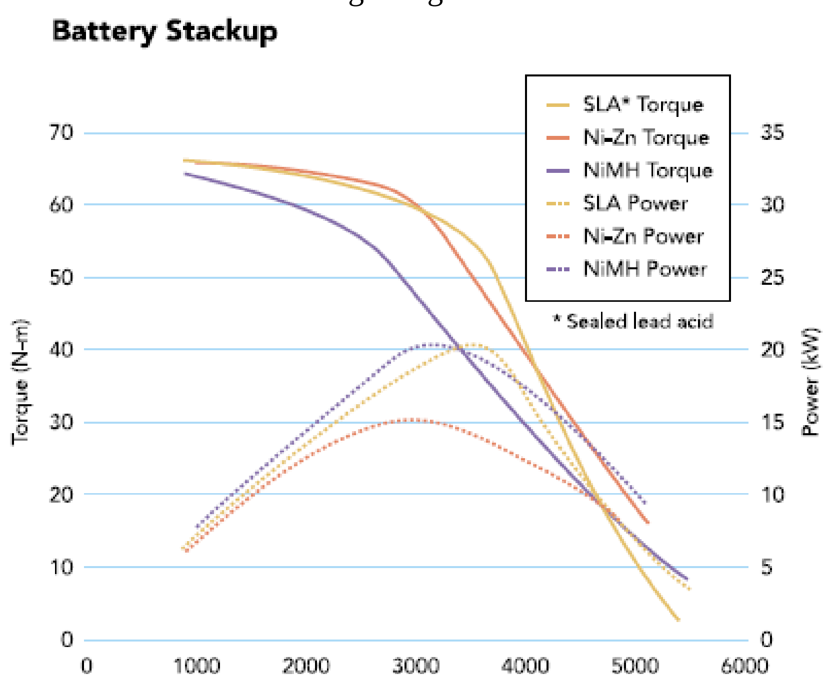


Fig. 1.1: Battery comparison between NiMH, SLA and Ni-Zn for power/torque/rpm in a scooter

1.3.4 Electric Motor, Gearbox and Controller

A brushless 125V DC electric motor with an integrated rear wheel gearbox solution is used in the scooter. It provides 20 kW of power at 3000 rpm. The DC motor is designed and manufactured specifically for electric scooters by Parker Hannifin's Divisione SBC [13] in Italy. This custom DC motor is lightweight, efficient and low cost. It converts electrical energy from the battery pack to drive the scooter's rear wheel through a single-stage planetary gearbox.

The single-stage, planetary gearbox represents a unique feature of the GT200H drive-train technology. The gearbox, prototyped by Getrag Gears GmbH [14] (exclusive suppliers of manual transmissions to Audi, Porsche, and Mercedes Benz), is integrated into the rear wheel of the scooter and provides a highly efficient gear reduction between the motor shaft and the road surface. The integrated gearbox and electric motor eliminate the need for gear shifting. The direct rear-wheel drive configuration of DC motor provides instant torque and also gives an acceleration boost there is no need to wait for fuel to pass through a carburetor.

The scooter's range is boosted by employing an intelligent controller system that optimizes the phase angle advance of the motor to get the most efficient operation out of it. The controller generates a pulsewidth-modulated signal that makes the DC motor operate as if it is running off a three-phase AC electrical supply. The controller also acts as the central control system of the scooter and it monitors pressure, temperature, voltage and current. It processes this information to optimize energy efficiency, to ensure normal operation and in the case of a hazard the control system is programmed to mitigate effects. More details of the control system operation are included in the safety analysis.

1.3.5 Scooter Bodywork/Frame

Our design employs a powerful battery pack that weighs 80kg. This excess weight adversely affects scooter performance. To accommodate this, major weight needed to be lost in other areas. We achieve this goal by replacing the steel frame of the scooter by aluminum one. This would reduce the frame's weight from 40kg to 11kg [15], limiting the overall hydrogen-powered scooter weight to less than 200kg. The overall increase in materials cost would be negligible (aluminum cost USD1/lb in March 2006). Alcoa Inc. provides customized aluminum applications for commercial transportation [16]. Moreover, Alcoa Technical Center has facilities to perform finite element analysis on newly designed scooter frames.

1.4 Spatial Arrangement

To preserve the clean Italian styling, our team will not make significant changes to the external looks of the scooter. A compact layout that ensures safety is necessary for the power module, hydrogen tank and battery pack. Below the seat is the storage area for two helmets. The hydrogen tank will be located directly below this storage, and will utilize the existing gasoline opening to take in hydrogen from a pump. The main dimensions of the scooter are shown in fig. 1.2. The power module and battery packs will be positioned below the tank as shown in figs. 1.3 and 1.4 below. Fig. 1.5 shows a CAD model of the motor with the gearbox and fig. 1.6 shows its location on the scooter.

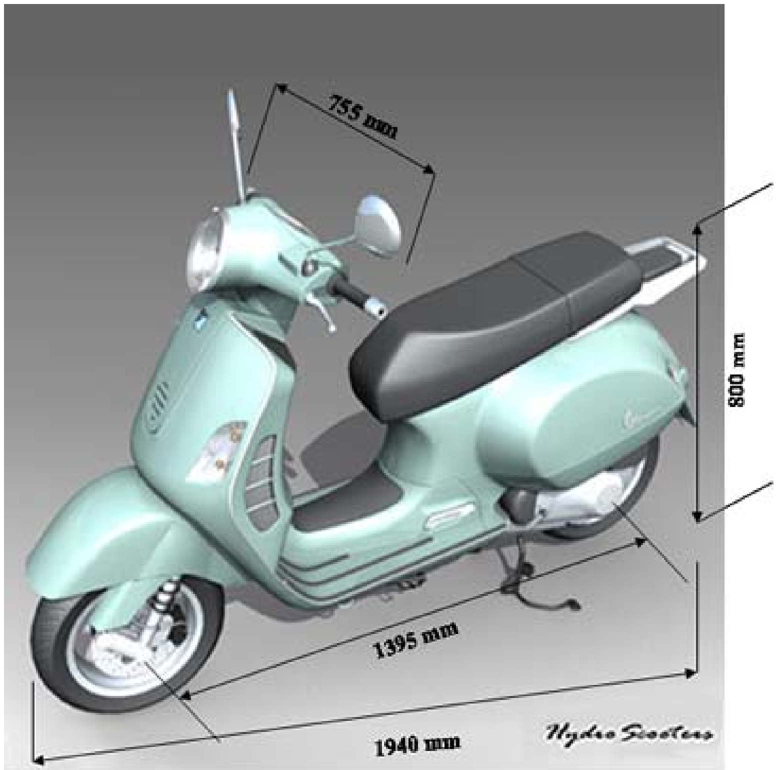


Fig. 1.2: CAD model of Vespa GT200 showing main dimensions

Fig. 1.3: GT200 internal combustion engine (ICE), shown with the seat and helmet storage removed

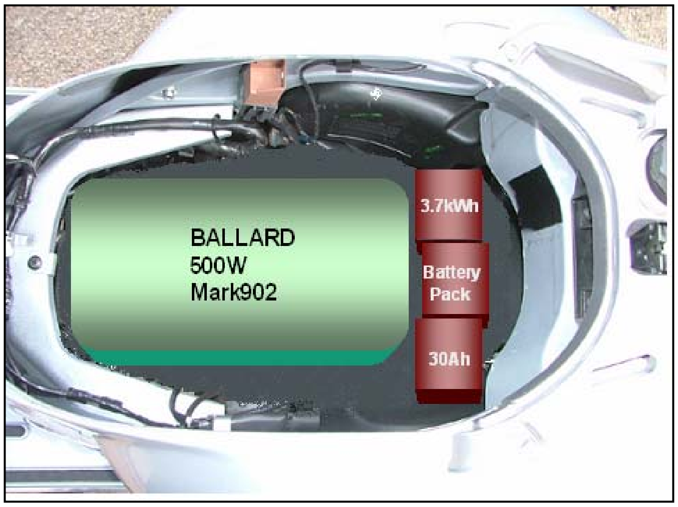


Fig. 1.4a: The ICE is removed and replaced with the PEMFC and battery pack

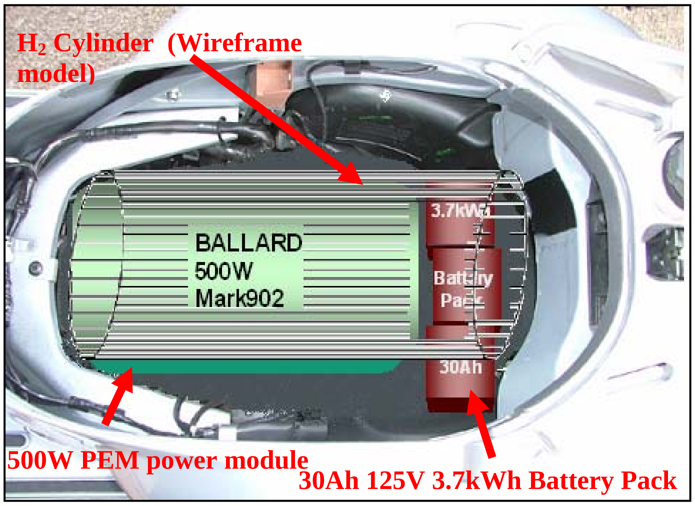


Fig. 1.4b: The hydrogen cylinder is placed over the PEMFC/battery pack

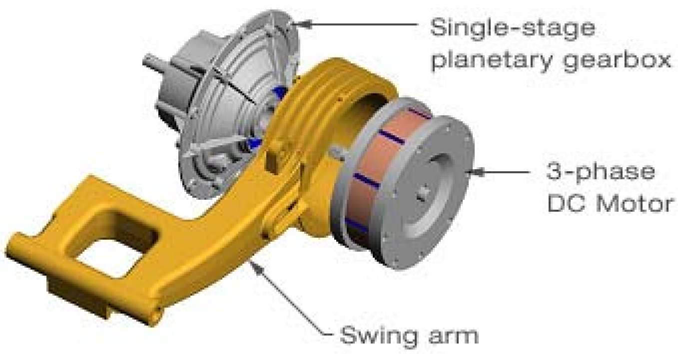


Fig 1.5a: 125V DC Brushless Motor with attached gearbox

Fig 1.5b: DC motor

Fig. 1.6a: Motor and gearbox location

Fig. 1.6b: Components such as silencer are removed

The table below summarizes the main components that are removed from the gasoline GT200 and lists the components to make it the GT200H.

	Component	Weight (kg)	Volume (Litres)
Remove	Engine Gas Fuel Tank Carburetor Air Filter Oil pump Exhaust system Transmission and chain system	50	140
	Starter battery	2	1
	Steel Frame	40	
	Silencer	1	located out of body
	Components to be removed	**93**	**141**
Put in	Power Module (500W)	15	42
	Hydrogen storage tank (compressed gas)	25	27.5
	High Pressure Regulator 3910-15-350	neg.	neg.
	Electric Motor (incl. Gearbox)	20	located out of body
	Controller	neg.	neg.
	Battery	80	30
	Al Frame	11.3	-
	Components to be added in	**151.3**	**99.5**
	Comment	**Total Weight =198.3**	**Volume added < Volume removed**

Table 1.2: Main components to be removed and added

1.5 Alternate Energy

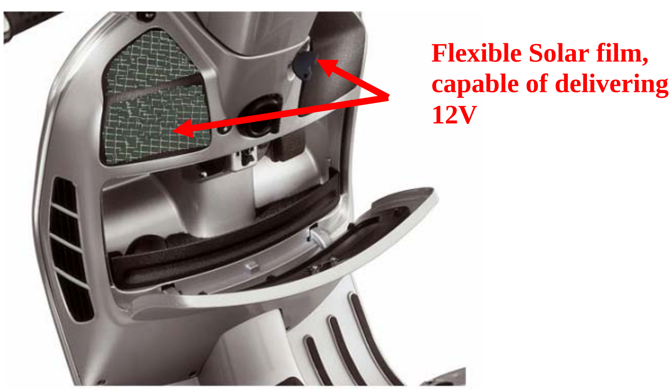


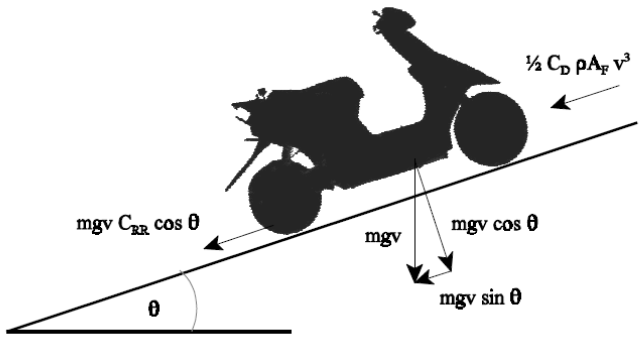
Fig. 1.7: Incorporating solar films on the scooter

Options for incorporating alternative renewable sources without changing the appearance include solar energy for the dashboard (lights, display, odometer) or to power auxiliary pumps that supply gas (oxygen/ hydrogen) to the fuel cell stack via solar panels. Shown below is a diagram of how solar photovoltaic cells could be used on the GT200H.

1.6 Fuel Cell Durability

A key technical challenge facing fuel cells is the need to increase durability and dependability. An important consideration is catalyst poisoning, which decreases fuel cell performance and longevity. By incorporating an appropriate nanomaterial catalyst, we can reduce cost and improve durability. For example, the FuelCellStore manufactures S-500 fuel cell system (500W) [17] that guarantees 20,000 hours runtime (~2.5 years of continuous operation).

1.7 Mathematical Model used in Calculation



$$P_{wheels} = (\, m a v \,) + (\, m g v \sin\theta \,) + (\, m g v C_{RR} \cos\theta \,) + (\, \tfrac{1}{2}\, \rho_{air} C_D A_F v^3 \,)$$

m = total mass of vehicle, passengers and cargo

θ = angle of slope

a = acceleration of vehicle

v = velocity of vehicle

C_{RR} = coefficient of tire rolling resistance.

ρ_{air} = density of air, approximately 1.23 kg•m^{-3}

C_D = drag coefficient

A_F = frontal area

Fig. 1.8: Free-body diagram of scooter [17]

To properly simulate the performance of a fuel cell scooter, a computer model was developed based on the physical parameters of the scooter [18]. This model calculates the instantaneous power required by the scooter for various driving patterns, and calculates various numerical performance characteristics: fuel consumed per kilometer, maximum power during driving cycle, average power during driving cycle, and overall hydrogen-to-mechanical-work conversion efficiency.

Power is calculated as power delivered to the wheel divided by the motor and controller efficiency, plus the auxiliary power demanded by lighting and control systems, plus "parasitic" power required by the fuel cell blowers and coolant pumps. The road is assumed to be level. There are several different physical forces to consider: air resistance (drag); the rolling resistance of the wheels; the force of gravity; and the normal force of the ground acting upon the vehicle. These forces must sum to zero if the scooter is held at a constant velocity, or to a net forward acceleration times mass if the vehicle is to accelerate.

In the computer model used to simulate vehicle performance, the various power demands are summed to a total mechanical power P_{wheels} demanded "at the wheels" by the motion of the vehicle (equation shown in Fig. 8). The inefficiencies in the system are applied afterwards to determine how much power must be put out by the power source:

$$P_{output} = (P_{wheels}) / \eta_{drivetrain} + P_{auxiliary} + P_{parasitics}$$

$P_{auxiliary}$ = power needed by auxiliary systems - headlights, signal lights, dashboard, etc.

$\eta_{drivetrain}$ = efficiency of the electric motor and controller subsystem

$P_{parasitics}$ = parasitic power needed by fuel cell system - blowers, fans, etc.

1.8 Exploiting Nanotechnology

The last few decades have witnessed a great revolution enabled through the exploitation of nanotechnology. As commercial applications of nanotechnology become economically viable they will significantly enhance the range and performance of the scooter. We will briefly discuss areas where the greatest improvements from these advances are realizable.

The PEM power module facilitates the electrochemical reaction between hydrogen and oxygen to produce water. The reaction is catalyzed by Platinum Group Metals (PGM) that are unfortunately very expensive. Nanotechnology has already enabled a ten-fold reduction of catalyst loading due to the increased surface area to volume ratio. In the future nanotechnology promises to provide cheaper alternatives (such as alloying Pt with transition metals or tailoring the Pt particle size [19]) to PGM catalysts that provide similar performance benefits.

NiMH battery incorporated in the scooter design provides reliable power. However, the battery has a poor energy density and it weighs half as much as the scooter. NiMH batteries are a matured technology and offer little promise of future development. On the other hand nano electrodes for Li ion batteries are being highly researched because of their high energy density. Their advantages include better accommodation of the strain of lithium insertion/removal, improving cycle life, higher contact area leading to higher charge/discharge rates [19].

The compressed hydrogen gas storage offers another venue where major improvement in performance is expected. As mentioned above carbon fiber reinforced tanks, although expensive, are commercially available on the market. The tanks offer higher storage density (upto 10,000 psig storage pressures) and significantly less weight. These improvements would result in significantly improved range and acceleration of the scooter.

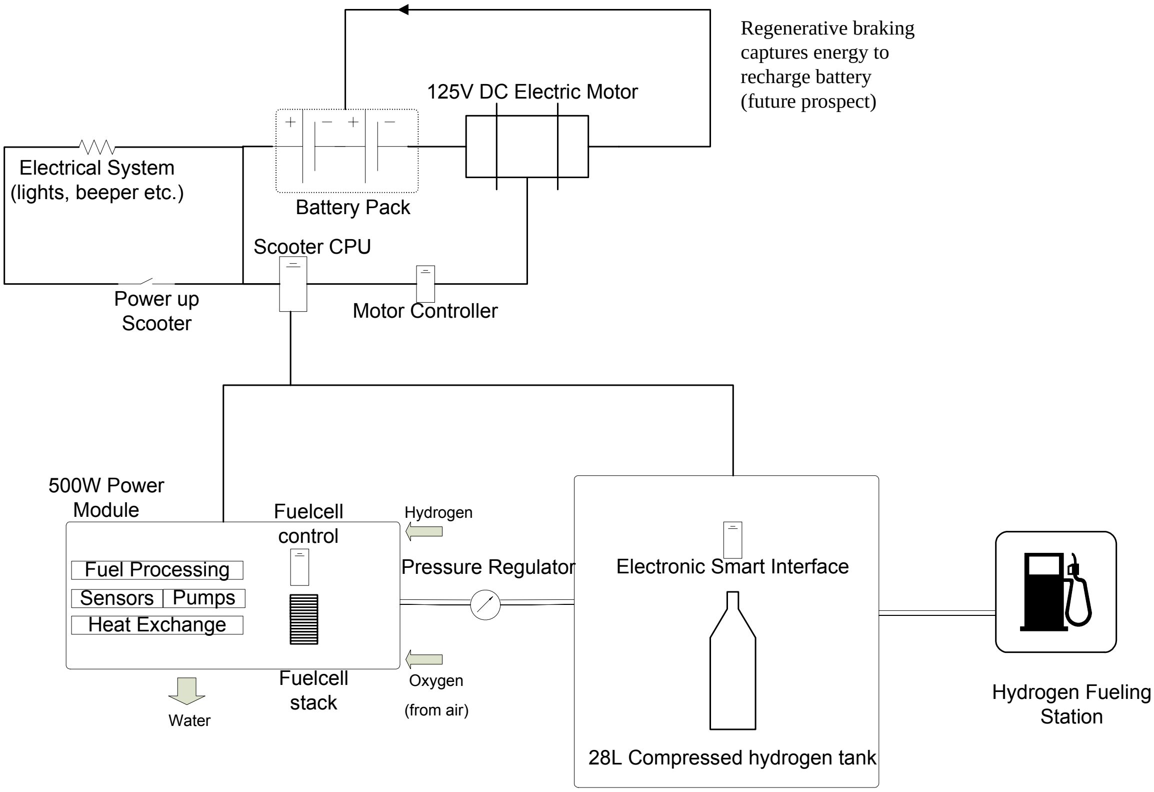
The scooter design currently incorporates a solar panel that powers the dashboard. Today photovoltaic devices are expensive and relatively inefficient. Recent advances in quantum dot sensitized flexible organic solar cells harness power from the entire solar spectrum and have the potential to improve efficiency. At the same time solution processing of organic solar cells promises to reduce costs to competitive levels.

Finally, we can use carbon fiber reinforced plastic frame on an aluminum chassis to reduce the weight of the scooter [20]. Carbon fiber reinforced plastics are already used in high performance vehicles; however cost is very high. With the development of low cost mass manufacturing strategies, the benefits of this material will be available to all vehicles.

1.9 Future direction

Retrofitting an existing gasoline scooter places limitation on the extent of optimization realizable. The best way to address this problem is to design a hydrogen scooter from the ground up, with design features optimized for the new scooter. For example, the lightweight Al frame could incorporate the battery pack within the frame, solar panels could be built into the dashboard to preserve clean styling and customized space-fitting storage tanks could be used. Moreover, the concept of regenerative braking further extends the range of the scooter by redirecting energy back into the battery during braking. The Toyota *Prius* and Honda *Insight* hybrid-electric vehicles already employ this technology, and it can easily be transferred to a scooter, at reasonable cost.

Scooter Process Flow Diagram



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2.0 Safety Analysis

The hydrogen-powered scooter is designed to address safety concerns while meeting the public's perception of safety. Safety concerns have been addressed at each step of the design phase. The design complies with codes and standards developed to regulate hydrogen powered vehicles [1]. Some of the relevant codes that apply to the scooter are summarized in the table below. The design also takes into consideration current practices and solutions adopted by competitors, e.g. Honda [2] and Aqwon [3].

Association	Code	Description
ISO	TC22 / SC21	Road vehicle standard – Electric road vehicle
EIHP	WP4 / WP5	Development of a world-wide harmonized regulation for hydrogen fueled road vehicles
UN	WP 29 GTR	Safety regulations for hydrogen vehicles
SAE	J 2600	Compressed hydrogen vehicle fueling connection devices
	J 2601	Compressed hydrogen vehicle fueling communication devices
	J 2719	H_2 quality specification guideline for fuel cell vehicles
CGA	G5.3	Commodity specification for hydrogen
CSA	HGV 2	Standards for hydrogen vehicle fuel containers
	HGV 3	Fuel system components for hydrogen gas powered vehicles
	HPRD 1	Basic requirements for pressure relief devices for compressed H_2 vehicle fuel containers

Table 2.1 Summary of codes and standards relevant to fuel cell vehicles [1]

A safe vehicle is one that functions according to expectations during normal operations; additionally, the vehicle must not pose an intolerable hazard to the rider and general public in extenuating circumstances, e.g. in an accident.

A hydrogen-powered vehicle offers several unique challenges to safe design. The most remarkable of these involve the safe storage of hydrogen on the vehicle. These challenges are effectively tackled by employing the best available technology, intelligent layout and knowledge of best practices in the industry.

2.1 General Design Strategy

The general design of the scooter has been motivated by overriding safety concerns. For example, these considerations have led to the spatial arrangement of fuel cell, rechargeable battery and storage tank in the rear compartment of the scooter. However, since the scope of the project is limited to retro fitting the current GT200 model, certain ideas that required a major overhaul of the design to optimize for a hydrogen powered vehicle could not be included.

The scooter can be visualized as two coupled flows, a gaseous hydrogen flow and current flow. These two systems are coupled at the fuel cell that converts gaseous hydrogen to water in the presence of atmospheric oxygen to yield a current flow. We have attempted to isolate these flows where possible to minimize the risk of hydrogen ignition. The idea is developed further in section 2.3.

The normal operation of the scooter is monitored by several pressure, temperature, current and voltage sensors placed at different locations in the scooter. These sensors feed this information to the central control system. The central control system is a specially design integrated circuit that is programmed to process these inputs. The control system can operate switches, open/close valves, display warnings, sound alarms, etc. based on this information.

In the case of control system failure a set of mechanically actuated switches and valves provide a second layer of security. These units can operate independently in the absence of the control system.

2.2 HAZOP and HAZAN

Hazards associated with leakage, rupture and accidents are expected to be significant. The team implemented the time-tested and industry-respected hazard and operability study (HAZOP) to identify all safety concerns [4]. HAZOP provides a systematic way to identify hazards and operability issues of a given design. The team followed through the P&ID iteratively, applying relevant guidewords, e.g. no flow, less flow and more flow to each component, thus systematically exploring the entire parameter space. The process not only identified major safety concerns, but equally importantly HAZOP lead to a better and more efficient design.

The final HAZOP analysis is followed by a hazard analysis (HAZAN). The aim of HAZAN is to quantify risks associated with the outstanding hazards. It is important to clarify that before a HAZAN is performed all reasonable efforts are made to avoid hazards identified. The risk analysis allows us to prioritize our limited resources towards minimizing the most significant risks. Risk is quantified using the heuristic outlined in the Table 2.2 below.

OCC (probability of occurrence)	1 – the cause of deviation will never happen 10 – the cause of deviation will always happen
DET (probability of detection): how often can we detect the deviation and prevent it before it happens.	1- always detectable and preventable 10 – Never preventable
SEV (severity of consequences): how bad damage can the deviation cause if the system in place fails.	1 – no damage done 10 – total annihilation
RPN (risk priority number): indicates what importance should be given to hazard and it is the product of the three numbers generated above.	1 – least concern worthy 1000 – most concern worthy

Table 2.2 HAZAN Risk Assessment Definitions

A sample of the Hazop analysis is provided in Table 2.3 below.

Guide word	Deviation	Possible causes	Consequences	Action Required	OCC	DET	SEV	RPN
None	no flow							
	hydrogen	1) storage tank empty	battery cannot be recharged	low pressure sensor in storage tank	9	1	3	27
		2) line blockage	same as (1)	low pressure sensor fuel cell	5	5	4	100
		3) line fracture	hydrogen leaked/ignition risk	turn off electric circuits	3	5	8	120
	current	4) battery drained	loss of dynamic control	low energy sensor on battery	8	2	4	64
		5) electric connection broken	loss of functionality	warn rider	5	4	6	120
	Reverse flow							
	hydrogen	6) drive off with fuel hose!	hydrogen vented to atmosphere	scooter starts only when seat latched	1	1	8	8
More of	more flow							
	hydrogen	7) regulator failure	fuel cell failure/explosion	high pressure detector at fuel cell	3	2	9	45
	current	8) short circuit	damage wiring/fuel cell/motor	electric fuse	4	2	7	56
	more pressure	9) same as (7)	hydrogen cross over → (7)	same as (7)				
	more temperature	10) short circuit	same as (8)	temperature sensor	4	2	7	56
		11) fuel-cell heat exchange failure						
Less of	less flow							
	hydrogen	12) same as (1) - (3) above						
	current	13) low battery	same as (4) - (5)					
	less temperature	14) extreme winter	fuel-cell startup time	electric heating coil	7	2	5	70
				ehtylene glycol coolant				
Other	physical damage	15) vehicular crash	hydrogen leak	safety release valves on tank	3	8	10	240
	spark ignition	16) static discharge	ignition of any leaked hydrogen	tank electrically grounded	4	6	7	168
				electric equipment rated for use				
	control system failure	17) software bug, hardware	loss of dynamic control	manual override switch	4	8	7	224
		18) power failure		mechanically activated actuators				

Table 2.3 Sample Hazop study

2.3 Top Priority Hazards and Mitigation

The most significant hazards as identified by the HAZAN are:

- Physical damage
- Control System failure
- Static discharge when fueling
- Hydrogen Leakage

2.3.1 Physical Damage

It should not be surprising that the greatest risk to a scooter driver originates from physical impact. Accidents are hazardous irrespective of the nature of vehicle involved; accidents are perceived to be an even greater cause for concern when hydrogen vehicles are involved. The risks of hydrogen ignition and explosion are real; however, they have been exaggerated in the minds of the public.

In many respects hydrogen as a fuel is safer than gasoline or diesel. Due to the greater energy conversion efficiency of the fuel cell with respect to an internal combustion engine, hydrogen powered vehicles need to carry only a third of the energy that is stored in gasoline. Additionally, hydrogen is highly volatile and in the event of a leak it quickly disperses into the atmosphere where it does not pose a hazard. Pressurized hydrogen tanks are made to withstand enormous impacts and they are designed to fail gracefully if at all. Simulated crash tests have demonstrated that hydrogen powered vehicles are at least as safe as gasoline powered vehicles.

The hydrogen tank on the scooter is carbon fiber reinforced with 2 pressure release valves that operate manually when the pressure in the tank exceeds the safety perceived safe limit. The tank thus vents the hydrogen to the atmosphere before an explosion could result.

2.3.2 Control System failure

The scooter works harmoniously under the programming of the central control system. The control system monitors various sensors for pressure, temperature, voltage, and current as hydrogen and electric power is harnessed in the scooter. The control unit processes these inputs and actuates switches to achieve specific targets. The system is therefore essential to maintain dynamic control of the scooter. If due to any reason, e.g. power failure or software/hardware malfunction, the control system fails, our ability to track the system is severely limited.

The scooter is designed with a number of mechanically activated switches and actuators that can operate in the absence of the control system. These include safety release valves on the hydrogen storage tank, and a manual override switch to stop hydrogen flow from tank to fuel cell. A warning alarm sounds when the control unit goes offline.

2.3.3 Static discharge

The flow of gas under high pressure through small apertures can result in instantaneous charging by friction. The situation is possibly hazardous because even a small discharge spark may ignite a mixture of hydrogen and oxygen causing an explosion. This situation is unlikely since no mixing with oxygen or air is allowed. However, very small amounts of hydrogen gas may leak from joints and connections, and if not vented these pose a hazard.

The scooter’s rear cavity that houses the hydrogen storage tank and other equipment is designed to vent any leaked hydrogen from an aperture at the top of the rear cavity of the scooter, away from the rider. The battery and motor and all other electric equipment are rated to operate under flammable environment. They are placed at the bottom of the rear compartment below the storage tank, so that any leaked hydrogen vents above them avoiding electrical contact. Similarly, all electrical connections are well insulated to minimize the chance of sparks.

2.3.4 Hydrogen Leak

Hydrogen leakage is a general safety concern. A number of measures are taken to ensure the safe storage of hydrogen as discussed in the sections above. Further precautions are taken to ensure that any leaked hydrogen is rapidly vented and the risk of ignition is minimized. Hydrogen leaks may develop due to several reasons.

Regular steel pipes and containers undergo hydrogen embrittlement over long exposures to hydrogen. This can lead to cracking and eventual leaking. However, all hydrogen bearing components on the scooter adhere to codes and standards that apply to hydrogen and are not subject to degradation processes.

The choking of hydrogen delivery pipes due to debris can cause the elevation of hydrogen pressure locally in these pipes which may lead to failure of joints, seals or pipes. To guard against this eventuality sensors are placed at several points in the hydrogen pipeline that monitor the pressure and temperature and report any abnormalities to the central control system. The problem can therefore be detected early and remedial action can be taken.

Finally, we feel the need to address a particular risk that is associated with refueling vehicles. Drivers have been known to drive out of the fueling station with the pump hose still plugged to their storage tank. Such an action is highly unlikely when refueling a scooter because the refueling duct lies directly underneath the rider's seat. As a second layer of safety the scooter does not start until the seat is properly latched into place, thus ensuring that the nozzle has been replaced.

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3.0 Environmental Analysis

This section will focus on the environmental benefits of the hydrogen scooter, especially in terms of environmental gentility in comparison to the conventional gasoline-powered scooter.

3.1 Comparison Basis

3.1.1 Gasoline-Powered Scooter

The data for the mileage of a Vespa Granturismo scooter was discovered at three sources. Vespa Canada states that the GT200's mileage is 31.9 km/L (75mpg) [1], which is the highest of the three and subject to some suspicion. Therefore, the average of two online rather more neutral sources, BikePoint [2] and the Washington Post [3], will be used. This value comes out to 27.4 km/L (64.4mpg).*

Based on this fuel efficiency and with a tank capacity of 9.5 L [4], the scooter range can be calculated at 260.3 km between refuelling which is close to that given by Vespa Canada of 258 km [1].

3.1.2 Hydrogen Scooter

We turn now to the hydrogen scooter with which we propose to replace the conventional gasoline-powered scooter. If we define global efficiency as the total efficiency in travelling from fuel production to energy that eventually moves the scooter, in comparison to another alternative energy transportation technology, battery-electric, the efficiencies, both theoretical and practical for hydrogen-powered vehicles tend to be significantly higher. In fact, Whitney Collela et al reports battery battery-powered scooters with global efficiencies as low as 5% leading her to state: "The battery bicycle's global efficiency of 5% is so low as to engender genuine concern as to whether an environmental improvement is being made with the substitution of two-stroke scooters for battery-powered ones." [10]

On the other hand, global fuel cell efficiency is known to be as high as 25% [7]. This can be realized if motor efficiencies, usually the limiting factor (see table 3.1) are enhanced through the use of a friction drive motor in place of a hub mounted motor. Collela reports such a motor produced by a Japanese company achieving efficiencies as high as 95%. Therefore, assuming as Table 3.1 demonstrates that fuel conversion efficiencies of ~50% and motor system efficiencies of ~90% can be reached in our design, a general efficiency of 45% should be used to evaluate the transfer of energy from hydrogen once produced to energy that actually moves the scooter wheels. The 25% is the global efficiency taking into account the production of hydrogen from coal. As Collela reports, with adequate technologies, fuel-cell powered scooters can attain a level of efficiencies very close to the theoretical maximum.

* BikePoint and Washington Post values

Battery scooter

	Power plant conversion of coal to electricity	Charging and discharging	Motor and drive system	Global efficiency
Estimated efficiency	35%	80%	90%	25%
Measured efficiency	35%	30%	50%	5%

Fuel cell scooter

	Gasification of coal to hydrogen and compression	Compression at refill station	Fuel conversion	Motor and drive system	Global efficiency
Estimated efficiency	64%	86%	50%	90%	25%
Measured efficiency	64%	86%	46%	50%	13%

Table 3.1: Efficiencies for Battery-powered and fuel-cell powered scooters [19]

The U.S. Department of Energy states that the energy of hydrogen is 120 MJ/kg with a standard volume of 11125.9 L hydrogen/kg hydrogen [5]. The efficiency of our electric motor for converting this to usable thrust is 90%. This high efficiency will be realized through the use of ‘thick coil’ armature technology on our DC brushless electric motors [6]. With an average fuel cell efficiency of 50% the overall efficiency of converting hydrogen to usable energy falls to 45%. Therefore, the effective energy of hydrogen is around 4.85 kJ/L, or 1.35 Wh/L.

According to Vespa Canada the maximum power required of the gas-powered Vespa Granturismo is 15.4 kW at 8500 rpm [8]. It will be assumed that this max power coincides with a maximum speed for the scooter of 120 km/h [4]. If we wish to mimick the power output of the conventional scooter, our hydrogen scooter should be capable of performing at the same peak power under similar overall conditions. This leads to a calculated fuel efficiency of 116.87km/kg H_2 (72.59 miles/kg H_2) as illustrated below. This seems reasonable as it is conservatively higher than efficiencies found for regular vehicles designed to be powered by hydrogen [9].

3.2 Calculation of hydrogen scooter efficiency - distance/kg hydrogen

At 120km/h (33.33m/s) we need 15.4 kW constant power
1L hydrogen = 0.00485 MJ
Time to consume 1L hydrogen = 0.00485 MJ/15.4 kJ/s = 0.315s
Distance travelled in this time = 0.315s X 33.33m/s = 10.5044 m
Therefore, 1 L of hydrogen takes us 10.504404 m (or 116.87km/kg H2)

3.3 Energy Consumption Comparison

The most energy intensive operations in the gasoline “well to pump” life cycle for converting the original crude oil product from the well to delivering it in usable gasoline form at the pump are the upstream extraction and downstream refining operations. These contribute most significantly to all forms of emissions, especially CO_2.

According to the 2004 annual report for Petro Canada [11], 38.1 million GJ of energy was used in upstream operations and 63.5 GJ of energy was used in downstream operations, to manufacture 56.6 thousand cubic metres of product per day. This works out to 1.844 GJ/m^3 oil equivalent upstream energy expenditure and 3.073 GJ/m^3 oil equivalent downstream energy expenditure. The 2005 Shell Canada Action Plan [12] explicitly gives 1.54 GJ/m^3 oil equivalent as the energy intensity per unit of exploration and production. A working average of energy expenditure on upstream crude oil extraction would be 1.69 GJ/ m^3 oil equivalent (or 0.268 GJ/bbl).

In order to continue with this analysis this average annual distance travelled needs to be estimated. Although a survey of scooter range was not obtained, a number of interesting sources of motorcycle range data was discovered. In particular, Huang and Preston at the University of Oxford reported a motorcycle studies (in which category they included scooters and mopeds) where they found a correlation between engine size and likely annual range (see Table 2) [13].

	Work, Business and Education	Shopping	Other personal business and escort	Visit friends	Other leisure	All purpose	Average Annual Mileage
50cc or less	56	8	9	21	7	100	2,270
50-125cc	67	10	4	13	5	100	3,000
125-500cc	46	9	7	20	18	100	3,210
500cc and over	37	6	6	16	35	100	4,290
All size	46	7	6	17	23	100	3,440

Table 3.2: Comparison of uses and distance by vehicle size [20]

Since our scooter has an engine size of 198cc we can estimate from this data that the average annual mileage will be round 3,210 miles, or 5,168 km. However, this data only spans the 1990s and one can predict that with increasing gasoline prices motorcycle use may have increased in the interim. Another source, the Transport Statistics Bulletin for Great Britain [14] which covers the same geographic area, cites 3,400 km/year average motorcycle travel distance between 1985 and 2003 but with 7,434 km/year in 2003, suggesting a significant increase in overall travel distance in this century. According to the US Bureau of Transportation Statistics and cited by Ride To Work, Inc [15], in the United States the average motorcycle travels 2,898 km/year, less than 40% the distance of its English counterpart. Taking these values as representative of the North American and European statistics, and using Fig 4.2 in which the predicted European market for hydrogen scooters in 2007 will be 12.7% compared to the North American market of 0.49%, according to presumed sales trends described in Section 4.2.2.1, the average scooter annual travel range can be estimated at 7,265 km.

3.4 Upstream

In terms of analysing the required gasoline for conventional scooters as well as the environmental impact of hydrogen scooters, we will constrain ourselves to the North American market for which data is more readily obtainable.

In Ontario the average scooter will travel around 2,898 km/year based on the North American values and the previously stated efficiency of the gasoline-powered GT200 is 27.4 km/L of gasoline. This works out to 105.76 L of gasoline required per scooter per year. According to our moderate sales scenario economic analysis, sales of the hydrogen-powered GT 200H will rise by 10% annually from 2007 after starting at 116 units (10% of regular North American sales of the conventional GT200). Then from 2011 on we predict a surge of sales increasing by 15% annually, as described in section 4.2.2.1. Therefore, we can estimate the amount of gasoline saved between 2007 and 2017 in North America due to the predicted sales of hydrogen-powered scooters in place of conventional scooters, as shown in Fig. 3.1. Using Canada as representative of North American crude oil production, since we calculated that an average energy for upstream oil extraction was 1.69 GJ/m^3 of oil equivalent, we can translate our require gasoline to the required energy for its production, as shown in Fig. 3.2.

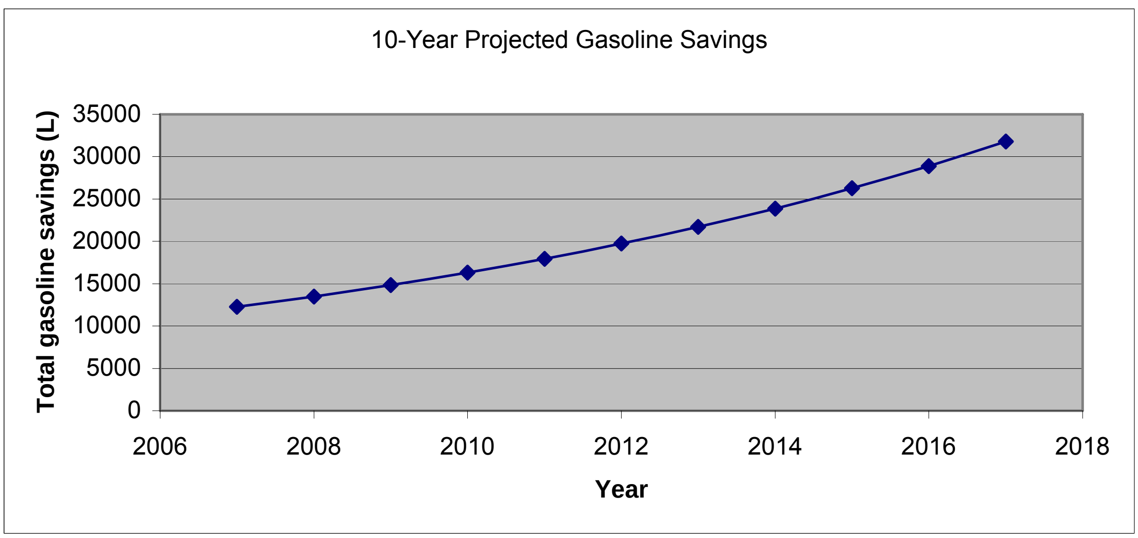

Figure 3.1: 10-Year Projected Gasoline Savings for North America

In order to evaluate the CO_2 emissions saved as a result of this savings in upstream energy expenditure, an approach similar to that found in the University of Toronto 2004 Hydrogen Fueling Station Design Proposal was employed [16]. In this approach we assume that crude oil is consumed to provide the required energy for extraction and make use of the following emission factor equation:

$$CO_2 \text{ emission} = \text{Energy used from source X} * CO_2 \text{ emission factor of source X.}$$

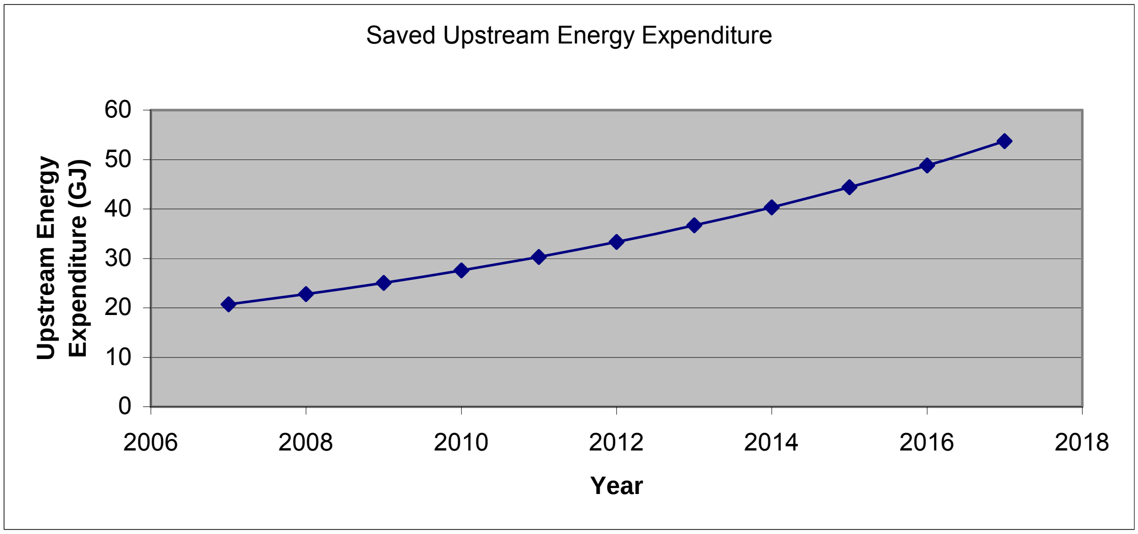

Figure 3.2: 10-Year Projected Upstream Energy Expenditure Savings

The CO_2 emission factor can be determined through the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, which the United Nations Framework Convention on Climate Change (UNFCCC) has described as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" in calculation of legally-binding targets during the first commitment period." [17]. The given value is 70tonnes of CO_2/TJ with a correction for carbon unoxidixed of 0.99 [32].

As an example, in 2007 the energy source was 20.708 GJ (or 0.02078 TJ) such that the CO_2 emissions saved comes out to 0.02078 TJ x 70 tonnes of CO_2/TJ X 0.99 = 1.44 tonnes of CO_2. Figure 3.3 demonstrates the CO2 emissions that are saved in North America through the proportional switch from conventional to hydrogen-powered scooters from 2007 to 2017. If the value for energy used from source were the same throughout the world, we could estimate worldwide savings on CO_2 emissions based on annual hydrogen powered scooter sales (again refer to section 4.2.2.1), as shown in Fig. 3.3

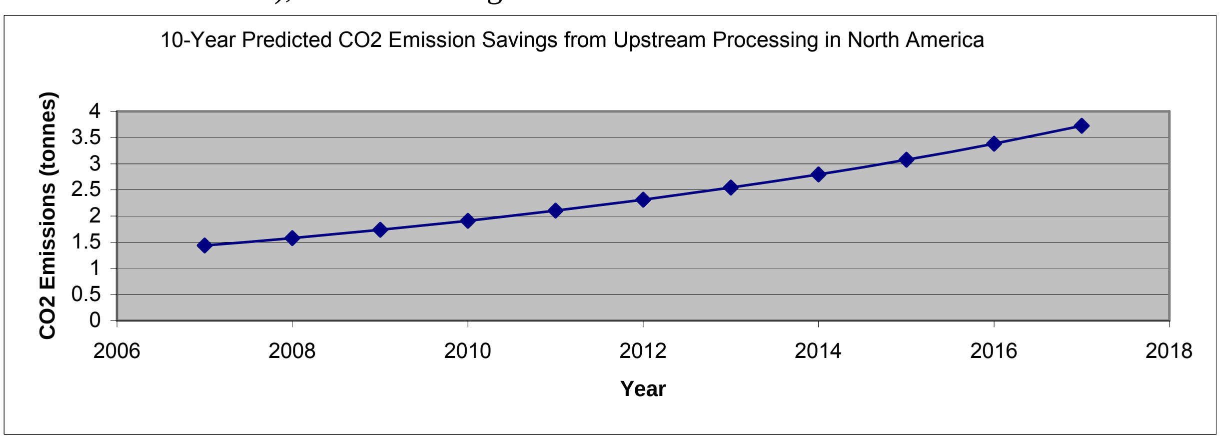

Figure 3.3: 10-Year Predicted CO_2 Emission Savings from Upstream Processing

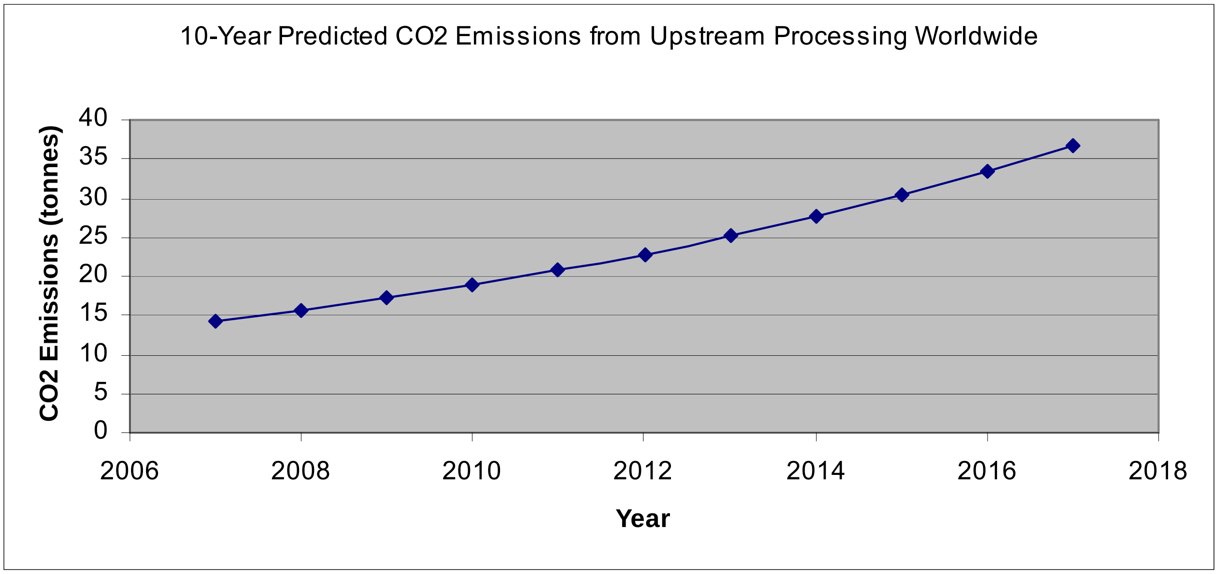

Figure 3.4: 10-Year Predicted CO_2 Emission Savings from Upstream Processing

3.5 Downstream

The Canadian Industry Energy End-Use Data and Analysis Centre provides the carbon dioxide emissions and energy consumption for the year 2004 for the petroleum products manufacturing refineries industry. The carbon dioxide emission value is 18.2 million tonnes over the year, with fuel gas specifically accounting for 7.97 million tonnes [18]. The energy consumption over the year came out to 377,877 TJ total, with 206,506 TJ consumption from refinery of fuel gas [19]. The actual units produced that gave rise to this energy consumption and CO_2 emission was 117,965,000m^3 [18]. Therefore, 1.75 GJ/m^3 and 67.56 kg/m^3. We can now use the amount of gasoline required for a given year in North America via figure E1 to calculate how much downstream energy consumption would be required and how much downstream CO_2 emissions we are saving (see figure 3.5)

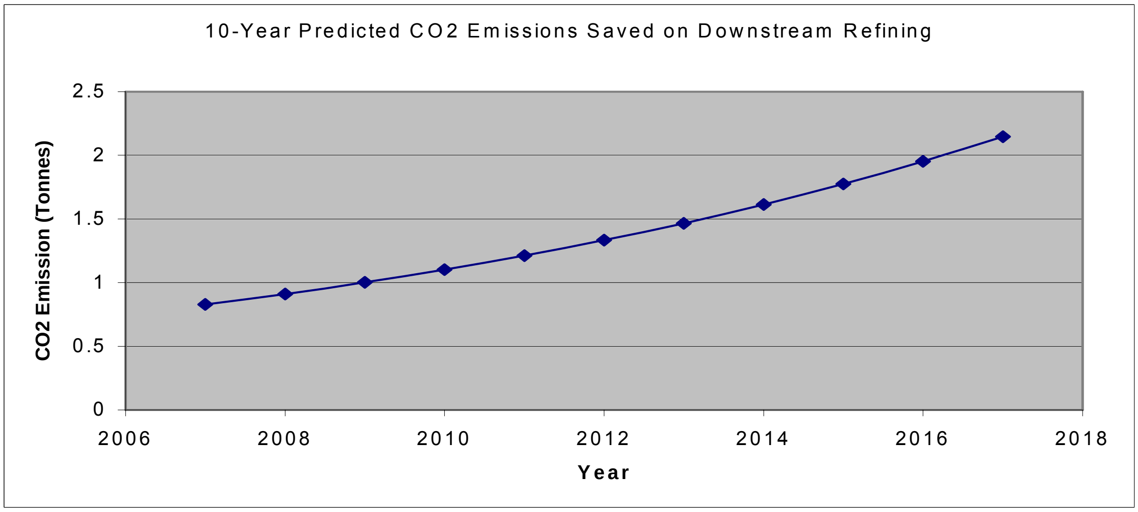

Figure 3.5: CO_2 Emissions Saved on Downstream Refining

3.6 Internal Combustion Engine Vehicle - Tank to Wheel CO2 Production

We will again follow the procedure and equation given in the University of Toronto 2004 Hydrogen Fueling Station Design Proposal was employed [16] for this portion of the analysis. The analysis is found in the "Revised 1996 IPCC Guidelines for National
Greenhouse Gas Inventories" which specifies 18.9 tonnes of C/TJ and 44.8 GJ/tonnes. It should also be noted that the molar weights of carbon in the reactant compared to CO_2 emitted is 12 moles: 44 moles, or 12 tonnes: 44 tonnes. The equation given for calculating CO_2 emission for the tank to wheel stage is therefore, for the example of 2007 in North America where we require 12,253 L of gasoline:

= 12,253 L of gasoline / 11125.94571 L/kg x 1000 tonnes/kg x 44.8 GJ/tones x 0.0189 tonnes C/GJ x 44.01 tonnes CO_2/12.01tonne C = 3,419 tonnes CO_2.

We can apply this equation to figure E1 to graph the CO_2 emission savings over North America during the period 2007-2017 due to tank to wheel CO_2 production, generating figure 3.6.

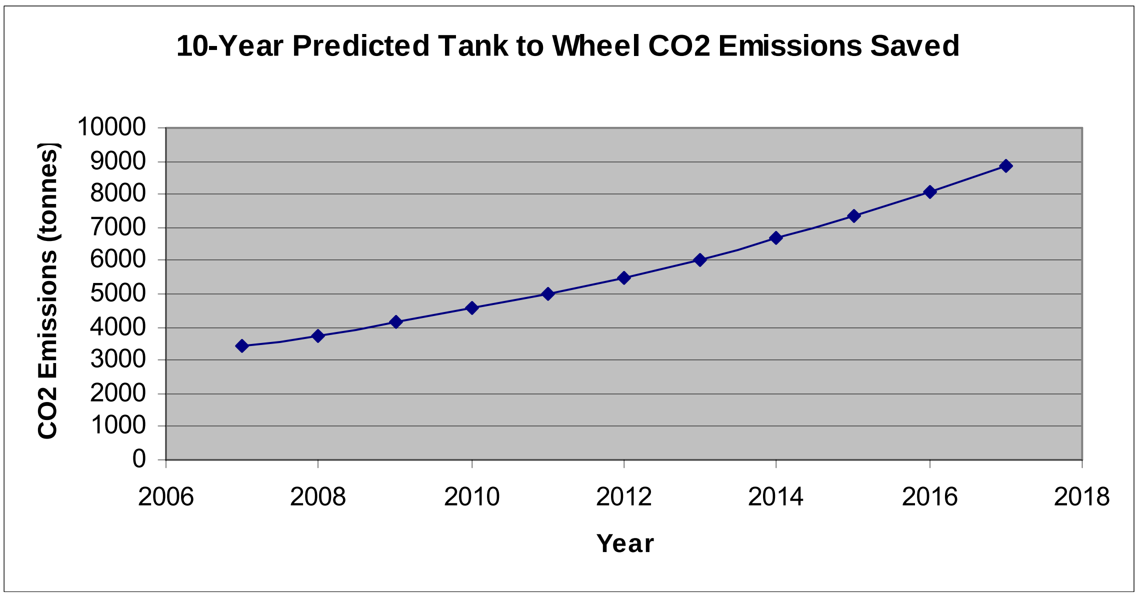

Figure 3.6: 10-Year Predicted Tank to Wheel CO_2 Emissions Saved

We now add the CO2 emissions saved from upstream processing, downstream processing and tank to wheel emissions to generate the amount of savings generated in North America if energy for producing hydrogen for the GT 200H came purely from non emitting sources (solar, wind, etc). This final graph is shown in Fig. 3.7, demonstrating that the greatest source of pollution is clearly the tank to wheel emissions.

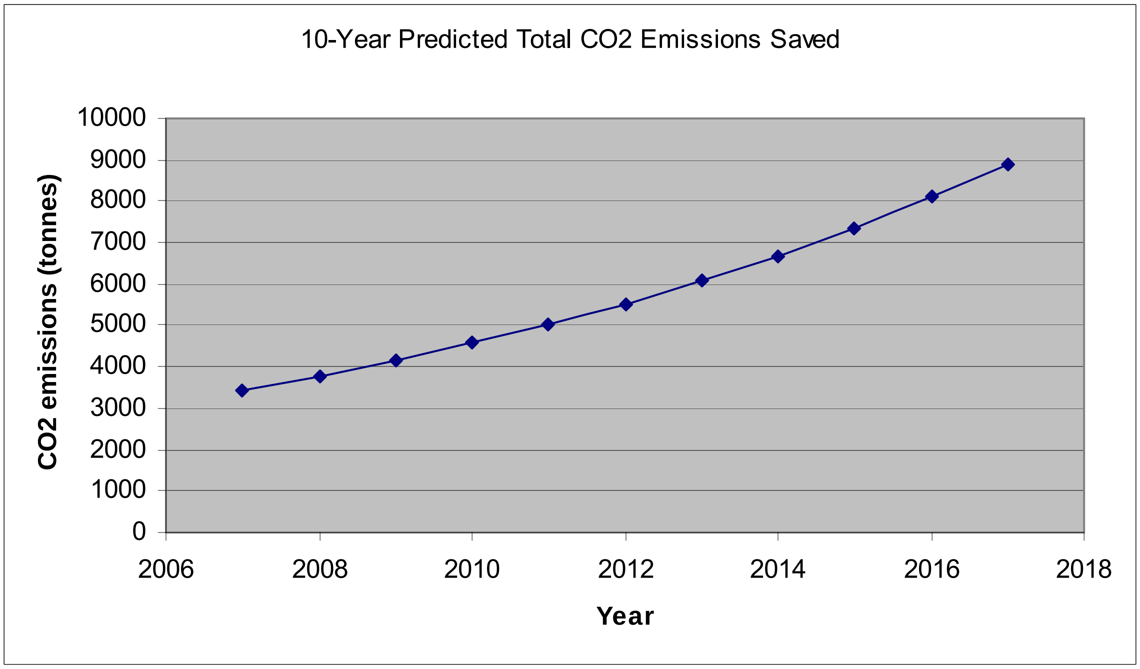

Fig. 3.7: 10-Year Predicted Total CO_2 Emissions Saved

3.7 Hydrogen Fuel Cell Scooter -Well-to-tank Energy Consumption and CO_2 Emission

We now consider the CO_2 emissions from the GT200H hydrogen-powered scooter alternative. Although it is conceivable that hydrogen could be produced through purely zero emission channels, such as wind, solar, nuclear, geothermal and hydropower, a more conservative analysis should use the combination of power sources that typically contribute to the grid using data provided by the OPG [20]. OPG data is shown in tables 3.3 and 3.4 .

Table 3.3: Power Breakdown from the Grid as of December 31, 2005

Source	Power Output (MW)
Hydroelectric	6855.00
Nuclear	6606.00
Wind	7.00
Green power hydroelectric	127.00
Fossil fuel	8578.00
TOTAL	22173.00

Table 3.4: Emissions from Fossil Fuel Plants

NO_x	26.04
SO_2	116.91
Total Acid gas	142.96
NO rate (Gg/TWH-delivered)	0.95
CO_2 (Tg)	27.10

Therefore, the total CO_2 emission is 27.10 Tg and the total power output for 1 year is calculated to be 1.942 X 10^{11} KWh.† Therefore, the equation:
Mass/Energy CO2 = (Total CO2 emissions) / (Total annual power output), works out to 139.5 kg CO_2/MWh as the specific emission value. Therefore, if the grid is utilized, 0.14 tonnes of CO_2 will be emitted for every MWh that needs to be drawn. We can go straight from the required 15.4 kW required by the conventional scooter at maximum power, assume an average speed of 60 km/h and annual distance traveled in North America of 2,898 km/year and calculate that the required annual energy comes out to 743.6 KWhr. This means that 0.104 tonnes of CO_2 are emitted annually for every hydrogen fuel-cell powered scooter.

3.8 Conclusion

The discussion in this section should have demonstrated the significant CO_2 emission savings obtained by hydrogen fuel cell powered scooters in comparison to conventional scooters. CO_2 emissions for a single North American scooter, taking the value from figure 3.7 for year 2007 and dividing by the number of scooters that it represents (~204) gives 17 tonnes/year on each scooter. This should be compared to the 0.104 tonnes/year on the hydrogen powered scooter. It is hoped that these figures will be helpful in marketing the scooter to an increasingly environmentally-conscious public throughout the world such that our sales predictions, as relied upon throughout this section, are in fact realized. Though we were unable to cover the other emission agents, table 3.4 from OPG demonstrates that SO_2, NO_x and acidic gases are all emitted in comparable or higher degree and hence a proportional savings in the emitted amounts of these chemicals would also contribute highly to improved environmental quality and all associated benefits.

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† Total power output for 1 year = 22,173 MW X 31,536,000s = 6.992e11 MJ = 1.942e11 KWh

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4.0 Economic and Marketing Business Plan Analysis

4.1 Overview

Our team has completed a detailed economic and business analysis of the fuel cell powered Vespa GT200H scooter. We have determined the production costs and revenue streams in each year of the analysis, based on a discounted cash flow (DCF) analysis with an after tax internal rate of return of 5% (IRR), for a 10 year period (2007 product launch to 2017). Furthermore, a simple fuel cost savings analysis in owning a hydrogen scooter is provided for marketing purposes.

Presented below are detailed analysis of the scooter production costs, proposed scooter retail prices, and other key marketing and business issues. All costs/prices in this analysis are in U.S. dollars. A sample of the DCF analysis is displayed in Table 4.3, and its constituent parts are explained in greater detail in the following sections. We expect to have the scooter conversion complete and available for sales distribution by May 2007 in both North American and European markets.

4.2 Key business/economic analysis issues

4.2.1 Projected cost estimates

A detailed analysis of the projected costs associated with the hydrogen scooter production was carried out. It is assumed that Vespa, our strategic partner, will bear all of the capital and land costs. Therefore, our analysis will focus on mainly the variable unit production costs.

4.2.1.1 Production cost estimates for the GT200H scooter

Under current technologies and production levels, we estimate the cost of building a GT200H scooter could be as much as **$7,568**. This includes the cost of manufacturing materials and components such as the fuel cell power module and battery. A fuel cell/electric hybrid scooter design was chosen, coupled with solar powered panels to power dashboard electronics. This decision was based purely on economic feasibility, since the inclusion of a NiMH battery allows for a *much* less powerful fuel cell to be used. This hybrid design appears to be a very competitive option in terms of production cost (with fuel cell modules costing about $3000/kW [1], a fuel-cell-only design would cost upwards of $30,000), which would severely lower the demand for the GT200H.

The method that we propose to estimate unit cost is to take the gas powered GT200 scooter retail price (MSRP $5,199 [2]), and remove the total cost of the major power system components that will be replaced (cost recovery), leaving us with a “base cost” for the vehicle shell, assembly, internal electronics, controls and other ancillaries. We then add back the cost of the newly replaced components (e.g. hydrogen fuel cell, storage system) to the “base cost”, and calculate a unit cost for the scooter assembly. Table 4.1 and 4.2 below show details for the cost recovery of unneeded parts, and the new components to be added.

Table 4.1: Cost recovery of unneeded ICE scooter components (credits)

Component	Supplier	Model/Part No.	Cost (US$)	Notes*
200cc Horizontal Four-Stroke Engine	Jiangmen Zhongyu Motor Group	ZY1P52QMI(GY6)	2000	1
Carburetor	Walbro	WVF-8	237	5
Fuel Tank (9.5 L)	N/A	N/A	76	1
Exhaust system (Muffler, Exhaust pipe)	ve-uk.com	VZ83265 (stainless steel)	285	2
Air Filter	Scooter Parts Direct	931997	13	3
Oil Filter/seals	ve-uk.com	VE60066	62	2
Oil Pump	Scooter Works USA	134913	80	4
Athena drive belt Transmission	ve-uk.com	VZ60424	42	2
Battery (comes with acid)	Scooter Parts Direct	PUYTX12-BS	73	3
Fuel Pump/Taps	BeedSpeed	[B]-12 166 0	47	9
		TOTAL CREDITS:	**$2,915**	

Table 4. 2: Fuel Cell Powered Scooter parts to be added (expenses)

Component	Supplier	Model	Cost (US$)	Notes*
Fuel Cell Power Module (0.5kW)	Ballard	Mark 902	1,500	6
Compressed hydrogen storage tank	fuelcellstore.com	SP22017-1	2,200	
High Pressure Regulator	fuelcellstore.com	3910-15-350	324	
Electric Motor (incl. Gearbox)	Parker Hannifin	125VDC Brushless motor	300	
All Digital Motor Controller	Parker Hannifin	N/A	100	
Battery	Gold Peak Batteries (H.K.)	NiMH 30 Ah, 3.7 kW-h	800	7
Flexible Solar Panel	Modern Outpost	PowerFilm 1200	60	10
"Base" cost (MSRP $5,199 - "Total Credits")	Vespa	GT200	2284	8
		TOTAL COST:	**$7,568**	

****Documentation and references for scooter components are provided in the References***

As shown in the scooter component cost breakdown (Figure 4.1), a large portion of the production costs is due to the hydrogen storage and fuel cell power module. Therefore, the *cost* of the systems was a significant factor in the choice of the current technologies that were to be used. After considering the technical feasibilities and costs, compressed H_2 tanks were chosen as the medium for hydrogen storage. Metal hydrides were rejected as a choice for hydrogen storage due to the lack of reliable commercial products and its high price ($16,000/kg H_2) [3].

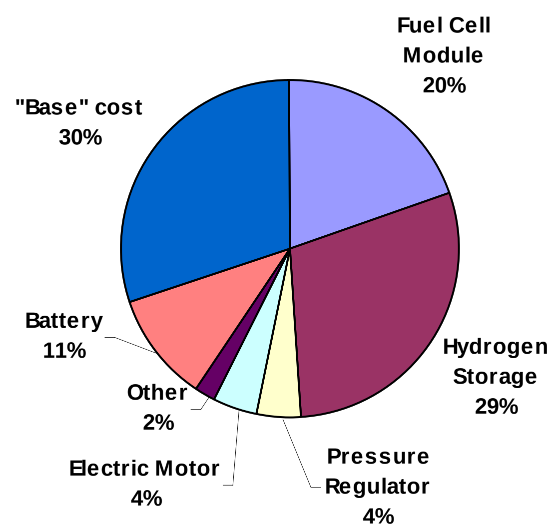


Figure 4.1: Scooter Component Cost Breakdown

The Ballard fuel cell power module makes up another significant portion of the scooter cost. As mentioned earlier, production costs were *significantly* reduced by coupling the fuel cell with a NiMH battery. It must be noted that production cost predictions are difficult to make, given the uncertainty involved with this emerging technology and the large number of years before the mass produced prices can be realized. Thus, these figures should be *treated as a rough estimate only*. The greatest uncertainties in these cost estimates are in the most expensive components: the fuel cell stack itself, the metal hydride storage unit, and in the case of the electric hybrid, the NiMH battery.

For the fuel cell and hydrogen storage options, a near term prediction was made based on low volume production of the parts.

It can be expected that as the technology matures and new developments are made, component costs will decrease and substantially lower our unit production costs. Long term U.S. Department of Energy predictions for high volume (500,000 units) PEM fuel cell production has been reduced to around $129/kW [4]. However, under current economic conditions, it is highly unlikely this production volume will be achieved in the next 10 years. Hydrogen storage options are also expected to go down, as alternate storage selections can be substituted for the current compressed H_2 tank design. One reference [4] indicates metal-hydride storage in large quantities costs only $2600/kg H_2, which would make it an attractive option for hydrogen storage. The other components are all “off-the-shelf” industrial parts and their cost is not expected to decrease dramatically due to advancing technology. On the other hand, better engineering integration and design specific to the scooter application might reduce overall costs. Given our relatively short-term projections and low volume production, however, we assume that production costs remain relatively constant through the 10-year analysis period.

Due to the low fuel cell prices predicted for the long run (30+ years), the (relatively) high expense of peaking power batteries eradicate the benefit of smaller fuel cells. Right now this is certainly not the case, as peaking power NiMH batteries currently cost approximately $211/kWh [5], while fuel cells are as high as $3,000 per kW.

In the short term, hybridization with peaking power batteries drastically reduces the price of the hydrogen scooter. In the long run when fuel cells are less expensive, the added complexity of batteries (and their lack of performance advantage over comparably-sized fuel cells) make them unnecessary. Nonetheless, hybrids might be required for the next several years in order to bridge the gap to inexpensive fuel cells.

4.2.1.2 Operating Costs/Taxes

These expenses may be incurred after the initial production. They include marketing and sales costs, overhead, administrative, labour, etc. The operating costs may also include warranty claims. For simplicity, all of the operating costs were lumped together and estimated to be 20% of all sales revenues. This is comparable to Piaggio’s 2005 financial statements [6]. Corporate income tax is assumed to be charged at the marginal rate, as projected net income figures are not substantial (see section 4.2.2). We assume an estimated constant tax rate of 15% in North American markets, 25% in the European markets, and 37.25% in Italy [7,8].

4.2.2 Revenue and Sales demand

As the hydrogen economy progresses, we will be able to sell more and more hydrogen powered scooters (i.e. an annual increase in the percentage growth of sales). Of course, this will be balanced by a *decrease* in sales due to fiercer competition. Thus, we shall simplify our analysis by assuming a *constant* percentage increase of scooter sales. Another point that we took into account is the higher scooter demand in Europe due to higher gasoline prices and better infrastructure for scooters (see Fig. 4.2)[9]. Thus, we have conducted separate analyses for North America, Europe, and Italy.

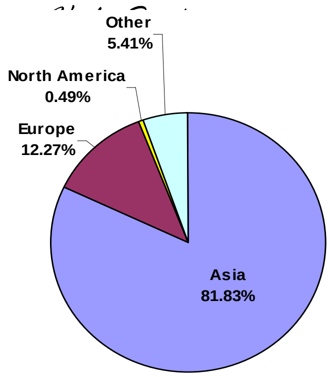


Fig. 4.2: Estimated Global Scooter Sales (2005)
Estimated Worldwide Total: 24.4 million

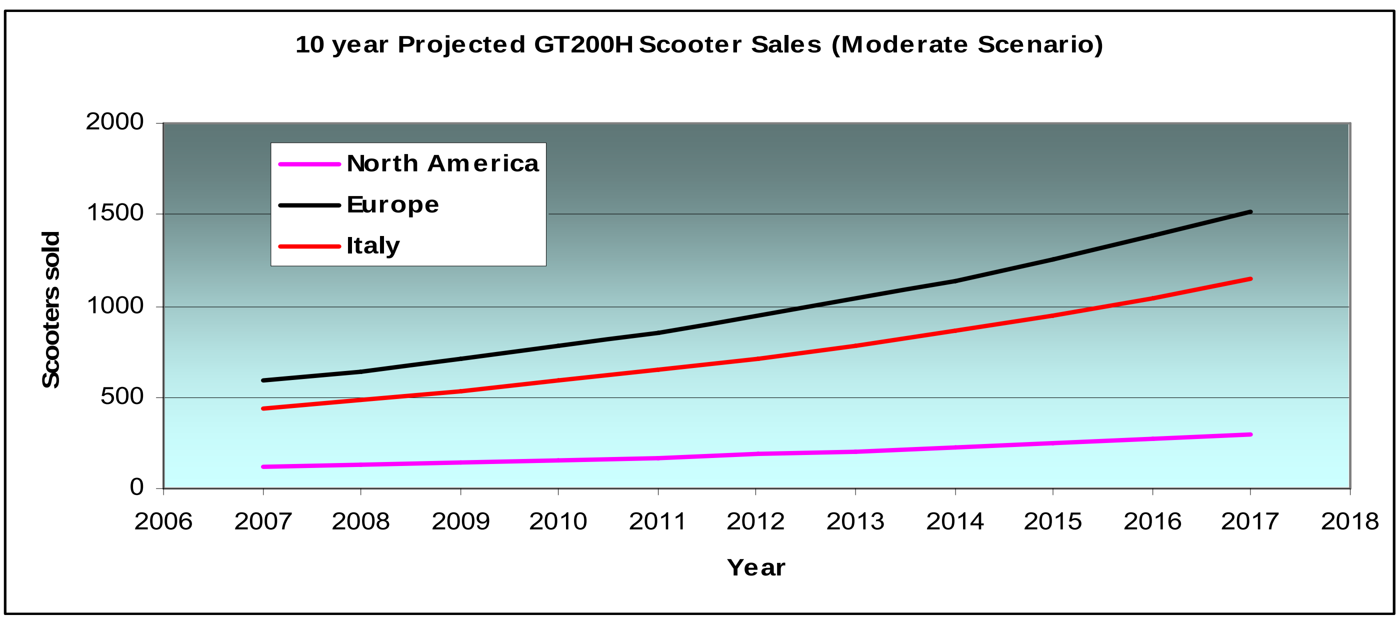
4.2.2.1 Sales Scenarios

Three hydrogen scooter demand scenarios were considered in this economic analysis: a conservative base case, a moderate scenario, and an optimistic high demand scenario. We accomplished this by taking the number of gas powered GT200 Vespa scooters that were sold in 2005 [4] and projected the sales growth to 2007. The 2007 sales projections will then be used as the starting year of the DCF analysis. This projected sales growth up to 2007 is based on an average 16.7% annual scooter demand increase in North America over the last 7 years [10], and an estimated 5% annual increase in Europe [11].

The "C*onservative*" *scenario* is based on minimum estimated number of hydrogen scooters that will be sold in 2007, the expected product launch. We estimate that a market penetration of 10% of the projected GT200 sales in 2007 will be achieved (approximately 1143 scooters total in both the North American and Europe markets). A conservative sales growth rate of **5% annually** is assumed. The *"Moderate" scenario* presumes that with a strong marketing campaign and a more favorable customer adoption rate, hydrogen sales will increase by **10% annually**. The *"Optimistic" scenario (high demand scenario)* represents the maximum **realistic** number of hydrogen scooters that we will be able to sell. In this scenario, we assume a very favorable initial hydrogen scooter adoption of 20% of all GT200 sales in 2007 (approximately 2285 scooters). A 10% annual sales growth rate is presumed, until 2010. We predict that by the end of this decade, the sales of hydrogen vehicles will shoot up by 15% annually due to improved hydrogen infrastructure, government initiatives such as California's Hydrogen Highways [12], and the Kyoto Protocol standards [13].

Wherever possible, results from each scenario are presented. However, in the spirit of brevity, only selected scenarios and market regions will be used to illustrate the findings. Figure 4.3 shows a 10-year projection of scooter sales for each market region under a moderate scenario. Figure 4.4 shows estimates for worldwide GT200H sales for each scenario.

Fig. 4.3 : 10 year Projected GT200H Scooter Sales (Moderate

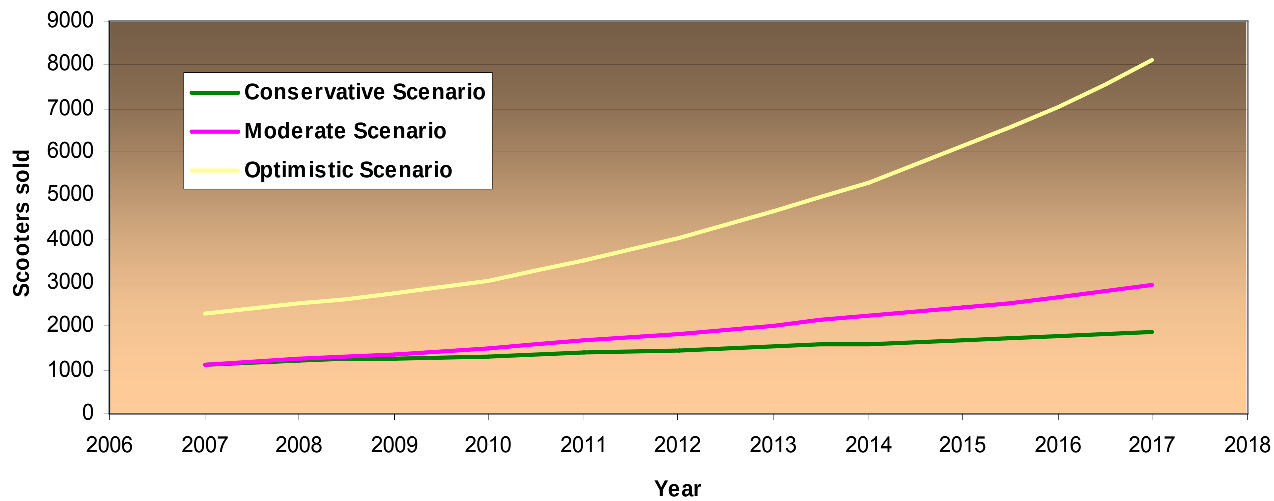


4.2.2.2 Scooter Pricing and Market Competition

Scooter pricing is a key issue in determining our profitability. As mentioned in earlier sections, the unit production cost of $7,568 is greater than the regular gasoline powered GT200 (which costs $5,200). As a result, the hydrogen GT200H must be priced at a significant premium in order to avoid annual losses. However, too high of a premium will make the GT200H unaffordable to the mass market. Research has shown that the average customer is only willing to pay up to a 20% premium on “environmentally friendly” new technologies [14].

The current cost analysis utilizes an after-tax IRR of 5% for a 10-year analysis to find the appropriate GT200H selling price. As shown in Figure 4.4, we believe we will sell about 1143 GT200H models to the North American and European markets during the first year (using conservative estimates). To do that, we will be charging **$9,157 per scooter**, representing a gross margin of roughly 17%, and a 76% premium over a regular gas powered GT200 scooter. Such margins are required due to our substantial production and operating expenses (see Table 4.3 for details).

Fig. 4.4 : 10 year Projected GT200H Worldwide Scooter Sales



We believe our pricing strategy will provide us with an appropriate balance of affordability for the customer, and profits for us as the manufacturer. Early adopters of hydrogen transportation technologies are usually heavily subsidized (e.g. Toyota Prius), and generate millions in annual losses. A lower priority is often placed on the generation of significant profits in exchange for early market penetration. Our relatively low cost design allows us to gain early access to the hydrogen vehicle market, whilst providing us with modest profits.

The GT200H scooter retail is priced competitively compared to other similar products, which are currently very few. Parker&Vectrix’s “Fuel Cell/Electric Hybrid”, expected to launch in 2006, retails for about $8,400. Numbers have been released of a $6,000 price tag for Intelligent Energy’s (UK) “ENV Motorbike” if a production run of 10,000 can be made. This is a rather optimistic view for the near future – currently, the ENV bike costs around $26,000 to produce [15]. Honda and Aprilla have developed light performance fuel cell scooter prototypes, however, no prices have been announced.

Although current *commercial* availability for hydrogen scooters is sparse, many major competitors such as Piaggio (Vespa's holding company), Yamaha, and Samsung are staged to launch products within the next 3 years.

4.2.3 Profitability

To truly make renewable energy a viable resource in the future, it must be economically feasible. HydroScooters has made a major commitment to becoming profitable in a short period of time. By minimizing scooter production costs and through government financial assistance, HydroScooters has made this project a financially sustainable venture over the projected 10 years. To determine how HydroScooters performs economically, the estimated costs and revenues were summed to get the earning before taxes (EBT). Appropriate taxes (see section 4.2.1.2) were then deducted from the EBT to calculate annual net earnings. These values were calculated for the projected 10 years of the project at present value. For illustrative purposes, Table 4.3 provides details for a sample DCF analysis that was performed for the European market. Figure 4.5 shows the 10-year projected annual net earnings of Hydro Scooters. It should be noted that HydroScooters will generate positive cash flows for every year, although operating margins are expected to be low. Despite this, we will reiterate again that the low margins will be offset by our early penetration into the hydrogen scooter market. Due to this early penetration, we expect to capture a significant market share over late competitors.

4.2.4 Other factors and income streams

There are a variety of potential scenarios and developments which may allow a more favorable economic environment, and in turn improve our profit margins.

As can be expected, net earnings from scooter sales alone are not particularly favorable. Therefore, we will rely on worldwide government hydrogen legislative policies and funding initiatives to provide additional income streams and help alleviate the costs. These policies may come in the form of corporate tax deductions, cost allowance subsidies, and direct grants [16]. Based on current and potential new legislative polices, we estimate that approximately 5% of the production costs can potentially be written off. These can be expected to accelerate by the end of the decade as governments from all over the world are trying to lower their dependence on foreign oil.

The recent launch of the EU carbon emissions credits trading system (ETS) [17] is also expected to generate additional sources of revenue. Though carbon emission credits are projected to be only a modest source of income, their value could potentially rise in the future if the price of emission credits were to increase due to extensive environmental lobbying. The value of the credits is calculated by multiplying the reduction in the amount of carbon produced from switching from gasoline to hydrogen (about 1.606 tonnes/vehicle/year) with the projected carbon emission price of $9.00/tones [18]. This provides a small income stream of about $15 per scooter sold.

Other favorable factors include the impact of international environmental policies such as the Kyoto protocol [19], which places strict greenhouse gas emissions standards for motor vehicles in participating nations. Many countries are starting to implement new legislation which provide customer tax rebates for the purchase of alternative fuel vehicles, and conversely, penalties for purchasing high emissions gasoline vehicles. As equipment costs decline and infrastructure is built, hydrogen fuel prices may become more competitive by 2010. Conversely, a dramatic increase in oil prices in the next decade is also expected due to increased demand from emerging nations, political instabilities, and diminishing supply. All of these issues will improve the demand for hydrogen fuel cell scooters.

YEAR	0	1	2	3	4	5	6	7	8	9	10	
Discounted Cash Flow Analysis (in thousands of USD)	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	TOTAL
Moderate Scenario												
Sales Revenue	5366.07	5902.68	6492.95	7142.24	7856.47	8642.11	9506.32	10456.96	11502.65	12652.92	13918.21	**99439.58**
Cost of Goods Sold	4434.77	4878.25	5366.07	5902.68	6492.95	7142.24	7856.47	8642.11	9506.32	10456.96	11502.65	
Operating Expenses	1073.21	1180.54	1298.59	1428.45	1571.29	1728.42	1901.26	2091.39	2300.53	2530.58	2783.64	
Other Income	230.21	253.23	278.55	306.41	337.05	370.75	407.83	448.61	493.47	542.82	597.10	
Tax exemptions/grants	221.74	243.91	268.30	295.13	324.65	357.11	392.82	432.11	475.32	522.85	575.13	
CO2 emissions credits	8.47	9.32	10.25	11.27	12.40	13.64	15.00	16.51	18.16	19.97	21.97	
EBT	88.30	97.13	106.84	117.52	129.27	142.20	156.42	172.06	189.27	208.20	229.02	
Taxes	22.07	24.28	26.71	29.38	32.32	35.55	39.11	43.02	47.32	52.05	57.25	
Net Income	66.22	72.84	80.13	88.14	96.96	106.65	117.32	129.05	141.95	156.15	171.76	**1227.17**
Cash Flows	66.22	72.84	80.13	88.14	96.96	106.65	117.32	129.05	141.95	156.15	171.76	
Discounted Cash Flows (5% IRR)	66.22	70.04	74.08	78.36	82.88	87.66	92.72	98.07	103.72	109.71	116.04	**979.49**

Table 4.3: DCF analysis for European moderate scenario analysis

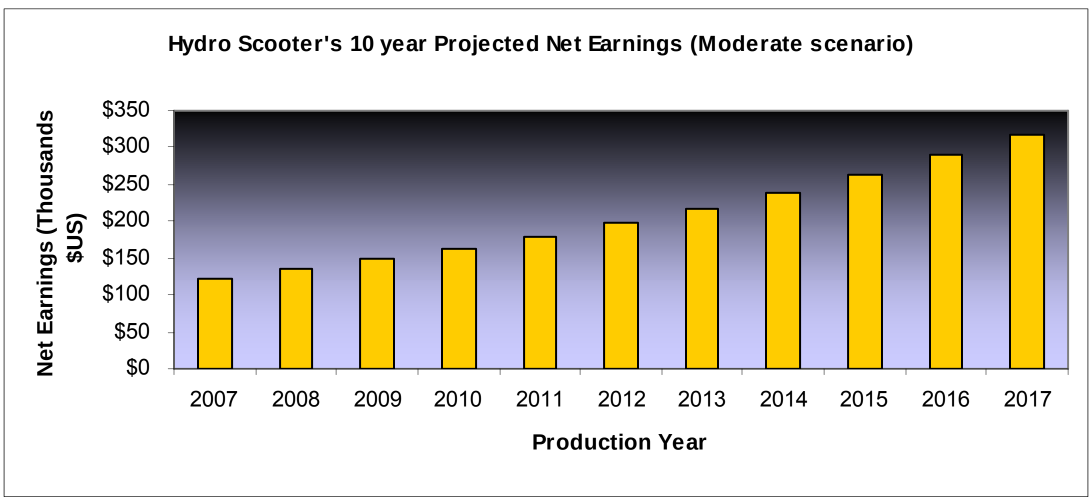


Figure 4.5: 10-year projected annual net earnings

4.2.5 Hydrogen Scooter Ownership benefits

Benefits to the consumer of owning a hydrogen-powered scooter will form part of our marketing strategy. Since hydrogen scooters will be priced at a significant premium, the marketing strategy must address this issue. Promotional issues will be addressed in the Education and Promotion section of this report.

4.2.5.1 Economic benefits of the GT200H

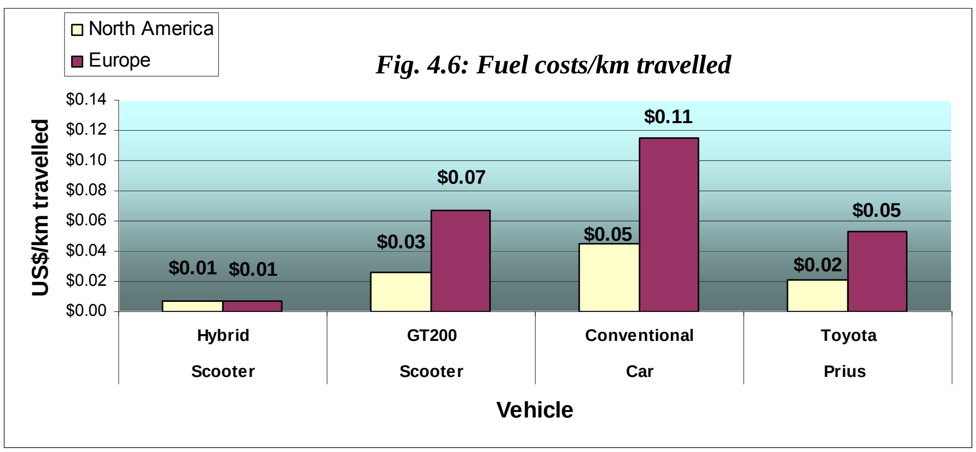
The superior fuel economy and potential savings in fuel costs will be the strongest marketing point of the hydrogen fuel cell scooter. Using a conventional internal combustion vehicle as a benchmark, we have provided a fuel cost savings analysis for 4 different vehicles

(GT200H scooter, GT200 scooter, conventional car, and Toyota Prius) as part of our marketing strategy. Our working assumptions are shown in Table 4.4. As shown in Figure 4.6, fuel costs in Europe are more than twice as high as gasoline prices in North America, making the GT200H an attractive transportation option in the European markets. Figure 4.7 illustrates the results of our annual fuel cost savings analysis.

Table 4.4: Working Assumptions for fuel cost savings

	Fuel Economy	**MSRP (USD)**	**Consumer Tax Rebates [20] (10% of purchase price)**
GT200 scooter [21]	20 km/L gasoline	$5,200	$0
Conventional car	11.7 km/L gasoline	$16,000	$0
Toyota Prius	25.34 km/L gasoline	$21,725	$2,173
GT200H scooter	0.8 km/g hydrogen	$9,157	$916

Distance traveled/yr.	14,600 km/year
Gasoline Prices - 2004 yr. end (North America) [22]	$0.53/L
Gasoline Prices (Europe)	$1.34/L
Hydrogen prices [23]	$5.70/kg



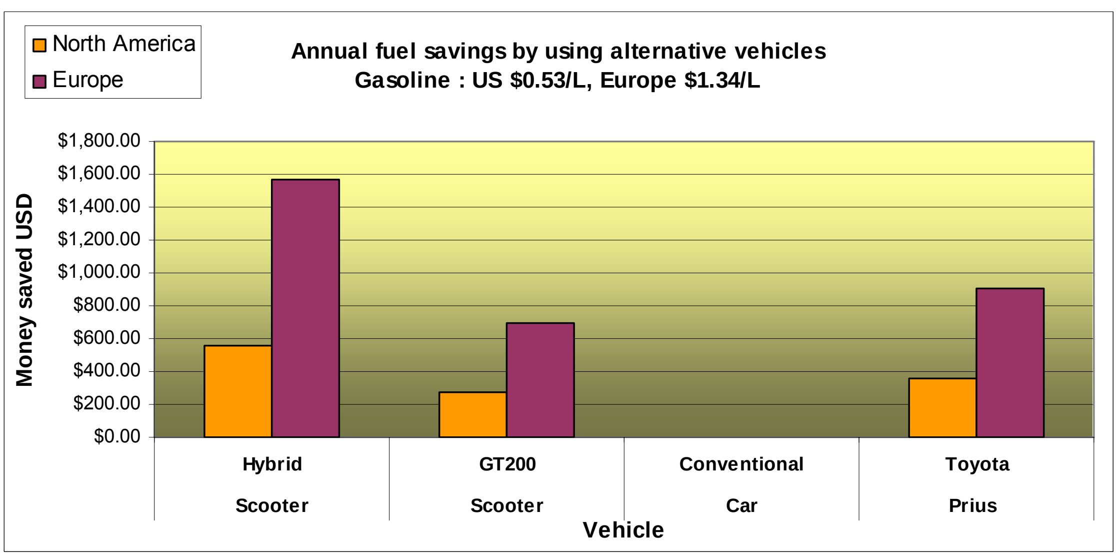


Fig. 4.7: Annual fuel savings by using alternative vehicles

From our analysis, we have concluded that the GT200H results in fuel savings of approximately 73% when traveling in North America, and about 89% in Europe. However, despite the enormous savings in fuel, at current gasoline prices, the high purchase price of the GT200H makes it a rather unattractive investment compared with the regular GT200. Even with the 10% consumer tax rebate, it will require upwards of **10 years** to breakeven when used in the North American markets. Unfortunately, this duration exceeds the expected lifetime of 7 years for the scooter battery and fuel cell. The outlook in Europe looks more favorable due to the higher gasoline prices, with a breakeven timeframe of **5 years**.

However, as mentioned earlier, as infrastructure is built, hydrogen fuel prices may become more competitive by 2010 (with a near goal target is $2-4/kg). Likewise, a sustained escalation of the price of oil could make the GT200H scooter a much more attractive purchase. For example, oil prices spiked 40% when Hurricane Katrina struck the U.S [24]. It is probable that gasoline prices will rise by this amount, if not more, over the next decade. In this scenario, even with the potentially higher costs of reforming natural gas into hydrogen, the breakeven timeframe for a GT200H will be greatly reduced due to dramatic fuel cost savings. Over the long term, we predict that the GT200H will be a cheaper option to drive than the gasoline powered GT200.

Additional savings the customer may receive include government financial incentives such as tax rebates. Also, electric scooters are not subject to road or property tax in many countries.

4.2.5.2 Social / environmental benefits

The premium price of hydrogen includes a number of benefits that are not immediately available to gasoline customers. According to a recent report by the International Center for Technology Advancement, the true cost of gas is between US$5.60-$15.14/gallon when one considers the tax subsidization of the oil industry, government program subsidies, protection costs involved in oil shipment and motor vehicle services, and the environmental, health and social costs of gasoline usage [25]. When considering these hidden costs, hydrogen is quite competitive economically with gasoline.

4.3 Closing Remarks

The biggest question remaining about the mass production of the GT200H concerns its high production cost. In order to compete with the internal combustion engine, fuel cell vehicle manufacturing costs must decrease substantially in the coming decade, along with the costs of hydrogen infrastructure and transport. Economies of scale will help as production volumes increase. But further advances in engineering, especially with respect to the fuel cell and hydrogen storage options will be essential.

In order to highlight hydrogen's strengths as a domestically produced, environmentally friendly product, the GT200H was designed and priced with a "first to market" priority, in order to gain early market share and reputation in the hydrogen vehicle market. This is the same business strategy Toyota and Honda employ with their Prius and FCX models respectively.

Although the final market for alternative fuel scooters is unknown, we forecast that hydrogen fuel cell scooters and hybrids will account for a tenth of the world's scooter market as early as 2015. We expect more than 150 million scooters, including alternative energy powered ones, to roam the world's streets by 2010 [25]. Demand for hydrogen powered scooters will be aided by world's governments which may soon urge carmakers to slash carbon dioxide emissions by 20% by 2010 [26]. And it wants them to cut nitrous oxide, hydrocarbons and carbon monoxide emissions by 80%. Furthermore, governments are giving tax breaks to consumers who buy "green" vehicles, and CO_2 emissions credits.

Sales of the GT200H, or any other commercial fuel cell vehicle, are not expected to be economically competitive, and will not be seen as a substitute product in the near future. Rather, the demand for fuel cell vehicles in the next ten years is likely to be due to its novel appeal as a domestically produced, environmentally friendly alternative to fossil fuel powered vehicles. Nevertheless, as one of the world's first commercially available hydrogen powered scooters, the GT200H has set a standard for Vespa and its competitors, and represents a premier design for introducing North Americans and Europeans to the promise of a hydrogen economy.

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5.0 Public Awareness and Education Plan

Public awareness and education is going to be a crucial ingredient in the market success of this project. At present, the public image of hydrogen fuel suffers greatly due to numerous misconceptions and hype. The way to win over the minds of the public is through a campaign aimed at increasing awareness and education.

The educational drive must begin well before the product is launched. This is so that the public forms positive associations with respect to hydrogen fuel and related technologies. Vespa can greatly benefit in this regard by joining forces with mature partners in the industry with a similar interest in popularizing hydrogen.

Addressing a workshop on hydrogen education in February 2004, the US Secretary of Energy Spencer Abraham said, “Achieving the vision of a hydrogen economy requires a revolution in the way we produce, use and store energy. This revolution will succeed only through cooperation among federal, state and local partners. It’s important that we share an understanding of how hydrogen fuel cell technology works, as well as challenges we face in realizing the vision.”[1]

The following educational awareness plan has been built on the guidelines laid down in the workshop mentioned above. The plan is organized into sections that focus on education, developing codes and standards, engaging decision-makers, building a vision for the hydrogen economy and exploiting the media.

5.1 Educational Plan

The education campaign needs to target a wide range of audiences and therefore the effort needs to focus on a variety of activities. Activities in schools could range from distributing toys to middle school students and offering research projects to engineering graduate students. Multi-media exhibits and presentations, websites, documentary films, training centers, demonstration programs, and newsletters could also serve to disseminate the message amongst the masses. Vespa should enter into strategic partnerships with industry, government agencies, professional/trade organizations, and foundations to leverage resources in order to increase the scale, reach and effect of educational efforts at all educational levels.

5.2 Codes and Standards

Another important aspect of increasing awareness is to make the information on hydrogen consistent and readily available. This is especial
lly true for codes and standards relevant to the development of hydrogen technology. At present there a great multitude of codes often with overlapping spheres of influence.

5.3 Engaging Decision Makers

Vespa and other stakeholders also need to engage the state and local decision makers. This can be achieved by organizing demonstration projects with a focus on incorporating educational plans. At the same time Vespa should explore existing educational efforts by the federal and local authorities and share their expertise in this area.

5.4 Build a Vision for the Hydrogen Economy

The public awareness campaign needs to raise the profile of the dialogue surrounding hydrogen and its many benefits. While it is no longer possible for anyone to ignore the ill effects of an oil-based economy the alternatives are not well established. The public should form associations between hydrogen and clean energy, energy security and cheap fuel. They need to be educated about hydrogen's track record in industry as a safe fuel when proper guidelines are followed.

5.5 Exploiting the Media

To canvass a broad population, Vespa will need to exploit the media to its benefit. A suitable platform to launch such a campaign would be through television infomercials and newspaper advertisements. At the same time increasing the visibility of Vespa's commitment to hydrogen through media events such as the annual Canadian National Exhibition (CNE), sustainable energy fairs and public energy discourses should help to engage the public positively.

Another strategy in this regard would be to acquire the services of a television celebrity to carry the hydrogen message. Similarly, the development of hydrogen champions on children's television to form positive associations in the minds of the next generation.

6.0 Marketing Plan/Promotion/Education

This section summarizes some of the promotional and marketing techniques that are employed to educate the consumer and to communicate the benefits of the GT200H scooter.

6.1 Target Market

The GT200H will target major metropolitan areas in North America and Europe. Asia was not chosen for sales distribution despite its high demand (see Fig. 4.2 in section 4.2.2.0) due to intense competition. Despite rapidly growing scooter interest in North America (nearly 20% annual growth since 1998), we expect the majority of our sales to come from Europe (see Fig.4.3 in section 4.2.2.1). As discussed earlier, scooters are far more popular in Europe than in North America, due to high fuel prices, congested city streets with limited parking, and a long history of accepting scooters as an acceptable mode of transportation [2]. As a result of this greater utility, Europeans are typically willing to spend more on their scooters than are Americans. Also, safety and emissions regulations between Europe and the USA vary greatly, which means scooters legal in Europe often require extensive modifications to legalize them in America. As of February 2006, there were more than 25 hydrogen fueling stations scattered across Europe, with many more in the process of being built [3]. Unfortunately, there are currently no major fueling stations in Italy, one of Vespa's largest markets. However, that may soon change as more fuel cell vehicles are introduced into the Italian markets.

In North America, our number one market will be California, due to favorable weather conditions, their focus on environmentally friendly transportation, and the Californian Hydrogen highway initiative. Furthermore, the state is well equipped with hydrogen infrastructure - there are more than 20 hydrogen fueling stations already built in California. We are uncertain whether there will be such a demand in Canada and the other U.S. states, although hydrogen-fueling infrastructure can be found in major cities such as Toronto and Michigan.

The GT200H scooters will be sold through a combination of company-owned stores, all-electric dealers, and direct sales to fleet buyers. These primary target customers include mainly the “early adopters” and “scooter enthusiasts” segments of the population. Other potential customers include wealthy white-collar executives looking for weekend toys, and commuters who are concerned with the environment and their health. The early adopters are expected to be a niche segment in 2007, the date of our product launch. It should also be noted that 30-40% of scooter buyers are women. Female customers are more apt to accessorize and personalize their scooters, and accessories can account for 20 percent of scooter manufacturer sales[4].

The general community will be targeted to increase hydrogen awareness, although we expect they will show little interest due to the high premium cost.

6.2 Penetrating the target market : Delivery solutions

Successful penetration of the target market can be achieved by implementing solutions to the following two objectives:

Objective 1: Position hydrogen as an attractive fuel source. Communicate to customers how the GT200H scooter will meet their energy needs.
Solution: a) Promote the benefits of hydrogen b) Make the transition seamless

a) Promote the following benefits of hydrogen as an alternative to conventional gasoline:

- **Environmental benefits**: The central focus of the marketing campaign will be to position hydrogen as a clean, renewable energy alternative and promote its reduced carbon emissions compared to gasoline. The reduction of CO_2 will alleviate the harmful effects of global warming such as climate volatility and the loss of biodiversity; it will have a favourable impact on local air quality allowing for a cleaner, more sustainable future (see section 4.2.5.2). There are an estimated 12 million scooters in use in the crowded cities of Europe today [5]. Global scooter production exceeds 17 million units annually and their use is expanding, with almost 20% yearly growth in North America. Pollution and noise are major problems in some of these crowded cities. We believe our non-polluting fuel cell scooter could play an important role in helping to alleviate these conditions. This feature is very appealing at a time when government air-quality standards are becoming more rigorous, and consumer interest in the environment is strong.
- **Gasoline independence**: Substituting gasoline for hydrogen diminishes reliance on foreign oil, and will lead to large savings in fuel costs (see section 4.2.5.1).
- **Safety**: Cars fuelled by hydrogen will not endanger customers or the community (refer to Section 2.0 for details about precautionary safety measures employed).

b) **Make the transition as seamless as possible for consumers**: The GT200H scooter has a similar range capacity and performance envelope compared to the gasoline version. Furthermore, it looks and behaves like a conventional gasoline scooter, except that it has greatly reduced gas emissions and noise. It will have a comparable user interface and controls. On the hydrogen infrastructure side, consumers visiting regular gasoline fuel stations will be made aware of other hydrogen stations in close geographical proximity, through billboards and flyers.

Objective 2: Accelerate commercialization of the hydrogen economy through education awareness not only for hydrogen customers but for the general public as well.
Solution: See Section 5.0 for ideas on facilitating education and acceptance.

6.3 Implementing the Marketing and Promotional Campaign

An effective marketing campaign will go a long way in convincing people to make the switch to hydrogen energy. Therefore, an aggressive promotion strategy will be implemented from the start. HydroScooters will target potential customers early in order to guarantee a large, lasting consumer base. Vespa's existing popularity and brand name (they command a 40% market share in Europe) [6] will undoubtedly aid our strategy.

Before the product launch in 2007, Hydro Scooters will make its name publicly known in various media, including billboards, flyers and newspaper advertisements. An effective advertising strategy currently used by Vespa that we will also employ is "product placement" [7]. This is the latest trend in advertising - where the tendency is to move away from in-your-face ads, where the product is the star, to scenes in movies, television, and video games that feature "real-life scenarios" with the product hovering seamlessly in the background. It is expected that media coverage will generate strong word of mouth interest as well. To build customer relationships, customer loyalty cards will be introduced so that all new Vespa owners will be informed about the GT200H option.

The launch of the marketing campaign also corresponds with the 2010 Winter Olympic Games in Vancouver, where it is anticipated that hydrogen and related technologies will receive significant national and international exposure due to the emerging hydrogen economy hub in British Columbia [8]. HydroScooters will capitalize on this opportunity by circulating marketing communications at this time.

Upon completion of the initial name recognition stage, the educational stage outlined in Ssection 5.0 will commence, in which HydroScooters will encourage public awareness of sustainable energy solutions and hydrogen as a form clean energy. This will serve to further expand our customer base.

A one-page advertisement is included in Section 6.4.

References - Education

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6.4 Poster


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