“All across the world, in every kind of environment and region known to man, increasingly dangerous weather patterns and devastating storms are abruptly putting an end to the long-running debate over whether or not climate change is real. Not only is it real, it’s here, and its effects are giving rise to a frighteningly new global phenomenon: the man-made natural disaster.”

-- President Barack H. Obama

Professor Arun Jain, School of Management, University at Buffalo, Buffalo, NY, USA prepared this case solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of management actions being effective or ineffective. Much of the information was obtained through secondary sources. Professor Jain wishes to thank Mr. Steve Finch, GM Tonawanda Engine Plant, Mr. Daniel B. O’Connell, Director Fuel Cell101X Service, Support & Infrastructure, Ms. Nina Price, GM Communications Manager, Ms. Melanie Buhrmaster-Bunch, Director of Corporate Relations, UB, and Dr. Romesh Kumar, Fuel Cell Department Head, Chemical Engineering Division, Argonne National Laboratory for their assistance in developing this case. Ms Rohini Gupta, MBA Program, School of Management, UB provided invaluable research assistance in revising the case.
Chevy Equinox Fuel Cell COV: How to Enter the Market?

Clara Barnowski got more than what she bargained for when she began driving an experimental hydrogen-powered, zero-emission car around West Chester county, New York. The 50-year-old teacher liked the brisk acceleration and uncanny quietness of the car, which is powered by a hydrogen fuel-cell stack that runs an electric motor and emits only water vapor via four slots on its rear end. “I bonded with it,” Ms Barnowski said of General Motors’ Equinox COV. What surprised her, however, was what she calls the “spewing of feelings” by other motorists tired of exorbitant fuel prices or worried about emissions. “People would roll down their windows at intersections, or give me the high-five or thumbs-up sign,” she recalled. “Their biggest question was, ‘When can I buy one?’.” This was music to the ears of the launch team of GM’s entry into the new power-train technology.

This COV is not yet available to retail customers, and mass production and commercial launch is planned for 2015. GM has been offering Equinoxes on a pilot basis to drivers who live near hydrogen filling stations to get their reaction to the vehicle. Over a billion dollars have been invested in perfecting the technology. It would cost billions more to go into the mass production mode. Some analysts doubt that fuel-cell cars, because of their costly infrastructure requirements, will ever come into widespread use. However, fuel-cell technology – along with hybrid and plug-in electric vehicles – is getting a boost from soaring petrol prices. A century after Henry Ford’s Model T revolutionized the way cars were made and sold, carmakers are developing new hybrid, hydrogen and electric models that will over time reduce their reliance on the internal combustion engine. Deutsche Bank, in a recent research report, forecast that motor vehicle technology would “change more significantly over the next five years than it has in the past 100”.

The launch team reminded itself of the financial straight jacket the company was in. The century-old GM is experiencing historic financial challenges that threaten the company’s longevity. The company received 52 billion dollars from the U.S. government ($ 6.7 billions in loans and 45.3 billions in company stocks) and 9.5 billions from the Canadian government (1.4 billions in loan and 8.5 billions in company stocks) as it restructured, negotiating concessions with its labor unions and jettisoning brands. The giant automotive manufacturer went through a brief Chapter 11 bankruptcy reorganization in 2009. It cut its brands in half, to four: Chevrolet, Cadillac, Buick and GMC, and shed 65,000 blue-collar jobs in the U.S. through buyouts, early retirement offers and layoffs. The automaker closed 14 factories and globally the company lost global leadership to Toyota. But, fading away in the dusk was not an option.

True to her heritage and the American spirit, management was determined to regain the lost premier status in the industry by winning back customers through superior products and customer focused technology. And succeed they did. On April 20, 2010, five years ahead of the
schedule, GM repaid her loans from the US and Canadian governments. Later in November, US Treasury sold 67% of its holdings in a successful IPO of the restructured company. Starting in the third quarter of 2010, the new GM became profitable again earning $4.7 billions in 2010. It increased to $7.6 billion in 2011 and $4.9 billion in 2012, a solid transformation from its sorry state.

With gasoline prices touching historic levels and no where to go but up and the global focus on green house effect, the alternative power train offered that opportunity. There was a strong belief within GM that if they make the right moves, success will be theirs. They had the technology and time was on their side. The team took out a blank sheet of paper and wondered about their move in 2015.

BUSINESS ENVIRONMENT

The planet earth is becoming warmer. How warm? Just a degree here and there, but those tiny increases manage to throw a great portion of nature out of balance. There are a lot of opinions about this. Some people feel that global warming is just nature running a bit of a temperature and that this will pass in due time. Of course time for the earth is measured in millions of years so it could take awhile. However, most environmental scientists agree that global warming is a man made predicament and as such has a definite cause. The resulting warmer climate will most probably cause more heat waves, more cases of heavy rainfall, and an increase in the number and severity of storms. Evidence suggests that glaciers are melting and rise of sea levels are eminent. All this will result in global misery. The UN secretary-general, Ban Ki-moon, has urged all countries to start tackling climate change. US President, Barack Obama, has reaffirmed US commitment to address the global warming through concrete efforts by America.

The primary cause of global warming is believed to be Carbon Dioxide emissions. CO2 is being pumped into our atmosphere at an ever increasing pace; the average annual concentration of CO2 in the atmosphere during 2010 was 389.78 ppm. During 2001-10, the annual increase has been 2.04ppm per year. Of course some of this is due to natural activity such as volcanic eruptions and people breathing. The Earth is equipped to easily absorb those into the normal regenerative process. The problem is with the increasingly large amount of fossil fuels being burned which emit large amounts of CO2 into the environment.

In 1988 United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established Intergovernmental Panel on Climate Change (IPCC) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis. The panel issued its report in September, 2013. It said it was "unequivocal" and that even if the world begins to moderate greenhouse gas emissions, warming is likely to cross the critical threshold of 2C by the end of this century. That would have serious consequences, including sea level rises, heat waves and changes to rainfall meaning dry regions get less and already wet areas receive more. The panel

1 http://co2now.org/
warned that the world cannot afford to keep emitting carbon dioxide as it has been doing in recent years. To avoid dangerous levels of climate change, beyond 2°C, the world can only emit a total of between 800 and 880 gigatonnes of carbon. Of this, about 530 gigatonnes had already been emitted by 2011. The former UN commissioner, Mary Robinson, warned that this will have "huge implications for social and economic development." In response to the report, the US secretary of state, John Kerry, said in a statement: "This is yet another wakeup call: those who deny the science or choose excuses over action are playing with fire." Introducing the report, Ban Ki-moon UN Secretary General said, "The heat is on. We must act."

**Supply and Demand for Fossil Fuels**

Oil has been the primary source of transportation related energy since the invention of automobiles. Historically, oil has been relatively easy and inexpensive to extract and convert to gasoline and diesel for automobile fuel. Figures 1 presents global oil production in 2010. The major sources of oil in the world are Middle-East, Africa, and Euro-Asia. The current and projected demand for oil and liquid fuels (liquid fuels include petroleum-derived fuels and non-petroleum-derived liquid fuels) across the globe are shown in Figures 2 and 3.
Figure 1: Global Oil Production in 2010

North America: 30%
Central & South America: 16%
Europe: 10%
Eurasia: 15%
Middle East: 9%
Africa: 6%
Asia & Oceania: 14%

Legend: 
- Green: North America
- Purple: Central & South America
- Orange: Europe
- Pink: Eurasia
- Red: Middle East
- Yellow: Africa
- Blue: Asia & Oceania
Figure 2
World Oil Consumption by Economic Group of Countries 1980-2009

- OPEC
- FSU (FORMER SOVIET UNION)
- ROW (REST OF WORLD)
- OECD
- CHINA AND INDIA
- Europe Brent Spot Price FOB (Dollars per Barrel)
The growth in demand for oil outside countries of the Organization for Economic Cooperation and Development (OECD) reflects projected rapid economic development in BRIC (Brazil, Russia, India, and China) countries. Figure 4 presents incremental oil demand by different sectors of global economies.
According to U.S. Energy Information Administration (EIA), America consumed about 138 billion gallons (or 3.3 billion barrels) of oil in 2010, about 378 million gallons (about 9 million barrels) per day. Roughly, about 37% of the crude oil used by U.S. refineries is produced in the United States. The rest is imported from other countries. Figure 5 shows sources of petroleum imports during 2010. The top five exporting countries to U.S. include - Canada, Mexico, Saudi Arabia, and Nigeria. Together, they accounted for 68% of crude oil imports in the U.S. during 2010 (Figure 5).

(Source: U.S. Energy Information Administration, Petroleum Supply Monthly (February 2011))
The International Energy Agency has estimated that in 2009, 23% of the global energy-related carbon dioxide emissions were generated by transportation sector of the economy (Figure 6).

Figure 6: Global CO2 Emission in 2009 by Sectors


The agency believes that the global car fleet will surge during the next 25 years. With economic prosperity, more households in China, India, and other emerging economies will buy a car. As shown in Figure 7, eventually the growth in the number of vehicles in OECD countries will be enveloped by growth in the number of private vehicles in rest of the world.

Figure 7: Passenger Vehicles
Reversing that trend will be difficult, because the oil-based products that create emissions – petrol, diesel and jet fuel – offer a uniquely attractive combination of cost and energy content relative to volume.

US and Canada use oil much more intensely then the rest of the world (See Figure 8). The difference is due to the energy usage in the transportation sector of US and Canada. The two countries depend much more on private vehicles to travel relatively long distances. As compared to the rest of the world, gasoline prices and taxes on them are low, and there is relatively lower reliance on public transportation. Furthermore, households in US and Canada have preference for relatively larger vehicles. The transportation sector accounts for over two third of the oil consumption in the US:

Figure 8: Global Consumption of Oil Per Capita

4.6% of the total world population inhabits America. However, as a nation the country consumes one quarter of all the oil produced in the world. Two thirds of the oil America uses every day is for transportation. There are about 249 million vehicles that use gasoline, and they each travel over 12,000 miles per year. The country has about 162,000 fueling stations that provide convenient refueling for consumers. Burning a gallon of gasoline produces about 19 pounds of carbon dioxide. According to energy experts, even if every vehicle on the street in America were a hybrid car, by 2025 the country would still need to use the same amount of oil then as it does right now.

Figure 9 shows the CO2 emissions by a typical American household. The vehicles driven in US over 1.7 billion tons of CO2 into the atmosphere each year. Each gallon of gasoline burn creates 20 pounds of CO2. That's about 6 to 9 tons of CO2 each year for a typical vehicle.
Figure 9: Source of CO2 Emissions for A Typical American Household

Figure 10 shows the amount of total Carbon Dioxide emissions during 1990-2008 by different sectors of U.S. economy.

**Figure 10: U.S. Energy Related Carbon Dioxide Emissions by the End User Sector, 1990-2008 (Million Metric Ton Carbon Dioxide)**


**Human Cost Of Climate Change and Efforts to Control It**

The climate change has dramatic effect on human health (Figure 11). The World Health Organization warns that climate change produced by green house effect cause ozone depletion,
land degradation, decline of fresh water, stress on food producing systems, and biodiversity all significantly impacting human health.

Figure 11: Effect of Green House Effects on Human Health

According to the International Energy Agency (IEA), the safe limit for global warming is 2°C. This will require that the world must hold emissions to no more than 450 parts per million (ppm) of carbon dioxide in the atmosphere. The current level is already 390 ppm while the world is busy building many fossil fueled power stations, energy guzzling factories, and energy inefficient buildings. Scientists fear that if fossil fuel usage policy is not rapidly changed, the world will “lose for ever” the chance to avoid dangerous climate change. Carbon dioxide, once released, stays in the atmosphere and continues to have a warming effect for about a century.
Public Policy

Policy makers at all levels of U.S. Government have recognized the risks of climate to human health and quality of life. When combined with fast depletion of oil supplies, it has become a hot button issue in the public arena. Starting in 1975 when the US experienced first oil crisis, CAFE (Corporate Average Fuel Economy) standards were imposed on all auto manufacturers in the US requiring them to increase their average miles per gallon (mpg) to 18 by 1978 and 27.5 by 1985. In October, 2009, the targets were raised by President Obama to increase mpg to 35.5 by 2016 and reduce CO2 to 250 grams per mile (YOUTUBE).

The 2016 fuel economy and CO2 emissions standards marked the first time the US has regulated greenhouse gas emissions. However, these standards are lower as compared to European Union standards, those of Japan or even China. China currently enforces an average fuel efficiency standard of 35.8 miles per gallon (mpg) and Japan demands 42.6 mpg. Europe meanwhile requires vehicles achieve 43.3 mpg by 2016. On November 16, 2011, ahead of the Durban Conference, the Obama administration proposed stronger fuel economy and greenhouse gas pollution standards for model year 2017-2025 passenger cars and light trucks. Cars, SUVs, minivans, and pickup trucks. These vehicles will be required to achieve fuel efficiency of 54.5 mpg. The state of California along with Connecticut, Hawaii, Massachusetts, Maryland and New Jersey have consistently adopted aggressive legislations to control emissions and greenhouse effects to the extent of taking federal government to court upon dithering by the US Congress and the administration.

Public Attitude Towards Climate Change

A poll of 16 nations--Bangladesh, Brazil, China, Egypt, France, India, Indonesia, Iran, Japan, Kenya, Mexico, Russia, Senegal, Turkey, the United States, and Vietnam--commissioned by the World Bank shows that public concern about climate change is high worldwide, but it's generally higher in developing countries. In most countries, large majorities across social classes is willing to pay to fight climate change. Public opinion polls suggest that US population (across the political spectrum) generally believes that global warming exists, caused by human actions, should be a national priority, and efforts need to be made to curb it. Appendix A presents results of recent public opinion polls on environmental issues.

ECONOMIC ENVIRONMENT

The U.S. economy went into recession in 2008. The perfect “storm” was caused by reckless lending practices of financial institutions, speculative bubble in real estate and equities, sharp increases in oil and food prices, and collapse of major financial institutions. In July, 2008 oil prices reached $147.30 a barrel! The outcome of this recession was a sharp decline in industrial production, retail sales, tightening of credit, and increase of unemployment. While western economies suffered, least effected were China, India, Brazil, Iran, Peru, and Peru. By November, 2009, U.S. unemployment rate reached 10.2%, the highest in 26 years.

The business conditions in North America are improving. According to the CBO, U.S. economy grew by 2.5% in 2010. It is expected to grow by 3.1% in 2011, 2.8% in 2012, and 2.8%
in 2012. The projected growth during 2013-2016 is 3.4%, and 2017-2021, 2.4%. The unemployment rate is expected to start declining in 2012 to 8.2% in 2012, 5.3% during 2013-16, and 5.2% during 2017-2021.

![Figure 12: U.S. Unemployment Rate](source)

Industry experts expect oil prices to continue to rise over the next few decades as more low-cost sources are depleted. Oil companies will have to look in increasingly challenging environments for oil deposits, which will drive oil prices higher. EIA expects the average real price of crude oil in 2035 to be $135 per barrel in 2009 dollars. Concerns extend far beyond economic security. The Council on Foreign Relations released a report in 2006 titled “National Security Consequences of U.S. Oil Dependency.” A task force detailed numerous concerns about how America’s growing reliance on oil compromises the safety of the nation. Much of the report focused on the political relationships between nations that demand oil and the nations that supply it. Many of these oil rich nations are in areas filled with political instability or hostility. Other nations violate human rights or even support policies like genocide. “Arab Spring” has introduced significant political instabilities in middle east and africa. Potentially, it could disrupt future oil supply and significantly raise price of oil. When combined with the dramatic growth of BRIC countries, the era of plentiful cheap oil has ended and it may be in the best interests of the United States and the world to look into alternatives to oil to ensure economic growth.

**AUTOMOTIVE POWERTRAINS**

Automotive industry has the option of using a number of different powertrains technologies to move a vehicle. Each have their advantages and disadvantages with respect to emissions, fuel consumption, and cost.

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INTERNAL COMBUSTION ENGINE (ICE)

A vehicle powered by internal combustion engine uses fossil fuels to create motion for movement. The principle is: put high-energy fuel in a small, enclosed space and ignite it. The ignition releases energy in the form of expanding gas. This force is applied to a movable component of an engine, such as the pistons or turbine blades. In the car engine the linear motion of the pistons is converted into rotational motion by the crankshaft. The rotational motion rotates the car's wheels thus providing movement over a distance. The trick is to create a constant cycle that will permit constant motion. Almost all cars currently use what is called a four-stroke combustion cycle to convert gasoline into motion. The four-stroke approach is also known as the Otto cycle, in honor of Nikolaus Otto, who invented it in 1867. The four strokes are illustrated in Figure 13 below:

Figure 13: Four Stroke Otto Cycle

The engine goes through four strokes (YOUTUBE):

a. The piston starts at the top, the intake valve opens, and the piston moves down to let the engine take in a cylinder-full of air and gasoline. This is the intake stroke. Only the tiniest drop of gasoline needs to be mixed into the air for this to work. (Part 1 of the video).

b. Then the piston moves back up to compress this fuel/air mixture. Compression makes the explosion more powerful. (Part 2 of the video)

c. When the piston reaches the top of its stroke, the spark plug emits a spark to ignite the gasoline. The gasoline charge in the cylinder explodes, driving the piston down. (Part 3 of the video)

d. Once the piston hits the bottom of its stroke, the exhaust valve opens and the exhaust leaves the cylinder to go out the tailpipe. (Part 4 of the video)
The internal combustion engines produce air pollution emissions, due to incomplete combustion of fuel. The main derivatives of the process are carbon dioxide $\text{CO}_2$, water and some soot—also called particulate matter (PM). The effects of inhaling particulate matter have been studied in humans and animals and include asthma, lung cancer, cardiovascular issues, and premature death. There are however some additional products of the combustion process that include nitrogen oxides and sulfur and some uncombusted hydrocarbons, depending on the operating conditions and the fuel-air ratio which are very harmful for the humans and the environment. Invented in 1680, ICE has gone through major changes and is ubiquitous in our daily life. This has significantly reduced its cost of manufacturing and resulting popularity. Given large number of moving parts and friction, the ICEs require regular maintenance, oil, filter, and spark plug changes adding to the life cycle cost of ICE equipped vehicle ownership. Presence of over 162,000 gas stations in U.S. makes it convenient to fuel an IC equipped vehicle. CNG can easily substitute for gasoline or diesel. Such natural gas vehicles are increasingly used in the Asia-Pacific region, Latin America, Europe, and America due to rising gasoline prices.

HYBRID ENGINE (HEV)

A hybrid system features a small fuel-efficient ICE gas engine combined with an electric motor that assists the ICE engine when accelerating (YOUTUBE). The electric motor is powered by batteries that recharge automatically when the vehicle is driven. There are two types of gasoline-electric hybrid cars: the parallel hybrid and the series hybrid. In a parallel hybrid car, a gasoline engine and an electric motor work together to move the car forward, while in a series hybrid the gasoline engine either directly powers an electric motor that powers the vehicle or charges batteries that will power the motor. The electric motor that drives the hybrid can also slow the car. In this mode, the electric motor acts as a generator and charges the batteries while the car is slowing down. When a hybrid car is stopped in traffic, the engine is temporarily shut off. It restarts automatically when put back into gear. In the Figure 14 below, the operating system of a typical hybrid car is depicted.
In most of the North-East and mid-west, winters are very punishing on engine’s using gasoline. The cold temperatures cause gasoline to thicken. That makes it difficult for the gas to combine with the intake air and provide the proper air-fuel mixture that an internal combustion engine needs. Not only it is harder to generate the correct mix, but the engine is also less powerful when the gas is cold. That means the vehicle ends up using more gas to do less work. While hybrids use their electric motors for slow-speed driving, their gasoline engines fire up when more power and speed are needed, and in cold weather, those engines are less efficient. What makes matters worse for hybrids is that because their IC engine is not in constant use, in cold weather, it can take them longer to warm up. Think about it: Regardless of where you live, there’s a good chance that you’ve gotten into a car on a cold morning. After a few miles of driving, even if those miles are driven slowly or in heavy traffic, the car gradually warms up. But in a hybrid, those few miles of driving may only use the gasoline engine part of the time, making it slower to warm up. That keeps the gasoline relatively cold and the engine running below maximum fuel efficiency. It could reduce MPG of hybrids to 30 or less depending upon the driving habits and weather conditions in much of North-East and mid-west, making such vehicles less economical. This will also be true in much of Europe where winter weather is severe. Appendix B provides a description of the currently available hybrid cars in the market.
PLUG-IN VEHICLES

Two types of plug-in vehicles are being offered: pure plug-in (PEV) and hybrid plug-in (PHEV). Both utilize a large lithium-ion battery that can be recharged. In PEV, the battery pack is recharged by connecting to common household electricity. The range from a single charge varies between 62 miles to 138 miles depending upon the driving style, load, traffic conditions, weather (i.e. wind, atmospheric density), and accessory used. PEVs contribute to cleaner air in cities because they produce no harmful pollution at the tailpipe from the onboard source of power. The amount of carbon dioxide emitted by PEVs depends on the emission intensity of the power source used to charge the vehicle, the efficiency of the said vehicle and the energy wasted in the charging process. An EV recharged from the existing US grid electricity emits about 115 grams of CO$_2$ per kilometer driven whereas a conventional US-market gasoline powered car emits 250 g(CO$_2$)/km. Figure 15 shows the the sources of electricity in the US in 2009. Among the sources used, coal and petroleum produce the greatest greenhouse gases.

Figure 15: U.S. Electricity Generation Sources(2009)

The PEV currently offered is Leaf sold by Nissan. Consumer Reports tested a Leaf loaner under cold-weather driven as a daily commuter. The magazine also reported one trip under a temperature of 10 °F (−12 °C) that began with the range panel indicator showing 20 miles remaining. After 8 miles the Leaf drastically lost power and dropped its speed and continued to run slower until the last stretch was completed almost at walking speed.
A Plug-in hybrid vehicle (PHEV) have a traditional gasoline powered internal combustion engine as well as an electric motor. As in PEV, the battery can be recharged by connecting to common household electricity. Like hybrid cars, the battery of PHEVs is recharged by ICEs. Plug-in hybrids can be driven for long distances—from a few miles to as much as 40 miles—without using any gasoline. The Figure 16 below describes the functioning of a PHEV vehicle.

**Figure 16: Plug in Hybrid Engine**

A study published in 2011 by the Belfer Center, Harvard University, found that the gasoline costs savings of plug-in electric cars over the vehicles’ lifetimes do not offset their higher purchase prices. This finding was estimated comparing their lifetime net present value at 2010 purchase and operating costs for the U.S. market, and assuming no government subsidies.

In the U.S. Chevrolet Volt is the only mass production PHEV available in the market. The EPA has rated Volt’s all-electric range to be of 35 miles, and an additional gasoline-only extended range of 344 miles. It has an EPA combined city/highway fuel economy of 93 MPG-e in all-electric mode, and 37 mpg-US in gasoline-only mode, for an overall combined gas-electric fuel economy rating of 60 mpg. Appendix C presents the likely PHEV’s to become available in the near future.

According to a report by the British consulting group Ricardo Plc, Electric and hybrid cars generate more carbon emissions during their production than current conventional, ICE vehicles. A typical medium-sized family car will create around 26 tons of CO₂ during its life cycle, while an electric vehicle (EV) will produce around 20 tons over its life, the report said. For a battery EV, 46% of its total carbon footprint is generated at the factory, before it has travelled a single mile.
FUEL-CELL (FCV)

A fuel cell is a device that uses hydrogen (or hydrogen rich fuel) and oxygen to create electricity. It consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat (View FUEL CELL ANIMATION). Since the conversion of the fuel to energy takes place via an electrochemical process, not combustion, the process is clean, quiet and highly efficient. If pure hydrogen is used as a fuel, fuel cells emit only heat and water, eliminating concerns about air pollution or greenhouse gases. There are several different types of fuel cells, each using a different chemistry. The Department of Energy (DOE) is focusing on the polymer exchange membrane fuel cell (PEMFC) as the most likely candidate for transportation applications. The PEMFC has a high power density and a relatively low operating temperature. The low operating temperature means that it doesn't take very long for the fuel cell to warm up and begin generating electricity. (View working of a Fuel cell equipped vehicle).

A Comparison of Different Power Trains

The Argonne National Laboratory of the U.S. Department of Energy had developed GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation), a full life-cycle model, that allows analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle from wells to wheels/vehicle-cycle basis. Table 1 and Figure 17 present total energy per mile in Btus used by different types of power trains-fuel combinations.

Table 1: Total Energy Used by Different Power Train-Fuel Combinations

<table>
<thead>
<tr>
<th>Conventional ICE Vehicle</th>
<th>ICE CNG</th>
<th>HEV Gasoline</th>
<th>PHEV Gasoline</th>
<th>FCV -NG SMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>5751</td>
<td>5,256</td>
<td>4,108</td>
<td>3,899</td>
<td>3,346</td>
</tr>
</tbody>
</table>

The GREET model shows that a vehicle using the conventional internal combustion engine uses more total energy than all other types of power train irrespective of the type of fuel (gasoline or compressed natural gas). The plugged-in hybrid engines are slightly superior to the pure hybrid engines in terms of the energy used. The most efficient combination is a fuel-cell power train using hydrogen produced from natural gas by using the steam methane reformer.
In Table 2 and Figure 18, the relative gain in mileage by competing power trains over the conventional ICE is presented. A hybrid engine offers a 40%+ mileage while a fuel-cell vehicle using natural gas (to produce hydrogen) offers a whopping 70%+ gain in mileage. This is in addition to the vehicle being clean, yielding zero emission, and no greenhouse gases.

Table 2: Relative Mileage Gain over Conventional Internal Combustion Engine

<table>
<thead>
<tr>
<th>Power Train-Fuel</th>
<th>Conventional ICE Vehicle</th>
<th>ICE CNG</th>
<th>HEV Gasoline</th>
<th>PHEV Gasoline</th>
<th>FCV -NG SMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.09</td>
<td>1.40</td>
<td>1.48</td>
<td>1.72</td>
<td></td>
</tr>
</tbody>
</table>
The first hydrogen fuel cell vehicle called Electrovan was developed by GM in 1966. However, it was abandoned because it was cost-prohibitive. The platinum used in the fuel cell was very expensive and the country lacked commitment to support building of a supporting hydrogen distribution structure in the country. In the early 90’s GM scientists worked with the Los Alamos National lab to develop a fuel cell system for use in cars. Later, the work was moved to Delphi to start making parts for the concept car. At that time, a research group was established in Rochester, NY. The group was expanded and moved to Honeoye Falls, New York in 1999. Since then, the size of the group has been expanded several times. Presently over a 1,000 people are working at GM research facilities in New York, Michigan, California, Mainz-Kastel (Germany), and Tokyo, Japan to address the issues of hydrogen storage, cost reduction, durability, and infrastructure development to ensure smooth commercial launch of a crossover vehicle to be called Equinox under the brand Chevrolet. Three features have guided the R&D and design of the vehicle: zero emission, high fuel economy, and zero reliance of petroleum in powering the vehicle. To date over a billion dollar have been invested in perfecting the technology. Appendix D briefly describes the various phases of the development of the vehicle. In the following Figure 19, the working of the fuel cells in Equinox is described.
Figure 19
Working of the Fuel Cells in Equinox

Part 1: Fuel cell systems

The diagram below represents GM's fuel-cell-powered Hy-wire. It outlines the Hy-wire's key parts and explains what they do.

1. Fuel cell stack
   Inside a fuel cell, electricity is created in the chemical reaction that occurs when hydrogen and oxygen are combined. To power a vehicle, hundreds of fuel cells are "stacked" together in a series, combining their individual electrical outputs.

2. Electric motor
   The stack sends electricity to the electric motor. The motor creates the mechanical power that turns the wheels to propel the vehicle.

3. Fuel tank
   A fuel tank stores hydrogen as fuel. GM's Hy-wire uses compressed gaseous hydrogen. Other fuel cell vehicles use liquid hydrogen fuel.

The Equinox looks like any other crossover on the outside, yet sets itself apart on the inside.
Part 2: The fuel cell

1. A single fuel cell generates about 0.7 volts of electricity, so hundreds of fuel cells are combined in a “stack” that generates enough electricity to power the electric motors.

2. The fuel cell needs two substances to generate power: oxygen and hydrogen. Oxygen is readily available from the air, but pure hydrogen must be supplied. Hydrogen is an abundant and renewable fuel. It can be obtained from hydrocarbons (petroleum, natural gas, biomass) or water (using solar energy and other energy sources). A fuel cell’s only emission is pure water.

Next steps:
- Anode
- Catalyst
- Proton Exchange Membrane (PEM)
- Cathode

Click on a numbered box to review
Part 3: Fuel cell chemistry

What happens on the anode side

1. Inside the fuel cell, pressurized hydrogen gas (H₂) is pumped through the negatively charged anode. The gas is forced through the catalyst.

2. When an H₂ molecule touches the catalyst, it splits into two hydrogen (H⁺) ions and two electrons (e⁻).

3. The electrons (e⁻) are conducted through the anode. They bypass the membrane and go through an external circuit (where they help turn an electric motor in a vehicle), and return to the cathode side of the fuel cell.

Chemistry: \[ 2H₂ \rightarrow 4H^+ + 4e^- \]

Click on a numbered box to review

What happens on the cathode side

1. Oxygen (O₂), from the air, enters the fuel cell on the cathode side. This gas is forced through the catalyst.

2. The catalyst splits the O₂ into two oxygen atoms.

3. Each oxygen atom attracts two H⁺ ions through the membrane.

4. Two H⁺ ions combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H₂O), which is emitted as exhaust.

Chemistry: \[ O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \]

The process repeats and generates electricity to move the electric motors and propel the vehicle.

Click on a numbered box to review
As shown in Table 2 and Figure 18, when powered with pure hydrogen obtained through natural gas, the Equinox will be the most efficient vehicle on the road. The fuel cell engine has one tenth of the moving parts in an ICE engine. Thus, from a frictional loss and wear out perspective, this engine will last longer than an ICE and will need lower maintenance. For example, there will be no need to replace oil, fuel filter, and spark plugs. Further, the fuel cell provides significant amount of electricity to the vehicle. This energy may be exported off the vehicle or can be used to perform many functions which earlier could not be performed on an electric, hybrid or ICE vehicle or needed mechanical actions. Besides, it has no harmful effect on the environment given that it has zero emissions.

The Equinox can presently carry 4 gallons of hydrogen which provides it a driving range of 200 miles @ 50 mpg. R&D work is presently being done at GM labs to expand the tank capacity to 6 gallons of hydrogen resulting in a 300 mile range for the vehicle. The onboard gadgetry will alert the driver when the fuel capacity has been reduced to 50 mile range. It would provide directions to get to the station to refuel the car. It would take about 12,000 stations (less than 10% of the current gas stations) to cover 80% of the US population to provide refueling within 5 miles of an owner’s home and within 25 miles on a highway.

The manufacturing cost of fuel cell stacks will be cheaper than the parts needed for ICE. It is anticipated that the overall cost of the fuel cell engine will decline dramatically with the increase in volume. The vehicle has been driven over a million miles and is being extensively tested at high altitudes, sea levels, extreme temperatures, and weather conditions (moisture, dryness) and has been adapted for worry free driving under all weather conditions. It has zero emission, and in fact produces pure water as a byproduct (YOUTUBE, YOUTUBE). The Stack life by 2015 is expected to be comparable to IC engines at 5,500 hours (approximately 120,000 miles). GM expects to offer warranty on the batteries similar to powertrains- 100,000 miles/10 years. Appendix E provides the various specifications of the current design of Chevy Equinox.

Competition

Viewing a significant growth opportunity, competition has also jumped into the bandwagon of hydrogen fuel-cell powered cars. These include major automotive manufacturers like BMW, Daimler, Honda, Hyundai, Toyota, and Kia. Appendix D provides a list of the vehicles tested/presented as potential entrants in this potentially lucrative market. Besides GM, Honda, Mercedes, BMW, Toyota, and Ford are presently road testing their vehicles. Ford’s Focus Fuel Cell vehicle has clocked over 865,000 miles. MSNBC reports that Toyota’s FCHV completed a road test from Osaka to Tokyo covering 350 miles, on a single tank with plenty of gas remaining (YOUTUBE). In 2010 Mercedes-Benz started leasing about 200 hydrogen fuel-cell powered F-Cell cars to customers in the U.S., Europe, Singapore, and Japan (YOUTUBE). This F-Cell vehicle is based on the B-Class four-door hatchback. It plans to commercialize an updated vehicle in 2014. BMW is testing hydrogen-powered 7-Series sedan using hydrogen internal combustion engines (H2ICEs). Like fuel cells, H2ICEs can be used in zero emission vehicles with exhaust emissions that are primarily water. Hydrogen, stored in cryogenic liquid form, provides a cruising range of over 125 miles with another 300 miles when running on a separate 19.5-gallon gasoline tank. BMW has followed up with the introduction of the mono-fuel Hydrogen 7 with an engine that’s been optimized to run exclusively on hydrogen. This version achieves even lower emissions, increased engine performance, reduced fuel consumption, and greater range than the bi-fuel Hydrogen 7 (YOUTUBE). Honda is field testing fuel-cell vehicle with their FCX Clarity which is available for lease to select people at a cost of $600 per month. It offers a 270 mile range (YOUTUBE). Ford launched a fleet of 30 fuel cell equipped Focus cars
for testing in the US, Canada, and Germany. It plans to offer fuel-cell electric vehicles in 2020s. Hyundai-Kia unveiled its first FCEV in 2000 through an SUV. They have been improving the efficiency and range of their vehicles and demonstrating it through Hyundai Tucson, Kia Sportage, Kia Borrego, and ix35. The company produced 1,000 units of ix35 for lease. In May 2012, it signed an MoU with Norwegian firm, Hydrogen Operation, to supply ix35 FCEV to public agencies, commercial fleets, and taxi firms in Norway. They plan to enter full commercial production of 10,000 unit in 2015.

Hyundai Vehicle to be launched in 2012

Not to be left behind, Toyota will unveil their hydrogen-fueled sedan, at Tokyo Auto show in December, 2011. Toyota says it has cut the cost of building fuel-cell vehicles by 90 percent and could sell its first hydrogen vehicle for $50,000 by 2015.

Toyota's FCV-R fuel cell concept vehicle

Honda and Ford are buying their technology from external suppliers while GM has developed the technology for fuel-cell internally. Daimler has developed some of the technology for fuel-cell internally but much is being bought from external suppliers. Use of external suppliers of technology limits the speed with which advancement takes place and increases the cost of the vehicle. Daimler’s focus is primarily in selling large, luxury cars and their entry is primarily to overcome their low fleet average mpg, an issue which is hurting them in Europe and North America.
Hydrogen Production

Hydrogen is an energy carrier—not an energy source—and energy is required to separate it from other compounds. Once it is separated and produced, hydrogen stores energy until it is delivered in a usable form, such as a gas delivered into a fuel cell. It can be produced from diverse, domestic resources including natural gas, renewable Electrolysis, coal or biomass, renewable liquid (e.g., ethanol, bio-fuel), nuclear Electrolysis, high-temperature thermochemical water-splitting, microbes, and photoelectrochemicals. Hydrogen production technologies are in various stages of development and substantial advancements are expected in the future. The environmental impact and energy efficiency of hydrogen depends greatly on how it is produced and the cost associated with it. Some projects are underway to decrease costs associated with hydrogen production (PDF). Hydrogen density is very low and will have to be squeezed into a denser form. It could be liquified but the cooling process requires a lot of energy and storage tanks are bulky, heavy, and expensive. It can also be compressed to 10,000 psi and stored in cylinders. An 8Kg cylinder provides enough energy for 300 miles. Research is in progress to trap hydrogen molecules at room temperature and pressure into metal hydride materials[^3]. These will make storage of hydrogen on the vehicle safe.

President Obama has described United States as the "Saudi Arabia of natural gas." According to EIA, in 2011 US had proved reserve of 343.8 trillion cubic feet of natural gas. A significant factor in the growth of this stock is result of expanding exploration and development activity in several of the nation's shale formations. Black Rock Investment Institute estimates that US has an additional 2,600 trillion cubic feet of unproven gas reserves. The major hydrogen-producing states are California, Louisiana, and Texas. Appendix G presents top 100 U.S. gas fields by 2009 proved reserves. At present, almost all of the hydrogen produced in the United States is used for refining petroleum, treating metals, producing fertilizer, and processing foods.

Distribution of Hydrogen

The infrastructure for the success of fuel-cell cars is a pre-requisite for rapid adoption. A fuel-cell vehicle will require easy access to hydrogen. For the vehicle to succeed beyond being a novelty item, the vehicle user should be able to fill-up the tank fast, must have easy access to fill-up stations, and the cost of fuel should be reasonable. Shell Oil Company recently estimated that an initial nationwide network of 11,000 hydrogen stations in cities and along interstate highways would cost about $12 billion. Full implementation in the US (serving 100 million hydrogen vehicles) might cost hundreds of billions of dollars over a period of several decades.

Members of the European Parliament (MEPs) have voted to develop the EU hydrogen highway network system in regard to technological and safety standards among the different countries. The European Union hydrogen highway network is at present a loose affiliation of H2 refueling stations developed by various countries. Leading the charge is Germany who has the most hydrogen refueling stations with 30 followed by everyone else. hopes to link the Norway HyNor Project with the mainland European nations with their Hydrogen Link project. Germany plans to build 1,000 hydrogen filling stations within next five years.

Japan launched their hydrogen highway project in 2002 and has built hydrogen fueling stations in 11 cities.

Figure 21: Japan’s Hydrogen Highway
The Japanese government is stepping in to address that chicken-and-egg problem. It's subsidizing fuel cell development and collaborating closely with energy and auto companies to build Japan's "hydrogen highway" of the future. The government has subsidized 13 hydrogen stations for fuel-cell cars, covering at least half of the $5 million to $6 million per station cost. In the known patriotic spirit of the Japanese, on January 12, 2011, 10 energy companies include JX Nippon Oil & Energy Corp., Idemitsu Kosan Co., and Cosmo Oil Co., as well as Tokyo Gas Co. and Osaka Gas Co. announced that they will seek to build some 100 hydrogen supply stations in Tokyo, Fukuoka, Aichi and Osaka to prepare for the launch of mass-produced hydrogen-powered fuel cell vehicles in 2015.

**Figure 22: A Hydrogen Refueling Station in Japan**

South Korea has developed their Hydrogen Highway system following the “cluster” model. The ten stations are located in large cities with six in Daejeon (2), Seoul, Dong-cho Dong Incheon, Mabuk, and Namyang. The Korean government has been working with Hyndai / Kia in testing their fuel cell vehicles and supporting them with hydrogen fueling stations.
Figure 23: Hydrogen Highway in South Korea

Most hydrogen used in the United States is produced at or close to where it is used—typically at large industrial sites. It is distributed through three methods: pipeline, high-pressure tube trailers, and liquified hydrogen tankers. Hydrogen contains less energy per unit volume than gasoline, transporting, storing, and delivering it to the point of end-use is more expensive.

US will need to strategically develop a hydrogen highway to enable the growth of fuel-cell vehicles in the country. California has lead the nation in building hydrogen refueling stations. California Governor Arnold Schwarzenegger, said in his State of the State address in 2004, "I am going to encourage the building of a hydrogen highway to take us to the environmental future. ... I intend to show the world that economic growth and the environment can coexist. And if you want to see it, then come to California". Schwarzenegger signed in 2007 Senate Bill (SB) 1505 which put the environmental requirements described in the California Hydrogen Highway Blueprint Plan into statute. As of January 2011, there were between 25 and 30 hydrogen fueling stations in California, mostly in and around Los Angeles. In February, 2005, Governor Jeb Bush of Florida said, "...the fuel of the future, hydrogen will diversify our energy portfolio and lessen the nation's dependence on foreign oil," as he unveiled Florida's Hydrogen Energy Technologies Act. Florida has two hydrogen fueling stations. In 2006 the East Coast Hydrogen Super
Highway was planned to extend from New York City to Albany, and further to upstate NY in order to reach Montreal, as well as especially to the west to Buffalo, along the major New York Thruway with further linking to the Interprovincial Hydrogen Corridor planned between Detroit, Toronto and Montreal. South Carolina also has a hydrogen freeway in the works. There are currently two hydrogen fueling stations, one each in Aiken and Columbia, SC. Mr. Tom Sullivan, founder and current chairman of the mega-successful Lumber Liquidators chain, bought Connecticut's Proton Energy Systems (which makes hydrogen electrolyzers) in an auction sale for $10.2 million in 2008. Inspired by the vision of a clean transportation system in the U.S., Mr. Sullivan is funding the Maine to Florida network of 10 to 12 stations ($1 to $3 million each) entirely on his own.

Mr. Sullivan (in white) opening his first Hydrogen Fueling Station

In May, 2013 the US Department of Energy launched H₂USA -- a new public-private partnership focused on advancing hydrogen infrastructure to support more transportation energy options for U.S. consumers, including fuel cell electric vehicles. It brings together automakers, government agencies, gas suppliers, and the hydrogen and fuel cell industries to coordinate research and identify cost-effective solutions to deploy infrastructure that can deliver affordable, clean hydrogen fuel in the United States. Current members include American Gas Association, Association of Global Automakers, the California Fuel Cell Partnership, the Electric Drive Transportation Association, the Fuel Cell and Hydrogen Energy Association, Hyundai Motor America, ITM Power, Massachusetts Hydrogen Coalition, Mercedes-Benz USA, Nissan North America Research and Development, Proton OnSite, Toyota Motor North America, General Motors, and American Honda Motor Company.

Safety of Hydrogen

For more than 60 years, the word "hydrogen" has evoked the newsreel images of the huge craft being consumed by a fireball as it drifted to the ground. However, it was not the
hydrogen that caused the disastrous fire aboard the famous Hindenburg zeppelin. According to Professor William D. Van Vorst, Professor Emeritus of Chemical Engineering at UCLA and Mr. Addison Bain, former manager, Hydrogen Programs, Kennedy Space Center, NASA, it was the material used to coat the “skin” of the airship outside, not the hydrogen inside that caused the disaster. In many cases, hydrogen is safer than the fuel used to power cars with IC engine. Carbon-based fuels tend to spread as liquids. When it burns, conventional fuel produces hot ash, creating radiant heat. This isn't the case with hydrogen. In its pure form, hydrogen burns no carbon and produces one-tenth the radiant heat of a hydrocarbon fire [source: RMI]. It burns rapidly, produces no smoke, and is non-toxic. What's more, when hydrogen leaks, it ascends rapidly into the atmosphere (it is 14.4 times lighter than air), so it has less time to burn [source: Princeton]. The explosive power of hydrogen is 22 times weaker than the explosive power of gasoline vapor. Hydrogen automakers are placing sensors located throughout the car to provide a warning in the event of a hydrogen leak. Should such a leak occur, the ventilation system is activated and an automatic system closes the main cut-off valves on the hydrogen tank. The high-voltage lines are electrically isolated. In the event of a collision, the system controller automatically shuts off the flow of hydrogen and electric current. Also, to prevent reverse flow from the tank, the hydrogen filler inlet has an integrated check valve. The storage tanks have gone through bonfire test, drop test, crash tests, vibration test, and permeation tests and have been found to be safe. According to the US Department of Energy, “Hydrogen can be produced, stored, and dispensed safely.” In a simultaneous hydrogen and gasoline fires, no damage occurred to hydrogen car while the gasoline car was completely destroyed.
**Home Hydrogen Refueling**

An attractive option for the fuel-cell vehicle owner will be to refill hydrogen by connecting it to an appliance located at home. Towards this Boston’s [ElectroChem](#) has proposed a novel Home Hydrogen Refueling (HHR) appliance. Employing their Integrated Flow Field (IFF) stack’s design in a highly reliable Proton Exchange Membrane (PEM) based electrolyzer system HHR can generate hydrogen at night using the off-peak electricity and fed it directly to the vehicle tank at 5000 psi. for daily commuting (See Figure 24). Given that typical daily driving consists of 30 miles, such a system would effectively “tops-off” the tank in the car each night. No other additional gas storage tank will be needed at home.

**Figure 24: Electro Chem’s Home Hydrogen Refueler System: HHR**

![Diagram of Electro Chem’s Home Hydrogen Refueler System: HHR](#)
According to ElectroChem this appliance can produce hydrogen for as little as $2.81/kg using off-peak power at $0.035/kWh assuming the appliance is produced at manufacturing volumes of 100,000 per year. Below are the operating parameters and costs of the appliance at this production volume:

Figure 25: Operating Parameters and Cost Data of HHR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Production Capacity</td>
<td>1 kg/day</td>
</tr>
<tr>
<td>Period of Operation</td>
<td>8 hrs</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>240 Volts (AC)</td>
</tr>
<tr>
<td>Power Use During Operation</td>
<td>6.3 kW</td>
</tr>
<tr>
<td>Physical Size</td>
<td>2 x 2 x 2 feet</td>
</tr>
<tr>
<td>Daily Commute</td>
<td>35 Miles</td>
</tr>
<tr>
<td>Mileage Efficiency of Vehicle</td>
<td>65.7 Miles per kg</td>
</tr>
<tr>
<td>Annual Mileage</td>
<td>12,000 Miles</td>
</tr>
<tr>
<td>Capacity Utilization</td>
<td>50%</td>
</tr>
<tr>
<td>Product Life</td>
<td>10 Years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost of the Appliance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Appliance Cost</td>
<td>$2,221</td>
</tr>
<tr>
<td>Annual Mortgage Cost</td>
<td>$331</td>
</tr>
<tr>
<td>Annual Maintenance</td>
<td>$50</td>
</tr>
<tr>
<td>Power Cost</td>
<td>$0.035/kW-hr</td>
</tr>
<tr>
<td>Power Cost of H2</td>
<td>$1.76/kg</td>
</tr>
<tr>
<td>Annual Power Cost @ 50% Utilization</td>
<td>$322</td>
</tr>
<tr>
<td>Total Annual Fuel Cost @ 50% Utilization</td>
<td>$703</td>
</tr>
<tr>
<td>H2 cost @ 50% Utilization</td>
<td>$3.85/kg</td>
</tr>
<tr>
<td>H2 cost @ 100% Utilization</td>
<td>$2.81/kg</td>
</tr>
</tbody>
</table>

Source: Babson Green MCFE Spring 2009 Home-Based Hydrogen Generator Market Study

Unlike Forecourt hydrogen refueling stations envisioned for refueling the vehicle, an HHR type system will be like recharging a cell phone, a concept familiar to most adults. They will have complete control over “refueling” location and time. Besides, they will not have to pay for the labor, land, building, and storage cost included in the price of gasoline bought from gasoline refueling stations. The HHR is inherently safe because there will be no hydrogen storage other than that inside the vehicle. Furthermore, on a national scale, far fewer refueling stations would be needed because they are only required for long trips (i.e., those greater than 300 miles). Besides, potentially this could offer great opportunity for utility companies to advance this infrastructure and enter the market by offering a competitive cost solution. This approach makes maximum use of the current grid capacity at times when demand is lowest. Pollution and carbon emissions caused by electrical generation can be addressed on a grid-wide basis. Solar, wind, and nuclear energy can all be used to power the grid. Appendix F provides a list of fuel cell companies.

Working with Plug Power, Inc. Honda has developed Home Energy Station IV. The system reforms natural gas to extract up to 3 normal cubic meters per hour (Nm3/hr) of hydrogen, which is stored in an inbuilt storage tank. This hydrogen is stored for later use by the vehicle, and can also be supplied to hydrogen appliances or fuel cells within the home. The heat generated by the reforming process can also provide hot water to the home. In addition to providing as much as 5 kilowatts of electrical power to the home, the Home Energy Station is also able to function as a backup power generation system during power outages. The projected price is $500. Using such a system to generate hydrogen and fuel an FCV vehicle can reduce total well-to-wheel CO2 emissions by sixty percent compared to an equivalent gasoline-fueled car.
THE CHALLENGE

Market

In 2010 11.59 million new cars were sold in America. During the same period China sold 18.06 million vehicles. Figure 27 shows the worldwide sale of auto during 2000-2010*

Figure 27: World Wide Sales of Auto

* Brazil, Russia, India and China.
It is expected that the overall vehicle sales will grow as the global economy recovers. Figure 28 shows new vehicle market share in 2010. General Motors regained its leadership position. Nearly one out of every five vehicles sold in in US was a GM product.

Figure 28: Auto Manufacturer Market Share in US in 2010

Figure 29 presents the share of hybrid cars in the total US new vehicle sales during 1999-2012. Of the 1.88 million hybrid cars sold during this period, Toyota Prius captured over 50% market share followed by Honda Civic with a share of 10.8%.
Hybrid sales have been influenced by tax subsidies offered to the buyers and the price of gasoline. Celebrities like Cameron Diaz, Leonardo Di Caprio, Alec Baldwin, Larry David, Harrison Ford, Kurt Russell, and Susan Sarandon have bought hybrid cars and have been singing their praise on TV talk shows and driving them to high visibility media events. It is widely believed that their adoption increased the popularity of low emission motoring and as such sales of hybrid cars. However, as compared to 2009, hybrid sales during 2010 decreased by 5.8%. During the same period, sales of all vehicle in the US increased by 11.1% when compared to 2009.

According to Green Car Reports, GM sold 17,760 Volts (a PHEV) since it’s launch in 2010. Nissan has sold 16,076 of their all electric PEVs, the Leaf, since its launch in 2011. The focus of GM has been to ensure stability of Volt’s in the event of an accident. In June, 2011 a fire occurred at a storage facility in Wisconsin after the Volt was crash tested by federal regulators. Then, on November 29, 2011 major newspapers and TV stations announced “fires in Chevrolet’s Volt”, “GM Scrambles to Defend Volt”. A Volt battery pack caught fire after being intentionally damaged a week earlier by NHSTA officials. The agency said that another battery pack emitted smoke and sparks after a similar test. Although the agency said that there was no evidence of fire problems in real-world crashes involving a Volt, alarming headlines swept the Internet within hours after NHSTA disclosure. Alarming headlines appeared: “Is the Chevy Volt Fire-Prone?”, “Chevrolet Volt comes under fire for setting on fire”. Some analysts have suggested that regardless of the outcome of the investigation, it could result in loss of
customers for Volt. Mr. Bill Visnic, an analyst with the auto-research Web site, Edmunds.com, said, “Consumers wary of the new electric vehicle technology have an array of less expensive, fuel-efficient options to choose from.”

Automobiles, Oil, and the U.S. Economy

Automobiles play a critical role in the fabric of the American society. They are the primary means of connecting people to each other, their place of work, businesses, and vacation. According to the U.S. Department of Transportation, the cumulative estimate of travel in the US was 2,006.7 billion miles. Automobile is the primary mode of travel in the country:

Figure 30: Passenger Travel Mode Choice by Number of Trips in 2010

![Passenger Travel Mode Choice](image)


During the past four decades, the number of registered vehicles in the country, and the number of vehicles per licensed driver has been growing. Prior to 1975, the country had roughly 1 vehicle per licensed driver, it reached 1.2 vehicles per driver in 2008. In 2008, there were 255,917,664 registered passenger cars. Of these, 137,079,843 were classified as automobiles. The United States is the only major industrialized nation to see its oil consumption surge since the oil shocks of the 1970s and 1980s. This can partly be explained by the fact that the United States has some of the lowest gasoline prices in the world, the least fuel-efficient cars on the roads, the lowest energy taxes, and the longest daily commutes of any industrialized nation. The result, United States consumes 20 million barrels of oil every day, of which 14 million

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5 Ibid

6 US Bureau of Transportation Statistics
barrels per day is consumed for transportation\textsuperscript{7}. More than 9.1 million barrels of oil are used per day for personal vehicles. The US economy has become dangerously dependent on foreign oil. 57\% of all oil consumed in the U.S. is imported, 6 million barrels of crude oil per day is imported from OPEC nations. In 2007, over 700 billion dollars flowed into OPEC nations from nations around the world. The global economy was rocked by unprecedented transfer of one trillion dollars from American, European, and Asian economies into Middle Eastern national treasuries in exchange of oil\textsuperscript{8}. Although the oil prices have come down since then, OPEC countries received over $800 billion in 2010. Over 80\% of world petroleum reserves are state-owned — controlled by countries that have the power to manipulate supply and price with impunity. With political instability, there is every reason to be concerned about likely future increases in price of oil.

Global demand for oil is rapidly increasing. China, India, and the Middle East are in the midst of exceptional economic booms and need cheap energy, which is largely subsidized by their governments, to keep growing and modernizing. The number of vehicles in China alone rose sevenfold between 1990 and 2006, to 37 million. China has now surpassed both Germany and Japan to become the second-largest car market in the world, and is set to overtake the United States by around 2015. China could have as many as 300 million vehicles by 2030. By 2030, India and China will import as much oil as the United States and Japan do today.

Over the past century, the world burned through a trillion barrels of oil. Another 1.2 trillion barrels of known conventional oil reserves wait to tapped, according to BP, one of the world’s biggest oil companies. It sounds like a lot. But given the current rate of growth in demand, a trillion of those barrels will be used up in less than 30 years. Today’s tensions are only likely to get worse in coming years. Consider a few numbers: the planet’s population is expected to grow by 50\% to nine billion by sometime in the middle of the century. The number of cars and trucks is projected to double in 30 years — to more than two billion — as developing nations rapidly modernize. And twice as many passenger jetliners, more than 36,000, will in all likelihood be crisscrossing the skies in 20 years. For producers it will mean somehow finding and pumping an additional 11 billion barrels of oil every year. Jeff Rubin, the former Chief Economist of CIBC World Markets warned at the Business of Climate Change Conference in 2009 that the price of oil will increase as much as to $200 barrel or $7 per gallon at the pump by 2015 (Watch his speech: YOU TUBE).

James Schlesinger, the nation’s first energy secretary in the 1970s, once said the United States was capable of only two approaches to its energy policy: “complacency or crisis.”\textsuperscript{9} The country has been living beyond its means,” said Vaclav Smil, a prominent energy expert at the University of Manitoba. “The situation is dire. We need to do relative sacrifices. But people don’t realize how dire the situation is.” Nobel physicist Steven Chu, U.S. Secretary of Energy said “The most direct way to reduce our dependency on foreign oil is to simply use less of it, starting with the cars and trucks we drive”\textsuperscript{9}. Fuel cells offer a road map for US and potentially, global oil independence.

\textsuperscript{7} \url{http://www.americanenergyindependence.com/}

\textsuperscript{8} Ibid.

\textsuperscript{9} Ibid.
Alternatives to Oil

An alternative to oil for country's mobility needs is natural gas. It is a naturally occurring gas mixture consisting primarily of methane, typically with 0–20% higher hydrocarbons. Natural gas is colorless, shapeless, and odorless in its pure form. Unlike other fossil fuels, natural gas is clean burning and emits lower levels of potentially harmful byproducts into the air. Compared to coal-generated electricity, natural gas produces little of the nitrogen, sulfur compounds and particulates that cause acid rain and smog. It yields half the carbon dioxide of coal and consumes 60% less water, while producing no soot or fly ash.

Natural gas is cheaper than oil and is available in abundance in the country (View video of Mad Money on Natural Gas). According to Energy Information Administration there are 2,543 trillion cubic feet (Tcf) of technically recoverable natural gas in the United States, an amount sufficient to meet North America's need for an estimated 100-plus year. At present terminals are being built in the country to export natural gas. Houston-based energy company Cheniere, has recently signed a deal with U.K.-based gas producer BG Group to ship 3.5 million tons a year of LNG out of its Sabine Pass terminal in Texas. Industry experts believe that instead of exporting, natural gas can be used to produce hydrogen in the country without any negative impact on meeting other domestic demands. According to the DOE, natural gas has a favorable hydrogen to carbon ratio (4:1) compared to coal (0.7:1) or biomass (1:1) and is the most affordable near term resource for producing large amounts of hydrogen.

Battery for Plug-in Vehicles

Hybrid cars and Plug-in Vehicles use Lithium-ion battery. Lithium is found combined in various minerals and in brine deposits that contain mostly salt. It can be extracted by evaporating salty pools filled by rivers that have washed over lithium-containing rocks. As the water evaporates, the lithium crystallizes as ionic salts, usually lithium chloride and lithium carbonate. Pure lithium can be produced by electrolysis. the mining and refining of lithium mars the landscape and produces wastes that could damage the environment. the majority of known lithium deposits are outside the United States. This may have some serious political implications. Some of the largest reserves are located in Bolivia, Chile, Australia, Argentina, and China. Thus, switch from oil to hybrid/plug-in vehicles could result in these countries becoming “Saudi Arabia of Lithium”. Further, although battery operated vehicles do not produce emissions, recharging of the batteries requires electricity frequently produced by burning coal or oil in power plants. This produces carbon dioxide, a greenhouse gas. Thus, using battery will neither reduce emissions nor make America energy independent.

Fuel- Cell Battery

Most fuel cells use a platinum catalyst and feldspar. The small quantity needed is available in plenty. Since, the use of platinum dose not exhaust the amount present in the battery, it can be reused over and over again. Recent research at Brookhaven National Laboratory could lead to the replacement of platinum by a gold-palladium coating which may
lessen demand for platinum. Another method would use iron and sulphur instead of platinum. This would even lower the cost of a fuel cell substantially.

**Developments in Automobile industry**

Automobile industry has been investing in R&D to enhance the safety, reliability, and comfort of the passengers. These include:

- Toyota’s **Pre-collision System (PCS)**, which uses cameras and radar that are attached to the vehicle, would automatically apply the brakes and “take over the steering controls from the driver” to steer away from hitting another car or a pedestrian.

- **Volvo’s City Safety System** which avoids low speed accidents that often happen in urban environments or slow moving traffic. The system runs a calculation 50 times per second to determine what braking speed is needed to avoid a collision based on the distance to the object in front and the car’s own speed. If the calculated braking force exceeds a given level without the driver responding, the danger of a collision is considered imminent and ‘City Safety’ helps avoid or reduce the consequences of a collision by automatically activating the car’s brakes and reducing the throttle. According to the **Insurance Institute for Highway Safety**, the technology helps reduce, and even prevent, low sped accidents. It is presently available in Volvo **XC60**. In 2009 Mercedes-Benz started offering a **Lane Keeping Assist System** in their E-Class and S-Class starting in 2009. It warns the driver if the car leaves its lane unintentionally.

- GM’s **Advanced Vision System** that allows the driver to see an enhanced version of what is going on around the car, even when visibility outside is poor. It shows the driver exactly where to drive, even when the driver cannot clearly see the road ahead because of fog or snow.

- GM’s Electric **Networked-Vehicle** (EN-V). It combines the Global Positioning System (GPS) with vehicle-to-vehicle communication and distance sensing technology. Using vehicle-based sensor and camera systems, EN-V can “sense” what’s around it, allowing the vehicle to react quickly to obstacles or changes in driving conditions. For example, if a pedestrian steps out in front of the vehicle, EN-V will decelerate to a slower and safer speed and stop sooner than today’s vehicles. The EN-V concept can be driven both manually and autonomously. Its autonomous operating capability offers the promise of reducing traffic congestion by allowing EN-V to automatically select the fastest route based on real-time traffic information. The concept also leverages wireless communications to enable a “social network” that can be used by drivers and occupants to communicate with friends or business associates while on the go. Power for the motors is provided by lithium-ion batteries that produce zero emissions. Recharging can occur from a conventional wall outlet using standard household power, allowing EN-V to travel at least 40 kilometers on a single charge. EN-V can also improve the efficiency of the public electric infrastructure since the

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vehicle can communicate with the electric grid to determine the best time to recharge based on overall usage. Its' autonomous vehicle technology offers mobility to people who would not be able to operate a vehicle on their own (elderly, handicapped, intoxicated, etc.). The concept was unveiled at the Shanghai International Trade Fair in 2010. Three two person En-V’s were unveiled (See the vehicles [YOUTUBE]).
GM’s On Star and On Star FMV provides subscription-based communications, in-vehicle security, automatic crash response, hands free calling, turn-by-turn navigation, and remote diagnostics systems throughout the United States, Canada and China. A similar service is known as ChevyStar in Latin American markets.

**Business Proposition**

The highway of products designed to enhance customer experience is littered with failed products. RCA’s Video Disk and Sony’s Betamax failed even though they offered superior benefits to viewers. TiVo is swimming in red ink even though it purports to offer benefits households seek. GM’s own electric vehicle, EV1 failed to capture the market even though it offered an environmentally friendly, clean commuter vehicle at a very attractive price.

The launch team is determined that Equinox will be a smashing success upon launch in the market. There is general agreement that it will take time to gain momentum for the vehicle. They would like to get a volume of 10,000 upon entry in the US in 2015. They want the size to grow by 25% each of the next five years. This would enable them to bring the cost down further and move into newer versions of the vehicle with even better performance. This is likely to be a long road. They would like to explore other opportunities where fuel cell could be applied. This could provide additional revenue stream for GM to support development and growth of fuel cell activities. Such opportunities could help bring down the cost of manufacturing. They wondered how they could benefit from Apple’s strategy of moving from iPod to iPod Touch, iPhone, and iPad using the base technology developed for iPod.

The team must decide who should be targeted for the car and to communicate the benefits of the car. They recognize that the innovators and early adopters would have a strong influence on accelerating growth in the demand of the product. What value proposition would be appropriate to position the vehicle? Americans also have proved fickle regarding fuel economy. They flocked to small cars when gas prices were high, but a Consumer Reports survey released last week showed respondents put safety, quality and value at the top of the list of factors they consider the most important when buying a new car. The number of people who listed "environmentally friendly/green" as one of their top three priorities fell eight percentage points over last year’s results. American consumers have emotional relationship with their cars. this extends beyond the benefits like speed, range, cost, etc. The team must find the message which will tug the heart of their target segment. They will face formidable competition from Toyota, Honda, and Ford within the fuel-cell car category and hybrid and PHEV vehicles in the broader mobility market.

Once the target segment(s) and positioning for the car has been decided, the team must decide how to maximize the impact of their advertising. They have 5 years on their hand. Over 5,000 people have already test driven the vehicle for over a million mile. Should they be looking to specific people for testing of the vehicle? Will it pay for them to use TV/magazines/newspapers/billboards now even when no vehicle is available for sale? Consultants have suggested that they make use of social media like Facebook and Twitter. The team is unsure how to use it to build demand (“must have” status) for the vehicle prior to launch. Should they at all use the traditional media to support Equinox and if yes how and for what purpose?

The launch team is unsure how much premium the consumers will be willing to pay over the IC and hybrid engine cars. Part of the premium could be justified by the savings due to better mileage and lower cost of maintenance. A fuel-cell car has about 10 per cent of the
moving parts of a conventional vehicle. Would the consumers be willing to pay more due to zero emission by the car? Will they value the vehicle for its ability to work in all environmental conditions-hot, cold, and damp? Given cheap electricity on board in the vehicle, what benefits could be added to turn Equinox into a must have vehicle like an **iPhone** or **iPad**? Typically, the revenue stream from the sale of a vehicle to the manufacturers ends upon completion of the transaction. The team wondered what can they offer to the customer to continue this revenue stream in the future. They surmised, if Apple can generate new revenues from the buyers of **iPod**, **iPhone**, and **iMac using iTunes**, a similar strategy should be possible for GM as well. Where practical, how should it be implemented? Should they adopt the business model of Apple and manage it themselves or outsource it and just become a silent recipient of cash? Will it transform the car from a commodity to a product differentiator? What specifically they must do to make it happen?

How much they should charge for the vehicle? Toyota’s president, Akio Toyoda, has indicated that the likely price of their Fuel cell vehicle will be **$50,000**. For comparison, a well equipped Nissan **Leaf** has suggested price of $37,250 while a Chevy **Volt** costs $39,145. There are state and federal level incentives for buying energy efficient vehicles which may reduce the actual price to the buying depending upon their place of residence. Both **Leaf** and **Volt** can be leased. In tandem with the purchase process, Nissan offers personal charging docks, which operate on a 220-volt supply, as well as their installation. Nissan is providing these home-charging stations, which will be built and installed by **AeroVironment, Inc.** as part of a one-stop-shop process that includes a home assessment. The average cost for the charging dock plus installation will be **$2,200**. Charging dock and installation may be eligible for tax credits. **Wall Street Journal** has described **Leaf** as “a car for a wealthy hobbyist, good for a trip of 100 miles after which it becomes an inert lump at the end of your driveway (or behind a tow truck) for the many hours it will take to recharge.” Should Chevy partner/subsidize purchase of a hydrogen generator for households to facilitate sale of their fuel cell car?

The launch team recognizes that it will be a marketing challenge to persuade Americans to give their vehicles another try after years of bad reviews. “We can only do so much talking [as GM], but others have to step in and start telling the stories for us,” opined a team member. Who can that person be and how to turn around the current thinking to be of help to Equinox?

When testing the car, Ms Barnowski was unable to visit her daughter in Boston because she would have been unable to refuel. However, she described testing the car as a “great experience.” “I felt like this was making history,” she said. “It is a chicken and egg situation”, says Katsuhiko Hirose, head of fuel system development for Toyota. “No one wants to invest in hydrogen filling stations because there are no cars around that would use them. But no one is going to buy a hydrogen car when they cannot refuel it easily.”

California Governor **Arnold Schwarzenegger**, in a **State of the State address** in 2004, said: “I am going to encourage the building of a hydrogen highway to take us to the environmental future. ... I intend to show the world that economic growth and the environment can coexist. And if you want to see it, then come to California”. Schwarzenegger signed in 2007 Senate Bill (SB) 1505 which put the environmental requirements described in the California Hydrogen Highway Blueprint Plan into statute. As of **January 2011**, there were between 25 and 30 hydrogen fueling stations, mostly in and around Los Angeles.

Recently **researchers in Israel** have come up with a very novel way of storing hydrogen. Instead of the bulky, super-insulated tanks, the Israeli team has figured out a way to pack
hydrogen into glass filaments that, once completed, will be slightly thicker than a human hair. The glass hairs, or "capillaries," are then bundled into a glass tube, 370 at a time, forming a "capillary array," about the width of a drinking straw. The scientists say that 11,000 of these arrays will fuel a car for 240 miles. They'll also take up less than half the space and weight of a conventional hydrogen storage tank. "We have shown new materials that can store more hydrogen than any other system," says Dan Eliezer, chief scientist of C.En Ltd., the company based in Geneva, Switzerland, where the Israelis are developing their invention [VIDEO].

In August, 2012, General Motors announced that they will shut down the Honeoye Falls Fuel Cell research and development facility. Honeoye Falls was instrumental in the development of the fuel cell system that went into the Project Driveway. General Motors employed approximately 220 people at the facility. It said that the technical work will be consolidated at their Pontiac, Michigan research facility. When offered option to move, 60 scientists chose to move. On July 1, 2013 GM and Honda announced a long-term, definitive master agreement to co-develop next-generation fuel cell system and hydrogen storage technologies, aiming for the 2020 time frame. The partnership between the largest U.S. automaker and Tokyo-based Honda is to include exchanging engineers, joint use of research facilities and shared sourcing of parts and materials, they said yesterday. The goal is a common hydrogen powertrain to make the low-polluting vehicles more affordable, they said, without providing details about prices or investment.

[CLICK TO VIEW CONFERENCE]

Appendix A

US Public Opinion on Environment

**NBC News/Wall Street Journal Poll** conducted by the polling organizations of Peter Hart (D) and Bill McInturff (R). Dec. 11-14, 2009. N=1,008 adults nationwide.

"From what you know about global climate change or global warming, which one of the following statements comes closest to your opinion? Global climate change has been established as a serious problem, and immediate action is necessary. There is enough evidence that climate change is taking place and some action should be taken. We don't know enough about global climate change, and more research is necessary before we take any actions. Concern about global climate change is unwarranted." Half sample (Form A), MoE ± 4.4

<table>
<thead>
<tr>
<th>Immediate Action</th>
<th>Some Action</th>
<th>More Research</th>
<th>Concern Unwarranted</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/11-14/09</td>
<td>23</td>
<td>%</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>10/22-25/09</td>
<td>29</td>
<td>31</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>1/17-20/07</td>
<td>34</td>
<td>30</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>6/9-12/06</td>
<td>29</td>
<td>30</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td>7/24-26/09</td>
<td>23</td>
<td>28</td>
<td>32</td>
<td>11</td>
</tr>
</tbody>
</table>

"I'm going to read you two statements. Please tell me whether the first statement or the second statement comes closer to your own view, even if neither is exactly right. Statement A: Global warming is caused more by human actions than by naturally occurring forces. Statement B: Global warming is caused more by naturally occurring forces than by human actions." Half sample (Form B), MoE ± 4.4

<table>
<thead>
<tr>
<th>Human Actions</th>
<th>Natural Forces</th>
<th>Both (vol.)</th>
<th>Neither (vol.)</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/11-14/09</td>
<td>74</td>
<td>20</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>


"As you may know, representatives from around the world are gathering for a United Nations conference on global climate change in Copenhagen. Do you favor or oppose the U.S. signing a binding global treaty at the Copenhagen meeting that would require the U.S. to significantly reduce greenhouse gas emissions?"

<table>
<thead>
<tr>
<th>Favor</th>
<th>Oppose</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/11-13/09</td>
<td>55</td>
<td>38</td>
</tr>
</tbody>
</table>

"Do you think the federal government should or should not regulate the release of greenhouse gases from sources like power plants, cars and factories in an effort to reduce global warming?"

<table>
<thead>
<tr>
<th>Date</th>
<th>Should</th>
<th>Should Not</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/10-13/09</td>
<td>65</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>6/18-21/09</td>
<td>75</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>4/21-24/09</td>
<td>75</td>
<td>21</td>
<td>4</td>
</tr>
</tbody>
</table>

"What if that significantly lowered greenhouse gases but raised your monthly energy expenses by 10 dollars a month? In that case, do you think the government should or should not regulate the release of greenhouse gases?" Half sample

<table>
<thead>
<tr>
<th>Date</th>
<th>Should</th>
<th>Should Not</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/10-13/09</td>
<td>60</td>
<td>37</td>
<td>3</td>
</tr>
</tbody>
</table>

"What if that significantly lowered greenhouse gases but raised your monthly energy expenses by 25 dollars a month? In that case, do you think the government should or should not regulate the release of greenhouse gases?" Half sample

<table>
<thead>
<tr>
<th>Date</th>
<th>Should</th>
<th>Should Not</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/10-13/09</td>
<td>55</td>
<td>42</td>
<td>3</td>
</tr>
</tbody>
</table>


"Which of the following statements comes closest to your view of global warming? Global warming is a proven fact and is mostly caused by emissions from cars and industrial facilities such as power plants and factories. Global warming is a proven fact and is mostly caused by natural changes that have nothing to do with emissions from cars and industrial facilities. Global warming is a theory that has not yet been proven." N=523 (Form A), MoE ± 4.5 overall

<table>
<thead>
<tr>
<th>Date</th>
<th>Fact: Cars, Industry</th>
<th>Fact: Natural Changes</th>
<th>An Unproven Theory</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
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<td>23%</td>
<td>31%</td>
<td>1%</td>
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<tr>
<td>Democrats</td>
<td>68%</td>
<td>18%</td>
<td>14%</td>
<td>1%</td>
</tr>
<tr>
<td>Republicans</td>
<td>25%</td>
<td>27%</td>
<td>47%</td>
<td>1%</td>
</tr>
<tr>
<td>6/4-5/08</td>
<td>54%</td>
<td>22%</td>
<td>23%</td>
<td>1%</td>
</tr>
<tr>
<td>10/12-14/07</td>
<td>56%</td>
<td>21%</td>
<td>21%</td>
<td>2%</td>
</tr>
<tr>
<td>5/4-6/07</td>
<td>54%</td>
<td>20%</td>
<td>22%</td>
<td>4%</td>
</tr>
</tbody>
</table>

"Which of these positions do you agree with most? The United States should reduce emissions of carbon dioxide and other gases that may contribute to global warming even if it does so by itself. The United States should reduce emissions of carbon dioxide and other gases that may contribute to global warming only if other countries do so as well. The United States should not reduce emissions of carbon dioxide and other gases regardless of what other countries do." N=518 (Form B), MoE ± 4.5

<table>
<thead>
<tr>
<th></th>
<th>Reduce Even If Alone</th>
<th>Reduce Only with Others</th>
<th>Should Not Reduce</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>12/2-3/09</td>
<td>58</td>
<td>17</td>
<td>24</td>
<td>2</td>
</tr>
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<td>10/12-14/07</td>
<td>66</td>
<td>16</td>
<td>15</td>
<td>3</td>
</tr>
</tbody>
</table>


"Do you believe global warming exists?"

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>12/8-9/09</td>
<td>63</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>Democrats</td>
<td>83</td>
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<td>5</td>
</tr>
<tr>
<td>Republicans</td>
<td>46</td>
<td>51</td>
<td>3</td>
</tr>
<tr>
<td>Independents</td>
<td>61</td>
<td>34</td>
<td>5</td>
</tr>
<tr>
<td>5/12-13/09</td>
<td>69</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>1/30-31/07</td>
<td>82</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>10/25-26/05</td>
<td>77</td>
<td>13</td>
<td>10</td>
</tr>
</tbody>
</table>

As asked of those who believe global warming exists (N=568, MoE ± 4):

"Do you believe global warming is caused by normal climate patterns or by people's behavior, such as driving and burning too much fossil fuel like coal and oil?"

<table>
<thead>
<tr>
<th></th>
<th>Normal Patterns</th>
<th>People's Behavior</th>
<th>Both (vol.)</th>
<th>Unsure</th>
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<tbody>
<tr>
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<td>3</td>
</tr>
<tr>
<td>1/30-31/07</td>
<td>14</td>
<td>41</td>
<td>38</td>
<td>8</td>
</tr>
<tr>
<td>10/25-26/05</td>
<td>17</td>
<td>46</td>
<td>30</td>
<td>6</td>
</tr>
</tbody>
</table>

"Do you think the global warming situation is best described as a crisis, a major problem but not a crisis, a minor problem, or is it not a problem at all?"

<table>
<thead>
<tr>
<th></th>
<th>A Crisis</th>
<th>A Major Problem</th>
<th>A Minor Problem</th>
<th>Net a Problem</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/8-9/09</td>
<td>17</td>
<td>33</td>
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</tr>
<tr>
<td>10/25-26/05</td>
<td>16</td>
<td>44</td>
<td>22</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>
Appendix B
Features of Hybrid Cars Presently Available

2010 Honda Civic Hybrid

4 door/5 seat sedan
transmission: CVT automatic or manual
mileage (mpg): 40 city/ 45 hwy
range per fillup: 850 miles
2009 US Base Retail Price: $23,800

Features
Full climate control, Micron air filtration
Anti-Lock Braking System (ABS)
Speed-Sensitive Volume Control (SVC)
New USB Audio Interface
Keyless Remote Entry

Dual-Stage Front and Dual Side Airbags
Anti-Theft Immobilizer
Available: Bluetooth HandsFreeLink®
Tire Pressure Monitoring System Indicator
Available: Honda Satellite Linked Navigation

Specifications
110-hp,8-Valve, SOHC, i-VTEC® 4-cylinder engine with Integrated Motor Assist IMA®
Drive-By-Wire™ Throttle System; Dual-point sequential ignition system
Electric Power Steering (EPS), variable-assist rack-and-pinion
Fuel Capacity/Type Required: 12.3 gallons (46 liters) / Regular Unleaded
Brakes: Power-assisted ventilated front disc/rear drum with Anti-lock Brake System (ABS)
Tires: P185/70R14 LLR (low rolling-resistance) on 14" aluminum alloy wheels; All-Season Radials

2010 Saturn Aura Hybrid

4 door/5 passenger midsize sedan
transmission: 4-speed automatic
mileage (mpg): 26 city/ 34 hwy
range per fillup: 420 - 550 miles
2010 US Base Retail Price: $26,240

Features
Single-zone automatic climate control
6 speaker radio system, audio input jack
Driver Shift Control - steering wheel shift control
Center high-mounted LED stoplight, LED tail lamps
2 12v power outlets, Center console dual-bin storage

Passenger Sensing System
Dual-Stage Front Airbags, Side Curtain Airbags
Advanced Audio System AM/FM/CD/MP3 (option)
XM® Satellite Radio (option), Bluetooth (option)
Theft Deterrent System

Specifications
ECOTEC 2.4L 4-cylinder (164 hp [122.3 kW] @ 6400 rpm, 159 lb-ft of torque
StabiliTrak, Stability Control with traction control
Front-wheel drive, 4-speed automatic transmission
Fuel Capacity/Type Required: 16.3 gallons (62 liters) / Regular Unleaded
Brakes: 4-wheel disc with 4-wheel Anti-lock Brake System (ABS)
Tires: P215/55R17 touring, blackwall 17" All-Season Radials; Tire inflation kit (deletes spare tire, jack, tool kit)
2010 Nissan Altima Hybrid

4 door/5 seat sedan
transmission: eCVT auto or 6-speed manual
mileage (mpg): 35 city/ 33 hwy
range per fillup (miles) : 600+
2010 US Base Retail Price: $26,780

Features
Air Conditioning, separate passenger climate control
Voice-activated GPS, traffic, weather, restaurant guide
Rear-view monitor (option)
Vehicle stability control system, traction control
XM Satellite Radio, DVD in-dash, iPod USB Connectivity

Keyless Remote Entry, Intelligent Key Feature
Driver, passenger, side head curtain airbags
Available Bluetooth Hands-free phone system
Tire inflation/pressure monitor
Anti-Theft Immobilizer, Trunk anti-trap device

Specifications
2.5 liter I-4, engine with 40-horsepower electric motor, delivering 199 lb-ft of torque
Horsepower: 198 hp @ 5200rpm
6-speed manual transmission; automatic transmission also available
Aluminum alloy body, front and rear crumple zones, side-impact door beams, anti-lock braking system
Fuel Capacity/Type Required: 20 gallons (75 liters) / Regular Unleaded
Tires: 215/60 R16 16” Lightweight Alloy, All-Season Radials

2010 Toyota Prius

4 door/5 seat sedan w/ liftback
transmission: CVT automatic
mileage (mpg): 51 city/ 48 hwy
range per fillup: 547 miles
2010 US Base Retail Price: $25,800

Features
Full climate control, CFC-Free Air Conditioning
Traffic reports integrated with DVD-based navigation system
Voice-activated navigation; “text to speech
Four-disc CD changer, MP3 CD support; 8 JBL speakers
Backup camera, adaptive cruise control

Smart Key System
Driver and front passenger Advanced Airbag System
Graphic display of steering wheel button settings
Satellite radio; Bluetooth phone interface
Heated/cooled seats; Solar roof option

Specifications (North American model)
1.8-liter inline 4-cylinder with hybrid system; Horsepower: 134 (gas-electric combined)
Available in four trim levels, which Toyota dubs II, III, IV, and V
Multi-point EFI with Electronic Throttle Control System with intelligence
Fuel Capacity/Type Required: 11.9 gallons (46 liters) / Regular Unleaded
Brakes: Power-assisted ventilated front disc/rear drum with standard Anti-lock Brake System (ABS)
Wheels: 15-in. 6-spoke alloy wheels with P185/65R15 tires
### 2010 Ford Fusion Hybrid

**4 door/5 passenger midsize sedan**  
Transmission: eCVT automatic  
Mileage (mpg): 41 city/36 hwy  
Range per fillup: up to 700 in-town miles  
*2010 US Base Retail Price: $27,625*

#### Features
- Dual-zone automatic temperature control  
- 2 12-volt power outlets, 110-volt power point  
- SmartGauge instrument cluster with EcoGuide  
- 6-disc in-dash CD, MP3-playback, Sirius Satellite Radio  
- Sync-equipped for voice-controlled audio  
- SecuriCode keyless entry pad, SecuriLock anti-theft  
- Rear view camera  
- Speed-sensitive windshield wipers  
- Fold-down fold-flat front passenger seat  
- Sony premium audio system

#### Specifications
- 2.5L 4-cylinder Atkinson-Cycle I-4 Hybrid engine, 106-horsepower AC electric motor  
- Horsepower (SAE net at rpm): 191 net; Torque: 136 @ 4500  
- Electric Power-Assisted Steering, All-Wheel Drive  
- 4-wheel anti-lock disc brakes; AdvanceTrac (ESC) w/brake activated traction control  
- Fuel Capacity/Type Required: 17.5 gallons / Regular Unleaded  
- Tires: P225/50VR17 all-season BSW tires, 17” 15-spoke aluminum wheels, Tire pressure monitoring system

### 2010 Toyota Camry Hybrid

**4 door/5 passenger midsize sedan**  
Transmission: CVT automatic  
Mileage (mpg): 33 city/34 hwy  
Range per fillup: 585 miles  
*2009 US Base Retail Price: $26,150*

#### Features
- Curtain side and driver’s knee air bags  
- Anti-skid traction control  
- Multi-adjustable front bucket seats  
- Tire-pressure monitor system  
- JBL audio system with Bluetooth technology  
- Keyless entry/starting system  
- Plasmacluster™ ionizer cabin air purifier  
- “ECO” button limits HVAC energy consumption  
- Heated outside rear-view mirrors  
- GPS navigation unit (optional)

#### Specifications
- Twin cam, 2.4L inline four-cylinder 2AZ-FXE Atkinson-cycle engine, which generates 147 hp  
- Horsepower: 192 net (gas-electric combined)  
- Electronically controlled continuously variable transmission (ECVT)  
- Fuel Capacity/Type Required: 17.2 gallons (63 liters) / Regular Unleaded  
- Brakes: Power-assisted ventilated 4-wheel disc brakes with standard Anti-lock Brake System (ABS)  
- Tires: Regular (not LRR) 16” All-Season Radials - 215/60; Wheels: 16” steel
2010 Honda Insight Hybrid

5 door hatchback/4.5 seat compact sedan
transmission: 4-speed CVT automatic
mileage (city/hwy): 40/43
range per fillup: 586 miles
2010 US Base Retail Price: $19,800

Features
Automatic climate control
Steering wheel mounted Multi Information Display
Tire pressure monitoring system, EcoAssist system
60/40 split rear fold-down seat back
Projector-beam halogen headlights w/chrome bezels

Specifications
1.3L SOHC MPFI 8-valve i-VTEC I4 engine w/permanent-magnet electric motor. Integrated Motor Assist.
Steering: Rack-and-pinion with electric power assist
Drivetrain: Front Wheel Drive
Fuel Capacity/Type Required: 10.6 gallons / Reguar Unleaded
Brakes: Power ventilated front disc/ rear drum brakes with 4-wheel ABS w/ electronic brake distribution (EBS)
Wheels: 15" steel; Tires: P175/65SR15 all season, blackwall, LLR

Outboard lower anchors & tethers for children
Air bags, dual-stage frontal and side-impact
Immobilizer theft deterrent system
Maintenance Minder system
Optional Satellite Navigation w/ Voice Recognition

2009 Ford Escape Hybrid

4 door/5 seat SUV
transmission: CVT automatic
mileage (city/hwy): 2wd 34/31 | 4wd 29/27
range per fillup: 435 - 510 miles
2009 US Base Retail Price: $29,305 (2WD)

Features
Manual Air Conditioning
AM/FM stereo with 6-disc in-dash CD system
Roof rack with 2 horizontal bars
Lip and rear-wheel spoilers, rear anti-roll bar
Voice-activated SYNC entertainment system

Specifications
2.5-liter inline four-cylinder engine, combined with a 65-kilowatt electric motor (optional 3.0 liter V6)
Horsepower: 170 (gas-electric combined); 230hp with 3.0 liter V6
Steering: Rack-and-pinion with electric power assist
Fuel Capacity/Type Required: 15 gallons (60 liters) / Reguar Unleaded
Brakes: Power-assisted ventilated 4-wheel disc with ABS and integrated regenerative braking
Tires: P235/70R16 A/S BSW tires; All-Season Radials, Hybrid-unique 16" aluminum wheels

Keyless Remote Entry
Driver and front passenger airbag system
Side air curtains, rollover sensor, front side airbags
Perimeter alarm
Sirius Travel Link system with 911 Assist
2010 Lexus RX 450h Hybrid

4 door/5 seat SUV
transmission: ECVT automatic
mileage (mpg): 32 city/ 28 hwy
range per fillup: 450 - 530 miles
2010 US Base Retail Price: $41,600 - $43,250

Features
- Dual-zone automatic climate control
- Voice activated navigation system
- Lexus 8-speaker sound system, 6-disk CD
- XM Nav, Traffic, Weather; standard Bluetooth
- Power tilt and slide moon roof
- Lexus Memory System for mirrors, seat, wheel
- Transceiver to operate garage doors, lights
- Smart Key remote entry system
- Part-time all-wheel drive (AWD)
- Accessory power outlet in cargo area

Specifications
- 3.5-liter V6 engine w/ Atkinson Cycle valve timing; front and rear high-output, permanent-magnet electric-drive motors
- Available in FWD and AWD versions; Horsepower: 296 total system horsepower
- Steering: Rack-and-pinion with electric power assist
- Fuel Capacity/Type Required: 17.2 gallons (65 liters) / Regular Unleaded
- Brakes: Four-wheel power-assisted disc brakes with regenerative function
- Wheels/Tires: 18-in alloy wheels with 235/65VR18 all-season tires

2009 Toyota Highlander

4 door/5 seat SUV
transmission: ECVT automatic
mileage (city/hwy): 2wd 33/28 | 4wd 31/27
range per fillup: 450 - 550 miles
2009 US Base Retail Price: $34,700

Features
- Power tilt/slide moonroof with sunshade
- CFC-free automatic digital climate control system
- Roof Rack System
- Color-keyed heated foldable power outside mirrors
- 3.5” multi-function display w/ backup camera
- 4-Wheel Drive with intelligence (4WD-i) (optional)
- AM/FM CD player with MP3/WMA playback
- HomeLink®5 universal transceiver
- Driver and passenger Advanced Airbag System
- Second-row roll-sensing side curtain airbags

Specifications
- 3.3-liter double overhead cam V6 gas motor; torque @ rpm: 212 @ 4400 (foot/pounds)
- Horsepower: 268 total system horsepower
- Steering: Electronic power steering (EPS) - rack-and-pinion with power assist
- Fuel Capacity/Type Required: 17.2 gallons (65 liters) / Regular Unleaded
- Brakes: Electronically controlled braking system with ABS and electronic brake distribution
- Wheels/Tires: 19-in. split 5-spoke aluminum alloy wheels with P245/65R19 all-season tires
2009 Mercury Mariner

4 door/5 seat SUV (available 2x4, 4x4)
transmission: ECVT automatic
mileage (city/hwy): 34/31 | 4wd 29/27
range per fillup: 400 - 510 miles
2009 US MSRP: 2wd: $29,750 4wd: $31,500

Features
Front dual reclining bucket seats
Rear and side privacy glass
AM/FM radio, 6-Disc CD changer, MP3 player
Remote keyless entry via key fob and door pad
Anti-Theft SecuriLock engine immobilizer

Specifications
2.5-liter I-4 Atkinson cycle engine, 133hp @ 6000rpm & electric motor 94hp @ 5000rpm
Horsepower: 153 total system horsepower
Steering: Electronic power steering (EPS) - rack-and-pinion with power assist
Fuel Capacity/Type Required: 15 gallons (57 liters) / Regular Unleaded
Brakes: 4-wheel anti-lock disc brakes, regenerative braking system
Wheels/Tires: 16-in x 7-in alloy wheels with SBRP235/70R16 BSW all-season tires

2009 Mazda Tribute

4 door/5 seat SUV (available 2x4, 4x4)
transmission: 4-speed auto; 5-speed manual
mileage (city/hwy): 34/31
range per fillup: 465 - 510 miles
2009 US MSRP: fwd: $28,175 4wd: $29,925

Features
Folding 60/40 rear seats w/ removable cushions
Rear and side privacy glass
AM/FM radio, CD with 4 speakers
Remote keyless entry via key fob and door pad
Anti-Theft SecuriLock engine immobilizer

Specifications
2.5-liter I-4 Atkinson cycle engine, 153hp @ 5800rpm & electric motor 94hp @ 5000rpm
Horsepower: 153 total system horsepower
Steering: Electronic power steering (EPS) - rack-and-pinion with power assist
Fuel Capacity/Type Required: 15 gallons (57 liters) / Regular Unleaded
Brakes: 4-wheel anti-lock disc brakes, Electronic Brake Force Distribution (EBFD)
Wheels/Tires: 16-in x 7-in aluminum alloy wheels with 235/70R16 all season T-rated tires
2010 scheduled releases:

- Porsche - hybrid Cayenne SUV, the first hybrid car from Porsche
- Chevrolet Volt - plug-in hybrid
- Honda Fit - small sedan entering the market at a low price for hybrids
- Honda CR-Z - hybrid sports car
- Hyundai Sonata - first Korean hybrid in the US. Will use lithium-ion batteries.
- Mercury Milan - new sedan model

2011 scheduled releases:

- Nissan Infiniti M35 - hybrid version of the luxury performance brand; Nissan’s first hybrid model
- Buick Regal - preliminary plans point to 2011 model featuring the drive train developed for the Saturn Vue.
# Appendix C
## Features of Proposed PHEV Vehicles

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Description and summary of official statements</th>
<th>Status of production</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFS Trinity</td>
<td>Prototype of lithium battery + supercapacitor combination for licensing by carmakers</td>
<td>With Ricardo, two prototype conversions of Saturn Vue hybrid to XH-150 PHEV-40s</td>
</tr>
<tr>
<td>Aptera</td>
<td>Futuristic lightweight $30,000 3-wheel vehicles in development</td>
<td>Taking deposits in CA on series-PHEV 2010 version to follow electric version in 2009.</td>
</tr>
<tr>
<td>Audi</td>
<td>Volkswagen-owned company exploring PHEVs</td>
<td>Metropoint Quatro Sub-compact PHEV Concept Car shown October 2007; PHEV of A1 Sportback under consideration</td>
</tr>
<tr>
<td>Bright Automotive</td>
<td>For-profit spin off from Rocky Mountain Institute designing lightweight PHEVs, successor to RMI’s 1990s &quot;Hypercar&quot; concept. Partnering with Alcoa, Duke Energy, Google.org, Johnson Controls</td>
<td>Indiana startup plans mass production in 2012.</td>
</tr>
<tr>
<td>BYD</td>
<td>BYD Automobile Company, Shenzhen, China (partially owned by Warren Buffett’s Mid-America Holdings), partnering with Volkswagen.</td>
<td>Plan F3DM $22,000 PHEV with 60-mile range for sale, now selling in China, in the US and Europe around 2011</td>
</tr>
<tr>
<td>Chrysler</td>
<td>ENVI division developing Town &amp; Country minivan, 200C EV concept and Jeep Patriot and Jeep Wrangler Unlimited SUVs, EREVs (series hybrids) with 40-mile range</td>
<td>One PHEV planned for sale in US by end of 2010, others by 2013.</td>
</tr>
<tr>
<td>Daimler/Mercedes</td>
<td>Took over Daimler/Chrysler Sprinter PHEV program. Showed BlueZERO E-CELL PLUS series PHEV concept in December '08.</td>
<td>Several dozen prototypes on 15-passenger van since 2004; now in second generation development; no production plans.</td>
</tr>
<tr>
<td>Fiskr</td>
<td>$80,000 Karma series luxury 50-mile range series PHEV, 5 Sunset convertible version. Partnering with Quantum Technologies.</td>
<td>1,300 pre-orders for small production runs in late 2009 and 7,500 in 2010. Established 26-dealer network.</td>
</tr>
<tr>
<td>Ford</td>
<td>Escape PHEV-40 around 2012. Small long-term evaluation program, including modeling of vehicle-to-grid building benefits and economics. begun with Southern California Edison, joined by EPRI, other utilities, US DOE. Batteries not yet. Has shown some concept fuel-cell PHEVs.</td>
<td>First Escape PHEV delivered to SCE Nov 2007; 20 in 2008-2009. (Several after-market companies have done PHEV conversions of the Ford Escape hybrid and one has done a retrofit of the F-150 pickup -- see Where PHEVs Are and ICE-Conversions.) Shifted earlier focus to all-electric Focus in 2011 with Magna.</td>
</tr>
<tr>
<td>General Motors</td>
<td>Chevy Volt series PHEV, which it calls &quot;extended range electric vehicle&quot; (EREV), part of &quot;E-Flex&quot; multi-fuel platform. Plans Cadillac Converj, OPEL Ampera, other versions. Planned Saturn Vue PHEV-10 may become GM or Buick.</td>
<td>Plans &quot;large demonstration fleet&quot; late 2009. Committed to sales of 10,000 or more vehicles in late 2010, with increasing production in 2011. See Chevy Volt for latest. Aims to get PHEV SUV on road in 2011; no production goal.</td>
</tr>
<tr>
<td>Honda</td>
<td>Sees PHEVs as having &quot;unnecessary fuel engine and fuel tank;&quot; promises all-electrics &quot;assuming we can come up with a really high-performing battery that we are working on currently.&quot; Doubts PHEVs have environmental benefits.</td>
<td>No known plug-ins being planned or on the road. Continues promotion and development of hydrogen as long-term strategy.</td>
</tr>
</tbody>
</table>
### Appendix C (Continued)

| **Jaguar** | Tata-owned company reported to be developing series PHEVs. | Based on SJ sedan and perhaps the SE roadster, expected 2011. |
| **Mazda** | Ford Partner was reported to be developing Series PHEV based on Mazda 5 MPV platform. | No announced plans. Company says it’s focusing on gasoline and hydrogen. |
| **Mitsubishi** | Introduces PX-MiEV four-wheel drive vehicle at Tokyo Auto Show, October 2009. | Concept vehicle, no announced production plans. |
| **Nissan** | Includes PHEVs in its long-term development program. | Focusing on all-electric, Nissan-Renault partnership with Better Place for EVs. |
| **Persu Mobility (formerly VentureOne)** | 3-wheel Persu Hybrid PHEV-20 in development. | Expected deposits in 2009 and first sales in CA in 2010. |
| **Saab** | GM-owned company exploring PHEVs. | Joint Venture with Volvo and others to research PHEVs. |
| **Suzuki** | Introduces Swift subcompact crossover series PHEV at Tokyo Auto Show, October 2009. | Concept vehicle, no announced production plans. |
| **Toyota** | 500 PHEV 2010-model Priuses with lithium batteries to be leased for fleet tests in 2009 (150 in U.S.). Commits to sell PHEVs in 2012. Agrees on environmental and economic benefits, though some presentations backtrack on that; says batteries need further development before commitment to mass-production. Says demand and whether people will plug in remain to be proven. | Mass-produced 2010 “third-generation” Prius, originally planned for 2009, still uses NiMH batteries. (Several aftermarket companies and organizations have converted hundreds of Priuses -- see Where PHEVs Are.) |
| **Visionary Vehicles** | Team w/Malcolm Bricklin (who brought the Subaru and the Yugo to America) aims for luxury PHEV. | Raising money to bring a PHEV to market. |
| **Volkswagen** | CEO says “Future belongs to electric cars,” has gained German government support for development. Expects production around 2014. | Space Up! Blue Concept PHEV Van with diesel or hydrogen fuel cells and rooftop photovoltaic. Plans for put 20 “Twin Drive” PHEV-30 prototypes on Golf platform in 2010. Partnership with BYD could accelerate PHEV plans. |
| **Volvo** | Ford-owned company has developed “ReCharge” concept vehicles with wheel motors. V70 parallel diesel hybrid prototypes | Working with Vattenfall utility for demonstration project using Ener1 batteries; aims for 2012 commercial launch. |
## Appendix D
GM Fuel Cell Vehicles Milestones

### 2007

January 1, 2007: General Motors Europe AG and other vehicle manufacturers including BMW Group, DaimlerChrysler AG, Ford Motor Company, MAN Nutzfahrzeuge AG, and Volkswagen AG, along with energy companies Shell Hydrogen B.V. and Total France, announced their joint approach to advance hydrogen as a fuel for road transport in Europe. In a common position paper, the companies defined a near and mid term action plan to pave the way for the introduction of hydrogen-based mobility in Europe.

### 2006

#### September 27, 2006:
GM announced that it extended its agreement with the United States Postal Service to test fuel cell vehicles for mail delivery. The announcement was made at the unveiling of a GM HydroGen3 fuel cell minivan that would be added to the U.S. Postal Service’s Irvine, California, fleet, and marked the first time a fuel cell vehicle would be used for mail delivery on the West Coast.

#### September 21, 2006:
The U.S. Army became the first customer of General Motors latest fuel cell technology as the automaker deployed the first vehicle of its next generation Chevrolet Equinox Fuel Cell vehicle fleet.

**September 17, 2006:** Chevrolet announced plans to launch the world's largest fuel cell vehicle fleet by committing to build more than 100 Chevrolet Equinox Fuel Cell vehicles and begin placing them with customers in the fall of 2007, as part of a comprehensive deployment plan dubbed "Project Driveway." Designed to gain comprehensive feedback on all aspects of the customer experience, Project Driveway becomes the first meaningful market test of fuel cell vehicles anywhere. A variety of drivers - in differing driving environments - will operate these vehicles and refuel with hydrogen in three geographic areas: California, the New York metropolitan area and Washington D.C.

**September 11, 2006:** General Motors announces a drivable version of the most technologically advanced automobile ever built - the Chevrolet Sequel, GM's solution to provide the world with a cleaner, petroleum-free vehicle that is better in nearly every way.

**May 11, 2006:** GM's pioneering 1966 Electrovan and AUTOonomy fuel cell concept car, that captured the world's attention when introduced by GM at the 2002 North American International Auto Show, were transported from the General Motors Heritage Center near Detroit to the Petersen Automotive Museum in Los Angeles for the exhibit, "Propulsion after Petroleum." The exhibit is designed to highlight the work that the automobile industry has done over the years to become less dependent on fossil fuels for efficiency, environmental and economic reasons.
April 22, 2006: In Detroit, home to GM's world headquarters, GM participated in Earth Day activities at the New Detroit Science Center with a hydrogen fuel cell-powered vehicle display and information on GM's research and development efforts in this future transportation arena. Additionally, GM sponsored the U.S. Department of Energy's National Science Bowl and hosted a hydrogen fuel cell vehicle ride and drive and hydrogen fuel cell model car challenge for student participants later that same month.

February 23, 2006: Department of Energy Secretary Samuel W. Bodman visited GM's Fuel Cell Activities Research Center in Honeoye Falls, NY, Thursday, February 23, 2006. Bodman's visit highlighted President Bush's $1.2 billion, five-year commitment to the Hydrogen Fuel Initiative. As part of President Bush's Advanced Energy Initiative, the Fiscal Year 2007 budget request for the Hydrogen Fuel Initiative was increased by $53 million to $289.5 million.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
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<tr>
<td>2005</td>
<td><strong>Sept. 29 - Oct. 1, 2005</strong>: GM and U.S. Army demonstrated hydrogen-powered fuel cell technologies designed for consumer use, and for U.S. military non-tactical vehicle applications, as part of a rolling fuel cell vehicle convoy featured during the 2005 California Fuel Cell Partnership (CaFCP) Road Rally. A modified Chevrolet Silverado equipped with two 94-kilowatt fuel cell stacks fueled by hydrogen, and GM's HydroGen3 fuel cell minivan, were among several fuel cell vehicles featured during CaFCP member caravans, educational displays and test-drive opportunities in several Sacramento and San Francisco Bay Area communities.</td>
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<tr>
<td></td>
<td><strong>June 3, 2005</strong>: Swedish furniture maker IKEA and General Motors announced that IKEA customers in Berlin, Germany would begin receiving service calls from an emission-free HydroGen3 fuel cell vehicle based on the Opel Zafira and fueled by liquid hydrogen. IKEA becomes the latest organization to partner with GM, joining FedEx, the U.S. Postal Service, Shell and the U.S. Army in taking advantage of the benefits of hydrogen fuel cell technology.</td>
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</table>
April 1, 2005: Senator Hillary Rodham Clinton joined GM and the U.S. military for the unveiling and ceremonial delivery of a GM fuel cell-powered pickup truck built for the U.S. military. Developing partnerships with customers like the U.S. military, whose goals match GM’s, will advance a hydrogen economy, help gain real-world experience with hydrogen and fuel cells and create the potential for additional future joint transportation ventures with the military.

January 27, 2005: GM announced that it will be providing 13 fuel cell-powered vehicles and that Shell Hydrogen LLC intends to establish New York State’s first hydrogen service station in the New York City metropolitan area in 2006. GM and Shell will be the only team bringing fuel cell vehicles and hydrogen refueling to the New York City metropolitan area under the U.S. Department of Energy’s Infrastructure Demonstration and Validation project.

January 10, 2005: GM’s Sequel was unveiled in Detroit. Sequel embodies GM’s vision of reinventing the automobile with a fusion of technologies that include advanced materials, electronic controls, computer software and advanced propulsion. The technology concepts first introduced in Autonomy and then Hy-wire have become much more real in the GM Sequel which demonstrates that the vision is real and eventually, fuel cells are the ultimate answer.

January 6, 2005: GM joined with Sandia National Lab in a partnership to design and test an advanced method for storing hydrogen. The 4-year, $10 million program is intended to develop and test tanks that store hydrogen in sodium aluminum hydride. The goal is to be able to store more hydrogen onboard that other hydrogen storage methods currently in use.
### 2004

**November 29, 2004:** Dow and GM launched the second phase of a joint project proving the viability of hydrogen fuel cells. In the first phase, announced in February 2004, a single GM test cell was connected to Dow’s power distribution grid and also to Dow’s hydrogen clean-up and pipeline system to generate electricity for powering up the Dow chemical plant. Phase II expands the project from a single GM test cell to a multi-cell pilot plant at Dow's Texas Operations in Freeport, Texas. The real-world data that is collected from this venture is being used to further the development of fuel cell technology.

**November 10, 2004:** A retail hydrogen fueling station opened in Washington DC as the centerpiece in a partnership announced between Shell and GM to develop hydrogen-fueled vehicles on a commercial scale. The station is the first at a retail gas station to service. It will service six GM fuel cell vehicles. Both compressed and liquid hydrogen refueling are available.

**October 30, 2004:** GM and Shanghai Automotive announced they will co-develop a demonstration vehicle using the latest fuel cell technology, building on GM’s HydroGen3 fuel cell vehicle. The two-year demonstration will begin in Shanghai in early 2005. It is designed to showcase the benefits of fuel cell vehicles in real life applications.

**October 14, 2004:** GM took top honors in several categories with it’s HydroGen3 fuel cell vehicle at the 2004 Michelin Bibendum competition in Shanghai. The competition pitted 74 hybrid, diesel and fuel cell vehicles, measuring everything from acceleration to fuel efficiency to CO2 emissions.
<table>
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<tr>
<th>Date</th>
<th>Event Description</th>
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<tr>
<td>September 8, 2004:</td>
<td>Governor Ehrlich of the state of Maryland announced plans to lease a GM HydroGen3 vehicle in a ceremony held at the state’s capitol. The vehicle will be used as part of the state’s fleet and represents a significant step forward in laying a foundation for a future economy driven by hydrogen. Maryland is also pursuing development of an hydrogen fueling station and industrial park where all of the buildings would be powered by hydrogen.</td>
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<tr>
<td>June 15, 2004:</td>
<td>GM and the U.S. Postal Service announced an arrangement whereby the U.S. Postal Service would lease a GM HydroGen3 fuel cell vehicle to add to its fleet of mail delivery vehicles in Washington DC. The vehicle is assigned to a postal delivery route in the Ft. Belvoir, Virginia vicinity. Postal delivery service with the vehicle was launched on September 8, 2004.</td>
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<tr>
<td>May 3, 2004:</td>
<td>GM set a new world distance record for fuel cell technology with a run of HydroGen3 over 6,000 miles through 14 European countries. The marathon run nearly doubled the previous distance record set by Daimler Chrysler in 2002.</td>
</tr>
<tr>
<td>February 10, 2004:</td>
<td>GM and Dow officially powered-up a stationery Fuel Cell Power Module at the Dow Chemical Company’s Freeport Texas plant. In the world’s largest fuel cell application at a chemical manufacturing site, Dow’s by-product hydrogen created as a part of Dow’s manufacturing processes will be converted to electricity by a GM fuel cell. The electricity that is generated will power up the plant.</td>
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<tr>
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<tr>
<td>August</td>
<td>GM demonstrates wheel hub motor technology that can provide a 60 percent increase in torque at the launch in hybrid and fuel cell vehicles.</td>
</tr>
<tr>
<td>July</td>
<td>GM and Federal Express announced a partnership where the HydroGen3 fuel cell vehicle will be used by Federal Express in the first commercial use of a fuel cell vehicle in Japan. FedEx will use the HydroGen3 vehicle during one year for regular delivery services in two downtown districts of Tokyo.</td>
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<tr>
<td>May</td>
<td>Launched Washington-based fleet of hydrogen-powered vehicles with test-drives of HydroGen3 fuel cell prototypes with Members of Congress.</td>
</tr>
<tr>
<td>May</td>
<td>Announced reaching an understanding with Dow Chemical Co. on the world’s largest fuel cell transaction to date. The intent is for GM to commercialize its hydrogen fuel cell technology to generate electricity from hydrogen created as a co-product at Dow’s Freeport, Texas operations. Dow could eventually use up to 35 megawatts of power generated by 500 fuel cell units.</td>
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<tr>
<td>April</td>
<td>Announced an agreement with the BMW Group to jointly develop refueling devices for liquid hydrogen vehicles and invited other carmakers and suppliers to join this initiative.</td>
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</tbody>
</table>
March: Japan's Ministry of Land, Infrastructure and Transport (MLIT) granted GM the first-ever approval to drive a liquid hydrogen-fueled vehicle on public roads in Japan. With a driving range of 400 kilometer (250 miles), HydroGen3 has the highest driving range of any fuel cell vehicle approved for public roads in Japan.

March: Announced a partnership with Shell Hydrogen which includes a demonstration of hydrogen fuel cell vehicles and fueling infrastructure technology in the Washington, D.C area. The demo features the nation’s first hydrogen pump at a Shell retail gas station to support a GM demo fleet of fuel cell vehicles.

February: Announced world’s first successful vehicle test of a 10,000 PSI (700 bar) hydrogen storage system. The new 20,000 PSI tank technology extends the range of the HydroGen3 fuel cell vehicle by 60-70 percent compared to an equivalent-sized 5,000 PSI system.

January: Hy-wire named “Car of the Future” by the Belgian Association of Professional Auto Journalists. The honor is awarded to the vehicle considered the most innovative, the most spectacular, the most original or the most practicable.

January: Revealed, with the U.S. Army, a diesel hybrid military pickup truck equipped with a fuel cell auxiliary power unit that could become the model for the Army’s new fleet of 30,000 light tactical vehicles by the end of the decade.

January: Hy-wire recognized with "Environmental Strategy Concept Car of the Year" by Automotive News; North American International Auto Show Eyes on Design award for “Most Significant Design Enabler” and "Golden Marker Award for Excellence in Design" by Car Styling Magazine.
<table>
<thead>
<tr>
<th>June: Showcased the AUTOonomy at the World Hydrogen Conference in Montreal.</th>
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<tr>
<td>May: Released initial results of European Well-to-Wheel study showing that fuel cell cars offer solution to curtail greenhouse gas emissions.</td>
</tr>
<tr>
<td>May: AUTOonomy awarded “Engine of the Year” Award in Best Concept category by &quot;Engine Technology International.&quot;</td>
</tr>
<tr>
<td>April: Demonstrated Chevrolet S-10 Gasoline-Fed Fuel Cell Vehicle, the world's first drivable fuel cell vehicle that extracts hydrogen from gasoline to produce electricity.</td>
</tr>
<tr>
<td>April: Delivered HydroGen1 to California Fuel Cell Partnership.</td>
</tr>
<tr>
<td>April: Exhibited Phoenix at an Earth Day exhibit in Beijing with U.S. Secretary of Commerce Donald Evans in attendance. The Phoenix is a fuel cell wagon developed jointly by the Pan Asia Automotive Technology Center (PATA), a joint venture of GM and the Shanghai Automotive Industry Corporation (SAIC).</td>
</tr>
<tr>
<td>March: Showcased AUTOonomy concept at Geneva Motor Show.</td>
</tr>
<tr>
<td>January: Unveiled AUTOonomy concept which is the first vehicle designed from the ground up around a fuel cell propulsion system and the first to combine fuel cells with x-by-wire technology.</td>
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</tbody>
</table>
2001

**October:** Unveiled with Hydrogenics a prototype fuel cell unit that provides back-up power to cell towers during power outages. Once fully developed, GM partner Hydrogenics to market and field test the fuel cell unit with Nextel in first quarter of 2002.

**October:** Participated in Michelin's Bibendum Challenge showcasing the HydroGen1 fuel celled-vehicle and QUANTUM's TriShield hydrogen storage cylinder. Announced HydroGen1 was the only fuel cell-powered vehicle to finish Bibendum's 350-kilometer course from Los Angeles to Las Vegas.

**October:** Released "2000-01 Sustainability Report" which highlights GM's efforts to develop hydrogen-powered fuel cell vehicles with 300 experts working on two continents.

**October:** Announced multi-year collaborative research agreement with ChevronTexaco to advance fuel cell technology and gasoline processing for fuel cell vehicles. Agreement will accelerate GM's efforts to offer a gasoline-fed fuel cell vehicle to retail customers.

**October:** Announced agreement with Suzuki Motor Corporation to collaborate on fuel cell vehicle development, focused on small cars.

**October:** GM Fuel Cell Technical Seminar attended by 150 media representatives at Tokyo Motor Show. Showcased HydroGen3 fuel cell vehicle.

**October:** Announced expansion of fuel cell development activity with Giner, Inc. to include applications beyond the transportation field, including hydrogen generation for refueling systems and regenerative fuel cells for stationary power.
<table>
<thead>
<tr>
<th>October:</th>
<th>Announced strategic alliance with Hydrogenics Corporation to accelerate fuel cell development into global commercial markets. Alliance includes shared intellectual property rights and joint efforts in fuel cell product development, engineering, prototyping, testing, branding and marketing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>September:</td>
<td>Showcased HydroGen3 at Frankfurt Auto Show. Announced that GM's latest fuel cell stack sets new world standard for power density that packs 60% more power than any competitor. New stack generates 1.75 kilowatts (kW) per liter at the Grove Conference.</td>
</tr>
<tr>
<td>August:</td>
<td>Showcased fuel cell stationary power unit capable of supplying electricity to homes and businesses at U of M's Traverse City Automotive Management Seminar.</td>
</tr>
<tr>
<td>August:</td>
<td>Unveiled Chevrolet S-10 pickup demonstrator featuring GM's Stack 2000 at U of M's Traverse City Automotive Management Seminar. (Stack 2000 generates electricity and has 25 percent higher power density than GM's Stack used at Mesa endurance trials in May 2001.)</td>
</tr>
<tr>
<td>August:</td>
<td>Unveiled Gen III, world's first gasoline fuel processor for fuel cell propulsion, at U of M's Traverse City Automotive Management Seminar. Gen III has the capacity to start in less than three minutes.</td>
</tr>
<tr>
<td>June:</td>
<td>Announced 25-year collaboration with General Hydrogen to accelerate the spread of a hydrogen infrastructure and to speed introduction of fuel cell vehicles into North America, Europe, Asia and emerging markets.</td>
</tr>
<tr>
<td>June:</td>
<td>Announced substantial minority ownership position in QUANTUM Technologies to develop hydrogen handling and electronic control technologies for fuel cell applications. QUANTUM is recognized as industry leader in hydrogen storage and handling in automotive applications.</td>
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<td>Month</td>
<td>Event</td>
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<tr>
<td>May</td>
<td>Set 15 international endurance records for fuel cell-powered vehicles by HydroGen1 at GM's Mesa, Arizona Proving Grounds. HydroGen1 completed 862 miles in 24-hour endurance run.</td>
</tr>
<tr>
<td>March</td>
<td>Released comprehensive Well-to-Wheel study by GM, Argonne National Laboratory, BP, ExxonMobil, and Shell showing that hydrogen-powered fuel cell vehicles offer the cleanest and most efficient combination of fuel and propulsion system in long-term.</td>
</tr>
<tr>
<td>March</td>
<td>Announced that GM has entered into discussions with QUANTUM Technologies to establish a business relationship.</td>
</tr>
<tr>
<td>January</td>
<td>Announced with Toyota progress on multi-year technology agreement and combining research on fuels for fuel cells and fuel infrastructure with ExxonMobil.</td>
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</tbody>
</table>

**2000**

<table>
<thead>
<tr>
<th>Month</th>
<th>Event</th>
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<tbody>
<tr>
<td>November</td>
<td>Announced breakthrough catalyst system with current generation gasoline fuel processor at more than 80 percent efficiency.</td>
</tr>
<tr>
<td>November</td>
<td>Showcased HydroGen1 at fuel cell technology seminar in China. (HydroGen1 achieved full power nearly 12 times faster in freezing conditions than same design unveiled in 1999.)</td>
</tr>
<tr>
<td>October</td>
<td>Joined California Fuel Cell Partnership (CaFCP) to advance state of fuel cell technology.</td>
</tr>
<tr>
<td>Month</td>
<td>Event</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>March</td>
<td>Introduced Opel Zafira demonstration car, with industry's most advanced operational automotive fuel cell stack, at Geneva International Motor Show.</td>
</tr>
<tr>
<td>January</td>
<td>Unveiled Precept FCEV, fuel cell electric vehicle and PNGV demonstrator, at North American International Auto Show in Detroit, Michigan, USA. (Designed to achieve 108 m.p.g. gasoline equivalent.)</td>
</tr>
<tr>
<td>April</td>
<td>Signed five-year technical agreement with Toyota to develop advanced vehicle technologies, including fuel cells.</td>
</tr>
<tr>
<td>September</td>
<td>Introduced first driveable fuel cell concept (Opel Zafira minivan) at Paris Motor Show.</td>
</tr>
<tr>
<td></td>
<td>Established Global Alternative Propulsion Center with facilities in Mainz-Kastel, Germany; Warren, Michigan, USA; and Honeoye Falls, New York, USA.</td>
</tr>
<tr>
<td></td>
<td>Signed agreement with ExxonMobil to conduct collaborative research on hardware and fuel options for advanced vehicles.</td>
</tr>
<tr>
<td>Year</td>
<td>Event</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>1996</td>
<td>GM/Exxon/Arco R&amp;D Agreement signed.</td>
</tr>
<tr>
<td>1995</td>
<td>Giner Stack Development Program initiated.</td>
</tr>
<tr>
<td>1968</td>
<td>Produced auto industry's first operational fuel cell-powered vehicle.</td>
</tr>
<tr>
<td>1964</td>
<td>Conducted first fuel cell testing</td>
</tr>
</tbody>
</table>
## Appendix E
### Current Specifications of Chevrolet Equinox

<table>
<thead>
<tr>
<th><strong>Vehicle type</strong></th>
<th>5-door, front-wheel-drive SUV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chassis</strong></td>
<td>Independent MacPherson struts front, independent, 4-link trailing arm rear, disc brakes front and rear, friction brake blending to maximize energy capture, electric power assist steering</td>
</tr>
<tr>
<td><strong>Seating capacity</strong></td>
<td>4</td>
</tr>
</tbody>
</table>

### DIMENSIONS

<table>
<thead>
<tr>
<th><strong>Wheelbase (in / mm):</strong></th>
<th>112.5 / 2858</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length (in / mm):</strong></td>
<td>188.8 / 4796</td>
</tr>
<tr>
<td><strong>Width (in / mm):</strong></td>
<td>71.4 / 1814</td>
</tr>
<tr>
<td><strong>Height (in / mm):</strong></td>
<td>69.3 / 1760</td>
</tr>
<tr>
<td><strong>Curb weight (lb / kg):</strong></td>
<td>4431 / 2010</td>
</tr>
<tr>
<td><strong>Cargo volume (cu ft / L)</strong></td>
<td>32.0 / 906.24</td>
</tr>
</tbody>
</table>

### FUEL STORAGE SYSTEM

<table>
<thead>
<tr>
<th><strong>Type</strong></th>
<th>3 carbon fiber fuel tanks, compressed gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Service pressure (psi / bars):</strong></td>
<td>10,000 / 700</td>
</tr>
<tr>
<td><strong>Storage capacity (lb / kg):</strong></td>
<td>9.24 / 4.2</td>
</tr>
</tbody>
</table>

### FUELL CELL SYSTEM

| **Power (kW)** | 93 |

### BATTERY SYSTEM

<table>
<thead>
<tr>
<th><strong>Type</strong></th>
<th>Nickel metal hydride battery pack; regenerative braking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power (kW)</strong></td>
<td>35</td>
</tr>
</tbody>
</table>

### ELECTRIC TRACTION SYSTEM

<p>| <strong>Front system</strong> | 3-phase asynchronous electric motor, FWD |</p>
<table>
<thead>
<tr>
<th><strong>Power (kW):</strong></th>
<th>73 continuous, 94 maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Torque (lb-ft / Nm):</strong></td>
<td>236 / 320</td>
</tr>
</tbody>
</table>

**PERFORMANCE**

| **Acceleration 0-60 mph (sec)** | 12 |
| **Top speed (mph / km/h)** | 100 / 160 |
| **Operating range (miles / km)** | 200 / 320 |

**Exterior Colors**
white, and premium tri-coat Glacier Gold

**Styling**
differentiated front and rear fascia, exhaust outlets, chrome accents, graphics

**Tire size**
P225/60R17, 17-inch aluminum wheels

**Interior Content**
Premium cloth (leather free) seats and trim, 2-passenger rear bench with center console

**Color & styling**
Glacier Gold theme with fabric and trim, unique floor mats and shift lever graphics

**Instrument panel**
kW meter, fuel cell energy display

**FUEL CELL PROPULSION SYSTEM**

| **Operating life (durability, miles / km)** | 2.5 years, 50,000 / 2.5 / 80,000 |
| **Freeze capacity** | Freeze capable without grid heater |
| **Operating temperature (F / C)** | -13 to +113 / -25 to +45 |

**Standard equipment**
OnStar with Turn-by-Turn Navigation; electronic control HVAC; driver side power seat; deep tint windows; heated seats; keyless entry; power door locks/windows; power steering; driver information system; cruise control; AM/FM/XM navigation radio

**Safety & security**
Expected to meet all applicable 2007 U.S. Federal Motor Vehicle Safety Standards (FMVSS); driver and passenger frontal air bags and roof rail side-impact air bags; ABS; traction control; StabiliTrak; OnStar; navigation system
| Product benefits                                                                 | No petroleum consumption; EPA-certified zero-emission vehicle (ZEV) that emits only water vapor; zero propulsion system (greenhouse gases-GHG) emissions; instantaneous torque |

### MOTAR TREND TEST RESULTS FOR 2008 MODEL

<table>
<thead>
<tr>
<th>TEST DATA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration to mph</td>
<td></td>
</tr>
<tr>
<td>0-30</td>
<td>3.0 sec</td>
</tr>
<tr>
<td>0-40</td>
<td>4.6</td>
</tr>
<tr>
<td>0-50</td>
<td>6.7</td>
</tr>
<tr>
<td>0-60</td>
<td>9.2</td>
</tr>
<tr>
<td>0-70</td>
<td>12.5</td>
</tr>
<tr>
<td>0-80</td>
<td>17.6</td>
</tr>
<tr>
<td>Passing, 45-65 mph</td>
<td>5.1</td>
</tr>
<tr>
<td>Quarter mile</td>
<td>17.1 sec @ 78.9 mph</td>
</tr>
<tr>
<td>Braking, 60-0 mph</td>
<td>130 ft</td>
</tr>
<tr>
<td>Lateral acceleration</td>
<td>0.72 g (avg)</td>
</tr>
<tr>
<td>MT figure eight</td>
<td>30.1 sec @ 0.52 g (avg)</td>
</tr>
</tbody>
</table>
Appendix F
Fuel-Cell Companies

Aemetrixics
Adaptive Materials Inc.
Angstrom Power Inc.
Ansaldo Fuel Cells SPA (Italy)
Anuvu Fuel Cell Products, Inc.
Aperion Energy Systems
Apollo energy Systems
Asia Pacific Fuel Cell Technologies, Ltd. (Taiwan)
Astris Energi Inc. (Canada)
Axane Fuel Cell Systems
Ball Aerospace
Ballard Power Systems (Canada)
Ceramic Fuel Cells, Ltd. (Australia)
CellTech Power
CeresPower (U.K.)
Clean Fuel Generation
CMR Fuel Cells (U.K.)
Dain-Analytic (Chevron Texaco)
DAVID Fuel Cell Components (Spain)
Delphi
Distributed Energy Systems
Direct Methanol Fuel Cell Corp.
DTI Energy, Inc.
Dupont
Eco Soul
Ectro-Chem-Technic
ElectroChem, Inc.
ENECO, Ltd.
Ener 1
Energy Conversion Devices
Energy Partners, L.C.
Energy visions, Inc.
Fideris, Inc.
Fuel Cell Energy, Inc.
Fuel Cell Control, Ltd.
Fuel Cell Technologies, Ltd.
GE Power Systems
GEFC
GenCell
General Motors
Giner Electrochemical Systems, LLC
Global Thermoelectric (Canada)
H2 ECONomy
H2Japan (Japan)
H Power (acquired by Plug Power)
Heliocentris (Germany, Canada)
Hoku Scientific
Honeywell
Hydrogenics

Ida TechGiner Electrochemical Systems, LLC.
Independent Power Technologies (Russia)
Intelligent Energy (U.K.)
Ishikawajima-Harima (Japan)
ITM Power, Ltd. (U.K.)
Johnson Matthey Fuel Cells (U.K.)
Kainos Energy
Lynxtech Industries, Ltd.
Manhattan Scientifics
Masterflex
McDermott Technology, Inc.
MTI MicroFuel Cells, Inc.
Medis Technologies, Inc.
Mitsubishi
Morgan Fuel Cell
Motorola
Nexth Power Systems, Inc.
Nedstack
Novars GmbH
Nu Element, Inc.
NuVant Systems
Nurvera Fuel Cells
P21 GmbH
Palcan Fuel Cells Ltd.
Plug Power
PolyFuel
Povair Fuel Cell (U.K.)
PowerZyme
Proton Energy Systems, Inc.
Quantum Technologies, Inc.
ReliOn
Renew Power
Rolls-Royce Plc
Schatz Energy Research Center
Siemens AG (Germany)
Smart Fuel Cell GmbH (Germany)
Sulzer Hexis Ltd. (Switzerland)
TechSys, Inc.
Tekion Solutions, Inc. (Canada)
Teledyne Energy Systems
Third Orbit Power Systems
Tij Technologies
Toshiba
Umicor
UTC Fuel Cells
Voller Energy
XCELLSIS
Ztek Corporation

Source: Hydrogen and Fuel Cell Investor
Appendix G

Top 100 U.S. Gas Fields By 2009 Proved Reserves

The Top 100 gas fields is from U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 2009 U.S. Energy Information Administration.