Alternative Fuels for Automobiles

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Submitted to:

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Abstract

Steadily escalating gasoline prices, increased environmental concerns, and poor international politics have sparked new interests for alternatively fueled vehicles. There are numerous alternative fuel technologies including gasoline-hybrids, diesels, full electrics, as well as hydrogen and ethanol. These technologies are changing rapidly and consumers are having difficulty trying to decipher which type of vehicle is the most worthy investment. This study provides a simple breakdown of the pros and cons of the alternative fuel technologies as well as a statistical review of the total ownership costs of the vehicle up to 100,000 miles.

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Executive Summary

The rebirth of the search for alternatively fueled vehicles has been encouraged by increased environmental concerns, gasoline prices, as well as international political conflicts. The alternatives include gasoline-hybrids, diesels, full electrics, as well as hydrogen and ethanol. This project consists of a summary of the different types of alternative fuel technologies, comparisons between each fuel technology and a conventional gasoline counterpart, and a cost analysis of the most promising vehicles. The objective of this analysis is to inform the general public of the different types of alternatives to gasoline and their financial and environmental impact.

The United States is forced to import oil from foreign countries because of the fast increase of fuel consumption in the transportation sector. As the demand for oil increases, so has the price of oil and its byproducts such as gasoline. Increased usage of these fossil fuels has led to the growth of greenhouse gases and the U.S. transportation sector, which represents about 10% of all energy consumption. *A Wedge Analysis of the U.S Transportation Sector* introduces concepts of stabilization wedges to reduce the Carbon Dioxide emission. Each wedge is an activity that creates 1GtC/y of carbon reduction. It is shown that a combination of different types of technology will result in different rates of emission reduction. The combination that predicts the most CO_2 emission reduction consists of the use of 45% E85, 20% electric hybrid, and 35% advance gasoline and diesel. An EPA study showed that ethanol blends have reduced ozone in most states. Ethanol is an environmental friendly fuel but it costs more than gasoline.

Hybrid and all electric vehicles are among the oldest types of automobiles. A hybrid electric vehicle is one that has a propulsion system consisting of two or more separate power sources. All electric vehicles differ from hybrids in the fact that there is no internal combustion engine used to produce power. The electric vehicle runs exclusively on electricity stored in its batteries. Hybrid and all electric cars use similar technology to increase fuel efficiency. For instance, regenerative breaking, low drag tires, and startup/shutoff engine

management. Hybrid vehicles come in three different types of drivetrains; parallel, series, and a combination. Because of its configuration, parallel hybrids are very efficient on the highway while not as efficient during city driving. On the other hand, series hybrids are more efficient during city driving. The combination drivetrains are the most efficient but are the most complex and therefore the most expensive. The drivetrains can also be split into four different degrees of hybridization. Hybrids can be full, power assist, mild, or plug in hybrid. Plug in hybrids cross the gap between all electric and hybrid cars. The 2010 Chevy Volt acts like an electric car within a 40 mile range but acts like a series hybrid after this.

Diesel powered vehicles have been around for more than a century. The engine was first designed and developed by Rudolf Diesel. It differs from an Otto cycle in that the air/fuel charge is ignited by means of high compression. An Otto cycle will use a spark to ignite the fuel. A diesel engine has a higher thermal efficiency mainly due to the higher compression ratio. Diesel engines also lack the throttling losses that gasoline engines have. This is a large pumping loss and inefficiency of the Otto cycle. In recent times, with the advent of turbocharging, better engine management and emissions controls, the diesel can be found in many passenger vehicles. However, in the United States, many misconceptions exist on the theory and operation of these engines. These misconceptions include unpleasant odors from the exhaust, slow performance, loud, etc. All in all, diesels are a powerful alternative to gasoline.

Hydrogen is the most common element found in earth. It is produced by the electrolysis of water or from fossil fuel. There are two hydrogen fuel technologies, one is the hydrogen fuel cell (HFC) and the other is an internal combustion engine (ICE). The hydrogen ICE is a dual fuel technology vehicle that is fueled by gasoline as well by hydrogen and increases the vehicle efficiency. This type of vehicle is currently under development therefore it is not available to purchase. It is also important to know that hydrogen ICE emissions are less than conventional gasoline and it also emits NO_X. The HFC produces electricity by combining hydrogen and oxygen, to power an electric motor. The HFC emits water vapor and no CO_2. The Honda FCX, a

HFC vehicle, is currently being leased for $600/month. With limited hydrogen fueling station it is not an economically viable.

A survey was conducted in order to obtain the opinion and basic knowledge level of Worcester Polytechnic Institute students between the ages of 18 and 25. The surveys were dispersed manually as well as electronically throughout campus. The surveys had an error percentage of 5.66 percent and a confidence level of 90 percent. The data was analyzed and plotted using Microsoft Excel. The mean, median, mode, and standard deviations were all calculated.

A total cost analysis between the gas-electric hybrids and diesels with the gasoline powered vehicles was conducted. This analysis factored in the price of fuel, initial cost of vehicle, and the vehicles fuel efficiency. By means of Microsoft Excel, several equations were worked out to calculate the vehicles total cost as a function of mileage. This analysis allows one to come to the conclusion of when a particular alternative to gasoline becomes equal to total cost of the gasoline counterpart.

In conclusion, the authors found the alternatives to gasoline to be more environmentally friendly than their gasoline equivalents. Through the cost analysis we found that gas-electric hybrids and diesels are longer termed investments. They typically required in excess of 50,000 miles in order to have a lower total cost. We found the cost per mile of the diesel and gas-electric hybrids was lower than that of the gasoline, but that the initial cost was also typically higher. Most diesel, gas-electric, and ethanol powered vehicles also have a tax-incentive through the government which can help reduce the overall cost.

Introduction

Increased gas prices as well as greater environmental concerns, have led many Americans to search for better alternatives to the conventional gasoline-powered automobiles. Due to misconception, confusion, and biased public opinion, consumers have been apprehensive towards alternatives such as diesel, gas-electric hybrids, all electric, as well as hydrogen and ethanol. With gasoline prices rising to record highs nation-wide, there has been increased interest in these vehicles. It is evident that clear and unbiased information on this topic is difficult to come by. Through in-depth research including overall life-cycle cost, comparisons, and the analysis of other studies on the matter, the inquiries will be of importance to anyone who owns or is planning to own a passenger or sport utility vehicle. The results will include life costs, cost-to-benefit ratios, vehicle comparisons, and performance statistics. The analysis will be divided into three groups; 20 % city – 80 % highway, and 80% city –20% highway. These figures will be based off of these assumptions; 100,000 mile life span over a ten-year period, every vehicle will be bought new at the MSRP (Manufacturer's Suggested Retail Price) including shipping and receiving, they will be driven in an equivalent manner, recommended factory service maintenance intervals will be followed, and lastly, fuel prices will be calculated from the peak prices as of July 17th, 2008. The outcome of this research is to enlighten the general public of the financial and environmental concerns on the alternatives to gasoline.

Literature Review/ Background

Oil Industry Background and History

Before the discovery of oil wells, oil was extracted from animals, vegetables and coal, and was used mostly for lighting and heating. New types of transportation vehicles, including all types of locomotives consumes the highest quantity of oil. Oil wells were discovered in Pennsylvania by Edwin Drake in 1859 that yielded at least 15 barrels a day. The United States became the nation that exported the most oil, grasping a strong hold in economical value. After many years of oil extraction and consumption led to the depletion of the wells, the U.S. was forced to import oil. The consequences today are brutal because now the world is facing Peak-Oil, a term use that indicates that the cost of extracting and refining oil is more or equal to the cost of oil itself. This means that for one barrel of oil extracted and refined, the process consumes one barrel of oil, hence it is not economically viable.

Oil is known to have been used since ancient times for medical and construction purposes, but in modern times oil has many applications, especially in energizing the transportation industry. The auto became extremely popular and with it, fuel consumption has grown exponentially over the past decades as have the carbon dioxide and monoxide emission that are of environmental concern.

Oil and the U.S.

As stated before, oil has become increasingly important to the world economy due to its employment to energize the transportation industry. As the world population grows exponentially, so does the demand for oil. Since oil wells have depleted in the United States, it has forced the U.S. to import oil making them dependent on other countries to meet the demand. To solve this problem the U.S. has invested in alternative technologies research like Gasoline-Hybrid, Full electric, Hydrogen, Ethanol, and many others.

For the past decades, oil has become important to the world economy due to its use to energize the world, specially the transportation sector as stated above. It is projected that the consumption of liquid fuels will increase from 84 million barrels per day in 2005 to 113 million barrels in 2030. The transportation sector accounts for a 74 percent increase from 2005 to 2030, since the new building are design with the purpose of energy efficiencies and sustainability.

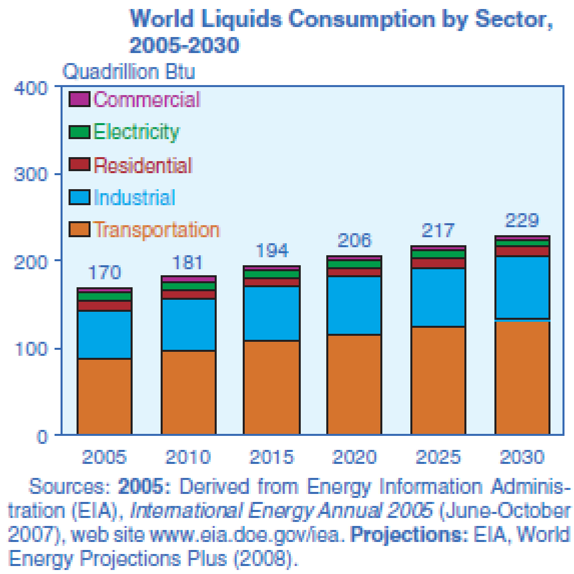


Figure 01 – World Liquids Consumption by Sector, 2005 – 2030

A study made by the Energy Information Administration (EIA) projects a 50 percent increase in world energy consumption by 2030, arising political concerns.[1]

[1] Conti , John, and Glen E. Sweetnam. "International Energy Outlook 2008." DOE/EIA-0484(2008): 1-35,79-86.

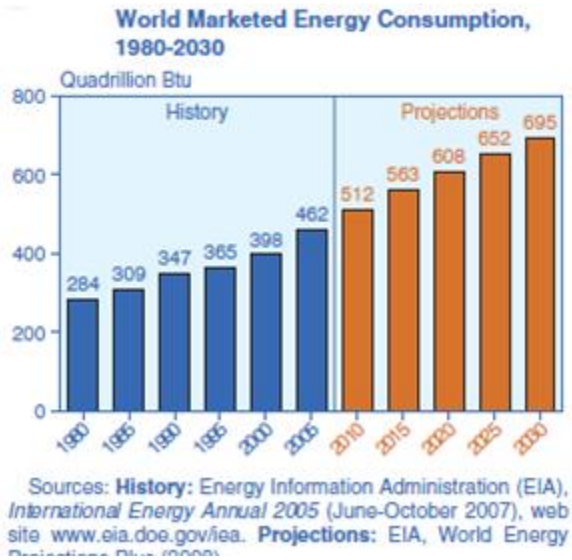


Figure 02 - World Marketed Energy Consumption, 1980 - 2030

Another study done by the EIA projects the amount of energy consumed worldwide by fuel type. It is expected that world oil price will remain high, the liquid fuels, are the slowest growing source of energy; liquid consumption increases at an average annual rate of 1.2 percent from 2005 to 2030.

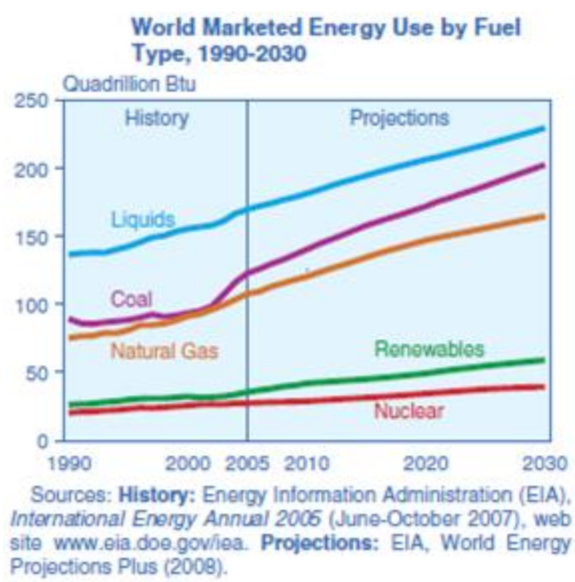


Figure 03 – World Marketed Energy Use by Fuel Type, 1990 - 2030

Coal and renewable energy are the fastest growing energy source, with consumption increasing by 2.0 percent and 2.1 percent respectively.[2] This increase is due the government incentives for renewable energy and environmental concern, and as for coal, it is cheap.

As shown above the most being consume energy source is the Liquids that includes petroleum-derived fuels and non-petroleum-derived fuels, such as ethanol and biodiesel, coal to liquids and gas to liquids. Petroleum coke, which is a solid, is included and also includes natural gas liquids, crude oil consumed as a fuel and liquid hydrogen.

Shown below is the projection of motor vehicle ownership by Organization for Economic Co-operation and Development (OECD)[3] region from 2005 to 2030.

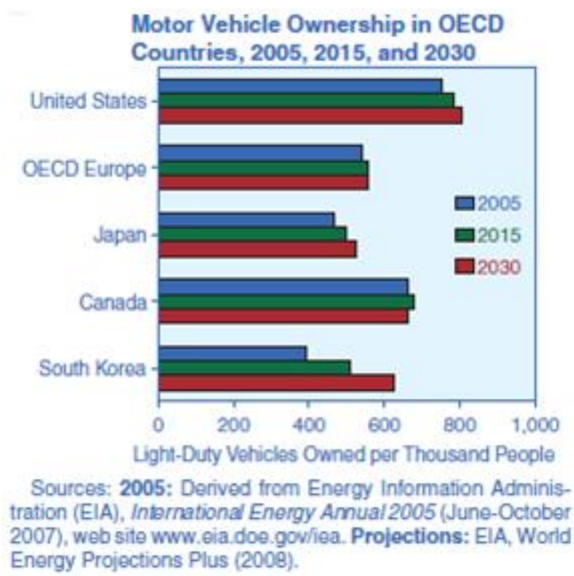


Figure 04 – Motor Vehicle Ownership in OECD Countries, 2005, 2015, and 2030

[2] Conti , John, and Glen E. Sweetnam. "International Energy Outlook 2008." DOE/EIA-0484(2008): 1-35,79-86.

[3] There are three basic country groupings in the **OECD: North America** (United States, Canada, and Mexico); **OECD Europe** (Europe—Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.); and **OECD Asia** (Japan, South Korea, and Australia/New Zealand). Non-OECD is divided into five separate regional subgroups: non-OECD Europe and Eurasia, non-OECD Asia, Africa, Middle East, and Central and South America. Russia is represented in non-OECD Europe and Eurasia; China and India are represented in non-OECD Asia; and Brazil is represented in Central and South America.

OECD Europe (Europe—Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom.); and **OECD Asia** (Japan, South Korea, and Australia/New Zealand). Non-OECD is divided into five separate regional subgroups: non-OECD Europe and Eurasia, non-OECD Asia, Africa, Middle East, and Central and South America. Russia is represented in non-OECD Europe and Eurasia; China and India are represented in non-OECD Asia; and Brazil is represented in Central and South America.

A trend is notice as the vehicle ownership increases, also does the change in liquid consumption for transportation energy from 2005 to 2030, especially in North America. The United States accounts for 70 percent of North America's liquid consumption.

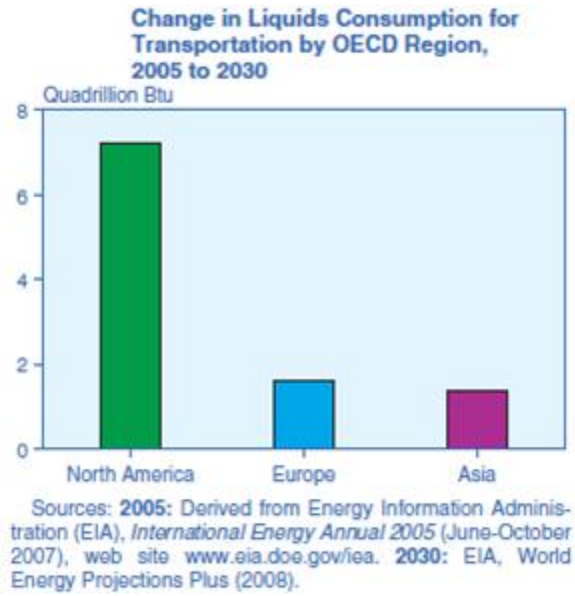


Figure 05 – Change in Liquids Consumption for Transportation by OECD Region, 2005 to 2030

This lead to the Energy Independence and Security Act 2007 (EISA) that require light-duty vehicles to reach fuel economy of 35 miles per gallon by 2020. It is of importance to know that U.S. ethanol consumption grows from 4.0 billion gallons in 2005 to 24.3 billion gallons in 2030.

Oil and Environmental Concerns

The transportation sector fuels are the fastest growing sources of greenhouse gases. The EPA study, *A Wedge Analysis of the U.S. Transportation Sector*, states:

"The U.S transportation sector represents approximately 10% of all energy-related greenhouse gas emissions worldwide. Over the next 50 years, rising numbers and use of vehicles could swell greenhouse gas emissions from U.S. transportation to 80% above current levels… There are three general approaches for reducing greenhouse gases in the transportation sector: 1) adopting advance vehicle technologies, 2) switching to low greenhouse gas (GHG) fuels, and 3) reducing vehicle miles traveled."[4]

A Wedge Analysis of the U.S. Transportation Sector introduces the concept of stabilization wedges and applies it to the U.S. transportation sector to illustrate the potential approaches that are capable to reduce both greenhouse gases and oil consumption. A wedge is an activity that creates 1GtC/y of carbon reduction. To reach about 550 ppm stabilization, the goal for the next 50 years is to achieve 7 wedges by avoiding 175 billion tons of carbon emission.[5] Each wedge represents an improvement in technology and/or product efficiency, for example, 2 billion vehicles achieving 60 mpg, improving coal plants efficiency, and installing windmills.

A global-scale stabilization triangle and the individual wedges (in green). Reproduced from Pacala, Socolow, *Science* (2004), 305, 968 with labels in red added. A business as usual emissions trajectory could result in atmospheric concentration levels 850 ppm CO_2 or greater. Removing the emissions embodied by the stabilization triangle would be analogous to emission pathways stabilizing below 550 ppm.

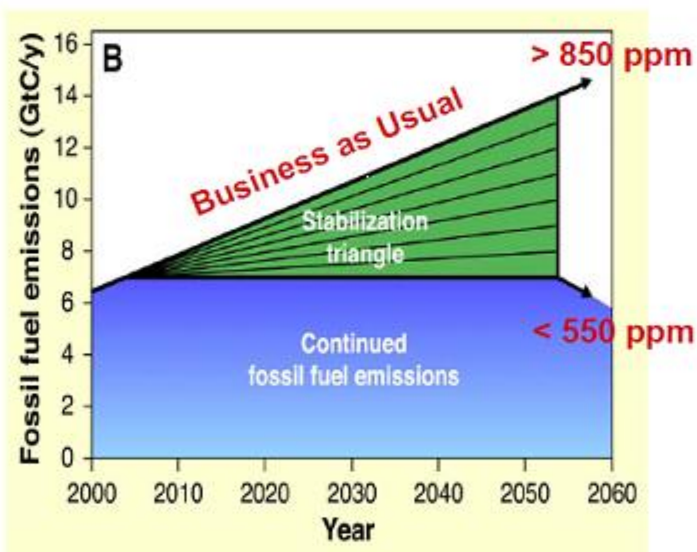


Figure 06[6]: Stabilization Wedges

[4] Hulsey, Brett. "Ethanol: A Convenient Solution to the 'Inconvenient Truth'." Moderate Ethanol Blends Can Save Money, Reduce Pollution and Improve Mileage (2007): 4.
[5] Socolow, Robert, and Stephen Pacal. ""Wedges": Early Mitigation with Familiar Technology." (2004): 1.
[6] Mui, Simon, and Jeff Alson. "A Wedge Analysis of the U.S. Transportation Sector." EPA420-R-07-007(2007): 5.

Another example is, in Figure 6, 1 to 2 wedges or all 7 wedges could represent the nine vehicle technology shown in Figure 7. It could also represent a combination of vehicle technology with a carbon reduction (capture) system.

Vehicle technology categories and their assumed fuel economy and GHG emissions relative to a baseline, conventional gasoline vehicle.

Vehicle Technology	Vehicle Fuel Economy Improvement[26]	Percent Reduction in GHG Emissions (fuel-cycle)[27]
	vs. Conventional Vehicle	
Advanced Gasoline Engine and Advanced Diesel Engine	35-40%	20-26%
Hybrid Electric Vehicle (Gasoline)	40%	29%
Hybrid Electric Vehicle (Diesel)	70%	35%
Optimized E85[28]	-4%	38 to 80%
Advanced Optimized E85[29]	30%	54 to 85%
Plug-In Hybrid Electric[30]	65%	31 to 62%
Electric	390%	31 to 94%
Fuel Cell[31]	270%	21-92%

Figure 07[7]: Vehicle Techology

In Figure 6, it is projected that in 50 years the GHG emissions from the USTS will grow 80% (200,000 MMT added by 2050) above current levels, due to the increase of vehicles and their use. If proper action is taken by the year 2050 GHG emission can be kept at constant level and even be reduced after the year 2050. Three parameters are taken into consideration to determine the amount of GHG emission (E) from the transportation sector. The vehicle fuel consumption (F), miles traveled (A) and carbon content of the fuel (C). This is called the EFAC equation[8]:

$$E = Emissions_{(Carbon)} = \underbrace{\left(\frac{Gallons}{Mile}\right)}_{Fuel\ Consumption}\underbrace{\left(\frac{miles\ \ traveled}{Vehicle}\right)}_{Activity}\underbrace{\left(\frac{mass\ C}{gallon}\right)}_{Carbon\ Content} = F \times A \times C$$

[7] Mui, Simon, and Jeff Alson. "A Wedge Analysis of the U.S. Transportation Sector." EPA420-R-07-007(2007): 13.
[8] Mui, Simon, and Jeff Alson. "A Wedge Analysis of the U.S. Transportation Sector." EPA420-R-07-007(2007): 9.

Diesel Background and History

Despite its huge success in Europe, the Diesel engine is largely unaccepted by passenger vehicles buyers in the United States. It makes up for half of the sales in Europe[9]. Named after Rudolph Diesel in 1893, the diesel engine was revolutionary in comparison to the other options (including steam) at the time. It provided higher thermal efficiencies, thus reducing fuel consumption and increasing power output (comparatively). Many false stereotypes on the operation and ownership of a diesel engine however continue to adversely affect its acceptance in America. Most of these stereotypes are from negative past experiences from the early 80's. Through strict emissions controls and advanced engine control units, the diesel engine is rivaling the gasoline engine in terms of performance.

The engine cycle is simple. Air is drawn into the cylinder by the reduced pressure created by the downward moving piston, following a compression cycle, fuel is added, combustion occurs, the power stroke is performed and then the products of combustion are exhausted to the atmosphere. Most modern diesels will use an exhaust driven turbocharger to recover thermal energy from the hot combustion products and use it to raise the manifold pressure of the intake. This allows for a greater brake mean effective pressure and increased power output for a given engine displacement. "Adding a turbocharger to a diesel does more than increase the amount of air available for combustion. The turbocharger also improves combustion efficiency by increasing the turbulence in the combustion chamber."[10]

Thermal efficiency[11] in such cycles is largely determined by the compression ratio.

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\left(\frac{\alpha^{\gamma}-1}{\gamma(\alpha-1)}\right)$$

[9] Robert, Bosch. "History of the diesel engine."Diesel-Engine Management Systems and Components. 4th ed. 2006 p.15
[10] MacInnes, Hugh. Turbochargers. New York: The Berkley Publishing Group, 1984.
[11] Nave, R.. "The Diesel Engine." 13 Dec 2008 <http://230nsc1.phy-astr.gsu.edu/hbase/thermo/diesel.html>.

Where

η_{th} is thermal efficiency
α is the cut-off ratio $\frac{V_3}{V_2}$ (ratio between the end and start volume for the combustion phase)
r is the compression ratio $\frac{V_1}{V_2}$
γ is ratio of specific heats (C_p/C_v)

Diesels typically operate at a higher compression ratio than gasoline due to the requirement of high cylinder pressures and temperatures to ignite fuel as it is injected. On most gasoline engines, fuel is added either at a throttle body, at the intake manifold, or on modern engines, in the cylinder head (similar to diesel). The reason why gasoline engines can't have as high of a compression ratio is due to pre-ignition by which the air-fuel mixture ignites before the spark plug fires. This is harmful to the engine components and can cause damage. Therefore, the compression ratio as well as the thermal efficiency is lower than that of compression ignition engines.

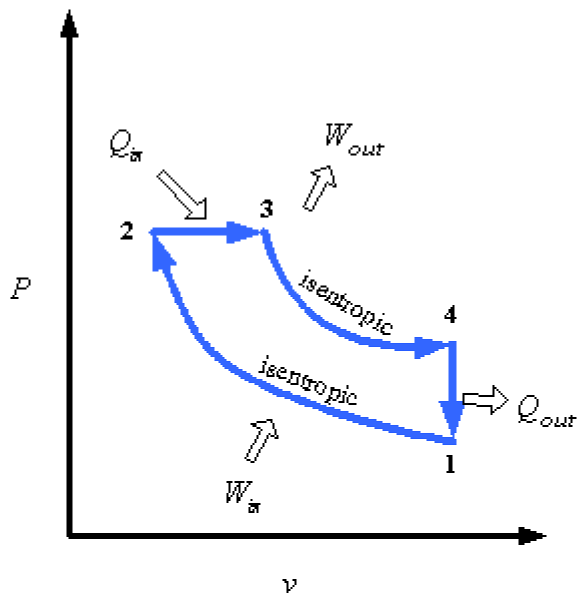
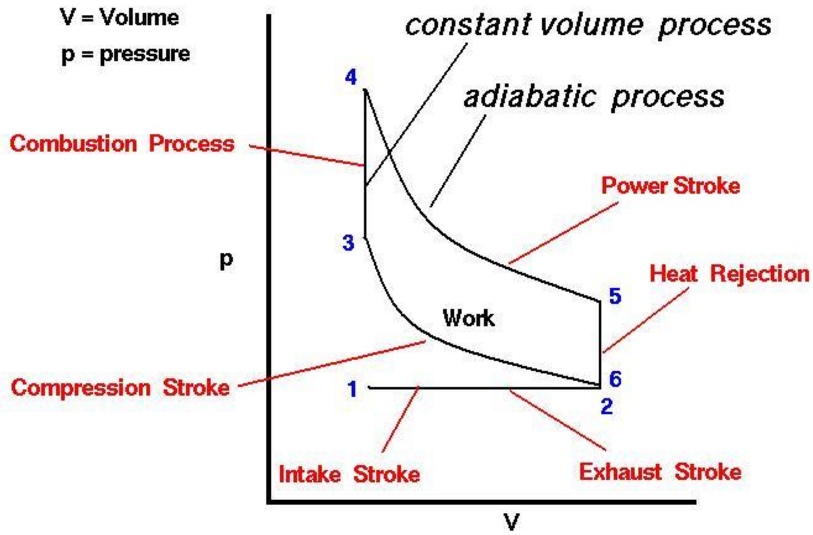


Figure 08: Diesel Cycle P-V Diagram



12

Figure 09: Otto Cycle

There are several main benefits of a diesel engine over a conventional gasoline engine. As previously mentioned, diesel engines typically have a higher compression ratio[13] (typically 18-22:1 compared to 9-11:1 in most gas engines). With the higher compression ratio comes the higher thermal efficiency. Diesel engines also have a lower specific fuel consumption[14] of 230-280g/kWhr compared to the 300-350g/kWhr of a naturally aspirated gasoline powered vehicle. Other benefits of diesels are that they run at lower rpm, potentially increasing the longevity of the engine. Diesel fuel also has a greater energy density than that regular gasoline. However, the lack of throttling losses is one of the primary benefits of a diesel engine.

One of the main benefits of diesels in city driving is the lack of a throttle plate. The amount of air (and consequently fuel) allowed into a gasoline engine is based off of the throttle plate. On a diesel, the air/fuel is controlled by adding more heat (fuel) to the combustion chamber making it speed up and want more air. Unfortunately, by having a throttle plate restriction, especially when idling, a large pressure drop occurs. This is called a pumping loss. The engine is attempting to pull air from the atmosphere while having a restriction in the way, therefore requiring work to be performed on the fluid. This work interaction lowers the overall fuel

[12] "Ideal Otto Cycle p-v Diagram." Ideal Otto Cycle. NASA. 16 Dec 2008 <http://www.grc.nasa.gov/WWW/K-12/airplane/otto.html>.
[13] Bosch, Robert. "Empirical values of data for calculation."Bosch Automotive Handbook. 7th Ed. 2007 p.509
[14] Bosch, Robert p.509

efficiency of the vehicle. When idling, a diesel will only use what is required to keeping the engine stable (idle) whereas a gasoline engine has to act as an air pump (pumping from lower pressure [after throttle plate] to higher back to ambient assuming no backpressure). This theory can easily be seen when looking at the estimated mpgs of the diesels in the city vs. the gasoline model.

Despite the benefits of a diesel engine, many people in the United States are still doubtful of their performance. In the author's opinion, as with the general consensus of the automotive magazines, is that the majority of the public feels that diesels are loud, smelly, slow, and inefficient. These myths are due to false stereotypes and perhaps poor personal experiences with diesels in the past. Diesels of yesteryear could fill a good amount of these perceptions but most definitely not the new models.

Emissions-wise, the new models have catalytic converters as well as some having urea injection. The emissions system is typically complex and reduces emissions immensely over previous generations. Also, the advent of Ultra Low Sulfur Diesel (15ppm) makes for cleaner emissions as well. This provides for a much cleaner smelling exhaust. "Today's passenger-car diesel engines use advanced (but expensive) induction, injection, combustion, and after treatment technology to produce an impressive combination of power, torque, and efficiency."[15] The exhaust does not come out black like it used to either. The black smoke was typically from the poorer emissions control. Unless a modern diesel is poorly tuned or the improper fuel used, it should not pump out black smoke. The myth of diesels being loud and obnoxious could easily be quelled if one was to actually hear one of the new models.

As far as pricing, diesels typically have more features than the base model. This inherently makes the price of the diesel model rise over the standard gasoline model. In a comparably equipped gasoline model, the price of the diesel engine isn't nearly as much as the difference between the diesel model and base gasoline. Due to high demand by the limited diesel enthusiasts and those who know of the benefits of diesels, the first groups of diesels to be sold typically come with a dealer markup. This markup has been verified (for the Jetta

[15] Jost, Kevin. "Diesel interest renewed." Automotive Engineering International April 2008: 6.

TDI) at $1,000 as stated by 3 different dealers in Massachusetts. This is typically offset by a $1300 tax incentive from the government. Most diesel models come with all of the luxury features such as power windows, locks, mirrors, etc. They should be compared with a higher end gasoline model.

Performance diesels are typically the last engine types looked at as an option. A sure example to crush this myth is to observe the success of the Audi R10 TDI. It won its maiden race as well as the 24 hours of LeMans[16]. It also competes in the American LeMans Series (ALMS). They are remarkably quiet, the only significant sound being the twin turbochargers feeding the 5.5L V12 diesel engine. There is barely ever any black smoke due to the large diesel particulate filters. Volkswagen also launched a TDI racing cup series[17] which allowed amateur racers to test the limits of a lightly modified Jetta TDI. Ad campaigns such as these help clear up the myth of diesels being slow. BMW has several high performance diesel models. One particular model, the 330d "sprints from a standstill to 60mph in just 6.1s, has an electronically limited top speed of 155mph and achieves the equivalent of 40mpg on the European driving cycle."[18] Another example is by Fiat Powertrain Technologies which has a 1.9L diesel producing 188hp and 295lb-ft of torque[19]. It uses two-stage turbocharging to provide a more constant acceleration and wider powerband.

[16] Audi. "Writing Motorsport History." Audi R10 TDI. Audi USA. 16 Dec 2008 <http://www.audiusa.com/audi/us/en2/experience/motorsport/r10.html>.
[17] "Meet the next generation of motorsport." VW Motorsport. VW Motorsport. 16 Dec 2008 <http://www.vw.com/vwhype/motorsport/en/us/#/jetta_tdi_cup/welcome>
[18] Carney, Dan. "Responsible road-burners." Automotive Engineering International Nov 2007: 68.
[19] Carney, Dan

Figure 10: Volkswagen Jetta TDI

Figure 11 – Audi R10 TDI

Aside from Motorsports, modern diesels have come a long way in terms of performance. The fifth generation of the Volkswagen Jetta comes with a 2.0 liter turbocharged 4 cylinder. It has 140hp and 236ft-lbs of torque. It holds the Guinness Book of World Records record for lowest fuel consumption across the 48 states at 58.82 miles per gallon. "In 20 days, driving across 48 states the Taylors drove 9,419 miles, exceeding 60 mpg on several legs of the record-setting run, spending only 6.9 cents per mile."[20] With proper gearing (such as with the 6 speed direct shift gearbox it comes with) , the prodigious torque easily makes up for the comparatively low 140hp. It is the area under the curve (power) and proper gearing that gets a car moving. Most diesels satisfy this by having a large amount of torque at lower engine speeds. Since diesels are slower speed engines than gasoline, they cannot obtain high power through high engine speeds. In any case, the other diesels offered by Mercedes (shown below as the E320 BlueTEC Sedan)[21] show about the same 0-60mph as the gasoline counterparts. BMW also offers several diesel models (mostly in Europe as of this date), all of which are comparable to gasoline models. In the end, diesels can surely hold their own.

[20] Vortex, VW. "2009 Jetta TDI Clean Diesel Breaks Guinness World Record for Lowest Fuel Consumption Across 48 States." VW Vortex 29 09 2008 16 Dec 2008 <http://www.vwvortex.com/artman/publish/volkswagen_news/article_2508.shtml>.

[21] "BlueTec Clean Diesel." BlueTEC: The Greenest Blue There Is. Mercedes Benz. 16 Dec 2008 <http://microsites.mbusa.com/microsite/bluetec/index.jsp>.

E350 Sedan	E320 BlueTEC Sedan
Sedan	Sedan
E-Class	E-Class
$54,075	$55,075
3.5L 24-valve V-6 engine	3.0L 24-valve V-6 diesel engine
268 hp @ 6,000 rpm	210 hp @ 3,800 rpm
0-60mph in 6.5 seconds	0-60mph in 6.6 seconds
5	5
24 mpg (Highway)	32 mpg (Highway)
17 mpg (City)	23 mpg (City)
15.9 cu ft	15.9 cu ft
2WD (rear-wheel drive)	2WD (rear-wheel drive)

Figure 12: Mercedes-Benz E-Class Comparison

Hybrid Background and History

Many believe that hybrid technology is a brand new development. The truth is that hybridized vehicles have been developed for over a century. The earliest hybrid vehicle design patent was filed on November 23, 1905 by H Piper[22]. The basic design is similar to today's modern hybrids. An electric motor was used in conjunction with a gasoline engine "to let the vehicle accelerate to a rip-roaring 40 kilometers (25 miles) per hour in a mere 10 seconds, instead of the usual 30[23]." Hybrid technology was also used in diesel electric locomotives starting in the 1920's[24]. Hybrid electric vehicle technology has been around since the 19th century, so it may come as somewhat of a surprise to see that the first volume production hybrid car was the first generation Toyota Prius. It went on sale in Japan in 1997 and has become the epitome of hybrid vehicles world-wide.

[22] Brasington, Leigh . "Hybrid Electric Vehicles (HEV)." Toyota Prius. 15 May 2008. 16 Dec 2008 <http://www.leighb.com/hybrid.htm>.
[23] Brasington, Leigh . "Hybrid Electric Vehicles (HEV)." Toyota Prius. 15 May 2008. 16 Dec 2008 <http://www.leighb.com/hybrid.htm>.
[24] Daniels, Rudolph. Trains across the Continent. second. Bloomington, In: Indiana University Press, 2000.

The definition of a hybrid vehicle is one that uses two or more separate power sources in its propulsion system. The most common type of hybrid is a hybrid electric vehicle or HEV which includes an internal combustion engine as well as electrical motors[25]. Modern hybrids can come with one of three different types of drivetrains. They include parallel, series, and a combination of both the parallel and series drivetrains. To make matters increasingly more complicated, there are 4 different “levels” a hybrid vehicle can be in: full hybrid, power assist hybrid, mild hybrid, and plug in hybrid.

The most commonly created hybrids today use parallel drivetrains[26]. They utilize a conventional internal combustion engine (ICE) as well as an electrical motor. The motor is usually placed between the engine and transmission of the vehicle so that the torque and speeds of the motor and engine combine. In most cases, the electric motor also seconds as an electric generator. This alleviates the need for separate alternator and conventional engine starter since the electric motor/generator can take the place of both of them. The energy created by the electric generator is stored in large battery packs that are higher voltage than the average 12 volts found in conventional vehicles. Both the engine and electric motor can drive the wheels in the parallel drivetrain configuration. Since the engine is directly connected to the wheels, “it eliminates the inefficiency of converting mechanical power to electricity and back, which makes these hybrids quite efficient on the highway.[27]”On the other hand, this setup reduces the benefits of hybrid technology in the city. This is because the engine cannot run efficiently in stop and go traffic. The battery packs in parallel hybrids are smaller than series because most of the work comes from the conventional engine. Some examples of hybrid vehicles with parallel drive trains are the Honda Insight, Civic, and Accord.

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[25] " Hybrid Vehicle Drivetrains." Nation Master. 2005. 09 015 2008 <http://www.nationmaster.com/encyclopedia/Hybrid-Vehicle-Drivetrains>.
[26] " Hybrid Vehicle Drivetrains." Nation Master.
[27] "Hybrids Under the Hood." Hybrid Center. 2007. 14 May 2008 <http://www.hybridcenter.org/hybrid-center-how-hybrid-cars-work-under-the-hood-2.html>.

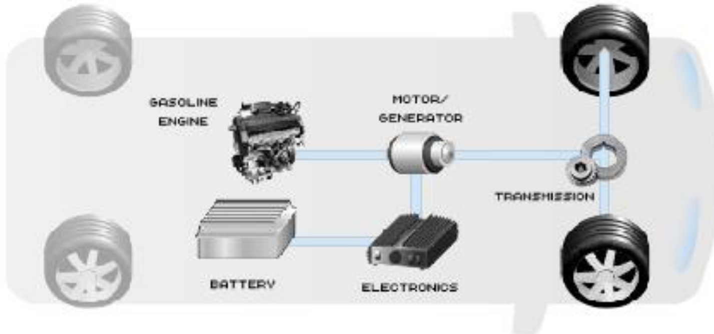

Figure 13 - Parallel Drivetrain[28]

Series drivetrains are the simplest hybrid configuration and are generally the most efficient types of hybrids during city driving. The reason is because there is no mechanical connection between the engine and the driving wheels. The engine is only used to power the electric generator and create electricity. The engine is very cost-effective because it is small and can constantly run at peak efficiency. The electric generator sends power to both the motor and to the batteries. The battery packs in series drive trains are much larger than that of parallel hybrids. The reasoning is because it needs to provide peak driving power. “This larger battery and motor, along with the generator, add to the cost, making series hybrids more expensive than parallel hybrids.[29]” There are applications where individual motors are integrated into the wheels allowing for a simplified traction control and all wheel drive applications. The concept Volvo Recharge is experimenting with this type of technology[30].

[28] "Hybrids Under the Hood."
[29] "Hybrids Under the Hood "
[30] Thomas, David. "Volvo ReCharge." Cars.com. 09 11 2007. 18 08 2008 <http://www.cars.com/go/features/autoshows/vehicle.jsp?vehicletype=concept&autoshowyear=2008&vehicle=concept_Volvo_ReCharge&make=Volvo&model=ReCharge>.

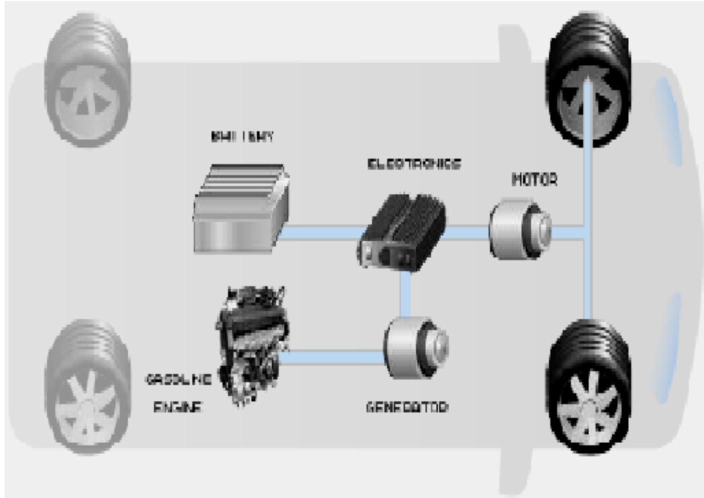

Figure 14- Series Drivetrain[31]

The most complicated drivetrain is one that is a combination of both series and parallel hybrids. "The engine can both drive the wheels directly (as in the parallel drivetrain) and be effectively disconnected from the wheels so that only the electric motor powers the wheels (as in the series drivetrain).[32]" At low speeds, the vehicle acts like a series hybrid. To minimize losses at higher speeds, the vehicle acts like a parallel hybrid, allowing the engine to do most of the work. This system is very costly because it needs a generator, a large battery pack, as well as more computing power to deal with the complexity of the dual power system. This type of technology can be seen in the Toyota Prius as well as the Ford Escape Hybrid.

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[31] "Hybrids Under the Hood "
[32] "Hybrids Under the Hood "

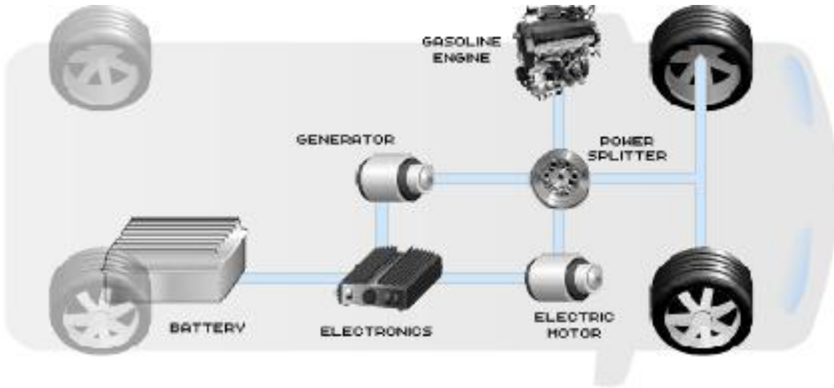

Figure 15 - Combination Drivetrain[33]

Hybrid vehicles can not only vary depending on their drivetrain styles, but also by their degree of hybridization. Full hybrids such as the Toyota Prius and the Ford Escape, can run using an engine, batteries and motor, or a combination of both. This is also seen in hybrids with parallel drivetrains. Full hybrids need a large battery pack as well as high computing power. The computer is necessary to oversee and control both driving systems. It analyses the amount of power requested by the driver and chooses the suitable combination based off engine loads and battery capacity. For instance, the Toyota Prius has five diverse driving modes. At idling the vehicle acts as an electric vehicle running completely off of battery power with the engine in the off position. The cruise regime on the other hand, uses both the engine and motor in unison. The computer splits the mechanical and electrical energy according to the power needs. For example, if the battery is in need of power, some of the electrical energy will be routed to the battery. The battery may also be charged if the engine or motor are working independently and has enough power to both sustain proper driving capability while directing power towards the battery. This is known as battery charge mode. The next regime is the power boost mode. When the driver is requesting a lot of power, whether for heavy acceleration or other large loads that neither a single power source can handle alone, it joins both boosting the overall power output. The final mode is the negative split mode where the vehicle is in cruise mode but the battery is fully

[33] "Hybrids Under the Hood "

charged. The battery applies power to both the motor and the engine. The reason for this is to use as much of the energy the system produces in order to be fully fuel efficient.

Power assist hybrids use the engine for its main means of power but will utilize the electrical motor for a torque booster. The motor is basically a very large starter motor that is located between the engine and the transmission. The electrical motor only operates when additional power is needed. The motor can also be used for quick start/stop engine management. When the vehicle is at rest, it can stop the engine and save on fuel. The power assist hybrid is also known as the integrated motor assist (IMA) and can be found in the 2006 Honda Civic Hybrid. Generally power assist hybrids can only propel a car on its own at low speeds this particular year of Civic was able to use the electric motor to propel the vehicle at medium speeds.

Some think of mild hybrids as not being true hybrids. The reason is because for the most part, they are conventional vehicles with start/ stop technology. An oversized starter motor is used to allow the engine to be stopped and started when the vehicle is breaking, coasting, or stopped. The motor brings the engine to an appropriate operating rpm before injecting any fuel. It is also capable of regenerative breaking using the motor to recapture otherwise lost energy.

The final type of hybrid is the plug in hybrid (PHEV). They can charge either through a 120 volt electrical outlet or by the onboard gasoline engine. When fully charged, PHEV have a range of about 40 miles before needing to be recharged. Most people commute less than that in a day and therefore these types of hybrids require no onboard charging (under 40 miles). Within this 40 mile range, the hybrid acts like an all electric vehicle running solemnly on battery power. After this initial 40 miles, the vehicle will act more like a hybrid, using its gas engine in either a parallel or series configuration. With the average electricity rate at about 9 cents per kWh, it would cost about a dollar to charge the battery reserve. It could be even cheaper if the battery is charged at night when electric rates are lower. In 2004, "CalCars produced the world's first plug-in Prius," the Prius+[34]. The smart two as well as a mini are both examples of PHEV.

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[34] "All About Plug-In Hybrids (PHEVs)." CalCars. 11 03 2008 <http://www.calcars.org/vehicles.html>.

There is no doubt that hybrids are a complex piece of machinery. The technologies they use to obtain greater gas mileage and are state of the art. Regenerative breaking is one of the main ways that hybrids recapture otherwise wasted energy. While braking, the motor applies resistance to the drivetrain which in turn causes the vehicle to slow down. The motor acts as a generator in this state and produces electricity from the captured kinetic energy which is used to charge the batteries for later usage. Another technology is the electric motor assist. The motor is used to aid the engine when higher power is needed. Hill climbing and acceleration are the two main utilizations for this. This technology allows for the usage of a smaller engine that is still able to offer similar driving dynamics as a larger engine sized model. The last technological feature used in hybrids is the automatic startup/shutdown of the engine. The engine is allowed to shut down upon idling where unnecessary fuel consumption occurs. The startup is smooth and virtually unnoticeable.

Not only can hybrids lower your fuel costs, but it can also lower your federal taxes. The IRS offers tax rebates on all cars purchased in the year 2006 onwards to the original owner of the vehicle[35]. There are strict rules that need to be applied in order for the rebate to be valid. The amount of the rebate is dependent on the type of vehicle purchased. The rebates can range from $500 to over $3000[36].

All Electric Background and History

All electric vehicles were amongst the earliest of automobiles. They use electric motors, batteries, and motor controllers instead of an internal combustion engine. True electric vehicles differ from hybrid electric vehicles in the fact that they do not have a charge sustaining internal combustion engine. **"**Unlike a hybrid car—which is fueled by gasoline and uses a battery and motor to improve efficiency—an electric car is

[35] "Alternative Motor Vehicle Credit." Internal Revenue Service. 10 3 2006. 9 10 2008 <http://www.irs.ustreas.gov/newsroom/article/0,,id=157632,00.html>.
[36] "Alternative Motor Vehicle Credit."

powered exclusively by electricity.[37]" Plug-in electric hybrids also do not fit into this category even though they are able to act like pure battery electric vehicles (BEV) while the battery is charged.

The first crude electric carriage was created between the years of 1832 and 1839 by a Scottish business man named Robert Anderson[38]. A Frenchman, Gaston Plante, and an American, Thomas Davidson, separately created more successful electric vehicles around 1842[39]. The vehicles were the first to use non-rechargeable electric cells. As time progressed, battery technology improved. This improved battery led the electric vehicle to hold many speed and distance records before the 20th century.

Americans began to give attention to EV after 1895. The first commercial application of EVs took place in New York City when a fleet of taxis was established. Early 20th century EV were nothing more than electrified horseless carriages. Between the years of 1899 and 1900, EV outsold all other types of vehicles (steam and gasoline). There were many advantages to these early electric cars. They did not have the vibration, smell, or difficult transmissions of gasoline vehicles. Steam cars had startup times that could range close to an hour on cold days. These early vehicles were ornate and designed for the upper class. They were easy to use and maintain. No manual cranking was necessary to start it[40].

By the 1930's, EV were obsolete. It was not until the 60's and 70's that electric cars were even spoken of again. The reasoning was because of the concerns about air pollution and the OPEC oil embargo. In the 1990's there was new legislature that required automakers to produce zero emissions vehicles. The U.S. 1990 Clean Air Act Amendment, the U.S. 1992 Energy Policy Act, and California's Zero Emission Vehicle (ZEV) Mandate were just a few examples. California's ZEV mandate required 2% of vehicles to be ZEV by the year 1998. The electric vehicle were produced in small quantities and as the legislature weakened, the automakers began to stop producing them. Some examples of the EVs produced during this timeframe included the GM EV-1 and the Toyota Rav4 –EV.

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[37] " Electric Cars: A Definitive Guide ." Hybrid Cars. 08 009 2008 <http://www.hybridcars.com/electric-car>.
[38] "The Early Years - Electric Cars (1890 - 1930) ." The History of Electric Vehicles. 08 09 2008 <http://inventors.about.com/library/weekly/aacarselectrica.htm>.
[39] "The Early Years - Electric Cars (1890 - 1930) ."
[40] Brasington, Leigh . "Hybrid Electric Vehicles (HEV)." Toyota Prius. 15 May 2008. 16 Dec 2008 <http://www.leighb.com/hybrid.htm>.

The GM EV-1 was the first modern electric vehicle produced by a major car company. It was introduced in 1996 and was only available for a 3 year/30,000 mile lease. The car was a 2-passenger sports car powered by a liquid-cooled alternating current motor and at first lead-acid batteries. The second generation, which came out in 1999, used nickel metal hydride batteries. With a top speed of 80 mph and a 0 to 50 time of about 7 seconds, this vehicle was quick compared to prior EVs.

According to 1996 film "Who killed the Electric Car?", GM argued that there was no interest for the vehicle[41]. After the CARB ZEV mandate was taken away on April 24, 2003, GM began to taking back and destroying all but a few of the EV-1s. There has been a lot of controversy about the reasoning behind it.

Starting in the year 2010, new electric vehicles will begin being sold. Some of which will be the Chevrolet Volt and the Nissan EV[42]. The Volt will cost between $35,000 – $40,000. The Volt will be a 5 door 5 passenger vehicle similar in size to the Toyota Prius. (http://www.chevy-volt.net/chevrolet-volt-specs.htm) It will be able to travel up to 40 miles before any charging needs to take place. Studies have shown that the average American commutes less than 40 miles a day, therefore no gasoline fuel has to be used. After the first 40 miles, a turbocharged three-cylinder engine runs between 1,500 and 1,800 revolutions per minute in order to recharge the batteries[43].

Figure 16: GM Chevy Volt

[41] *Who Killed the Electric Car?.* Dir. Chris Paine, Sony Pictures Classics. Sony Pictures Classics, 2006, video recording**.**
[42] Robinson, Aaron. "2010 Nissan EV." Car and Driver 12 2008: 96.
[43] Chevy Volt Concept Car. 08 05 2008<http://www.chevy-volt.net/>.

"Electric cars produce no tailpipe emissions, reduce our dependency on oil, and are cheaper to operate.[44]" Although there are no tailpipe emissions, the power plants still are producing greenhouse gases. All electric cars can be much more environmentally friendly if the electricity that they use comes from a power source such as solar or wind power.

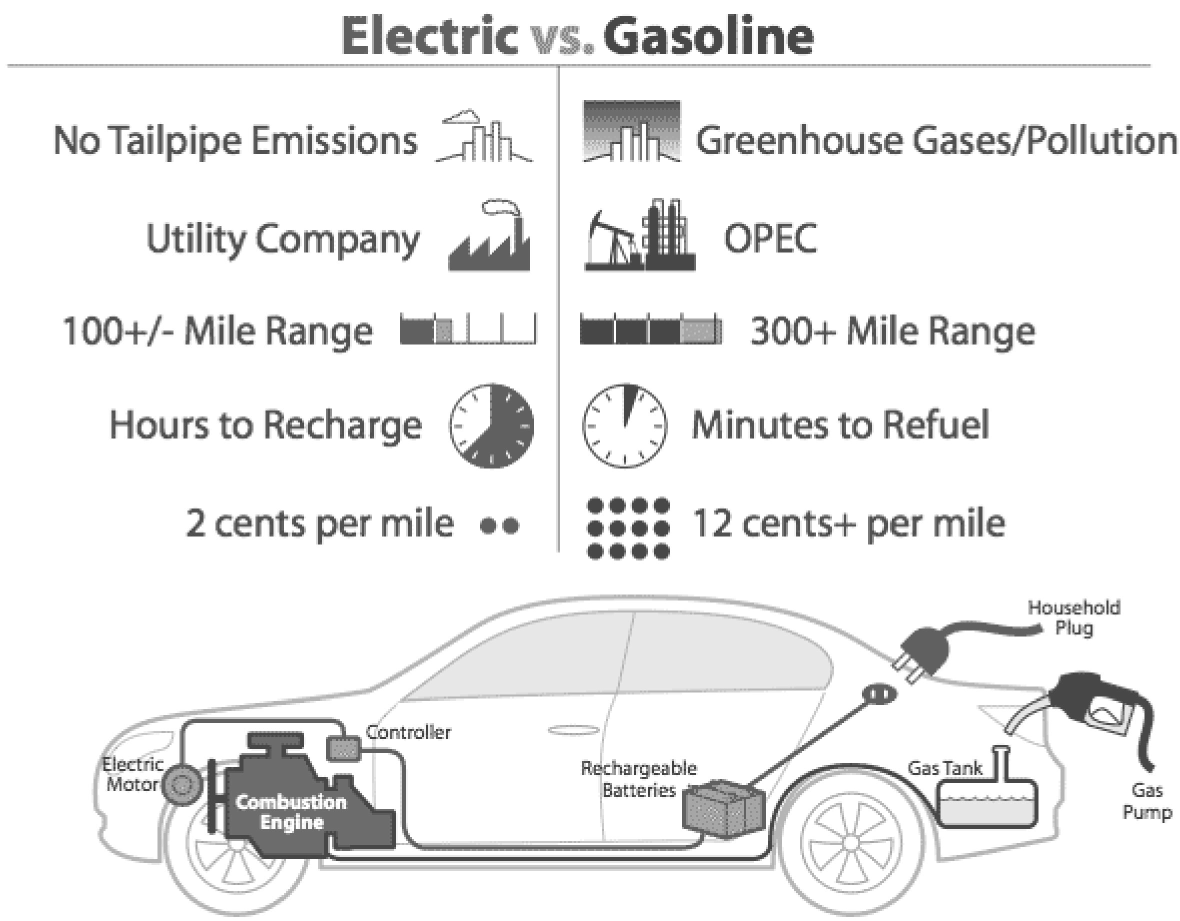

Figure 17: Electric vs. Gasoline[45]

Ethanol

Ethanol is a domestically available renewable energy source that is produced from common crops such as corn and sugar cane. It is the same type of alcohol found in alcoholic beverages (ethyl alcohol) and can be used as a biofuel for the transportation sector.

[44] "Electric Cars: A Definitive Guide." Hybrid Cars. 09 09 2008 <http://www.hybridcars.com/electric-car>.
[45] " Electric Cars: A Definitive Guide ."

Ethanol may be blended with unleaded gasoline in varying fractions. Most vehicle models can use E10, which consists of 10 % ethanol and 90% gasoline, without any alteration to the engine. Other similar blends consist of 20% and 30% known as E20 and E30 respectively. E85 which can only be used in flex fuel vehicles (FFVs), consist of 85% ethanol and 15% gasoline.

There are various methods for producing ethanol. All the methods break down the crop or biomass into starches and sugar and then ferment them to produce alcohol. The most commonly used method consists of a process known as dry milling. The starch is converted to sugar, which then is fermented into ethanol. The wet milling ethanol process separates all the fibers, proteins, and germs from crop and the starch is then fermented to produce ethanol. Another method that is currently under research produces cellulosic ethanol. Cellulosic ethanol is the same product as ethanol but uses biomass instead of feedstock. Since biomass is composed of complex sugars, acid hydrolysis or enzymatic hydrolysis is used to break down the complex sugar into simple sugars, and finally fermented into ethanol.

Ethanol Environmental Impact:

Ethanol is a 100% renewable source of energy, but it has being debated that it causes more environmental damage than it does good. The heavy machinery and the processes used to produce ethanol discharge carbon dioxide into the atmosphere. Ethanol can be environmental friendly if the machinery used in the cultivation emits little or no carbon particulates and uses renewable fuel. It is also a fact that the crops absorb carbon dioxide from the atmosphere and during the process of ethanol production the CO_2 is released back, having a net carbon dioxide emission of almost zero.

Studies done by the EPA and other environmental agencies have proven that ethanol-gasoline blends reduce carbon dioxide, ozone pollution, and improve gas mileage[46]. A major cause of ozone is carbon dioxide

[46] Note: If vehicle is not optimize to for ethanol blends, it may experience a 10-15% reduction in fuel economy.

emission and therefore the amount on ozone is measured in exceedance days per year[47]. In January of 2004, the state of New York starting using E10[48]. In 2006 it was reported that there was 5.5 ozone exceedance days per year. Compared to 2004, that averaged 21.5 exceedance days per year, which comes out to be a 68% reduction. Also California adopted E6 in 2004. In 2005, California Air Resource Board (CARB) data showed a 22% in reduction exceedance days in South Coast since 2003 using one-hour ozone standard.
Similar reduction were shown in the states of Connecticut, Denver, Michigan and many other that adopted ethanol blends.

A study done by the EPA shows that ethanol vehicle focus will have the fastest reduction impact on GHG emission compared to hybrid electric, advanced gasoline, diesel vehicles and hydrogen. If combined, a total of 5 wedges (As stated before, a wedge is an activity that creates 1GtC/y of carbon reduction) could be achieve as shown in Figure 13 a, b, c. “Three examples of system approaches that achieve 5 wedges. Example (a) assumes predominantly hybrid electric vehicles, including plug-in hybrids, by 2050. Example (b) assumes nearly half the vehicles run on E85, equivalent to 90 billion gallons of ethanol by 2050. Example (c) assumes technologies that require electricity (electric vehicles, plug-in hybrids) and hydrogen (fuel cell vehicles) as fuels.”[49]

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[47] Note: Exceedance days are days with an 8-hour average ozone concentration of more than .0075ppm

[48] Hulsey, Brett, and Brook Coleman. "Clearing the Air with Ethanol." A review of the real world impact from fuels blended with ethanol (2006): 4-8.

[49] Mui, Simon, and Jeff Alson. "A Wedge Analysis of the U.S. Transportation Sector." EPA420-R-07-007(2007): 20-21.

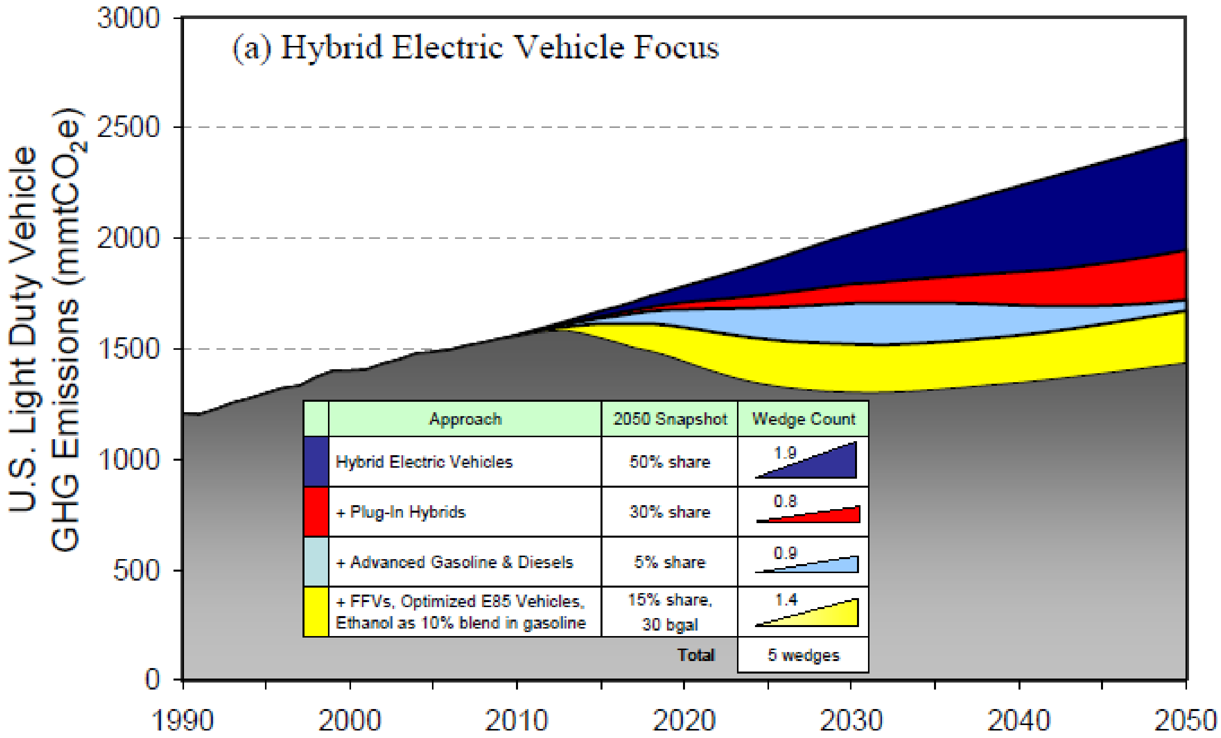

Figure 18a. Hybrid Electric Vehicle Focus

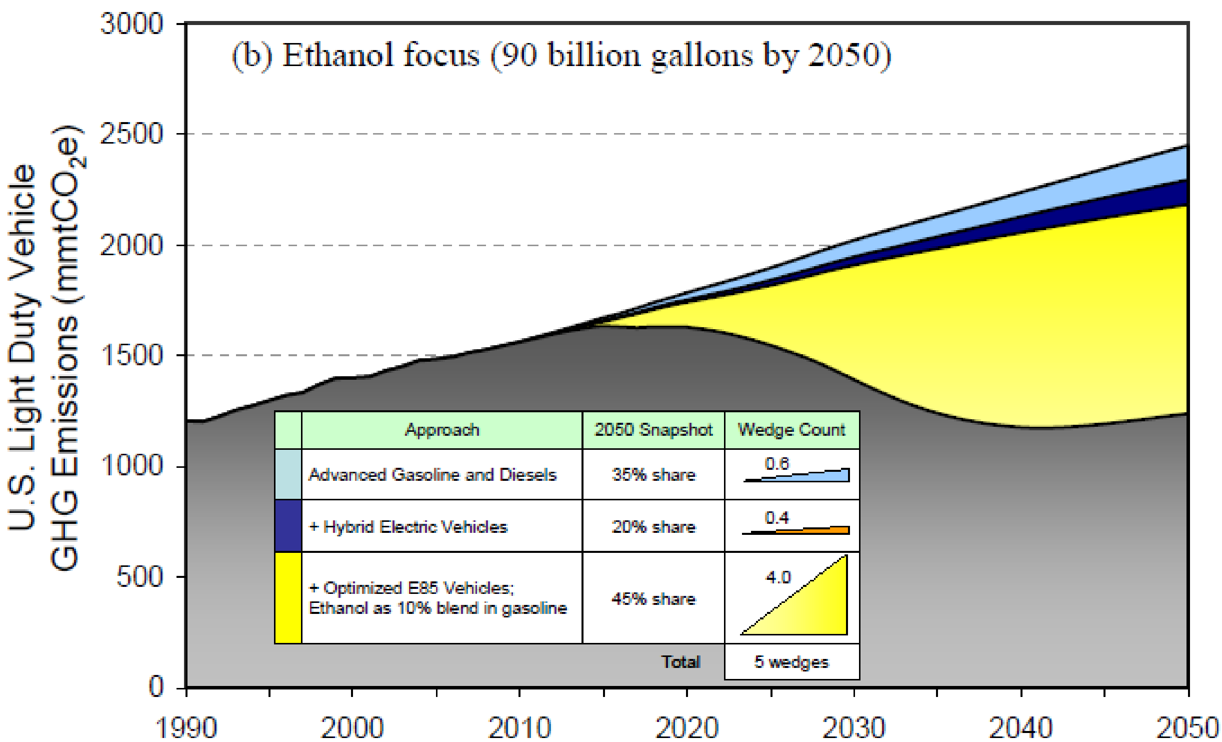

Figure 18b. Ethanol Focus

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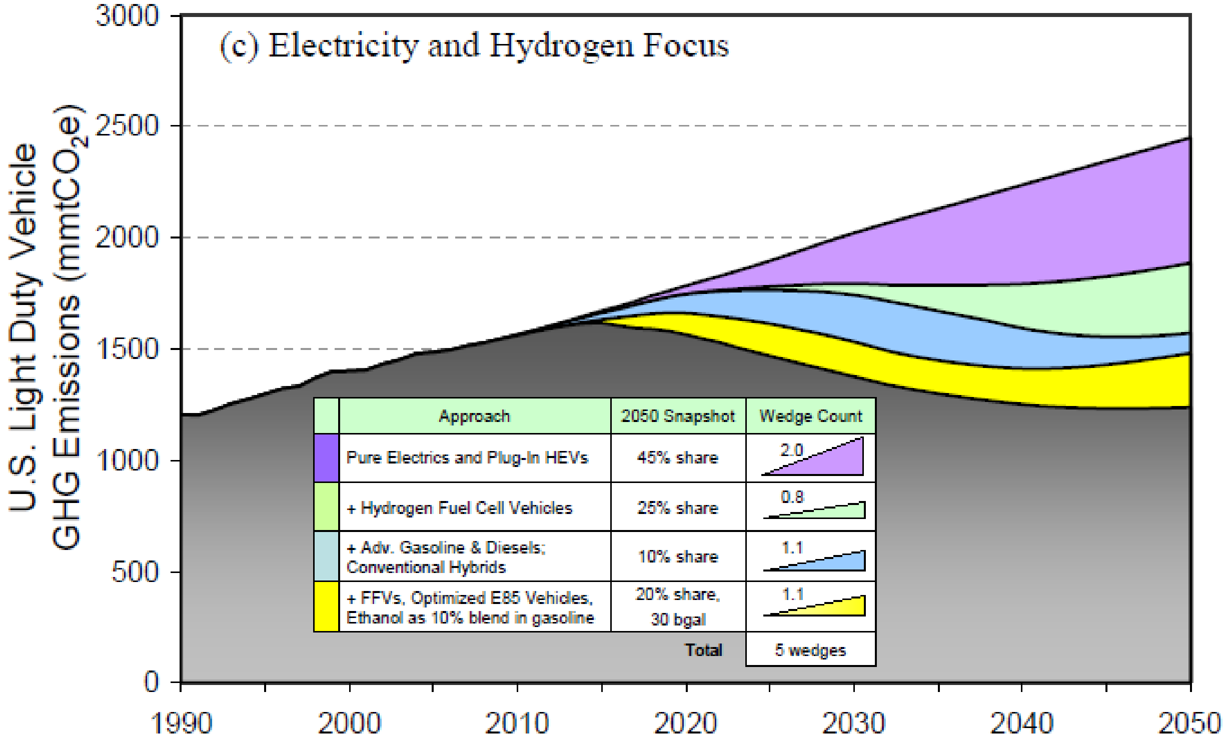

Figure 18c. Electricity and Hydrogen Focus

Vehicle Emissions are graded by both the EPA and CARB. The EPA uses a tier and bin scale, while CARB uses vehicle descriptions. A summary of both scales can be seen in Appendix C.

Ethanol vs. Gasoline

In April of 2000, E85 cost $1.80 per gallon and rose to $3.55 in January of 2008. As for gasoline In April of 2008 the price was $1.52 and rose to $2.98 in January 2008. Also, the price of ethanol depends on the distance[50] from the production facility to the distributer. Hence the farther away from a production facility the ethanol is, the higher the prices tend to be. E85 is less efficient due to the lower energy content than gasoline.

[50] "Pros and Cons of Ethanol." The Upside of Ethanol. 27 Sep 2006. HybridCars. 16 Dec 2008 <http://www.hybridcars.com/ethanol/benefits-drawbacks.html>.

Thus a gallon of E85 cannot take vehicles as far as conventional gasoline would.[51] A 1998 FFV Ford Taurus is compare to it gasoline counterpart. Figure 20 shows that the FFV consumes more fuel per miles than the gasoline vehicle.

The advantage of ethanol is that it reduces CO_2 emissions as shown in figure 21, a better acceleration as shown in figure 19.

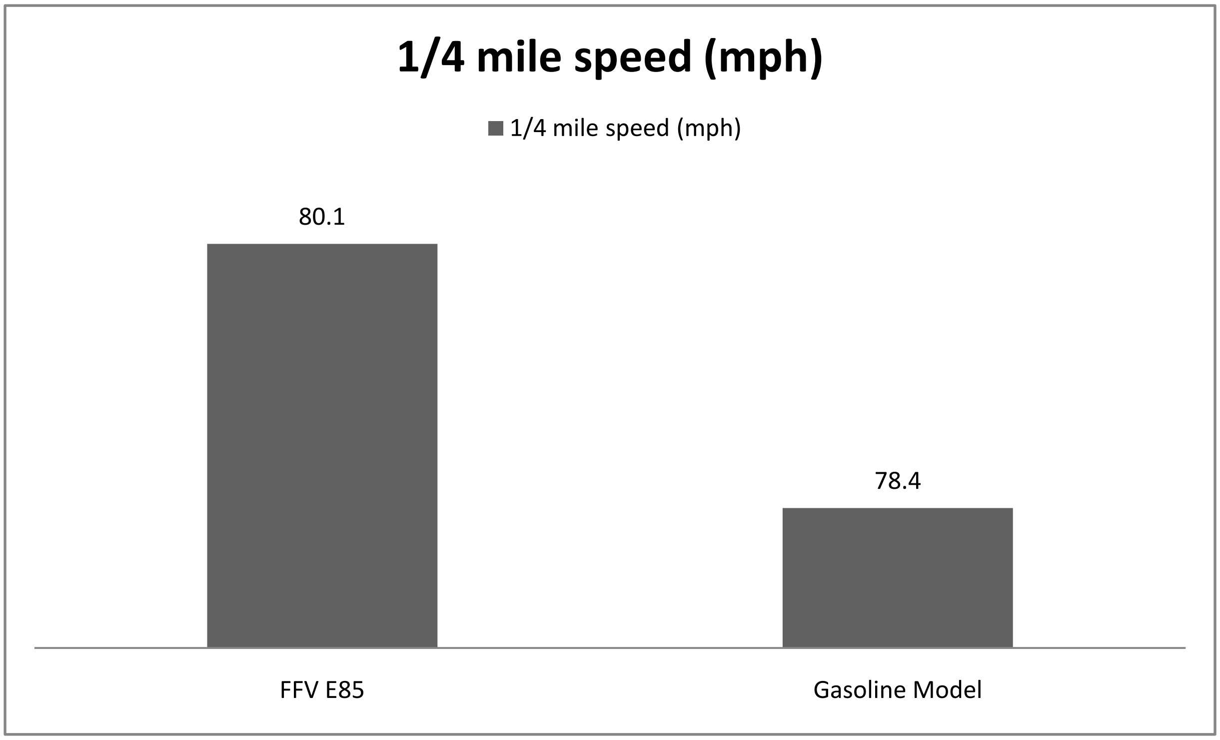

Figure 19: Quarter Mile Speed

[51] Combs, Susan. "The Energy Report 2008." Publication 96-1266 05/06/2008 16 Dec 2008 <http://www.window.state.tx.us/specialrpt/energy/>.

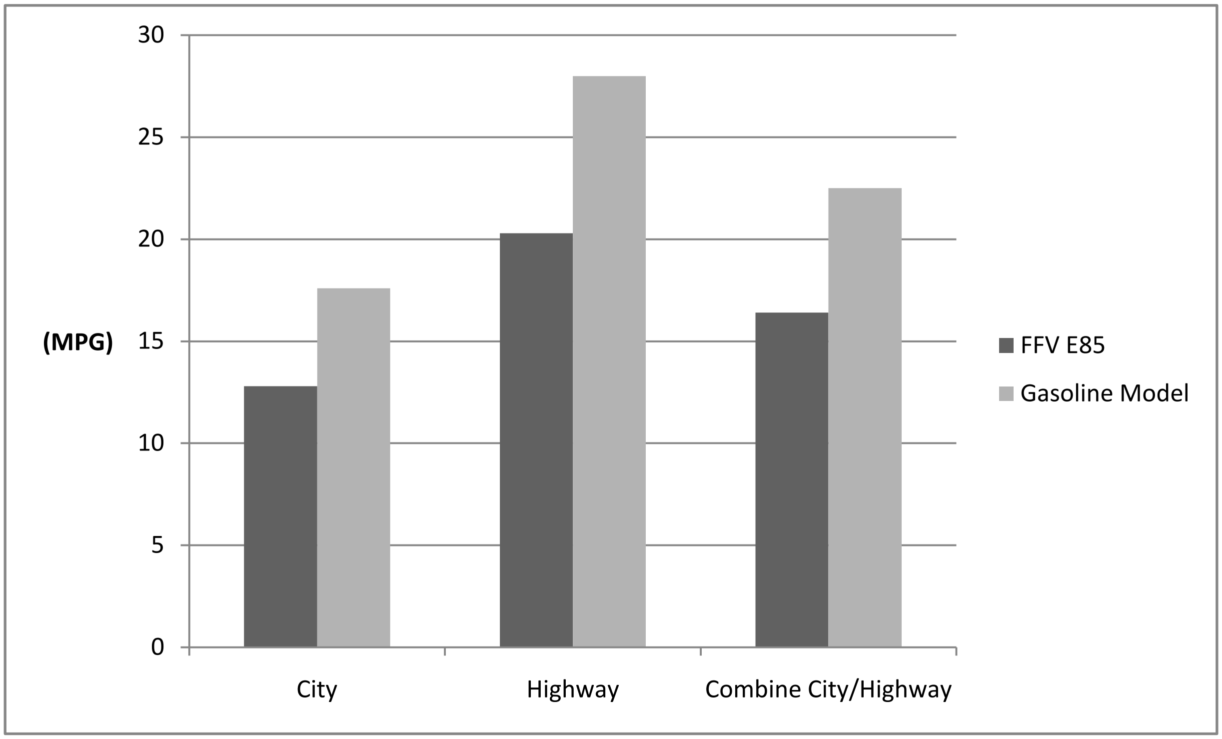

Figure 20: Miles per Gallon

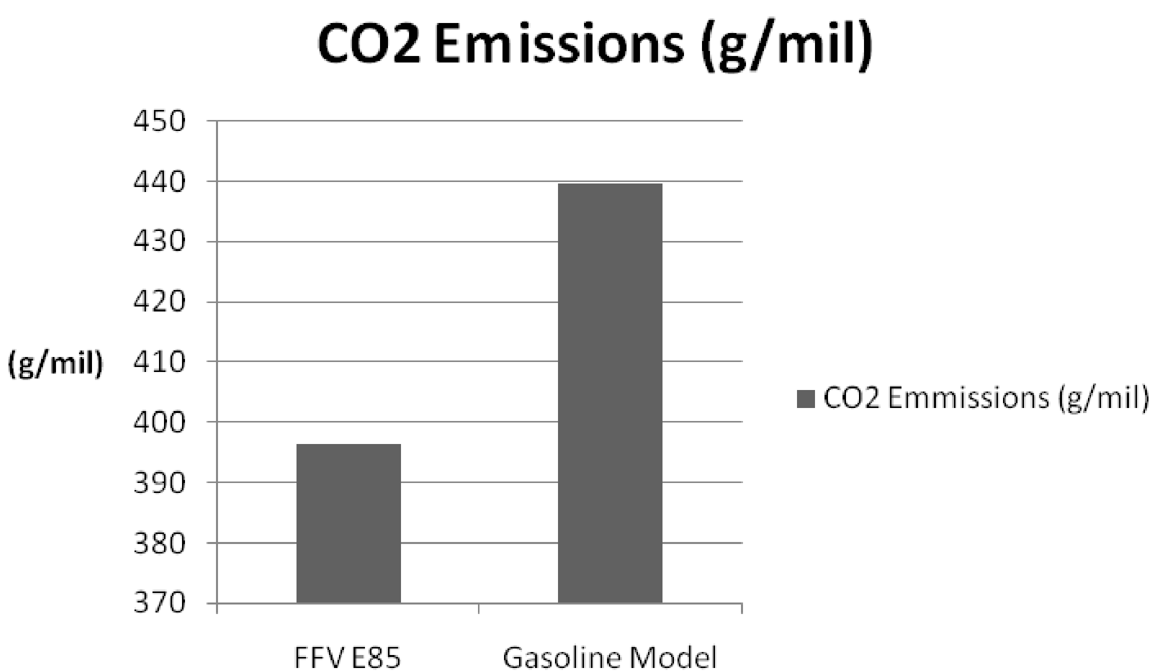

Figure 21: CO_2 Emissions

Emissions were measured using duplicate test performed in each vehicle using EPA's Federal Test Procedure

Hydrogen

Hydrogen is an abundant source of renewable energy that can be used to power the transportation industry. Hydrogen prototype cars have been around for years and recently highly known car manufacturers such as BMW and Honda are bringing hydrogen vehicles to the market.

There exist two types of hydrogen technologies. One technology uses an internal combustion engine (ICE) similar to the gasoline engine. The second type of technology is the hydrogen fuel cell (HFC). It produces electricity to power an electric motor by combining hydrogen and oxygen in a membrane. The advantage of the ICE is that it could work as a dual-fuel, consuming hydrogen and gasoline, such as the BMW 745h sedan. When a hydrogen fueling station is not available, the car is able to run on gasoline. A disadvantage for this type of technology is that it has a lower efficiency than FCV and Nitrous Oxide control is required.[52] A disadvantage of the HFC is that great amount energy is wasted as heat. Both technologies share some disadvantages due to the fact that hydrogen is currently very expensive, not because it is rare but because it is difficult to produce, handle and store, requiring massive tanks like those from compressed natural gas or complex insulated tanks if stored as a cryogenic (very cold) liquid like liquefied natural gas. Also, currently hydrogen is produced by natural gas; hence it still emits carbon particulates through the production process and most importantly is non-renewable. This means that the cheapest and most efficient process to produce hydrogen is from fossil fuel and not from other means like electrolysis, which uses electricity from a renewable source like solar or wind to split the water into its main components: hydrogen and oxygen, still having a great impact to the environment.

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[52] Gnorich, Bruno. "Hydrogen Internal Combustion Engine." Road2Hy. 19 Nov 2008. 16 Dec 2008 <http://www.ika.rwth-aachen.de/r2h/index.php/Hydrogen_Internal_Combustion_Engine#Activities_by_BMW>.

Hydrogen Environmental Impact:

As stated previously, hydrogen fuel can be produced by the electrolysis of water using electricity from a non polluting source. When used in a FCV no pollutants are produced except if used in ICE small amounts of nitrogen oxides is produced. Furthermore no CO_2 is emitted, only water vapor. Although hydrogen fuel has gained environmental and political momentum, concern has been rising due to the fact that most of the hydrogen is produced from fossil fuel. Currently only 4% is generated using electricity (electrolysis) that comes directly from fossil fuels or other source of energy. Some recent worldwide hydrogen production totals are shown below.[53]

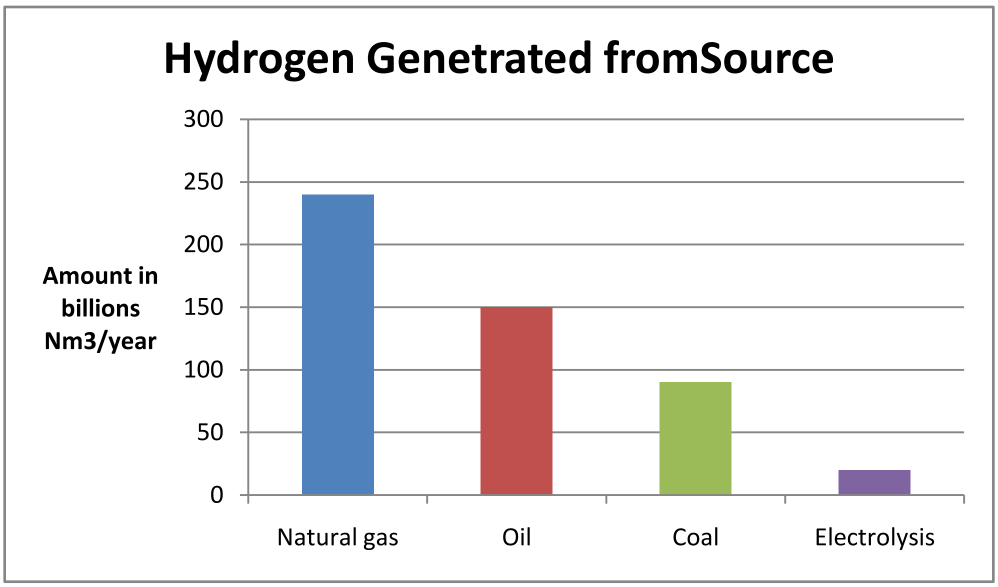

Figure 22a: Hydrogen Generated from Source

[53] "Frequently Asked Questions." Hydrogen, Clean Energy for the Future. National Hydrogen Association. 16 Dec 2008 <http://www.hydrogenassociation.org/general/faqs.asp#cost>.

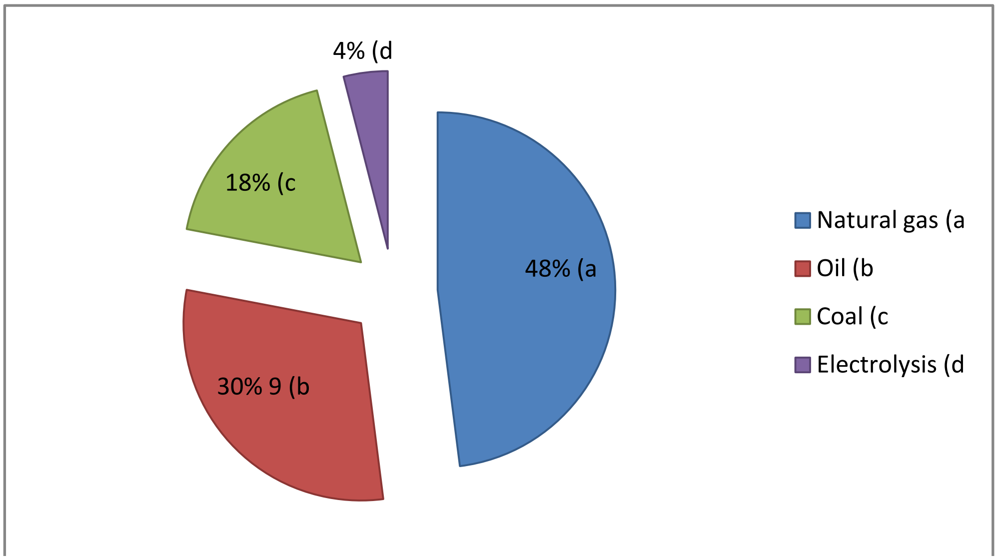

Figure 22b: Hydrogen Generated from Source

Hydrogen Economy and Political Implications:

Hydrogen, when utilized properly, has the potential to entirely replace fossil fuels altogether, transforming the United State largely oil based economy, to a new hydrogen economy. The *FY 2003 Progress Report* states:

"The President's FreedomCAR and Hydrogen Fuel Initiative are designed to reverse America's growing dependence on foreign oil by developing the technology to enable production of hydrogen-powered fuel cell vehicles and fueling infrastructure to support them. This initiative was chosen not only because of the energy security benefits associated with a domestic fuel that can be produced from a wide range of feedstocks, but also because of the potential environmental benefits in both transportation and stationary markets"[54].

[54] Chalk, Steven. "Progress Report for Hydrogen, Fuel Cells and Infrastructure Technologies Program." Energy Efficiency and Renewable Energy FY 2003(2003):

Also stated in the *FY 2003 Progress Report*, the hydrogen fuel technology "…will provide an economic development path for the integrated production of energy services such as electricity, transportation fuels, and heating and cooling" and will offer opportunities for

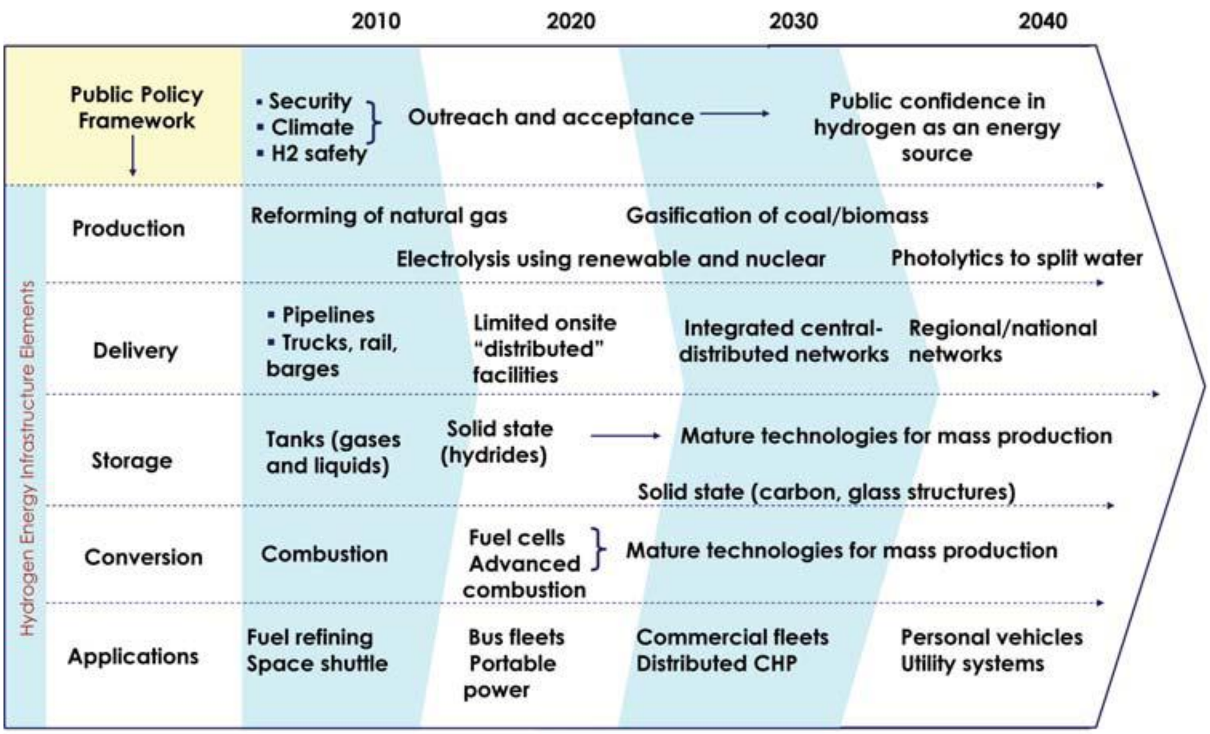

Figure 23: Transition to Hydrogen Economy:[55]

the development of new centers of economic growth. However, it will take at least 40 years for the United States of America to completely implement this type of technology (see the chart "Transition to Hydrogen Economy").

The government has incentives to promote the growth of the Hydrogen Industries as well as to secure the U.S. interests and be energy independent.

"Hydrogen fuel cells represent one of the most encouraging, innovative technologies of our era... One of the greatest results of using hydrogen power, of course, will be energy independence for this nation… thinks

[55] Combs, Susan. "The Energy Report 2008." Publication 96-1266 05/06/2008 16 Dec 2008 <http://www.window.state.tx.us/specialrpt/energy/>.

about a legacy here at home, about making investments today that will make future citizens of our country less dependent on foreign sources of energy. And so that's why I'm going to work with Congress to move this nation forward on hydrogen fuel cell technologies. It is in our national interest that we do so"[56]

- President George W. Bush

Currently the U.S. consumes 9 million tons of hydrogen a year most of which is consumed by the manufacture and the remaining, a very low percent, is sold for profit. In the near future hydrogen fuel will be sold in greater quantities to energies the transportation industry, forcing the automobile industry to evolve. This is of importance to the U.S. economy, because 12% of our non-agricultural exports are automobiles.

"The success of current U.S. industry is also of vital importance to the well-being of our people and of the Nation as a whole. For example, the U.S. auto industry is the largest automotive industry in the world, producing 30% more vehicles than the second largest producer, Japan. For every worker directly employed by an auto manufacturer, there are nearly seven spin-off jobs. America's automakers are among the largest purchasers of aluminum, copper, iron, lead, plastics, rubber, textiles, vinyl, steel and computer chips. The auto industry is also a major exporter, accounting for 12% of all non-agricultural exports. Remaining competitive in the international market is essential to the U.S. economy."[57]

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[56] President George W. Bush, The National Building Museum, February 6, 2003

[57] Chalk, Steven. "Progress Report for Hydrogen, Fuel Cells and Infrastructure Technologies Program." Energy Efficiency and Renewable Energy FY 2003(2003):

Hydrogen Fuel vs. Gasoline:

As the supply of oil decreases and the demand increase, gasoline prices are also increasing. The average price for a regular gas price was $3.13 at the first half of the year 2008 and it even reached at least $4 a gallon.

"What we are facing is increasing demand in a supply-constrained market," says Robert Bryce, author of *Gusher of Lies: The Dangerous Delusions of 'Energy Independence.'*

As for hydrogen, the Department of Energy (DOE) has announced that the cost goal of hydrogen fuel delivered and untaxed will be about $2.00-3.00/gge (gasoline gallon equivalent[58]) for 2010. This is based on hydrogen produced and distributed from natural gas reforming. Hydrogen is not sold by volume but by weight. The strategy that the DOE is implementing is that hydrogen should cost no more than gasoline on an equivalent energy basis. Since most if not all hydrogen sold as fuel for cars is generated from fossil fuel the price of Hydrogen depends on the price of the fossil fuel.

Here it is demonstrated the increase of gas price per gallon (taxed) from 1999 to 2008.[59]

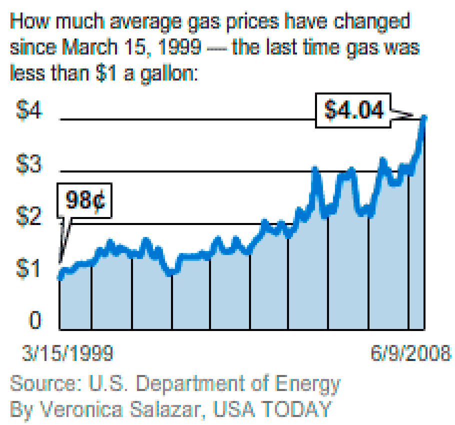


Figure 24: Price of Gas

[58] Note: One kilogram of hydrogen contains approximately the same energy as one gallon of gasoline.

[59] Wolf, Richard and Paul Davidson. "Which way out of rising gasoline costs?." 28 Feb 2008 16 Dec 2008 .

Internal Combustion Engine vs. Fuel Cell:

BMW Hydrogen 7[60]

- 191kW / 260hp
- 290 lb-ft at 4300rpm
- Top speed 143mph
- Total rage 435miles (125 in hydrogen mode and 300 miles in gasoline mode)
- Hydrogen ICE

Honda FCX[61]

- 100kW / 134 hp
- 189 at lb-ft from 0-3056rpm
- Top speed 100mph
- Total range 280 miles
- Hydrogen Fuel Cell

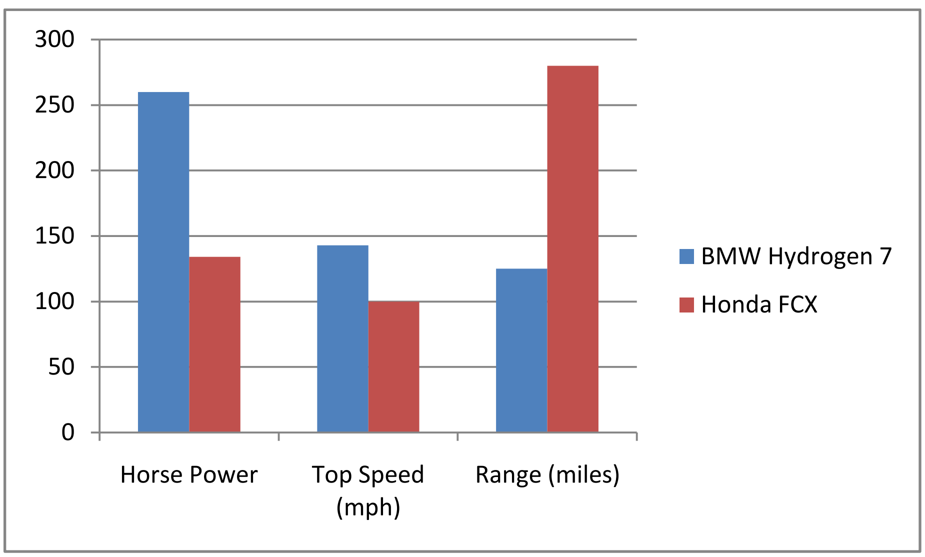


Figure 25: BMW Hydrogen 7 Vs. Honda FXC

Note that this chart only projects the vehicle characteristics using Hydrogen Fuel.

[60] BMW, "BMW CleanEnregy." 16 Dec 2008 <http://www.bmw.com/com/en/insights/technology/cleanenergy/phase_2/cleanenergy.html>.
[61] Honda, "Frequently Ask Questions." 2008 16 Dec 2008 <http://automobiles.honda.com/fcx-clarity/faq.aspx>.

Methodology

Oil Industry

The information that is represented in this research is a summary of the International Energy Outlook 2008 and the Energy Efficiency and Renewable Energy, both divisions of the U.S Department of Energy. The International Energy Outlook 2008 was prepared by the Energy Information Administration END NOTE (www.eia.doe.gov/oiaf/ieo/index.html), which is an independent statistical and analytical agency within the U.S. Department of Energy.

To explain the rise of oil cost and environmental concerns, which lead to the search for alternative fuel, graphs and data where taken directly from the report and summarized. The summary mostly includes the analysis that concerns the United States and its transportation sector. To represent the high oil price and political concern, Chapter 1 "World Energy Demand and Economic Outlook" of the International Energy Outlook 2008 is summarized. Graphs projecting world energy consumption from 1980 to 2030 and world energy consumption by fuel type are used to explain the causes of high oil prices, the need for oil independence and the percentage increase of consumed fuel by type (Liquids and Renewable are emphasizes).

To characterize the reason for the search for alternative fuels for the transportation sector Chapter 2 "Liquid Fuels" and Chapter 6 "Transportation Sector Energy Consumption", from International Energy Outlook 2008, are summarized. Graphs and data of energy consumption by sector (Residential, Electricity, Transportation, Industrial and Commercial) from 2005 to 2030 are used to represent the projected increase of energy consumed by the transportation sector in comparison with the sectors stated before. Graphs and data of world liquids consumption, supply, and production is used to compare the United Sates consumption, import and production of liquid fuels to the rest of the world.

Diesels Methodology

The methodologies in the graphs of the cost of ownership (minus routine maintenance) were researched to provide the most accurate unbiased results. Data was taken from the vehicle manufacturer's websites as far as engine specifications and performance. For the vehicle's fuel efficiency, the Environmental Protection Agency's ratings were used. In the case of the Volkswagen Jetta TDI, an additional set of graphs were used that had data that was both tested with a third party company (AMCI, Automotive Marketing Consultants Incorporated) as well as being generally accepted by most magazines (Car & Driver, Motor Trend, Edmunds, etc.)

The vehicles chosen to be compared are popular models and viable options to most consumers. These vehicles have a standard gasoline powered model but also either a diesel or gasoline-hybrid model. The automobiles chosen to be critiqued were the 2009 Volkswagen Jetta, 2008 Honda Civic, 2008 Toyota Camry, 2008 Mercedes E-Class, and 2008 Jeep Grand Cherokee. Each of these vehicles chosen is unique in their own class of vehicles. Vehicles had to be to carry at least 4 passengers, and be available in all 50 states for purchase. Vehicle should also be in mass production and readily available to customers. The comparisons were also limited to mainstream sedans as well as the smaller SUV. Although there are several options in the market for larger SUV's as hybrids, it is rarely the case that they perform in a positive manner. As far as diesels in the pickup truck industry, they are already tried and proven to be desirable and therefore no technical analysis is required to disprove any myths.

The important parameters required for the testing were mainly the initial cost, the price of the fuel, and the estimated miles per gallon. The initial costs were typically the base Manufactured Suggested Retail Price (MSRP) for the model. In most cases, the diesel or hybrid model had more standard and luxury features than compared to the base gasoline model so a comparable gasoline model was chosen (typically a mid-range model). After finding the suggested MSRP, additional fees were included such as dealer markups (typical of the VW diesels) as well as hybrid and/or diesel tax rebates. Although manufacturers may offer additional deals, to limit complexity, these were neglected.

The price of fuel was an important and ever varying parameter. In 2006, the price of diesel was less than the price of gasoline. Within the past year diesel has been averaging at about 20% more than the price of gasoline. The source for the price of fuel is the "Daily Fuel Gauge Report" (http://www.fuelgaugereport.com/) from the American Automobile Association (AAA). The website reports the average national price of several types of fuels including regular, mid-grade, premium, diesel, and E85. According to the website: **"**AAA's Daily Fuel Gauge Report is updated each day and is the most comprehensive retail gasoline survey available. Everyday up to 100,000 self-serve stations are surveyed." The fuel prices used on the analysis were that of the highest fuel prices in the summer of 2008. On July 17th, 2008 the price of regular unleaded was $4.114 per gallon and the price of diesel was $4.845 per gallon. The price differential between Diesel and Gasoline is currently 17.7% which is close to the average difference between the two. The gap in the prices in the United States between diesel and gasoline is growing however. As an approximation, when the price of diesel grows to over 25% of the price of gasoline. (I.E gasoline at $4/gal and diesel at $5/gal), then the cost/mile benefit is reduced significantly. At about 30-35%, the cost per mile of the diesel will equal the cost per mile with gasoline. However, with the higher initial cost of diesels, this leads to an unfavorable economic return. Reformulations to Ultra Low Sulfur Diesel (ULSD) as well as several other reasons have caused the price of diesel to continue to rise.

In order to produce the end results, several calculations had to be performed. The first step was to calculate the cost/mile. Simply by dividing the cost of the fuel per gallon by the mpg rating develops the cost/mile.

Cost/mile= Cost of fuel per gallon / Miles travelled per gallon

This calculation was performed for both the city and highway ratings. A small matrix was set up for varying driving styles. The two mainstream approaches were the city and highway commuter. The city commuter was set to 80% driving in the city and 20% on the highway. The highway commuter was set to 80% highway and 20% city. The combined mpg rating for the city commuting driving style was calculated by multiplying the city mpg by .8 and the highway mpg by .2 and adding the results. The same logic was performed for the highway commuting style. With this new combined mpg the cost per mile was found but using the same logic as which was first done which is the cost of the fuel per gallon divided by the combined mpg. After the cost per miles were figured out for each of the driving styles and each of the vehicle variations, the next step was simply to multiply the cost per mile by miles driven (in 10,000 mile intervals) and add the vehicle initial price to that result.

The graph is plotted with the miles travelled in the x-axis and the total cost in the y-axis. Both of the two variations are plotted on the same graph to show when (if at all) the total cost intersects. The axes were cleaned up and standardized between the highway and city commuters for consistency and readability. The graphs were smooth lined scatterplots with the alternative to gasoline using a dotted line for black and white readability.

The first segment to be analyzed were the Diesels from Mercedes, Jeep, and Volkswagen. The Volkswagen Jetta is the most mainstream diesel model available. It is powered by a 2.0L turbocharged direct injection engine and mated to a 5 speed manual or 6 speed direct shift gearbox transmission. It has 140hp at 4000rpm and a steady 236lb-ft of torque from 1750-2500rpm. It is based off of the already successful Jetta sedan. The results for the Volkswagen were better those of most hybrids in the market. The EPA rates the Diesel at 30mpg city and 41mpg on the highway but several magazines have proven the diesel much more worthy of mid-40’s (mpg) on the highway and around 40 in the city. According to a third party testing agency, AMCI, the TDI faired 38mpg city and 44mpg on the highway in their testing.

The results for the diesel are promising, even with the higher price of diesel vs. gas and the dealer markups. Using a template for the various total vehicle cost comparisons, the graph clearly showss when the diesel starts to surpass the gasoline vehicle in total operating cost. Due to the complexity and variations with the fuel economy rating on the Jetta, two separate graphs were also compiled using the AMCI test results (in addition to the EPA results). Using the highway commuter regime (80% highway, 20% city), the Diesel surpassed the gasoline at about 110,000 miles using the EPA ratings and at about 80,000 miles using the AMCI ratings. Using the city commuting regime, the diesel surpassed the gasoline at about 95,000 miles with the EPA ratings and at about 50,000 miles with the AMCI ratings. Maintenance costs for both the gasoline and the diesel are comparible as evidenced by a factory maintenance recommended service with prices.

The next vehicle in the comparison of gasoline vs. diesel was the Mercedes E-class. The Mercedes comparison is an example for a higher end luxury vehicle that still performs well with a diesel engine. The diesel engine only had a $1000 premium over the gasoline model before any applicable tax rebates. On that note, it performed rather well in the overall cost (MSRP + Fuel) of the vehicle. During the highway commuter cycle, the Diesel overtook the gasoline at around 45,000 miles. With the city cycle, it overtook the gasoline at around an even more impressive 35,000 miles. With all of the same performance as the 3.5L gasoline, the Diesel balanced costs after 35,000 miles or about 3 years at 12,000 miles a year.

In the sport utility segment, the Jeep Grand Cherokee offers a 3.0L V6 Common Rail Diesel. The other engines available are 3.7L, 4.7L, and 5.7L gasoline engines. The diesel provides the towing capacity of the Hemi with the vehicle performance of the 4.7L V8 but with the fuel economy of the V6. The diesel model is over $1500 more than the 4.7L V8 gas model but it still was cheaper to operate over the gasoline before 100,000 miles as shown by the graphs. On the EPA highway cycle, the diesel does not produce any savings over the gasoline model till over 100,000 miles with the current prices and premium over the gasoline model. However, in the city cycle the diesel passes the gasoline at about 85,000 miles. In either case, the diesel doesn’t surpass the gasoline economically unless you plan on keeping the vehicle for a longer amount of time. The diesel still has the benefits of towing capacity and off-road capability due to low end torque but economically it isn't as good in the short term.

The other subjects to the comparison are gasoline-electric hybrids. The two presented in this examination were the Toyota Camry and Honda Civic. Both the Camry and the Civic have been tried and true products from their respective Japanese companies for many years. The styling of the hybrids isn't much different than the standard gasoline models and most people wouldn't be able to notice the difference other than performance-wise. The popular Toyota Prius was not compared as the test was between a gasoline and a very similar gas-electric hybrid (or diesel), preferably a like model.

From the makers of the famous Prius is the Toyota Camry Hybrid. The Camry has been known for its reliability over the years. The Toyota has 192hp giving it better vehicle performance than the Prius, making it more desirable to some consumers. The Toyota performed well when compared to a "comparably equipped" model according to the Toyota website. There is surely a premium to pay of over $2,000 up front after the tax rebates. However, in the city cycle, the hybrid outdoes the gas model after 40,000 miles. On the highway cycle it takes to around 100,000 miles before it pays off. This proves that the strong point of most hybrids is in the city.

The other hybrid vehicle to be used for comparison is the Honda Civic Hybrid. The Civic Hybrid surely has a premium over the base model (about 50%). However, like most hybrid models, they typically have more features which can make them comparable to a higher and more expensive model. The civic hybrid without navigation proves itself to be most comparable to the Civic EX. Both are 4 door, automatic and neither have the leather such as that on the EX-L. See figure _ for comparison from the Honda website. The economic performance of the civic hybrid is very comparable to the Toyota Camry Hybrid vs. Gas model. The intersection between the gas and gas-hybrid is around 70,000 miles on the highway cycle and at around 35,000 miles for the city cycle. When used in the city, the return comes rather quickly. This is likely why you are starting to see them used a taxis, zip-cars, etc.

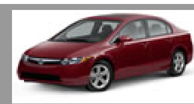
QUALITY & VALUE ANALYSIS Overall Value	 BUILD CHANGE TRIM	 CHANGE REMOVE	 CHANGE REMOVE
Model	2009 Honda Civic Hybrid Hybrid Continuously Variable Transmission	2008 Honda Civic Sedan EX 5-Spd AT	2008 Honda Civic Sedan EX-L 5-Spd AT
Base Price MSRP	$23,550	$19,510	$20,710
Comparably Equipped Price	$24,220	$20,180 + DPI*	$21,380 + DPI*
Destination Charge	$670	$670	$670
ALG Residual Value % After 36 Months	Not Listed	61%	60%
ALG Residual Value % After 60 Months	Not Listed	41%	40%
5-year Maintenance & Repair Costs	$2,069	$2,100	$2,100
Ownership Cost Rating	Excellent	Excellent	Excellent
Fuel-Economy (City)	40	25	25
Fuel-Economy (Highway)	45	36	36
Combined Fuel-Economy (City/Highway)	42	29	29
QUALITY & VALUE ANALYSIS Warranty			
Model	2009 Honda Civic Hybrid Hybrid Continuously Variable Transmission	2008 Honda Civic Sedan EX 5-Spd AT	2008 Honda Civic Sedan EX-L 5-Spd AT
Basic Warranty (Months)	36	36	36
Basic Warranty (Miles)	36000	36000	36000
Powertrain Warranty (Months)	60	60	60
Powertrain Warranty (Miles)	60000	60000	60000
PERFORMANCE & ENGINEERING Engine & Transmission			
Model	2009 Honda Civic Hybrid Hybrid Continuously Variable Transmission	2008 Honda Civic Sedan EX 5-Spd AT	2008 Honda Civic Sedan EX-L 5-Spd AT
Engine	i-VTEC® 1.3L I4	1.8L I4	1.8L I4
Engine Cylinders	4	4	4
Driveline	Front Wheel Drive	Front Wheel Drive	Front Wheel Drive
Engine Displacement	1339	1799	1799

Figure 26: Honda Civic Comparison

An important thing to note when having any sort of comparison is error and variabilities. Such variabilites are additional options on vehicles, tax rebates, local dealer incentives, manufacturer's incentives, exclusions of hybrids and/or diesels to certain ad programs, etc. Tax breaks were used when applicable for the test which aided the non-strictly gasoline vehicle in the analysis. Other factors are dealer markups, which hurt the Volkswagen Jetta TDI Also, one could easily pick the base model Civic and it would take well over 100,000 miles to pay off. However, a compromise between options and trim levels was accomplished in order to provide the most fair and accurate comparison.

Hybrids and All Electrics

There were many different types of research and analysis methods used during this study. Statistical as well as analytical analysis took place throughout the project timeframe. The majority of the initial research and analysis was analytical. The reason for this is because preliminary research had to be conducted prior to any comparison of vehicles or public opinion. Information was gathered from copious sources from the internet, books, and magazines such as Car and Driver, Hispanic Business, and Smart Money. This information was collected and organized into useful formats using both Microsoft Word and Excel.

After the initial research, vehicle cost per mile comparisons for a specified few hybrid vehicles were constructed. The vehicles were chosen based on their initial cost, fuel per mile rating, as well as for ease of evaluation. When comparing hybrid vehicles to their gas counterparts, the utmost care was taken to insure that the vehicles (feature wise) were as close as possible. For instance, for the Honda Civic, the hybrid came from the factory with many extra features that were not found on the base and other lower models. A model was chosen based on the standard features on both of the vehicles so that they would be as similar as possible.

Hydrogen and Ethanol

The Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/) and the PUBLIC LAW 109–58—AUG. 8, 2005 are used to explain the Hydrogen fuel and Ethanol fuel environmental impact, economical-political implementation and social awareness. Hydrogen and Ethanol fuels where chosen due to the implementation of high government incentives and the likelihood of a viable economical infrastructure to energize the transportation sector.

The Honda FCX Clarity (fuel cell) was chosen to be reviewed against the BMW 745h sedan (gasoline and liquid hydrogen, ICE) to characterize the difference in range, top speed, and efficiencies. The Honda FCX Clarity and the BMW 745h sedan were chosen to go under review due to the difference on how they convert hydrogen fuel to mechanical energy.

The price of hydrogen fuel is compared to gasoline using the "gasoline gallon equivalent" (gge) as a measurement. The gge is the measurement of energy content of hydrogen versus gasoline. Approximately one kilogram of hydrogen contains the same energy as one gallon of gasoline.

The report "Clearing the Air with Ethanol" was used to explain the concept of exceedance days per year and showed various states that had reduction in ozone. The report "A Wedge Analysis of the U.S. Transportation Sector" is used to show the impact of different combination of technologies that could reduces CO2 emissions.

The 1998 Ford Taurus was chosen to be compare with it E85 FFV counterpart. Three acceleration tests were conducted (1) elapsed time from 0 to 60mph at wide open throttle, loaded and unloaded; (2) elapsed time from 40 to 60 mph at wide open throttle; (3) elapsed time and maximum speed at ¼ mile. Values are the average of 6 measurements. To measure the fuel economy in an urban driving cycle- a distance of 2 miles with 8 stops was conducted. Highway fuel economy used a 70-mph average driving cycle with no stops. The 150-mile trip alternated between urban and highway cycles until 150 miles were reached. Results are reported in

70% highway driving for total trip. Emissions were measured using duplicate test performed in each vehicle using EPA's Federal Test.

Survey

A major portion of this study was to collect the public opinion and knowledge using proper surveying techniques, objectives, questions, and hypothesis. The objective of the survey was to acquire the public opinion as well as basic knowledge of 18 to 25 year old Worcester Polytechnic Institute students on the subject matter. The hypothesis was that the general public is misguided when it comes to knowledge of alternative fuel technology. There were ten questions that we wanted answered. Cluster sampling was selected to best fit our needs[62]. At first, the sample size was unknown. We were able to find out the correct survey sample size based on both standard deviations as well as using an online calculator. The formula used to find the standard deviation was:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2},$$

Where Xi is the given value from the sample, $\overline{x}$ is the mean of the sample, and n is the number of samples. The results for both 90 and 95 percent confidence levels were within a few percent of each other. In order to be 90 and 95 percent confident with our results, we needed 170 and 220 samples respectively. Random samples were taken both in person as well as in an online format. The majority of the samples came from both a four hour survey given in the campus center as well as though a professor. The online surveys were dispersed between ASME (American Society of Mechanical Engineers), SAE (Society of Automotive Engineers), and the Outing Club.

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[62] Fink, Arlene. How to Analyze Survey Data. First. Thousand Oaks, California: SAGE Publications Ltd. , 1995.
Fink, Arlene. How to Design Surveys. First. Thousand Oaks, California: SAGE Publications Ltd. , 1995.
Fink, Arlene. How to Report on Surveys. First. Thousand Oaks, California: SAGE Publications Ltd. , 1995.
Fink, Arlene. How to Sample in Surveys. First. Thousand Oaks, California: SAGE Publications Ltd. , 1995.

Results and Analysis

Survey Results and Analysis

There were a total of 199 surveys collected. With a population size of 3500 available WPI students between the ages of 18 and 25. This gave us an error percentage of 5.66 at a confidence level of 90 percent. (http://www.raosoft.com/samplesize.html) The data was reduced using Microsoft Excel. The mean, median, mode and standard deviation were calculated for each question. Graphs were also created to illustrate the answer dispersion. The graphical analysis can be seen in appendix B.

The average automotive knowledge of the surveyed individuals was a 2.62 on a scale of 1 to 5. (1 being the least knowledgeable and 5 being an expert) The standard deviation is equal to $^{+}/_{-}$ 1.09. The median and mode were both equal to 3. The graph is slightly skewed to the left because the mean is slightly smaller than the median.

Automotive Knowledge

Mean	2.62	Median	3
Mode	3	Standard Deviation	1.09

Table 01: Survey Results

According to the survey results, the primary driving force behind the search for alternative fuels is environmental concerns. This is followed by the price of gasoline and then independence from foreign oil, respectively. The reduction of this data differed from that of the first question. The data was split into the three groups (environmental concerns, price of gasoline, and independence from foreign oil) and analyzed independently. For the price of gasoline category, the mean score was a 1.98 on a scale of 1 – 3. (1 being the most important and 3 being the least) The median and mode were both 2. Therefore, the price of gasoline was ranked number two. The standard deviation was $^{+}/_{-}$ .76.

Price of Gasoline

Mean	1.98	Median	2
Mode	2	Standard Deviation	0.76

Table 02: Survey Question 1 Price of Gasoline

For environmental concerns, the mean, median, and mode were 1.83, 2, and 1 respectively. The standard deviation was $^{+}/_{-}$ .85. Environmental concerns were selected as the most important because of the lower mean and because of its mode of 1.

Environmental Concerns

Mean	1.83	Median	2
Mode	1	Standard Deviation	0.85

Table 03: Survey Question 1 Environmental concerns

Independence from foreign oil was chosen to be the least important with mean of 2.2 and a mode of 3. The median was 2 but this is because the data is skewed to the left. The standard deviation is $^{+}/_{-}$ .80.

Independence from Foreign Oil

Mean	2.2	Median	2
Mode	3	Standard Deviation	0.80

Table 04: Question 1 Independence from Foreign Oil

Question 2 inquired whether or not the price of gasoline has affected the driving habits of the surveyors. 67 percent said that the increase in fuel cost has led them to stray from their normal driving habits, whether by carpooling or driving slower. The standard deviation was $^{+}/_{-}$ .47 and was calculated using a scale from 1 – 2. (1 being yes and 2 being no) The mean was 1.33 and the mode and median were both found to be 1.

Driving Habits

Mean	1.33	Median	1
Mode	1	Standard Deviation	0.47

Table 05: Survey Question 2 Driving Habits

Based on the results, almost 70 percent of the public have changed their travel plans due to the price of gasoline. The average was 1.31 (on a scale of 1 – 2 with 1 being yes and 2 being no) with a standard deviation of $^{+}/_{-}$ .46. The median and mode were once again both 1.

Travel Plans

Mean	1.31	Median	1
Mode	1	Standard Deviation	0.46

Table 06: Survey Question 3 Travel Plans

Question 4 data was reduced in a manner similar to question 1. According to the survey data, participants buy cars based on price, fuel efficiency, performance, brand, and then environmental friendliness, respectively. The scale ranged from 1 to 5, with 1 being the most influential and 5 being the least. Price was the most important factor with a mean of 2.38 $^{+}/_{-}$ 1.31. The median was 2 while the mode was 1.

Price

Mean	2.38	Median	2
Mode	1	Standard Deviation	1.31

Table 07: Survey Question 4 Price

Fuel efficiency had a mean of 2.76 $^{+}/_{-}$ 1.27. The median and mode were both 2. It was therefore ranked as the second most important influential characteristic when buying a vehicle.

Fuel efficiency

Mean	2.76	Median	2
Mode	2	Standard Deviation	1.27

Table 08: Survey Question 4 Fuel Efficiency

Performance was ranked third with a mean of 2.68 $^{+}/_{-}$ 1.29 and both a median and mode of 3.

Performance

Mean	2.68	Median	3
Mode	3	Standard Deviation	1.29

Table 09: Survey Question 4 Performance

The second least influential characteristic when buying a car is the brand. The median and mode were both 4. The average was 2.68 $^{+}/_{-}$ 1.31.

Brand

Mean	3.66	Median	4
Mode	4	Standard Deviation	1.31

Table 10: Survey Question 4 Brand

The least influential was environmental friendliness. The mean was 3.58, while the median was 4 and the mode was 5. The standard deviation was $^{+}/_{-}$ 1.42. It is odd that in question 1 environmental concern was ranked first whereas environmental friendliness is ranked last for buying a vehicle.

Environmental Friendliness

Mean	3.58	Median	4
Mode	5	Standard Deviation	1.42

Table 11: Survey Question 4 Environmental Friendliness

According to the survey results, the most fuel efficient type of vehicle is full electric followed by gasoline-hybrids, diesels, and conventional gasoline respectively. The scale was 1 to 4, 1 having the best and 4 having the worst fuel efficiency. The mean for full electric was 1.86 $^{+}/_{-}$ 1.12. Both the median and mode were equal to 1.

Full Electric

Mean	1.86	Median	1
Mode	1	Standard Deviation	1.12

Table 12: Survey Question 5 Full Electric

Gasoline – hybrids averaged 2.15 $^{+}/_{-}$ .87 with median and mode both equal to 2.

Gasoline-Hybrid

Mean	2.15	Median	2
Mode	2	Standard Deviation	0.87

Table 13: Survey Question 5 Gasoline – Hybrid

Diesel vehicles were ranked third in fuel efficiency with medians and modes of 3. The mean was 2.83 and a standard deviation of $^{+}/_{-}$ .95.

Diesel

Mean	2.83	Median	3
Mode	3	Standard Deviation	0.95

Table 14: Survey Question 5 Diesel

Gasoline vehicles were ranked the least fuel efficient with a mean of 3.10 $^{+}/_{-}$ 1.04. The median was 3 and the mode was 4.

Gasoline

Mean	3.1	Median	3
Mode	4	Standard Deviation	1.04

Table 15: Survey Question 5 Gasoline

The United States government should invest in hydrogen technology according to the results. This question was scored on a scale of 1 – 3. 1 was ethanol, 2 was hydrogen, and 3 was full electric. The mean was 2.09 with a standard deviation of $^{+}/_{-}$ .72. The median and mode were both 2.

U.S. Investment

Mean	2.09	Median	2
Mode	2	Standard Deviation	0.72

Table 16: Survey Question 6 U.S. Investment

Question 7 asked to choose a vehicle given a choice of Volkswagen Jetta TDI, Honda Accord, GM Chevy Volt, and Honda Civic Hybrid. The choices represented the four vehicle types discussed in question 5. (Diesel, gasoline, full electric, and gasoline hybrid) The scale was 1-4 with Volkswagen Jetta TDI being 1, Honda Accord being 2, GM Chevy Volt being 3, and Honda Civic Hybrid being 4. The mode of the data was 4 whereas the median was 3. The average was 2.69 $^{+}/_{-}$ 1.22. The Honda Civic hybrid was the vehicle chosen most.

Vehicle Choice

Mean	2.69	Median	3
Mode	4	Standard Deviation	1.22

Table 17: Survey Question 7 Vehicle Choice

The estimated annual mileage for WPI students is between 0 – 5000 miles. The choices were 0 – 5000, 5000 – 10000, 10000 – 15000, and 15000 miles plus which were represented by the numbers 1 – 4 respectively. The mean was 2.01 $^{+}/_{-}$ .99. The median was 2 while the mode was 1.

Average Yearly Mileage

Mean	2.01	Median	2
Mode	1	Standard Deviation	0.99

Table 18: Survey Question 8 Annual Mileage

The final survey question asked about the newly installed WPI hybrid only parking. There were five possible choices that were represented by the numbers 1-5. The options were strongly support, support, neutral, disagree, and strongly disagree. (Strongly support was 1 and strongly disagree was 5) The average of the surveys was neutral with a mean of 2.89 $^{+}/_{-}$ 1.32. The median and mode were both equal to 3.

Hybrid Parking Spaces

Mean	2.89	Median	3
Mode	3	Standard Deviation	1.32

Table 19: Survey Question 9 Hybrid Parking

Conclusion and Recommendations

In the opinion of the authors, some of the alternatives to gasoline powered vehicles are acceptable options. In environmental terms, hybrids, ethanol, and diesel powered vehicles produce less CO_2 emissions per mile. The alternatives also include high technology items and gadgetry which make them more desirable to tech savvy individuals. The gasoline alternative models are also typically the highest trim levels and contain the according luxury features compared to the gasoline model.

In an economic sense, both diesels and gasoline electric hybrids are geared towards being a longer term investment as it takes time to see any financial savings. When E85 is corrected for its lower energy, it costs more per mile than regular gasoline. Since the infrastructure for hydrogen is still being implemented, the initial costs are being relayed to the consumers. When methods of production of ethanol and hydrogen become more efficient, then they will be economically viable. Depending on the price of fuel in comparison to the initial cost premium, the return investments accrue quickly. Most held the largest advantage if primarily used for city commuting as the alternatives have technologies to minimize fuel usage by means of either turning off the primary engine or having very low idle fuel consumption due to no throttling losses. However, despite the better cost per mile ratios, most alternatives needed at least 4-5 years to recoup the initial cost premium. If the price of gasoline was to drop significantly, then the economic benefits of the alternatives would be negligible, possibly even negative.

In an environmental sense, the alternatives to gasoline were better for the environment. All electric vehicles would be powered from the grid using renewable energy, which is more efficient than an ICE. The environmental impact can be lowered further if the electricity from the grid was provided from renewable sources such as wind, hydroelectric, and solar. Diesel's produce less energy per mile despite creating more pollution per gallon due to the increase fuel efficiency. Pollution is further lowered due to the extensive emissions systems on the vehicle. Hydrogen fuel cells are better for the environment due to the fact that the only emission is water vapor. Gas-electric hybrids combine the battery power (which recovers vehicle energy from braking) and disables the internal combustion engine when at a stop to provide less emissions. This is the case because the internal combustion engine is used less.

In conclusion, hybrids and diesels make economic sense over time, have better emissions ratings, and typically have higher technological features. The price margin to a comparably equipped gasoline model isn't much, typically less than $1000 after applicable tax credits. The authors feel that if the consumer is interested in a long term investment with high technology, then an alternative to gasoline is the best option. With increased public understanding of the alternatives to conventional gasoline vehicles, one can make a better judgment on the matter. Diesels and hybrids have come a long way in recent times and the outlook for the future is ever promising.

Afterword

The time frame in which the Interactive Qualifying Project was set was in the summer of 2008. At said time, the price of fuel for passenger vehicles was at a record high. As previously stated in the executive summary, the total financial benefit of most gasoline hybrids and diesels was very dependent on the price of fuel. During the summer, the price of Diesel was approximately 15-20% more than the price of gasoline. However, Diesels typically had a 30% advantage in the cost per mile. Diesel powered vehicles also had an initial cost premium over the gasoline counterpart. By using these two factors, the overall vehicle cost comparison was established. The total costs of diesels and gasoline electric hybrids would eventually equate the gasoline counterparts after a certain number of miles.

This Interactive Qualifying Project was due in December of 2008. At this time, the price of gasoline has dropped considerably in comparison to the prices of the summer of 20008. The price of Diesel has dropped as well, but much less than the price of gasoline. As of December 9th, 2008 the price of gasoline was $1.698/gallon and the price of diesel was $2.629/gallon. At those rates, the price of diesel was 54.8% greater than the price of gasoline. As previously stated, diesels typically had a 30% advantage on the cost per mile. Unfortunately to diesels, with the prices of December 9th, 2008 they will never provide a cost benefit between the higher initial cost *and* the greater cost per mile.

As far as gasoline hybrids are concerned, they too relied on their superior cost/mile operating costs. The hybrids had initial cost premiums over the gasoline models, and like the diesels, they relied on their cheaper operating costs to recoup the difference with the greater initial cost. However, when the price of fuel lowers greatly as it did, this makes it less of a factor in the total cost. Similar to the diesels, gas hybrids are rarely paying themselves back, even at 100,000 miles.

After all is said and done in December of 2008, diesels and gasoline hybrids typically do not pay themselves off within a typical vehicle lifespan. However, they are still alternatives to gasoline, allow for less emissions, less dependence on foreign oil, etc. All in all, they can still be a great investment in the case that gasoline prices increases greatly once again.

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Glossary

A

Aerodynamics – the study of the forces on a body by fluids such as air. Important in design of vehicle shapes to provide a lower load at vehicle speed.
Air pollution – the collective polluting of the atmosphere by the reactants of combustion.
Alcohol Fuels – any fuel that is based off of alcohol such as ethanol, methanol, and blends of each.
Alternative Fuels – considered to be any alternative to a 100% gasoline mixture.

B

Batteries (for hybrid drive) – battery technology has varied over the years from nickel metal hydride to the modern lithium ion. Energy is stored here and is used to power the electric motor and vehicle accessories.
Biodiesel – a mix of diesel that is synthetically made and not from 100% crude oil.
Braking, Regenerative – a braking system that helps recover the vehicle's kinetic energy for reuse.

C

Calorific value of air/fuel mixture – measure of energy in a fuel. This is directly related to the power capable to be extracted by the fuel. A typical gasoline mixture has about 40MJ per kilogram.
CARB - California Air Resources Board, group that makes decisions regarding emissions for automobiles.
Capacitor - device similar to a battery used to store larger amounts of energy.
Carbon Dioxide - a greenhouse gas that is a combustion product. This is said to be the primary cause of global warming.
Catalytic Converter - an emissions component routed in the exhaust that is used to "complete" combustion and convert carbon monoxide, nitric oxides, and other hazardous gases to CO2 and H2O.
Cellulosic Ethanol- A biofuel refined from cellulose, the fibrous material that makes up most of the plant matter in wheat, switch grass, corn stalks, rice straw, and even wood chips
Combustion - the exothermal chemical reaction between a hydrocarbon such as gasoline or diesel that is used in an internal combustion engine as a source for power.
Common Rail Diesel - a diesel injection system that has a common high pressure fuel rail.
Continuously Variable Transmission - a transmission that is typically operated using a belt and two variable radius pulleys to be able to keep the engine in its peak powerband as much as possible.

D

Diesel Engine – an engine that uses the heat of compression to auto-ignite the air/fuel mixture. Typically has a compression ratio between 14 and 20 to 1 and is more thermally efficient than a gasoline engine.
Diesel Particulate filters – (DPF) an inline filter in the exhaust that helps remove larger particulates due to combustion.
Direct Injection – a fueling method that injects a fuel at high pressure directly in the cylinder head. Advantages are better control of fuel detonation and options such as effective lean-burning (lambda > 1)
Drag Coefficient – an aerodynamic coefficient that describes the shape of a body. The lower the better. This combined with surface area, vehicle speed, and density of air can give you the force of the vehicle.
Drivetrain – this is the assembly of components that use the power from the engine through various stages to provide the proper forces and velocities through a method of gear reductions. Typical components are the transmission, transfer case (if 4wd or AWD), driveshafts, differentials, and axles. A drivetrains layout can determine the intended uses and capabilities of a vehicle.

E

ECU – engine control unit – controls various functions of an engine by using various sensors to determine the proper amount of fuel to inject, ignition timing, and many other important parameters.
Electric car – a car that uses electricity and electric motors to drive the wheels. Similar to series drivetrain hybrid vehicles.
Emissions – the products of combustion in an internal combustion engine. Typically composed of water vapor, carbon dioxide, nitrogen, and various other species such as carbon monoxide and NO_x's.
Environmental Protection Agency – (EPA) an independent federal agency established to coordinate programs aimed at reducing pollution and protecting the environment
Evaporative emissions – hydrocarbons (gasoline and oil), which vaporize and escape from an automobile's engine and fuel system
Exhaust – products of combustion typically composed of unburned hydrocarbons, carbon dioxide, carbon monoxide, nitric oxides, and variations of sulfur (in diesels).
Exhaust treatment – emissions devices such as catalytic converters or diesel particulate filters that remove or convert harmful pollutants into more less toxic substances.

F
Flexible Fuel Vehicles- (FFVs), vehicles capable of using gasoline and any ethanol blend up to 85%
Fuel consumption – the amount of fuel consumed over a specified distance. Typically in
Fuel Types – there are several options with varying performance parameters such as knock resistance, energy density, and volatility.

G
Gasoline Direct Injection – fueling method in gasoline vehicles that follows the fuel injection methods of diesels. The fuel injector is mounted directly in the cylinder head and sprays directly into the combustion chamber. Pressures are typically very large compared to the typical 3bar manifold injection.
Gasoline gallon equivalent- (gge) a measurement that describe the amount of energy of a substance to the amount of energy in one gallon of gasoline
Global Warming –An increase in the average temperature of the earth's atmosphere, that causes climate change.
Glow plug – a plug that is used to preheat the combustion chamber of a diesel engine in order to ease starting. Modern diesels rely less on glow plugs due to advanced engine management.
Greenhouse gas – Any of the atmospheric gases that contribute to the greenhouse effect by absorbing infrared radiation produced by solar warming of the Earth's surface.

H
Hydrocarbons – a molecule composed of hydrogen and carbon that is found in crude oil. Examples are butane, heptanes and octane.
Hydrogen Vehicle- a vehicle that either uses fuel cells for energy or has hydrogen stored onboard.

I
Ignition systems – process in which fuel-air mixture is combusted by means of spark (Otto cycle) or by the heat of compression (Diesel cycle).
Intercooling – the process of removing the heat of compression of turbocharging. The temperature is reduced and the cooler air has a greater density allowing for greater power potential as well as lower intake temperatures to prevent preignition and knock.
Internal Combustion Engine – any engine in which combustion takes place over a cyclical internal process. Examples are diesel and Otto cycle engines.

L

Lambda – the air to fuel ratio of the incoming charge. Engine management systems use oxygen sensors to monitor both the engine and catalytic converter efficiency. For gasoline, a lambda or 1 is 14.7 parts air for 1 part gasoline. Keeping the value at the stoich value of 1 allows for low amounts of pollutants.

M

Mild Hybrid – hybrid whose engine turns off during coasting, braking, or stopped and restarted quickly and cleanly when needed.

O

OPEC - Organization of Petroleum Exporting Countries- group that attempts to regulate price of oil.
Otto cycle- internal combustion engine cycle in which fuel is ignited by a high voltage spark through a spark plug.

P

Parallel hybrid drive – a hybrid drivetrain that allows either an electrical motor or engine to directly turn the wheels of the vehicle. (they can also be used in conjunction.)
Peak-Oil- a term that indicates that the cost of extracting and refining oil is more or equal to the cost of oil itself
Piezo fuel injector – a fuel injector that relies on Piezo electric technology to offer rapid fueling solutions. These are used in gasoline direct injection engines as well as diesel engines.
Plug in Hybrid – PHEV – Hybrids that can be plugged into an electrical source to recharge its batteries. It also has a backup internal combustion engine.
Power assist hybrid – a hybrid vehicle that relies on its conventional engine to drive the wheels with an electric motor that inputs additional torque.
Prius – The volume production hybrid car that was put on sale in Japan in 1997.

S

Series hybrid drive – hybrid vehicle drivetrains that only use electrical motors to turn the wheels. Either use energy stored on board or a gasoline engine as a generator to the battery.

T

Turbocharger – a device that captures exhaust energy and uses is to power a compressor that raises the pressure of the incoming air. This allows cars to use a lower displacement engine for better fuel consumption yet having the power of a naturally aspirated vehicle with a larger displacement.

V

Variable Valve Timing – a system of cam timing that can vary the characteristics of the valves. This allows for better control of the powerband and can help fuel economy.

Equation

Car = k_1(combined environmental impact rating)+k_2(combined mileage rating)+k_3(Initial cost rating)+k_4(Long term operational cost rating)+k_5(Driving dynamics rating)+k_6(fun/coolness factor rating)

Constants	Category
k_1	Overall Environmental Impact
k_2	Combined Mileage
k_3	Initial Cost
k_4	Long term operating cost
k_5	Driving Dynamics (0-60mph, 1/4 mile)
k_6	Fun/Coolness Factor

Note: the constants add up to 1 (i.e. tenths)
ratings are based off of vehicle ratings

Environmentalist

Category	Weight	Note
Overall Environmental Impact	0.35	Includes emissions, battery disposal, etc.
Combined Mileage	0.2	Combination between city and highway EPA ratings
Initial Cost	0.1	Initial Price of vehicle after government rebates
Long term operating cost	0.1	Cost/Mile, routine maintenance
Driving Dynamics (0-60mph, 1/4 mile)	0.05	(0-60mph, 1/4 mile)
Fun/Coolness Factor	0.2	"Different"
Total	1	

Economist

Category	Weight	Note
Overall Environmental Impact	0.15	Includes emissions, battery disposal, etc.
Combined Mileage	0.15	Combination between city and highway EPA ratings
Initial Cost	0.25	Initial Price of vehicle after government rebates
Long term operating cost	0.25	Cost/Mile, routine maintenance
Driving Dynamics (0-60mph, 1/4 mile)	0.1	(0-60mph, 1/4 mile)
Fun/Coolness Factor	0.1	"Different"
Total	1	

Enthusiast

Category	Weight	Note
Overall Environmental Impact	0.1	Includes emissions, battery disposal, etc.
Combined Mileage	0.1	Combination between city and highway EPA ratings
Initial Cost	0.15	Initial Price of vehicle after government rebates
Long term operating cost	0.1	Cost/Mile, routine maintenance
Driving Dynamics (0-60mph, 1/4 mile)	0.35	(0-60mph, 1/4 mile)
Fun/Coolness Factor	0.2	"Different"
Total	1	

Table 20: Survey Question 9 Hybrid Parking

Toyota Prius

Category	Rating	Note
Overall Environmental Impact	7	
Combined Mileage	10	
Initial Cost	6	
Long term operating cost	7	
Driving Dynamics (0-60mph, 1/4 mile)	3	
Fun/Coolness Factor	6	
Total	39	

	Environmentalist	
Category	Weight	Total
Overall Environmental Impact	0.35	2.45
Combined Mileage	0.2	2
Initial Cost	0.1	0.6
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.05	0.15
Fun/Coolness Factor	0.2	1.2
Score	1	71

	Enthusiast	
Category	Weight	Total
Overall Environmental Impact	0.1	0.7
Combined Mileage	0.1	1
Initial Cost	0.15	0.9
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.35	1.05
Fun/Coolness Factor	0.2	1.2
Score	1	55.5

	Economist	
Category	Weight	Total
Overall Environmental Impact	0.15	1.05
Combined Mileage	0.15	1.5
Initial Cost	0.25	1.5
Long term operating cost	0.25	1.75
Driving Dynamics (0-60mph, 1/4 mile)	0.1	0.3
Fun/Coolness Factor	0.1	0.6
Score	1	67

Table 21: Survey Question 9 Hybrid Parking

Volkswagen Jetta TDI

Category	Rating	Note
Overall Environmental Impact	8	
Combined Mileage	9	
Initial Cost	5	
Long term operating cost	7	
Driving Dynamics (0-60mph, 1/4 mile)	7	
Fun/Coolness Factor	7	
Total	43	

	Environmentalist	
Category	Weight	Total
Overall Environmental Impact	0.35	2.8
Combined Mileage	0.2	1.8
Initial Cost	0.1	0.5
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.05	0.35
Fun/Coolness Factor	0.2	1.4
Score	1	75.5

	Enthusiast	
Category	Weight	Total
Overall Environmental Impact	0.1	0.8
Combined Mileage	0.1	0.9
Initial Cost	0.15	0.75
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.35	2.45
Fun/Coolness Factor	0.2	1.4
Score	1	70

	Economist	
Category	Weight	Total
Overall Environmental Impact	0.15	1.2
Combined Mileage	0.15	1.35
Initial Cost	0.25	1.25
Long term operating cost	0.25	1.75
Driving Dynamics (0-60mph, 1/4 mile)	0.1	0.7
Fun/Coolness Factor	0.1	0.7
Score	1	43

Table 22: Survey Question 9 Hybrid Parking

Volkswagen Jetta GLI

Category	Rating	Note
Overall Environmental Impact	7	
Combined Mileage	7	
Initial Cost	6	
Long term operating cost	7	
Driving Dynamics (0-60mph, 1/4 mile)	10	
Fun/Coolness Factor	9	
Total	46	

	Environmentalist	
Category	Weight	Total
Overall Environmental Impact	0.35	2.45
Combined Mileage	0.2	1.4
Initial Cost	0.1	0.6
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.05	0.5
Fun/Coolness Factor	0.2	1.8
Score	1	74.5

	Enthusiast	
Category	Weight	Total
Overall Environmental Impact	0.1	0.7
Combined Mileage	0.1	0.7
Initial Cost	0.15	0.9
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.35	3.5
Fun/Coolness Factor	0.2	1.8
Score	1	83

	Economist	
Category	Weight	Total
Overall Environmental Impact	0.15	1.05
Combined Mileage	0.15	1.05
Initial Cost	0.25	1.5
Long term operating cost	0.25	1.75
Driving Dynamics (0-60mph, 1/4 mile)	0.1	1
Fun/Coolness Factor	0.1	0.9
Score	1	72.5

Table 23: Survey Question 9 Hybrid Parking

GM Volt

Category	Rating	Note
Overall Environmental Impact	8	
Combined Mileage	10	
Initial Cost	5	
Long term operating cost	6	
Driving Dynamics (0-60mph, 1/4 mile)	7	
Fun/Coolness Factor	9	
Total	45	

	Environmentalist	
Category	Weight	Total
Overall Environmental Impact	0.35	2.8
Combined Mileage	0.2	2
Initial Cost	0.1	0.5
Long term operating cost	0.1	0.6
Driving Dynamics (0-60mph, 1/4 mile)	0.05	0.35
Fun/Coolness Factor	0.2	1.8
Score	1	80.5

	Enthusiast	
Category	Weight	Total
Overall Environmental Impact	0.1	0.8
Combined Mileage	0.1	1
Initial Cost	0.15	0.75
Long term operating cost	0.1	0.6
Driving Dynamics (0-60mph, 1/4 mile)	0.35	2.45
Fun/Coolness Factor	0.2	1.8
Score	1	74

	Economist	
Category	Weight	Total
Overall Environmental Impact	0.15	1.2
Combined Mileage	0.15	1.5
Initial Cost	0.25	1.25
Long term operating cost	0.25	1.5
Driving Dynamics (0-60mph, 1/4 mile)	0.1	0.7
Fun/Coolness Factor	0.1	0.9
Score	1	70.5

Table 24: Survey Question 9 Hybrid Parking

Toyota Camry Hybrid

Category	Rating	Note
Overall Environmental Impact	8	
Combined Mileage	8	
Initial Cost	7	
Long term operating cost	7	
Driving Dynamics (0-60mph, 1/4 mile)	6	
Fun/Coolness Factor	4	
Total	40	

	Environmentalist	
Category	Weight	Total
Overall Environmental Impact	0.35	2.8
Combined Mileage	0.2	1.6
Initial Cost	0.1	0.7
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.05	0.3
Fun/Coolness Factor	0.2	0.8
Score	1	69

	Enthusiast	
Category	Weight	Total
Overall Environmental Impact	0.1	0.8
Combined Mileage	0.1	0.8
Initial Cost	0.15	1.05
Long term operating cost	0.1	0.7
Driving Dynamics (0-60mph, 1/4 mile)	0.35	2.1
Fun/Coolness Factor	0.2	0.8
Score	1	62.5

	Economist	
Category	Weight	Total
Overall Environmental Impact	0.15	1.2
Combined Mileage	0.15	1.2
Initial Cost	0.25	1.75
Long term operating cost	0.25	1.75

Table 25: Survey Question 9 Hybrid Parking

Honda Civic LX

Category	Rating	Note
Overall Environmental Impact	6	
Combined Mileage	8	
Initial Cost	10	
Long term operating cost	8	
Driving Dynamics (0-60mph, 1/4 mile)	5	
Fun/Coolness Factor	5	
Total	42	

	Environmentalist	
Category	Weight	Total
Overall Environmental Impact	0.35	2.1
Combined Mileage	0.2	1.6
Initial Cost	0.1	1
Long term operating cost	0.1	0.8
Driving Dynamics (0-60mph, 1/4 mile)	0.05	0.25
Fun/Coolness Factor	0.2	1
Score	1	67.5

	Enthusiast	
Category	Weight	Total
Overall Environmental Impact	0.1	0.6
Combined Mileage	0.1	0.8
Initial Cost	0.15	1.5
Long term operating cost	0.1	0.8
Driving Dynamics (0-60mph, 1/4 mile)	0.35	1.75
Fun/Coolness Factor	0.2	1
Score	1	64.5

	Economist	
Category	Weight	Total
Overall Environmental Impact	0.15	0.9
Combined Mileage	0.15	1.2
Initial Cost	0.25	2.5
Long term operating cost	0.25	2
Driving Dynamics (0-60mph, 1/4 mile)	0.1	0.5
Fun/Coolness Factor	0.1	0.5
Score	1	76

Table 26: Survey Question 9 Hybrid Parking

Appendix A Cost Analysis

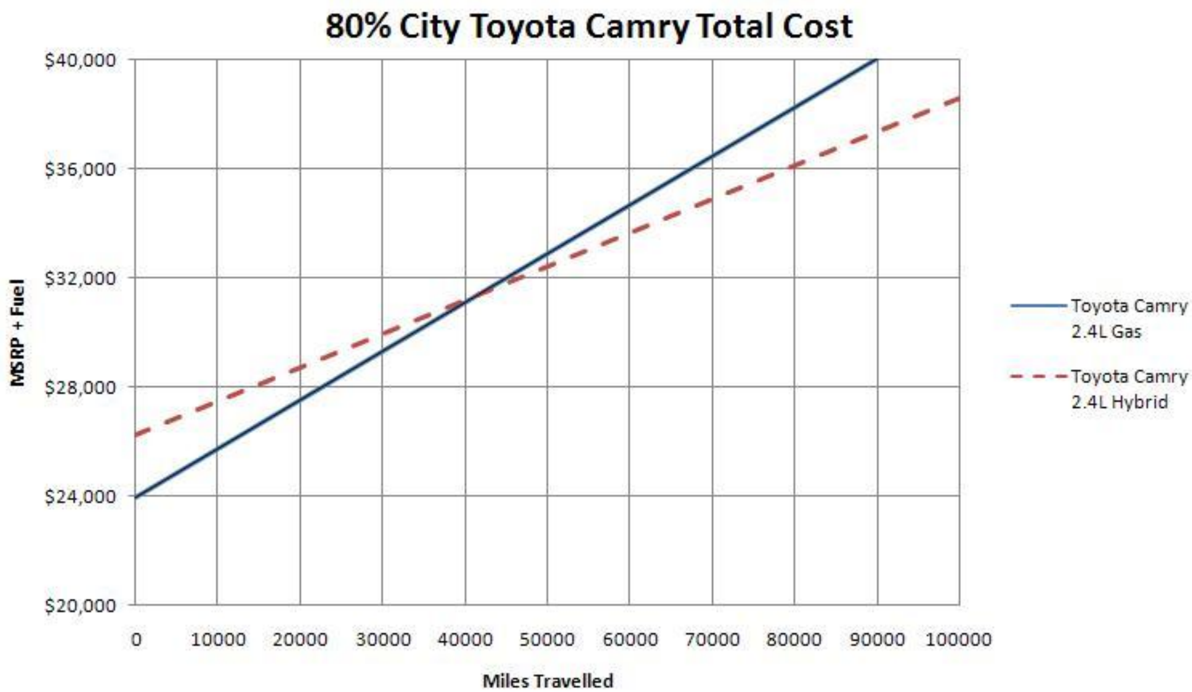

Figure 27 – Cost vs. Mile (80%City) Toyota Camry

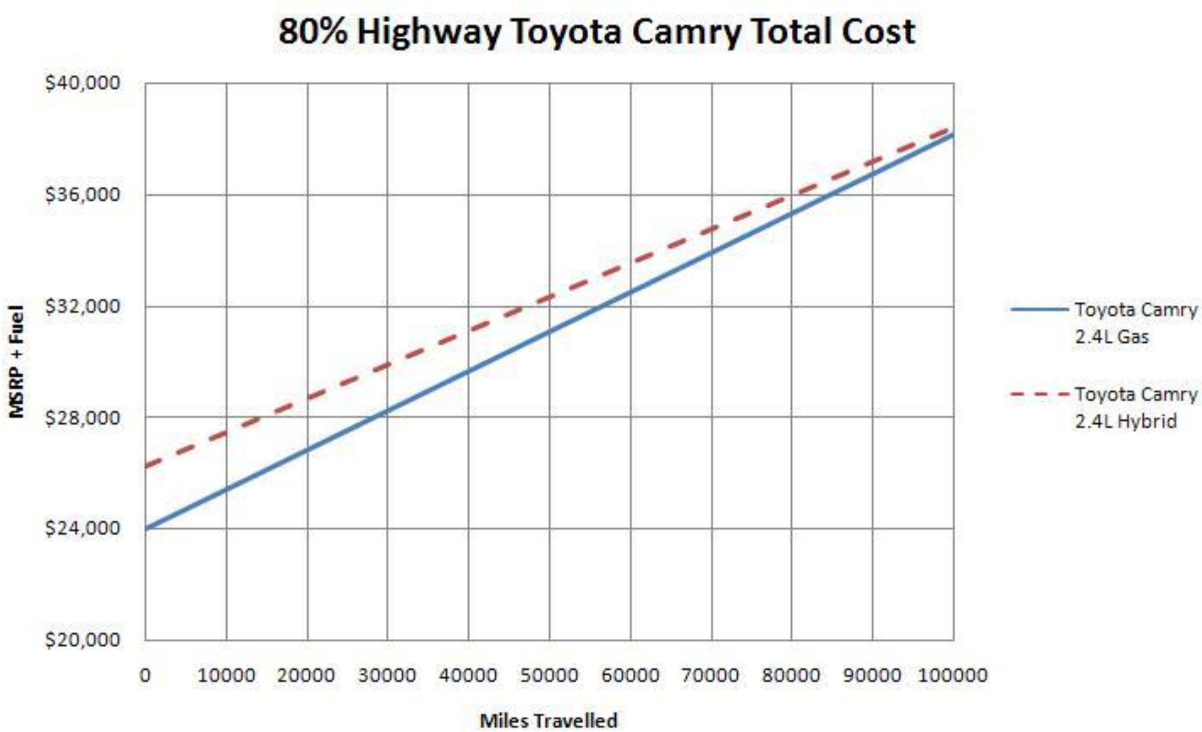

Figure 28 – Cost vs. Mile (80%Highway) Toyota Camry

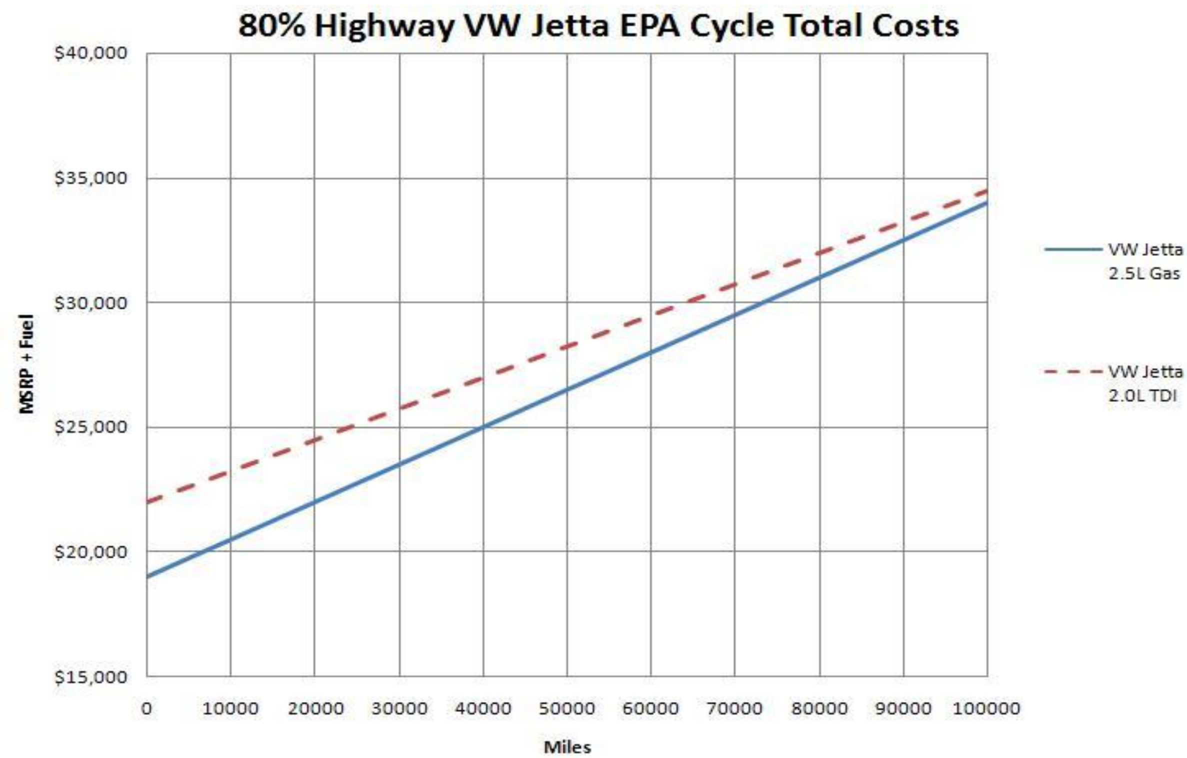

Figure 29 – Cost vs. Mile (80%Highway) Volkswagen Jetta EPA Ratings Based

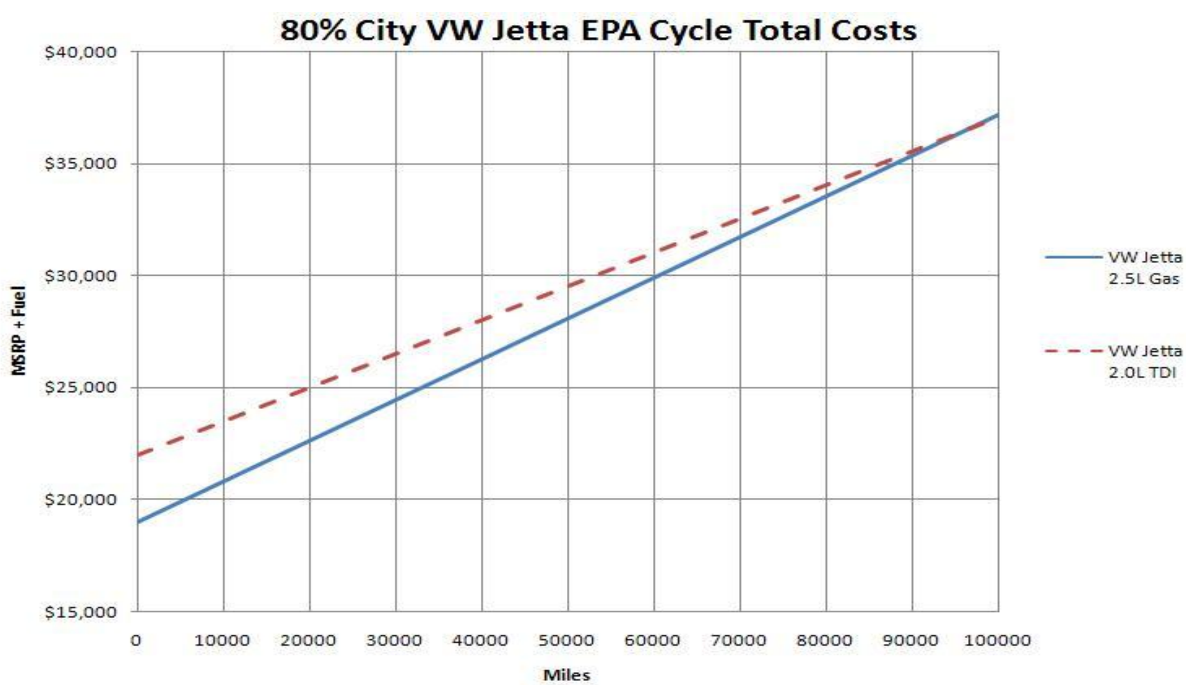

Figure 30 – Cost vs. Mile (80%City) Volkswagen Jetta EPA Ratings Based

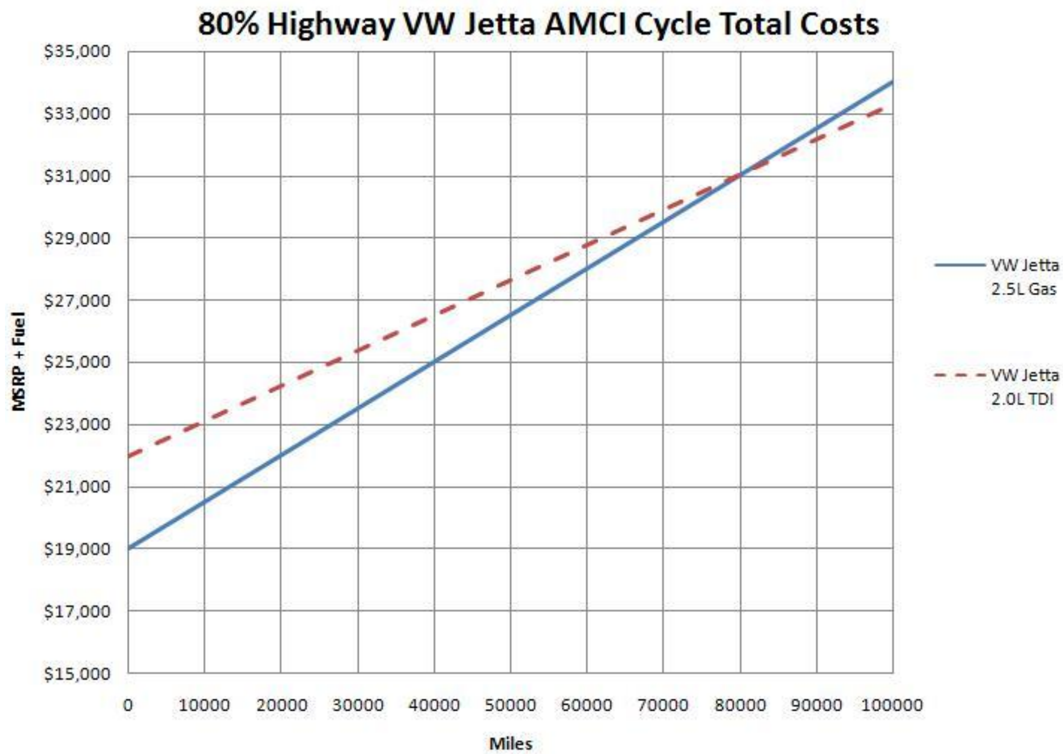

Figure 31 – Cost vs. Mile (80%Highway) Volkswagen Jetta AMCI Ratings Based

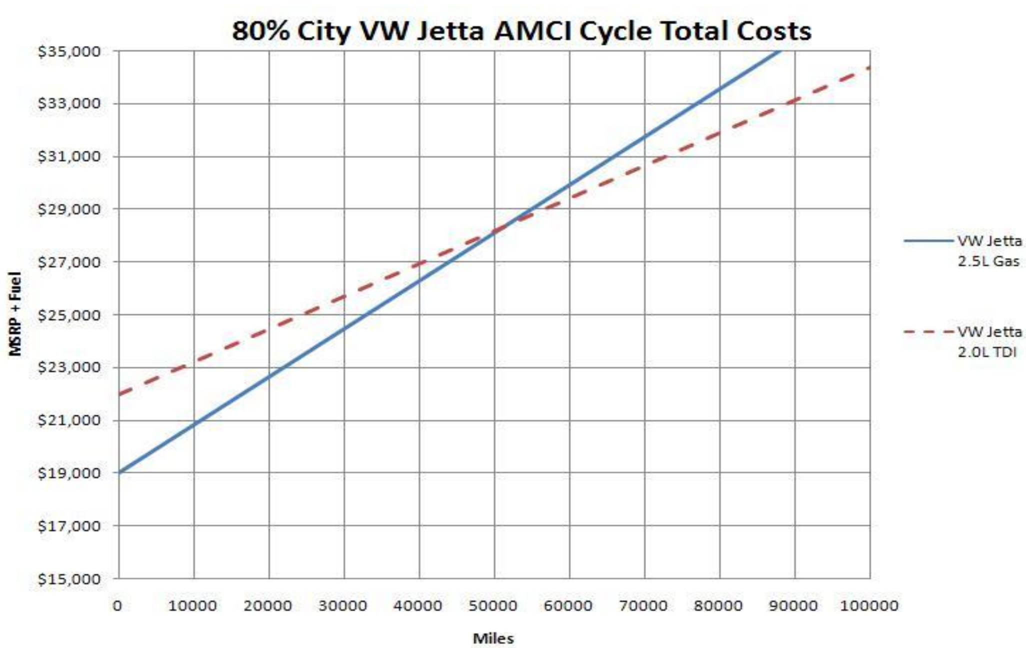

Figure 32 – Cost vs. Mile (80%City) Volkswagen Jetta AMCI Ratings Based

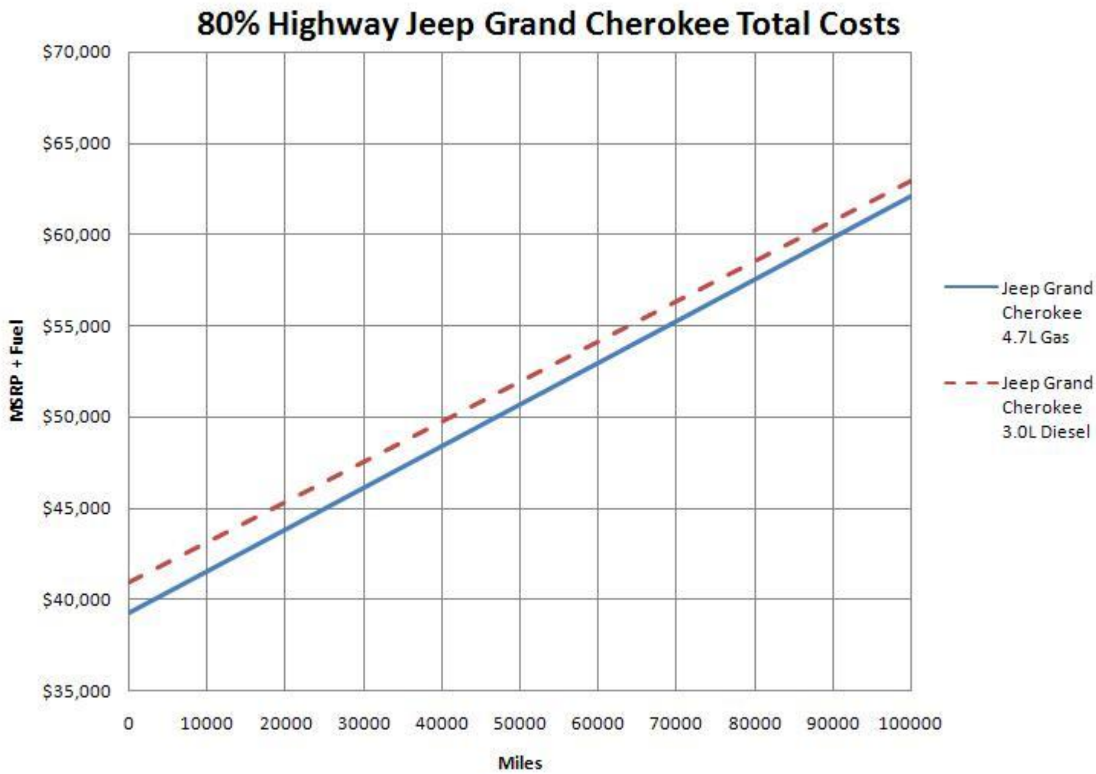

Figure 33 – Cost vs. Mile (80%Highway) Jeep Grand Cherokee

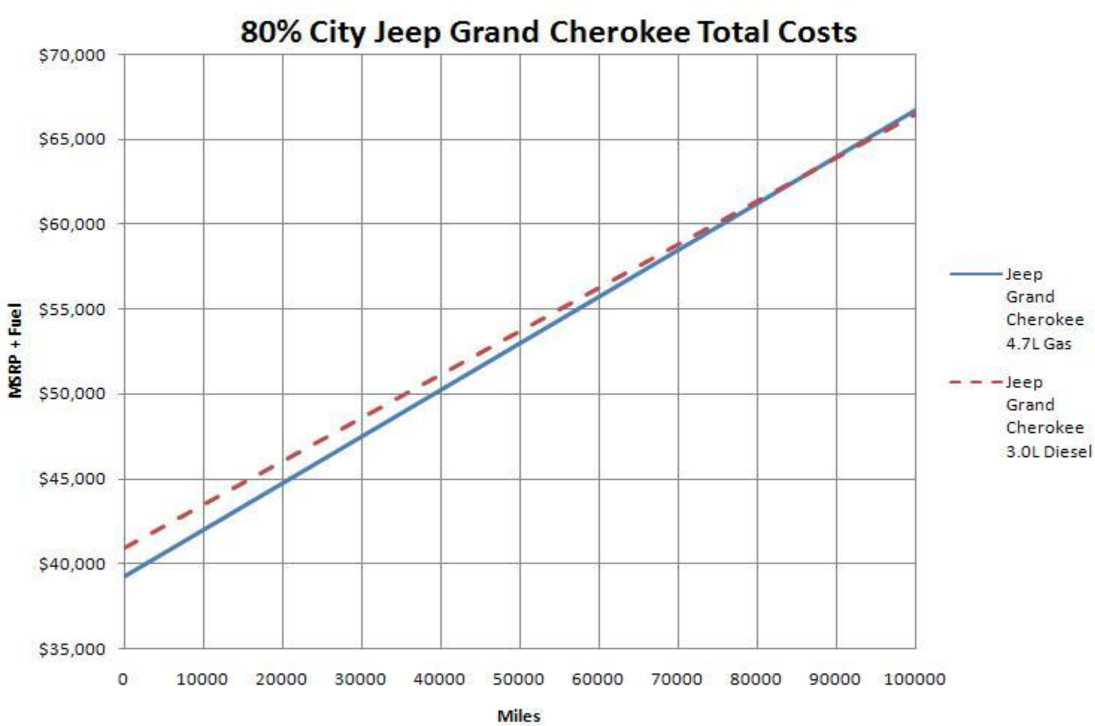

Figure 34 – Cost vs. Mile (80%City) Jeep Grand Cherokee

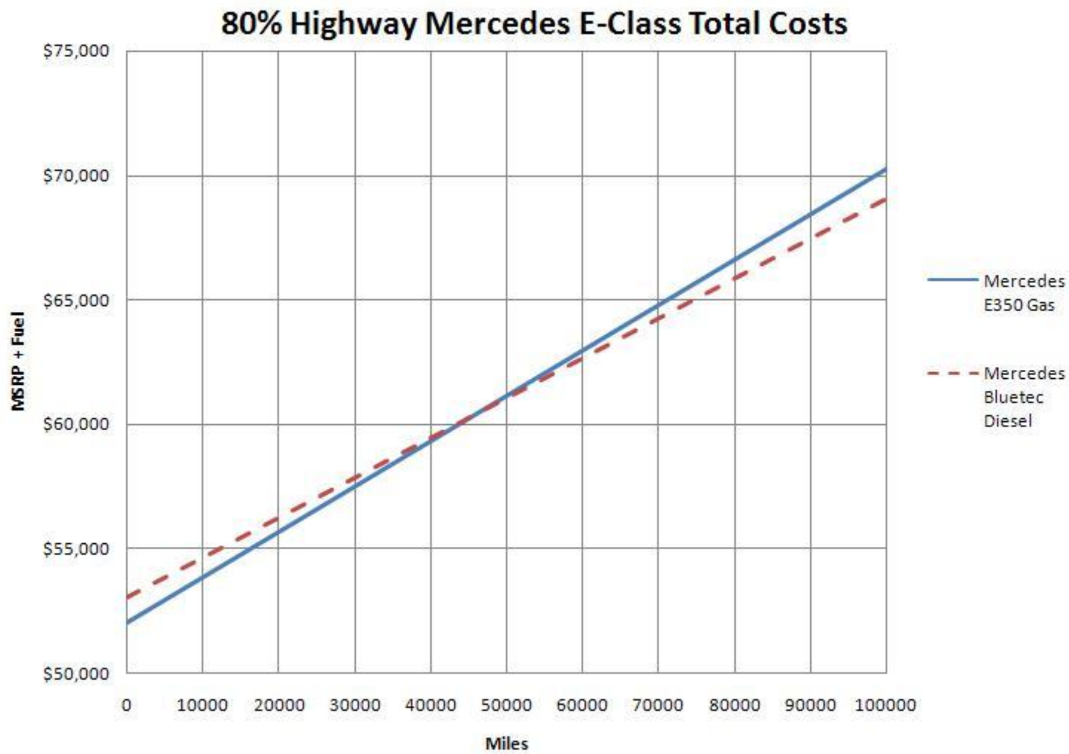

Figure 35 – Cost vs. Mile (80%Highway) Mercedes E-Class

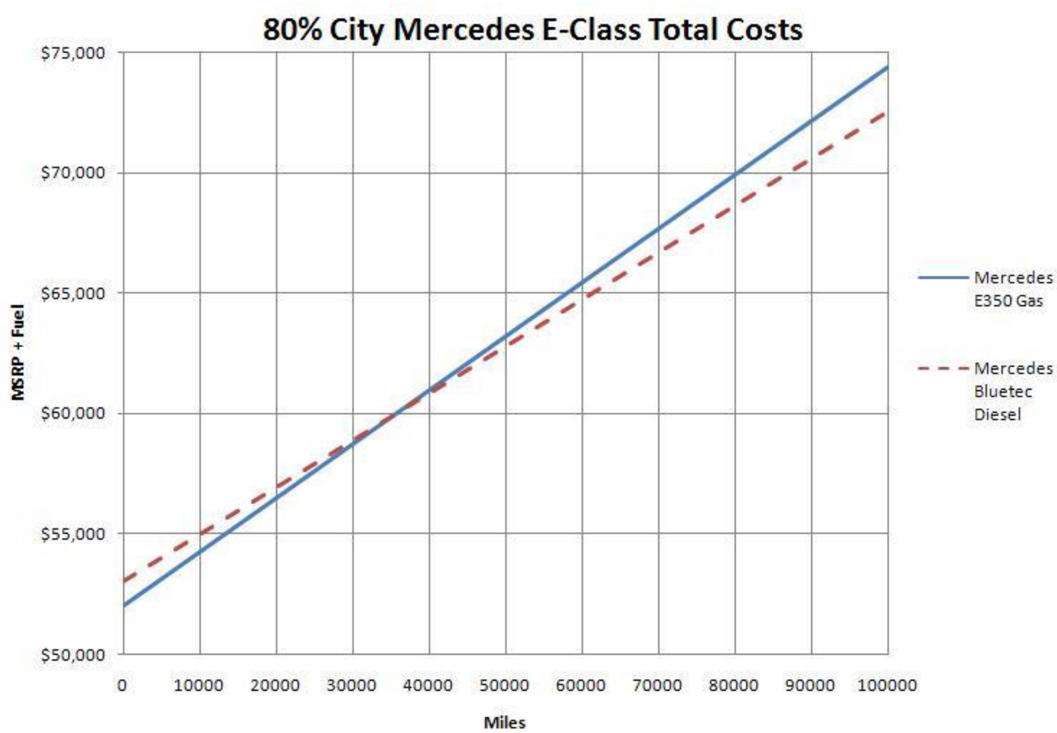

Figure 36– Cost vs. Mile (80%City) Mercedes E-Class

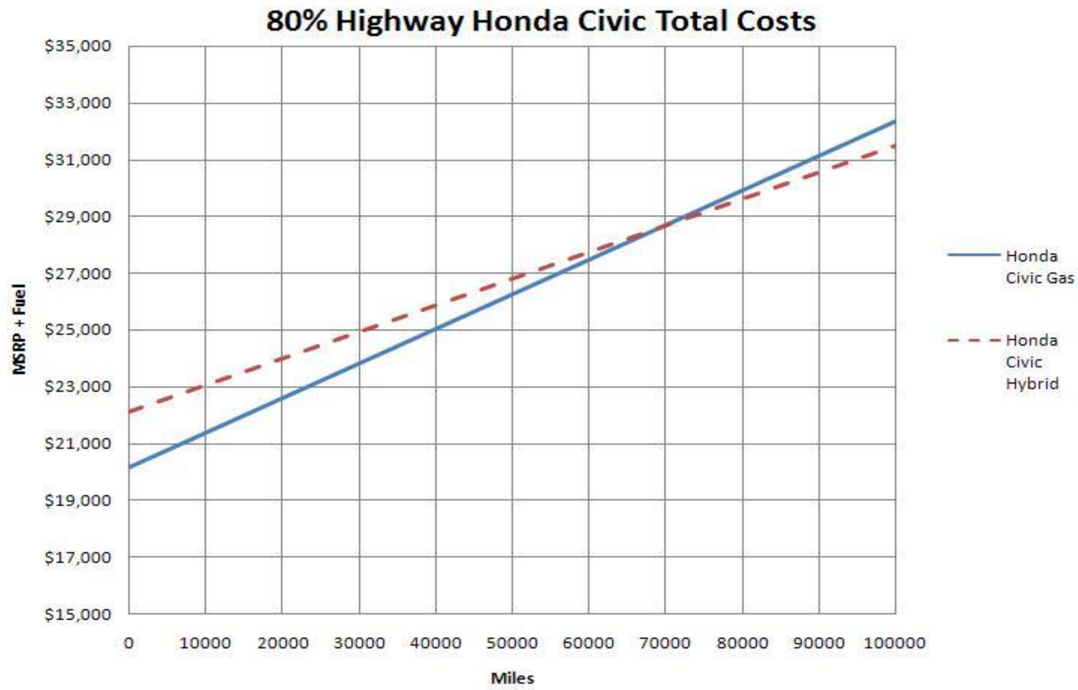

Figure 37 – Cost vs. Mile (80%Highway) 2008 Honda Civic Hybrid

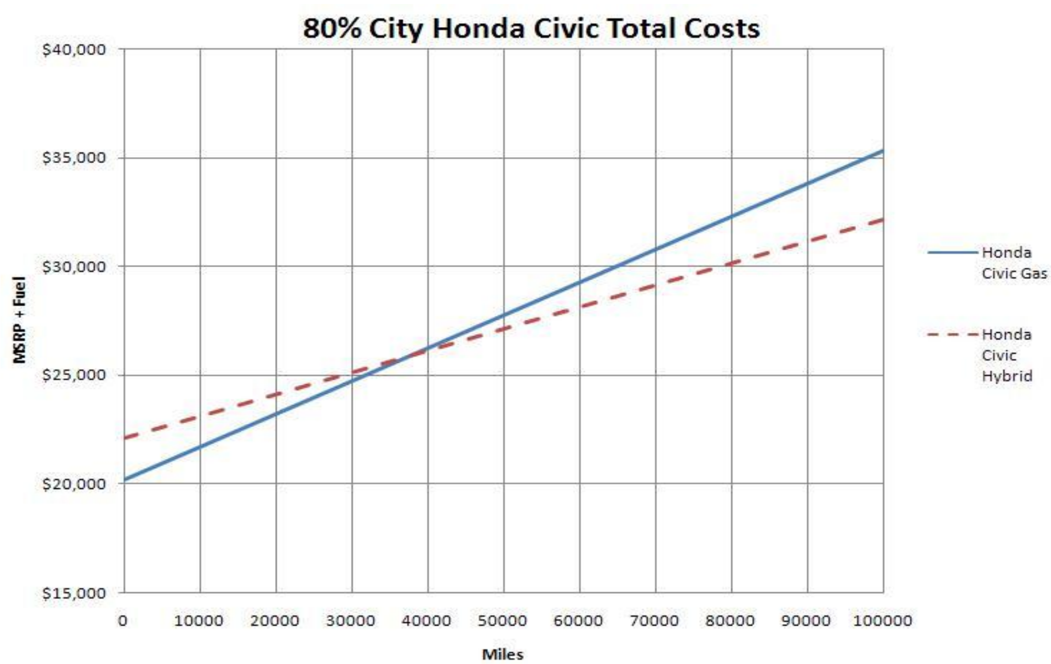

Figure 38 – Cost vs. Mile (80%City) 2008 Honda Civic Hybrid

	A	B	C	D	E	F	G
1	2009 VW Jetta TDI	2.5L Gas	2.0 TDI		Fuel Prices as of Summer Max National Average According to AAA		
2	HP	170	140		MPG Ratings from EPA		
3	Torque	177	258				
4	MPG City	21	30	38			
5	MPG Hwy	29	41	44			
6	0-60	8.5	9				
7	Price of Fuel	4.114	4.845				
8	Cost (MSRP)	19000	22000				
9	Cost/Mile City	=B7/B4	=C7/C4				
10							
11	City/Hwy Ratio	Average Miles per Gallon					
12		2.5 Gas	TDI				
13	80/20	=PRODUCT((0.8*B4)+(0.2*B5))	=PRODUCT((0.8*C4)+(0.2*C5))				
14	50/50	=PRODUCT((B4+B5)/2)	=PRODUCT((C4+C5)/2)				
15	20/80	=PRODUCT((0.2*B4)+(0.8*B5))	=PRODUCT((0.2*C4)+(0.8*C5))				
16							
17	Gasoline			Diesel			
18	Miles Driven	Cost per mile		Miles Driven	Cost per mile		
19	80/20	=PRODUCT(B7/B13)		80/20	=PRODUCT(C7/C13)		
20	50/50	=PRODUCT(B7/B14)		50/50	=PRODUCT(C7/C14)		
21	20/80	=PRODUCT(B7/B15)		20/80	=PRODUCT(C7/C15)		
22							
23	80% City	0	10000	20000	30000		
24	Gas	=SUM(B8+(B19*B23))	=SUM(B8+(B19*C23))	=SUM(B8+(B19*D23))	=SUM(B8+(B19*E23))		
25	Diesel	=SUM(C8+(E19*B23))	=SUM(C8+(E19*C23))	=SUM(C8+(E19*D23))	=SUM(C8+(E19*E23))		
26							
27	80% Highway	0	10000	20000	30000		
28	Gas	=(B27*$E$21)+$B$8	=(C27*$B$21)+$B$8	=(D27*$B$21)+$B$8	=(E27*$B$21)+$B$8		
29	Diesel	=(B27*$E$21)+$C$8	=(C27*$E$21)+$C$8	=(D27*$E$21)+$C$8	=(E27*$E$21)+$C$8		
30							

Table a: Methods for Total Cost Analysis

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	2009 VW Jetta TDI	2.5L Gas	2.0 TDI		Fuel Prices as of Summer Max National Average According to AAA								
2	HP	170	140		MPG Ratings from EPA								
3	Torque	177	258										
4	MPG City	21	30	38									
5	MPG Hwy	29	41	44									
6	0-60	8.5	9										
7	Price of Fuel	$4.114	$4.845										
8	Cost (MSRP)	$19,000	$22,000										
9	Cost/Mile City	0.196	0.162										
10													
11	City/Hwy Ratio	Average Miles per Gallon											
12		2.5 Gas	TDI										
13	80/20	22.6	32.2										
14	50/50	25	35.5										
15	20/80	27.4	38.8										
16													
17	Gasoline			Diesel									
18	Miles Driven	Cost per mile		Miles Driven	Cost per mile								
19	80/20	0.1820		80/20	0.1505								
20	50/50	0.1646		50/50	0.1365								
21	20/80	0.1501		20/80	0.1249								
22													
23	80% City	0	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	
24	Gas	19,000.00	20,820.35	22,640.71	24,461.06	26,281.42	28,101.77	29,922.12	31,742.48	33,562.83	35,383.19	37,203.54	
25	Diesel	22,000.00	23,504.66	25,009.32	26,513.98	28,018.63	29,523.29	31,027.95	32,532.61	34,037.27	35,541.93	37,046.58	
26													
27	80% Highway	0	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	
28	Gas	19,000.00	20,501.46	22,002.92	23,504.38	25,005.84	26,507.30	28,008.76	29,510.22	31,011.68	32,513.14	34,014.60	
29	Diesel	22,000.00	23,248.71	24,497.42	25,746.13	26,994.85	28,243.56	29,492.27	30,740.98	31,989.69	33,238.40	34,487.11	
30													

Table b: Methods for Total Cost Analysis

Appendix B Survey

Survey Results

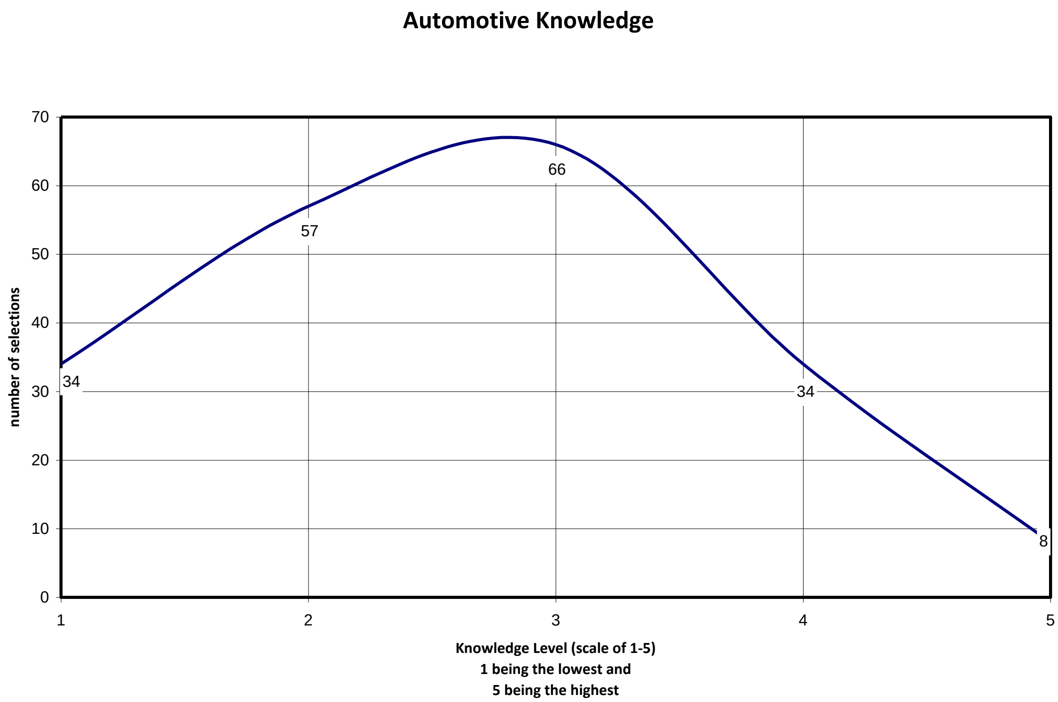

Figure 39: Automotive Knowledge

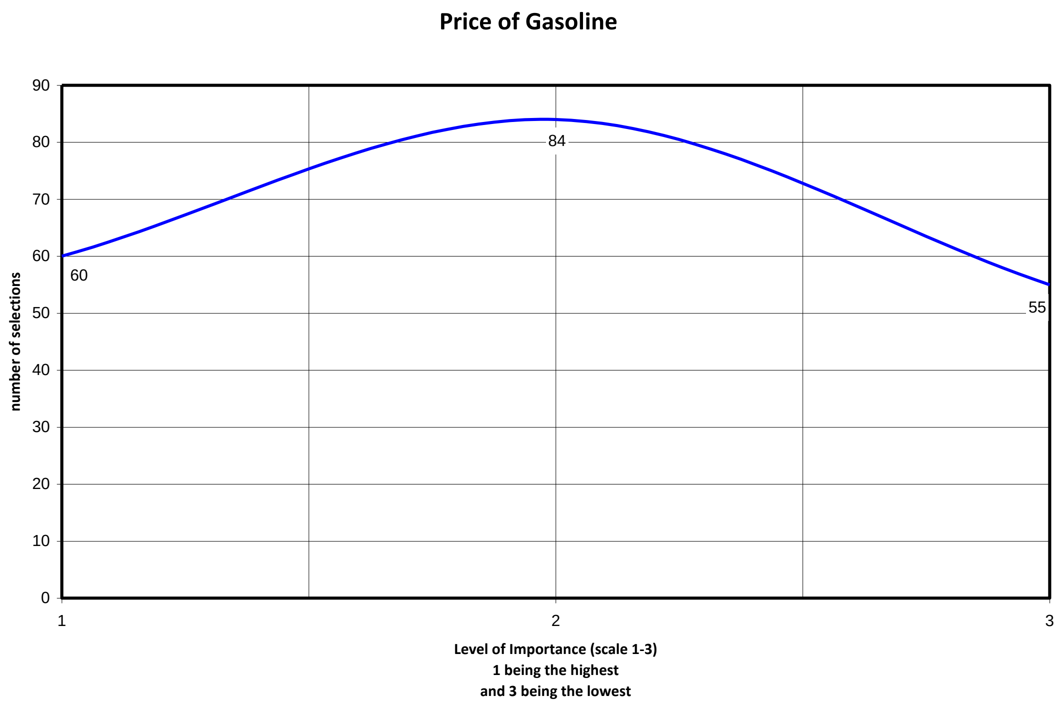

Figure 40: Survey Question 1 Price of Gasoline

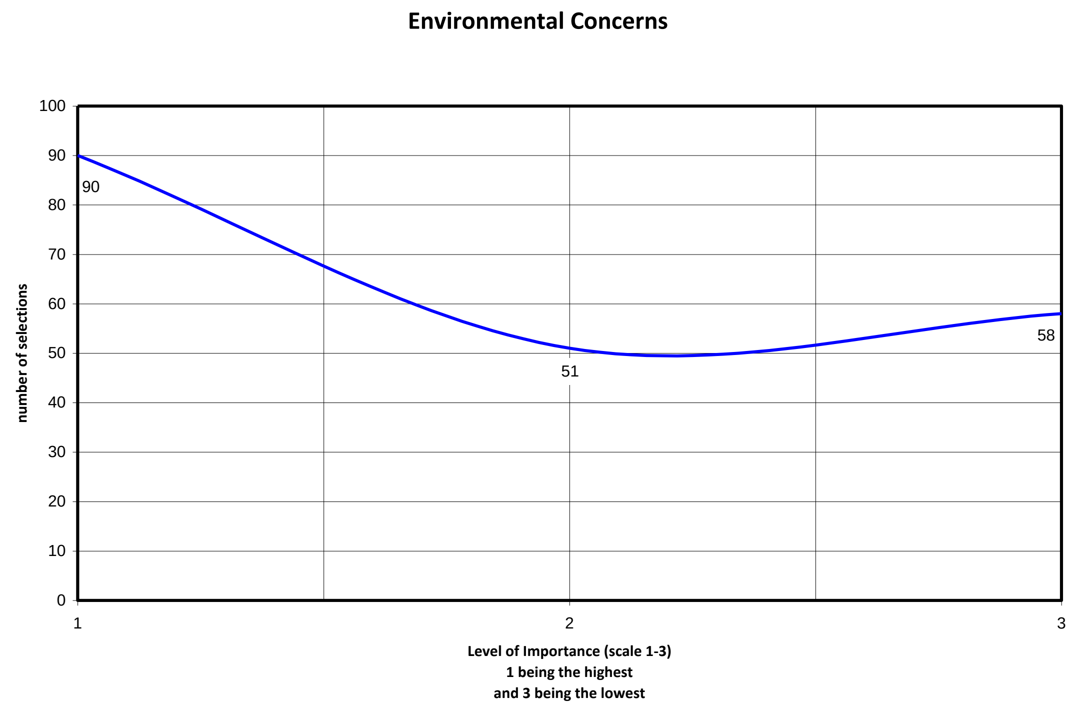

Figure 41: Survey Question 1 Environmental Concerns

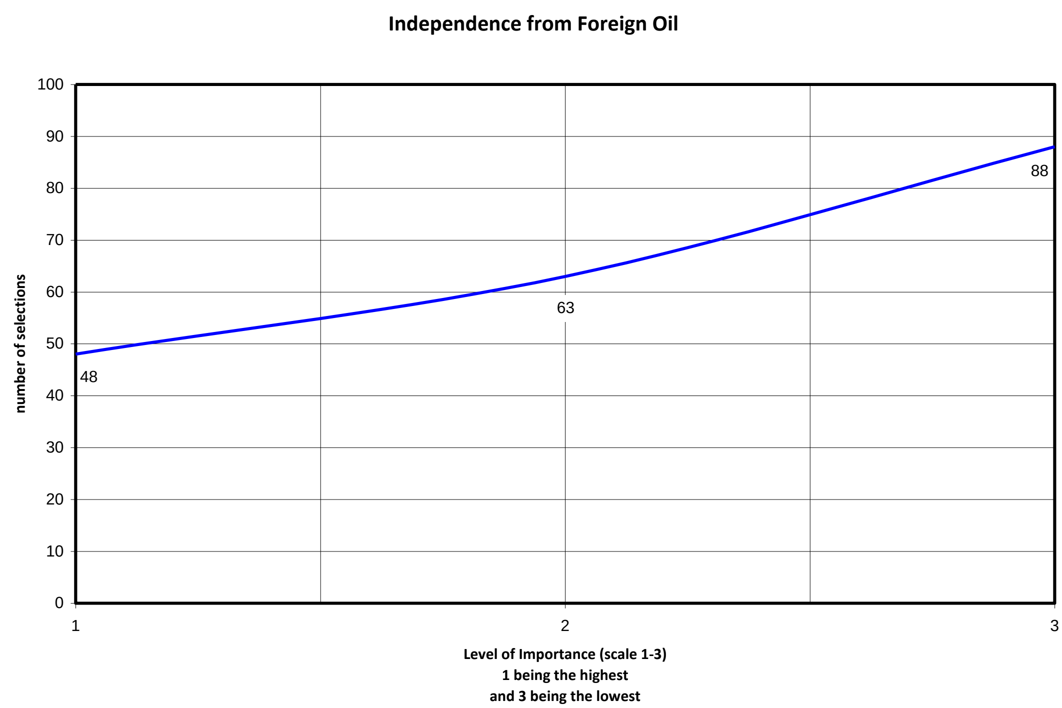

Figure 42: Survey Question 1 Independence from Foreign Oil

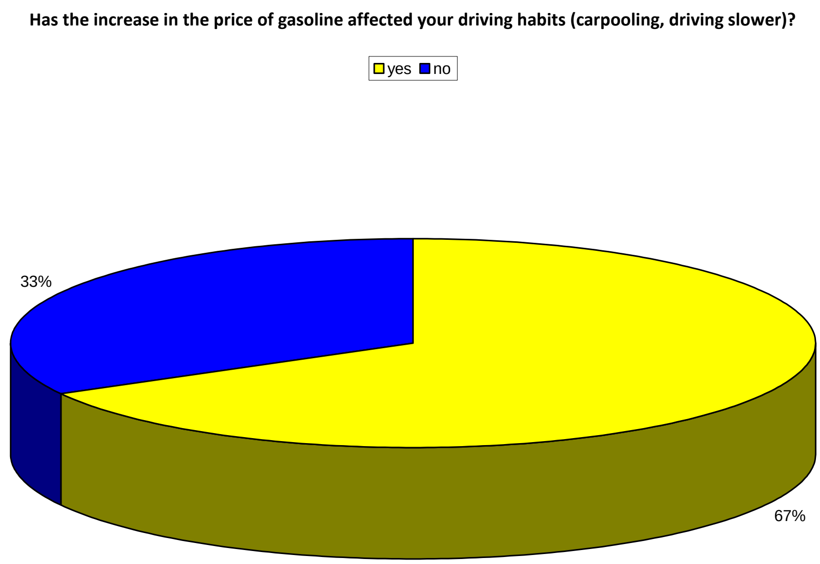

Figure 43: Survey Question 2 Driving habits

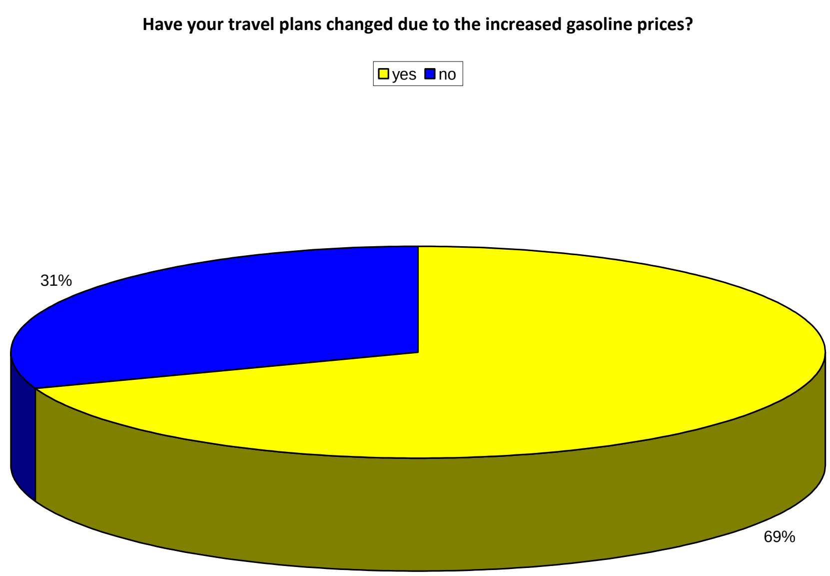

Figure 44: Survey Question 3 Travel plans

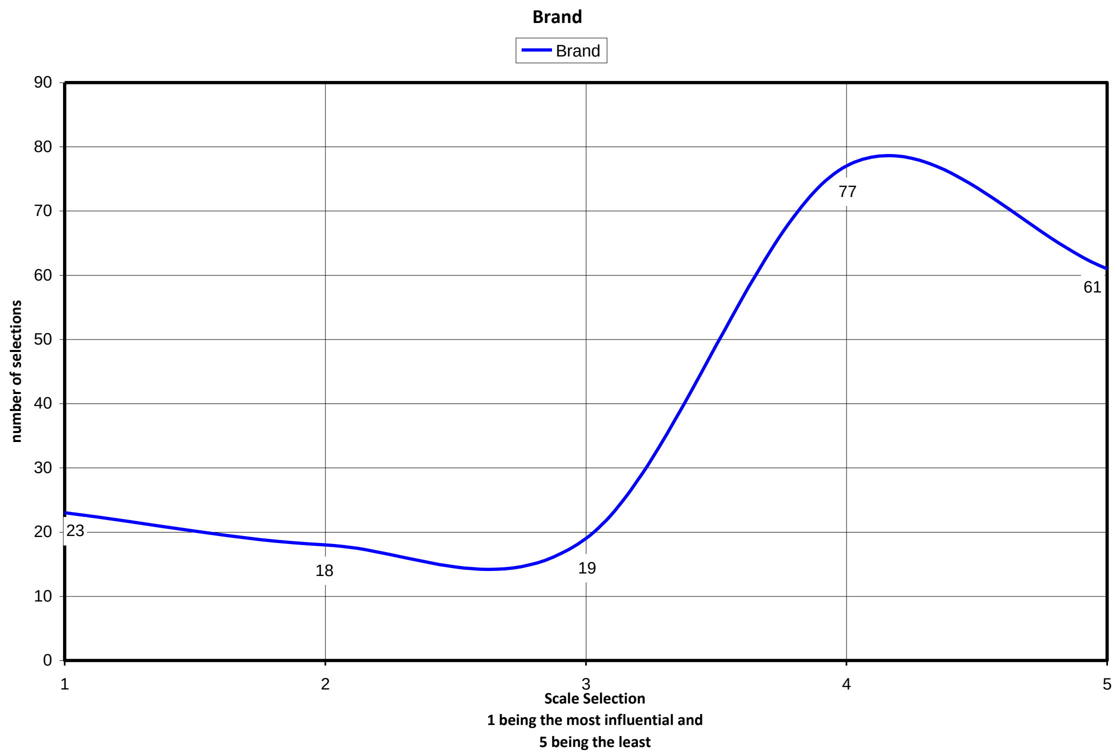

Figure 45: Survey Question 4 Brand

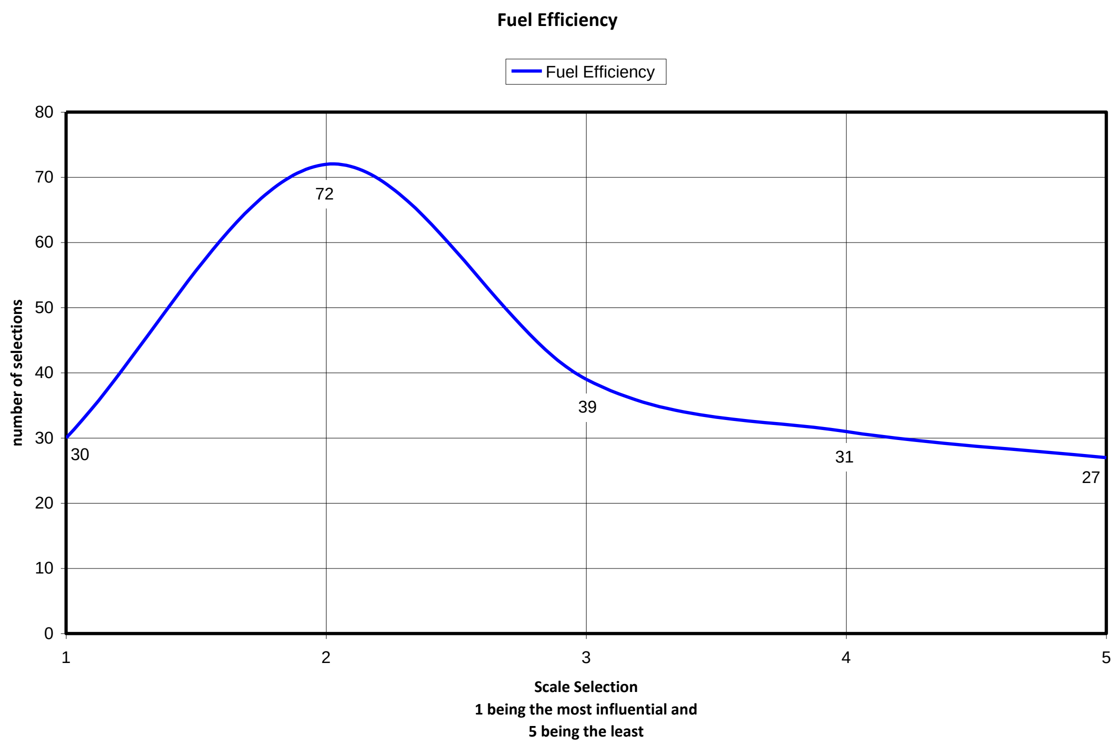

Figure 46: Survey Question 4 Fuel Efficiency

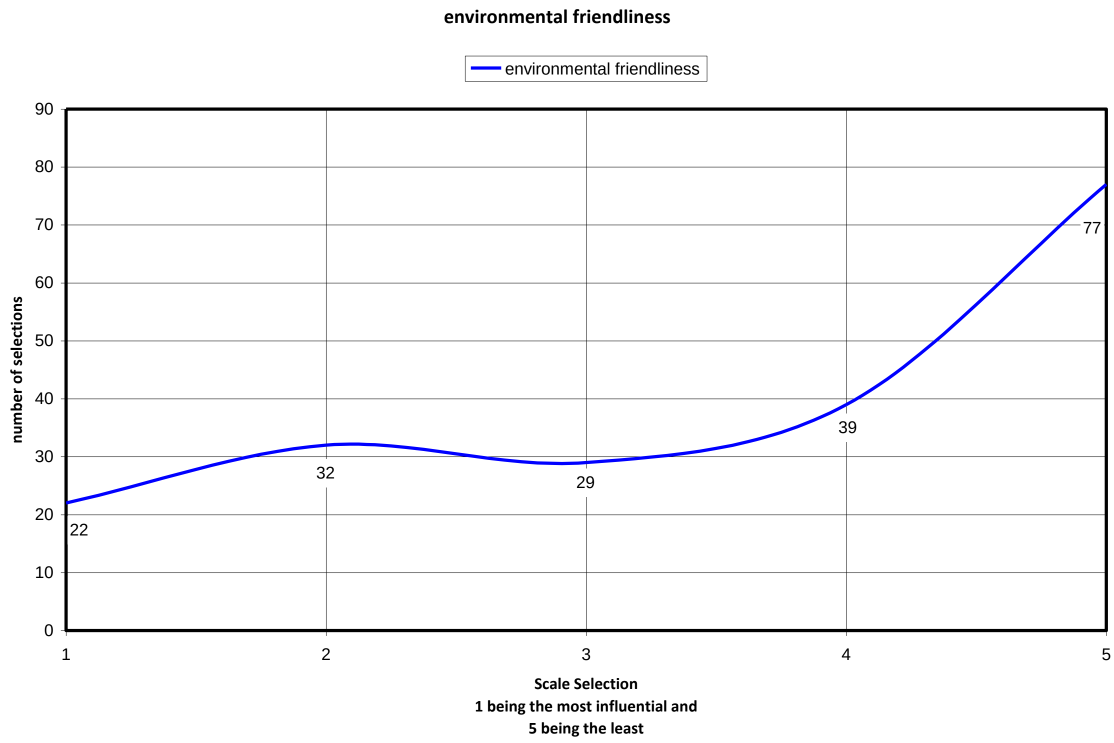

Figure 47: Survey Question 4 Environmental Friendliness

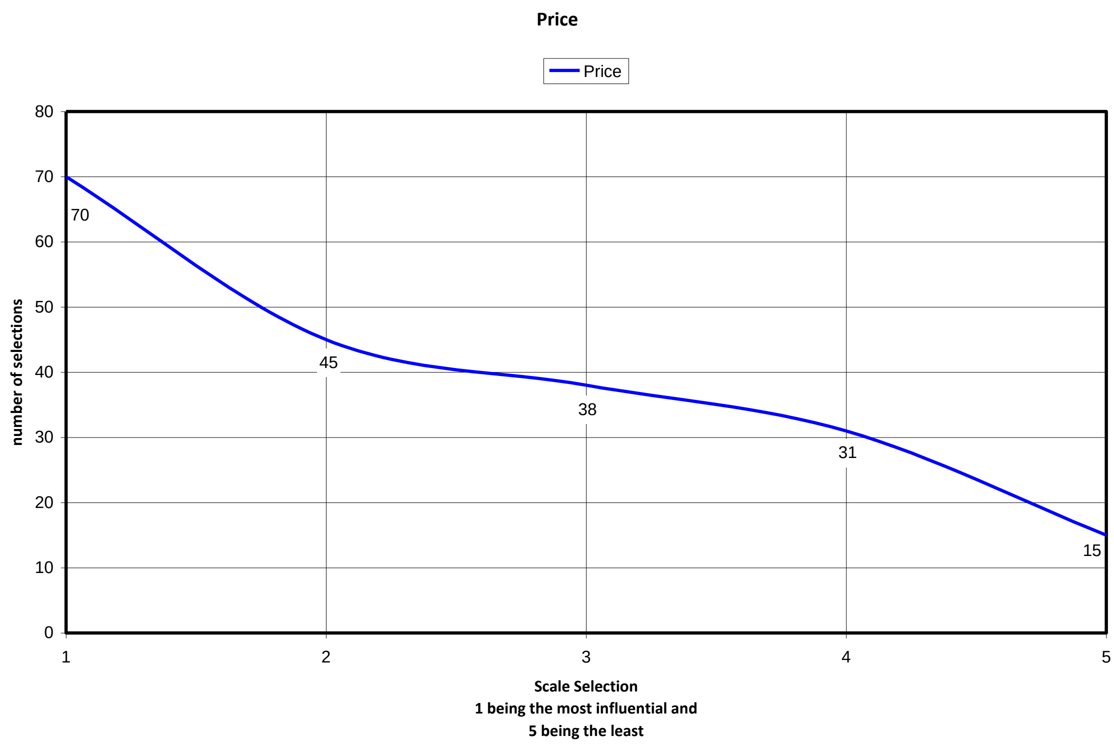

Figure 48: Survey Question 4 Price

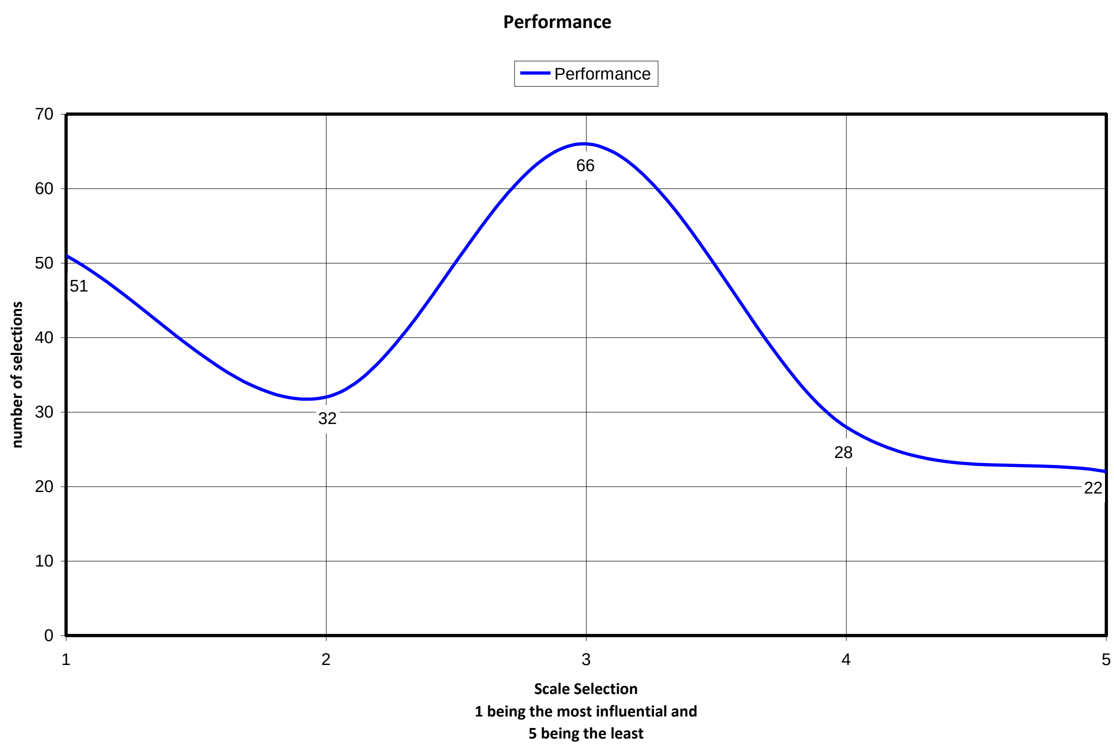

Figure 49: Survey Question 4 Performance

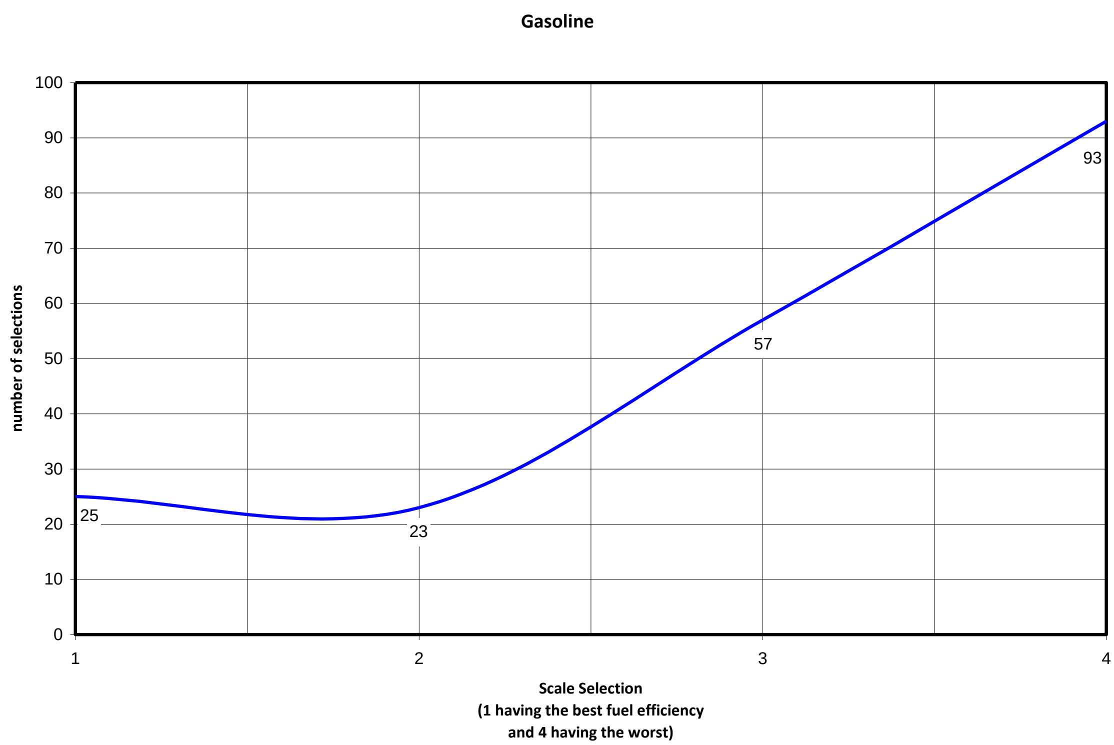

Figure 50: Survey Question 5 Gasoline

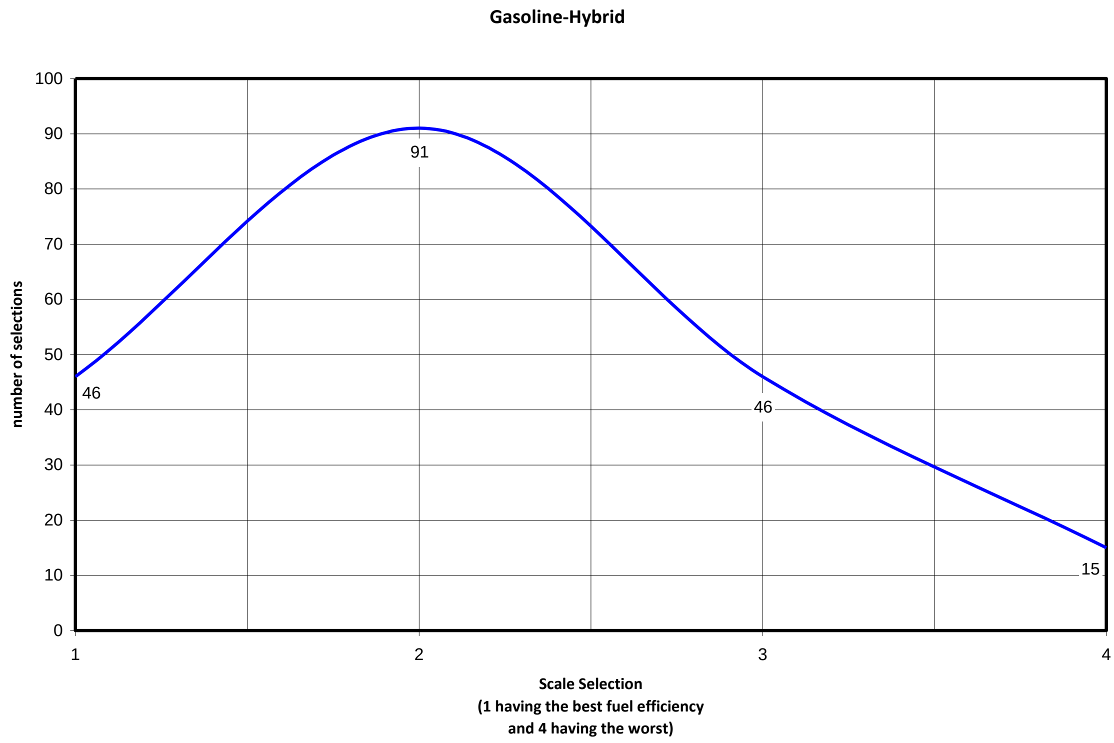

Figure 51: Survey Question 5 Gasoline-Hybrid

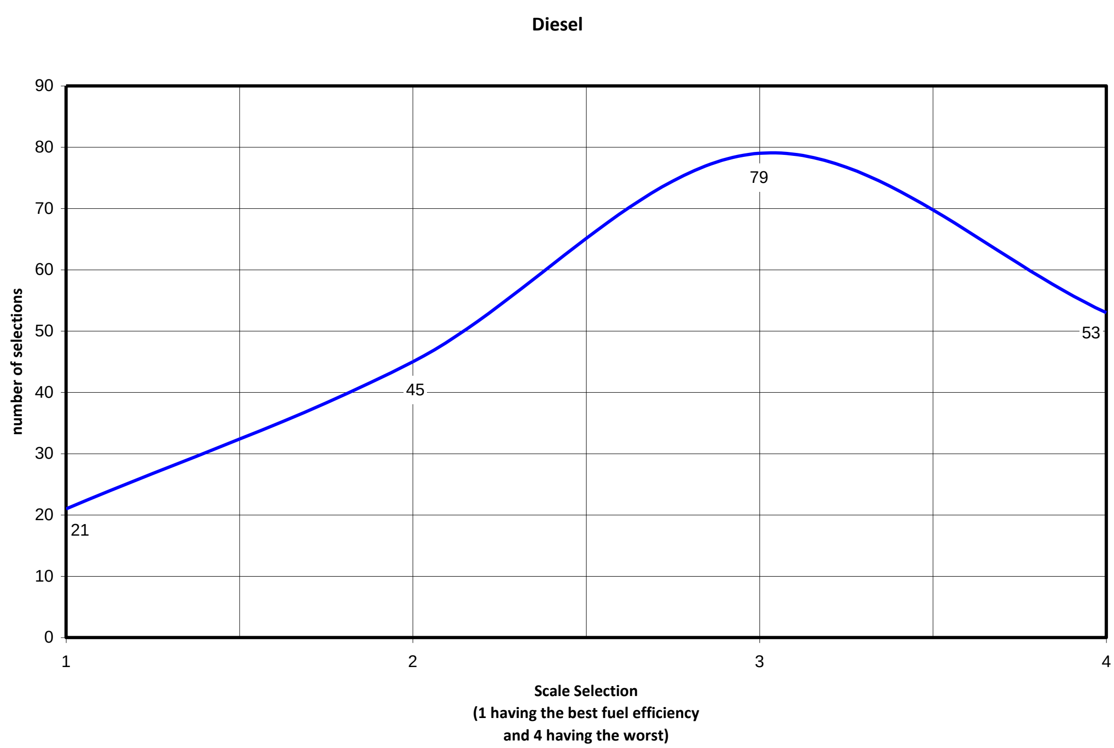

Figure 52: Survey Question 5 Diesel

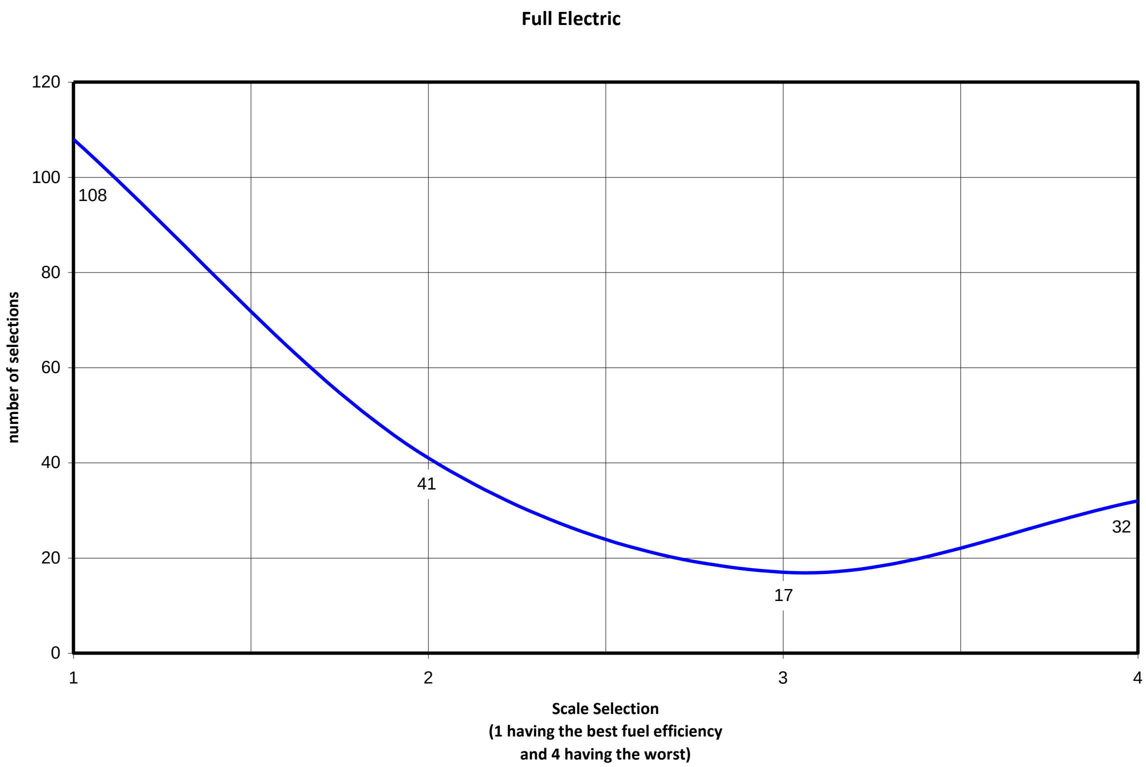

Figure 53: Survey Question 5 Full Electric

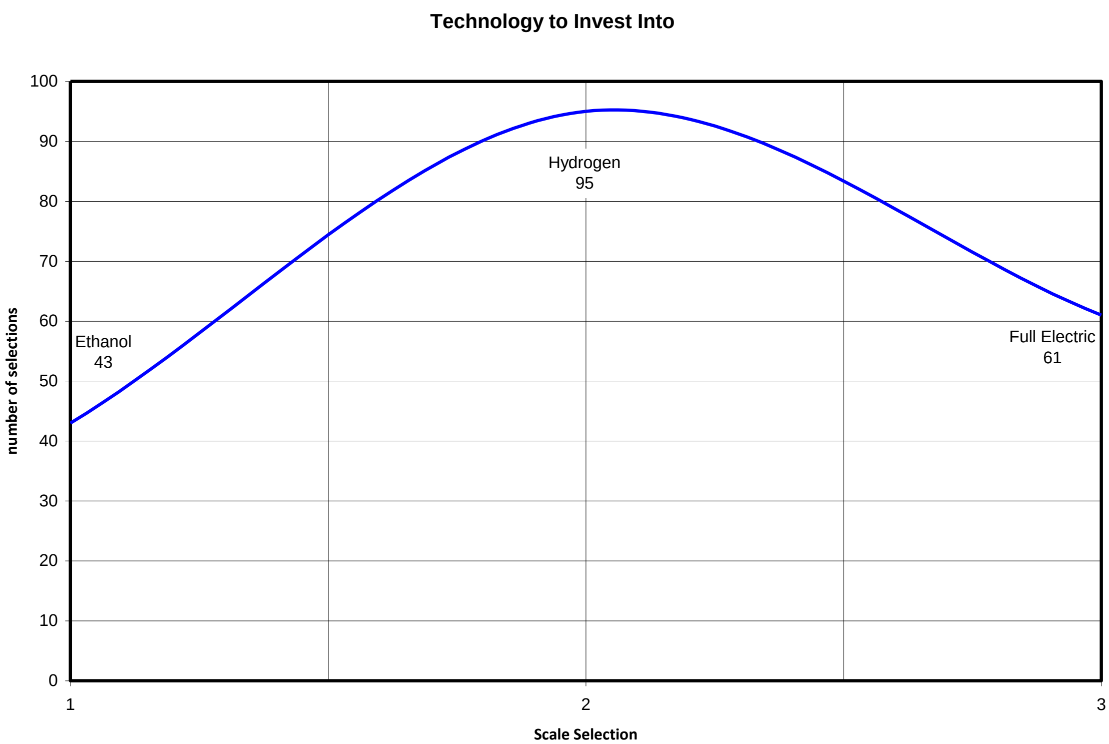

Figure 54: Survey Question 5 U.S. Investment

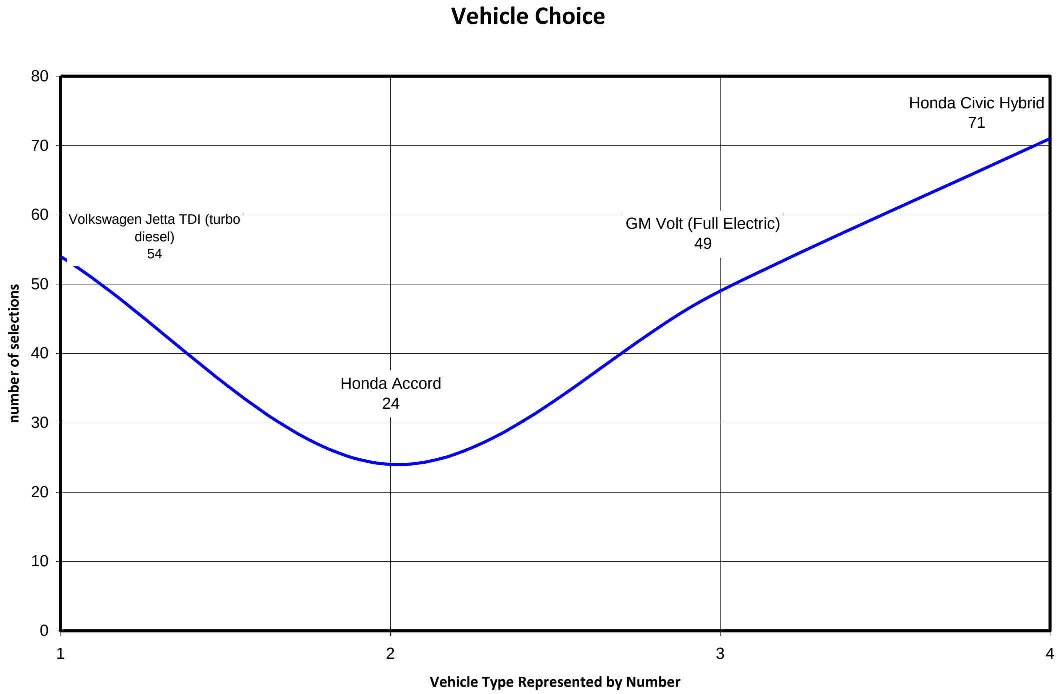

Figure 55: Survey Question 7 Vehicle Choice

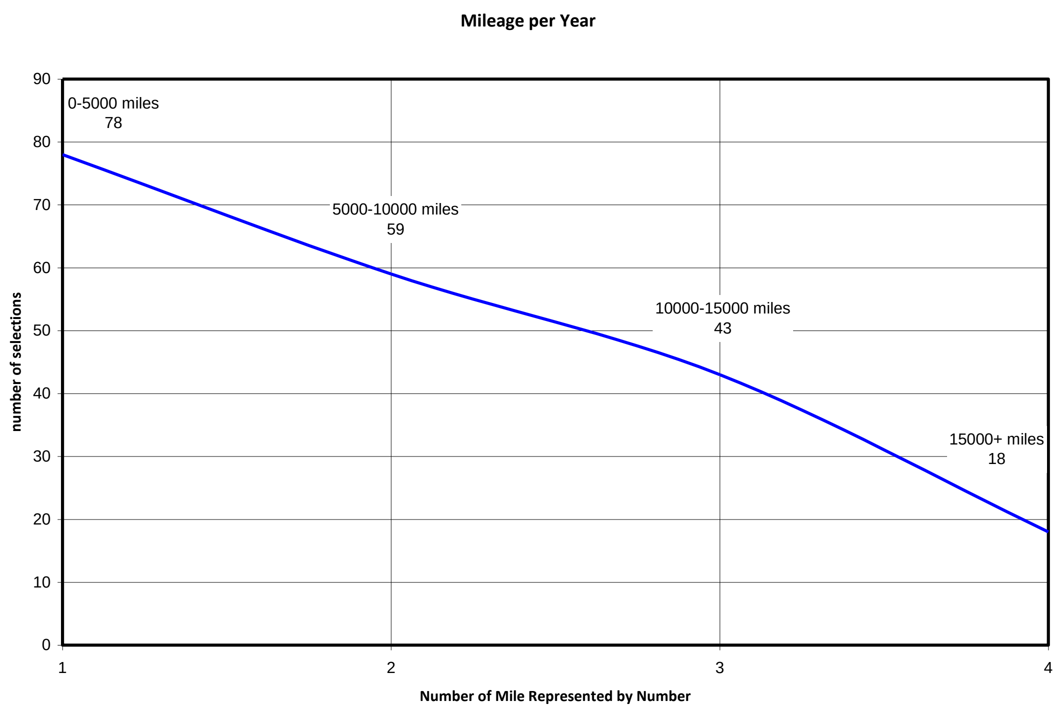

Figure 56: Survey Question 4 Yearly Mileage

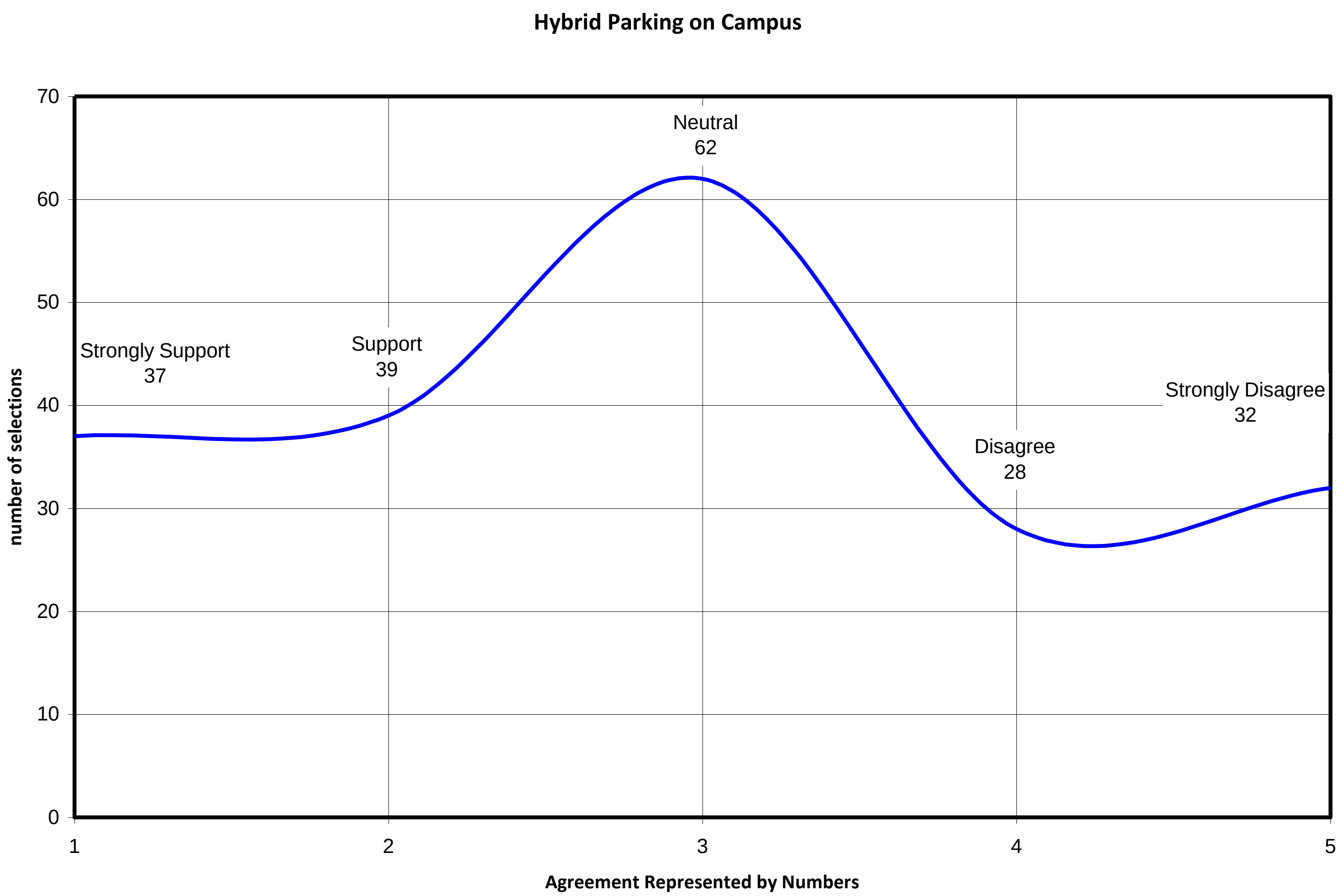

Figure 57: Survey Question 10 Hybrid Parking

Appendix C EPA and CARB Emissions

EPA Vehicle Emissions Grading	Nox Standards (g/mi)
Tier 2, Bin 10 *	0.60
Tier 2, Bin 9-6 *: Cleaner than bin 10	0.10 - 0.30
Tier 2, Bin 5: Average	0.07
Tier 2, Bins 4-2	0.02 - 0.04
Tier 1, Bin 1: Cleanest, equivalent to CARB's ZEV standard	0.00

* : expired in 2006

CARB Phase II		Examples
Low-Emission Vehicle All light vehicles sold nationwide for model years 2004 and beyond were required to be LEV.	LEV	
Ultra-Low-Emission Vehicle Ultra Low Emissions Vehicle, fifty percent cleaner than LEV-II. The LEV rating was required on all new cars sold in California starting in 2004.	ULEV	2007 Honda Odyssey
Super Ultra-Low-Emission Vehicle Super Ultra Low Emissions Vehicle are 90% cleaner than conventional gasoline vehicles. SULEVs emit substantially lower levels of hydrocarbons, carbon monoxide, nitrous oxides and particulate matter than conventional vehicles.	SULEV	Toyota Prius, Honda Insight
Partial Zero-Emission Vehicle Partial Zero Emissions Vehicle, the same as SULEV but with a near-zero evaporative emissions standard and a 15-year, 150,000 mile warranty on emissions equipment.	PZEV	2007 Honda Accord LX, SE, EX, EX-L
Zero Emissions Vehicle A Zero Emissions Vehicle has zero tailpipe emissions and emits 98 percent cleaner emissions than the current model year's average vehicle. Electric vehicles and fuel cell vehicles qualify as ZEVs.	ZEV	Honda FCX

Table 27: EPA and CARB Emissions[63,64,65]

[63] "Clean Vehicles + Clean Fuel = Cleaner Air." EPA. 01 2004. EPA. 03 12 2008 <http://www.epa.gov/tier2/420f04002.pdf>.
[64] Gable, Scott. "What is ULEV - Ultra Low Emissions Vehicle?." Hybrid Cars and Alt Fuels. About.com. 17 Dec 2008 <http://alternativefuels.about.com/od/glossary/g/ULEV.htm>.
[65] Chee, Brian. "Clean-burning, Efficient Cars." Autosite. 17 Dec 2008 <http://www.autosite.com/content/shared/articles/templates/index.cfm/article_page_order_int/8/article_id_int/1478>.