The Road To Hybrid Vehicles

An Interactive Qualifying Project Report

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by

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Abstract

The goals of this Interactive Qualifying Project were (i) to provide a means for an average person to understand the concept of hybrid electric vehicles, (ii) to provide a background of the development of modern transportation, (iii) to evaluate the impact HEVs would have on the environment and society if they were to become widely accepted, and (iv) to determine what knowledge people currently have about HEVs. These goals were met through the use of research, interviews, and a survey.

Chapter 1: Introduction

This project is being performed to study hybrid electric vehicles in today's society. There is an increasing awareness of the impact that our everyday lives and modern technology have on the environment. Stricter government standards limiting pollution has pushed the automobile industry to develop technology that reduces the contribution of vehicle emissions to the degradation of the environment. Since the internal combustion engine is a major contributor to the pollution problem, we find that there is now a fairly rapid growth in electric vehicle and hybrid electric vehicle (HEV) technology. In this project, we focus on understanding the state-of-the-art in HEV science, and the evolution of the technology to its current status, and explore the impact that HEVs will have on our economy and our environment.

A hybrid electric vehicle is a vehicle that has two sources of motive energy; one of the sources being an electric motor, and the other source being an internal combustion engine, gas turbine, diesel engine, or a lean-burn gasoline engine. In Chapter 2 , we give a more detailed description of HEVs. We provide a history of automobile development, showing how ICE, EV and HEV technology have evolved since the first half of the 19th century. Next, an explanation of some of the more innovative systems in the hybrid vehicle is discussed followed by an explanation of some of the differences in the hybrid and conventional systems.

In Chapter 3, we present the various hybrid electric vehicles that are ready for the commercial market in the United States, and we make a comparison between the important characteristics of these vehicles with the comparable internal combustion engine type car.

In Chapter 4, we focus on the environmental, economical and social issues that are relevant to the growth of the HEV industry. There is a discussion of the emissions that arise from motor vehicles and the level to which they contribute to the destruction of the environment. We will also see how the EPA measures these levels and how putting HEVs into regular usage could reduce these emission numbers. Since HEVs represent a major paradigm shift in automobile technology, it is feasible that employment will be affected in the automobile as well as in the petroleum industry, given that the bulk of the oil used in the U.S. is used in transportation. We will also investigate how oil prices have changed through the years and, given this history, what we may expect to happen to oil production and oil prices if HEVs were to become a major mode of transportation in the United States.

Finally, we investigated the public's awareness and perception of hybrid electric vehicles and tried to gauge how much did people know about HEVs. In order to make this assessment, we developed a questionnaire which we distributed to the students, staff, and faculty of WPI, as well as some persons off-campus. The results of this survey and the inferences from these results are presented in Chapter 5 of this project.

Chapter 2: Background

In this chapter, we discuss many different aspects that pertain to the development of HEVs. In section 2.1, we give the definition for a hybrid electric vehicle. In this section, parallel, series and combination configuration are looked at in depth. In sections 2.2.1, 2.2.2, and 2.2.3, the histories of the HEV, the EV, and the ICE are given, respectively. The timeline in section 2.2 gives an overview of the major developments of automobile technology from 1760 until the present. First came the EVs, then the ICEs, then they tried a combination of the two, the HEV. The time line shows important events in the history of these three groups. Section 2.5 illustrates some of the new technology used in HEVs, while section 2.6 discusses different types of energy storage units such as batteries and fuel cells.

2.1 What is an HEV?

A hybrid electric vehicle (HEV) is a vehicle that has two sources of motive energy, one of which is an electric motor. Sources of motive force can be separated into two groups. The first group, which comprises internal combustion engines, gas turbines, diesel engines, and lean-burn gasoline engines, are usually referred to as the hybrid power units (HPU). The lean-burn engine is a more efficient version of a conventional internal combustion engine. The diesel engine is also a popular traditional engine while the gas turbine is relatively new technology in the automobile field. Most HPU systems release emissions since some sort of combustion occurs. The second group consists of flywheels, batteries, and ultra-capacitors. Members of this group are used to power an electric motor. A hybrid electric vehicle will have one member of each group. The most common combination for an HEV in modern day production seems to be the use of a gasoline engine and batteries. No matter what combination is used, there are three ways to configure the motive system of an HEV; using a series, parallel or combination configuration [11].

The series configured HEV uses only the electric motor for motive force. The hybrid power unit, more commonly referred to as an HPU (usually a gas engine), is used to power a generator, which charges the batteries. In this configuration, the HPU supplies no direct motive force for the vehicle. Usually the vehicle will run off the battery (therefore producing no emissions) until the batteries are drained to a certain level. At that time, the HPU turns on and supplies the motor and batteries with power until the batteries are sufficiently charged. The advantages of this configuration are that the HPU does not run constantly, therefore emissions are low, and the range (the distance that the vehicle can travel on one tank of gas) is extended. The disadvantage is a lack of power as the vehicle is running on the electric motor alone, which is weak, compared to a traditional ICE engine [12].

In an HEV that is configured in a parallel fashion, the HPU and the electric motor can both provide direct motive force for the vehicle. Either unit can be used by itself or a combination of the two units can be used to maximize the power produced. The advantage to this configuration is the power produced, as both motors are driving the vehicle. The major disadvantage is the fact that the battery must be charged from an external source [12].

For vehicles currently in production, the most popular configuration is the combination configuration. This system merges both the parallel and series concepts.

Both the HPU and the electric motor provide direct motive force, as in the parallel configuration, while the HPU also has the ability to charge the battery, as in the series configuration. A hybrid of this type holds the advantages of both types of systems. The range of the vehicle is extended through the use of onboard charging and the motive power produced is maximized through the use of both propulsion systems [12].

Although the current HEVs use gas engines and batteries, technology is still being developed to improve upon these systems. While more efficient batteries are still being developed they could be altogether replaced by fuel cells, flywheels, or ultra-capacitors in the future. More efficient gas turbines, diesel engines, or many other alternate fuel engines could replace the gas engine now used in HEVs.

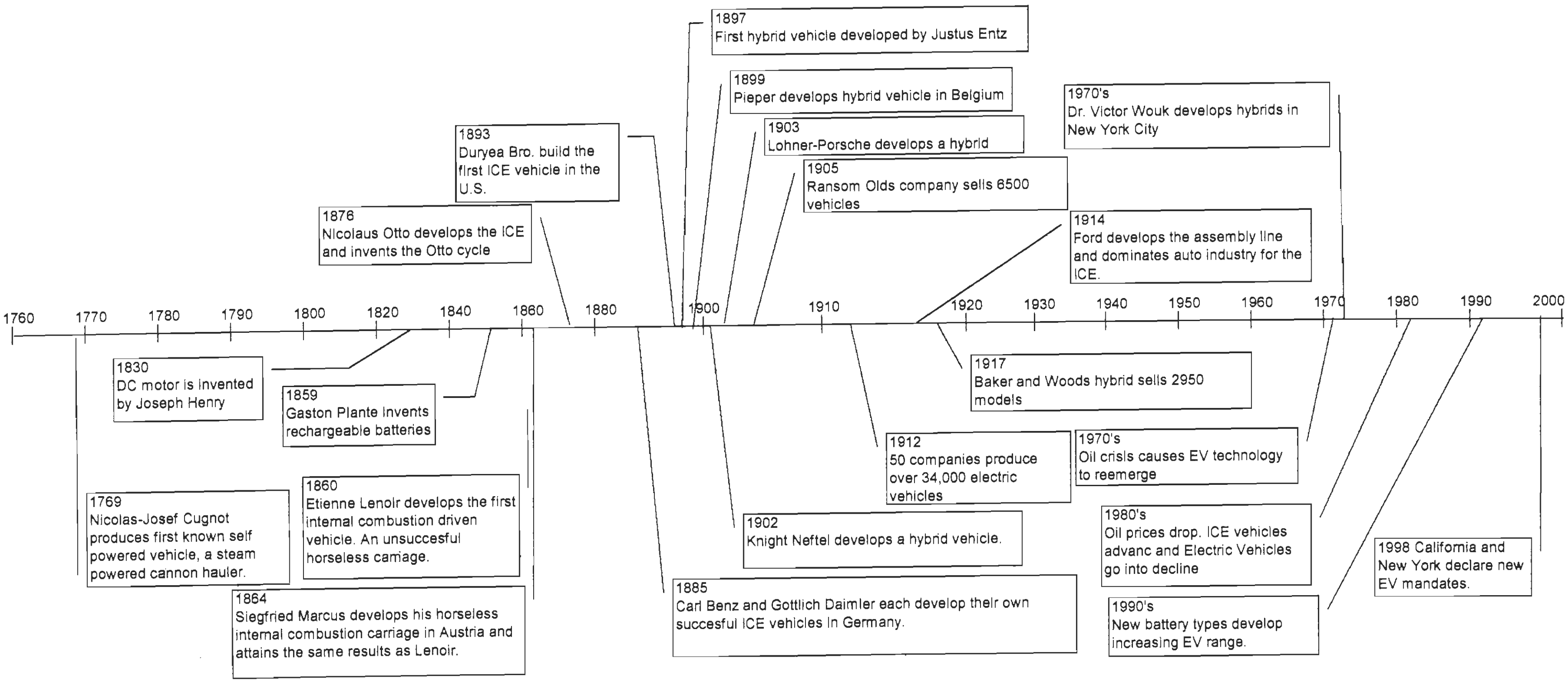
2.2 Automobile History

The timeline on the next page gives an overview of the major technological achievements in automotive history. In sections 2.2.1 through 2.2.3, we expound further on major developments in HEV, EV, and ICE vehicles over the years.

2.2.1 History of HEVs

The idea of the hybrid electric vehicle goes back to the late 1800s when engineers wanted to "combine the high efficiency of the electric drive train with the remarkable energy storage of petroleum fuels" [30]. The electric vehicle of those days had a drive train efficiency of about 90%, while the gas-powered vehicle had a drive train efficiency of approximately 15%. Although the electric vehicle had superior drive train efficiency, it did not generate nearly as much power as a gas-powered engine did. Engineers thought if

Timeline of / Automobile Technological Advancements



they combined the two forms of energy, then the vehicle would have the combined advantages of the gas and electric vehicles of those days [30].

Justus B. Entz, an engineer, designed and built the first hybrid in the United States. Entz was the chief engineer at the Electric Storage Battery Company of Philadelphia, PA. The vehicle was built and tested in 1898, at the Pope Factory in Hartford, CT. Entz's design for this vehicle was of the parallel fashion, that is, both the electric and gas motor were used to move the vehicle. The first test drive was conducted by Entz, one of his mechanics, and Hiram Percy Maxim, an early designer of gas and electric vehicles. The test drive was going well until Maxim tried to get out of the vehicle. While stepping down, his foot got tangled with the wire that carried the electric current. The wire broke and an "electric arc" pierced the fuel tank, igniting the gasoline and the vehicle. Entz and the Pope Factory never made another hybrid vehicle [30].

The next attempt was made by a man by the name of Knight Neftel in 1902. Neftel built the vehicle to compete in the NY-Boston Reliability test. This was an endurance race for all types of vehicles. Neftel was the only competitor to enter a hybrid vehicle. His hybrid design was of the series fashion, that is, the gas-powered engine was only used to charge the battery, while the electric engine is what moved the vehicle. Although Neftel's hybrid made a satisfactory run, he was never heard from again [30].

Two men by the name of Baker and Woods designed the next hybrid vehicle. Their plan was to have a vehicle that could be driven by gas only, electric only or both at the same time. This idea was called the "dual drive principle." After a few experiments, the two men gave up on the vehicle because it was too costly to produce and maintain. In

1917, their "dual drive" vehicle sold for $2,950. This was nearly $2,310 more than other vehicles at that time [30].

The Thomas B. Jeffery Company of Wisconsin constructed its own hybrid in 1912. It was called the "1913 Model Cross-Country Gasoline Electric Motor Car." This hybrid was fairly successful but was eventually discontinued because it was still not as powerful as gas-powered vehicles. Like Neftel's hybrid, the Jeffery hybrid was a series vehicle. The engine design is used in current hybrid designs [30].

American companies were not the only ones building hybrid vehicles around the turn of the century. There were also a few Europeans experimenting with this technology. In Paris, around 1899, the Pieper vehicle from Belgium was first introduced. This vehicle had a small, air-cooled gas engine connected to an electric motor powered by lead acid batteries. The electric motor and the gas engine were both used to move the vehicle, making it a parallel configuration [30]. Another notable company from Europe was Lohner-Porsche. In 1903, they designed a rather powerful hybrid, which had an electric motor connected to each wheel. This vehicle was of the series design [30].

Hybrid technology, for the most part, ceased to exist from the 1920s to the 1960s. In the early 1970s, a man by the name of Dr. Victor Wouk started experimenting with hybrid technology again. Wouk, who is considered to be the leader of modern hybrid technology, liked the idea of a multi-powered electric vehicle. His work on the hybrid was geared toward making a more powerful, longer life battery, while reducing emissions that were polluting the air. Dr. Wouk's experimenting did go well, but the large batteries had to be contained in very large vehicles, such as vans. Since, the hybrids were still not as powerful as the gas-powered vehicle and the bulkiness of the batteries was difficult to contend with, the hybrid technology did not appeal to the public [30].

Hybrid technology development did not stop throughout the1980s and 1990s, but they were not dependable enough to offer to the public. It is now the year 2000 and the HEV has finally hit the U.S. market.

2.2.2 History of EVs

The first DC motor was invented by a man named Joseph Henry in 1831. This invention sparked engineers' interest in electric-powered vehicles and thus began research on the subject. The designs of these first EVs were always changing as engineers tried to make an electric vehicle for two passengers, increase top speed, and make the body weather resistant. Development of EVs started in the 1800s, but real progress wasn't made until 1859 when Gaston Plante, a French engineer, invented rechargeable batteries [6].

After the invention of the rechargeable battery, the EV industry quickly expanded. Over 50 companies worked to produce over 34,000 electric cars in 1912. At this point in time, gas-powered cars were still very unreliable. They required the driver to "crank" the vehicle before driving; therefore EVs were a welcomed alternative. EVs were quieter, more reliable, and more efficient than gas-powered cars, but their limited range led to a decrease in their popularity [6]. With the invention of the electric starter, an increase in reliability, and the cheap price of gasoline, gas-powered cars took over the market and the EV industry was lost [29].

The oil crisis of the 1970s, and concern for pollution in heavily populated cities created a renewed interest in the desire for electric/hybrid vehicles. Sebring/Vanguard, General Motors [11], and Ford developed several electric vehicle models to accommodate this change but the high cost of these EVs made them very difficult to sell. Most carmakers could not afford to make electric cars or could not make a profit. These companies abandoned major research and production of EVs [29].

In the 1980s, oil prices dropped and gas-powered cars became more efficient. New automobiles were getting better gas mileage, and were being equipped with anti-pollution devices. The decrease in oil-prices caused the automobile industry to focus more on what people wanted out of their vehicle, power, which the EV lacked [29].

By the 1990s people had become more environmentally alert and were concerned how the pollution caused by gas-powered cars affected the environment. The emissions from vehicles was still causing great damage. This prompted the government and carmakers to look for ways to improve the air quality. Electric vehicles provided one feasible solution, as they used no ICE engine of any kind so there would be little to no emissions from these vehicles. Carmakers were not willing to risk entering that industry again because of its past problems. The only EVs on the road were those converted from gas-powered cars by hobbyists [23].

Significant changes came about in the 1990s as new types of batteries were being developed. These batteries could greatly extend the range of EVs. Carmakers found ways to increase the efficiency of their vehicles. This increase gave EVs the boost in performance and range that they needed. However, the high price of batteries kept carmakers from bringing EVs to the average consumer. It seemed that the only demand for EVs were in companies that needed fleets of vehicles to travel short distances at a time. They were quick to buy a vehicle that was quiet, could be refueled for practically nothing, and was nearly maintenance free [23].

California and New York implemented legislation to force carmakers to sell EVs because they realized how much the use of EVs could reduce the pollution level in their cities. Most car companies gave little funding for research of EVs. In order to satisfy the states, most carmakers have simply converted one of their gas-powered models into an electric version, and did not expand at all on the technology. In 1998, California and New York declared mandates stating that 2% of all vehicles sold in their states had to be electric cars. Carmakers spent more money fighting these mandates than they did researching. In the end, the mandate was repealed [6].

2.2.3 History of ICE Vehicles

The first documented case of a self-powered vehicle was in 1769 in France. An army engineer by the name of Nicolas-Joseph Cugnot built a three-wheeled steam driven machine. The steam engine used an external flame to boil water in a sealed tank. As the water boiled it created steam and built up pressure in the tank, this pressure was then used to move a piston and create motion. The vehicle moved extremely slowly, and had to stop at very short intervals to build up more steam. Although this was the first documented self-powered vehicle, it was viewed as a failure in its time. The project was abandoned. Several other inventors across the world tried to improve on the idea with no real success. Most of these steam-powered vehicles were large, slow, and difficult to maneuver [24].

The first known attempts to use an internal combustion engine to propel a vehicle were made in the 1860s. A standard ICE engine works on the principle that a petroleum-fuel of some kind is mixed with air, which is then compressed by a piston. This mixture is then ignited with a spark and combusts to produce mechanical energy. This in turn powers the vehicle. A French inventor by the name of Etienne Lenoir mounted an engine he had developed onto a carriage and used the engine to propel the carriage at a speed of one mile an hour. This poor output discouraged Lenoir and he abandoned his experiment. In 1864 an Austrian inventor, Siegfreid Marcus, mounted an engine of his own design onto a cart and ended his experimentation with the same misfortune as Lenoir, considering his efforts as a waste of time [33]. A giant innovation in the development of internal combustion engines came in 1876 when the German inventor Nicolaus Otto created an engine cycle that uses four strokes to produce maximum combustion, which is known as the Otto cycle [24].

The Otto cycle was an important innovation because it made the ICE far more efficient than it had been. The cycle used four strokes of the piston to maximize the combustion. The first stroke of the piston was a downward stroke, which created a vacuum and drew the air fuel mixture in to the cylinder. The next upward stroke compressed the mixture. On the third stroke the mixture was ignited and the piston was forced downward. On the fourth and final stroke, the combusted mixture was forced out of the cylinder by the piston. The major contribution to efficiency in this cycle comes from the fact that the mixture is compressed when it is combusted. This makes the mixture more explosive and allows the piston to harness more of the energy that is released [1].

The first successful vehicles powered by internal combustion engines came out of Germany. Carl Benz and Gottlich Daimler both designed and built successful vehicles in the 1880s. Benz developed a three-wheeled vehicle. Though the output of this vehicle was not impressive, the vehicle featured some important system for future vehicles such as, electrical ignition, differential, valves, cooling system, carburetor and braking systems. Daimler developed an engine, which produced more horsepower and ran at a higher RPM. These two inventors argued publicly over whose design was better and each continued to refine his inventions. When Daimler died in 1900, his name was removed from his company and it was renamed Mercedes. In 1926, the two companies merged to form Mercedes-Benz. By the mid 1890s, self-propelled vehicles were common in Paris the term automobile was coined [33].

In the United States, the industry was a bit behind. The first successful internal combustion vehicle wasn't built in the U.S. until 1893. It was built by the Duryea brothers from Peoria, Illinois and was manufactured in Springfield, Massachusetts. The first financially successful motor company in the U.S. was the Olds Company. This company started as a steam vehicle manufacturer in 1887 and switched to internal combustion in 1896. By the year 1905, 6500 Oldsmobiles were being sold annually. In 1903, Henry Ford opened the Ford Motor Company. The company was only moderately successful until 1914, when Ford opened the first assembly line and became the dominant force in the auto industry for the next eighteen years. By the year 1924, half of the cars in the world were Fords [24]. Ford's grasp on the auto industry ended after World War I.

Its monopoly had caused the closing of some small auto companies and the making of others. General Motors was incorporated in 1908 and was a merger of several smaller companies (Buick, Cadillac, Olds, and Pontiac). This company along with Dodge and Chevrolet provided competition for Ford.

By 1930, the modern automobile was mechanically developed [24]. Any improvements in the automobile since 1930 have been mostly the result of technological developments in areas such as safety, efficiency, performance, and emissions output. Innovations in machining, manufacturing, and computers have led to more efficient, stylish, and modern automobiles.

2.3 New Technology

With the advent of HEV technology, many new automobile systems and technologies have been developed. Efforts have been made to maximize efficiency in existing systems, while new systems have been developed to replace obsolete systems. This section looks at three of these systems: regenerative braking, the thermal management system, and the energy management system. A brief explanation is given for each system.

Regenerative Braking

Regenerative braking refers to the innovative braking system used in modern hybrid electric vehicles. This system converts the kinetic energy of the moving vehicle into electrical energy to enhance the range and efficiency of the vehicle by recharging the energy storage device [5].

The braking system works in a reverse fashion of an electric motor. While a motor utilizes the fact that current passing through a coil of wire creates a magnetic force on a metal shaft that sits within the coil causing the shaft to spin, the regenerative braking system makes use of the reverse operation. A metal rod attached to a spinning automobile wheel sits within an coil of wire. When the brakes are applied, this coil is attached to a load and the spinning magnetic rod induces an electric current in the coil. Thus, kinetic energy is converted to electric energy which is stored in the electric storage unit. At the same time, the electric current in the coil induces a force on the spinning rod which counters its motion and causes the wheel to lose kinetic energy and to eventually stop spinning - braking.

Today, mechanical brakes are combined with regenerative braking, but in the future, mechanical brakes may only be needed in emergency stop situations [11].

Thermal Management System

The thermal management system of a hybrid vehicle controls the temperature in five major components of the hybrid electric vehicle system. These components are the batteries, power units, exhaust system, fuel system, and waste utilization. The management system absorbs heat from some of these systems and distributes it. For example, hybrids have batteries that, when operating, reach temperatures that are extremely high. For safety purposes, these batteries have to be contained in special compartments that regulate the temperature. Batteries have also been proven to perform best when they are operating at a certain temperature [5]. The thermal management system controls the system that monitors and adjusts the battery temperature.

Power units can reach unsafe temperatures just as the batteries do. They also need to be cooled properly for safety reasons. This is another function that the management system performs. When a vehicle is started after it has not been running for several hours, it is considered to be a cold start. An objective of the management system is to continuously warm the hybrid engine, even when the vehicle is off. This prevents a cold start and therefore reduces the amount of exhaust emitted. Many emissions not only come from the burning of the fuel, but also from evaporation from the fuel tank. The thermal management system also helps regulate the amount of emissions released from the fuel tank.

Since the hybrid power units in hybrid vehicles are generally small, they do not produce enough heat to warm the cabin as is done in conventional ICEs. Heat absorbed by the thermal management system is used for this purpose [4]. This is referred to as waste heat utilization.

Energy Management System

The energy management system in a hybrid performs a simple task. It controls all of the electrical functions and monitors the flow of electrical energy in the vehicle. Accessories such as lights and the air-conditioner are controlled by the energy management system. The energy management control system also controls energy coming in from regenerative braking and the HPU, and going out to the batteries and electric motor [4].

2.4 HEV vs. ICE

In this section, we compare and discuss a few of the different systems used in an HEV, and in a traditional motor vehicle. We make a comparison between the different systems. This section helps to illustrate how the traditional ICE vehicle systems are adapted and have been improved for use in the HEV. In particular, we look at tires and rims, suspension, steering, charging, cooling, and heating.

Tires and Rims

Most average car tires are operated at a pressure of 33-35 p.s.i, while modern hybrid and electric vehicles are operated at higher tire inflation, about 50 p.s.i. This increased tire pressure reduces the rolling friction of the tire and results in less energy loss. Also, the rims on modern hybrid vehicles are much lighter than standard vehicles, about half the weight, resulting in less power loss. This reduction in power loss allows the vehicle's range to be extended and uses less energy to do so.

Suspension

The suspension system in a vehicle is the system of linkages that allows the vehicle to travel over rough roads and still provide a smooth ride for its passengers. The suspension in hybrid vehicles uses the same basic principles as conventional vehicles with some minor exceptions. The suspension in hybrid vehicles had to be designed to work with harder tires, due to the increased air pressure, and more attention was paid to the weight of the system.

Steering

In a conventional vehicle, the steering runs off of a hydraulic pump that receives its power from the combustion engine. This is possible in a conventional vehicle because the engine is always rotating. In contrast, a hybrid vehicle's electric motor is not always rotating. In order to solve this problem, a separate smaller electric motor is used to run a hydraulic pump and provide power assisted steering.

Charging

In a conventional vehicle, all electrical components run off of an alternator when the vehicle is running. This alternator also charges the standard car battery while driving. In a hybrid vehicle, most components run off of the battery in the car, which is much larger than that of a conventional vehicle and stores much more energy. The means by which this battery is charged depends on the configuration of the vehicle. In most cases the battery is either charged by an external charger or by a separate alternate fuel motor and generator inside the vehicle. In most modern HEVs regenerative braking also helps charge the battery.

Cooling

In a conventional vehicle, cooling is provided by liquid forced through a radiator with fans. In a hybrid vehicle, the electric motor is sufficiently cooled by air. However, in some hybrid, vehicles the HPU is liquid cooled and a similar system is used. Generally this system is much smaller than that of a conventional vehicle. In some hybrid vehicles, the HPU is also air-cooled.

Heating

In conventional vehicles, the heating system is run off of the liquid coolant system. In the absence of this system, hybrid vehicles use a variety of alternatives from electric heaters to alternate fueled heaters.

2.5 Batteries and other Storage Units

When fuel is converted into energy in a hybrid electric vehicle, the energy must be stored somewhere until it is used. The energy storage unit varies from HEV to HEV, but the most common is the battery. Other energy storage units include the fuel cell and the flywheel.

A battery is a device that stores electrical energy through the use of chemical reactions. The most common battery used in HEVs today is the lead acid battery. In a lead acid battery, the negative electrode (anode) is made of solid lead, while the positive electrode (cathode) is made of lead oxide. These electrodes are submerged in a solution of sulfuric acid and water (see figure 1). When the external circuit is open no chemical reactions take place. When an electrical load is connected to the battery, the transfer of electrons from one electrode to another allows for a reaction to take place. The negative electrode reacts with the sulfuric acid to produce a lead sulfate and water. This reaction also releases electrons into the external circuit, resulting in a continuous electron flow. When these electrons reach the positive electrode, they cause it to react with the sulfuric acid and more lead sulfate and water are produced. The sulfate is a solid that coats the lead electrodes while the water makes the acid solution more diluted. The accumulated coating and continued dilution eventually render the battery "dead". These reactions result in the continuous flow of electrons through the external circuit (see figure 1).

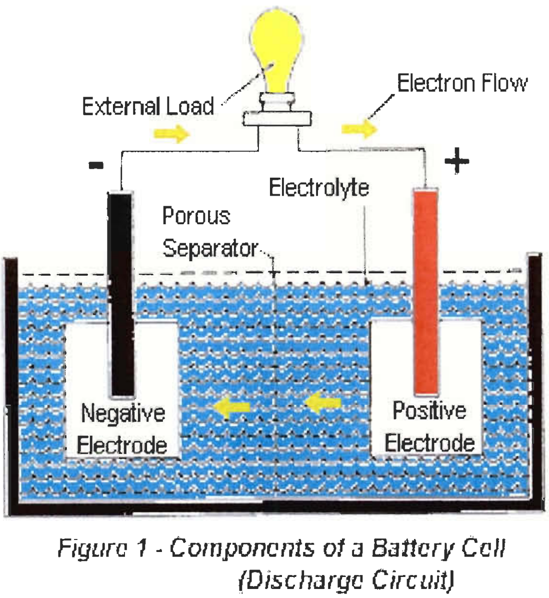


Figure 1

Lead acid batteries currently come in three different voltages: 6V, 8V, and 12V. A 6V battery should be used if the operator is most concerned about range, while a 12V battery would be used if the operator were seeking performance (meaning power). The 8V battery offers the best of both worlds. The operator gets a battery with good range and also performance. Eight volt batteries are currently used in golf carts. The specifics for a lead acid battery are listed in table 1.

	Pb Acid
Specific E*	**33 Wh/kg**
E* Density	**92 W/kg**
SP	**75 W/kg**
Cycle Life	**400-800**

Table 1

Specific energy (E*) measures the total amount of energy in watt-hours which the battery can store per kilogram of mass. The energy density of a lead acid battery is the amount of energy a battery has in relation to its mass. A lighter battery with the same specific energy would have a higher energy density. Specific power (SP) is the maximum number of watts per kilogram a battery delivers at different charge levels. The SP is highest when the battery is fully charged. The cited SP is usually measured when the battery is about 80% charged. As the battery is discharged, the SP and acceleration ability of the vehicle decrease. The cycle-life of a battery is the number of times the battery can be charged and discharged before losing power. This means, when the cycle-life of a battery has been reached, each charge after that will not fill the battery capacity. Lead acid batteries average a weight of 65 lbs.

One problem with the lead acid battery is that it is affected by weather. The concentration of sulfuric acid contained in the battery changes as the temperature does. If it is 0° C, the battery will only operate at 70% of it's charge. At 110°, the battery will work too hard and discharge much faster. The recommended efficiency level for a battery used to power a vehicle is achieved at 78 degrees. An insulated box is also recommended for superior performance. As for maintenance, the lead acid battery should be cleaned once a month with distilled water and baking soda to prevent ion tracking, which is an accumulation of dirt and moisture that creates tracks on the battery. These tracks may affect charging because they act as a ground.

Batteries that are currently being tested but are not yet in production are referred to as near term batteries. The specifics for near term batteries are given in table 2.

Near Term Batteries

	Near Term
Specific E*	**42 Wh/kg**
E* Density	**93 Wh/L**
SP	**240 W/kg**
Cycle Life	**800-1000**

Table 2

Nickel iron and nickel cadmium are two near term batteries that are currently being used in Europe and Japan. NiCd and NiFe have very high densities. Cadmium is an element that can be made from recycling copper, lead, zinc and cadmium. There are a couple of disadvantages to the NiCd battery. One is that after extended use, the battery overheats. Also, cadmium is toxic, so recycling must be done very carefully. A disadvantage to the NiFe battery is that it can build up an unsafe level of hydrogen, which can be dangerous. This problem is currently being worked on.

Batteries that are still in the invention stage are called mid-term batteries (Table 3).

Mid-Term Batteries

	Mid-Term
Specific E*	80-100 Wh/kg
E* Density	N/A
SP	150-200 W/kg
Cycle Life	600

Table 3

Nickel-metal hydride is one of the current mid-term batteries. A NiMH battery is made up of non-toxic recyclable material that is environmentally friendly. It gets twice the range and life cycle of a lead acid battery and it can be overcharged. That is, the battery can be charged past its full limit. The metal part of the NiMH is an alloy composed of vanadium, titanium, nickel and other metals. Another midterm battery is the NaS (sodium sulfur). The battery must be kept at a temperature of 310-350° C because the sodium and sulfur must be kept molten to work properly. When this type of battery is used there is a safety concern because the temperature of the battery is so high.

Batteries that are being tested but are still mainly on the drawing table are long term batteries (Table 4)

Long Term Batteries

	Long term
Specific E*	400 Wh/kg
E* Density	N/A
SP	400 W/kg
Cycle Life	1000 +

Table 4

Lithium–Ion batteries are currently being tested as long-term batteries. The specifics are very high, but are very expensive.

Some other energy storage concepts that are just beginning to be tested are flywheels and fuel cells. A flywheel is a wheel with a 12-inch diameter that is spun by a small motor. After enough momentum is built up, the wheel spins at about 100,000-RPM's, or 1,666 times a second. Magnets on the wheel's axle spin rapidly around wire coils and produce electricity, which is transferred to the motor that controls the wheels on the car. The flywheel has one major disadvantage. One flywheel does not produce enough energy to power a car. There would have to be many in the car and that can become cumbersome because each wheel weighs about 90 lbs.

Fuel cells operate like batteries, but do not require recharging as long as fuel is supplied. A fuel cell consists of two electrodes enclosing an electrolyte (figure 2). Oxygen is fed into one end of the cell and hydrogen into the other. A catalyst makes the hydrogen atom split into a proton and an electron. The electron is routed around the electrolyte as the proton passes right through it. When the proton and the electron meet again on the other side, they combine with the oxygen molecule and create water. As the electron is routed, it is used as energy for the vehicle.

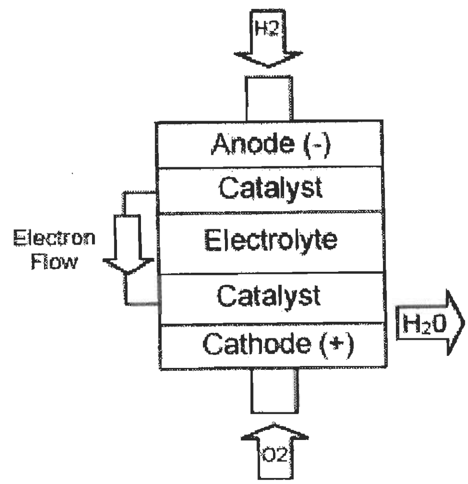

H2
Anode (-)
Catalyst
Electron
Flow
Electrolyte
Catalyst
H₂0
Cathode (+)
O2

Figure 2

Chapter 3: Current Technology

3.1 Current HEV Models

As of May 2000, there is only one hybrid vehicle on the market in the U.S., the Honda Insight. In June, Toyota will introduce its hybrid vehicle, the Prius. General Motors is currently working on several concept hybrid vehicles.

3.1.1 Honda Insight

As a leading automotive company throughout the world, Honda has had the opportunity to introduce the first production gasoline-electric hybrid automobile sold in the United States, beating the Toyota Prius by only a little over half of a year. Honda uses batteries to supply the electric motor with energy and a lean burn gasoline engine (ICE) as a HPU.. The Insight has been named one of the top 100 achievements of 1999 by "Popular Science" [22]. The Insight is an HEV that runs in a combination configuration, switching from the gas engine to the electric motor during acceleration, therefore reducing the amount of gas used by the car. The mileage is 61mpg in the city and 70+mpg on the highway. The ICE is a lean-burn 3 cylinder with 1.0-liter displacement. Lean-burn means that there is more air than gas used in the cylinders, which increases the fuel efficiency. The electric motor runs on 120 D-batteries that are constantly being charged by regenerative braking and the ICE [13].

The combination setup in the Insight works as follows. The electric motor is bolted to the crankshaft that converts engine energy into electric power that feeds the 120 batteries. This is a combination setup with both the gasoline engine and the electric engine driving the car. There is virtually no possible way for the batteries to die as they are continuously charging while driving and braking. The only scenario that may cause the battery to drain would be driving at speeds over 100 mph for a prolonged period of time. However, to avoid this scenario the electric motor is automatically shut off at speeds over 100mph.

Honda is pricing the Insight at $18,880 (MSRP) [26]. According to "Popular Science" and other sources, Honda is losing money on this venture, but is willing to suffer the losses to gain experience and to gauge buyer reaction. Only about 4,000 will be released in the US [19].

The Insight is one of the lightest cars on the road today, due to the aluminum space frame and the fact that the Insight is only a two-seater. Though aluminum is more expensive than steel, when used in combination with recycled plastic, it is said to extend the life of the car substantially. This is due to the fact that aluminum is less likely to rust and the mix of aluminum and plastic makes the car more likely to bounce back from the minor dents that are acquired through daily driving. The Insight is a two-seater with a sizable cargo space in back. This design was chosen to reduce the weight and to allow room for the storage of batteries, which are located under the car. Honda has reported that there are usually two or fewer people in a vehicle in 80% of all trips. The Insight was designed to be a commuter car and as most car trips have two or fewer people in the vehicle, the Insight is sufficient for most people to get back and forth to work in.

Due to the fact that attention was paid to the weight and other energy saving features, the Insight is one of the cleaner running vehicles. It meets California's Ultra Low Emissions Vehicle (ULEV) standards. The Insight uses less gas then a normal automobile and therefore there is a reduction in the depletion of natural resources [13].

Another added feature the Insight has to boost mileage is an Idle Stop feature, which automatically turns the engine off when the car is stopped and shifted into neutral. As soon as the car is put back into first gear, the engine is re-engaged. This feature does not function until after the car has been warmed up for 10 minutes. The automatic restart only takes a tenth of a nanosecond.

Though the Insight is a lighter car it is still equipped with modern safety features. The Insight meets the safety standards for 2003 for side-impact and head-injury protection. The Insight is equipped with ABS (Anti-lock Braking System), dual airbags, front crush zone, front and rear crumple zones, steel door beams, built-in head restraints, and 3-point seat belts [3].

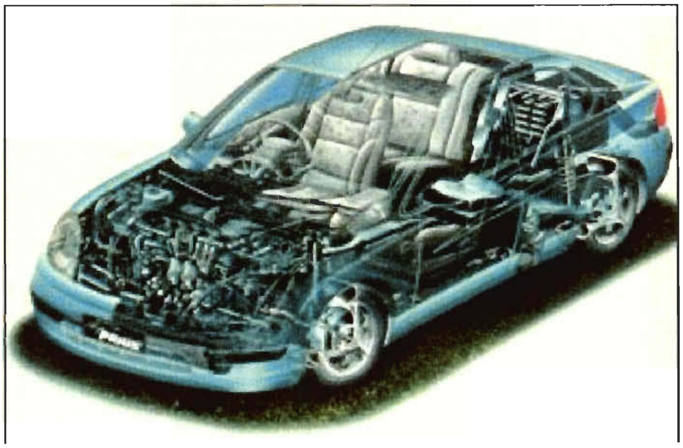
3.1.2 Toyota Prius

The Toyota Prius is a four door midsize sedan and is one of the first mass produced hybrid cars in the world. The Prius is considered a hybrid vehicle because it is powered alternately by both a super-efficient gasoline engine and an electric battery that never needs recharging. It currently achieves 66 miles per gallon and reduces emissions by up to 90 percent in Japan when compared to a conventional gasoline-powered compact. It emits 90 percent less carbon monoxide, hydrocarbons, and nitrogen oxide. The Prius is currently being widely used in Japan, and sold over 10,000 units last year which shows promise for Toyota in the USA [3]. Users in Japan report achieving 84 mpg. It will be available in the US in limited numbers in 2000. Currently, Toyota is running a demo program across the country to show America what the Prius is capable of. The projected release date for the Prius is June 17th and it is expected to be sold for just under $20,000 [3].

Toyota has named its hybrid engine system the total hybrid engine system (THS). The HPU is a 1.5-liter internal combustion engine. This engine and the electric motor work in tandem, depending on the driving situation, to complement, augment and even defer to one another [30].

Toyota's Prius is actually a combination of series and parallel hybrid components. When traveling slowly, Prius moves on electric power alone. When accelerating the gasoline engine takes over. The combustion engine works in tandem with the electric motor, and is capable of utilizing a 31-kilowatt supercharger to give more power. The Prius is then capable of speeds of 95-100 miles an hour with 101 horsepower (combined ICE and Electric motor) [30].

This interchange of the gas engine, generator, electric motor and battery pack is fully automatic and governed by a system of computers and a power splitter. Power is handled via a continuously variable transmission. It is a system of belts constantly searching for the best way to deliver the energy. Developed by Honda, it has been around for years and was never made popular [3].



The battery compartment is stored between the rear seat backs and the trunk and remains fully charged for as long as the engine is running. This battery pack consists of 240-D cell nickel-metal-hydride batteries. These are batteries used in a common flashlight [16]. These never need to be recharged because they are kept charged by a combination of a generator powered by the ICE and regenerative braking mechanisms. The battery is designed for energy output rather than storage as in an electric vehicle. The system is designed to maintain the battery pack at between something less than a full charge and 60 percent of full charge. With no need for repetitive deep discharges, which are really what wears on battery life, the power-pack can be used for the life of the car, which is approximately 250,000 miles [32]. The battery pack costs $6,000 to replace [29].

The aerodynamic styling of Prius contributes greatly to the fuel economy and makes for a quieter ride. An upper body shape ensures a smooth airflow combined with a flat under-floor to achieve a drag coefficient of only 0.31. Despite the Prius' short length and tall height, this shape greatly increases fuel economy, especially during high-speed driving (TMC). Adopting a new body frame structure has minimized vehicle weight. This structure is made light through the use of leading-edge technology. Positioning of ultra-high tensile strength steel plates, and induction hardening of the center pillar reduce the size of the total hybrid system (THS). Using lightweight aluminum wheels as standard equipment also help make the Prius more fuel-efficient. This gives the tires a low rolling-resistance, which helps the Prius to conserve energy [29].

3.1.3 General Motors Triax

Although General Motors has focused mainly on developing their electric vehicles they do have several hybrid vehicles in the various stages of production. The company currently has three major hybrid projects in development. These are the series hybrid, the parallel hybrid, and the Triax.

The series vehicle is a four-passenger car, which uses an AC electric motor for motive force and a gas turbine as an HPU to power an AC generator. The electric motor provides the car with a maximum of 137 horsepower. The turbine and generator can produce about 40 kilowatts of power, which is enough to power the hybrid electric vehicle up to 80 m.p.h. The vehicle can be driven in two modes. In hybrid mode, the HPU turns on automatically whenever the battery charge drops below 40% and charges the battery to roughly 50% of its maximum charge. In this mode, the vehicle gets up to 60 miles per gallon and has a regulated top speed of 80 miles per hour. If the driver chooses they may able to simply flip a switch and disable the HPU. The vehicle is then in zero emissions mode and can be driven up to 40 miles before recharging is needed [12].

The GM so called parallel vehicle is actually a combination configuration powered by an AC motor and a three cylinder diesel engine. The electric motor is located at the front of the vehicle and supplies the front wheels with motive force. The diesel engine is located at the rear of the vehicle and supplies the rear wheels with motive force when needed. The diesel engine also runs a generator to provide the battery with an onboard charge source, this fact makes the vehicle a combination vehicle.. In hybrid mode the vehicle is capable of getting about 80 m.p.g. and can reach a regulated speed of 80 m.p.h. The vehicle produces an impressive 219 horsepower and has a range of about 550 miles. This vehicle is also capable of traveling in zero emissions mode for about 40 miles [12].

The Chevrolet Triax is GM's newest development. The Triax is different because the consumer can decide what kind of propulsion system they wish to have installed when ordering the vehicle. Drivers are able to choose from four-wheel drive electric, four-wheel drive hybrid electric, or two wheel drive internal combustion engines. The Triax was unveiled a short time ago and information is limited at this time due to the fact that it is still only a concept vehicle [20].

3.2 Specification Comparison of HEV vs. ICEV

The chart on the following page is a comparison of some of the standard specifications of the Honda Insight, Toyota Prius, and the Honda Civic. This chart is given to provide a reference as to the differences and similarities of these vehicles.

Specification Comparison of HEV vs. ICEV

Specifications	Honda Insight	Honda Civic	Toyota Prius
Dimensions -Length -Width -Height	 3.9 meters 1.7 meters 1.4 meters	 4.2 meters 1.7 meters 1.4 meters	 4.3 meters 1.7 meters 1.5 meters
Engine Type	Lean-burn inline 3-cylinder with Variable Valve Timing and Lift Technology(VTEC-E), 1.0-liter, 12-Valve SOHC	Aluminum Alloy with in-line 4 16-valve SOHC	Atkinson Cycle engine Electric Fuel injection 1500 cc, 1.5-liter DOHC 16-valve, 4 cylinders Variable Valve Timing w/ Intelligence
Electric Motor	10kw	N/A	30kw
Battery	120 D NiMH, 280 volts	Lead-Acid, 12 volts	240 D NiMH, 280 volts
Range	700 mi. per 10.6 gal. Tank	300 mi. per 10 gal. Tank	850 mi. per 10 gal. Tank
Regenerative Braking	Ventilated front disc rear drum brakes w/ ABS	N/A	Ventilated front disc rear drum brakes w/ ABS
Max. Speed	104 mph		100 mph
Horse Power	67 hp	106 hp	101 hp
Fuel Efficiency	65 mpg	34 mpg	66 mpg

Chapter 4: Economical and Environmental Issues

This chapter addresses economical and environmental issues relating to HEV use in the US. In the first section, we will have a discussion about the emissions produced by ICEs, and how these emissions affect the environment. In the second section, the effects of HEVs on employment will be investigated. In the final section of the chapter, the impact that increased HEV purchases may have on the oil industry will be discussed.

4.1 Emissions

As an ICE vehicle is driven, the combustion reactions taking place in the engine produce gases which are released into the atmosphere. These gases are termed emissions and consist of carbon monoxide, nitrous oxide, methane, and carbon dioxide [10]. These emissions are measured in tons per year and for every car this quantity is different. Besides being detrimental to the health of human beings, emissions destroy the environment. The fuel economy of a vehicle is directly related to the emissions discharged by that vehicle. The lower the fuel economy or miles per gallon (mpg), the more emissions will be put out over a given distance because it will take more gasoline to move a vehicle that distance. For example, a car that gets 31mpg would use 2 gallons of gasoline to drive 60 miles while a car that gets 20mpg would use 3 gallons to drive that same distance. Therefore, the car that gets 31mpg is more fuel-efficient than the car that gets 20mpg. A car with a high value for fuel economy not only cuts down on the emissions given off into the surrounding environment, but also saves the driver money and uses less of our natural resources.

The warming effect of the earth's atmosphere is called the greenhouse effect. Light energy from the sun, which passes through the earth's atmosphere, is absorbed by the earth's surface and re-radiated into the atmosphere as heat energy. The atmosphere then traps the heat energy, creating a situation similar to that which occurs in a car with its windows rolled up. There are three gasses emitted by a vehicle which lead to the greenhouse effect: carbon monoxide, nitrous oxide, and methane. A number of scientists believe that the emission of CO_2 and other gases into the atmosphere may increase the greenhouse effect also [10]. The greenhouse gases are changing the climate on this planet with many consequences such as more extreme weather, rising sea levels, threats to agriculture and wildlife, and public health risks.

As a result of all the air pollution, over 100 million Americans live in areas that have failed at least one National Ambient Air Quality Standard. With the new focus on air quality, all new cars must meet federal emission standards and in many states cars are tested when inspected. As is clear from figure 3, the U.S. is the leading producer or carbon dioxide emissions [10].

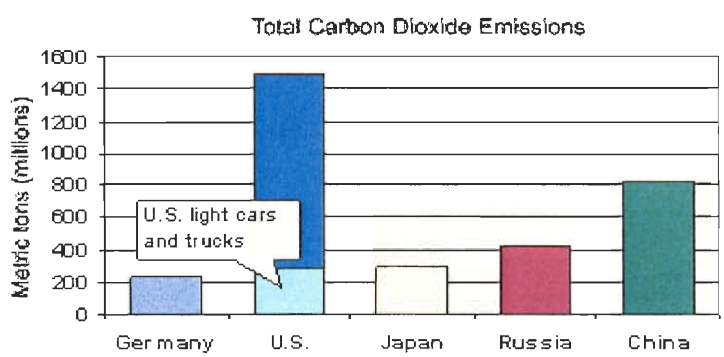


Figure 3

Another result of all the harmful gases that are put into the air every year by transportation vehicles is acid rain. Acid rain is rain with a pH less than 5.2. Principal components of acid rain are nitric and sulfuric acid. These acids are formed by combining nitrogen and sulfur oxides with water vapor in the atmosphere [10].

The EPA (Environmental Protection Agency) measures the fuel economy of every new type of car using a city test and a highway test to obtain this value. The city test consists of a 7.5 mile, stop and go trip with an average speed of 20mph. This test takes 23 minutes with 18 stops and it uses both a warm and cold start. The highway test is a 10-mile trip at an average speed of 48mph. The highway trip has little idling time, no stops and uses only a warm start. To make the two tests more realistic, the city estimate is lowered by 10%, and the highway estimate is lowered by 22% [9].

When the EPA calculates the amount of emissions discharged by a vehicle they take other factors into account other than the amount of exhaust emitted by the vehicle. This number is obtained from the amount of emissions released during various steps from production, to refining, to distribution, to the use of the petroleum. Every new type of car is different, some burn less fuel, some are cleaner burning, and some are gas-guzzlers. An infrared analyzer measures the amount of emissions a car gives off. The infrared analyzer is a steel tube which, when placed into the end of the vehicles tail pipe, vacuums the exhaust into a machine that measures the parts per million (PPM) of the sample. It detects hydrocarbons and carbon monoxide. These gases add to global warming, cause health defects, deplete resources (such as natural gases, oil), and cause acid rain.

Although today's vehicles are more fuel-efficient than they were in the past, they are still not as efficient as we would like them to be. According to the US Department of Energy and EPA, modern vehicles only use about 15% of the potential energy in the fuel to move or propel the car and to run accessories such as air conditioning and power steering. The rest of the energy is lost at a variety of different times as the fuel is used in the vehicle.

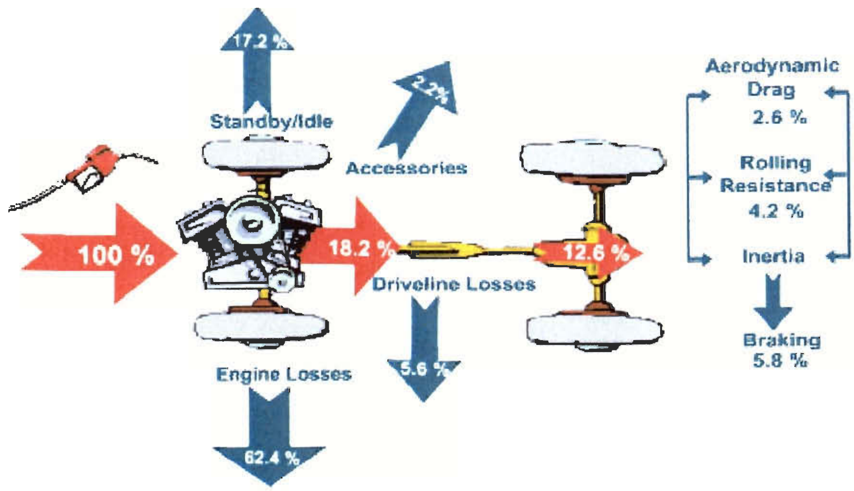


Figure 4

We see from figure 4 that of the energy content in a gallon of gasoline, 62% is lost to engine friction, engine-pumping losses, and to waste heat. In city driving, 17% is lost to idling at traffic signals or in traffic. Passenger comfort and accessories needed for the vehicles operation take another 2%. From here we are working with a little over 18% of the energy in the gasoline, but then there is a 5% loss in the drive train due to friction and slippage. About 12.6% of the original fuel energy finally makes it to the wheels and provides acceleration for the vehicle. At this point an additional 6.8% is lost due to aerodynamic drag and rolling resistance, and 5.8% is lost from braking. In the city, the acceleration has the greatest need for energy, followed by rolling resistance and aerodynamic drag. On the highway, the order is reversed with aerodynamic drag requiring the most energy [9]. Any motor vehicle needs energy to accelerate (overcome inertia), push air out of the way (aerodynamic drag), and to overcome the friction from the tires, wheels, and axles (rolling resistance). The fuel that the vehicle burns is the needed energy to overcome the obstacles [9].

In addition to the actual emission emitted by a vehicle, oil spills also cause harm to the environment. Over 9 million gallons of petroleum are spilled into U.S. waters a year. Since over half of the oil consumed in the U.S. goes to transportation, an increase in more fuel-efficient cars would reduce the amount of oil used and therefore reduce the amount spilled annually.

Total Tons of Emissions emitted a Year in the US (in millions)

(Short Ton = 2,000 lbs.)

Year	Emissions In Short Tons
1970	129.08
1980	115.63
1986	109.2
1987	108.01
1988	115.85
1989	103.14
1990	100.65
1991	97.38
1992	94.04
1993	94.13
1994	98.78
1995	92.1

Table 5

Table 5 above gives statistics for emission outputs of conventional vehicles. We consider the question: what would happen if 50% of cars on the road were HEVs? How much, if any, would emissions be reduced? The Honda Insight emits approximately 3.0 tons of emissions a year, while its ICE counterpart, the Honda Civic, emits approximately

6.2 tons [9]. Based on 1995 statistics, what would happen if 50% of the vehicles on the road were HEVs? First, the 92.1 million tons emitted by ICE vehicles would be cut in half because there are half the amount of ICEs on the roads. So that leaves 46.05 million tons being emitted by ICE's. Add back half of 46.05 million tons because HEVs emit roughly half the emissions that an ICE does. This gives us approximately 69.1 million tons emitted a year. This is an emissions level that is significantly lower than what has been seen in at least the last quarter of a century [2].

4.2 Employment during HEV integration

Advancement in the world of technology is, of course, a great achievement in our society, yet there are also ramifications. One area in which such consequences may be seen is employment. In this section, we will examine such effects specifically in the oil and automobile industries. We will also cover issues dealing with the logistics of incorporating HEVs in the auto world. Will, for example, the shift in technology occur slowly, allowing workers the opportunity to retrain, or will they be rendered unemployed because they were not afforded the opportunity to become accustomed to this new, possibly intimidating technology?

In the 1800s, the primary source of employment was in the agricultural business [27]. Americans raised crops such as wheat, corn, and rice. They also reared and managed livestock for the dairy and meat industry. At the turn of the century, during the industrial revolution, there was a transfer of jobs to the manufacturing industry [27]. People were now employed as machinists, engineers, miners, and construction workers instead of farmers because there was a bigger demand in this industry. The amount of people employed in the agricultural industry was decreasing as employment in the manufacturing industry was increasing. The transition from an abundance of jobs in the agricultural industry to an abundance of jobs in the manufacturing industry took over one hundred years to complete [27]. Since the shift from the agricultural industry to the manufacturing industry was gradual, people had enough time to become retrained for jobs in the new industry.

Fifty years ago, service became the dominant industry [27]. Medicine, law, pharmaceuticals and tourism are examples of fields in the service industry. Many people realized that the jobs of the manufacturing industry were very dangerous and sometimes physically harmful to their health. The jobs in the service industry were for the most part in a better working environment. People were now getting higher education and becoming service professionals [27]. Again, like the transition from the agricultural industry to the manufacturing industry, the transition was so slow that people had the opportunity to familiarize themselves with the new industry.

We are currently in the midst of a major transition into the information technology age. The information technology industry deals with moving data quickly and efficiently via computers and microprocessors. The information technology industry is moving rapidly to replace the service industry as the leading industry in the US. If, for example, almost any service can be purchased over the Internet, why aren't more people in the service industry losing their jobs? One reason may be that the information technology industry is not moving as fast as it could be. Although the shift is quick, society is moving along just as swiftly. Almost every person comes into contact with a computer during his or her daily activities, whether it is at home or in the work place.

With this new technology, comes a better-informed society. Another reason why the information technology industry is not creating more unemployment is because there is a trade-off going on. Some jobs are being eliminated because of the Internet, but there are others being created because there is a need to create and maintain these web sites and to provide the services being offered.

Since society is moving just as fast as the information technology industry we can make a comparison to past experience in such times of transition. Industries in the past were moving slower but society was moving just as slowly. It can be suggested that society will continue to move at the same pace and therefore employment will not be adversely affected.

The next topic discussed will be how the changes in auto technology might affect employment in the oil industry. The oil industry is primarily made up of two sectors, the service sector and the production sector [14]. The service sector is the part where the physical work, like drilling and pumping, is done. The production sector does the planning for drilling. They decide where to drill and find new ways to drill more efficiently.

From 1982 to the present, there has been a steady decrease in jobs in the service sector of the oil industry, for a total loss of almost 400,000 jobs [14]. The employment in the service sector of the oil industry fluctuates with gasoline prices. The connection is, when gas prices go up, there is a need for more oil to reduce the prices. If there is a need for more oil, then there is a need for more workers to drill, pump and ship the oil. With the incorporation of HEVs into regular use, the demand for gasoline will go down therefore reducing employment in the service sector. Employment will also decrease in this sector because of improved technology which makes finding and retrieving oil easier. For example, horizontal drilling is a new way of retrieving oil. It has a higher probability than vertical drilling of finding oil because the drilling is done obliquely across the substrata [14].

When there is a new production method, the service sector loses jobs and the production sector gains jobs. New drilling methods require more research, engineering, and market studies so new jobs are created in the production sector.

The Department of Energy projects that by the year 2010, employment in the oil industry, as a whole, will increase because oil production will have to increase to lower oil prices [14]. This projection was made with the thinking that the demand for oil would remain the same up until 2010. However, if the HEV becomes very popular, this projection may have to be modified because the demand for oil will not be as high as it is expected to be due to the fact that HEVs use less gasoline to operate.

The final topic discussed will be the effect of new technology on employment in the auto industry. In the early 1900s, there were not many people employed in the auto industry because automobiles were not very popular. This small amount of employees remained fairly constant until World War II, when the demand for automobiles became very high. Many new jobs were created and in 1947, employment in the auto industry peaked. Of the 3.9 million automobiles made worldwide, 80 percent of them were made in the United States.

The early 1970s were a turning point in the auto industry. U.S. companies started producing very large cars nicknamed "gas-guzzlers". They were so termed because they were very inefficient, getting approximately 15 miles per gallon. These new, bigger cars were in high demand because they were very powerful, and though they required a great amount of fuel to run, the low gasoline prices made this a non-issue for most purchasers. The highway system was in good shape and some areas were not as heavily populated as they are now so the big car was relatively not inconvenient. At this same time, Japan was also producing many automobiles but, unlike the U.S., Japan was making smaller, more fuel efficient cars. The style of automobile for the Asian countries was a compact design because the high population density of the countries made space efficiency a serious concern.

From 1973 to 1979, the U.S. went through an oil crisis. There was a great shortage of oil. Many gas stations were closed and prices soared due to an insufficient supply of oil. This crisis dramatically slowed economic growth and hindered people from buying expensive items. Gas prices soared and the general public wanted more fuel-efficient cars. Since Japan had already cornered the market for smaller, more fuel-efficient cars, many Americans began purchasing Japanese automobiles. By the early 1980s, Japan had taken over 33 percent of the U.S. sales [25].

From 1979 to 1989, there was a net loss of 105,000 jobs. (figure 5) From 1979 to mid 1980 alone, more than 335,000 jobs were lost due to the fact that Americans turned to the foreign industry to buy their vehicles. The U.S. industry rebounded a little from mid 1980 to mid 1981, restoring approximately 110,000 jobs. Again, from 1981 to the end of 1982, the auto industry cut employment. The 185,000 jobs lost here were primarily do to the economic depression that the U.S. was battling. Finally, in 1983, U.S. automobile companies started producing more fuel-efficient vehicles. From 1983 to 1987, employment in the auto industry grew by 255,000 jobs due to a strong economy. At the beginning of 1987, sales of domestically produced vehicles fell because, although the U.S. was producing more fuel efficient cars, many people returned to purchasing foreign

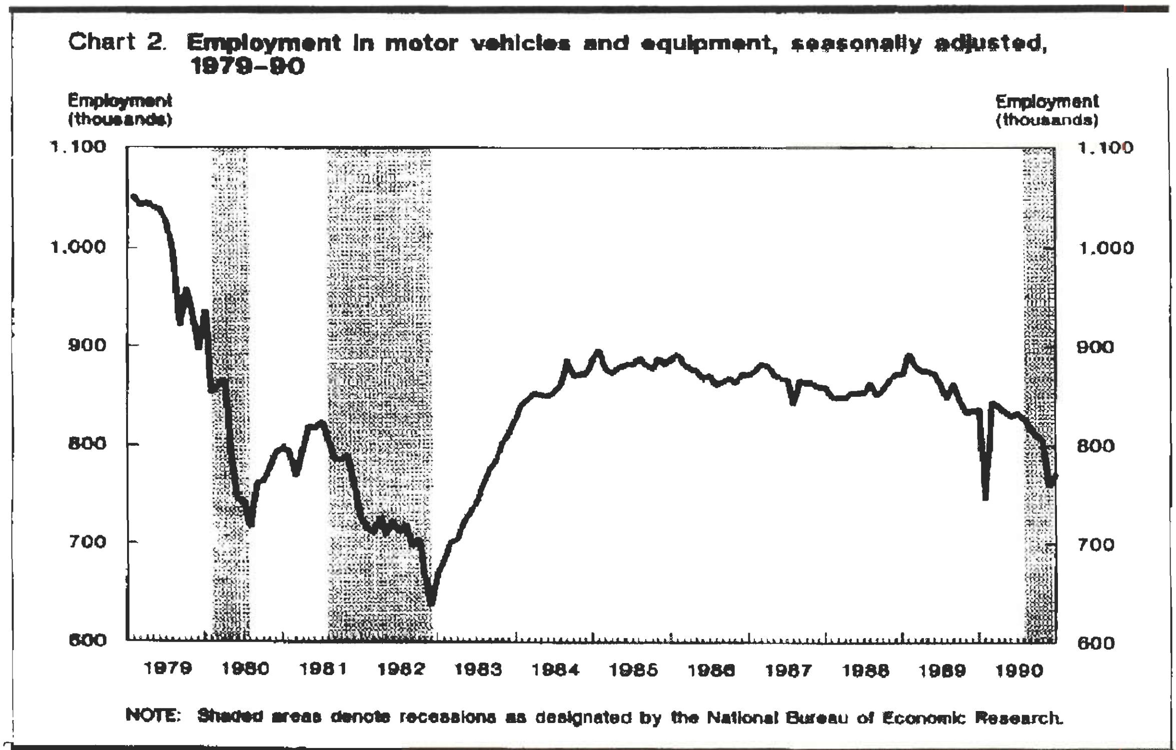


Chart 2. **Employment in motor vehicles and equipment, seasonally adjusted, 1979–90**

NOTE: Shaded areas denote recessions as designated by the National Bureau of Economic Research.

1992, more than 100,000 jobs have been created because of a rebounding economy [25].

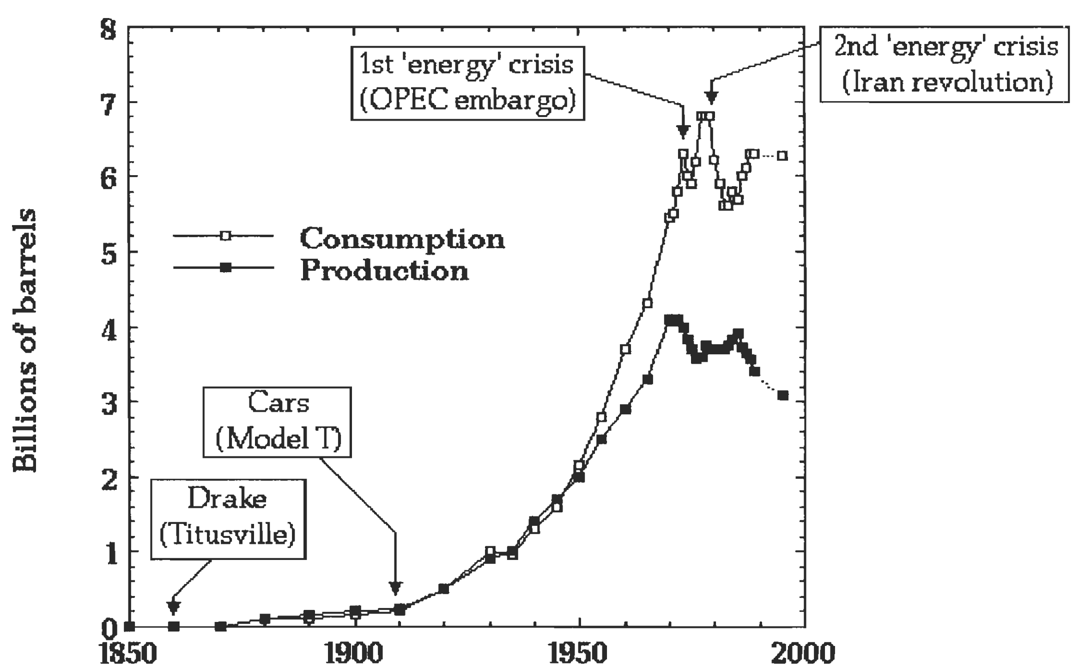
Based on these past numbers of how technology affected employment, can any inferences be made about the future of employment in the auto industry? Let us speak specifically about what would happen if the HEV were to comprise a significant portion of the automobiles on the road. It is the opinion of the authors of this paper that the transition from the conventional automobile to the HEV will be so slow that employment will not be adversely affected. As of today, Honda is the only company with an HEV on the market. Toyota has planned the release of their HEV to be in June. It is going to take several years for these new vehicles to catch on. Many people will have reservations about purchasing a vehicle that does not run strictly on gasoline. By the time society is ready to start purchasing HEVs, those people whose employment could be affected by this change, would have either retrained or retired.

In conclusion, barring a drastic change in the economy, it is felt that employment will not be severely hurt. The transition from the ICE to the HEV will be slow enough to not impact employment in a negative way.

4.3 Oil Industry

4.3.1 Factors affecting oil prices

The United States is extremely dependent on oil as a fuel for energy. Approximately 40% of all energy produced in the U.S. is derived from crude oil. This equates to using 17 million barrels of oil per day. Fifty-three percent of the oil used, or 9 million barrels a day, is used for transportation [8]. These statistics show that the advent of HEVs in society would have a serious impact on the oil industry.



In the United States, the rate of consumption of oil has not kept up with the rate of domestic production since the sixties (Figure 6). The country thus relies heavily on imported oil. Imports were at a high in 1993 at 44% of the total oil consumed [7]. The major producer of oil in the world is OPEC, the Organization of Petroleum Exporting Countries, which was formed in 1960, consisting of six counties. Another six were added by the end of 1971, for a total of twelve countries which are: Algeria, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela. These countries produce about half of the world's oil supply, giving them an immense amount of control over the price of oil [8].

Physical events also affect the price of oil, usually indirectly through OPEC. Occurrences such as wars, abnormally warm winters, and over production affect the price of crude oil. Ultimately though it appears that OPEC controls the price of oil. When any one of the above mentioned events occur the organization has the power to cut production, limit supply, and force oil prices up.

History of oil prices

Before 1974, the price of oil was pretty constant, except for the minor rises due to inflation. By the end of 1974, there was a drastic change. The price of oil was almost four times greater than it was two years before because of an attack on Israel by the Arab nations. The U.S. took the side of Israel and therefore OPEC, being mostly Arab nations, placed an embargo on oil to any country supporting Israel [21].

In 1979, another crisis caused oil prices to rise again, after a short stable period. A revolution in Iran and then the Iran/Iraq War caused oil prices to more than double from $14 per barrel in 1978 to $35 per barrel in 1981 (figure 7). From 1982 to 1985, OPEC attempted to set oil quotas. The goal of the quotas was to limit production of the world's more dominant oil producing nations, and stabilize oil prices. Although these quotas were set, the countries that composed OPEC continuously produced more oil than allotted. These countries were trying to increase profit, but ended up forcing the price of oil down. The price of oil was then relatively stable until the advent of the Gulf War. The war caused a cut in oil production that would have sent oil prices higher than they rose, if it wasn't for the strategic petroleum reserve.

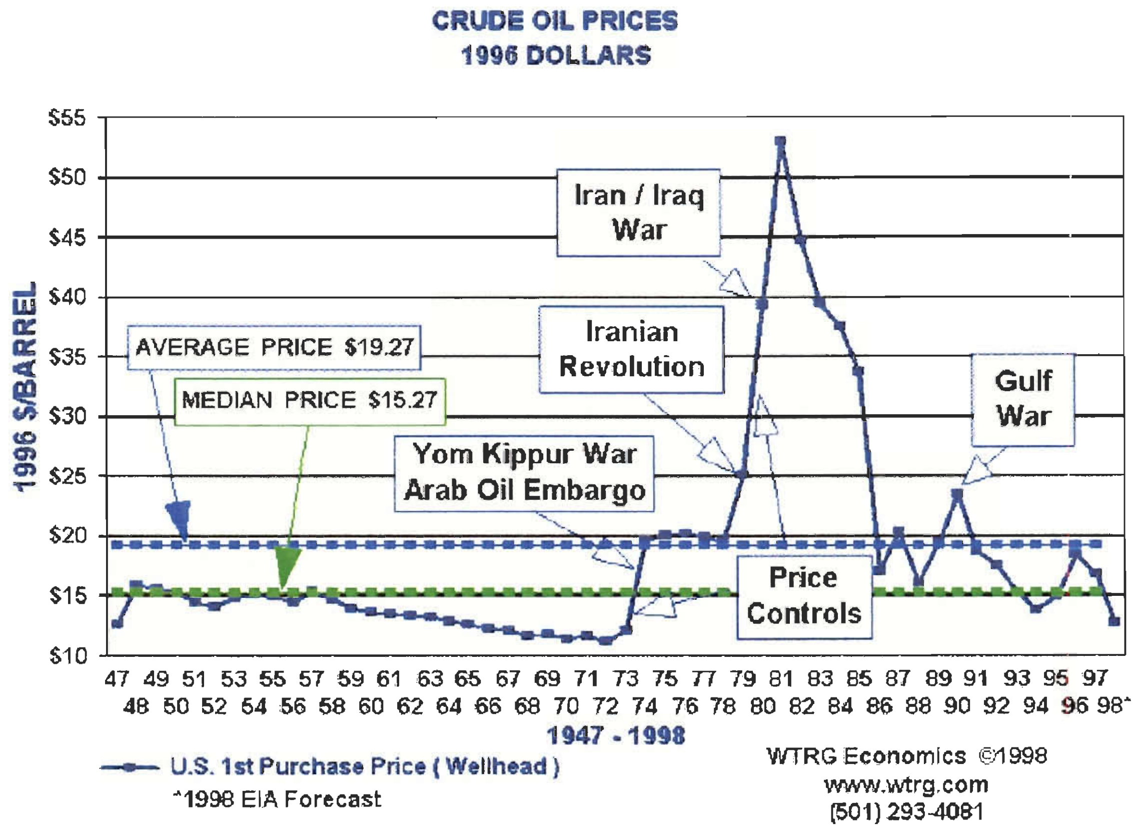


Figure 7

OPEC has cut production in the past. During the oil crisis they cut production and oil prices increased by 400% [21]. This spurred the government to initiate the Strategic Petroleum Reserve (SPR). This is a series of oil storage tanks along the Gulf of Mexico coast which currently store roughly 561 million barrels of oil. The reserves are used to battle the price control of OPEC and are for emergency use during war times. Although these reserves do seem like a necessity they only store enough oil to feed the country for one month. With a current price tag of twenty billion dollars this hardly seems like a worthwhile investment [4].

OPEC has also limited production in response to low oil demands at other times. Low oil demands have occurred due to unusually warm weather. At these times OPEC has cut production and forced prices to rise. Although prices did rise in these cases, when inflation is taken into account the price of oil has remained relatively constant over the years [21].

4.3.2 Future of oil prices in the U.S.

Considering the factors discussed earlier, an educated assumption can be made about what would happen to oil prices if HEVs were to become integrated into society. Initially oil prices would undoubtedly rise due to the lowered oil consumption, since OPEC would cut oil production. However, it seems that this would not last. OPEC would have to consider the fact that cutting production in the past was a way to deal with temporary drops in consumption. HEVs would represent a permanent and increasing drop in consumption. Raising oil prices would most likely spur consumers to accept HEVs more easily and only decrease consumption more. OPEC would undoubtedly realize this and most likely lower oil prices.

Another issue that is worth mentioning is the hope of the U.S. becoming a self-sufficient nation in terms of oil consumption. As stated earlier, the U.S. uses 53% of its oil for transportation. Meanwhile, oil import levels reached a high of 44% in 1993. The consequences of cutting the use of oil for transportation are obvious from these two figures. If HEVs were integrated into society it would not be a far step for the nation to become self-dependent in terms of oil.

4.3.4 Impact of oil prices on society

Average crude oil prices for the first half of the year 2000 are likely to be about double the price compared to the same time last year. This is due to the fact that OPEC has cut oil production. As a result, current U.S. oil inventories are down 13% from last year, forcing prices up [17]. The higher crude oil prices mean higher petroleum product prices, with yearly increases averaging 25-31 cents per gallon. Next year, though, crude oil prices are projected to fall, meaning lower petroleum product prices [4].

In March, regular unleaded, gasoline prices hit its highest level ever, averaging above $1.50 per gallon. The projected price was 15 percent lower than the price spike during the Persian Gulf War in 1990 and 42 percent lower than the all-time highest price of March 1981. Crude oil prices and spot prices for motor gasoline have been easing recently. We expect retail gasoline prices to average about $1.45-$1.50 per gallon during the summer driving season, then to continue to decline [4]. This is due to the fact that, throughout history, petroleum prices have always been higher in the summer months due to commuters going on vacation thus driving more [17].

In most parts of the nation, the pump price increases have been similar, increasing by about 25-31 cents per gallon since the beginning of the year in most places. However, in California the pump price has jumped by about 40 cents per gallon reaching a price of almost $2.00. Prices are higher in California because state law requires a cleaner, costlier type of gasoline (California Air Resources Board, or CARB, gasoline), and the local supply for CARB gasoline is tight [4].

Diesel fuel oil prices have also increased greatly this year. On the national level the price is expected to peak in early spring. In the Northeast, the average retail price has fallen substantially from the record highs of mid-February, when the market for diesel was greatly affected by the strained heating oil situation due to the cold winter months. Diesel prices for the rest of the country should follow the trend of the seasonal motor gasoline prices [4].

These sudden steep fuel prices have the potential to affect our booming economy greatly though. Truckers who move our foods and supplies all over the country are being forced off the road due to the high pump prices. Seventy percent of truckers work in private sectors and are unable to buy diesel in bulk as other trucking companies often do. These men and women make their money off of a very tight profit margin (about 3-4 percent) [17]. The high pump prices have eliminated this profit for them, so they are actually losing money for every mile that they drive their trucks. In most cases, a new truck would get somewhere between 6-7 mpg. Realistically, most trucks aren't brand new and are only getting 4-5 mpg. This requires a larger sum of money to fuel their trucks; so more money is lost. The American Trucking Association (ATA) has been lobbying for the President to open the Strategic Petroleum Reserve in order to alleviate high shipping costs until prices go down [17].

This past winter was a very costly one for heating oil customers, particularly during the first quarter of the year. Historically, as oil prices climb, so does diesel. Particularly when a cold winter diverts more oil for home heating. The cold weather, rising crude oil costs and, low supplies propelled prices to record heights. Residential heating oil prices averaged $1.34 per gallon in the first quarter, 54 cents more per gallon more than year-ago. This spring, heating fuel prices should fall as seasonal demand decreases.

Chapter 5: Hybrid Electric Vehicle Survey

As a part of research for this project a survey was distributed. The purpose of the survey was to determine the public's perception and knowledge of HEVs, and to ascertain if more fuel efficient and environmentally friendly vehicles are attractive to the public. The survey was distributed to the faculty, staff and students at WPI, as well as a number people outside of WPI in early March, 2000. The survey is found in Appendix 2.

We received approximately 150 completed responses from the sample group. Fifty-four percent of the respondents were male, and 46% were female. Eight-two percent were age twenty-five and under, since the majority of people polled were college and high school students.

Question 4: Approximately how many miles do you drive your vehicle annually? (In thousands)

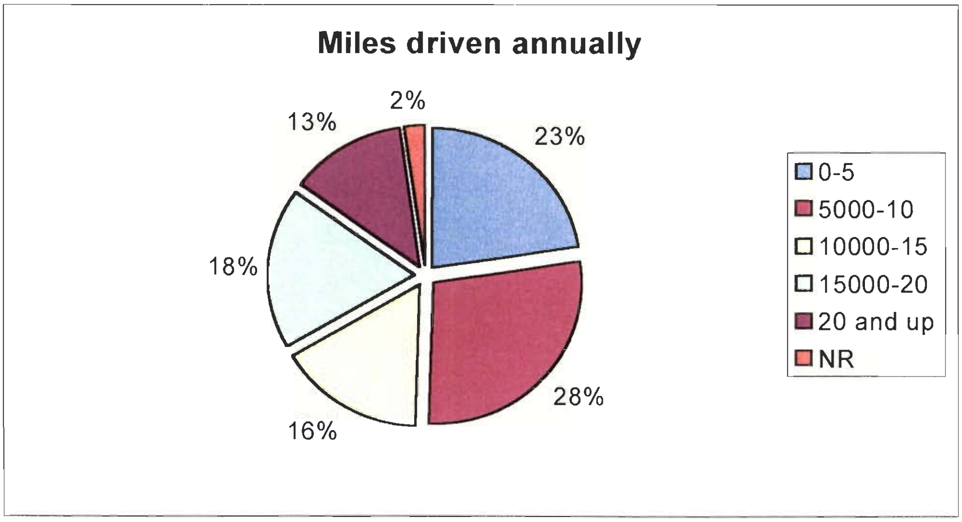


Figure 8

Question 4 of the survey asked how many miles those surveyed currently drive in a year. Figure 9 displays the distribution of the responses in the ranges, 0-5,000, 5,000-10,000, 10,000-15,000, 15,000-20,000, and 20,000 and up. About half of the respondents drive 0-10,000 miles annually. These numbers may not be truly representative of the U.S. population since a majority of the respondents were college and since the greater part of their year is spent at school, not a lot of traveling is done.

Question 5: Would you consider yourself to be up to date with current technologies in the auto industry?

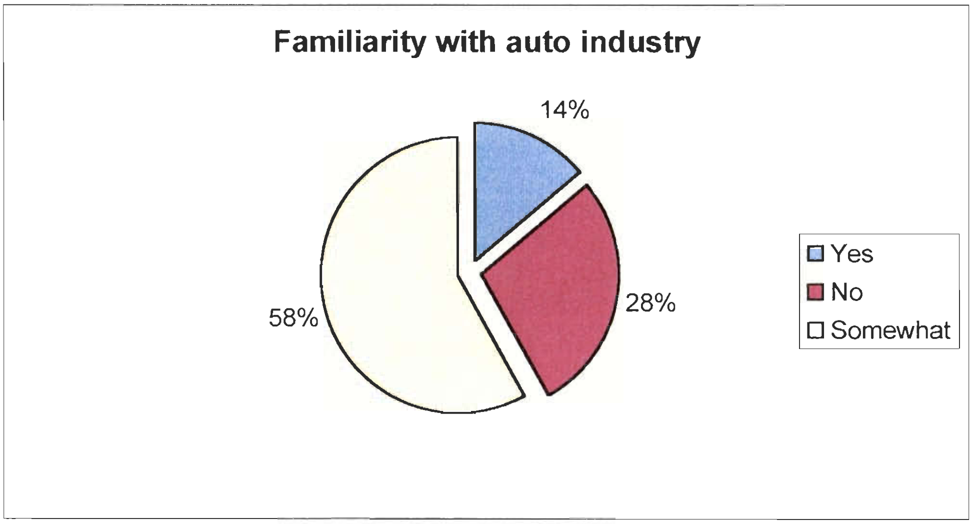


Figure 9

Question 6: Are you aware of the recent developments in HEV technology?

Figure 10

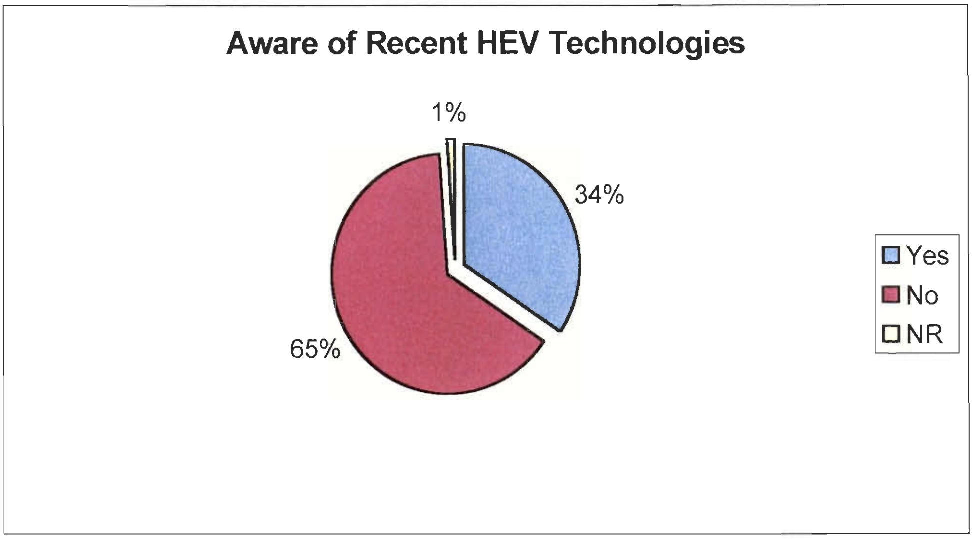


Figure 9 displays the results for question 5 which was asked to see how people assessed their general knowledgeable about current automobile technology. The majority of the respondents (72%) felt that they were either up-to-date or at least somewhat up-to-date with the technology. However, the results of question 11 illustrated in Figure 10 show that only 34% of those polled were aware of the recent advancements in HEV technology. We believe that this is because there has not been much television marketing of the hybrid vehicles. On the other hand, there have been many magazine and newspaper articles about HEVs, so apparently our respondents have not paid much attention to information in the print media.

Question 7: Do you know of any HEVs currently on the market in the US?

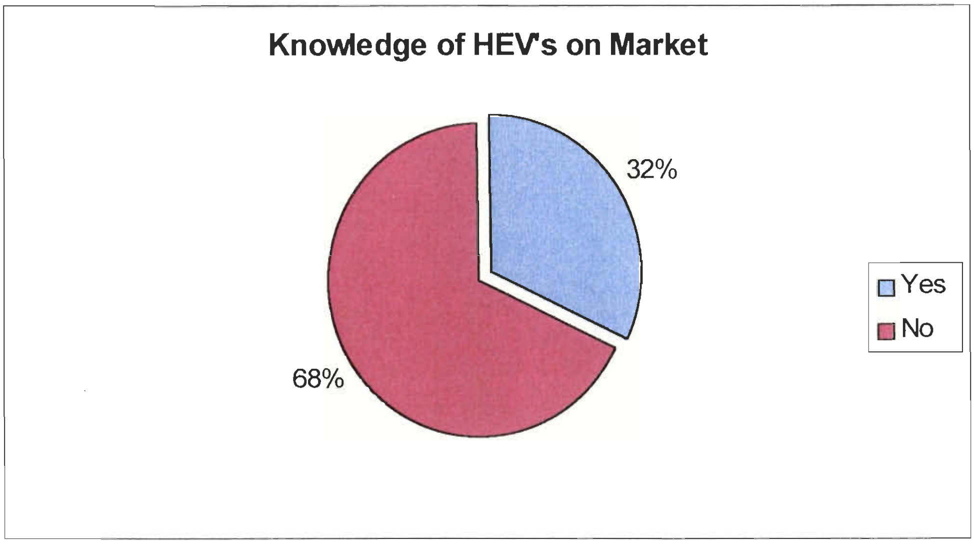


Figure 11

Question 7 was asked to see if people were aware of any HEVs on the market at that time. At the time this survey was given, Honda had just released their hybrid car, and the commercials are not frequently aired. We assumed that people would know very little about hybrid electric vehicles and by looking at figure 11, it is clear that our assumption was correct. Sixty-eight percent of the people polled had no knowledge of HEVs on the market.

Question 8: The average compact vehicle gets 31 miles per gallon. What gas mileage do you think an HEV would get?

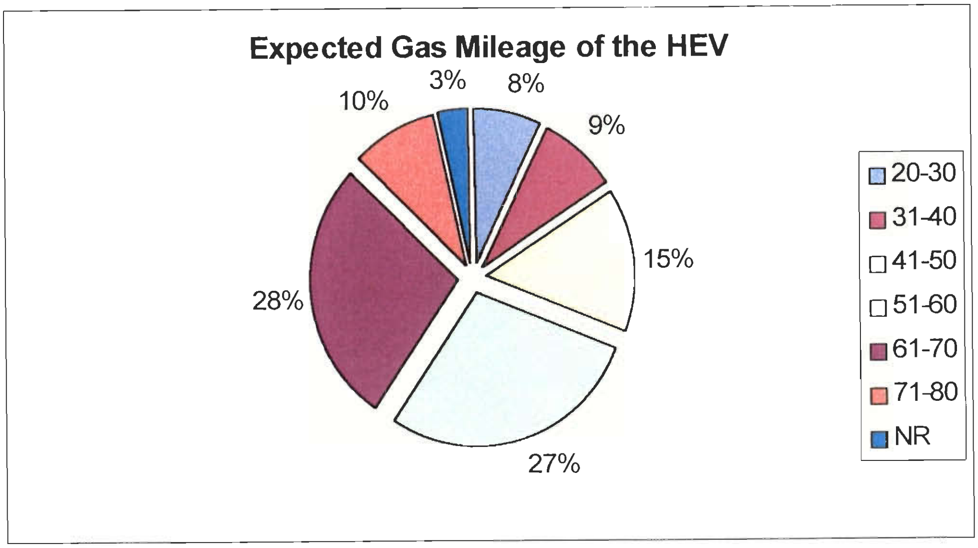


Figure 12

This question asked consumers what mileage they would expect an HEV to get. In the survey, we stated that the average compact car attains 31 mpg. Knowing that the general public did not know much about HEVs (from figure 11), we speculated that those polled would not know the gas mileage of an HEV and guess it to be lower than it actually is. Above we see there is a wide distribution as to what consumers think HEVs would get. Most participants in the survey were quite correct seeing that the majority of responses were in the range of 61-70 and 51-60 proving our guess incorrect. Both the Honda Insight and the Toyota Prius achieve mileage in these ranges.

Question 9: Please rate the importance you would place on each concern when purchasing a vehicle from 1 to 5.

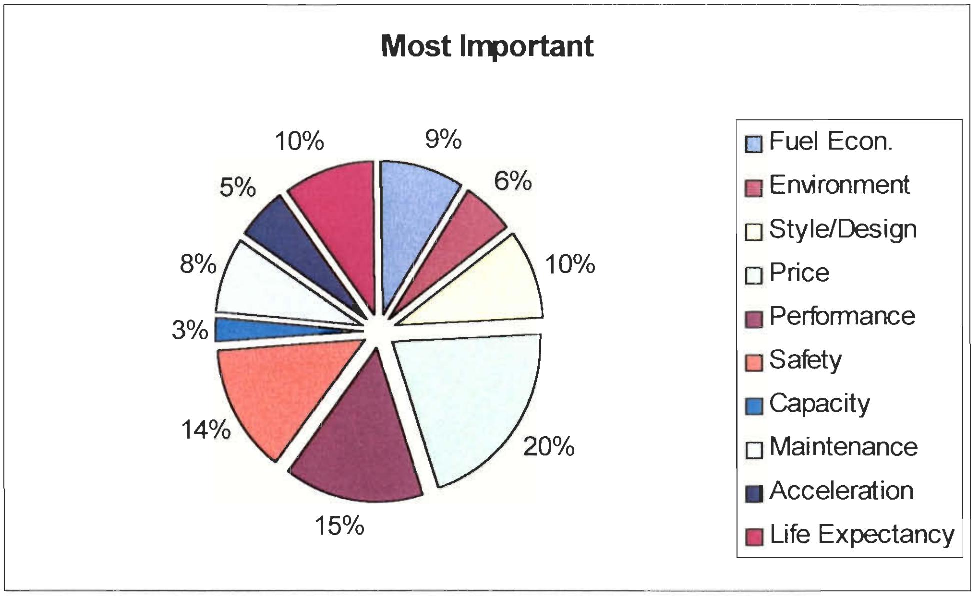


Figure 13

Question 9 was asked because we wanted to get a feeling of what concerns people have when purchasing a vehicle. It can be seen from the chart above that price was the most important concern when purchasing a vehicle, followed closely by performance and safety. With the exception of capacity, responses in each of the other categories were almost equally distributed. When asked if the environment was a big concern when purchasing a vehicle, only 6% of the people polled stated that the environment was a major concern of theirs. Since performance was fairly important to people when purchasing a vehicle, we can guess that some would be reluctant to buy a vehicle that is somewhat less powerful.

Question 9 (continued)

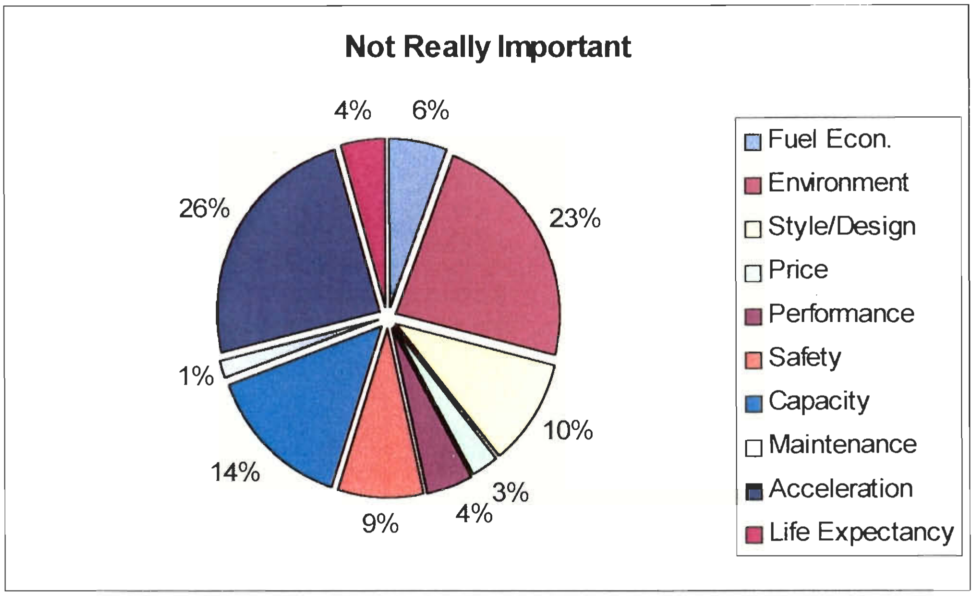


Figure 14

Figure 14 displays what concerns people felt were not really a concern when purchasing a vehicle. Acceleration and the environment were the two least important concerns to people when purchasing a vehicle with a 26% and 23% response respectively. It can be seen from the previous two charts that if the category was the majority at the most important level, then it was the minority at the least important level and vice-versa.

Question 10: If you were to purchase an HEV, would you want its appearance to match today's standards or appear more distinct?

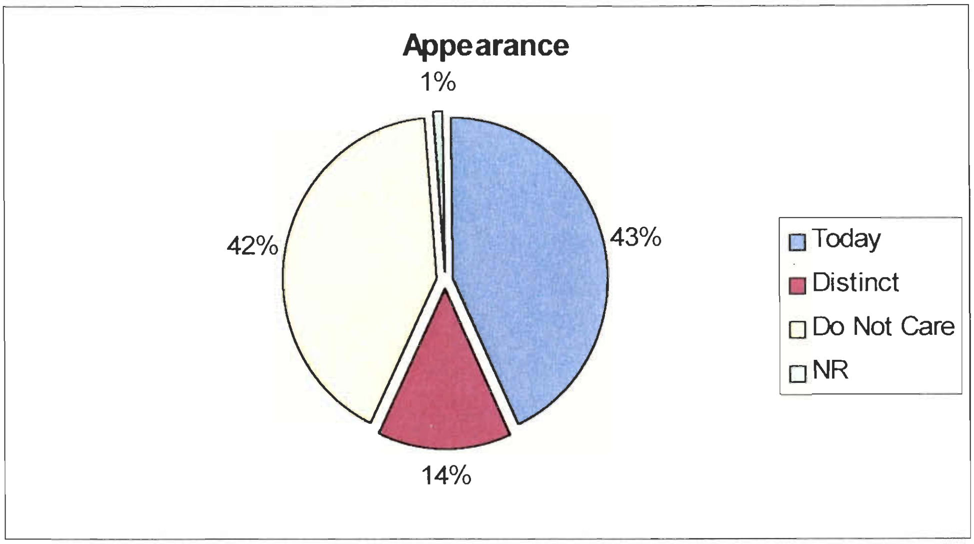


Figure 15

Some of the current HEVs being developed have a somewhat distinct body design as compared to current automobile styles. In the survey, the question of whether or not consumers would want their vehicle to appear distinct or to match current standards was posed. The above chart shows that while 43% would want the vehicle to match today's standards, an almost equal 42% stated that appearance was not a factor. A minority of 14% would prefer a more distinct look.

Question 11: If purchasing an HEV, would you be willing to sacrifice some power for a gain in mileage and a reduction in emissions?

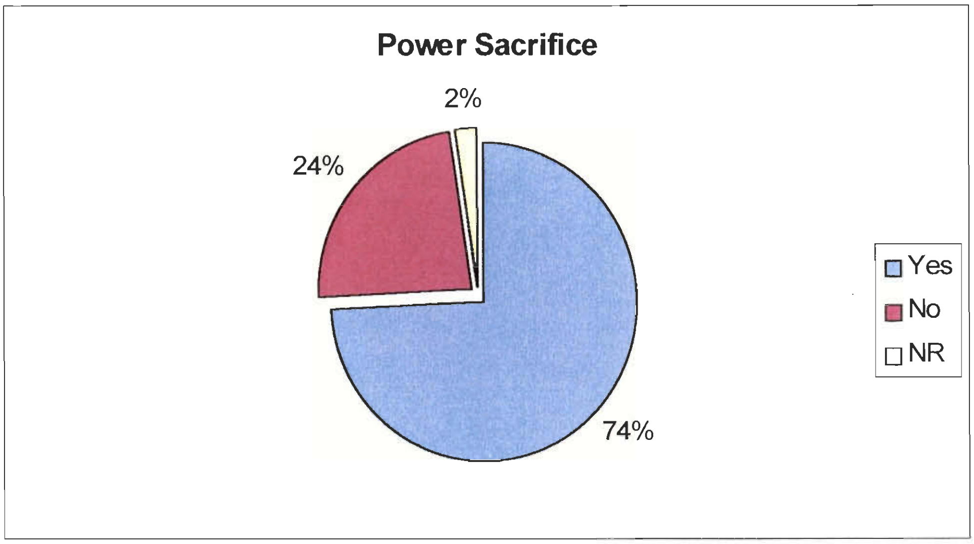


Figure 16

One of the major preconceptions about HEVs is that they are under powered. Question 11 asked whether or not consumers would be willing to sacrifice some power for a gain in mileage and a reduction in emissions. We hypothesized that the public would not be willing to sacrifice power for a gain in mileage and a reduction of emissions. Of those responding to the survey, 74% stated that this was a legitimate sacrifice while 24% said they would not be willing to make this sacrifice. This leads us to believe that many people would be willing to purchase an HEV if their other concerns were put to rest. The Toyota Prius has a horsepower that is on par with that of the Honda Civic while the Honda insight is a bit lower. While the ~~insight~~ Prius has 101 horsepower the insight has only 67. The comparable Honda civic is listed as having 106 horsepower. See the comparison table in Section 3.2.

Question 12: How much would you be willing to spend on an HEV?

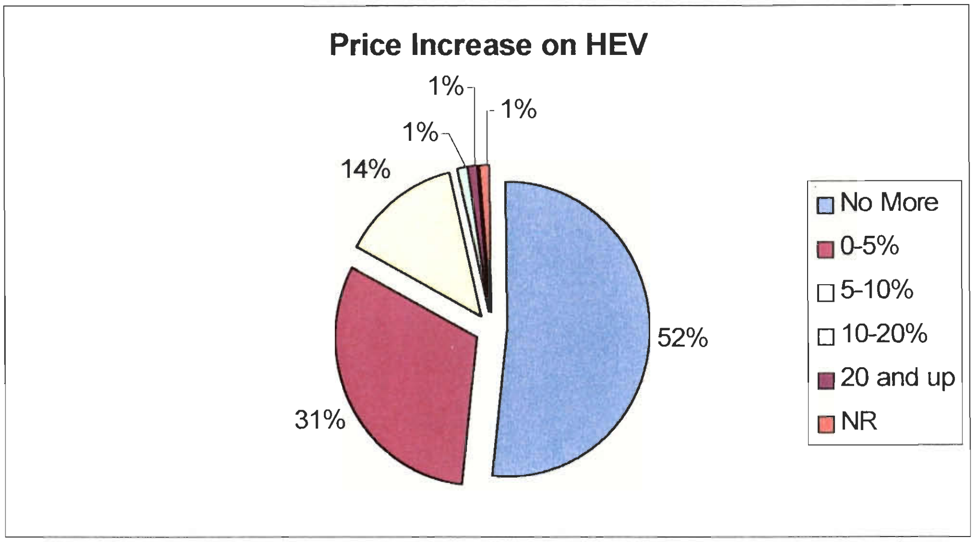


Figure 17

A major factor in the production and sale of current HEVs is the price of the vehicle. In the survey, the issue of an increase in price was raised. The cost of production of HEVs is slightly higher than that of conventional vehicles. This will lead to slightly higher retail prices for hybrids. This question was asked to see whether or not a person would be willing to pay a little more for a more fuel-efficient vehicle. We figured that people would not want a price increase at all. Fifty-two percent of the people polled said that they would not want an increase in price at all. Thirty one percent of the people stated that up to a 5% increase would be acceptable. While not many people would consider an increase more than this reasonable 14% would consider a 5-10% increase reasonable. Both the Honda Insight and Toyota Prius are priced around the $20,000 mark. This is nearly average for vehicles in their size category.

Question 13: A standard car accelerates from 0 to 60 mph in 8 seconds. How long would you expect an HEV to accelerate from 0 to 60 mph in? (seconds)

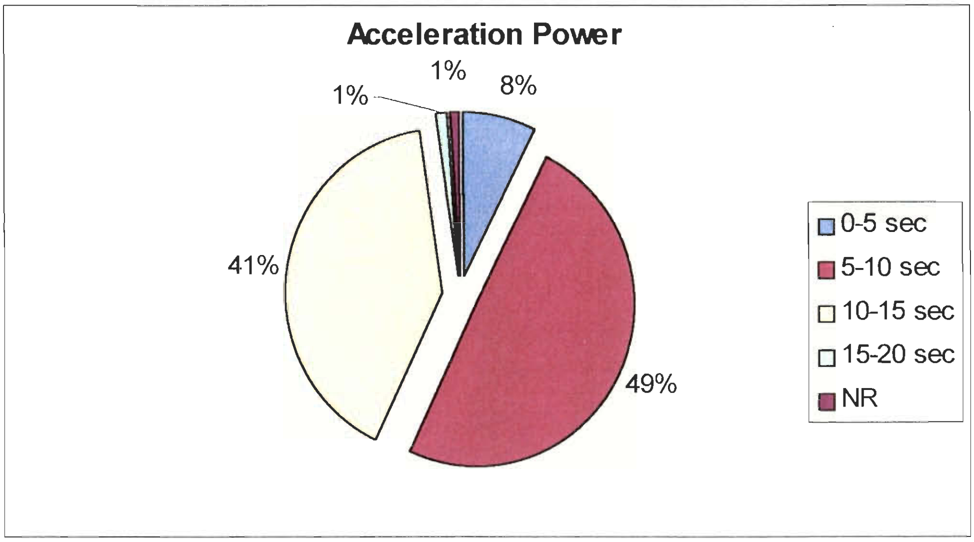


Figure 18

As shown in the earlier question on power, a majority of people would not mind a power loss. It seemed to us that most people would not know what the average acceleration for a standard compact car was. In order to alleviate this confusion, we wrote next to the acceleration speeds the types of cars that can achieve these rates. Forty-nine percent would still want the vehicle to perform within the same range as an average car. An almost equal percentage of people also stated that a somewhat slower vehicle would be acceptable. The hybrid vehicles currently or soon to be available are average in this category. When extra acceleration is needed, both engine systems are used. This fact makes up for any power loss that is present.

Question 14: Would you consider buying a compact or two-passenger vehicle?

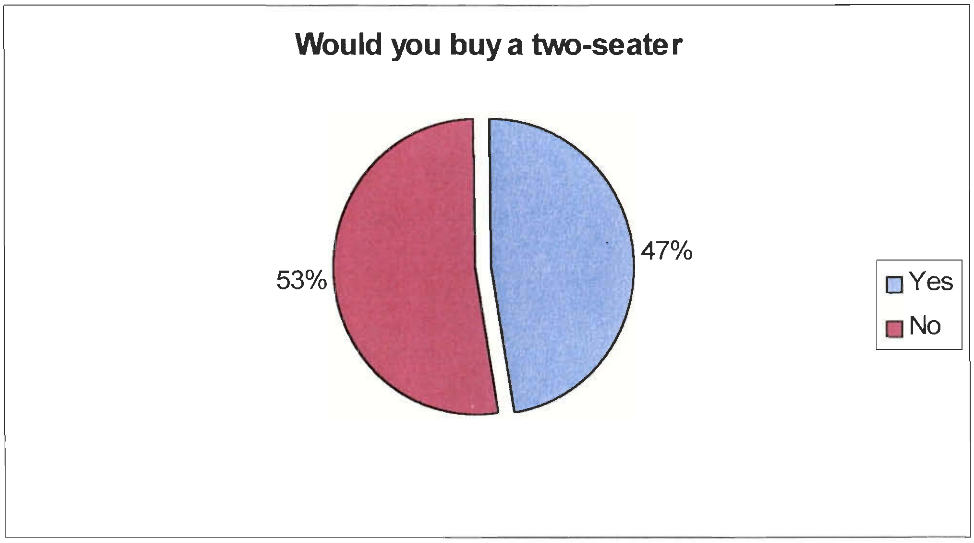


Figure 19

Current HEVs being developed consist of a variety of types. Some of these are more compact vehicles with limited passenger capacity such as the Honda Insight. In the survey the question of whether or not a consumer would consider purchasing a more compact or two-passenger vehicle was posed. The results of this question were quite even with 47% of people considering a two-seater and 53% not considering a two-seater.

Question 15: The average vehicle has a life expectancy of 150,000 miles. Would you expect an HEV to have a greater life expectancy?

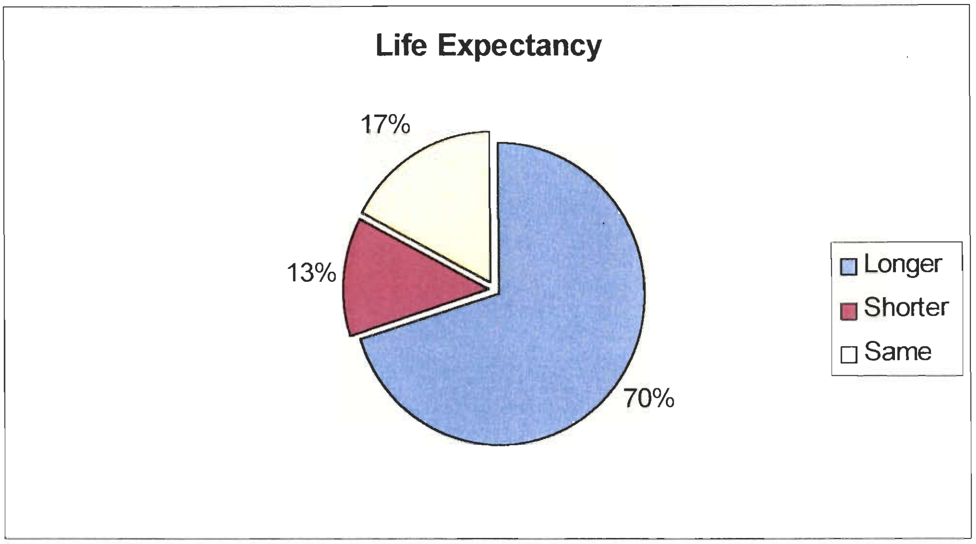


Figure 20

A major concern for the engineers in the production of HEVs was the life of the vehicle. Question 15 was asked to see what life expectancy the polled expected from the HEV. The major perception of people is that the HEV should last longer than a normal vehicle. This is reflected in figure 21. The sample group proved to be accurate because the life expectancy of an HEV is approximately 250,000 miles compared to 150,000 miles for conventional vehicles.

Question 16: What maintenance concerns would you have about purchasing an HEV?

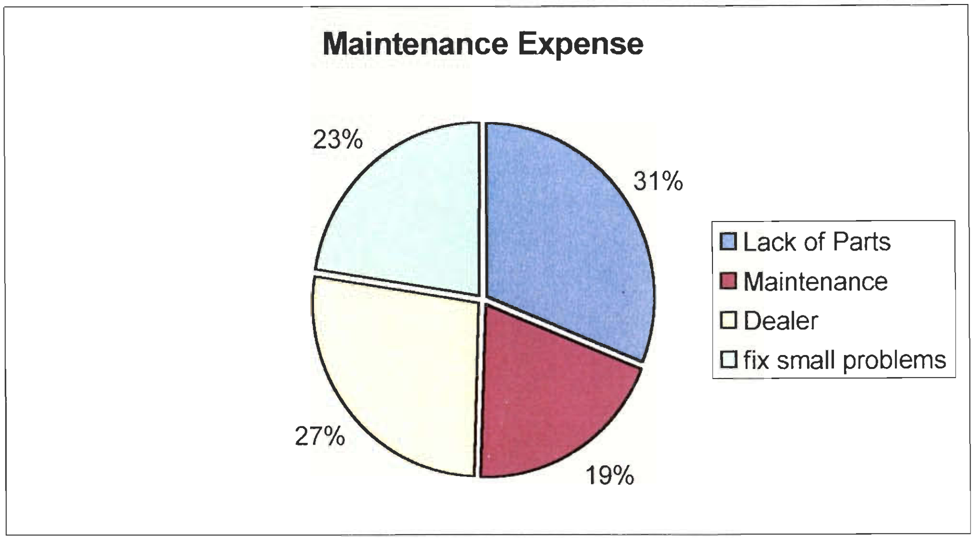


Figure 21

Question 16 was posed in the survey to get a feeling of what maintenance concerns the public has about HEVs. Four major areas of maintenance concerns were raised, lack of parts, maintenance, sending it to the dealer to be fixed, and fixing small problems oneself. The most concern was placed on a lack of parts. This is due to the rarity of HEVs and hence the unavailability of parts. We concluded that individuals taking the survey were unsure if there would be parts readily available to fix the HEV because it is new technology. Currently, the majority of mechanics are not educated about hybrid electric vehicles and the only alternative is to take the vehicle to the dealer. Performing simple maintenance at home, and dealer availability were the next two most popular concerns, while expense was the least popular concern.

Question 17: Would you buy an HEV?

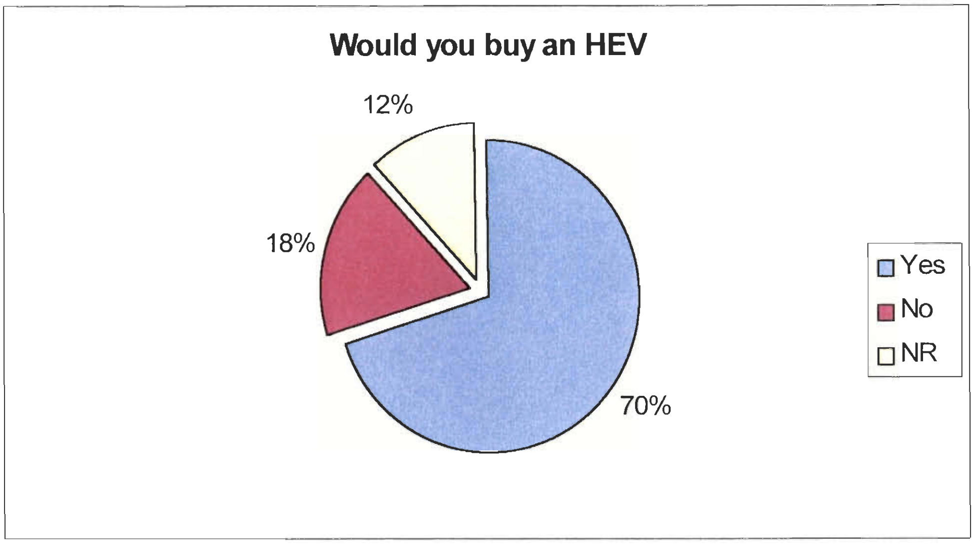


Figure 22

The final question in the survey asked whether or not the person would purchase an HEV and asked the respondents to give a reason. Seventy percent of the people surveyed stated that they would purchase one with only 18% not considering an HEV. The major factor for people who would buy the vehicles was environmental reasons and the increase in gas mileage. The major reason for not buying the vehicle was that people did not trust the new technology, it hasn't been time tested.

Chapter 6: Conclusion

The goals of this project, as previously stated, were to gain an understanding of HEV technology, to evaluate their impact on the environment and society, and to assess societies knowledge and perceptions of HEVs. Each of these goals was addressed in the preceding chapters.

An understanding of HEVs was gained through research of literature and news articles. The first step taken was to explain exactly what an HEV is and the basic principles of how they work. The different configurations of HEVs, series, parallel, and combination, were all explained. It was discovered that while there are three configurations of HEVs the most popular type to date is the combination configuration. Next, a history of HEV, EV, and ICE vehicles was discussed. It was discovered that while the ICE automobile is the most popular form of transportation today, the concepts of EVs and HEVs have been around for some time. Both types of vehicles were in development during the late 1800s. Vehicles of these types were either large, underpowered, or not practical enough to endure. The innovations made in ICE technology led to the fall off of HEV and ICE development and the ICE vehicle was widely accepted as the vehicle of the day. During recent times, however, the HEV and ICE have become more popular and most major auto companies have at least developmental models. Following the histories of these vehicles some of the more innovative technologies of HEVs was discussed. Some of these systems are the regenerative braking system, the energy management system, and the thermal management system. Along with this, an explanation of some of the differences between

ICE and HEV systems is given. A number of the systems in a hybrid vehicle differ from the systems in a conventional vehicle. This is due to the fact that more attention was paid to the weight and efficiency of the components in the hybrid systems and also because of the mechanical differences between the vehicles. Some of the systems explained are the tires and rims, suspension, steering, charging, cooling and heating systems. One of the major differences between an ICE vehicle and an HEV is the battery. An explanation of these differences and how a battery works is given. Once HEV technology was explained an overview of some of the models now available or in development was given. These models are from Honda, Toyota and GM. The Honda Insight is available in the U.S. now while the Toyota Prius will soon be on the market. The GM models are still in the developmental stages.

The next issue addressed was the social and environmental impacts of HEVs. The first step taken was to explain the emissions given off by an ICE vehicle and their effects on the environment. HEVs would decrease this effect substantially therefore this is an important driving force for the advancement of HEV technology. We also investigated the effect of HEVs on employment. Research was done on past changes in technology and how they affected employment. Based on this research it was determined that the change from ICE and HEV would not have any major effects on employment. This is due to the fact that although the industry is changing relatively fast, people are adapting and becoming educated at nearly the same rate. Next, we looked at the oil industry. Factors that affect the price of oil were explained and inferences were made as to how HEVs would affect these prices. It was determined that prices would rise initially but would eventually become lower. The resulting lower consumption of oil in the U.S. if HEVs were to replace ICEs on the road, also spurs hope for a self sufficient nation in terms of oil imports.

In the final section of the paper, the knowledge and perceptions of our peers is investigated through the use of a survey included in appendix two. The survey was circulated to mostly college age students. The major fact learned in the survey was that people are not very well educated about HEVs. While most people surveyed appeared receptive towards the idea of an HEV, their knowledge and awareness of the topic was limited. This leads to the conclusion that HEV technology needs to be publicized more than it is at the time of this study. If the goal of hybrid vehicles becoming successful in modern society is to be achieved, the public must be made more educated about the relevant facts.

The Interactive Qualifying Report presented in this paper was performed with several goals in mind. These goals were to provide a means for an average person to understand the concept of hybrid vehicles, provide a background of the development of modern transportation, evaluate the impact HEVs would have on the environment and society if they were to become widely accepted, and to determine what kind of knowledge people currently have about HEVs. These goals were met through the use of research, interviews, and a survey. The results presented would be useful to several groups. An individual who wished to learn more about HEV's would find the report very useful. Automobile companies would also find the report useful. These companies could use the survey to determine what issues need to be addressed in ad campaigns.

Appendix 1

Hybrid Electric Vehicle Terms

Batteries: Batteries store and deliver electrical energy by initiating and reversing chemical reactions. Chemical reactions cause the flow and transfer of electrons to form chemical products.

Cycle: A cycle is one complete charge/discharge sequence of a battery.

Cycle Life: Number of cycles a battery will undergo before being "worn out."

Driveline Efficiency: The measure of the amount of energy produced in an engine or motor that is used for propulsion (i.e. not wasted).

Electrolyte: The medium of ion transfer between anode and cathode within a battery. Usually liquid or paste which is either acidic or basic.

Energy Density: Amount of energy a battery has in relation to its size. High density in a smaller battery

EV: Electric Vehicle

Fuel Cell: An electrochemical engine (no moving parts) that converts the chemical energy of a fuel, such as hydrogen, and an oxidant, such as oxygen, directly to electricity.

Flywheel: Flywheels store energy mechanically. To absorb energy, the flywheel converts electrical energy to kinetic energy (using a built-in motor), making the flywheel's high-strength rotor spin faster. To deliver energy, some of the kinetic energy stored in the rotor is converted to electrical energy using the motor in reverse (as a generator), slowing the rotor down.

Horsepower: A measurement of power. A horse exerting one horsepower can raise 331 pounds of coal 100 feet in a minute.

Hybrid Power Unit (HPU): An HPU converts fuel into energy.

Hybrid Vehicle: A Hybrid Electric Vehicle (HEV) is a vehicle that has two sources of motive energy, one of them being an electric motor.

Long Term Batteries: Batteries that are still being tested

Midterm Batteries: Batteries that are being tested and are in some vehicles.

Near Term Batteries: Batteries that are very close ,or are, being used

Parallel Hybrid: An HEV with a parallel configuration has a direct mechanical connection between the hybrid power unit (HPU) and the wheels as in a conventional vehicle, but has an electric motor driving the wheels as well.

Range: The distance that a vehicle can travel on a charge. Also the distance a car can travel on one tank of gas.

Regenerative Braking: In its simplest form, regenerative braking describes the ability of a vehicle to usefully convert some of its kinetic energy from the spinning wheels, at the time the vehicle must be slowed or stopped, into electric energy.

Rolling Losses: The amount of energy lost as a result of tire rolling resistance.

Rolling Resistance Coefficient: A measure of the drag created by friction between the tires of a moving car and the pavement.

Series Hybrid: An HEV with a series configuration uses the heat engine with a generator to supply electricity for the battery pack and electric motor. Series HEVs have no mechanical connection between the hybrid power unit (HPU) and the wheels; therefore, all motive power is transferred electrically to an electric motor that drives the wheels.

Specific Energy: The total amount of energy in Watt-hours that the battery can store per kg of mass.

Specific Power: Maximum number of Watts/kg a battery delivers at different charge levels. Highest when fully charged. Usually measured when battery charge is at 80%. As the battery is discharged the SP and acceleration ability go down.

ULEV: Ultra Low Emissions Vehicle

Ultra-Capacitors: Ultra-capacitors store electrical energy by accumulating and separating unlike charges. To discharge the ultra-capacitor, a load is applied between the two terminals so that charge can flow through it.

Appendix 2

Hybrid Electric Vehicle Survey

A hybrid electric vehicle (HEV) is a vehicle that utilizes two power sources to perform its function. The most popular current HEV technology consists of a small gasoline powered internal combustion engine (ICE) and an electric motor. The ICE serves two purposes in current models; it helps to propel the vehicle and is also used to charge batteries that in turn power the electric motor. The electric motor's main function is to propel the vehicle. Some benefits resulting from the integration of HEVs into society would be a reduction in pollution levels and a reduction in the use of fossil fuels.

1. Sex ___Male ___Female

2. Age ___under 16 ___16-25 ___26-35 ___36-45 ___46-55 ___56 and older

3. Occupation ________________________________

4. Approximately how many miles do you drive your vehicle annually? (In thousands)?
___0-5 ___5-10 ___10-15 ___15-20 ___20 and up

5. Would you consider yourself to be up to date with current technologies in the automobile industry?
___Yes ___No ___Somewhat

6. Are you aware of the recent developments in HEV technology?
___Yes ___No

7. Do you know of any HEVs currently on the market in the US?
___Yes ___No

8. The following is a list of concerns that auto consumers might have. Please rate the importance you would place on each concern when purchasing a vehicle from 1 to 5.

	Least				Most
Fuel economy	**1**	**2**	**3**	**4**	**5**
Environmentally Sound	**1**	**2**	**3**	**4**	**5**
Style/Design	**1**	**2**	**3**	**4**	**5**
Price	**1**	**2**	**3**	**4**	**5**
Performance	**1**	**2**	**3**	**4**	**5**
Safety	**1**	**2**	**3**	**4**	**5**
Passenger Capacity	**1**	**2**	**3**	**4**	**5**
Maintenance	**1**	**2**	**3**	**4**	**5**
Luxury/Accessories	**1**	**2**	**3**	**4**	**5**
Life Expectancy	**1**	**2**	**3**	**4**	**5**

9. The average compact vehicle gets 31 miles per gallon. What gas mileage do you think an HEV would get?
___20-31 ___32-40 ___41-50 ___51-60 ___61-70 ___71-80

10. If you were to purchase an HEV, would you want its appearance to match today's standards or appear more distinct?
___Today's standards ___More distinct ___ doesn't matter

11. If purchasing an HEV, would you be willing to sacrifice some power for a gain in mileage and a reduction in emissions?

___Yes ___No

12. How much would you be willing to spend on an HEV?
___the same as a normal vehicle
___0-5% more than a normal vehicle
___5-10% more than a normal vehicle
___ 10-20% more than a normal vehicle
___more than 20% more than a normal vehicle

13. A standard car accelerates from 0 to 60 mph in 8 seconds. How long would you expect an HEV to accelerate from 0 to 60 mph in? (seconds)
___0-6 (sports car)
___5-10 (average car)
___10-15 (somewhat slow vehicle)
___15-20 (under powered vehicle)

14. Would you consider buying a compact or two-passenger vehicle?
___Yes ___No

16. The average vehicle has a life expectancy of 150,000 miles. Would you expect an HEV to have longer or shorter life expectancy?
___Longer ___Shorter ___Same

17. What maintenance concerns would you have about purchasing an HEV? (Check all that apply)
___Lack of parts/time it takes to receive them
___Maintenance expense
___Having to bring the HEV to the dealer instead of your local garage
___Not being able to fix small problems yourself
___Other______________________________

18. Would you purchase an HEV?
___Yes ___No

Reason____

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