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Should You Buy A Hybrid Car?

John Paul McCann

Worcester Polytechnic Institute

Matthew David Dooman

Worcester Polytechnic Institute

Patrick James Ennis

Worcester Polytechnic Institute

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Project Number: HGV-0210

SHOULD YOU BUY A HYBRID CAR?

An Interactive Qualifying Project Report

Submitted to the Faculty

of the

Worcester Polytechnic Institute

in Partial Fulfillment of the Requirements for the

Degree of Bachelor of Science

By

Matt Dooman

Patrick Ennis

John Paul McCann

Date: March 15, 2010

Professor Helen G. Vassallo

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I. INTRODUCTION

Hybrid cars are advertised as the green solution to ending America's dependence on foreign oil, but do they deliver on that promise? Car companies would have one believe that hybrids are the future of the auto industry, and this may be the case, but there are many different types out there offering higher mileage with the confidence to say, "We are the future of the automotive industry." The inevitable question crossing consumers' minds is: Which hybrid car do I buy, and what benefits should I expect from purchasing one?

There are a few main types of hybrids available to consumers: Electric-gas, fully electric, hydrogen, and hydraulic. Each type has its advantages and disadvantages, but the electric-gas hybrids currently dominate the marketplace.

With all these options consumers have a big decision to make while buying a hybrid vehicle, or even if they should buy one at all. Consumers look to buy hybrids for three main reasons: to save money, to reduce pollution, and to help end dependency of foreign oil.¹ Typically it takes four to five years to make a return on spending a few extra thousand dollars up front to purchase a hybrid. When many consumers make their purchase they may not even realize that they will not see a return on their investment for a number of years under normal driving conditions. While some drivers will see vast improvements on their miles per gallon, others will see very little. For a city driver a hybrid car is definitely a great way to help reduce greenhouse gasses and increase miles per gallon, but for someone who mostly put highway miles on a car, a hybrid may not be the right choice. Buying an alternative energy car is a great way to make a statement to the world; the consumer does not rely on foreign oil, and will support alternative energy.

This team will guide the consumer through all the current and upcoming hybrid possibilities to find a solution that may fit his needs, and simultaneously help to save the environment.

II. BACKGROUND

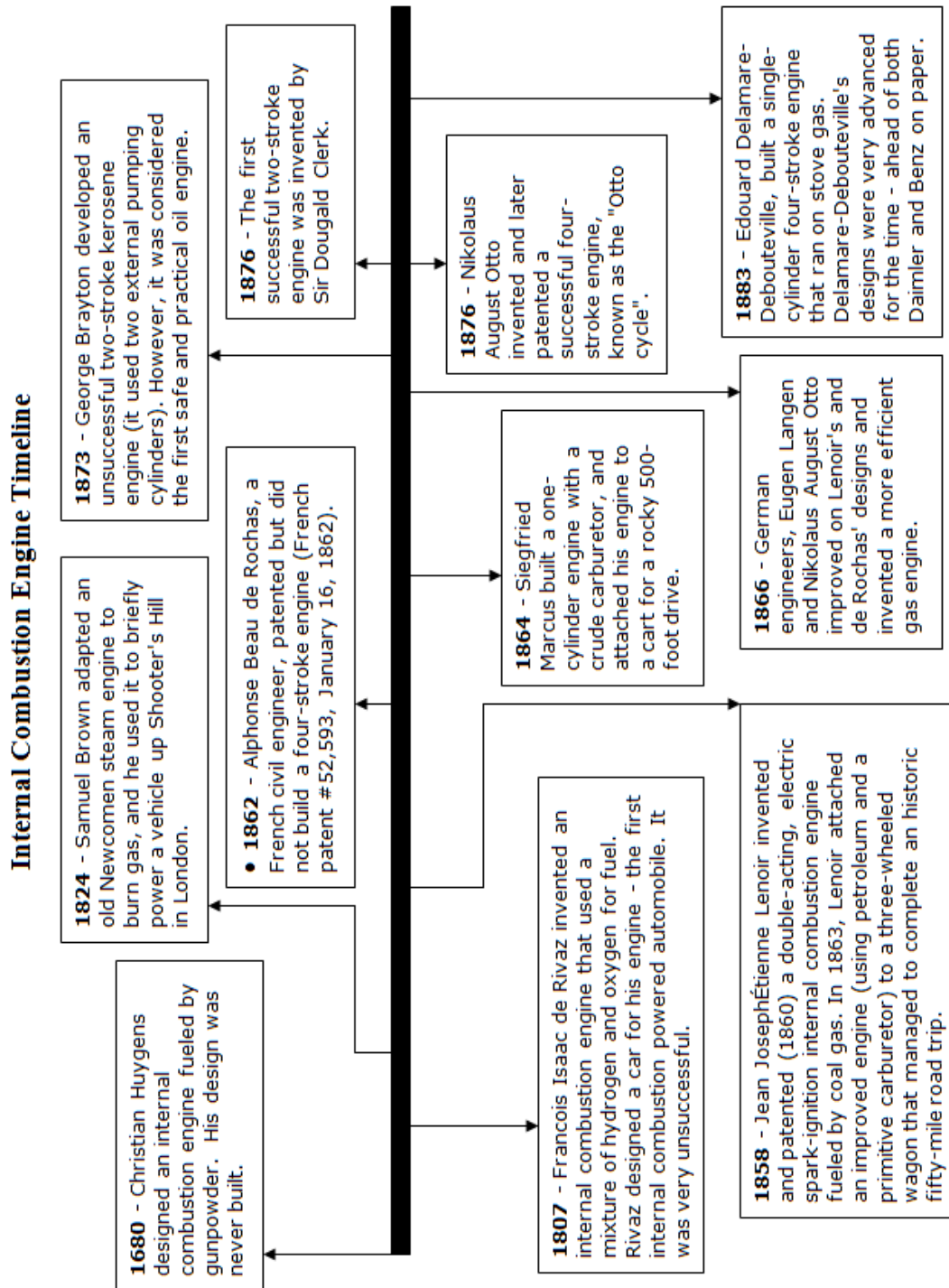


Figure 1: Internal Combustion Engine Timeline

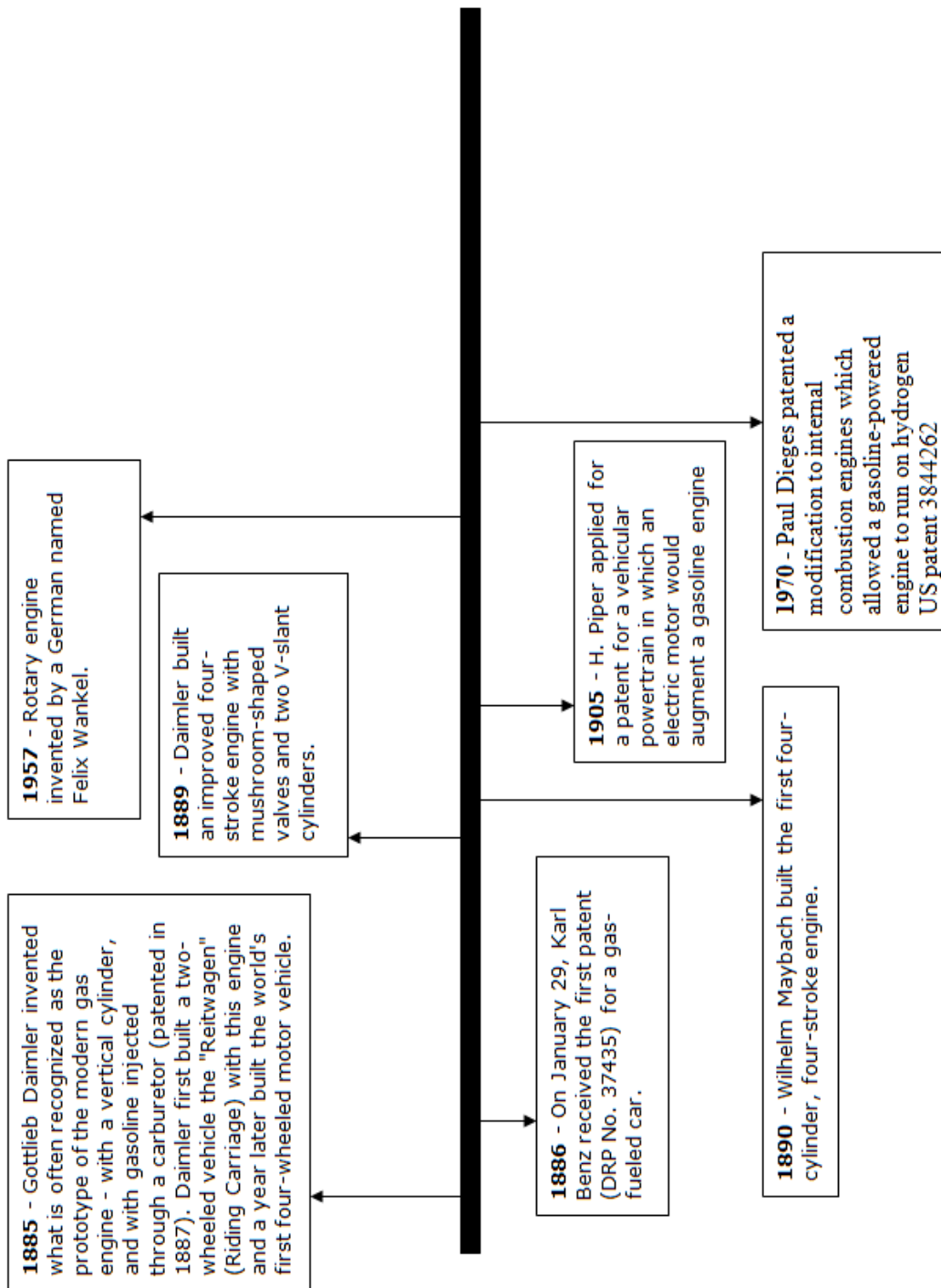


Figure 2: Internal Combustion Engine Timeline

History of Internal Combustion Automobile Engine

Hybrid cars are relatively new when seen in the timeline of consumer automobiles. Hybrids are currently in a period of rapid technological advancement and have begun to be marketed to the masses. They are following a similar path to that of the internal combustion engine on the way to mass acceptance. It also seems as though all vehicles using alternate fuels are following the same path. Many of the same concerns brought up during the dawn of the internal combustion engine are being brought up yet again concerning hybrids as well as other alternate fuel sources.

These concerns include safety, reliability, cost effectiveness, as well as many other potential issues. Similar concerns over internal combustion engines were resolved over time due to continued research, advancements in automobile technology, and clarification, which allowed the internal combustion engine to gain the popularity that it has today. Hybrids, as well as vehicles using other alternative fuels, will more than likely have to overcome the same hurdles to gain an equal or greater amount of public acceptance than internal combustion vehicles.

When comparing the hybrid evolution and acceptance timeline to that of the internal combustion engine, it can be seen that the hybrid is evolving at a faster pace due to the fact that hybrids use an already developed internal combustion engine and the idea of a mechanically powered vehicle is not a brand new concept. This will not be the case for alternative fuel vehicles that use technologies that have never been seen before or have a reputation for being dangerous or unreliable. These types of alternative fuel vehicles will have to go through the same scrutiny that the internal combustion engine did in its early years.

III. METHODS

- c. Interviews
 - i. Professors
 - 1. Van De Ven
 - 2. Norton
 - ii. Dealers
 - iii. Student Interviews
- d. Test Drives
- e. Literature

IV. RESULTS

Summary of Interviews

Van de Ven

Question 1: “What types of hybrid cars are currently on the market?” Professor Van de Ven answered that basic electric hybrids are available in small and medium passenger cars and trucks, and hydraulic hybrids are available in large trucks, such as garbage trucks and UPS trucks.

Question 2: “How does the drive train of these hybrids work?” Professor Van de Ven explained that in parallel hybrids the engine is used to drive the wheels, but another motor can also be used to drive the wheels. He went on to explain that in series hybrids the engine does not drive the wheels, but drives a device that powers another motor, which in turn drives the wheels. He also indicated that series hybrids are more efficient, but parallel hybrids are easier to retrofit and have a mechanical failsafe.

Question 3: “What types of hybrids are available to consumers?” Van de Ven told the team that electrical hybrids are available, and the only consumer hydraulic hybrids are custom vehicles and research vehicles.

Question 4: “What are the other types of hybrids that are being used?” Van de Ven then explained that large trucks, like garbage trucks and UPS trucks, used hydraulic hybrid technology. He said the reason for this is the large size of the hydraulic accumulator.

Question 5: “Would you buy a hybrid?” Professor Van de Ven likes the ideas of hybrids since it makes consumers aware of the different options they have, but doesn’t

feel that electric hybrids are the best way of improving efficiency. He also mentioned that diesel engines get the same fuel mileage as hybrids do.

Question 6: “What hybrids have the brightest future?” Van de Ven felt that hydraulic hybrids could become very popular with all the work being put into the technology. With new technology hydraulic hybrids could get the same energy out of a smaller accumulator. Also hydraulic hybrids do not have parts that would wear out like an electric hybrid does.

Question 7: “What does driving a hybrid feel like?” Professor Van de Ven’s hybrid driving experience was driving a series hydraulic hybrid. He said that the biggest difference was the aggressive engine management. He also said that the hydraulic motor produces more torque than a gasoline engine, which allows more power in a smaller package.²

Norton

Question 1: “What types of hybrid cars are currently on the market?” Professor Norton responded by talking about the different electric hybrids being produced for consumers today. He talked about the how General Motors makes hybrid cars, trucks, and SUVs, but the larger vehicles do not see a large increase in fuel mileage, like the cars do.

Question 2: “How does the drive train of these hybrids work?” Norton explained that the Prius has the most exotic drive train. He went on to explain that the Prius has a complicated control system to power the vehicle depending on the load on the engine. In light load situations the Prius uses only electrical power, and under higher load situations the Prius uses both gas and electrical power.

Question 3: “Where are the other types of hybrids being used?” Professor Norton explained that the idea of a hybrid drive train is nothing new. He talked about how diesel electric hybrids are used on locomotive trains, since an electric motor has full torque at zero revolutions per minute.

Question 4: “Would you buy a hybrid?” Professor Norton responded that he would not buy a hybrid car. He does not have a commute that would benefit from a hybrid car. He also buys cars that handle and perform well. He feels that hybrid cars are econoboxes with fancy drive trains.

Question 5: “What hybrids had the brightest future?” Norton did not have any opinion of this.

Question 6: “What does driving a hybrid feel like?” Since Professor Norton has not driven a hybrid he could not answer this question.³

Dealer

Question 1: “How well do hybrids sell?” He told the team that nationally about one tenth of Toyota’s cars sales are hybrids.

Question 2: “What are consumer responses to hybrids, and do people have basic knowledge of them?” He explained that many people are open to the idea, but also do not have enough information on them. When people come looking specifically for hybrids they are usually very knowledgeable and have done research prior to coming into the dealership.

Question 3: “What are your personal feelings toward hybrids?” He said that he likes them since they are better for the environment, better on gas, and reliable.

Question 4: “What are the main consumers concerns regarding hybrids?” Houde said that most popular question is if the cars need to be plugged in and how the cars work. He also said that reliability is another common question.

Question 5: “Do hybrids have any specific maintenance intervals, and if so what are they?” Houde said that the maintenance intervals of a hybrid are the same as a regular car. He also explained that the hybrid system is relatively simple and self-contained.

Question 6: “What is the expected battery life, and when do they need to be replaced?” Houde told the team that in the ten years that the Prius has been in production there have only been 17 batteries replaced, and only three were due to defective batteries. He also mentioned that the warranty on the batteries is ten years.

Question 7: “Are sales people pushing hybrids over gasoline powered cars?” Houde said that they are not pushed over gasoline powered cars, but he will mention hybrids to people when a hybrid is in their price range and meets the requirements customers are looking for.

Question 8: “Does Toyota offer any incentives for hybrid buyers?” Houde said that there were currently none, but they do qualify like other cars.

Question 9: “Do hybrid buys ever come back unhappy with their new hybrid car?” Houde said that he has never had anyone come back unhappy. He also mentioned that many customers refer their friends to buy hybrid cars.

Question 10: “What is the average turnaround for hybrids?” He said that lease returns are the main cause for hybrids to come back. Many people keep their hybrids,

which makes used hybrids rare. He also said that some people trade in their current hybrid for a new model.⁴

Student Interviews

The first question the team asked on the general public survey was: “Have you heard of hybrids?” 18 participants responded “Yes” and no participants responded “No.” The participants were then asked: “Have you heard positive or negative things?” 14 participants responded “Positive” and nine participants responded “Negative.” The overlap is due to some participants responding with both answers.

The next question asked was: “Have you driven a hybrid?” Three participants responded “Yes” and 15 participants responded “No.” The participants who had driven a hybrid were then asked: “Was it a positive or negative experience?” One participant responded “Positive” and two participants responded “Negative.”

The next question asked was: “Do you know anyone who owns a hybrid?” 12 participants responded “Yes” and six participants responded “No.” The participants who responded “Yes” were then asked: “Do the owners have positive or negative feelings towards hybrids?” Ten participants responded “Positive” and three participants responded “Negative.” Again, the overlap is due to some participants responding with both answers.

The final question the participants were asked was: “Would you buy a hybrid?” Ten participants responded “Yes” and eight participants responded “No.” The participants who responded “Yes” were then asked for what reasons they would purchase a hybrid vehicle. In response to the fuel economy of hybrid vehicles, eight participants responded “Yes” it would be a reason that they would purchase a hybrid vehicle and two

participants responded “No.” In response to the reliability of hybrid vehicles, seven participants responded “Yes” it would be a reason that they would purchase a hybrid vehicle and three participants responded “No.” In response to the environmental safety of hybrid vehicles, nine participants responded “Yes” it would be a reason that they would purchase a hybrid vehicle and one participant responded “No.” In response to the status associated with owning a hybrid vehicle, two participants responded “Yes” it would be a reason that they would purchase a hybrid vehicle and eight responded “No.”

After reviewing the results of this survey the team realizes that there are mixed feelings toward hybrid vehicles, but the majority is in favor of them. The team was also surprised to discover that everyone interviewed had previously heard about hybrid vehicles, which shows that the marketing done by manufacturers has succeeded in its goal to inform the public about hybrid vehicles. Even though the population is aware of the presence of hybrid cars in the marketplace, their purpose and uses remain not fully explained by current marketing campaigns.

Summary of Test Drive

After test-driving a Lexus RX400h, an SUV hybrid made by Lexus, the team found that there are only a few driving differences. One team member said, “It did not feel sluggish,” and “It felt normal, but sounded different.” The team member did not find any of these things to be a problem, but realized that some drivers may panic if they do not hear that familiar sound of the internal combustion engine while they are accelerating.

V. DISCUSSION

History of the Internal Combustion Engine

An internal combustion engine (Figure 3) is defined as an engine of one or more working cylinders in which the process of combustion takes place within the cylinders,⁵ or any type of machine that obtains mechanical energy directly from the expenditure of the chemical energy of fuel burned in a combustion chamber that is an integral part of the engine.³ The types of internal combustion engines currently in use in automobiles are: the Otto-cycle, the diesel, and the rotary engine. The Otto-cycle and the diesel are currently the most common internal-combustion engines in automobiles.

The Otto-cycle engine, invented by the German engineer Nikolaus August Otto, is the most common piston engine, and runs primarily on gasoline, although it can be modified to run on a variety of fuel sources. The diesel engine, invented by the German engineer Rudolf Christian Karl Diesel, operates on a different principle and usually uses oil as a fuel; it is used primarily in trucks and buses, but can be found in some automobiles.⁷

The essential parts of Otto-cycle and diesel engines are similar. The combustion chamber consists of a cylinder, which is closed at one end and in which a close-fitting piston slides. The in-and-out motion of the piston varies the volume of the chamber between the inner face of the piston and the closed end of the cylinder. The outer face of the piston is attached to a crankshaft by a connecting rod. The crankshaft transforms the reciprocating motion of the piston into rotary motion. In multi-cylindere d engines the crankshaft has one offset portion, so that the power from each cylinder is applied to the crankshaft at the appropriate point in its rotation. Crankshafts have heavy flywheels and

counterweights, which by their inertia minimize irregularity in the motion of the shaft and thus reduce harshness and vibration. Engines may have from one to as many as 28 cylinders, the most common being four, six, and eight cylinder engines.⁶

Fuel Supply

The fuel supply of an internal-combustion engine consists of a tank, a fuel pump, and a device for vaporizing or atomizing the liquid fuel. This device has historically been a carburetor in Otto-cycle engines and a mechanical fuel-injection system in diesel engines. However, by the 1990s electronic fuel-injection systems were being used in most Otto-cycle and diesel engines, providing more precise control over the fuel-air mixture to improve performance and fuel economy, and to reduce exhaust emissions. The vaporized fuel in most multi-cylindered engines is conveyed to the cylinders through a branched pipe called the intake manifold; in many engines, a similar exhaust manifold is provided to carry off the gases produced by combustion. The fuel is admitted to each cylinder and the waste gases are exhausted through mechanically operated valves. The valves are normally held closed by the pressure of springs and are opened at the proper time during the operating cycle by cams on a rotating camshaft that is geared to the crankshaft.⁶

Ignition

In all engines some means of igniting the fuel in the cylinder must be provided. The ignition system of Otto-cycle engine consists of a source of low-voltage direct current electricity that is connected to an ignition coil. The current is interrupted many

times a second by an automatic switch. The pulsations of the current induce a pulsating, high-voltage current. The high-voltage current is led to each cylinder in turn by the distributor. The actual ignition device is the spark plug, an insulated conductor set in the wall or top of each cylinder. At the inner end of the spark plug is a small gap between two wires. The high-voltage current arcs across this gap, yielding the spark that ignites the fuel mixture in the cylinder. By the 1990s, spark plugs had been replaced in most new automotive engines by fuel-injectors, and electronic actuators had replaced traditional distributors. Most automotive engine manufacturers had begun producing multi-valve engines, which improves acceleration without sacrificing fuel economy. These engines typically have four valves per cylinder, twice that of standard engines, to improve air flow in the intake and exhaust cycles.⁶

The Otto Cycle

The ordinary Otto-cycle engine is a four-stroke engine, in which the pistons make four strokes, two toward the head of a cylinder and two away from the head, in a complete power cycle. During the first stroke of the cycle, the piston moves away from the cylinder head while simultaneously opening the intake valve. The motion of the piston during this stroke pulls a mixture of fuel and air into the combustion chamber. During the next stroke the piston moves toward the cylinder head and compresses the fuel mixture in the combustion chamber. At the moment when the piston reaches the end of this stroke and the volume of the combustion chamber is at a minimum, the fuel mixture is ignited by the spark plug or injector and burns, expanding and exerting a pressure on the piston, which is then driven away from the cylinder head in the third stroke. During the final stroke, the exhaust valve is opened and the piston moves toward the cylinder

head, driving the exhaust gases out of the combustion chamber and leaving the cylinder ready to repeat the cycle. The efficiency of a modern Otto-cycle engine is limited by certain factors, such as losses by cooling and by friction. The efficiencies of good modern Otto-cycle engines range between 20 and 25 percent, meaning that only 20 to 25 percent of the heat energy of the fuel is transformed into mechanical energy.⁶

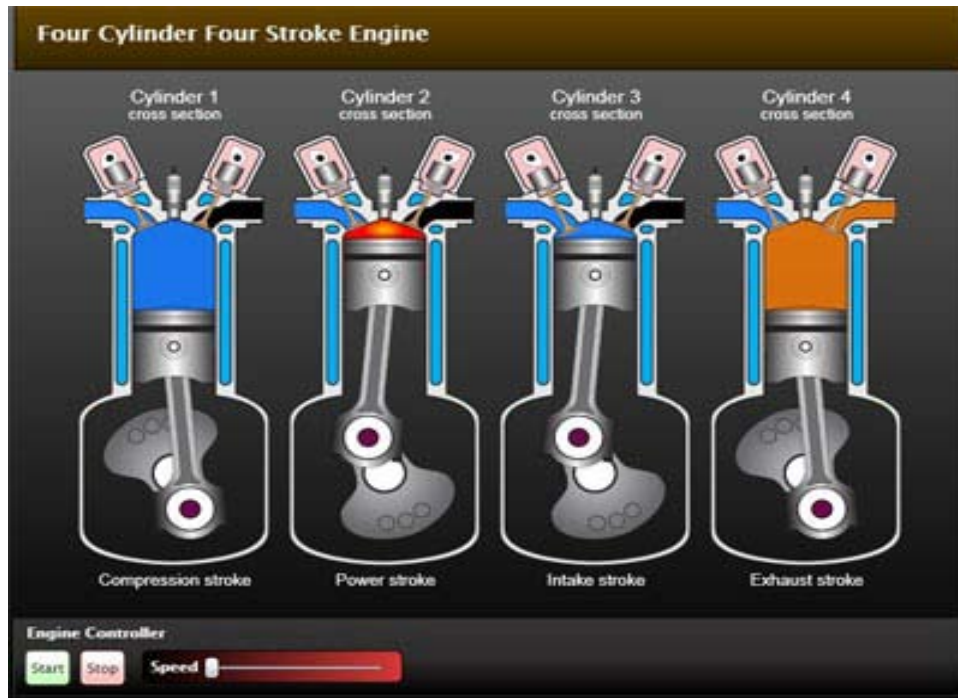


Figure 3: Otto Cycle⁸

The Diesel Cycle

Theoretically the diesel cycle differs from the Otto cycle in that combustion takes place at constant volume rather than at constant pressure. Most diesels are four-stroke engines operating slightly differently than Otto cycle engines. The first stroke draws air, but no fuel, into the combustion chamber through an intake valve. On the second stroke the air is compressed to a fraction of its former volume and is thereby heated to about 440° C. At the end of this stroke vaporized fuel is injected into the combustion chamber and burns instantly due to the high temperature of the air in the chamber. Some diesels

have auxiliary electrical ignition systems to ignite the fuel when the engine starts, and until it warms up. This combustion drives the piston back on the third stroke of the cycle. The fourth stroke is an exhaust stroke. The efficiency of the diesel engine is inherently greater than that of any Otto cycle engine and in actual engines today is slightly more than 40 percent. Diesel engines are in general slow-speed engines with crankshaft speeds of 100 to 700 rpm compared to 2500 to 5000 rpm for typical Otto cycle engines. Diesel engines are widely used in trucks and buses and gained brief popularity in the U.S. after the oil crises of the 1970s. High emissions, excess noise, and generally poor performance combined with soft fuel prices and stringent federal emissions standards in the 1980s and '90s set back the use of diesels in automobiles.⁶ There is a small market of turbocharged automotive diesels today, but they pale in comparison to automobiles using the Otto cycle.

Two Stroke Engines

Otto-cycle and diesel engines can also be designed to operate as two-stroke engines; these engines have a power stroke every other stroke of the piston instead of once every four strokes. The efficiency of such engines is usually less than that of four-stroke engines, however, the power of a two-stroke engine is more than half that of a four-stroke engine of comparable size. The general principle of the two-stroke engine is to shorten the periods in which fuel is introduced to the combustion chamber and in which the spent gases are exhausted to a small fraction of the duration of a stroke instead of allowing each of these operations to occupy a full stroke. In the two-stroke cycle the fuel mixture or air is introduced through the intake port when the piston is fully withdrawn from the cylinder. The compression stroke follows and the charge is ignited at

the end of this stroke. The piston then moves outward on the power stroke, uncovering the exhaust port and permitting the gases to escape. Two-stroke engines are most commonly used in motorcycles, boats, and lawn mowers; however, automakers were developing two-stroke Otto-cycle engines using advanced electronics, with large-scale production expected in the mid- to late 1990s. These engines are about 25 percent less bulky and about 15 percent more fuel efficient than standard four-stroke Otto-cycle engines.⁶

Wankel Engine

In the 1950s the German engineer Felix Wankel developed his concept of an internal combustion engine of a radically new design, in which a three-cornered rotor turning in a roughly oval chamber replaced the piston and cylinder. (Figure 4) The fuel-air mixture is drawn in through an intake port and trapped between one face of the turning rotor and the wall of the oval chamber. The turning of the rotor compresses the mixture, which is ignited by a spark plug. The exhaust gases are then expelled through an exhaust port by the action of the turning rotor. The cycle takes place alternately at each face of the rotor, giving three power strokes for each turn of the rotor. The engine offers practically vibration-free operation, and its mechanical simplicity provides low manufacturing costs. The rotary usually runs on gasoline but is adaptable to alternative fuels. With the rise in gasoline prices during the 1970s and '80s, the rotary's compact size and lower weight as compared with piston engines increased its value and importance as an automobile engine. Its popularity soon waned because of difficulty in meeting exhaust emission standards and low fuel efficiency.⁶ By the mid-1990s only one automaker continued to offer rotary-powered cars, Mazda.



Figure 4: Wankel Cycle⁸

Ongoing concern with fuel efficiency and exhaust emissions of internal combustion engines, particularly in automobiles, has prompted their continued modification. New fuel sources, and engine modifications are in constant development as the race to find the next type of automobile engine continues. This race has brought this team to hybrid cars, where the team will evaluate the effectiveness of these new developments in the automobile market.

Types of Hybrids

Gas Electric Hybrids

There are two main types of hybrids that are available on the market today, the series hybrid (Figure 5) and the parallel hybrid. (Figure 6) They differ significantly with different advantages and disadvantages respectfully. The main difference is the way in which the motors are used to propel the vehicle together.

In series hybrids the gasoline engine connects to the generator and is used solely for recharging the batteries.⁹ This type of hybrid is the simplest, but is more expensive than its parallel counterpart. These hybrids also have a more powerful battery pack, since the electric motor is the only way that the car's wheels are powered. The high-speed

motors included in this type of hybrid do not require a complicated transmission clutch system, and because of this, there are fewer moving parts, and therefore a simpler design with fewer possibilities for failure. The motors do not need to change gears or use a gasoline engine to power the wheels, so they perform best in the stop-and-go traffic of a city, where pure gasoline cars are at their dirtiest and least efficient. Unfortunately, this type of engine lacks the power of a traditional gasoline engine making series hybrids difficult to drive on highways when quick acceleration is crucial to change lanes.

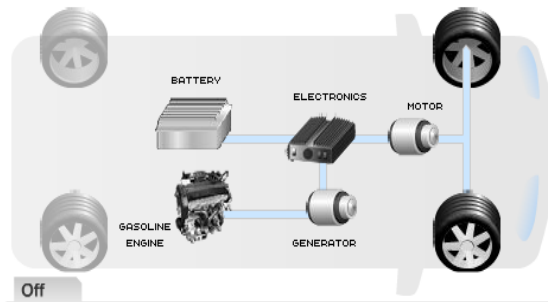


Figure 5: Series Hybrid Drivetrain⁹

The other type of hybrid is the parallel hybrid. In this hybrid the gasoline engine and the electric components both run the motor.⁹ This makes the parallel hybrid better at accelerating and general highway performance, but still has some of the same problems as other gasoline powered cars in that these waste gasoline while idling. This type of hybrid also has a lower cost than its series counterparts due to the smaller battery pack required for operation. A consumer switching from a gasoline-powered vehicle will find a parallel hybrid an easier transition than a series hybrid because he will not notice such a stark difference in the ability of the car to accelerate even at high speeds.

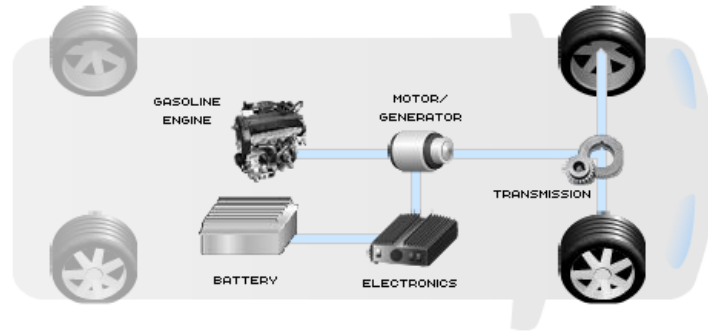


Figure 6: Parallel Hybrid Drivetrain⁹

There are other types of hybrids being tested and sold, but they are not common at this time and are not the focus of this project. Some of these alternative hybrids include combinations of series and parallel drive trains, fully electric cars, other alternative fuel cars, and even “muscle hybrids.” The industry is developing new technologies to make all of these cars possible.

Electric Hybrids

The electric hybrid that is closest to production is the Chevrolet Volt. The Volt is an extended range hybrid, as classified by Chevrolet, which is set to go on sale late 2010 as a 2011 model. The Volt was originally designed as an electric vehicle to be a successor to the EV-1, General Motor’s electric vehicle. While the EV-1 was strictly an electric car that needed to be plugged in, the Volt has the same ability, but also has the ability to produce electricity using the gasoline engine. The Volt is a series hybrid, using only the electric motor to produce the motion and the gasoline engine to produce electricity to charge the batteries. Unlike the Prius and Insight, the Volt can use only electricity and never need the gasoline engine if it is charged on a nightly basis. The addition of the plug allows the Volt to get much better fuel economy and significantly reduce the emissions of greenhouse gasses. With the current hybrids on the market there

is no way for the Prius to never use the gasoline engine. Unfortunately, since the Volt is not in production yet, there is limited information available about the specifications. The fuel economy testing numbers are not yet available for the Volt. Since this is one of the first cars of its kind, the EPA does not have a standard set for plug-in electric vehicles. Based on the draft EPA testing standards for plug in electric vehicles, the Volt is expected to get over 230 miles per gallon.¹⁰

One of the design challenges of the Volt was to keep the driving experience similar to that of a gasoline powered car. Because the gasoline engine does not power the wheels when the car is running on electricity; some modern technology developed to utilize the modern combustion engine is no longer applicable. One example is in the braking system. On a traditional car there is a brake booster that uses the vacuum created by the engine to increase the force to the brake calipers. Since there is no engine constantly running, power brakes cannot be used. To compensate for this shortcoming, the Volt uses both hydraulic and regenerative braking. According to Motor Trend, “The brake pedal feels quite natural.”¹¹ Motor Trend also stated that when the Volt changes from regenerative braking to hydraulic there is no change in brake effort.¹¹ While this testing was not done with the Chevrolet Volt, it was done using a test mule. The test mule was the 2011 Chevrolet Cruze, which is similar to the size of the Volt, and has been outfitted with the drive train from the Volt.¹¹ Minor differences in feel, such as the feeling of braking, could potentially cause a car to not sell. If there was a major difference in feel between the Volt and traditional internal combustion vehicles, then there would be a major affect on sales numbers.

The performance of the Volt, based off the test mule, was adequate. The zero to sixty times were between nine and ten seconds according to both Motor Trend and Car and Driver, which is average for cars of similar size.^{11,12} General Motors' zero to sixty time target is around eight and a half seconds. The Volt primarily uses an electric motor for motion, and because of this it needs special attention during design to keep the accelerator pedal feel the same as a regular car. An electric motor wants to deliver the entire torque at once, which feels very different than a conventional vehicle. When driving the Volt test mule, the acceleration never felt weird or unusual.¹¹ According to USA Today, the Volt's acceleration has the potential to embarrass muscle car drivers.¹³

While the Volt is a plug-in hybrid, it does not require any additional devices installed in the car to charge. The Volt uses a new plug that all electric vehicles will use called the SAE J1772 standard plug.¹⁴ The plug has a special connector that connects to the vehicle and runs on household 120 VAC. Chevrolet will also be offering a 240VAC charging system for a faster charge. Using a standard 120 VAC outlet, the Volt should take between six and seven hours to fully charge. Using the 240 VAC charging system, GM is hoping to charge the Volt in only two or three hours.¹² Unlike previous electric cars there will be one standard plug for plug-in vehicles. Having a standard plug will reduce consumers' fears of finding a place to charge their vehicle. With the standard plug, places like parking garages, parking lots, hotels, and homes could be potential charging points thus increasing the range of the electric vehicle.

The Volt is expected to have a sticker price around \$40,000, and GM is hoping that the Volt will qualify for the \$7,500 electric car tax credit to help ease the investment.¹³ The Volt will cost about twice as much as the Prius and other hybrids of

similar size, but the Volt does have the potential to not only push this new technology, but because of the tax credit, be a viable alternative vehicle. As with any new technology the price is high now, but over time as the technology integrates itself the prices will drop making them more reasonable for the average consumer.

Hydrogen Hybrids

Hydrogen vehicles are one of the new technologies being discussed as the best way to eliminate the US dependence on fossil fuels. According to Hydrogencarsnow.com hydrogen cars can offer zero emission vehicles, unlike current “green” vehicles.¹⁵ The biggest obstacle currently keeping hydrogen vehicles off the road is the lack of hydrogen infrastructure and the cost to either buy a hydrogen car, or convert an internal combustion engine to run on hydrogen. According to an MSNBC article, the chairman of Hydrogen Car Company cites an article from 1969 stating that: “Americans will drive hydrogen cars in 10 years.”¹⁶

There are two different ways of using hydrogen to power vehicles. Hydrogen can be used to directly power an engine to move the vehicle, or the hydrogen can be used with a fuel cell to power an electric motor to drive the vehicle, which is similar to a series hybrid vehicle. One major advantage of hydrogen fuel cells is that they can be used as electric vehicles if batteries are used to store the excess electric energy. The addition of a battery would allow the vehicle to still be used if hydrogen is not available as long as there was electricity left in the battery. According to the same MSNBC article, one of the biggest issues with hydrogen vehicles is the great expense to purchase a vehicles and components, since the vehicles are not currently being mass produced.¹⁶

Currently the Honda FCX Clarity is the only commercially produced hydrogen vehicle available in the United States. While the FCX is commercially produced, only approximately 200 of them will be leased for \$600/month for three years in Southern California only.¹⁷ Since the lease price is so high, and the number of vehicles available so low, only wealthy early adopters can afford to lease them. To lease a FCX Clarity the potential consumer must fill out a survey from Honda that discusses vehicle needs, vehicle storage, driving habits, and financial situation.¹⁸ The FCX Clarity uses a hydrogen fuel cell to power an electric motor. The only way to power the Clarity's motor is through the batteries, which are charged by the hydrogen fuel cell.

One of the biggest differences between hydrogen and traditional combustion vehicles is refueling. To refuel a traditional gasoline vehicle, the operator drives up to the pump and starts fueling. The only part that the operator needs to decide correctly is the octane rating of the fuel and at some stations whether to choose gasoline or diesel fuel. With a hydrogen fuel vehicle, there are two different pressures that are used. Some cars can use both, while others can use only one pressure hydrogen. The hydrogen tanks have a data port that communicates with the pump to determine the amount of fuel needed along with some other information.¹⁸ While there are two different pressure nozzles in use, the two are not interchangeable thus preventing the wrong pressure from being used.¹⁹ Having tanks with different pressures is similar to knowing what octane fuel the consumer's car requires. While it may initially seem dangerous, it is something being dealt with today, only in a slightly different manner.

Although hydrogen fuel cell vehicles do have a future in the distant automobile industry, unfortunately the infrastructure is not currently available to support the wide

spread use of hydrogen vehicles. Until the infrastructure is in place there are many other notable hybrid technologies that do not require such a nationwide overhaul.

Hydraulic Hybrids

In an interview with a Worcester Polytechnic Professor, James Van de Ven, the team learned a great deal about the different types of hybrids currently on the market, and types of hybrids that are still in the design and testing phases. Currently the only types of hybrid vehicles on the market for consumers are gas-electric hybrids. In the commercial market, however, hydraulic hybrids are currently being used much more extensively. Hydraulic hybrids are being used in “garbage trucks, passenger vans, shuttle vans, and UPS trucks” says Van de Ven. Hydraulic hybrids can be used in both parallel and series hybrids. Series and parallel hydraulic hybrids work the same way as electric hybrids do, but they use a hydraulic pump instead of an electric generator. Of the two types of hydraulic hybrids the series hybrid is the most efficient, but the parallel hybrid allows for a mechanical failsafe. Electric hybrids and hydraulic hybrids are very similar to each other. (Table 1)

	Electric	Hydraulic
“Charging” Device	Electric Generator	Hydraulic Pump
Propulsion Device	Electric Motor	Hydraulic Motor
Energy Storage Device	Batteries	Accumulator

Table 1: Electric and Hydraulic Hybrid Equivalent Parts

With the current hydraulic hybrid technology the accumulator would need to be about thirty liters to power a passenger car. This is one of the biggest factors contributing to reasons as to why there are no hydraulic hybrids on the passenger market. When asked

what technology has the brightest future in the hybrid market, Van de Ven indicated that, “(Hydraulics) are a new technology with a higher energy density.” With this new technology there could be a large change of an order of magnitude in hydraulic hybrids. What this means is that the same passenger car mentioned above that would have needed a thirty-liter accumulator, would only need a three-liter accumulator without compromising power. Another advantage that Van de Ven cited was the fact that hydraulics have “nothing to wear out on the hydraulic system.” This would make the use of a hydraulic hybrid much cleaner, since there are no batteries to recycle. Another major advantage with hydraulic hybrids is that the average passenger car could regain the majority of its energy back from high speed braking. This break would allow the engine to remain off for longer periods of time, since the vehicle could regain more of the braking energy than with an electric hybrid.²

Another topic covered during the interview with Professor Van de Ven was the feeling of driving a hydraulic hybrid. The only type of hydraulic hybrid that Professor Van de Ven has driven was a series hybrid. He indicated that it does take some getting used to. When the vehicle is “started,” the familiar sound of an engine idling is not there. The only way for the driver to know that the vehicle is turned on is by seeing the lights on the dashboard indicating that the car is on. Once the operator starts driving, the only sound that can be heard is a small whine from the hydraulic motor. When the engine starts up to re-pressurize the accumulators the engine immediately begins to run at wide-open throttle; its most efficient speed, which boosts gas mileage. Running the engine at peak efficiency is called “aggressive engine management” and is one of the main reasons that series hybrids can get better fuel economy than parallel hybrids. Van de Ven said,

“The most different aspect of driving a hydraulic hybrid compared to driving a traditional gas car is the aggressive engine management, since the engine only runs at wide-open throttle. This can be confusing when braking because the engine can be running at wide-open throttle, while the car is slowing down.” When asked about the acceleration of a hydraulic hybrid Van de Ven said that hydraulic hybrids have “incredible acceleration and could easily burn tires as long as you would like.” The reason for this Van de Ven explained, is that hydraulic motors have a “flat torque curve unlike a gas engine that starts at zero.” Since the torque curve is flat there is much more power for short periods of time. This means is that when one’s need a lot of power, such as accelerating on the highway or from a stoplight, the car will respond very quickly.

Van de Ven felt that electric hybrids were a stepping-stone, which “make people aware of consumer’s choices that they have”. He also mentioned that there are a lot more efficient ways of make hydraulic drive trains. One of the topics he discussed was how clean diesel will play a role in the future hybrid market. While he does like the idea of people being aware of the choices they have, he believes there are more efficient hybrid technologies out there.³

Compressed Natural Gas (CNG) Hybrids

While electric-gas hybrids are the most popular of the alternative fuel vehicles, there are other lesser-known options available to consumers, one of which is compressed natural gas (CNG). The Honda Civic GX has been named the greenest car by ACEEE.²⁰ Since CNG vehicles have been available, over the past ten years, governments and companies have purchased them in the form of fleet vehicles. The reason for their popularity in fleets is that “fleets have their own refueling systems and mechanics,”²¹

allowing the owners to overcome the two biggest hurdles of owning CNG vehicles.

The lack of infrastructure for CNG vehicles has been the largest reason for their lack of popularity in the United States. In the US there are just 772 compressed natural gas fueling stations, as of 9/14/2009, according to the US Department of Energy's website.²² While the number of stations is relatively small it is not representative of the placement of stations throughout the country. Out of the 772 total stations 386 of them are in 3 states; California, New York, and Oklahoma.²³ The majority of the remaining states have fewer than 20 CNG fueling stations a piece, with some states having none at all, making it nearly impossible to drive a CNG vehicle most places in the US.^{22,23}

Fueling

One way to combat the lack of fueling stations is home fueling. The only mainstream home fueling system producer, FuelMaker, went bankrupt.²⁴ Before FuelMaker went bankrupt they produced the Phill home fueling system. FuelMaker was owned by Honda and marketed as a convenient way to fuel the Civic GX and to reduce the hassle of finding a CNG fueling station.²⁴ The Phill home fueling system allowed owners to fuel any CNG vehicle in about four hours using household natural gas and the Phill system to compress the fuel. With CNG vehicles never catching on, it was difficult to sell the system.²⁴

In the past more auto makers had produced CNG vehicles. Ford, General Motors, and Chrysler had all produced CNG vehicles, however they were sold for fleet use. Since they targeted such a small market, their CNG programs never reached the consumer market. Ford stopped production of CNG Vehicles in late 2003 to shift its focus to

producing other green fuel technologies that could be mass marketed.²⁵

While CNG has both advantages and disadvantages, one of the major advantages is that a majority of natural gas is produced in North America. Using a resource that is produced in North America would help keep the prices stable and reduce the dependence on foreign oil.²⁶ CNG burning engines produce less smog causing emissions, less soot, and fewer greenhouse gasses than their traditional gasoline counterparts.²⁴ One of the pitfalls of CNG is the lower energy density and the reduced range of the vehicles. Many of the CNG vehicles have a range between 200 and 300 miles depending on the size of the tank, and while this is not that much less than a traditional gasoline engine, the lack of fueling stations does make the range of the car a much larger factor.

While other companies have produced CNG vehicles in the past, Honda is the only company still producing a commercially available CNG vehicle in the United States today. Limiting its popularity even more is the fact that it is only for sale in New York and California because Honda feels that those are the only states that have the infrastructure to handle the fueling.²¹ Another major drawback to the Civic GX is the price. The base Civic GX costs just over \$25,000 whereas the base Civic is just under \$16,000 and the Civic electric-gas Hybrid is just over \$23,000.²⁷ Another major drawback is the lack of trunk space. In the Civic GX, the CNG tanks are in the trunk limiting the trunk space to just 6 cubic feet from the standard 12 cubic feet in the base model.²⁸ Not only is the trunk space reduced but the performance is also lowered. The GX makes less horsepower and torque than the gasoline equivalent and is also heavier, which hurts the performance even more. Even with the advantages of cleaner burning fuel, many drawbacks remain that make CNG vehicles unsuitable for mass market production.

	Gas Mileage	Range	Cost to Fill	Time to Fill	Availability	Number of Fueling Stations	Cost	Dangerous Emissions
Gas	21 mpg	300 - 400 miles	\$30 - \$60	minutes	Readily available	Numerous	\$15,000 - \$30,000	Many
Gas Electric Hybrid	46 mpg	400 - 600 miles	\$24 - \$42	minutes	Readily available	Numerous	\$18,000 - \$36,000	Minimal
Electric	200+ mpg ¹	200 - 300 miles	\$1 - \$5	3 hours – 5 hours	Available	Numerous ³	\$60,000+	None
Hydrogen	74 mpg ¹	50 - 300 miles ²	\$5 - \$15	minutes	Hard to find	Few	\$100,000+ ⁴	None

Note: Hydraulic hybrids were not included because the system is currently too large for passenger vehicles and that is what this report is focused on.

- 1 These mpg ratings are based on a system to determine equivalencies based around the energy density of different fuels.
- 2 The reason for the large range is due to the fact that hydrogen cars use fuel more readily when travelling at speeds above 45 mph
- 3 Some electric cars can be charged using a normal house outlet while others need an outlet that is different and not transportable
- 4 Hydrogen cars are currently very hard to find. The figure given is for a conversion to hydrogen in a gas car. Consumer gas cars bought new cost around one million dollars.

Table 2: Hybrid Comparison Table²⁹

How Hybrids Work

Technology of Hybrids

Regenerative Braking

Regenerative braking uses the energy lost during braking, most of which is lost in the form of heat, to recharge the batteries. Hybrids use this technology to boost their gas mileage. Instead of using traditional friction brakes and losing all of the energy of the moving car, hybrid cars simply turn their electric motor in reverse thus slowing the wheels of the car. Turning the motor in reverse charges the batteries by using the electric motor as a generator. However, regenerative brakes are not without drawbacks; the electric motor thrown into reverse is not enough to stop the vehicle at higher speeds. Consequently hybrids also have traditional friction brakes in addition to the regenerative braking system to ensure that the car can stop in any situation. The regenerative braking technology is one of the main reasons why hybrid cars get exceptionally good city gas mileage compared to gas only counterparts. During stop and go traffic, typical of city driving, a hybrid equipped with regenerative brakes does not need to use its friction brakes. This means that not only is the motor turned off and not wasting any battery power, but the motor is actually working as a generator to charge the batteries while stopping in the city. Regenerative braking is optimized when the car is at low speeds.³⁰

Lightweight Materials

Lightweight materials are a large factor in why hybrid cars get such amazing gas mileage. Force is defined as the amount that an object weighs multiplied by the speed at which the object picks up speed, also called acceleration. In order to decrease the amount

of force needed to move a vehicle there are two possibilities: reduce the weight of the vehicle or decrease the acceleration. Since high acceleration is sometimes required, reducing the weight is the most viable solution. By reducing the amount of force needed to move a vehicle, a smaller engine can be used and, therefore, use less fuel; or in the case of hybrids use less stored battery power. As a result, lightweight materials used in hybrid cars are effective at increasing fuel economy.

Lightweight materials have been used to help solve problems in a variety of fields. The bulk of these advancements took place in the fields of airplane design and space shuttle design. While the advances in these fields have been very helpful, they are too expensive to be implemented in all facets of manufacturing. In hybrid cars it is important that the materials used have a balance of low cost and low weight. In the hybrid car industry, the development of cost effective lightweight materials has led to a large increase in fuel economy.

The materials developed include aluminum alloys, carbon fibers, plastics and others. Such materials allow vehicles to be lightweight while still capable of meeting the other standard strength requirements for a motor vehicle. All of the technology that has been developed in lightweight materials is crucial in the fuel economy of hybrid vehicles.³¹

Aerodynamic Design

Aerodynamics is another way hybrid vehicles achieve their improved gas mileage. The aerodynamics of a car is controlled by drag. Drag works in a way similar to friction, acting against the movement of a body. The drag equation is governed by

multiple variables which include: the “thickness” of the air, the cross sectional area of the vehicle, the speed at which the vehicle is moving, and a coefficient of drag. If any of these variables are decreased the drag will also be decreased, so minimal values for each of these variables are ideal. The “thickness” of air and speed of the vehicle are constants, but the coefficient of drag and cross sectional area are the variables that can be changed. The values for coefficients of drag are generally much smaller and more difficult to change than the cross sectional area, so it was obvious to designers that in order to reduce drag a new shape for the vehicles had to be designed. For this reason hybrid cars have an “awkward” shape. These shapes serve to minimize cross sectional area and at the same time reduce the coefficient of drag. These designs have been worked on extensively and are close to being as efficient as possible, while still maintaining an aesthetically pleasing shape. The difference between cars designed with this knowledge in mind and those that were not is vast. The Toyota Prius has a drag area that is less than one fourth that of a Hummer. This means that the Prius requires less than one fourth the energy required to move a Hummer through the air at the same speed. This illustrates one of the reasons for the significant difference in gas mileage of these two vehicles.

The ways to reduce the coefficient of drag include covering wheel wells, reducing the slope of the windshield, redesigning the grille, and many other things. All of these factors are taken into account in the design of a hybrid vehicle.

The shape of the car is also very important in reducing the drag. The most aerodynamic shape has been proven to be a teardrop shape. While this is not currently used it has been tried in the past. A car was designed in 1922 that utilized the teardrop shape and had a drag coefficient lower than almost all cars on the market today.

Unfortunately the unusual shape of a hybrid car turns off many people, thereby reducing sales.³² Is a hybrid consumer concerned mostly with the shape, or are there other aspects to a hybrid car that make it socially acceptable?

Low Rolling Resistance Tires

These tires use a combination of different materials and different tread designs to reduce the amount of friction between the car and the ground. While these differences are small, they are significant enough to take into consideration by designers to increase gas mileage in hybrid cars.

These tires offer small bonuses to fuel economy, but at what cost? Many people question the stopping ability and durability of these tires, usually based on rumors or outdated information. In a recent study, it was found that low rolling resistance tires provide an increase in fuel economy by up to two and a half miles per gallon and a decrease in stopping distance. The tires have been further developed to increase fuel economy, stopping power, and handling. These tires also normally come with warranties that occasionally go all the way up to 90,000 miles. The tires that are now available are better in every way than the older low rolling resistance tires, which are a great addition to the technologies for hybrid cars.

The removal of the doubts in these tires makes them very appealing to potential hybrid car owners and the data associated with them should be made more readily available for consumers.³³

Hybrids and People

Profiling Potential Hybrid Owners

The typical hybrid owner is seen as a responsible, environmentally conscious individual who weighs his decisions thoughtfully, drives defensively, and is not prone to erratic behavior. He wants to support the environment and has at least a few extra thousand dollars to purchase a more economic vehicle and showcase his status. Is this actually the case, or are hybrid owners just like the rest of us: looking to save a few dollars and trying to help the environment at the same time?

Hybrid owners receive a discount on auto insurance.³⁴ This discount is given because hybrid owners are seen as mature individuals who are less likely to get into an accident, not because the cars are actually any safer than regular gas-guzzlers. In many cases, hybrids are actually less protective in a crash. All the technology used to squeeze out extra gas mileage can compromise handling, acceleration, and stability on the road in less than ideal driving conditions. Even so, insurance agencies are still willing to give up to a ten percent discount on insurance plans simply because the hybrid owners are perceived as responsible, defensive drivers.³⁴

These same thoughtful defensive drivers manage to acquire 66 percent more speeding tickets than non-hybrid owners.³⁴ The results from a recent consumer survey by Topline Strategy Group found that 73% of Prius owners surveyed acted like mass-market consumers (they had a financial incentive to purchase the vehicle such as lower sticker price or operating costs than other choices considered) versus 23% of early adopters who paid a premium over alternative choices to purchase the hybrid.³⁵ Now that hybrid cars have become mainstream, the majority of hybrid consumers are looking for an

environmentally friendly form of transportation, with the possibility of saving money in the long term. While there are still consumers buying hybrid cars that fit the stereotypical hybrid owner, they are now in the minority. As time goes on, hybrid cars will continue making their way into average consumer's homes, thereby changing the way hybrid consumers are perceived.

Consumer's Acceptance of Hybrid Cars

While the reactions to hybrids have obviously been positive, there are some people that have negative reactions towards hybrids. The complexity that the hybrid system adds to the vehicle can be viewed as a negative to simplicity and reparability. A do it yourself mechanic, or even a small one or two bay garage, would not have the ability to perform work on the hybrid system without some type of training. The Prius is similar to other gasoline vehicles, but there are small differences that can cause major issues if the proper procedure is not followed when performing maintenance to the vehicle. The main attraction of hybrid cars is the increased fuel economy. To maximize gas mileage, many functions normally driven by a belt have been replaced with more efficient electric motors. For example, the Prius A/C system uses an electric compressor, which requires special oil, which some garages may be unfamiliar with, or may not even carry. If the system has even one percent contamination from traditional compressor oil, it would ruin the entire system.³⁶ This would make it hard for a small garage to perform A/C work on hybrids without special training.

One author explained the feelings of the general public with respect to hybrids as mixed. According to the article, 61% of people were concerned with the expense of

fixing the complicated hybrid system. Six percent of new car shoppers are willing to spend any premium on hybrid technology, while others feel that in the next five to ten years there will be a jump in fuel economy and the performance of the traditional gasoline engine. The number one issue that consumers fear is the repair costs on hybrid specific parts and battery replacement. While the fuel economy may increase with hybrids, many consumers feel that the cost of performing maintenance will cause a hybrid to cost more over the life of a car.³⁵

Some car enthusiasts believe that high performance cars won't see the advantage of hybrids. Carol Shelby is best known for the Shelby Cobra. The Shelby Cobra is a small two seat vehicle produced by Carol Shelby in the 60's and 70's. The idea behind the Cobra is to produce a small, lightweight vehicle with a high horse power V-8. The main idea behind the Selby Cobra is to be fast and light to get the most out of every horsepower. Shelby got the idea from smaller British cars, but wanted a larger engine in them so the cars could go faster. Carol Shelby is also well known for producing higher horsepower mustangs such as the GT350 and GT500. Both the GT350 and GT500 were modified Mustangs that produced more power and increased handling, making them higher performance cars. Carol Shelby sees electric hybrids as never being able to be used in a muscle car and, consequently, not for everyone.³⁷

The overall feelings of potential owners toward hybrids are very mixed. Hybrids do have a large following and some consumers are willing to pay a premium to own one. If after ten years of experience, owners find that most hybrids need major work and would be considered "totaled;" then those people who are worried about the prices of repairs will continue to buy traditional gasoline powered vehicles. On the other hand, if

hybrids last twenty years with no major problems, then many more people would probably be willing to spend the extra money to buy one. Like any new technology, as it ages and people see first hand how well the technology holds up over time, then hybrid cars will either increase or decrease in popularity. People need to see the cost of ownership and the advantages and disadvantages first hand to make a decision on whether it would be worth spending the extra money for hybrid technology.

Norton Interview

Talking to Professor Norton was very different than talking with Professor Van de Ven. Before the interview started Professor Norton mentioned that he did not have a vast knowledge of hybrid cars and most of what he knew was from reading about them in magazines.

The first thing that Professor Norton talked about was the different types of hybrids being used today. He also mentioned how hybrid drive trains are being added to SUVs and trucks to help gain fuel economy, however the gains are not very large and are usually only a few miles per gallon.

We also discussed other uses of hybrid drive trains. Another example of a hybrid drive train is a locomotive that uses diesel and electricity for power. Professor Norton noted that a major advantage of using an electric motor to drive a train is the torque at low RPM. Locomotives that use diesel fuel use it only to power a generator, which is then used to power the electric motor. This is the best way to drive trains since they need a lot of torque at low RPMs, which a gas engine does not provide.

The group then asked whether Professor Norton owns a hybrid. Norton's response was

that he does not and that he “isn’t too anxious to buy one.” He went on to say that hybrids do not meet his buying constraints. This led to the question of what Norton looks for in a car. When buying new cars Professor Norton “wants handling and performance,” which hybrids do not offer. Norton went on to describe hybrids as “econoboxes with fancy drive trains.” He also mentioned that hybrids do not suit his type of driving, and said that hybrids are best for city stop and go driving, where the max torque at zero RPMs is most useful. Unfortunately Professor Norton has not driven a hybrid so he could not comment on the driving feel.³

Student Interviews

The team interviewed eighteen Worcester Polytechnic Institute Students to find out what the general populace has heard about hybrid vehicles.

The first question posed to the interviewee was whether they have heard of hybrid vehicles prior to the interview. All eighteen participants polled had previously heard about hybrids. This demonstrates the success of the hybrid marketing campaign in alerting the populace of the availability of hybrid vehicles. The second part of the question asked what the interviewee has heard about hybrid vehicles, positive or negative. The results of this question show that interviewees had heard mixed reviews of hybrid vehicles. While some interviewees heard one way, or the other, there were some who heard both positive and negative information regarding hybrid vehicles.

The next question posed to the participants asked whether or not they had driven a hybrid vehicle before. The vast majority of interviewees had not driven a hybrid car

before. The few people who had driven hybrids had mixed feelings as to whether they preferred them to their non-hybrid counterparts.

The next question asked whether the participant knows of anyone who owns a hybrid vehicle. The question served to find out how hybrid vehicle owners feel about the cars they have purchased. The majority of interviewees who knew someone with a hybrid vehicle believed that they preferred it to non-hybrid cars they had owned previously.

The final question of the survey asked whether or not the participant would buy a hybrid vehicle based on what they had heard from marketing, friends, and family. The responses were split between yes and no. When the participants who responded yes were asked why they would purchase a hybrid they agreed that fuel savings and environmental reasons were the main reasons why they would purchase a hybrid vehicle. The reliability was also a contributing factor, but was not seen as being as important in comparison to the aforementioned qualities. The only quality included in the survey that was viewed as being unimportant in the decision to buy a hybrid car was the status associated with ownership.

After reviewing the results of this survey the team realizes that there are mixed feelings toward hybrid vehicles, but the majority is in favor of them. The team was also surprised to discover that everyone interviewed had previously heard about hybrid vehicles, which shows that the marketing done by manufacturers has succeeded in its goal to inform the public about hybrid vehicles. Even though the population is aware of the presence of hybrid cars in the marketplace, their purpose and uses remain not fully explained by current marketing campaigns.

Dealer Interview

In order to learn about hybrid sales, the team interviewed Derek Houde, Sales and Leasing Supervisor at Harr Toyota. The team learned that hybrids make up about one tenth of Toyota's car sales nationally. In this past year Toyota has sold over one million hybrids.

The team asked about the costumers who came in looking for new cars and what their reactions are to hybrids. Houde said that many customers come in looking for a car and are open to hybrids, while others will come in looking specifically for a hybrid. He said the biggest difference between those two types of customers is that the customers looking for a hybrid generally have done more research on hybrids, whereas people open to hybrids have not and often ask how they work. A popular question that Houde said he gets is if the hybrids need to be plugged in.

The team also asked Houde about customer satisfaction regarding hybrids. He told the team that he has never had anyone come back unhappy after buying a hybrid, and that many customers refer their friends to buy hybrids after purchasing one themselves. The group also asked whether people ever trade in their hybrid and go back to gasoline cars. Houde said that those people to whom he has sold a hybrid usually buy another one.

Another frequent question is what the warranty on the car is. Houde then explained that it depends on the part. The batteries for example have a 10 year or 150 thousand mile warranty and the hybrid components have a 10 year or 100 thousand mile warranty. The team asked when the batteries ever need to be replaced and if any have needed to be replaced yet. Houde said that only "17 (batteries) were replaced in the

nation since 2000, and of that only three were due to defects.” The team asked about the other 14 batteries and he said that they were replaced due to user error. There are two ways to kill the hybrid battery in Toyota Hybrids. One is to cover the battery-cooling vent, and the other is to run the car without gasoline, which completely drains the batteries. The team also asked about the maintenance interval and if there were any hybrid specific maintenance that needed to be done. Houde told the team that the maintenance intervals are the same as any other vehicle and that the hybrid system is self contained and needs no additional maintenance.⁴

Cost of Owning a Hybrid

Cost Effectiveness of Hybrid Cars

Hybrid cars are constantly being advertised for their great fuel economy and the amount of money that reduction in fuel costs will save an owner every year. But how much money does one actually save every year from this fuel economy? Based on the averages of many popular hybrid cars, the average fuel economy gained is between five and ten mpg. Using the federal standard of 15,000 miles driven in a year, the average hybrid user is consuming between 50 and 150 fewer gallons of gas a year. At a price of \$3.00 per gallon, the average hybrid user is saving between \$150.00 and \$450.00 per year. While this seems like an amazing savings, the figures are deceiving. Just by buying a hybrid car one is paying a “premium” between \$1,500.00 and \$2,500.00. What this means is that it can take up to ten years to make back the paid premium in fuel savings. This ten year period is longer than some people keep their cars.

The ten years discussed is for the situation where the fuel savings is the least and

many popular hybrids have a much lower payback period of about four years. Also, many insurance companies offer lower costs for hybrid users. In addition to the insurance savings some hybrids receive a tax break to encourage consumers to buy hybrid cars. This means that over time many hybrids offer monetary benefits, but they may be much less than those advertised. The savings are minimal and are not enough for most people to pay the upfront premium meaning that the majority of hybrids will be bought by eco-friendly drivers. (Table 3) The sales of hybrids with the average driver will therefore depend greatly on how well the hybrids are marketed.²⁹

	Average Cost (\$)	Average Premium (\$)^{1,4}	Increase in Fuel Economy (mpg)⁴	Annual Fuel Savings (gallons)²	Annual Fuel Savings (\$)³	Payback Period (years)¹
Toyota Prius	22,279	2,303	16.1	117	351	6.5
Toyota Camry	25,200	1,381	6.1	66	198	7.0
Ford Escape	25,075	2,310	7.4	98	294	7.9
Saturn Vue	24,170	1,774	5	65	195	9.1
Mercury Mariner	26,588	2,842	7.4	98	294	9.7
Honda Civic	22,337	2,734	11	79	237	11.5
Nissan Altima	24,944	2,221	5.4	57	171	13.0
Lexus GS450h	54,900	2,280	2.4	46	138	16.5
Lexus RX400h	41,047	4,767	4.4	88	264	18.0
Toyota Highlander	39,448	6,986	3.7	65	195	35.8
Lexus LS600h L	104,000	15,458	0	0	0	N/A

¹ Takes into account tax credits as of 2008 but does not take insurance breaks into account

² Based on driving 10,000 miles per year

³ Based on gas costs of \$3 per gallon

⁴ Over comparable non-hybrid model

Table 3: Cost Effectiveness

Tax Breaks on Hybrid Cars

With the recent increase in people wanting to buy hybrid cars to help the environment, save money, or for whatever other reason they see fit, the government has given tax breaks to people buying hybrid cars in an effort to push the environmental turn around. Tax credits are different for every brand of car. Rules have been implemented that make it so that after a certain number of cars are sold by one car company the amount of the tax break begins to fall. So while this tax credit is very helpful it will not last forever and is only helpful to those people that buy hybrids early in the cycle. As soon as the 60,000th hybrid car is sold by one company, the decline in tax credit begins. The credit remains at the full 100% for the first calendar quarter after the 60,000 alternative fuel vehicles are sold for a particular manufacturer. For the second and third quarters after the 60,000 cars are sold, 50% of the credit can be claimed. Finally, for the fourth and fifth quarters after the 60,000 car is sold, 25% of the credit can be claimed. After the fifth quarter, there is no tax credit given for that manufacturer anymore. (Table 4) As of the quarter ending June 30, 2006 Toyota sold its 60,000th alternative fuel vehicle. Beginning October 1, 2006 the tax credit began to drop. Therefore, the incentive to buy hybrid cars is here for now but will be gone quickly as more people begin to buy these alternative fuel cars.³⁸

Number of Units Sold	Amount of Time After 60,000 Cars Sold	Percent of Tax Break Given
<60,000	N/A	100%
>60,000	1 Quarter	100%
>60,000	2-3 Quarters	50%
>60,000	4-5 Quarters	25%
>60,000	>5 Quarters	0%

Table 4: Hybrid Tax Break Schedule

Safety

While hybrids are known for their fuel economy and eco-friendliness, they are seldom praised for their impeccable safety features. One of the things that many people may not realize is that because these cars are so new, they implement safety features that many combustion engine cars lack.

The first aspect of safety that the group examined was the crash test ratings of hybrid cars. Hybrids perform well, if not better, than their gas powered counterparts. These hybrids are receiving the highest crash test ratings, which on paper put them on the same level as exceptional gasoline powered cars. Skeptics will tell you that these crash test ratings are distributed unfairly. For side impact crash test ratings the hybrids are hit by the equivalent of an SUV, but for front and rear crash tests, they are tested against a car of similar size. This means that the front and rear crash test ratings only really apply if a car that is the same size as a hybrid hits the driver.

There are many ways that hybrid car designers go about countering the dangers of producing a car smaller than most of those they will encounter on the road. The first of these is a complete set of airbags, standard. While most cars on the road have a minimum of driver and passenger airbags, only the newest cars come equipped with a complete set of airbags. These airbags add an extra level of passenger safety that customers are looking for. Another safety feature implemented by hybrid car designers is a much more sophisticated driver side cage. These cages are made out of new age materials that are both lighter and stronger than those previously used. The cages are also more efficiently designed using technology prominent in car racing. Another technology that has been honed by hybrid car designers is traction and stability control. While these technologies are not new, the hybrid car designers are making sure that the hybrids are equipped with the newest versions of the technology, giving their drivers an advantage over the majority of other vehicles on the road. The fact that hybrids are low to the ground also helps these technologies to be even more effective.

The goal of hybrid safety is to save the occupants at all costs, and while this may lead to more damage to the car, it does mean that hybrid car accidents will have a lower fatality rate. The improvements to current generation hybrids are a huge selling point that should be more widely advertised alongside the fuel economy rather than having the fuel economy overshadow the other features of these cars.³⁹

Test Drives

Lexus RX400h

After test-driving a Lexus RX400h, an SUV hybrid made by Lexus, there are some driving differences that are worth noting. Since it's an SUV, the Lexus RX400h handled as expected, the extra weight of the battery was not noticeable, and one team member said, "It did not feel sluggish." The extra weight of a large battery was a great concern to this team, and while the weight of an SUV is substantially greater than that of the average sedan it was nice to experience the normalcy of the feel when on the road. While the Lexus felt normal it sounded different when braking at slow speeds. When slowing down, the engine will shut off to conserve fuel and the regenerative braking will recharge the battery. A team member said, "It felt normal, but sounded different." The internal whine of the electric motor tuning in the opposite direction to recover energy is very quiet and would not be noticeable if the radio were turned on. It may concern some drivers that if one is accelerating slowly the internal combustion engine will not turn on right away to conserve fuel. The team member did not find this to be a problem, but realized that some drivers may panic if they do not hear that familiar sound of the internal combustion engine while they are accelerating.

VI. CONCLUSIONS AND RECOMMENDATIONS

Hybrids, especially the gas-electric hybrids this team has focused on, are not the solution to end our dependence on foreign oil. This team would recommend not buying a hybrid car unless the consumer does a lot of city driving, or is very environmentally conscious. If on the other hand the consumer does mostly highway driving, or has a very short commute it is in his best interest to purchase a normal internal combustion vehicle. Future hybrid cars may come down in price making them practical for the average consumer, but until that happens, owning a hybrid may not worth the extra up front technological cost.

There are some areas of hybrid cars that may be of interest to consumers, or the enthusiast, that this team decided not to research for this guide, or mentioned only briefly. This team believes there is a wealth of untapped potential in hybrid technology. Improving the “greenness” of hybrid cars, developing higher efficiency batteries, or developing a hydrogen infrastructure are all future possibilities that could transform transportation in the United States. With so many technologies vying to lead the automotive industry into the future, consumers can only ask themselves: “Which one will change transportation forever?”

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IX. APPENDIX

Interviews

Van de Ven Interview

What types of hybrids currently exist (diagram if needed):

Basically electric hybrids small and medium passenger cars: prius insight, highlander small SUV. Large truck market hydraulic hybrids: garbage trucks, passenger vans, shuttle vans, UPS truck.

Drive train

-parallel: engine → trans → hydraulic pump → drive wheels (easier)
-series engine → pump → motor → drive (fully hydraulic drive)

series system highest efficiency, but great job designing transmission
parallel easier to retro fit . mechanical failsafe

30L accumulator in passenger car

Car will regain majority of energy from high-speed braking (60-70) 1500Kg

Of those type what are currently on the market as passenger cars?

One offs and research vehicles

What market are the other hybrid vehicles being used in?

Electrical passenger cars
Hydraulic Large trucks

Would you buy a hybrid? Why/why not? What type?

Which has the brightest future, if any?

New technology for more energy density so there is a future. Order of magnitude. 30L → 3L would compete with plug vehicles

Electric is a stepping stone

Recycling batters every 8-10 year. junk yards filled with batteries. Nothing to wear out in the hydraulic system and of life Is much cleaner, no parts to recycle .

Order of magniute

Pressure 5000 PSI range
3000 was pervious
moving toward 7000 PSI

Higher PSI= more power

Electrical Hybrids

Step in the right direct. Improving efficiency, makes people aware of consumer choices that they have. But a lot more efficient way of doing it. Diesel cars get the same. More in the long term but helping make people aware. Clean diesel technology will be interesting to see where it goes.

Driving feeling

Aggressive engine management: when on runs at full efficiency. Engine off, small hydraulic whine. Quarter mile engine kicks in at full horse power even when stopping the engine is at WOT. Incredible acceleration easily burn tires as long as you want to. Flat torque curve unlike gas where is starts at 0. Much more power in small packages.

Noton Interview

What types of hybrids currently exist (diagram if needed):

Prius

Insight (older 1999)

Civic and SUV

Camry Highlander

GM hybrid trucks and suburban SUV line Fairly simple flywheel with torque converter power plants in series.

16-18/19

Drive train

Prius most exotic. Run on gas electric gas both elaborate control system. Light load el only. Performance demand gas engine kicks in. 2 parallel power pants.

Civic is simpler

What market are the other hybrid vehicles being used in?

locomotive. Diesel electric. Electric drive train diesel used for generating electricity.

Can't find a better drive than electric for train since has such large mass to accelerate.

Original steam locomotive doesn't have the limitation of rpm to generate torque. Steam has high torque at low rpm. Direct drive

Would you buy a hybrid? Why/why not? What type?

Don't own. Not too anxious to buy one. Model being offered don't satisfy Norton's car

buying constraints. Wants handling and performance. Fancy drive train econobox, type of

driving doesn't. max torque at zero rpm. More for city driving.

Dealer interview

What are the sales numbers for hybrids? Breakdown between models?

National 1 million plus. 1/10 of totals sales hybrids

What are the customer reactions to hybrids when they come in to look at them? Do they have a basic knowledge of them? Do the people who come in know that is what they are getting?

Open to idea of hybrids, don't know enough, not closed minded. If they come in specifically for hybrids then very gun ho about hybrids. Also usually have done a lot of research.

Your personal feelings toward hybrids:

Great. Better warranty, better for the environment, better MPG, and reliable

What are the main/common concerns and questions from customers?

Does it need to be plugged in? More or less reliable? How it works?

What are the maintenance intervals for a hybrid? What needs to be done at each interval?

5,000 miles like a regular ca. nothing hybrid specific. Pretty simplistic system and self contained

What is the expected battery life of a hybrid? Have any needed to have the batteries replaced?

Warranty 10 years. Far better . out of approx 10 million sold only 17 replaced in the nation since 2000. 3 were defective, other 14 were caused by user error. (Vent in car covered and running out of gas and completely draining battery.

Are hybrids pushed over gasoline cars?

Pushed equally. Will suggest if in the price range that people are looking at and meets other needs.

Does corporate offer any incentives to get customers in hybrid vehicles?

Not currently. But sometimes offer low financing or rebate, just like other cars.

Do hybrids ever get returned or have customers come back unhappy with a hybrid?

What is the over all customer satisfaction with hybrids?

Nope. All customers love it. Customers usually refer others.

What is the average turn around rate on a hybrid? Do people upgrade to newer hybrid or go back to traditional gasoline cars?

Lease returns are the major people that upgrade to new ones. Used hybrids are rare. Hybrid customers stay hybrid customers.

What is the cost of the hybrid specific maintenance?

Nothing. Expect gas engine to run longer since it is used less overall.

Student Interviews

General Population Interview

1) Have you heard of Hybrids?

YES

NO

2) Have you heard positive or negative things?

POSITIVE

NEGATIVE

3) Have you driven a Hybrid?

YES

NO

Was it a positive or negative?

POSITIVE

NEGATIVE

4) Do you know anyone who owns a Hybrid?

YES

NO

Do they have positive or negative feelings to Hybrids?

POSITIVE

NEGATIVE

5) Would you buy a Hybrid?

YES

NO

Why?

-MPG/Fuel Saving

YES

NO

-Reliability

YES

NO

-Environmental Reasons

YES

NO

-Status

YES

NO

-Other

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NEGATIVE

3) **Have you driven a Hybrid?**

YES

NO

Was it a positive or negative?

POSITIVE

NEGATIVE

4) **Do you know anyone who owns a Hybrid?**

YES

NO

Do they have positive or negative feelings to Hybrids?

POSITIVE

NEGATIVE

5) **Would you buy a Hybrid?**

YES

NO

Why?

-MPG/Fuel Saving

YES

NO

-Reliability

YES

NO

-Environmental Reasons

YES

NO

-Status

YES

NO

-Other

General Population Interview

1) Have you heard of Hybrids?

YES

NO

2) Have you heard positive or negative things?

POSITIVE

NEGATIVE

3) Have you driven a Hybrid?

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4) Do you know anyone who owns a Hybrid?

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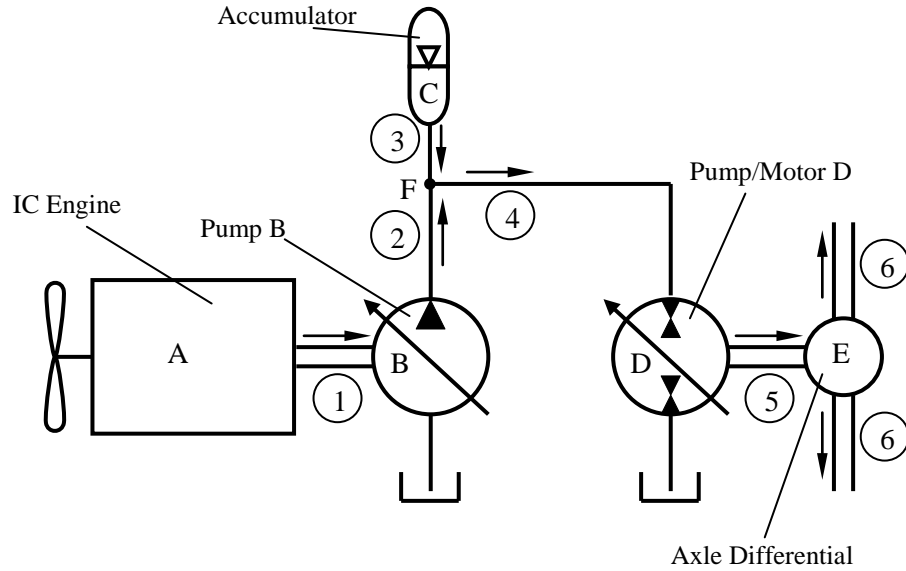
-Status

YES NO

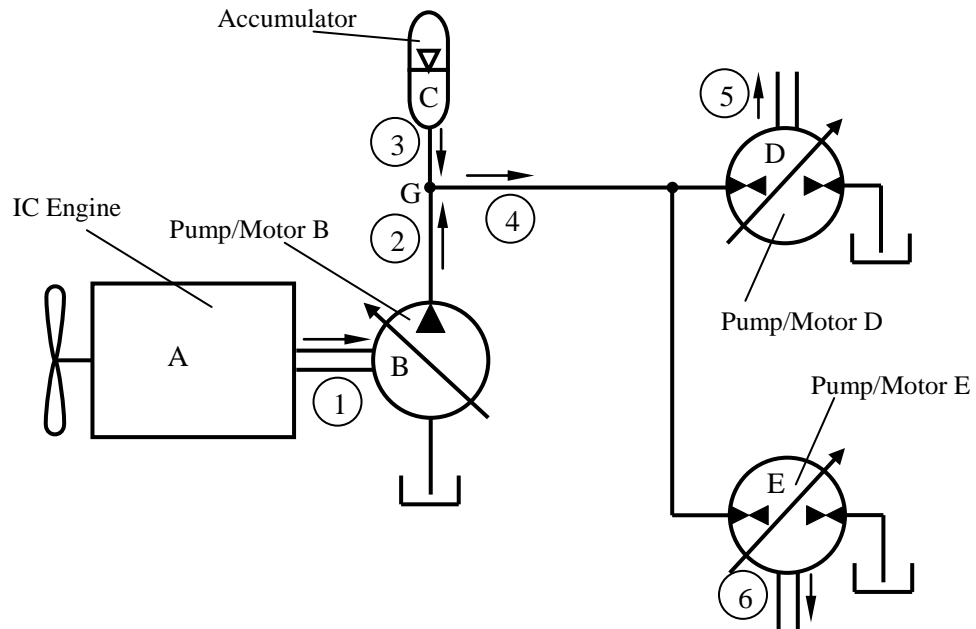
-Other

Additional Figures
Series Hydraulic Hybrid System

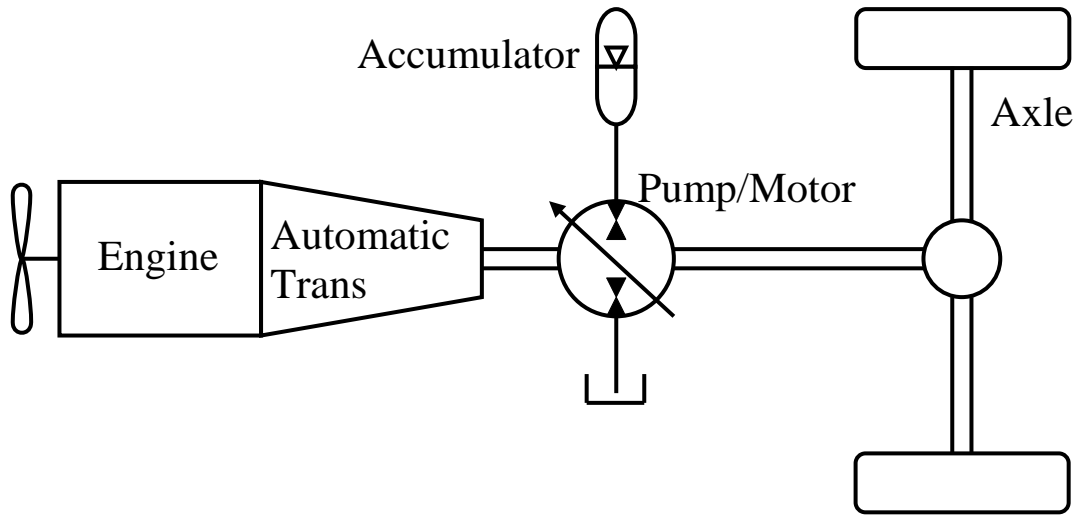
Differential Driven



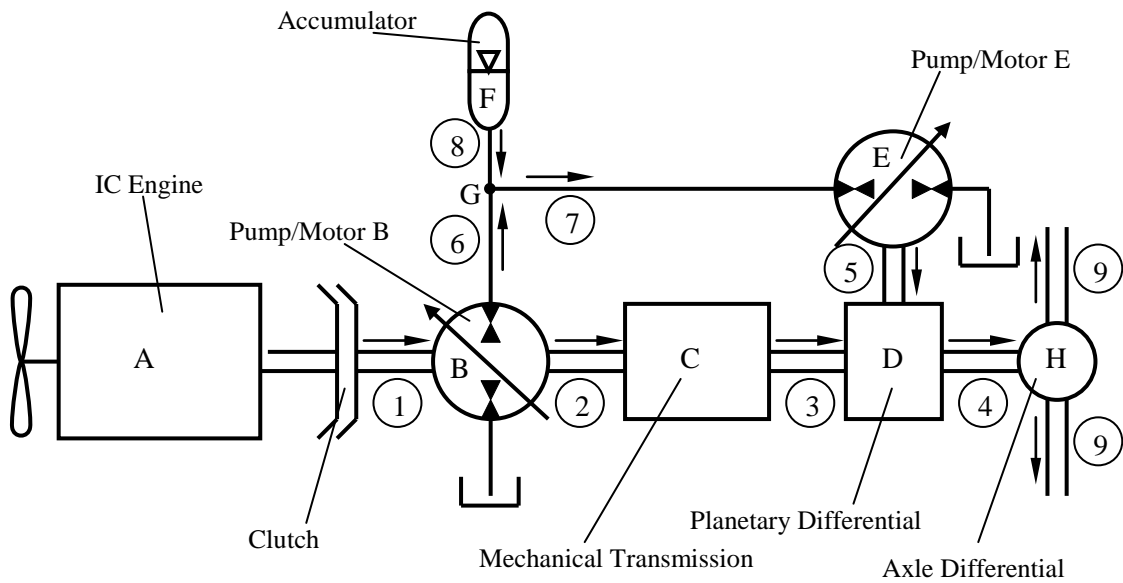
Individual Wheel Pump/Motors



Parallel Hydraulic Hybrid System



Hydro-Mechanical (Power Split) Hybrid System



Hydro-Mechanical (Power-Split) with Independent Wheel Torque Control

