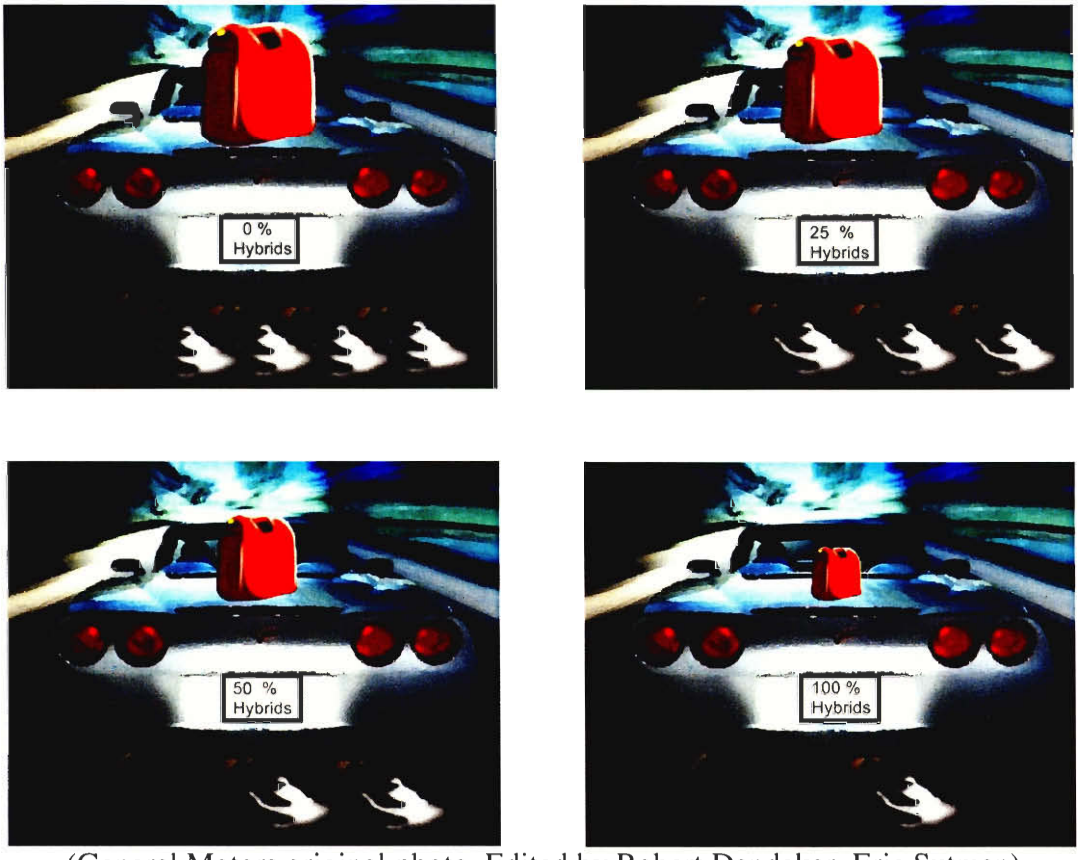
05 D042 I
AG-HC04-41

# Hybrid Vehicle Contribution towards Gasoline Savings and Cleaner Air




(General Motors original photo. Edited by Robert Dandekar, Eric Sutman)

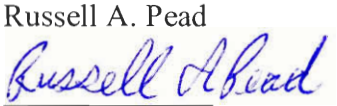
# Hybrid Vehicle Contribution towards Gasoline Savings and Cleaner Air

An Interactive Qualifying Project Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Josh Beaulieu

Robert Dandekar

Russell A. Pead



Report Submitted to:
Professor Arthur Gerstenfeld

Date: 1 March 2005

Table of Contents

List of Figures

## Abstract

The United States consumes approximately **one fourth of the world's oil**, with a large portion used as gasoline in passenger vehicles. Burning all of the gasoline is not only costly but creates serious environmental problems. With hybrid vehicles leading the way, gasoline consumption could be reduced drastically, and air pollution will start to subside as well, as an effect of more efficient cars. When we estimate 25% of total vehicles in use will be hybrid vehicles by the year 2015, we can reduce the amount of gasoline burned by 12%. Furthermore, we also envision an educated estimate of saving more than 81 tons of nitrous-oxide emissions per day in the states such as California. These savings would amount to just under 30,000 tons per year, which will provide better health conditions statewide. The potential benefits of hybrids as stated above could be reality in the near future. A survey of 76 participants showed the majority of people desire the benefits of a hybrid vehicle such as fuel savings and low pollution, and would even pay extra compared to the cost of a conventional vehicle to own a hybrid vehicle. Interviews showed that the majority favored taking steps to encourage hybrid use. It is safe to assume that hybrids will grow into a large portion of vehicles on the road in the near future, bringing with them their economic and environmental benefits.

# Chapter 1: Introduction

The Environmental Protection Agency (EPA) started in 1970 (2). There exists an even stronger need for the EPA now than when it first began in 1970 as our dependency on foreign oil has grown and pollution now significantly affects health conditions around the world. America's position as the world's only remaining Superpower requires us to solve many global problems. America consumes 7.19 billion barrels of oil per year (according to 2002 EPA data). America needs to cut back its dependency on foreign oil to reduce some of the political power that oil companies hold in their hands. Less political influence from oil companies will make America more of an independent nation where oil concerns would not taint foreign policies as much as they do currently. The U.S. spends over $300 billion per year on oil. A significant portion of that spending goes towards inefficient transportation. The combustion engine has been in use for over 100 years; alternative solutions, or combinations of solutions, have started to appear in the market as newer technology develops. The next few years will bring about some of the best technology ever used to help save the environment, which will also reduce the amount of money the U.S. spends on oil imports. Spending within America is important to circulate money to help boost the U.S. economy back to a higher stable state. In order to boost the U.S. economy, more money should be spent within America to help economic growth. Money circulated in the U.S. provides more money for schools, Medicare, or even bringing down the national debt that is lost to foreign nations.

A main part of this paper will define the systems and standards developed by the EPA to help decrease air pollution and fuel consumption for all vehicles in America. EPA

standards only apply in America. Foreign automakers that have to meet the strict EPA standards in the U.S. will simultaneously meet the less stringent requirements of other nations. In effect, the U.S. is making an effort to decrease foreign oil dependency and lower air pollution, which will help create more efficient vehicles for the rest of the world. Vehicles that are more efficient will help countries where fuel may cost several times the amount per gallon of gasoline in America.

The reader should take away certain ideas and information concerning the importance of independency with foreign oil and the increase in efficiency to optimize air quality. The U.S. will have a need for oil for many years to come due to the development of American society. Even though the U.S. will still be powerful if dependence on foreign oil is not reduced, the savings of 100 billion dollars per year remaining in America will undoubtedly make a positive difference for the progress of society. Several manufacturing cities have trouble keeping pollution down due to the large number of vehicles and other sources of pollution. Reductions in vehicle emissions will noticeably change the quality of air for the surrounding environment and communities.

Another goal of our project is to raise awareness and provide insight into the effects of clean and fuel-efficient vehicles. The benefit of hybrid cars is a cleaner environment that will improve the health of many individuals through pollution reduction. These benefits come from lesser carbon dioxide ($CO_2$) emissions that deplete our ozone layer. The reduction of nitrous oxides ($NO_x$) also reduces the effects of global warming. Hybrid vehicles are a strong alternative to fight the effects of pollution on our environment. These vehicles recover the high energy loss associated with most conventional vehicles through a process called regenerative braking. Air pollution and oil

consumption with our further use of automobiles in society is a consequence that many drivers do not realize. However, our gasoline cost and pollution savings potential with new hybrid technology provides drivers the opportunity to reduce dependency on foreign sources of oil.

An important concern with pollution is the numerous effects it poses on our environment. It affects health and well-being of the entities that make up our earth, more so as humankind has discovered the fascination over form versus basic function. Basic transportation does not meet the needs of travel for many drivers around the world. Hybrids provide efficient and clean powertrains in various forms of vehicles that suit the needs of changing interest among the public. For example, consumer focus in North America with light trucks has grown to outpace smaller passenger vehicles within the last five years. "Just as we're a nation of obsessive dieters who keep getting fatter, we can't seem to stop ourselves when it comes to driving big-gulp cars," says Toyota sales executive Don Esmond (Naughton). The application of hybrid technology in sport-utility vehicles (SUVs) would provide the best benefits as these popular vehicles pollute higher than passenger cars with relatively smaller engines.

Hybrid vehicles provide a cleaner and more effective design over standard gasoline engines as they generate electricity from braking, storing it in a battery for future use. As people understand the effects of pollution on our environment, the benefit of hybrid vehicles will become apparent. However, the number of hybrid vehicles manufactured has not kept up with public demand as the interest toward hybrid vehicles increases.

Hybrid cars provide an educated approximation about savings and benefits provided through efficient and cleaner running technologies. This is important as we look at American dependency on foreign oil and the increasing pollution levels in the world's largest cities. Pollution affects the world around us, and the extensive use of hybrid vehicles will benefit our environment in many ways. Hybrid vehicles are convenient and provide environmental benefits through lower greenhouse gas emissions.

## Chapter 2: Background & Literature Review

Hybrid vehicles continue to develop interest in the eyes of consumers as fuel costs remain at elevated levels. They also provide excellent economy and convenience from the standpoint of electric vehicles, which require periodic recharging from a wall-mounted power source. The hybrid flexibility encourages expanded forms of this technology into the future, such as dual-stage hybrid systems and fuel cell vehicles. Hybrid technologies still face criticism from many customers that mileage is not at acceptable levels, however. This judgment comes in regard to Environmental Protection Agency (EPA) fuel economy tests on vehicles sold in the United States. The test is approaching thirty years of age, and adjustments in its formula have not compensated for the driving habits of 2005. One component that drives these inaccuracies in the EPA fuel economy tests is the use of Continuously Variable Transmissions (CVTs) in most hybrid vehicles, which behave quite differently than the traditional automatic transmission. Although efficient at low revolutions per minute (RPM), these CVTs run at consistently higher RPM cycles at highway speeds as their design is optimized for lower speed driving operation, as in a city environment. Due to the design of most hybrids, constant engine operation is required at highway speeds. This can further reduce the highway fuel

economy in combination with 65 mph speed limits and the use of air conditioning within the vehicle. The EPA testing has not considered that the average American driver spends more time commuting than in the past, and traffic idling time has increased as well (Shartin).

The California Air Resources Board (CARB) sets emissions ratings for vehicles sold in the United States. It defines these ratings through acronyms such as 'LEV', which stands for Low-Emissions Vehicle. The 'S' stands for Super and 'U' stands for Ultra, as seen with 'SULEV'. Each increasing level of definition has a lower emissions tolerance to account for newer regulations. Honda Motor Company develops Civic hybrids that meet the ULEV and SULEV-ratings (Honda). The improvement of the SULEV emissions rating over the LEV rating is an 89% reduction in hydrocarbon emissions. The SULEV-rated Civic produces approximately one kilogram of hydrocarbons per 100,000 miles of driving. It also produces 93% less $NO_x$ emissions over the same mileage. Civic hybrids in California and northeastern states are required to be Advanced Technology Partial Zero-Emissions Vehicles (AT-PZEV), which produce no evaporative emissions (Perry). To reduce $NO_x$ emissions, Honda developed a special catalytic converter for hybrids that converts $NO_x$ and $CO_x$ into water vapor, carbon dioxide, and nitrogen more effectively than a catalytic converter on gasoline-only vehicles.

Richard Truett of Automotive News views the effects of hybrids to be most beneficial in trucks, primarily as other options such as the Ford Focus with its 2.3-liter gas engine achieve Partial Zero Emissions Vehicle (PZEV) ratings. This PZEV rating matches most Honda and Toyota hybrid vehicles. Truett believes that small hybrid cars

are best suited for places like Japan, where idling and traffic levels are lengthy, and diesels are inconvenient due to limited supplies of fuel (Truett).

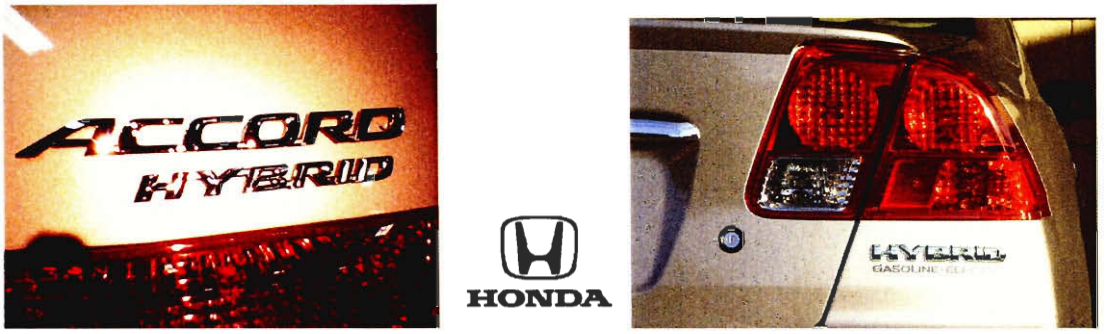
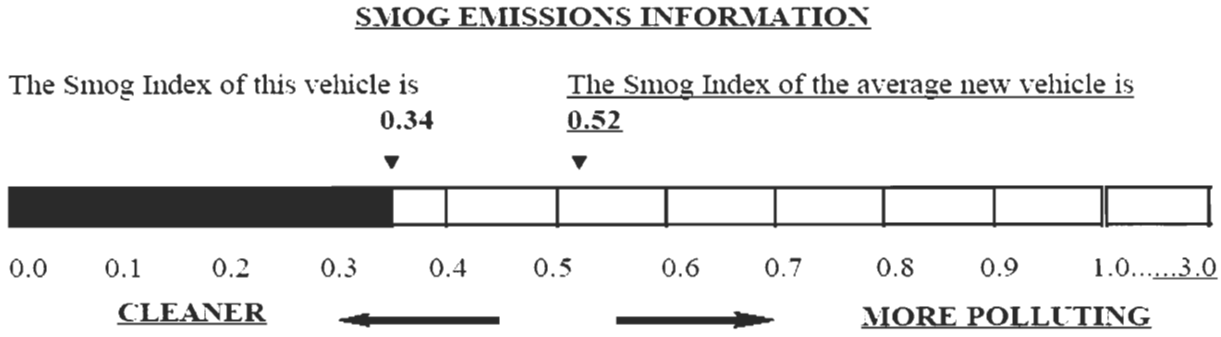



Figure 1: **The Honda Accord (left) and Civic (right) hybrids provide a combination of performance and fuel efficiency for American families. (Robert Dandekar and Honda Motor Company)**

The EPA developed its test to measure the fuel economy of cars (EPA #1). The purpose of their Fuel Economy Guide is to allow car buyers to compare fuel economy estimates of various cars. Smog is defined as a combination of smoke, ozone, hydrocarbons, nitrogen oxides, and other chemically reactive compounds which may result may that cause adverse health effects. One source of smog is motor vehicles (CARB). CARB developed a scale in the 1990s, to provide buyers of new automobiles a better perspective of air pollution from each vehicle, shown in Figure 2 on the following page. The Smog Index (SI) indicates the relative level of smog-forming pollutants emitted by the vehicle, created for model year 1998 to provide consumers with an understanding of vehicle emissions. The lower the SI value, the lower the emissions are for that vehicle.




| 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 and subsequent |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.54 | 0.53 | 0.52 | 0.50 | 0.47 | 0.36 | 0.27 | 0.19 | 0.18 | 0.18 | 0.17 |

**Figure 2: The figure (top) shows consumers the relative index of pollutant emissions of a vehicle compared to the average value within its class. The lower the value, the cleaner the vehicle will operate. The table (bottom) shows the Smog Index regulations set by CARB year to year. (CARB)**

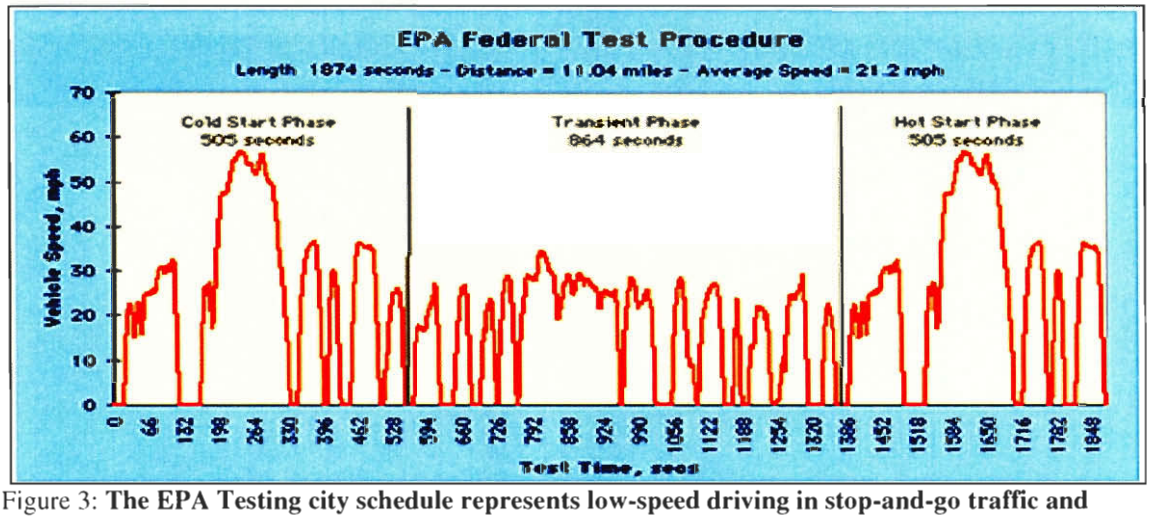



Figure 3: **The EPA Testing city schedule represents low-speed driving in stop-and-go traffic and lengthy idling. (EPA #1)**

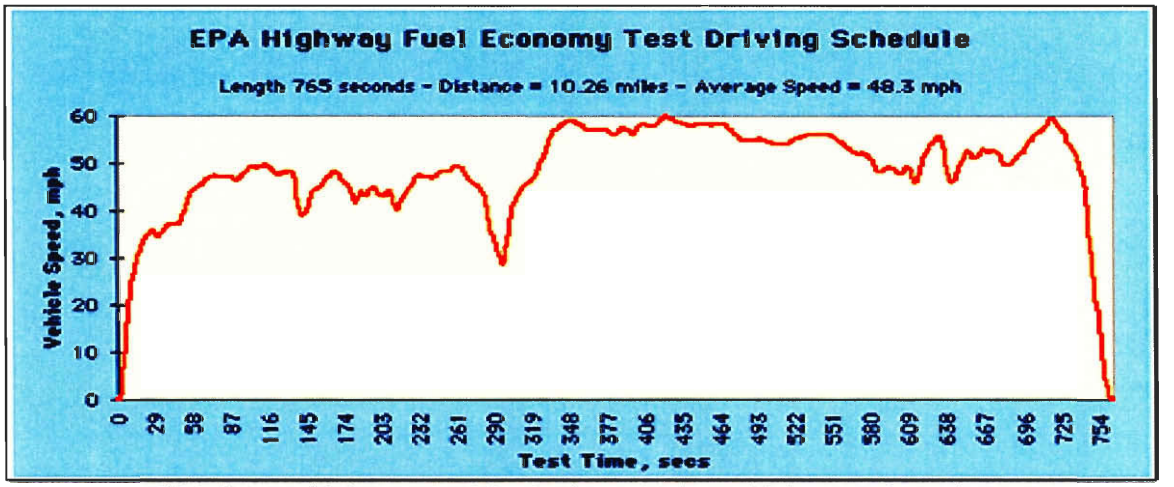


Figure 4: **The EPA Testing highway schedule simulates driving at higher speeds, with no stops and limited idling. (EPA #1)**

Figure 3 on this page and Figure 4 on the previous page display the EPA fuel economy testing procedure for city driving and highway driving, respectively. The graphs indicate the speed at which a vehicle is running on a dynamometer at each second of the test. This provides the EPA with a simulation that approximates the fuel economy of vehicles tested.

In recent automotive tests conducted by Motor Trend (Markus), hybrid vehicles face an average of 25 percent lower fuel economy according to their EPA tests in general driving environments. The EPA does give estimate ranges for vehicles under city and highway driving. However, the lower fuel economy in hybrids relates to other factors such as speed limits and longer traffic time, CVTs, and frequent use of air conditioning. The agency does not require the use of air conditioning during its tests, revealing a significant flaw in the testing system. The other factor that the EPA does not currently consider is higher speed limits on the highway. The maximum speed the test reaches is 60 mph indicated in Figures 3 and 4 above, which do not meet the average highway speed limits of 65 mph today. When most highway speed limits increased to 65 mph, the threshold for average actual driving speed increased to 75 mph. The limitation of

aerodynamics and other drag associated with higher speeds causes an exponential effect as speed rises. This higher speed attributes to greater engine RPM, an increase in the drag on vehicles, as well as greater tire friction with the road surface.

Aside from these irregularities, Honda plans to double its American sales of hybrid vehicles through the introduction of the Accord Hybrid (Tierney). Honda plans to sell about twenty thousand units, with total hybrid sales around forty-five thousand units. Toyota Prius sales in 2004 have reached thirty-one thousand vehicles in the world hybrid market, with about 52,000 units expected this year.

The United States is currently the world's largest consumer of petroleum, and is responsible for approximately one fourth of total demand. The amount of oil that the United States can produce itself is far below its own consumption, 56.1% of oil consumed in the US must be imported from other countries (EIA #3). This gap has created numerous economic and political problems for the United States. The vast amount of oil that needs to be imported is largely responsible for the United States' trade deficit, and leaves the American economy at the mercy of outside forces. Many of the countries that supply oil to the United States are less than reliable; the OPEC embargo of the 1970s is an example. OPEC countries account for 4.5 million barrels out of 9.6 million barrels of crude oil per day imported to the United States (EIA #3). A breakdown of the top suppliers of crude oil to the United States is shown in Figure 5.

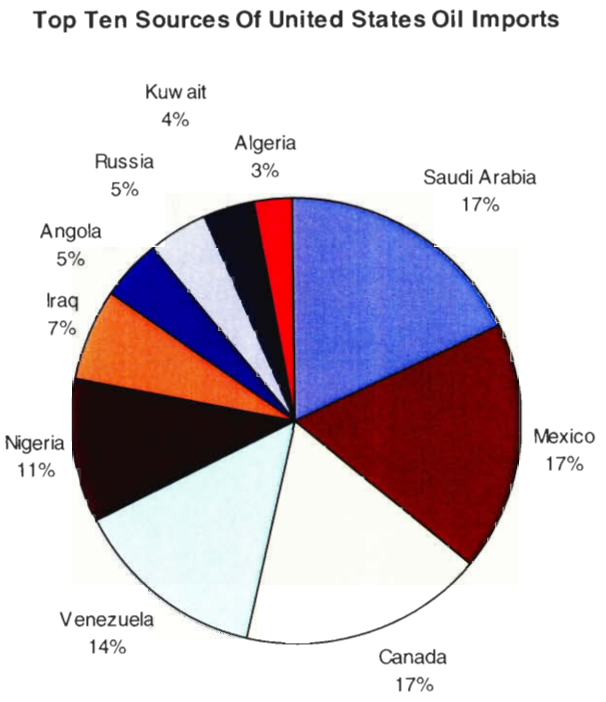



Figure 5: **Top Ten Sources of United States Oil Imports (EIA #1)**

As the United States' own capacity to produce oil is fixed, the only way to reduce its dependency on foreign oil is to reduce demand. Hybrid technology is a promising new way to do just that. The majority of oil consumed by the United States is in the form of gasoline for passenger vehicles, 68% of oil is used for transportation (EIA #3). If the amount of gasoline required to operate passenger vehicles can be lowered, then the United States can apply that savings to its foreign oil dependency.

# Chapter 3: Methodology

Our team used a variety of research methods to understand the effect of hybrid vehicles to reduce oil imports, and protect our environment from the hazards of air pollution. One large source of information on fuel economy we used was from the Environmental Protection Agency (Department of Energy/EPA). The EPA provided resources for fuel economy, such as their Fuel Economy Guide, that listed the fuel efficiency for each vehicle sold in the United States. The manual allowed us to compare all vehicles with mileage estimates for model year 2005. The EPA website also provided vehicle testing and mileage estimate procedures, which led to criticism by our team toward the effectiveness of this test, relative to the driving style of an average American driver of today. The understanding of EPA testing and the operational characteristics of hybrid vehicles verified the source of bias of the EPA mileage estimates. Resources such as Toyota Motor Sales, advice columns, road tests, newspaper articles, radio programs and technical handbooks provided valuable information. From this, we made conclusions about the potential of hybrids to become a key component of refined transportation in our society.

As part of our methodology, we tried to understand the opinion concerning hybrid vehicles from a broader perspective. Public events were a great opportunity to express the advantages of hybrid technology and receive feedback on customer criteria. One team member took a trip to the 2004 New England International Auto Show in Boston and local car dealership Bernardi Honda of Natick, Massachusetts to get a better understanding of consumer focus on hybrid vehicles. This information helped confirm the

growing market for hybrids within New England. From these dealership visits, our team was able to learn the practical and efficient design of hybrid cars.

In December 2004, we distributed a questionnaire to 76 participants including college students, faculty, and other members of the community. We circulated the questionnaire over a broad population in order to understand the thoughts of consumers about environmental protection, now and in the future. Contacting a professor at WPI that owns a hybrid vehicle helped to understand the effects of fuel economy and driving habits. Her input verified our understanding that normal driving styles lead to higher than normal deviation from EPA figure. A test drive of our advisor's hybrid vehicle also helped to understand the benefits and driving characteristics of hybrid cars, seen through the quiet and controlled nature of the Prius hybrid vehicle.

News articles and publications developed our experience with the latest developments on hybrid car introductions and improvements in design. The latest developments and model debuts allowed a deeper vision into the possibilities of fuel saving with the use of hybrids. A number of resources, such as the U.S. Department of Energy, provided enough data to tabulate oil savings that the United States would encounter if specific percentage of hybrids were on the road. We also researched available information from the EPA in order to understand the emissions ratings of various vehicles and their relationship with fuel economy.

One team member came across a radio program that helped understand a new dual-stage hybrid system that General Motors and DaimlerChrysler are quickly designing through cooperative competition (General Motors-DaimlerChrysler dual-stage hybrid). Finally, we interviewed several professors of higher education from WPI who expressed

their vision on this latest form of technology transportation. They provided us with an educated view about how hybrids will provide the largest benefits in our evolving society.

## Chapter 4: Findings

Air pollution concerns humankind since the world's population shares the same air. Vehicles provide a source of pollution, and drivers can decide to help cut down on this problem through the environmentally friendly purchase of a hybrid vehicle. All classes of vehicles will eventually be able to take advantage of the air pollution savings of today's hybrid technology. However, the scope of light trucks and cars will be the only classes of vehicles addressed.

Several pollutants hold presence in the air of the world. However, the two most important pollutants are Smog, Nitrogen Oxides ($NO_x$) and Non-Methane Organic Gases (NMOG), and gases like carbon dioxide ($CO_2$) that increase global warming. Emission tests of both pollutants are completed on all vehicles in the US according to the standards of the Environmental Protection Agency (EPA), with the most recent information concerning 2004 models.

Global warming occurs as greenhouse gases such as carbon dioxide trap heat, causing the Earth's overall temperature to increase. When the Earth heats up higher than the normal climate limits, then ice caps will start to melt and climates will change. The world needs to start preserving the Earth now while we still have a chance to fix the current damage. Even one person can make a difference by purchasing a new hybrid vehicle. Even though manufacturers are coming out with cars with the strictest standards of pollution ever, everyone should do their part in helping to preserve the Earth. The EPA

website has a Green Vehicle Guide with all of the vehicles from 2004 with a Smog and $CO_2$ rating. The Green Vehicle Guide comes from a dependable source, the EPA, to recognize the environmental emissions from vehicles on today's market. Even for buyers who may not consider a hybrid as their best option, the Green Vehicle Guide will allow them to compare any other class of vehicle to help cut down on pollution.

Cars with better gas mileage release fewer amounts of carbon dioxide into the air. Even if the cost savings appeal more than the emissions reductions, you still help the environment when buying a hybrid vehicle due to lower levels of greenhouse gases. Figure 6 and Figure 7 below show the rating system for the Air Pollution on the left and for the Greenhouse Gas Emissions on the right, respectively. The scales range from zero to ten in integer increments with 10 as the best score and 0 as the worst. Due to the process of combustion, better gas mileage means a more efficient combustion process thereby producing less carbon dioxide. Contrarily, lower mileage creates more carbon dioxide due to an inefficient combustion cycle. Figure 9 shows how the vehicles with lower levels of carbon dioxide emissions achieve better gas mileage as compared to those with higher levels of carbon dioxide.

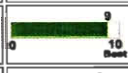
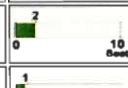
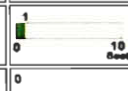
| Pounds of Smog-Forming Pollution Per 15,000 Miles | Emission / Air Pollution Score |
|---|---|
| 0 - 1.0 |  |
| 2.8 - 4.1 |  |
| 5.3 - 6.3 |  |
| 7.9 - 11.8 |  |
| 12.3 - 12.9 |  |
| 15.1 - 19.8 |  |
| 20.8 - 25.0 |  |
| 27.4 - 36.3 |  |
| 39.0 - 40.6 |  |
| 43.7 - 58.8 |  |
| 63.8 - 121.1 |  |

Figure 6: **Air Pollution Rating System (EPA #2)**

**Fuel Economy: Combined mpg**

| Greenhouse Gas Score | Pounds $CO_2$ per mile | Gasoline |
|---|---|---|
| **10** | Less than 0.45 | 44 and higher |
| **9** | 0.45 to 0.54 | 36 to 43 |
| **8** | 0.55 to 0.64 | 30 to 35 |
| **7** | 0.65 to 0.74 | 26 to 29 |
| **6** | 0.75 to 0.84 | 23 to 25 |
| **5** | 0.85 to 0.94 | 21 to 22 |
| **4** | 0.95 to 1.04 | 19 to 20 |
| **3** | 1.05 to 1.14 | 17 to 18 |
| **2** | 1.15 to 1.24 | 16 |
| **1** | 1.25 to 1.34 | 15 |
| **0** | 1.35 and up | 14 and lower |

Figure 7: **$CO_2$ Rating System (EPA #2)**

Figure 8 lists the vehicles including in the results used in Figure 9. The vehicles listed in bold are the manual transmission versions of the vehicle, and all vehicles listed take gasoline.

| Vehicles | Air Pollution Score | Greenhouse Gas Score | CITY mpg | HWY mpg |
|---|---|---|---|---|
| Honda Insight | 10 | 10 | 57 | 56 |
| Toyota Prius | 10 | 10 | 60 | 51 |
| **Civic Hybrid** | 10 | 10 | 47 | 48 |
| Honda Civic | 10 | 9 | 30 | 34 |
| **Mazda 3** | 10 | 8 | 28 | 35 |
| **Ford Focus** | 10 | 7 | 25 | 33 |
| **Ford Focus Wagon** | 10 | 7 | 25 | 33 |
| Honda Accord | 10 | 7 | 24 | 34 |
| **Nissan Altima** | 10 | 6 | 23 | 29 |
| Subaru Outback | 10 | 6 | 21 | 28 |
| Lexus RX330 | 9 | 5 | 18 | 24 |
| **Acura RSX** | 8 | 8 | 27 | 33 |

Figure 8: **List of Vehicles Used for Figure 9 (EPA #2)**

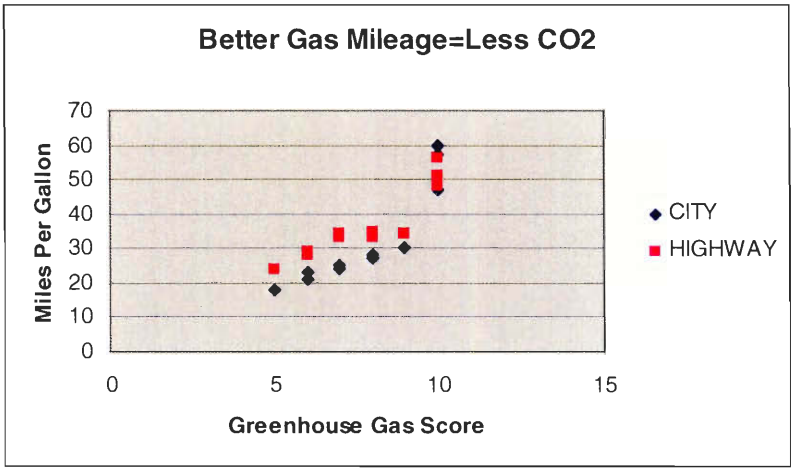



Figure 9: **Shows how better gas mileage indicates lesser $CO_2$ emissions (Russell Pead)**

Another key aspect of vehicles with lower $CO_2$ levels is the better gas mileage achieved from higher efficiency engines. Better gas mileage means retaining our current resources for longer time since the Earth has limited resources. Once used up, resources

have to be found elsewhere, but until then, we need to conserve our oil supply for everyday items that need oil.

The exact amount of gasoline that can be saved by switching to hybrid vehicles depends on a number of factors. Fuel economy can vary drastically with driving habits, road conditions, and even the weather. Even more problems are encountered when trying to apply gasoline savings from country to country. The shorter distances traveled, availability of public transportation, and the widespread use of diesel fuel mean that the average European driver consumes much less gasoline than their American counterpart. These and other problems encountered when calculating fuel savings across the globe make it hard to say just how much gasoline could be saved worldwide. However, with the United States consuming approximately **one fourth of the world's oil**, it would make an important example of the potential benefits of hybrids.

The total gasoline consumption in the United States in 2003 was 138,608 million gallons, with 97% being consumed for highway use (BTS). That means that the total amount of gasoline used by passenger cars and light trucks was 1.34 billion gallons. It will be assumed for the purpose of this report that hybrid vehicles will get on average twice the fuel economy of their conventional counterparts. This assumption is based on hybrid vehicles currently available, which may not be the best indicator of the actual fuel economy in the future since there are only a limited number of hybrid vehicle models currently on the market. Though almost every major vehicle manufacturer has plans to create hybrid models, it is impossible to say what their fuel economy will be since they are still on the drawing board. The actual fuel economy of hybrid vehicles in the future may be less than twice than that of conventional vehicles, or it may be more. However,

with the current average of twice the fuel economy, the United States could have saved 67,045 million gallons of gasoline in 2003 if every gasoline-powered highway vehicle was a hybrid. That amounts to 48.4% of all the gasoline consumed in the US for that year, Figure 10 shows a graphical representation of the portion of gasoline saved. The numbers given in this report only apply to passenger cars and light trucks, the only vehicles that current technology can convert into hybrids. It is assumed that larger vehicles, such as tractor-trailers, remain unchanged.

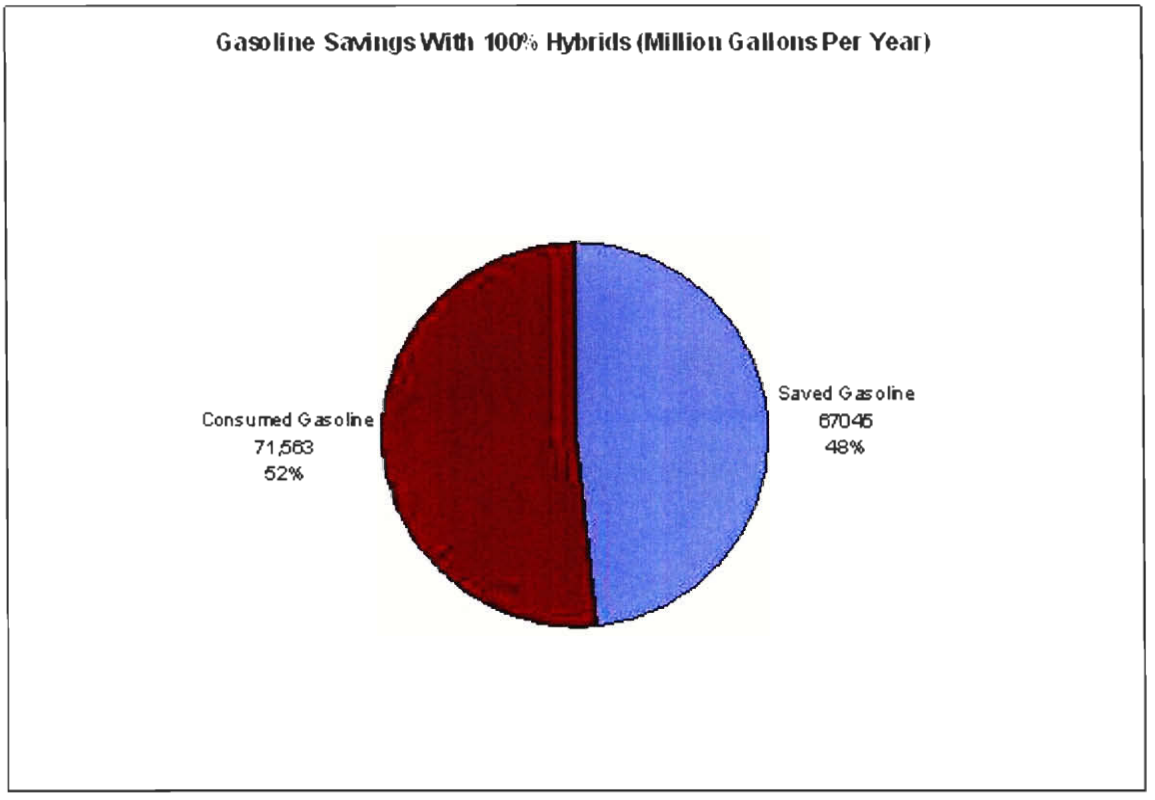



Figure 10: **Gasoline Savings with 100% Hybrids**

While a 48% drop in gasoline consumption is an impressive number, it may not be realistic to assume that every car on the American highways will one day be a hybrid, especially not in the near future. A 25% conversion however, is much more realistic in the short term, and with current hybrid vehicle sales it could be a reality very soon. A

25% conversion could save 16,761 million gallons of gasoline, or 12.1% of the United States' total gasoline consumption for 2003, shown in Figure 11.

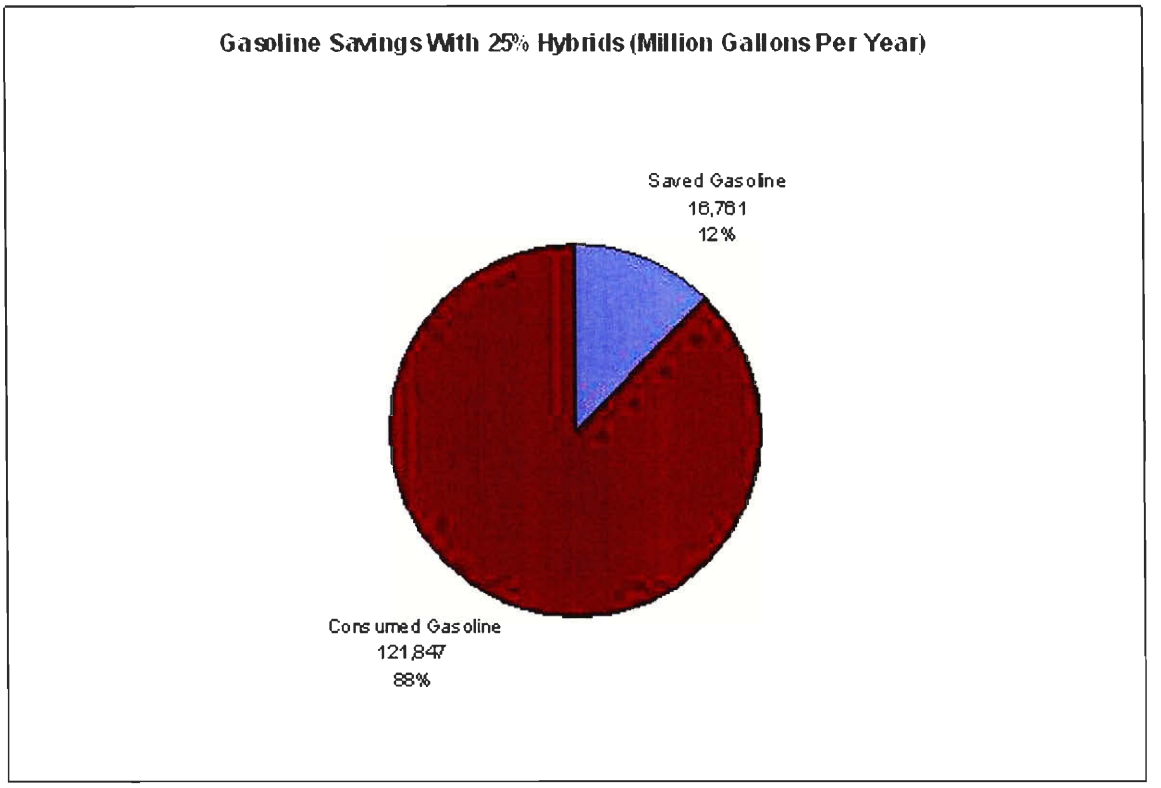



Figure 11: **Gasoline Savings with 25% Hybrids**

With the potential savings of gasoline offered by hybrids, and the current economic and political problems with importing oil in the United States today, it might be interesting to see how much hybrids could reduce oil imports. Unfortunately, the calculations required to determine the amount of oil saved are extremely difficult if not impossible due to the nature of crude oil. Oil is imported into the United States in the form of crude oil, which can be made into not only gasoline but also every other petroleum product we use. The difficulty arises in the fact that every standard 42-gallon barrel of oil yields exactly 19.9 gallons of gasoline (EIA #2). The remainder of each barrel is turned into other products such as tar, propane, and plastics. The ratio of

gasoline and other products cannot be changed. Only a certain percentage of crude oil can be turned into gasoline. If the United States cuts its gasoline requirement in half, or eliminates the need for gasoline, it still would require the other petroleum products that crude oil provides. This means that it is impossible to calculate the exact amount of crude oil that can be saved without also knowing if consumption of all the other petroleum products that are derived from crude oil can be cut as well. It is beyond the scope of this report to estimate the demand for all petroleum products; however, it is very likely that reducing gasoline consumption will reduce crude oil consumption. The amount by which it can be reduced is a matter of conjecture.

Hybrid vehicles are quite fuel efficient, though poor driving habits in 2005 with a hybrid system tends to have a larger toll on efficiency, significantly more than the average gasoline-only vehicle. Hybrid vehicles tend to require more energy to run the air conditioning systems, so the efficiency when interacting with the electric motor decreases quickly as the small gasoline engine must start to control demand from acceleration, electronics, and the Heating-Ventilation-Air Conditioning (HVAC) system. A test ride of a 2004 Toyota Prius hybrid allowed us to determine the benefits of a hybrid interface with the application of everyday city and highway driving. The vehicle was achieving a calculated average of 55 miles per gallon (mpg) at the time. From this experience, a team member noticed the power available at highway speeds was limited. The mating of a small hybrid engine and a CVT causes a lack of power at these speeds. The efficiency of these vehicles at higher engine RPM decreases and there becomes less benefit of the hybrid system at high speeds. An analogy of this efficiency concern is through the overall vehicle powertrain being a single speed motor, with higher speeds providing a high RPM

operation and lower fuel economy. This indicates the benefits of full-hybrid powertrains in areas of idling traffic such as major cities, in the regard of lower emissions and better fuel economy. As hybrid models begin to suit the tastes of America's average driver through larger engines and optimized economy, response in hybrids sales will be noticed quickly.


Figure 12: **The pictures above are of the 2004 Toyota Prius model we tested. Rear offset photo (Top Left), side offset photo (Top Right), Multi-Informational Display (Bottom Left), under the hood: 1.5-Liter engine with Toyota's Hybrid Synergy Drive (Bottom Right). (Robert Dandekar)**

Figure 12 above contains four photos of the 2004 Toyota Prius hybrid vehicle. This is the second generation Prius, which provides improved fuel efficiency over the previous model year. Prius vehicles use a multi-informational display that indicates estimated average gas mileage, and the operational state of the hybrid system. The Hybrid Synergy Drive is a Toyota-developed system that effectively integrates the gasoline and electric motor output. The Prius also has a smart cooling system that enables a flow of hot coolant into a large cylindrical thermos when the vehicle is shut off. The

objective of this system is to provide warm coolant flow to the gasoline engine upon vehicle startup to reduce cold-start emissions, which contain higher concentrations of toxic pollutants as the catalytic converter has not reached an ideal operational temperature. The 2005 Honda Civic hybrid, for example, achieves a Smog Index ranking of .09, compared to the average index of a 2005 vehicle at .80 (CARB).

Generally, the average person will look at an EPA window sticker and compare the fuel economy ratings. They will compare these values among vehicles they are considering to purchase, but it is unlikely that they will look at the smog index rating for each vehicle. For most consumers, the stated miles-per-gallon values are more important than particulate and smog index. This one factor is unnoticed by the consumer.

The irregularities of hybrids is seen through the response of a WPI Biology Professor; indicating that she achieves fuel economy close to EPA figures only through changing driving behavior from real-time fuel economy indicators. This means that normal driving would result in fuel economy that does not meet the EPA numbers. We understood from our interviews that people would value the benefit of a cleaner environment, even though fuel economy estimates do not always provide a precise indication of actual mileage.

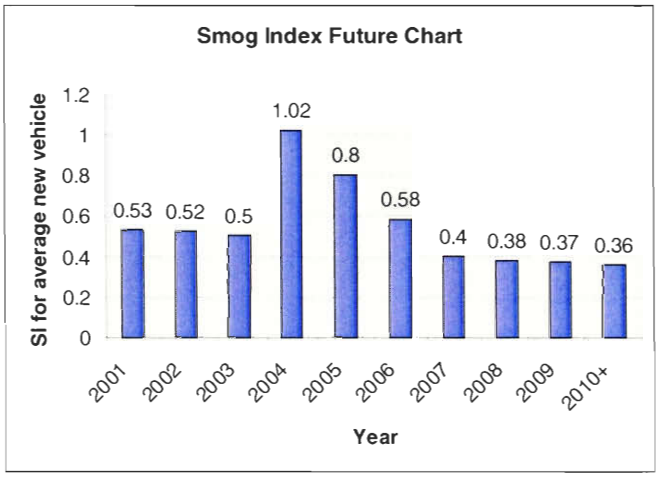



Figure 13: **The requirements for smog index rating set by the California Air Resources Board (CARB) for the average new vehicle (CARB).**

The California Air Resources Board (CARB) developed a Smog Index in the late 1990s to give car buyers a representation of pollution emitted by each vehicle. This developed into the Smog Index (SI), which compares each vehicle to the emissions of an average new vehicle of the model year. In Figure 13 above, there is an overall decline of the SI levels beyond 2004. The values are stricter each year, and hybrid vehicles will help vehicle manufacturers to meet these requirements.

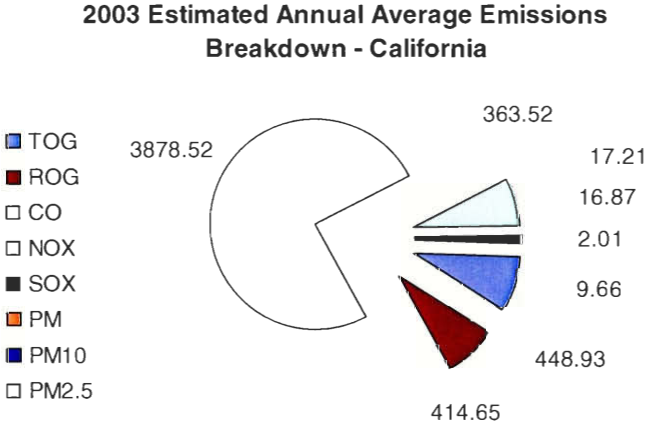



Figure 14: **Seen above are the details of average emissions by pollutant in (Tons/day) on statewide California roads. CO is a large percentage of the breakdown (CARB).**

According to Figure 14 on the previous page, carbon monoxide pollutants compose more than half the emissions in the air from passenger vehicles. Hybrid vehicles can greatly reduce nitrous oxides and carbon oxides. Hybrid vehicles help to reduce $CO_2$ levels by up to 50% and $NO_x$ levels by up to 90%. This shows that a large benefit to our environment is possible through further encouragement of hybrid technology around the world.

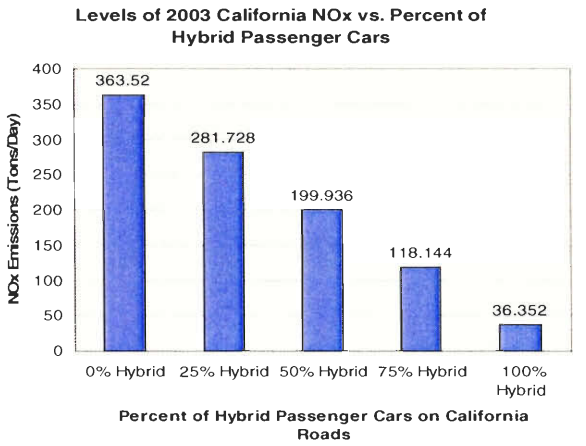



Figure 15: **This figure presents the potential benefit in NOx levels depending on the concentration of hybrids that are on the road in California (CARB).**

Shown in Figure 15 above, a significant change in NOx emissions comes from hybrid vehicles. This difference leads the way towards protecting and preserving our natural resources. For example, when hybrids make up 25% of new car sales in California, $NO_x$ (Nitrogen Oxides include nitric oxide and nitrogen dioxide) emissions will be reduced by eighty-two tons per day and $CO_2$ (Carbon Dioxide) pollution up to 12.5% statewide (CARB #1).

# Chapter 5: International Focus on Hybrid Vehicles

Plans from American and Japanese automakers describe a large push to develop hybrids for foreign markets (Inoue and Ying). GM establishment in China has been significant over the past decade, including brands such as Cadillac and Buick. Such names represent a growing car market in China, and hybrid vehicles under these names could provide an increase in fuel economy and emissions control. Hybrid GM products would benefit the atmosphere in these highly polluted areas, and provide Chinese customers with vehicles of high owner appreciation and popularity.

European sales of hybrid vehicles are slowly growing, indicating a demand for hybrid electric cars in a region of the world where cars are predominantly diesel-powered. Toyota and Honda hybrids in the United States and Japan have been an expanding market. However, the hybrid presence in China is quite limited and air pollution continues to maintain high levels. The progress made to reduce pollution through tighter regulation did not produce visible benefit as a large expansion of China's automotive infrastructure has occurred in recent years.

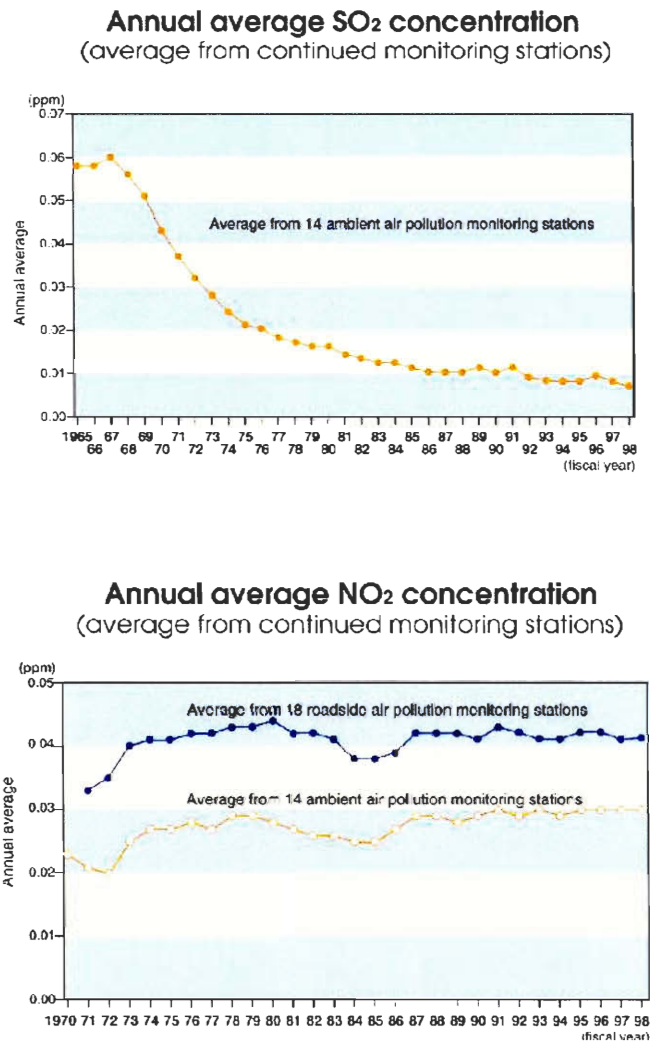



Figure 16: **The (top) graph shows the annual average sulfur dioxide concentration in Japan from 1965 through 1998.The (bottom) graph shows Japan's annual average of nitrogen dioxide concentration during the same period (Japan's Ministry of the Environment).**

The efforts to reduce air pollution in Asia over the last several years have increased significantly, but other factors seem to have caused limited change in the data of pollution concentrations in these regions. In Japan, $NO_x$ emissions have been steady after 1988, as shown in Figure 16, above. Stringent rules on $NO_x$ exist for diesel-powered vehicles; however, this was not the case for gasoline vehicles. With the growing demand in the Japanese market for vehicles, the increase has been counterproductive toward the regulations stated in 1996. This resulted in stationary $NO_x$ levels. Air pollution caused by

sulfur dioxide decreased dramatically from regulations on emissions from stationary sources and on sulfur content of fossil fuels (Japan's Ministry of the Environment).

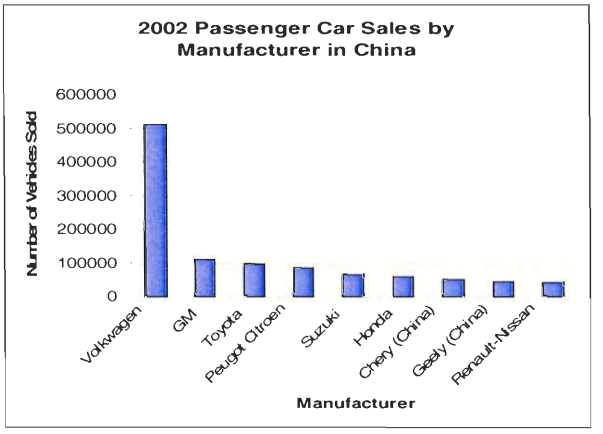



Figure 17: **This chart represents the share of China's domestic car sales between each manufacturer for 2002 (Research Institute of Economy, Trade and Industry, 2003).**

Currently, the Chinese auto market is in growing mode, allowing sales to increase significantly over the years (Kwan). Sales of GM in China had reached more than 194,000 units by 2003, showing a significant change in sales (China Economic Network #1). The breakdown of manufacturer sales in China is shown in Figure 17, above. Most of the vehicles sold in 2002 were gasoline powered, as the use of electric vehicles did not fit effectively into the Chinese market. If hybrid technology were encouraged, gasoline vehicle sales would not grow significantly, providing environmental benefits from a decrease in air pollution.

On September 16th, 2004, Toyota announced it would build Prius hybrids in China by 2005 (Inoue and Ying). According to thecarconnection.com, General Motors (GM) announced in late September 2004 they were planning a significant introduction sequence of hybrid cars for the Chinese market (Brenda Priddy and Company). GM plans to build two new hybrid models in China for the Chinese domestic market.


Figure 18: **The above pictures indicate the Toyota and Lexus involvement with hybrid technology (Top), further seen by the upcoming Lexus GS 450h (Middle), and RX 400h (Bottom) pictured at the New England International Auto Show in November 2004. (Toyota Motor Sales and Robert Dandekar)**

Worldwide, the sales of hybrid models have expanded with the debut of several models in the next few years. As shown in Figure 18 above, Lexus, the luxury division of Toyota Motor Sales will produce the first luxury SUV, the RX 400h, in spring 2005. In the fall of the same year, a new hybrid sedan, the GS 450h will be developed with a design that emphasizes performance. This shows a change in the hybrid market to emphasize the capabilities of hybrid vehicles though various vehicle characteristics, aside from efficiency and ecosystem-friendliness alone. Lexus will begin to focus its hybrid

lineup toward their performance in order to encourage the popularity of these environmentally conscious automobiles worldwide.

The number of hybrid vehicles on the road in Europe continues to grow at a steady pace. Toyota announced that demand for hybrids in Europe has outpaced sales estimates (China Economic Network #2). Originally, Toyota planned to sell 5,000 Toyota Priuses in 2004. The current estimate claims sales of 8,200 units by the end of the year. Toyota is also projecting sales of 15,000 units in Europe for 2005 alone.

Through a venture with Guangzhou Automobile Group in China, Honda Motor Company may begin production of hybrid vehicles in the coming months. "If costs of and demands for hybrid cars in China reach our requirements, we will start production soon," executive vice-president of the venture, Zeng Qinghong said. Honda's venture will create a new 265 million dollar factory in South China that may assist in the production of hybrid vehicles such as the Honda Accord, in the near future (Qiao).

In Europe, hybrid sales of the Toyota Prius are relatively low, with 8,500 units in 2004 (Madslien). Worldwide Prius sales measured 43,000 units in 2003. With sales slated to increase, Toyota has boosted production worldwide to about 130 thousand units, with about 13,000 in Europe.


Figure 19: **Pictured above is Ford Motor Company's Escape Hybrid Sport-Utility Vehicle (SUV). This was the first SUV in the world to have a hybrid system, showing an application to reduce pollution and improve gas mileage for heavy vehicles. (Ford Motor Company)**

# Chapter 6: Conclusions

Hybrid technology could have an enormous impact on gasoline consumption in the United States. If 25% of passenger vehicles on the road were hybrids, the total amount of gasoline burned in the United States could have been reduced by 12%. Gasoline consumption would drop by 48% if every passenger vehicle were a hybrid. These numbers only apply to passenger vehicles, such as cars and light trucks. Estimating the amount of crude oil that can be saved is very difficult and beyond the scope of this project, but it is very likely that crude oil consumption would also drop with a decrease in gasoline consumption. Hybrid technology could possibly aid the United States in reducing its foreign oil dependency.

Imprecise values from the EPA fuel economy tests can be attributed to the test procedures, which are outdated and cannot suit the expectations of every hybrid vehicle owner. The EPA estimated fuel economy ratings do not represent an accurate summary measure to test newer vehicle technologies and modern driving habits. Although hybrids do not always achieve their estimated mileage figures, they do provide a significant improvement over gasoline engines in respect to fuel economy and partial-zero emissions. Hybrid cars currently are the best alternative toward the future of transportation, and their acceptance in society will lead the way to a cleaner and safer future. As pollution continues to affect our lives on a daily basis, the time has come to adapt newer technologies of transportation into the ways in which we live.

Pollution figures in developing nations support our understanding of hybrid technology use around the world. The majority of hybrid car sales have not reached countries where pollution reduction is critical. China, a highly polluted country, has

concentrated on pure electric vehicles, even though hybrid cars seem logical toward cost savings and smog reduction. The most applicable market for small hybrid cars is in Japan, China, India, Russia, and other congested populations. In the United States, the use of hybrid technology in sport-utility vehicles would provide a significant reduction of pollution from the vehicles that pollute the most and outsell smaller passenger cars.

What we may conclude from European hybrid car sales figures is that hybrid demand continues to rise even within a predominantly diesel engine driven region of the world. The international focus on hybrid vehicles displays a different picture. Diesels in Europe, although efficient in terms of fuel costs, still pollute much more than hybrid vehicles. Hybrids are changing the strong diesel market in Europe, and will become a larger part of non-diesel sales through the application of a broader-application dual-stage hybrid system in the coming years. Respectively, hybrid sales in developing nations of the world, such as China, seem quite limited. This limited market focus in congested regions is one source of error that causes pollution levels to remain high in these countries. Toyota and Honda have not expanded the use of this technology in the places that require it most. Part of this conundrum is the strict environmental policy of hybrids in China, which causes automakers to move cautiously. If hybrids sell in such countries, through stricter regulation, we could save lives and limit long-term environmental problems, such as global warming.

If automakers were to develop and mass-produce various hybrid vehicle classes in Japan, significant pollution reduction would exist as hybrid vehicles emit 10% of $NO_x$ emissions and 50% of $CO_2$ as compared to gasoline engines. This is the most justifiable types of markets where health effects and fuel savings would create an effective product.

As products such as the Honda Accord, Lexus RX 400h, Toyota Highlander, Ford Five Hundred, GMC Sierra, and Lexus GS 450h become hybridized, the appeal of these vehicles will increase significantly as popular models mated with at least six-cylinder engines will push performance and economy into a single package. Our research about hybrid cars points to the overall justification that gasoline-electric hybrid powertrains currently are the best alternative to a gasoline-only system. The sale of hybrids will help our world to ensure a safer and healthier future through lesser dependence on foreign oil and cleaner air. Models such as the Honda Insight, Toyota Prius, Honda Civic, and Ford Escape are leading the way of advanced technology that provides performance of average vehicles and the emissions of the cleanest vehicles on the road.

Through our research, we have been able to find a considerable advantage of using hybrids in polluted regions around the world. In America, the use of hybrid technology should focus on higher polluting vehicles. Correspondingly, automakers must consider markets that have a larger need for pollution reduction. The expansion of hybrid-model variety such as large cars and sport-utility vehicles will lead American drivers to convert to clean and efficient transportation technologies.

Through a questionnaire, we have determined that most consumers are conscious about the saving gas costs and reducing air pollutants. We conducted this study through the students and faculty members of WPI, as well as people outside of WPI. Overall, most drivers are willing to pay about 10% extra to purchase a hybrid vehicle. This value tends to be lower with students, as they expect the technology to be an integral part of the vehicle and cost effective enough to balance the price of the hybrid system and the gas savings over a few years.

# Chapter 7: Future Direction

As hybrid vehicle introductions continue to expand the market, hybrid technology will be understood in terms of how economical and clean they are. This is shown by the DaimlerChrysler and General Motors partnership to develop a multi-stage hybrid system. This design will promote excellent fuel economy over a broader range of driving conditions and vehicle types. It is expected to arrive by 2008. The system can work with a diesel or gasoline engines from small cars to large pickup trucks. Such a system is analogous to a two-speed transmission, providing better control of engine RPM than a theoretical one-speed transmission configuration of other hybrids already being sold.

With all of the new hybrid technology planned to enter the market and the demand for fuel-efficient vehicles, it is safe to assume hybrid vehicles are going to be on American roadways well into the future. They will always be a portion of all the vehicles on the road, and they may even replace conventional vehicles entirely in the future. The limitations of current technology mean that only small vehicles like passenger cars can be designed as hybrids, but that will soon change. Many motor companies have either hybrid heavy truck prototypes or plans for them on the drawing board. There is no technological rule that says hybrids have to be small - even enormous mining dump trucks have had diesel-electric drives for a number of years. There exists no reason each vehicle on the road today cannot be replaced by a hybrid, with similar or increased performance in the near future. If production was high enough, every passenger car and light truck could be replaced with a hybrid this year. Another factor that must be considered in estimating the future share of hybrid vehicles in the American market is public demand for them. While it is true that hybrid vehicles cannot be built fast enough to satisfy demand, the

production numbers are so low that they do not give an accurate indication of the total demand. On a survey conducted to gain a better understanding of public demand for hybrid technology, 76 participants were asked to rate on a scale of 1 to 10 the importance of reducing air pollution and buying less gas were in the purchase of a hybrid vehicle. The average importance of reducing air pollution ranked 8.02, and the average importance of buying less gas ranked 9.00. This suggests that as long as hybrid vehicles continue to produce less pollution and/or burn less fuel than conventional vehicles, there will be a demand for them. When asked how much more money they would pay over the cost of a conventional vehicle to own a hybrid, the average participant said 9.36%. Given the fact that most hybrids cost about 10% more than similar conventional vehicles, this survey suggests that the extra cost associated with hybrid vehicles will not considerably affect demand. This is especially true since the extra cost of hybrid vehicles is expected to come down as production goes up.

Interviews were also conducted to examine the public's perception of hybrid vehicles. These also suggested an interest in the pollution and fuel economy aspects of hybrid technology, but more importantly showed what the perceived drawbacks might be. Safety was ranked as one of the most important factors in a vehicle by the majority of the interviewed participants, and there were some concerns about the safety of hybrid vehicles. Hybrid vehicles seem to have the attached stigma of being small and heavy, and having poor impact resistance. Reliability was another concern among interviewees. Concerns about both the life of the relatively large battery and the ease of general maintenance were a factor. The interviews did show however, that the majority of people favor hybrid use, and would encourage others to use hybrid technology. Possible

encouragements such as tax breaks, insurance rate decreases, government support for research, and education campaigns were all suggested by interviewees. Overall, the use of hybrid technology is on the rise, and there does not seem to be any reason why it will not continue to grow. It is not out of the realm of possibility that hybrid vehicles will soon be as numerous or even outnumber conventionally powered vehicles (Bitar, Clarke, Daigneault, Emanuel, Gerstenfeld, King, Weir, and Wilkes).

# Works Cited


Bitar, Stephen. Personal Interview. 3 Feb. 2005.

Brenda Priddy And Company. "GM Planning Major Hybrid Invasion of China." The Car Connection Daily Edition. 22 Sept. 2004. 29 Jan. 2005 <http://www.thecarconnection.com>.

California Air Resources Board (CARB #1). California Air Resources Board Home. 27 Feb. 2005 < http://www.arb.ca.gov/homepage.htm>.

California Air Resources Board (CARB #2). Glossary of Air Pollution Terms. 27 Jan. 2004 <http://www.arb.ca.gov/html/gloss.htm#S>.

Clarke, Edward. Personal Interview. 14 Feb. 2005.

Daigneault, Dean. Personal Interview. 3 Feb. 2005.

Emanuel, Alexander. Personal Interview. 3 Feb. 2005.

"General Motors-DaimlerChrysler dual-stage hybrid." Market Wrap. Host Mark Mills. Tiger Financial News Network. WBIX, Boston. 28 Jan. 2005.

Gerstenfeld, Arthur. Personal Interview. 15 Feb. 2005.

"GM Expects Car Sales to Pick Up." #1 China Economic Network. 3 Nov. 2004 <http://en.ce.cn/Business/Enterprise/picnews/200410/31/t20041031_2142093.shtml>.

Honda. "2004 Honda Civic Hybrid." Engineering: Sales Reference Manual. 20 Oct. 2004.

Inoue, Kae and Ying, Tian. "Toyota in joint venture to build hybrid cars in China." Bloomberg News. 16 Sept. 2004. 12 Jan. 2004 <http://www.iht.com/articles/538902.html>.

Japan. Ministry of the Environment. "State of Japan's Environment at a Glance- Air Pollution." 20 Dec. 2004 <http://www.env.go.jp/en/jeg/air/p_air.html>.

King, Brian. Personal Interview. 31 Jan. 2005.

Kwan, Chi Hung. "China In Transition: On China Becoming a Major Auto Power - The need to enhance international competitiveness." Research Institute of Economy, Trade, and Industry (RIETI). 20 June 2003. 1 Feb. 2005 <http://www.rieti.go.jp/en/china/03062001.html>.

Madslien, Jorn. "How hybrid power surprised the car industry." BBC News. 16 Nov. 2004. 24 Jan. 2005 <http://news.bbc.co.uk/2/hi/business/4015831.stm>.

Markus, Frank. "Road Test: 2004 Honda Civic Hybrid, 2004 Toyota Prius, 2004 Honda Insight, 2003 Toyota Prius." Motor Trend. May 2004. 17 Feb. 2005 <http://motortrend.com/roadtests/alternative/112_0405_hybrid/index10.html>.

Naughton, Keith. "Green & Mean." Newsweek. 22 Nov. 2004. 10 Feb. 2005 <http://www.msnbc.msn.com/id/6479959/site/newsweek/>.

Perry, Mike. Bernardi Honda of Natick, MA 01760. 20 Oct. 2004.

Qiao, Yu. "Honda planning to build hybrid-powered autos." China Daily. 23 Nov. 2004. 12 Dec. 2004 <http://www.chinadaily.com.cn/english/doc/200411/23/content_393923.htm#>.

Shartin, Emily. "Colorful, catchy sign concerns commuter." The Boston Globe: Starts & Stops/West. 28 Nov. 2004.

Tierney, Christine. "Honda sets lofty hybrid sales target: Automaker projects double the U.S. sales of 2005 models." The Detroit News. 8 Oct. 2004. 10 Feb. 2005 <http://www.detnews.com/2004/autosinsider/0410/11/c01-297532.htm>.

"Toyota predicts Prius sales will double." #2 China Economic Network. 24 Sept. 2004

Truett, Richard. "Civic Hybrid and Prius overrated; Much-touted cars don't live up to their

EPA ratings." Automotive News. 10 May 2004.
Tufte, Edward. Visual Explanations. Connecticut: Graphics Press, 1997.
United States. Bureau of Transportation Statistics (BTS). "Table 4-7: Domestic Demand for Gasoline" 27 Feb. 2005 <http://www.bts.gov/publications/national_transportation_statistics/2004/html/table_04_07.html>.
United States. Department of Energy. Environmental Protection Agency. Model Year 2005 Fuel Economy Guide. 26 Feb. 2005 < http://www.epa.gov/otaq/mpg.htm>.
United States. Energy Information Administration (EIA #1). "Crude Oil and Petroleum Imports Top Fifteen Countries" 27 Feb. 2005 <http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/company_level_imports/current/import.html>.
United States. Energy Information Administration (EIA #2). "Gallons of Gasoline From One Barrel Of Crude Oil" 27 Feb. 2005 <http://www.eia.doe.gov/neic/experts/expertanswers.html>.
United States. Energy Information Administration (EIA #3). "Petroleum Quick Stats." 27 Feb. 2005 <http://www.eia.doe.gov/neic/quickfacts/quickoil.html>.
United States. Environmental Protection Agency (EPA #1). "Fuel Economy Test Schedules." 20 Dec. 2004 <http://www.fueleconomy.gov/feg/fe_test_schedules.shtml>.
United States. Environmental Protection Agency (EPA #2). "Green Vehicle Guide." 18 Feb. 2005 <http://www.epa.gov/greenvehicles/all-rank-04.htm>.
Weir, William. Personal Interview. 14 Feb. 2005.
Wilkes, John. Personal Interview. 4 Feb. 2005.