

An Analysis of Hybrid-Electric Vehicles as the Car of the Future

by

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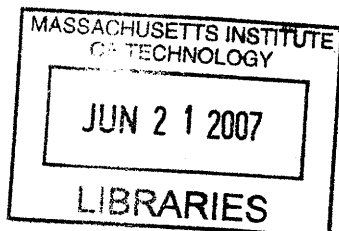
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Heejay Kang

**Submitted to the Department of Mechanical Engineering
on May 11, 2007 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in Engineering
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Abstract:

This thesis will examine the validity of the benefits of the Hybrid-Electric Vehicle(HEV). With the recent focus on energy initiatives, reflected through Bush's state of the union, as well as President Hockfield's MIT Energy Initiative, we are heavily investing resources to tackle the energy consumption problem. The HEV is widely touted as the apparent answer to the global environmental concerns as a substitute to the conventional vehicle that can lower fuel usage and toxic emissions. We explore this environmentally responsible claim through four spectrums of interest: the consumer, the automaker, the government, and the environmentalist. After determining the different parameters that affect HEV integration, we can do a more thorough analysis of energy and cost consumption through the whole vehicle lifecycle, through the process of production, use, and disposal in a comparative study with other alternative fuel vehicles. We conclude with a policy recommendation to integrating HEV vehicles as a sustainable industry and how it fits into the picture for the future of the transportation industry.

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Table of Contents

Abstract:	2
Acknowledgements	3
Table of Contents	4
1. Introduction	5
1.1 Context.....	5
1.2 Road Map	5
2. Background.....	6
2.1 Honda Integrated Motor Assist(IMA)	9
2.2 Toyota Prius.....	10
2.3 GM transmission.....	11
2.4 Ford Fiesta	12
3. Evaluation of HEV.....	13
3.1 Consumer perspective	15
3.2 Automakers	21
3.2.1 A look at the Electric Vehicle	22
3.2.2 Effect of Hybrid Sales in Auto industry	22
3.3 Government.....	23
3.4 Environmental Groups	24
4. Comparative Analysis	25
4.1 Life Cycle Analysis(LCA) & Life Cycle Cost Analysis (LCCA)	26
5. Future Projections	28
5.1 Plug-in Hybrids.....	31
6. Conclusion	32
7. References	34
Appendix A: Willingness to pay for New Vehicle.....	37
Appendix B: International Agreements.....	38

1. Introduction

Since the inception of the motor-vehicle industry in the early 1900's, the mainstream appeal has been with the petroleum and other natural gas resources. While other energy technologies have since been developed, fuel vehicles have maintained the top spot as the affordable and convenient source of energy. In the spectrum of the transportation history, hybrid vehicles only recently broke into the industry with the widespread popularity of the Toyota Prius.

1.1 Context

The Hybrid-Electric Vehicle(HEV) has reached a point in its life cycle where it will either take off as a mainstream product or slowly fade away as an obsolete technology. This critical point happens to coincide with an external societal energy crisis, where the transportation sector is feeling pressure to develop an energy alternative that effectively deals with our nation's oil instability and global environmental concerns. The transportation sector is a multiple offender accounting for 33 percent of U.S. CO2 emissions, 27 percent of total U.S. energy demand, and two-thirds of U.S. oil consumption [1]. Because the United States is dependent on imported oil, which is tied to the political volatility in the Middle East, the necessary transportation energy policy is a matter of national security, as much as it is an environmental policy. Already there is much government and privately-funded research being done to support R&D in this field. In the 2008 Federal budget alone, advanced hybrid and plug-in hybrid was allotted \$81 million to further battery technologies[2]. However, there is still a considerable amount of money being spent for other aspects of energy research such as solar energy, biofuels, and hydrogen fuels. As one of top contenders in the race for alternative fuel sources, we would like to assess its performance and track its progression. Has HEV sales reached a peak only to be followed by a slump or is it still on the rise?

1.2 Road Map

To conduct this study, we will be using a systematic procedure to examine the status quo of the industry. We will look at the biggest players in industry and examine the various technologies they are developing to target efficiency, specifically in the control systems and transmission. Following the close look at this particular technology, we will examine the hybrid-electric vehicle market with respect to other alternative fuel and energy endeavors that the United States is currently pursuing. Looking at both Life Cycle Cost and Life Cycle Analysis studies for the various energy markets, we will make an assessment on the HEV's comparative performance.

Then, we will look at the future outlook for HEV as a technology and an industry in the light of four viewpoints: the consumer, the environmentalists, the auto companies and the government. Which groups' voice will ultimately dictate the next move for the HEV industry? Is this a sustainable and worthwhile endeavor or just an intermediary step that will only exhaust us of further resources, until the next new development? With increasing global concern over pollution issues, it is also a policy question on whether this is an appropriate use of our current resources, both time and money. Finally, we will look at projections made for HEV sales in the coming years and see whether it aligns with any of our aforementioned viewpoints.

2. Background

Hybrid Electric Vehicles (HEV) are neither fully electric nor fully gas-powered, but contain benefits of both components. While the power train interactions vary from model to model, the key to the HEV's popularity is its high fuel efficiency. HEV's require a smaller engine than a conventional vehicle as the electric motor can serve as a power-assist or the sole source at low speeds[3]. Because of a smaller engine, with lighter components and a lower part count, the engine is able to operate at a higher efficiency. HEV's are able to capture and reuse energy during the braking action, in which most cases, there is energy loss through heat in a conventional fuel vehicle.

In general, HEV's can be categorized into two different categories depending on the orientation of the drivetrains. In a series drivetrain(Fig. 1), the wheels are solely driven by the electric motor that sources its power from either the battery or a generator which is driven by an engine. Thus, the engine is not directly coupled to the wheels of the car, but to a

generator, which converts the mechanical energy of the engine to electric energy. This electric energy can then be split to charging the battery or driving the motor that connects to the transmission. When more power is required to drive the vehicle, the motor draws power from both the battery and the engine. The benefit of a series drivetrain is that the mechanical engine is able to operate in a constant efficient speed while continuously converting energy to be charged or used to drive the vehicle. However, it is not as popular as it once was because it has inherent efficiency problems as it goes through a double power conversion that is exacerbated in long-distance driving or heavy load conditions.

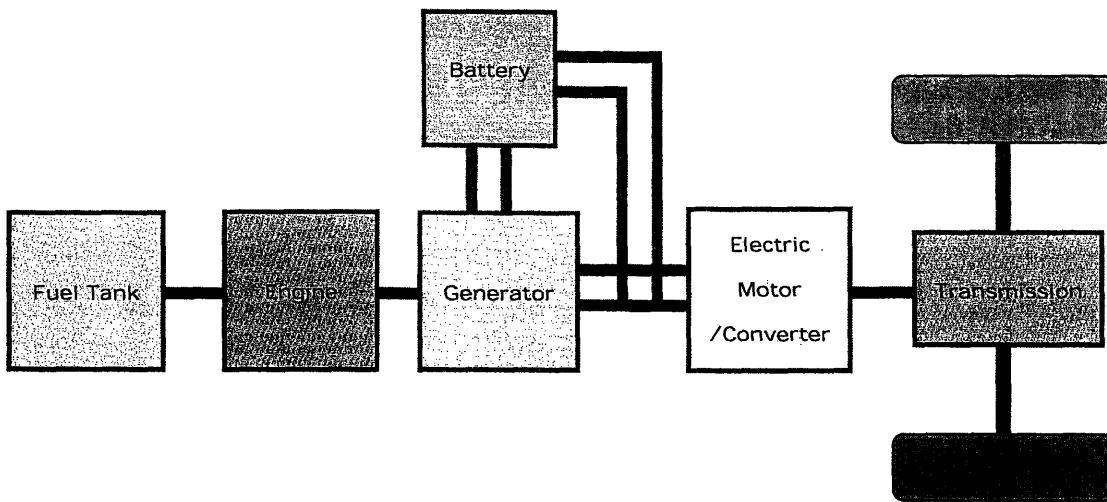


Figure 1. Series Drivetrain

The more common hybrid setup is when the power systems are in parallel mode (Fig. 2). In this configuration, both the electric motor and the engine are connected to a mechanical transmission. They can be connected by a single axis in true parallel such that the combined torques would add up. However, in most automobiles, there is a differential gear system so that torque applied must be the same, and the speed adds up [4]. The parallel setup allows for the engine, the motor, or both to be operating to power the vehicle. It combines the advantages of both systems coupling the two power sources using a power split device.

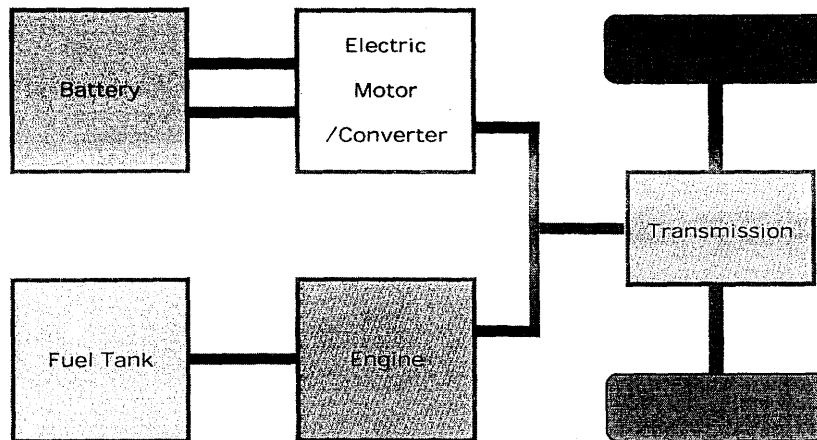


Figure 2. Parallel Hybrid Drivetrain

At startup and low speeds, only the electric motor is engaged. Once the car is in normal cruising mode, the engine power is split between the wheels and the generator, which drives the motor. In acceleration mode, the battery also supplies energy to the motor to increase power. Finally, in deceleration mode, we see the HEV engage in a regenerating brake system, function like the electric vehicle described above. The motor acts as a generator driven by the vehicle's wheels, converts the kinetic energy to electric energy which can be stored in the battery.

As hybrid technology becomes more developed, the parallel drivetrain has broken out into three distinct categories[5]:

- Micro hybrids feature stop/start functionality with no electric propulsion support. Other features include efficient generator, regenerative braking, comfort stop/start.
- Mild hybrids can have all of the above plus limited electrification of propulsion, typically 5-12 kW and less than 1kWh storage capacity.
- Full hybrids feature a high electrification of propulsion, typically more than 20 kW and more than 1kWh storage capacity. They have a power assist feature, usually in association with a smaller internal combustion engine than is needed for the base vehicle and limited zero emission (electric only) operation using its own on-board electric motor.

2.1 Honda Integrated Motor Assist(IMA)

The Insight is one of the first hybrids to reach the market and aimed for super efficiency by reducing and simplifying all aspects of the vehicle. The Insight employed the first generation of the Integrated Motor Assist(IMA) technology, which adds a lot of torque added to the low end of the speed range, where the engine is weaker. The electric motor takes the peak torque of the Insight from 66 pound-feet at 4,800 rpm to 79 pound-feet at 1,500 rpm[6]. This system is a modified parallel hybrid, where the motor is directly coupled to the engine. As a power-assist hybrid, the motor can only provide extra power in acceleration as opposed to a full hybrid which can run on the electric motor alone. Because the electric power needed is lower, it has a much smaller battery pack. It does have the ability to start the motor so that no starter is necessary in the system. Since the Insight, Honda has updated its IMA system in its Civic and Accord hybrid models, which is now more space-efficient. Apart from the hybrid design, there are other design components that contribute to the Insight having the best efficiency on the market. The parts have been condensed in both number and size with the elimination of parts, choice of material and aerodynamic design to reduce weight and drag.

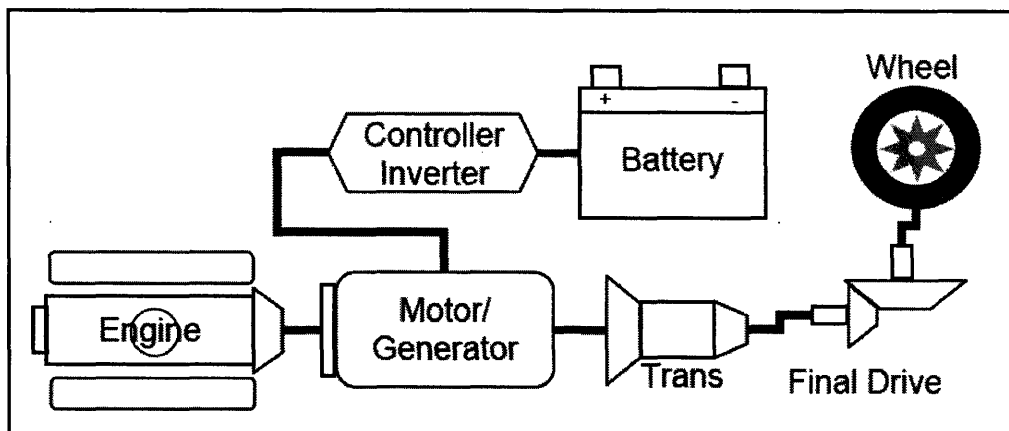


Figure 3. Honda Integrated Motor Assist System

Table 1. Honda Civic Hybrid Specs

Honda Civic Hybrid 2007	
Engine:	1.3 L / 4 cylinder/ 8 valves
Max Power:	110 hp
Transmission:	CVT

Weight:	2,875lbs (1,304kg)
Emissions Rating:	AT PZEV
Fuel Economy(city/hwy):	49 / 51 mpg
0-60 mph:	11.7 s
MSRP:	\$22,600

2.2 Toyota Prius

One of the top-selling and most technologically challenging systems are contained in the Toyota Prius. It combines the advantageous elements of both parallel and series hybrid drive. Using a power split device(PSD)(Fig. 4), it can operate with either engine, electric, or both for parallel drive, but also the speed output to the wheels is not determined by the engine speed, and it can charge battery and provide output to the wheels. The PSD also eliminates the need for a gearbox for the transmission and a starter because the motor is simply used to start the engine.

The system contains a four-cylinder engine that is particularly small for a car of its size at 1300kg[7]. This is managed by the fact that the electric motors and battery can supplement the necessary excess power when necessary, which allows for a smaller engine. The max speed of the engine is also capped at 5000rpm, which allows for it to be made with lighter components and keep it more efficient. Because of the power-splitting transmission, the vehicle can start in all-electric mode so that the engine does not need to be on at low-speed where the mechanical portion is least efficient. Because the power demands for normal drive mode are closer to the peak power of this size engine, it can operate at higher efficiency. The engine is only turned on when the driver requires more power to drive or to recharge the battery. Also, the electric mode is what is running in reverse so there is no excess room necessary to house reverse gears.

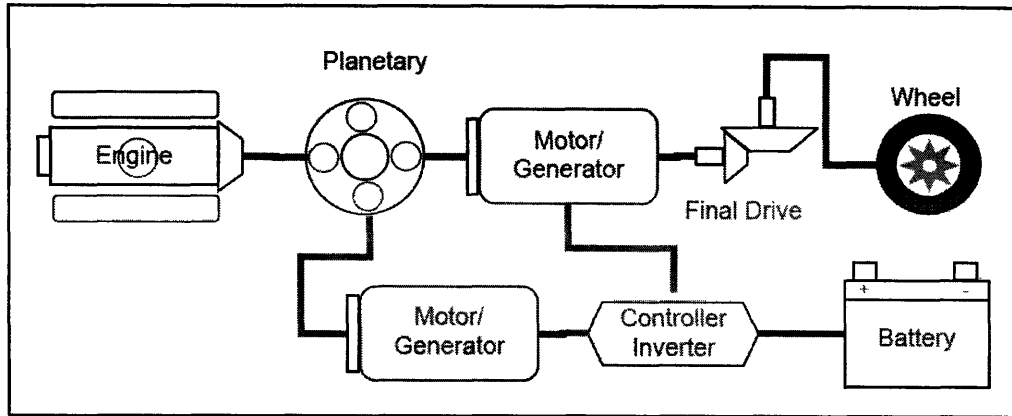


Figure 4. Toyota Power Split System

Table 2. Toyota Prius Specs

Toyota Prius 2007	
Engine:	1.5L / 4 cylinder/ 16 valves
Max Power:	76 hp
Transmission:	Electric CVT
Weight:	2,932 lbs (1,330kg)
Emissions Rating:	AT PZEV
Fuel Economy(city/hwy):	60 / 51 mpg
0-60 mph:	10.5(consumer guide)
MSRP:	\$22,175

2.3 GM transmission

While GM is still trailing to the Japanese companies in terms of hybrid technology they are looking to develop a transmission system that will further improve the efficiency. They are looking at a two-mode hybrid transmission that can run in hybrid, electric-only, and engine-only mode. In this control system, the motors that drive the wheels will be swapped out for fixed gears, locking the engine to the drive shaft[8]. However, this is done seamless with the synchronization done by the electric motors. This is the opposite argument of using electric only in low RPM with minimal torque. At higher torques, the electric motors will actually put a drag on the engine, and affect efficiency[8]. The main difference to the Input-Split Hybrid, such as the Prius design, is the addition of a second planetary gearset, and the addition of two clutches (which can actually operate as one)[9]. This enables the switching

(two-modes) of the percentage of mechanically vs. electrically transmitted power, and in order to cope both with low- and high-speed regimes, only smaller electrical motors with much less power and torque can be used.

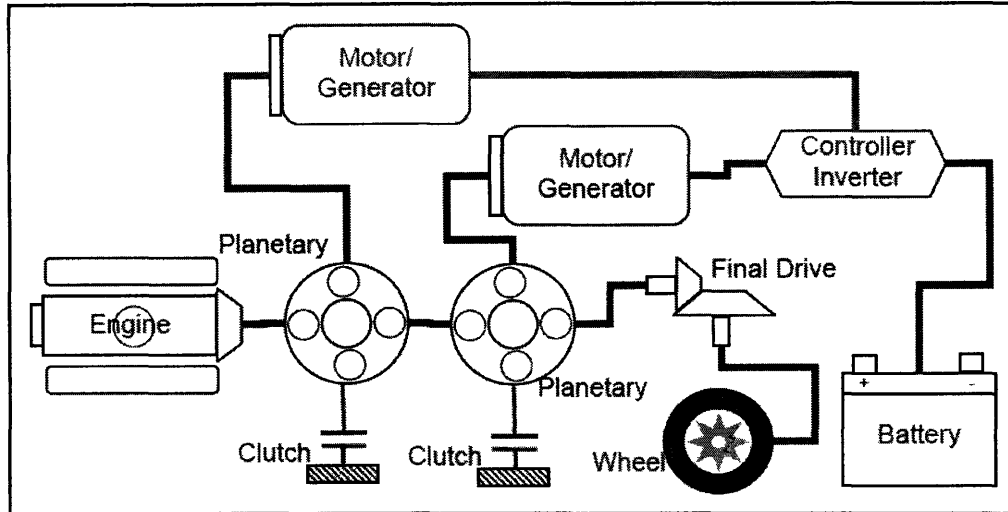


Figure 5. GM-DCX HEV System

2.4 Ford Fiesta

While Hybrids represent a moderate portion of sales in the United States, in Europe, the hybrid wave hasn't caught on yet. The European market is mainly dominated by diesels as the alternative fuel of choice and hybrids have only recently been introduced to the market. The Ford Fiesta is a concept car under development in Germany that may change this story. A supermini vehicle designed and sold primarily in Europe, the new micro hybrid Fiesta is designed primarily for stop-and-go type city driving. Ford has partnered with Valeo, a French supplier of electrical car systems, to utilize their belt-driven starter-alternator reversible system (StARS). With the added system, it has the potential to improve fuel economy and emissions by 15 percent[10].

The engine is turned off whenever the car comes to a stop and an integrated system of sensors enables the engine instantly and silently to start again when the brake pedal is released or when the accelerator or clutch pedal is operated[11]. It also houses an intelligent control system that ensures that the system does not operate during parking maneuvers. The advanced regenerative braking system allows the system to maximize the electrical energy stored during braking. The marriage of Valeo's electrical system and Ford's advanced

software makes this system cleaner than the Euro IV standard. "We worked very hard to ensure that drivers didn't have to change their driving habits when behind the wheel of this micro hybrid concept Ford Fiesta and that everything was straightforward to use and easy to understand," said Don Kees, technical leader on the project[10].

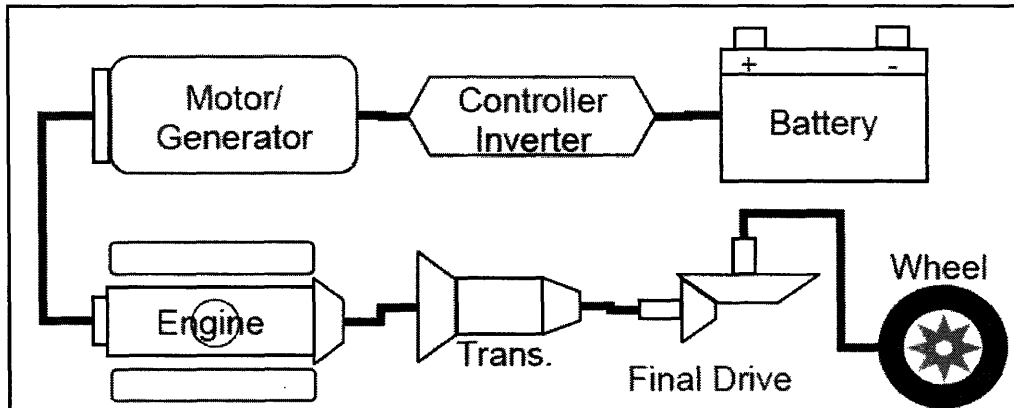


Figure 6. StARS or Belt Starter-Generator System

sTable 3. Ford Fiesta Specs

Ford Fiesta	
Engine:	1.4L / 4 cylinder/ 16 valves
Max Power:	80hp
Transmission:	5-speed manual
Weight:	3,351 lbs (1,520kg)
CO2 emissions:	147 g/km
Fuel Economy(urban/extra urb.):	34.4
0-60 mph:	12.3s
MSRP:	N/A

3. Evaluation of HEV

The hybrid vehicle tackles two issues: the finite source of energy sources and the level of emissions caused by current fuel sources. Compared with the 27.5 miles per gallon(mpg) Corporate Average Fuel Economy (CAFE) standard for passenger cars, the average mpg for the Accord, Civic, Escape, Insight and Prius hybrids is 46 mpg, and an even higher average value of 55 mpg for the leading two hybrids the Prius and Insight[12]. While reducing the amount of fuel consumption deals directly with vehicle's efficiency, there are other components in a hybrid vehicle that may cause deleterious effects in the long-term. The

battery component in the top hybrid vehicles are typically covered by an eight-year warranty and consumers will have to deal with replacement and disposal issues[13]. Because it is a young industry, this area has not come up as an issue, but as hybrids pervade the vehicular industry further and age, these issues will begin to emerge as a forefront.

The two main approaches to looking at alternative energy sources are through cost-efficiency and energy-efficiency. As a preliminary look, we will look at a comparison of cars manufactured with conventional engines and hybrid engines and look at their fuel economy (Table 4) and fuel cost savings (Table 5).

Table 4. Comparison of EPA Fuel Economy values between conventional and hybrid drivetrain

	Conv. Powertrain			HEV Powertrain			% Improvement		
	City	HWY	Comp	City	HWY	Comp	City	HWY	Comp
2007 Honda Civic CV: 1.8L, 5 Auto HEV: 1.3L, CVT	30	40	34.5	49	51	49.9	63%	28%	45%
Honda Accord CV: 3.0L, 5 Auto HEV: 3.0L, 5 Auto	20	29	24.1	28	35	31.2	40%	21%	30%
Toyota Camry CV: 2.4L, 5 Auto HEV: 2.4L, CVT	24	33	28.1	40	38	39.1	67%	15%	39%
Toyota Highlander CV: 3.3L, 5 Auto HEV: 3.3L, CVT	18	24	20.7	31	27	29.2	72%	13%	41%
Lexus Rx 4WD CV: 3.5L, 5 Auto HEV: 3.3L, CVT	20	25	22.3	31	27	29.2	55%	8%	31%
Mercury Mariner 4WD CV: 2.3L, 5 Auto HEV: 2.3L, CVT	21	24	22.4	32	29	30.7	52%	21%	37%

Data from 2007 Fuel Economy Guide, Honda.com, Toyota.com

Table 5. Comparison of Annual Fuel Cost of Conventional and Hybrid drivetrains

	Annual Fuel Cost		Savings	
	Conventional	HEV	\$ amount	%

2007 Honda Civic	\$1,204	\$795	\$409	34%
Honda Accord	\$1,729	\$1,284	\$445	26%
Toyota Camry	\$1,471	\$1,018	\$453	31%
Toyota Highlander	\$1,892	\$1,371	\$521	28%
Lexus Rx 4WD	\$1,945	\$1,475	\$470	24%
Mercury Mariner 4WD	\$1,809	\$1,284	\$525	29%

Data from 2007 Fuel Economy Guide, Honda.com, Toyota.com

However, we quickly see that this is not a cut-and-dry process because there are numerous external factors that affect the eventual efficiencies. We will be discussing findings by research done on HEV's and alternative fuel technologies that explore these methods. In order to make an educated decision on what is the best choice for our society, we need to look at it in context of the different players in the equation of HEV production, manufacture, sales, and use. From the close look at this, we can also see if any of these players are specifically holding us back from this industry really taking off. After we make this assessment, we can determine the best prescription for the energy deficiency problem we have and see if HEV is really the lasting solution or if it's merely a transition technology.

What we want to try and do is figure out what parameters matter to these different groups so people, costs, regulation, efficiency

3.1 Consumer perspective

With the media buzz, celebrity backing, and sleek designs, hybrids are beginning to have an established place in the automobile market. While hybrid sales have been following sales projections, it is still only a marginal percentage of the motor-vehicle market and has yet to break into the mainstream market. To get into the psyche of the customer, we must examine all the factors that affect their purchasing decision. The NREL(National Renewable Energy Laboratory), under the direction of the U.S. Department of Energy, put together a study in January 2006 to figure out American public views on various

transportation, energy, and environmental issues.

We first look at what vehicle attributes are valued by a customer. In the early 80's, the majority of buyers looked for fuel economy and dependability. In the mid 80's we saw the transition to a heavier reliance on dependability, high quality, and low prices. Since that point the spectrum has leveled out and most recently in 2004 and 2005, safety and dependability are higher concerns. This seems to establish the fact that while gas prices are going up in recent years, it's not enough to swing the whole spectrum of car purchasers. The trend has been slowly going towards safety, quality, and dependability. Also, while fuel economy is still a concern, the varied income levels in our society are diluting the effect of rising gas prices[13].

Table 6. Trends in Vehicle-Attribute Preference(selected years 1980-2005)

Attributes	1980	1985	1996	2000	2001	May 2004	May 2005
Fuel Economy	42	8	7	10	10	22	12
Dependability	31	41	34	32	29	26	33
Low Price	14	29	11	11	8	10	6
Quality	4	12	19	21	22	19	20
Safety	9	10	29	24	29	23	26
N/A	0	0	0	2	1	0	3

Something worth looking into is why fuel economy is not a top concern to consumers. With rising prices of fuel, there is also the environmental aspect where the level of emission is getting worse each year. It is possible that the level of awareness that is appropriate for the current energy crisis does not exist within the general public. However, we see from the study that the majority of the public have considered the energy situation a serious or fairly serious issue ever since the 70's(Fig. 7). However, the public is approximately split on the likelihood of our nation facing an energy shortage(Fig. 8). The public has also acknowledged lifestyle changes and financial hardship as a result of the recent gas price increases(Fig. 9).[13]

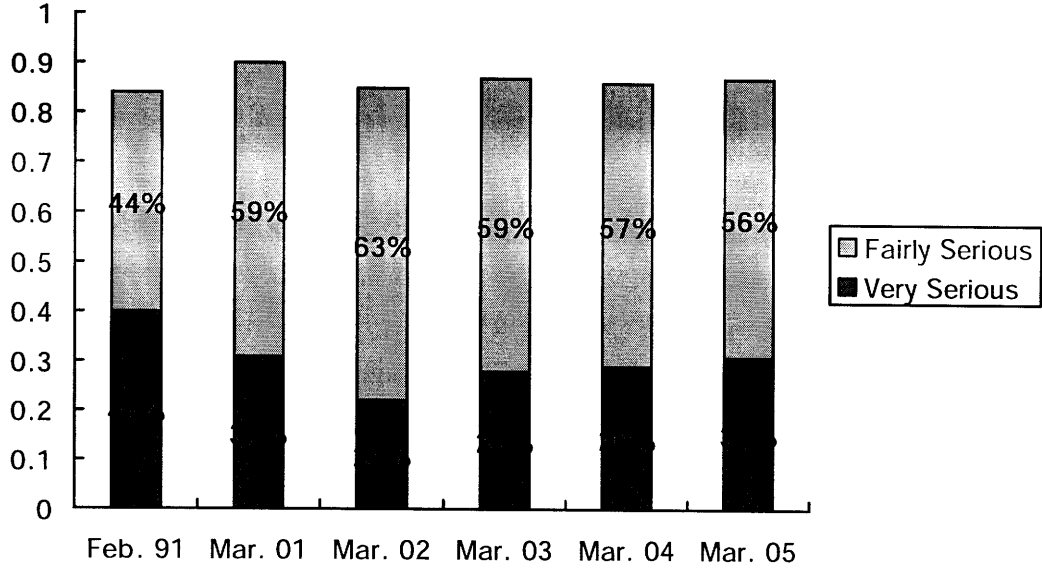


Figure 7. Seriousness of Energy Situation(selected years 1991-2005)

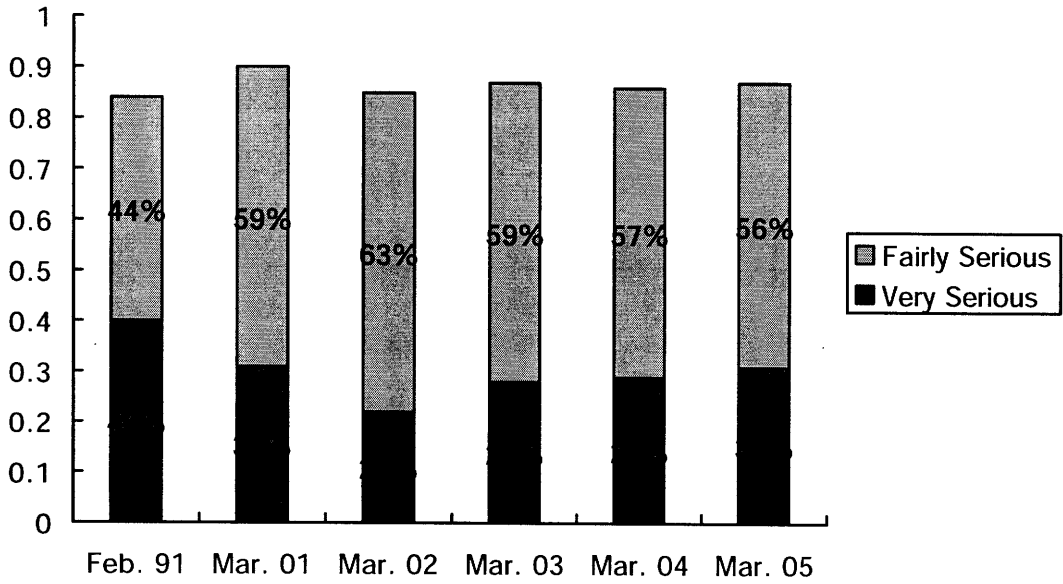


Figure 8. Likelihood to face an energy shortage(2001-2005)

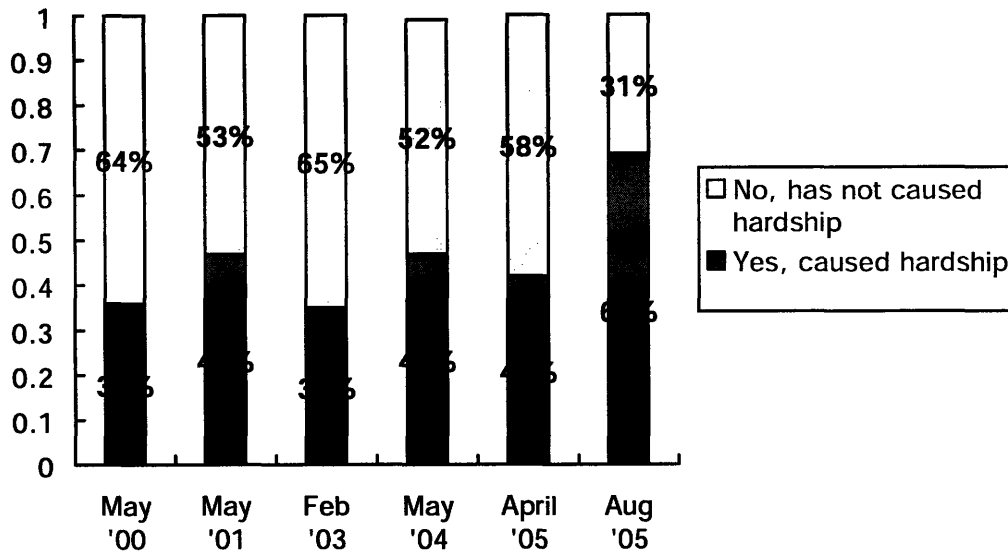


Figure 9. Gas Price Increase – Effect on Finances (2001-2005)

Now we come to the interesting questions of car purchases. Surprisingly 51% percent of users say that they will be willing to pay a premium for a hybrid at the gas price of 2.50, and 44 will at the price of 1.50 (see Appendix A). Electricity is the best alternative to fuel according to users in 2000 and 4 but not by a lot. And this may be due to constant media speculation and government focus, and something that people are familiar with. Then, a series of interesting figure may reveal the issue with hybrid vehicle purchase. While 55 percent of consumers would consider the purchase of a hybrid vehicle(Fig. 10), only 42% is likely to buy, and of these only 7 percent is a definite purchase(Fig. 11) [13]. Thus, we see a sharp drop in turnover from consideration of a hybrid to an actual purchase, because then we would be seeing a much higher figure for hybrid car sales. So, we see the thought has entered people's minds but the final incentive to purchase is really not making the cut.

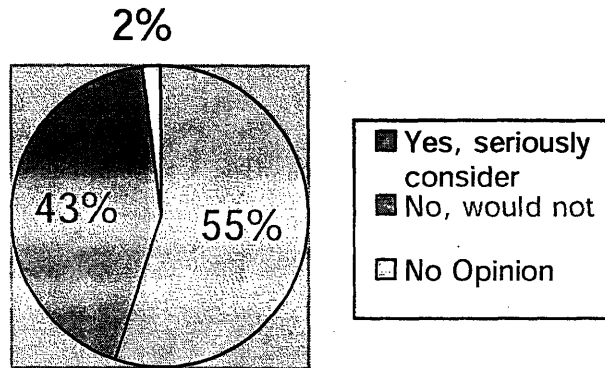


Figure 10. Level of Consideration for Gas-Electric Hybrid(August 2005)

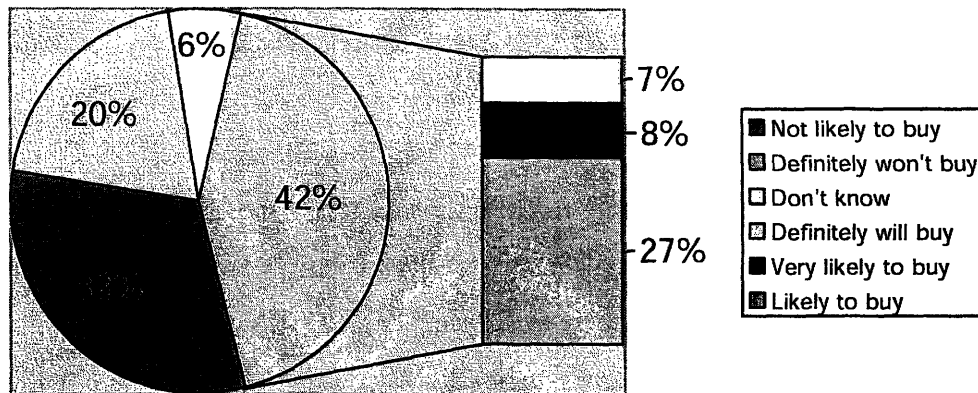


Figure 11. Vehicle-Purchase Preferences – Hybrid-electric vs. Diesel (2004)

As evidenced by the data, while there is awareness and concern about the environment and hiking fuel prices, it does not seem to be enough to necessitate a major move to embrace a new technology. "...[T]he days of \$3 for a gallon of gas are still in their minds when they shop for a car, so a hybrid is still on their list; it's just that consumers will be less willing to pay a premium to own one"[15]

There is definitely a financial penalty for owning a hybrid, both in the purchase process and lifecycle. Edmunds.com conducted a study of purchase price to decide the breakeven point of a hybrid vehicle purchase with fuel price and tax benefits(Table 7). Of vehicles that have an equivalent hybrid, the Ford Escape has the earliest break even point of 2.9 years. However, the widely popular Toyota Camry Hybrid takes 8.2 years to break even

compared to the six-cylinder Camry LE. Notably, the Lexus RX 400h takes 13.6 years to break even with the Lexus RX350. The data shows that the break even year does go down depending on the mileage of the car. [16]

The popular Prius has no conventional equivalent and was compared to the Camry LE model, taking only 2.1 years to break even. However, this study factored in a federal tax credit of \$3,150 which will be dropped to \$1,575, because Toyota has reached the 60,000-uni-per-manufacturer cap for federal tax benefits.

Table 7: Edmunds Study of Breakeven rate per hybrid vehicle

<u>Year/Make/Model</u>	<u>Years to Break Even</u>	
	15,000 mi	25,000 mi
2007 Saturn Vue vs. Greenline	5.7	3.4
2007 Ford Escape XLT vs. Hybrid	2.9	1.7
2007 Mercury Mariner vs. Hybrid	7.8	4.7
2006 Honda Civic EX vs. Hybrid	6.1	3.7
2006 Honda Accord EX v6 vs Hybrid	11.3	6.8
2006 Toyota Corolla vs. Prius	13.6	8.2
2006 Toyota Camry vs. Prius	2.1	1.2
2007 Toyota Camry XLS vs. Hybrid	5.8	3.5
2007 Toyota Camry LE vs. Hybrid	8.2	4.9
2006 Toyota Highlander Limited vs. Hybrid	15.5	9.3
2007 Lexus RX 350 vs. 400h	13.6	8.2
2007 Lexus RX 430 vs. 450h	15.1	9.1

It is evident as we enter into this new era, that with government, media, and other avenues really pushing the environmental issue channel, consumers are beginning to see their life affected by the energy crisis. However, we must remember our consumers are multifaceted. Though costs do play a large factor, there are other reasons that hybrid user are who they are. On top of the savings, some users are looking to make a statement, whether it is as a green user or a tech-savvy fan. Also, the hybrid may be particularly

convenient depending on lifestyle; for example, a city driver who drives at low speeds in traffic will probably save a lot more in fuel costs than a highway driver.

Also, consumers are not given a binary option of conventional vehicles or hybrid vehicles. The diversity of the marketplace offers many ways to save money, whether it is in a transmission design or weight-reduction that increases efficiency. There are also a myriad of alternative fuel vehicles brimming on the marketplace. Consumers will always look to maximize their utility, and it varies whether they are most sensitive to cost, availability, style, or any of the other vehicle attributes previously discussed. Thus, depending on how hybrid vehicle are presented in the market place and viewed through government policy will affect mainstream acceptance of the hybrid vehicle.

3.2 Automakers

So what does all this mean for the motor-vehicle industry? While the automakers recognize the consumer and the environment as important factors that shape the industry, ultimately they must act as a business enterprise. The resources they put towards research and developing advanced technology is so they can match their moves with the evolution of society and support their multibillion dollar industry. At this point, the United States faces two major obstacles in this transition to a new transportation technology.

The first is that there is already such a solid foundation laid out for conventional vehicles with the present technology. Accordingly, there is an incredible amount of money required to build a new infrastructure and it is difficult for the motor-vehicle industry to move without its complementary industries making parallel moves. Thus, to take such a big risk, they are heavily reliant on the government to create incentives to help their investment needs. In order to win their support, they need to show that their solution has reasonable sustainability and is a worthy investment for environmental progress. Thus, automakers are tasked with finding a long-term solution that is environmentally acceptable but at the same time will not cripple their industry. The central challenge for any alternative fuel vehicle(AFV) seeking government support beyond R&D is that the deployment of the AFVs and the infrastructure to support them must cost effectively address some energy or environmental problems facing the nation.[17]

3.2.1 A look at the Electric Vehicle

The electric vehicle came into sight in the late 90's, largely spurred by a renewed interest in electric cars to meet Zero Emission Vehicle(ZEV) standards in California. After developing the new technology and investing in the EV1, a consumer electric vehicle, GM abruptly pulled the plug on the venture and reclaimed all the vehicles out on lease and had them impounded[18]. While the limited range on the batteries that the vehicles ran on is typically cited as a reason for the halt in the industry, there are other more glaring reasons why GM halted this initiative. GM, Daimler Chrysler, along with the oil companies vehemently fought to reverse the ZEV mandate passed by the California Air Resources Board(CARB). Many suspect that the motor-vehicle industry and the oil companies realized that if the electric car caught on, they would make both competitive fuel pricing and conventional vehicle maintenance costs obsolete, essentially crippling their means of making revenue.

3.2.2 Effect of Hybrid Sales in Auto industry

While it doesn't seem to be as imminent, the gaining popularity of the hybrid vehicle could unearth these problems once again for these industries. However, now there are even more issues clouding the advancement of hybrid car technology. While the hybrid car industry is growing, the leaders in this market are overseas, with Japanese manufacturers Honda and Toyota leading the pack. If there is a noted consumer shift to hybrids, this will cost our domestic manufacturing industry as well as hurt the job market[19]. The auto industry is a significant employer in the United States. According to the Bureau of Labor Statistics, manufacturers of motor vehicles and equipment employed an estimated 923,570 workers in 2001[20]. If the majority of supplier and assembly work for these new vehicles takes place overseas, this could displace up to 200,00 U.S. jobs(Fig. 12).[19]

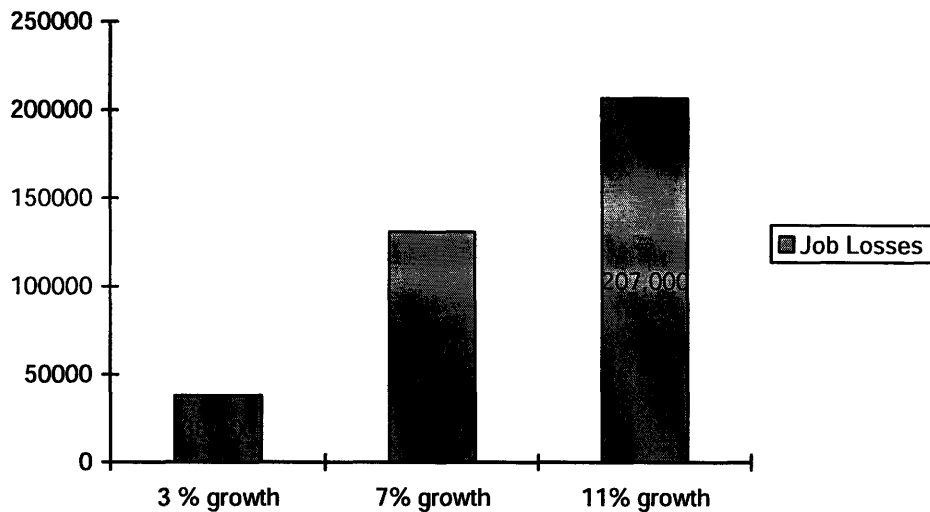


Figure 12. Impact of Job loss with hybrid/diesel Powertrain vehicle market growth

*This figure represents job loss under different market growth scenarios

The United States is already at a disadvantage because they have not been able to gain a strong foothold in foreign markets as Asian manufacturers have done. Not only will this hurt their export figures, the foreign competition is now threatening domestic market share. The industry's trade deficit has been growing significantly since the mid-1990s, exceeding \$115 billion in 2000[19]. This is a cry to the government for help. The United States is already in a number of international agreements(see Appendix B) that are crucial to the motor vehicle industry. However, the amount of potential deficit requires strong government policy to protect our domestic market, which is against the free trade policy the U.S. government has maintained for the last few decades.

3.3 Government

For the government the search for an alternative energy source is not simply an environmental concern but a necessary need for national security. Bush's 2007 state of the union was largely focused on the energy issue, and the mission the U.S. government faces is how to lessen our dependence on foreign petroleum from unstable regions of the world. With gas prices at an all-time high at the price of \$3.07 a gallon, which will be surpassed in upcoming years, we see the need for change, yet it is hard to plan out how to be free from our dependence when 97% of all energy consumed by our vehicles are petroleum based.[17]

The government has the unique task of serving multiple interests. They must serve themselves, i.e. serve the best interest of the country, but also considering the components of the nation, which include the consumers and industry. Essentially, the government has the role of balancing and maintaining people's happiness and order, while keeping in line with their own agendas. They need to craft legislation that factors in all this and direct the consumers and business to a reasonable direction.

However, many of the solutions that we are faced to make to better society requires infrastructure changes and could prove to be costly to the U.S. According to Automotive News, the growth in the popularity of gasoline-electric hybrids can be more costly to our society than many environmentalists and federal government realize. The calculations were made based on the base case of the popular Japanese-manufactured Toyota Prius. With a Prius that is driven five years and 125,000 miles our national crude oil trade debt can be reduced by \$3000. However, to counter this benefit, the importing of a Prius would increase our trade debt by \$13,000[21].

The government is already deep in debt and a lot on their agenda such as highway repair and healthcare. While it is becoming increasingly obvious that the environmental impact of our transportation and oil use needs to be brought to the plate, they may need to think a little more about the financial impact to importing the most popular hybrids. Domestic manufacture can aid this issue, either by Toyota or a domestic brand. For a smart solution, they do need to invest money in other projects if domestic companies will not beat out the Japanese brands for the top spot. Other alternatives include, as discussed other fuel sources, or fuel cell vehicles. There requires a delicate balance between ecological and economic concerns.

The economic effects that concern the automakers are just as relevant to the government as the welfare of our nation's economy is reliant on the major players in our chief industries. The government especially has to deal with effects on the job market in the context of social welfare and must guide the gradual transition for business and labor force towards alternative fuels. While hydrogen is one of the most sought after alternative fuel, it requires so much effort because of the required change in gasoline infrastructure[17].

3.4 Environmental Groups

The last spectrum we will discuss is the position of the environmental groups. The environmentalists have always been portrayed in a skewed manner, either as a hot-headed activist or tree-hugging hippies. However, we must recognize that they play a vital role in the solution for a future transportation structure. The pure environmentalist thinks of the bigger picture and puts the sustainability of our planet, and thus our civilizations survival above immediate concerns of consumers, business, or government. To them, the present players must take a couple hits for our society to make necessary improvements and move towards the better path. It is necessary for this group to exist and present a strong view, because it will inevitably be diluted in the different channels that they work through.

In order to be heard among the conflicting demands of energy companies, automakers, and environmentalists, it is usually a smart move for the environmentalist to work through organized government channels to be heard. As an agency of the federal government, it can enact a sort of power to the government, but ultimately their top concern is to protect the interests of humankind and the environment, not the government. At the same time the government needs to work with these environmental groups because it is common that the political process makes it difficult to make progress on energy issues[22]. Other groups such as the Energy Future Coalition or the National Commission on Energy Policy can work with government to get funding and establish a medium to set more reasonable goals to take the United States closer to the appropriate ideal for environmental protection and sustainability.

A specific issue that environmentalists have spoken out on is the emissions caused by automobiles. They have showed their support for plug-in technology, however groups such as the Energy Future Coalition and National Commission on Energy Policy have indicated problems with the nation's 50-year-old electrical grid, especially since the black of 2003, which affected the Northeastern United States region, [22]. Going through with plug-in technology would be with the realization that powering cars with electricity is only as good as power plants that produce electricity and there are significant issues to with plugging into current electrical grids.

4. Comparative Analysis

Looking at the individual parameters that affect HEV, we have laid out the

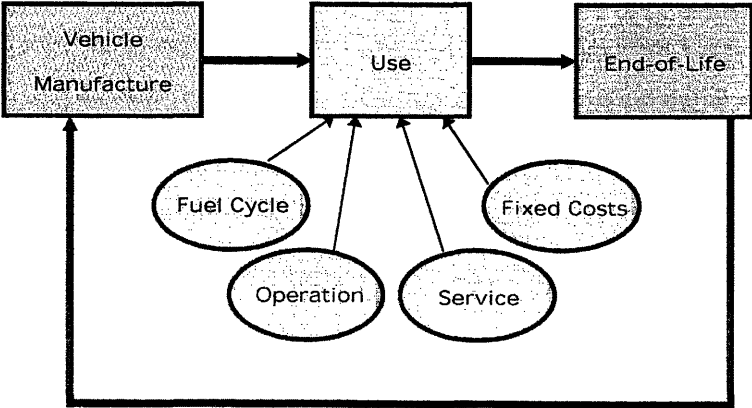
groundwork for discussing how the Hybrid-Electric Vehicle stacks up against the other available technologies. We took a preliminary look at the efficiency of the hybrid counterparts to conventional vehicles in terms of fuel amount and cost savings. There were mixed views on whether the initial premium paid was justified by these savings and other life-term benefits. It is evident that there are many assumed inputs, such as a stagnant fuel cost for a short-term outlook, that make this a very subjective analysis of prescribing the best technology for a sustainable future.

In order to do a more thorough analysis, we will approach in terms of cost-efficiency and energy-efficiency relative to other alternative fuel technologies.

4.1 Life Cycle Analysis(LCA) & Life Cycle Cost Analysis (LCCA)

Life Cycle Analysis and Life Cycle Cost Analysis examines and factors in the monetary or energy costs associated with each stage of the life-cycle model of a motor vehicle (Fig. 13). Most LCA and LCCA analyses have analogous costs for cost and energy because energy costing processes society are usually penalized with a higher cost, such as extracting raw mat, refining, processing, or clean up.

Figure 13. Life cycle model of an automobile



Life cycle cost analysis typically includes fuel cost, capital cost, and component wear cost[23]. The capital cost in alternative technologies mainly refers to the cost of the power unit, whether it is an ICE or a fuel cell. In a study of comparative alternative powertrain

systems, the hybrid system's performance was evaluated factoring in:

- how the vehicle is being implemented, i.e. the environment it is being driven, in
- how do fluctuations of future fossil fuel costs affect the different alternative technologies.

Hybrid-Electric Vehicles emerged as a promising candidate to conventional vehicle, as it utilizes multiple "power units" to deliver efficiency. While both efficient, fuel cells and batteries have their drawbacks: fuel cells are expensive and batteries have a low energy density. ICEs have thus far served as the cheapest alternative, but a hybrid system could potentially avoid some of these obstacles. [23]

The two parameters that were varied were vehicle type and time setting. Three vehicle identities that were considered: the car with combined city and highway driving; the city bus with frequent stops in an urban area; and the intercity bus on the highway running at constant speeds for long periods of time. The time scenarios were present time (year 2005), future-extrapolated (year 2020), and future-oil crisis (year 2020). For each scenario, with a combination of these conditions, an optimal powertrain configuration was found.

The analysis demonstrated that in current times, a hybrid powertrain could be effective but only for certain applications, such as the stop and go action of the city bus. The model proved difficult for a cost effective hybrid car to be developed with today's technology. The analysis found that even the most cost effective hybrid car has comparable life cycle costs to a conventional vehicle because the savings in fuel consumption is not enough to compensate the initial cost of the power unit in the 2005 scenario. However, the high gas prices and competitive price-cutting for electrical part prices in future scenarios proved HEVs to be more cost effective. Electric cars powered by LiIon batteries demonstrate the least energy consumption at a low price in 2020. This is due to a low fuel cost(i.e. electricity) but this is heavily reliant on the assumption that their energy density increases six-fold. Moreover, LiIon batteries would never have the capacity to power a bus, which requires a high power source with a long lifetime.

Thus, the most cost effective vehicle in this analysis is one that finds a balance between the purchase price, i.e. initial power unit cost and operating cost, i.e. fuel cost. While according to the model, fuel cells may be the most cost-effective because of its independence from fossil fuel prices, it is still a questionable technology for the next ten year

horizon. Though more susceptible to fuel prices, the multitude of different hybrid powertrains provide a feasible option especially in the case of high efficiency in an urban environment and cheap electrical power.

Taking a societal LCC approaches looks at externality costs such as pollution emission damage costs and oil supply insecurity. The best fuel option with externality costs is a hybrid vehicle with Compressed Natural Gas. However, this required infrastructure change, puts it at as much of a disadvantage as a fuel cell vehicle, especially because with externality costs, its attractiveness goes down. While externality valuations are uncertain, because they are hard to quantify like health costs. For low externality, the base case of an ICE is best. For high externality costs, the Hydrogen FCV is best because the air pollution and emission costs are ballooned. However, at medium externality costs, the FCV is merely on par with Ices and Hybrids with alternative fuels. Now, the one thing that hasn't been taken into account is costs for infrastructure change. As we can expect externalities to keep increasing, while a move to H₂ may be in the future, an infrastructure change of this magnitude will take a lot of time and money, so what to do in the interim. Also there are alternatives such as biofuels or natural gases. So, the issue is what to do in the interim and the proper policy that combines a short-term and long-term strategy. It seems from the analysis that for hybrids have already entered the short-term market and we need to keep pushing the trend to challenge its advancement and maintain it as a sustainable venture.

5. Future Projections

So, what does the future hold for hybrid vehicles and its place in the future transportation sector? In January 2006, J.D. Power and Associates reported that US hybrid-electric sales volumes were expected to grow by 268 percent between 2005 and 2012. While this is a large percent increase, we realize it is still only about 1.3 percent of the U.S. light-vehicle sales and 4.2 by 2012[23-24]. However, there are mixed views whether hybrids are here to stay. A technology is largely pursued or not depending on its competition. We saw in many of the analyses that hydrogen fuel cell vehicles seem to be the alternative fuel vehicle of choice but delayed for infrastructure and requisite technology barriers. It is said that hydrogen vehicles which is an effort that many people seem to be heavily invested in is unlikely to pull through as it promised. In particular, it is unlikely that

hydrogen vehicles will achieve a significant market penetration by 2030[17].

So in the meantime, this leaves for the other developing technologies to try and get in the passing lane to take the lead spot as the next future vehicle. The matter is of urgency, as the transportation sector is responsible for generating nearly half of the 40% rise in US CO2 emissions projected for 2025. The need for an alternative energy is not merely a call from the environmental community but for national security. Currently, with gasoline accounting for 97 percent of energy used in transport, U.S. is heavily dependent on the world's oil. American consumption alone is expected to grow nearly 50 percent over the next 20 years.[17]

The difficulty in the search for America's next top fuel source is that there is no clear winner here. There are significant barriers including costs, on-board fuel storage, infrastructure and competition. Many manufacturers are taking varied approaches to overcoming these barriers and beating out the competition. Current products on the market include the Toyota Prius, a gas-electric hybrid, while Volkswagen is featuring its new Golf Biofuel, which runs on gasoline or natural gas. GM is displaying its concept Sequel car with hydrogen technology, and Honda's FCX, a hydrogen fuel-cell vehicle.

"Diesel is popular in Europe, clearly, but it's a short-term trend," said Laurent Aebi, a product specialist at Honda Motor Co., which was displaying its new FCX fuel cell car, powered by an electric motor that uses hydrogen as its energy source. "I give it another 10 years maximum. After that it will be the hybrid car. But both the diesel car and hybrid car are a transition as we head to fuel cell cars or pure electric cars." [26]

Alternative fuel vehicles are at an inherent market disadvantage because of the heavy infrastructure that is already in place for fuel use. It is essentially a chicken and egg problem: alternative fuel vehicles will not be bought without a fueling infrastructure, but infrastructure will not be pursued without significant vehicle sales. Thus, they require government support and policy pushing, but at the same time, it is difficult for government to provide these incentives when there is no cost-effective solution to the energy/environment issues[17]. However, there are still strong believers in the hybrid vehicle as the car of the future, such as current leaders in hybrid vehicles, Toyota. Yoshio Ishizaka, an executive

vice president at Toyota Motor Corp., the world's second-biggest carmaker, went further. "Hybrid is really not an intermediate technology," he said, predicting it would even power sports cars some day. "We think hybrid is the technology we have to see for the future." [26]

One of the plus sides of HEVs that are constantly improving such as the Toyota Prius and Ford Escape hybrid who now meet PZEV requirements is that these products work with the current fueling infrastructure. However, for the hybrid to reach mainstream appeal, it needs to cater to the wide spectrum of users in the automotive market. Because consumers don't tend to change their lifestyle habits, products need to be available in sectors that meet their needs. Some say the approach should be to launch greater numbers into volume-selling segments where buyers are concerned with fuel efficiency [27]. While hybrids currently scheduled for production include large luxury cars and SUVs, these are considered niche markets with declining sales and users who are less concerned with fuel efficiency. Models that need to be provided are full-size pickups or buses. Prestige, volume and budget-brand carmakers alike should target the higher-selling lower-medium and upper-medium segments in particular, where competitively priced hybrid power would attract significant numbers of both fleet and retail buyers. "Those purchasing cars in these segments are amongst the most sensitive to vehicle fuel economy and purchase price. The selling price of an upper-medium car may be less than with a large SUV or luxury saloon, but the carmaker would almost certainly have the opportunity to sell them in far greater numbers." [28]

Thus, a necessary policy by the government must come threefold to address these barriers. We will discuss this in terms of marketing strategy, whether it is push or trust. In one sense, the government needs to push the need for change upon our society, and the most effective way of doing this is to establish tighter environmental policies, specifically for clean fuels and emissions. On the other side of this argument, we need a trust strategy that will encourage consumers and manufacturers to partake in the market of alternative fuel, specifically hybrid vehicles. We see that this type of marketing strategy has been working for tax benefits for hybrid owners, as well as attaching a positive association with hybrid vehicles. As important as consumers are manufacturers are the ones who need to provide products that consumers are looking for. To achieve the market supply necessary to promote this product, the government should supply a similar type of tax credit for capital

investment to re-equip or expand manufacturing facilities associated with hybrid production[1].

As we have prefaced, there is no clear solution at this point. For the near ere time frame, hybrid technology seems to be an answer that has already arrived, we must be working on a long-term solution. This may not necessarily be hydrogen fuel-cell technology, which is why research needs to be done concurrently on a parallel path that continues hybrid technology as well as fuel-cell development.

5.1 Plug-in Hybrids

A promising development in the hybrid arena is the concept of a plug-in hybrid. Essentially, it provides all the benefits of a hybrid, but increases its electric range by allowing it to plug into the electric grid and further reducing fuel consumption. This will especially be efficient in a city-driving setting where operating at short distances at lower speeds will allow the vehicle to run in electric mode a majority of the time, and qualify it as a ZEV (zero-emission vehicle) in cities. This also reduces the amount of emission from running in ICE mode. The greenhouse gas benefits can also be tracked down to the recharging part of the cycle. It is inefficient to generate hydrogen and store it on-board and then run it through a fuel cell, resulting in about 20% well-to-wheels efficiency. However, in the case of charging an on-board battery there is 80% efficiency[17].

The plug-in hybrid also tackles one of the most challenging aspects of the electric vehicle which is its limited range due to its battery pack. While it runs in gasoline mode, there is also a amount of regenerative braking that can be utilized to recharge. As battery technology continues to develop, the system will be even more efficient with reduced weight and cost. A very specific benefit that the plug-in hybrid could bring is as a generator that could provide grid voltage increase when necessary. This type of service may be compensated by utilities, so for a fleet or corporate sponsor of these vehicles, this system could be a revenue generator[29].

It is not to say the plug-in hybrid does not come without its problems. Though the electricity markets aren't experiencing as much of a price increase as fuel, electricity prices are still expected to grow by 3.1 percent during 2008[29]. Also, there have been recent regional power outages, which demonstrate the complexity of the production and delivery of

electricity. Having a fleet of vehicles plugging into this system needs planned expansion.

6. Conclusion

Ultimately, the race for the best alternative fuel vehicle depends on the relative societal LCC's and valuation that society assigns to externalities, via regulations or other policy actions.[30] We have discussed the different types of hybrids and advanced mechanical couplings that allow the energy flow transition between an ICE and electrical component to be more efficient. As we wait for the breakthrough in battery technology, each automobile manufacturer is challenged to develop inventive configurations that maximize efficiency.

Looking at cost comparisons, it follows that cost is not enough to get people to buy premium. Current hybrid users are either a 'green' user, i.e. environmentalists who value the environment, or lead users, such as celebrities who are looking to start the trend to mainstream hybrid use. In the onset of any trend, the initial users take the hit of high costs. In order to accelerate market penetration[1], the government needs to play a more aggressive role to "buy down" the initial cost to make this an option considered beside traditional vehicles. While the hydrogen fuel-cell vehicle seems to be the government's unofficial poster-baby for the car of the future, it is a long time until it can be implemented. When solving problems, we are most often told to see the big picture and look towards a more long-term solution. In this case, we have looked so far in the future for a sustainable vehicle that we have not set a clear action for the near short-term. The current market is littered with products and consumers are unclear of the choice to make. While it is worthwhile to be focusing on research such as battery technology and infrastructure issues for the future, the government must draft an effective policy to prepare for the eventual shift.

Another thing to note is that hybrid powertrains are more sustainable than many perceive and not merely a transition technology. Mechanical solutions have always been the basis for a stable product. We may find with testing in the future that failure rates are typically higher for a more complex technology such as a hydrogen fuel cell. Consumer preferences show that familiarity and durability are preferred and they may resist a new technology if it doesn't provide a cure-all solution as heavily promised. We need to be ready with an alternative that will be reliable but still combats the emissions fuel issue,

meaning we cannot stay with our current ICE technology. Now, especially with the prospect of plug-in hybrids, fuel consumption can be significantly reduced. The changing face of our society could open the path for multiple technologies to pan out, depending on the application. For urban environments, an electric vehicle may be more cost effective than fuel cell technology.

While the government has been tasked to provide a policy, the requirement is not that they choose one technology. It is acceptable to have a multi-pronged approach; while they are already pursuing multiple areas of research, such as biofuels, fuel cells, and hybrids it is important to prescribe a specific solution for now. It is not unlikely that the future car will go towards a path of convergence as many new technologies have done. The car of the future can be a hybrid vehicle fueled with biofuels hybridized with a fuel cell electric component. The life cycle analysis showed that different systems were applicable to different driving profiles and environments. With the ever changing face of the planet, it is our duty to develop as much as possible and be prepared for an alternative.

A promising new endeavor is the plug-in hybrid that will utilize the electric grid system. This is highly appropriate for an urban environments, is either for commercial or fleet use, but again a strategy for integration needs to be incited by the government. There is a lot of hesitation to make the first move. If the government makes moves to lay down the groundwork for infrastructure, auto companies and players in the technology sector will have more incentive to move forward. It is the social responsibility of all players: the automotive industry, consumers, and environmentalist to push for their rights to create a solution that meets the right balance of needs.

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Appendix A: Willingness to pay for New Vehicle
 from [1]

Table A-1. Gas prices near 2.50 per gallon and Amount willing to pay for new Vehicle(May 2005)

Types of Vehicle	Percent (%)
Pay an additional \$2,500 to buy a hybrid version of your vehicle that reduced your gasoline use by 30%	37
Pay an additional \$4,000 to buy a plug-in hybrid version of your vehicle that could reduce your gasoline use by 45% if you traveled about 20 miles per day on its battery only	14
Neither	44
Don't Know	4
Total	99

Table A-2. Gas prices near \$1.50 per gallon and Amount willing to pay for new Vehicle(May 2005)

Types of Vehicle	Percent (%)
Pay an additional \$2,500 to buy a hybrid version of your vehicle that reduced your gasoline use by 30%	34
Pay an additional \$4,000 to buy a plug-in hybrid version of your vehicle that could reduce your gasoline use by 45% if you traveled about 20 miles per day on its battery only	10
Neither	51
Don't Know	5
Total	100

Appendix B: International Agreements from [20]

United States-Japan Automotive Framework Agreement

In August 1995 the United States-Japan Automotive Framework Agreement came into being. The five-year agreement, which culminated two years of intensive negotiations, was crafted to increase U.S. and other foreign access to the Japanese motor vehicle and parts market. According to the U.S. Department of Commerce, the three main goals of the Agreement were improved access to Japan's motor vehicle distribution system; increased purchases of U.S. parts by Japanese automakers; and deregulation of Japan's \$60 billion replacement parts market.

North American Free Trade Agreement (NAFTA)

Within the U.S. market, analysts expected increased exports for the revitalized domestic producers, in part because of the passage of the North American Free Trade Agreement (NAFTA), which in its first few months pushed a dramatic surge in U.S. car sales to Mexico. In keeping with the Clinton administration's policy to open foreign markets for the U.S. automotive industry, NAFTA was signed in 1993 and implemented on January 1, 1994. Increased market access for U.S. automotive products in Mexico was imperative, especially since trade in motor vehicles was essentially one way—from Mexico into the United States. In the years since the implementation of NAFTA, the U.S. automotive industry experienced significant benefits.

Korea's Memorandum of Understanding

In 1993 the U.S. automotive industry requested assistance from the Clinton administration to open the Korean auto market to U.S. automobiles. In September 1995 the Korean government signed a Memorandum of Understanding (MOU) with the United States, under which it explicitly committed to increase access for U.S. and other foreign passenger vehicles. On October 20, 1998, negotiators from the Department of Commerce and the White House Office of U.S. Trade reached an agreement with South Korea that substantially improved on the previous agreement. In addition to passenger cars, coverage was extended to

minivans and sport-utility vehicles. Burdensome South Korean standards and procedures were reduced along with the tax on motor vehicles. It also introduced a system of secured financing to facilitate the purchase of U.S. vehicles and committed the South Korean government to a publicity campaign to improve perceptions of foreign automobiles.

Agreement on Global Technical Regulations

In March 1998 negotiators agreed on a global means for governments to develop and harmonize regulations on motor vehicles' design and performance. While offering an opportunity for the cooperative development of safety and environmental regulations (through globally uniform governmental technical regulations), it provided a predictable framework for a global automotive industry. Established under the auspices of the United Nations Economic Commission, the negotiators had consisted of representatives from the United States, Japan, and the European Community