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# A PRIMER ON LOW EMISSION VEHICLES

An Interactive Qualifying Project Report
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By

William M. Marjerison William M. Marjerison Jr.
Shinya Segawa S. Segawa

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Approved:
Professor Lok C. Lew Yan Voon, Advisor

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# Chapter 1: Introduction

Environmental problems have become increasingly serious around the world. Major problems include air and water pollution, global warming, and exploitation of natural resources. One of the suspected causes of environmental problems is the use of cars, which is familiar and essential to the lives of many people in developed countries. Cars can certainly contribute to air pollution and be responsible for significant energy consumption. The US Department of Energy has announced that "vehicle emissions are the leading source of U.S. air pollution, which jeopardizes our health"[1]. Since many people, and for that matter, society itself, relies on cars everyday, there is a very high likelihood that people can contribute to solving environmental problems through the choices they make concerning cars. This project will address some of the problems associated with conventional cars and give information about alternatives to conventional cars, which are environmentally friendly. We hope that readers will become aware of the interrelation between their choices concerning cars and the environment.

In the project, we will discuss low emission vehicles (LEVs) and zero emission vehicles (ZEVs) as alternatives to conventional cars. The goal of the project is to educate a layperson to understand the importance of an LEV or ZEV in an optimal and rational way. Since the intended audience is a layperson, we will not delve into the technical aspects, and will instead provide adequate explanations on important technical terms whenever necessary. In order to achieve the stated goal, we will cover four broad topics, namely health issues, environmental problems, the economy of LEVs and ZEVs, and policies and tax incentives that promote LEVs and ZEVs.

As an example of the current situation regarding LEVs and ZEVs, 10% of the 50 million cars sold in 2002 were LEVs and ZEVs in Japan, which is a leading country in adopting hybrid cars and other LEVs. The breakdown of those vehicles is as follows: 92% gasoline cars considered to be LEV; 5% Liquefied Petroleum Gas (LPG) cars; 2% hybrid cars; 0.3% Compressed Natural Gas (CNG) cars. Only 500 electric cars and 90 methanol cars had been registered[2]. Fuel cell cars were not available yet.

An integral part of this project is the discussion of currently available LEVs and ZEVs to allow an intelligent assessment of the various options available. We will explain the basic

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[1] http://www.ccities.doe.gov/vbg/

[2] http://www.mlit.go.jp/touhoku/kk/kk02.pdf

technological differences between each category. We will also compare each type of cars. Specific areas of interest include: emissions, efficiency, price of the vehicle, price of fuel, the distance that such a vehicle travels per refill, the availability of the car, availability of refueling facilities, time to refill, and tax benefits.

We hope that knowledge about conventional vehicles, their benefits and drawbacks, and further information about LEVs and ZEVs will help the reader to understand that LEVs and ZEVs are viable alternatives to conventional vehicles, perhaps with additional benefits. Here is where technology and society fit together. The project provides technical data that can make a difference for society. It is the reason why this project is a suitable IQP.

Research will be done primarily through the Internet. Some of the most important websites will be policy-related, such as those by the California Air Resources Board, the Department of Energy, and the Environmental Protection Agency. To report on current and developing technological trends, we will consult the websites of Ballard Power Systems, Toyota, Honda, Daimler-Chrysler, General Motors, and Ford Motors, among other companies. Scientific background, including the electrochemistry of fuel cells and batteries, will come primarily from journals and recent books published in the field. For further reference, we will include interviews with a hybrid car user and a representative of a Japanese municipality that is promoting a citywide adoption of LEVs and ZEVs in the appendix. We will not use a survey only because of the time restriction and lack of means.

The report consists of seven chapters. Chapter 2 summarizes health issues, environmental problems, and economical considerations regarding the world's oil supply, which are related to and caused by the use of conventional cars. Chapter 3 introduces the major classes of LEVs and ZEVs. We will compare the characteristics of each vehicle class. Chapter 4 introduces key industry players and highlights their achievements so far. Chapter 5 explains legislations intended to promote LEVs and ZEVs such as regulations, tax incentives, and public funding. Chapter 6 analyzes the data gathered and estimates what is going to happen. Since we did not intend to include the analysis when we started the project, it is only done as much as time permitted. Lastly, Chapter 7 outlines the key points of this paper.

# Chapter 2: Problems with Conventional Cars

There are many problems with the use of conventional gasoline vehicles. The major ones are human health issues caused by toxic car emissions, environmental destruction caused by air pollution and global warming, and risk of high dependence on foreign and domestic oil. This chapter will summarize important problems associated with conventional vehicles.

## *2.1 Risks to human health*

The four major elements in the car emission cause human health problems are hydrocarbons (HC), nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM). HC and NOx are responsible for photochemical smog. Photochemical smog occurs when HC and NOx react with other elements in the atmosphere. The process of forming photochemical smog starts when the sunlight hits NOx:

$$NO_2 \rightarrow NO + O$$

Then an oxygen atom reacts with an oxygen molecule in the atmosphere and a HC from car emissions:

$$O + O_2 \rightarrow O_3$$
$$O + HC \rightarrow (HC)O$$

$(HC)O$ is a very reactive compound. It easily reacts with oxygen to form bicarbonate ($HCO_3$). $HCO_3$ reacts further with oxygen to form more ozone ($O_3$) and reacts with nitrogen dioxide ($NO_2$) to form peroxyacyl nitrates (PAN). NOx, $O_3$, and PAN are the major constituents of photochemical smog. They can cause headaches and are strong irritants to the pulmonary alveoli and eyes, which can cause various respiratory and optical problems. Furthermore, HC itself is known to be carcinogenic.

CO is known to disturb the human respiratory system. It has 250 times greater affinity to hemoglobin than does oxygen; normally, hemoglobin attaches to and circulates oxygen throughout the body. So, inhaling too much CO causes various health problems by preventing proper circulation of oxygen.

PM is mainly emitted by diesel cars. It is the fine particles of carbon clusters with diameters of near 0.3 microns that are produced during the combustion. They can penetrate deep into the lungs and reach the alveoli, and causes various respiratory diseases including lung cancer. Fine particle pollution is responsible for about 60,000 deaths a year, roughly 3% of all US mortality[3].

## *2.2 Impact on the environment*

### 2.2.1 Acid rain

Acid rain is formed when sulfur oxides (SOx) and NOx react with atmospheric water vapor. Some portion of SOx and NOx are emitted from cars, and therefore, cars contribute to acid rain. Acid rain damages plants and animals. Acid rain melts certain toxic metals into soils, which damages trees that absorb them. Also, acid rain can directly hit leaves of plants and disrupt photosynthesis. High acidity in lakes kills plankton, and fish die because of the lack of nutrients for which they rely on plankton. Acid rain erodes buildings, basements, and statues, reducing their lifespan. The damage caused by acid rain works its way through the food chain, affecting much of nature.

### 2.2.2 Global warming

Global warming is the phenomenon whereby greenhouse gases increase the average temperature of the earth. It has been said that the emission of greenhouse gases from human economic activities is the cause of global warming. The major greenhouse gas is carbon dioxide ($CO_2$). It contributes 60% of total global warming[4]. As Figure 2.1 shows, the United States is the country with the largest $CO_2$ emissions, and transportation accounts for 23% of the US $CO_2$ emission (Figure 2.2). The transportation in the US is responsible for 5% of world's $CO_2$ emission. Therefore, it is a significant contributor to global warming.

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[3] P158 of *Natural Gas Vehicles*

[4] http://www.env.go.jp/earth/cop3/kanren/kaisetu/9.html

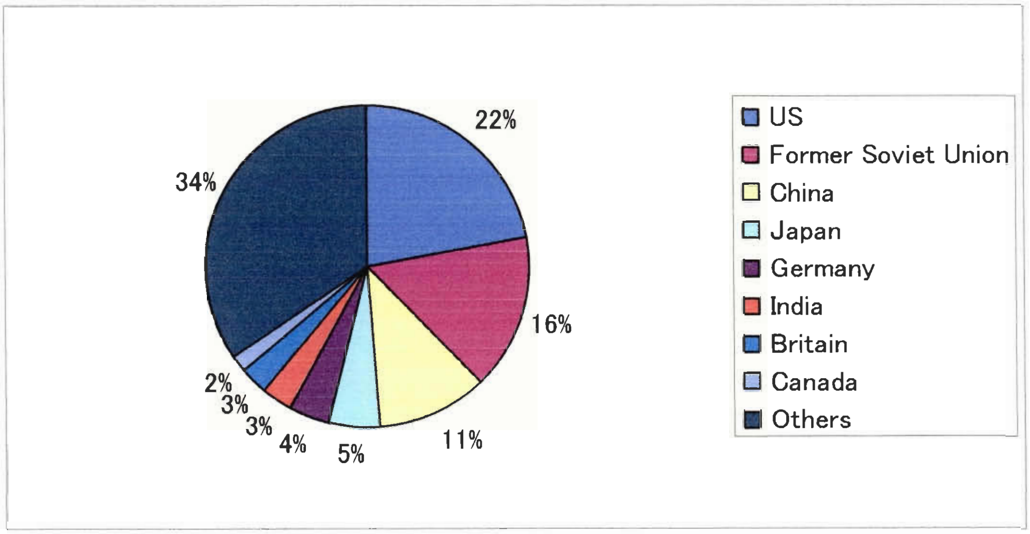

**Figure 2.1 $CO_2$ emissions by country (1990)[5]**

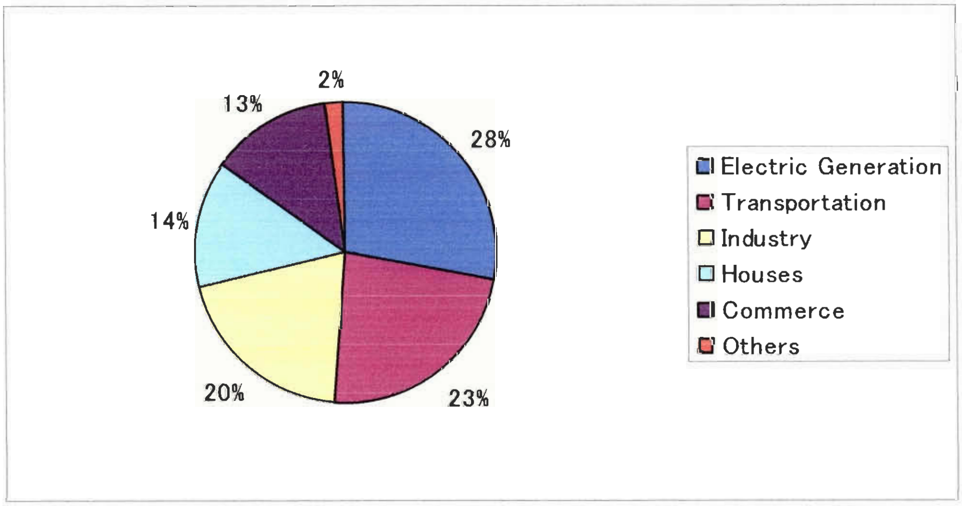

**Figure 2.2 Sources of $CO_2$ emission in the US[6]**

Global warming implies many climatic changes. As global temperatures go up, ice in the North and South polar caps will melt, and water levels will rise because of it and because of thermal expansion. Land below the sea level will have to be abandoned. There will be more floods and droughts, agricultural adversity, destruction of ecosystems, and further outbreak tropical diseases in temperate zones. Since global warming proceeds very slowly, it is hard to distinguish between what is caused by global warming and what is caused by short-term changes. This is why some countries are reluctant to reduce greenhouse-gas emissions solely on concerns about global warming. We should nevertheless seriously

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[5] http://www.env.go.jp/earth/cop3/kanren/kaisetu/10.html

[6] http://homepage3.nifty.com/shin_homepage/Environmental_Study/es_globalwarming6.htm

consider reducing greenhouse-gas emissions, because if the predicted changes occur, it would be extremely challenging to reverse those trends.

## *2.3 Problems with high dependence on oil*

The US consumed 19.7 million barrels of oil per day in 2000[7]. Roughly 54% of the consumption (10.6 million barrels per day) was used to fuel vehicles[8]. The US imported more than half of the oil consumed (10.4 million barrels per day), and 12.6% of the consumption (2.5 million barrels per day) was imported from the Persian Gulf[9]. So, within the US, the use of gasoline cars depends significantly on foreign countries, especially the Middle-Eastern nations. Table 2.3 shows the top ten countries with the largest oil reserves. Five of the countries listed are in the Middle East. Some oil-exporting countries are politically unstable, necessitating military presence. It is estimated that between $10 billion and $40 billion per year has to be spent in order to maintain military presence in that region[10]. But even if a US military presence stabilizes oil-exporting countries, overseas deployment of troops is still not economically favorable because more than half of the world's oil reserves are present in Middle East (Figure 2.4). Changes in only one region of the world could affect the US economy drastically.

**Table 2.3 Oil reserves by country[11]**

| | Country | Reserves (billion bbl.) | % of World Reserves |
|---|---|---|---|
| 1 | Saudi Arabia | 208 | 22.9 |
| 2 | Russia | 127 | 14.0 |
| 3 | Iraq | 75 | 8.2 |
| 4 | Iran | 75 | 8.2 |
| 5 | UAE | 55 | 6.0 |
| 6 | Kuwait | 52 | 5.7 |
| 7 | USA | 30 | 3.3 |
| 8 | Kazakhstan | 29 | 3.2 |

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[7] http://www.ott.doe.gov/facts/archives/fotw191.shtml

[8] http://www.eia.doe.gov/cneaf/alternate/page/datatables/table10.html

[9] http://www.ott.doe.gov/facts/archives/fotw191.shtml

[10] P18 of *Natural Gas Vehicles*

[11] http://www.infoseek.livedoor.net/~informant/toukei/worldoilgas.htm

| | Country | Reserves (billion bbl.) | % of World Reserves |
|---|---|---|---|
| 9 | Venezuela | 25 | 2.8 |
| 10 | Libya | 23 | 2.6 |

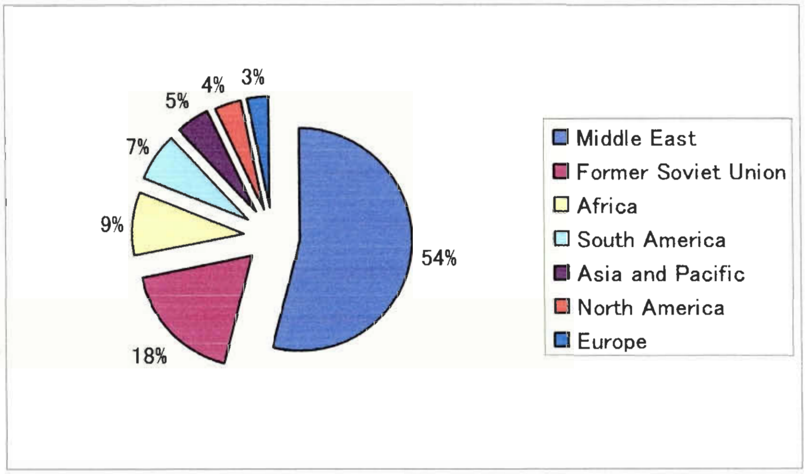

**Figure 2.4 Oil reserves by region**[12]

Another problem of using oil is that it is a depletable energy source (non-renewable energy source). According to one projection, the world's oil will run out in 33.3 years[13]. The estimate is based on the assumption that no new oil wells are found and the oil consumption remains at current levels. For these years, increase in oil production due to new oil wells found equals increase in consumption. It makes the estimate of reserves be constantly about 30 years in last several years. No one really knows for how many years oil will actually last. Yet, oil is non-renewable, and it will be depleted some day. We do have to look for the alternative in the near future.

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[12] http://www.infoseek.livedoor.net/~informant/toukei/worldoilgas.htm

[13] http://www.infoseek.livedoor.net/~informant/toukei/worldoilgas.htm

# Chapter 3: Major Categories of Cars

In this chapter, we will introduce the major types of LEVs and ZEVs. They are hybrid, natural gas, liquefied petroleum gas (LPG), fuel cell, electric, and methanol and other cars. We will explain basic technical and economical aspects of those cars. Then we will compare each type of cars to see the merits and weaknesses in each.

## *3.1 Hybrid cars*

Hybrid cars have a combination of internal combustion engines and electric motors. Currently, petrol and diesel engines are used for internal combustion engines. Electric motors operate while hybrid cars are in the driving range in which the internal combustion engines are relatively inefficient. The hybrid system improves the fuel efficiency of the vehicles.

### 3.1.1 Technology

Hybrid cars use both electric motors and internal combustion engines to generate power. Figure 3.1 shows the engine of a Toyota New Prius with two power generators. Unlike electric cars, which generate power fully from electric motors, hybrid cars use electric motors only to assist internal combustion engines. Electric motors are charged automatically as internal combustion engines operate. This is the fundamental difference between hybrid and electric cars. Currently, there is a combination of gasoline engines and electric motors, and also a combination of diesel engines and electric motors.

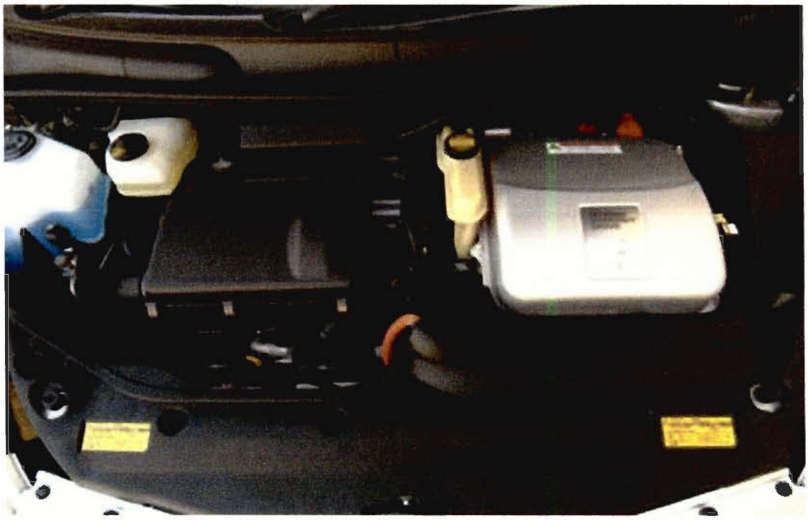

**Figure 3.1 Engine of Toyota New Prius**[14]

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[14] http://www.autobytel-japan.com/~~ncar/impression~~/203/index.cfm

The question we can ask is: why do we need electric motors to assist internal combustion engines? The answer is electric motors can operate more efficiently than internal combustion engines in certain speed ranges. At low speeds, internal combustion engines are inefficient. In hybrid cars, electric motors operate at low speed ranges whereas internal combustion engines operate at high speeds and charge on-board batteries. Also, in ordinary gasoline cars, braking energy is dissipated entirely as heat. About 30% of the energy generated is lost while braking[15]. On the contrary, hybrid cars store braking energy as electricity in the batteries. For these two reasons, electric motors are needed to assist internal combustion engines. Thus, hybrid cars are more efficient than ordinal gasoline cars.

According to Toyota, hybrid cars can be categorized mainly into three types according to how the electric motors are used[16]. One type is what Toyota calls a mild hybrid, which is installed in Crowns. In those systems, electric motors are only used when the car is at a stop. Cars shut off the engines completely, and only their electric motors operate in order to eliminate idling emissions in neighborhood and urban areas. Braking energy is stored as electricity. The benefit of this type is the low cost of introduction, which is possible because only small electric motors are necessary. Mild hybrid cars and gasoline cars cost nearly the same price.

The second type uses electric motors in wider speed ranges. In this second type, electric motors charge electricity when they operate at high speeds. They also store braking energy as electricity. Electric motors assist engines when driving slowly and help with acceleration. Toyota Prius, Honda Insight, Civic Hybrid, Toyota Estima, and Toyota Alphard fall in this category.

The third type uses electric motors all the time. The electric motors generate electricity from internal combustion engines and power the cars together. The internal combustion engines are only used to generate electricity. Since the internal combustion engine can operate at a constant rate, the burning process is more efficient, and thus, the emission is cleaner. While the other two types are aimed to improve gas mileage, this type is aimed reducing the emissions of three toxic gases (NOx, HC, and CO). This type of hybrid system is installed in buses, which usually operate at slow speeds than passenger cars. Internal combustion is relatively inefficient at those speeds. Toyota Coaster is such a vehicle.

The difference in batteries between gasoline and hybrid cars is the number installed and the type of batteries used. For gasoline cars, there is only one 12V battery pack installed since it

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[15] P. 24 of *Zero Emission Vehicle Study*

[16] http://www.toyota.co.jp/ecocar/

is not used for many purposes. Electricity is needed to start up the engine and to use lights, among other purposes. On the other hand, hybrid cars, in the case of Honda Insight, use twenty 144V battery packs in series[17]. Hybrid cars have to store much electricity to power the entire car, so they need more battery packs. Furthermore, gasoline cars typically have lead-acid batteries, whereas hybrid cars have nickel metal hydride batteries. Nickel hydride batteries have only been developed recently.

Hybrid cars tend to weigh more than gasoline cars because of the many battery packs and additional on-board systems to control the electric motors (e.g. 2,660lb for Honda Civic Hybrid, whereas 2,440lb for Honda Civic[18]). It is important to note that hybrid cars are actually less efficient than gasoline cars if they run only on internal combustion engines. Hybrids can also be less efficient than gasoline cars when, for example, driving on highways. Hybrid cars are, nevertheless, much more efficient than gasoline cars in cities. New Toyota Prius can travel 55 miles per gallon, compared to the 28 miles per gallon average for other sedans[19].

The maintenance costs of hybrids are close to the costs for gasoline cars. The two important differences are battery replacement and routine maintenance of the electric system. The batteries on hybrids are expected to last for five years, and they are covered by warranties. The Insight has an eight-year/80,000-mile warranty and the Prius has eight-year/100,000-mile warranty. Batteries can be replaced free of charge until warranties expire. Without warranties, batteries cost several thousand dollars[20]. The warranties, however, should last the lifetime of most hybrid cars. Except for routine check ups, hybrid car maintenance is similar to maintenance for gasoline cars.

Table 3.2 compares the mileage and emissions of hybrid cars with the performance of non-hybrids of the same vehicle class. The bottom sub-table shows the average performance of non-hybrid cars according to vehicle class.

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[17] http://www.honda.co.jp/auto-lineup/insight/grade_data/

[18] http://www.honda.co.jp/auto-lineup/

[19] http://www.toyota.co.jp/Showroom/carlineup/index.html

[20] http://ibs.howstuffworks.com/ibs/char/hybrid-car18.htm

**Table 3.2 Performance of hybrids and non-hybrids**[21,22,23]

| | Mileage (mpg) | NOx (g/km) | HC (g/km) | CO (g/km) | $CO_2$ (g/km) |
|---|---|---|---|---|---|
| Sedan | | | | | |
| Toyota | | | | | |
| Prius | 45 | 0.02 | 0.02 | 0.67 | Not available |
| New Prius | 55 | 0.02 | 0.02 | 0.67 | 76.1 |
| Corolla (non-hybrid) | 38 | 0.025 | 0.025 | 1.15 | 147 |
| Honda | | | | | |
| Insight | 56 | 0.03 | 0.02 | 0.30 | 73.7 |
| Civic Hybrid | 47 | 0.025 | 0.025 | 0.50 | 80.0 |
| Civic (non-hybrid) | 37 | 0.025 | 0.025 | 1.15 | 140 |
| Large sedan | | | | | |
| Crown (mild hybrid) | 31 | 0.02 | 0.02 | 0.67 | 181 |
| Crown (non-hybrid) | 27 | 0.02 | 0.02 | 0.67 | 207 |
| Mini-van | | | | | |
| Estima Hybrid | 32 | 0.02 | 0.02 | 0.67 | 127 |
| Alphard Hybrid | 41 | 0.02 | 0.02 | 0.67 | 144 |
| Estima (non-hybrid) | 22 | 0.06 | 0.06 | 0.67 | 251 |

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[21] http://www.jama.or.jp/eco/eco_car/clean_energy/clean_energy_07.html

[22] http://www.fueleconomy.gov/

[23] http://www.mlit.go.jp/

| | Mileage (mpg) | NOx (g/km) | HC (g/km) | CO (g/km) | $CO_2$ (g/km) |
|---|---|---|---|---|---|
| Small bus | | | | | |
| Coaster Hybrid | Not available | 0.09 | 0.28 | 2.00 | Not available |
| Coaster (LPG) | Not available | 1.69 | 0.44 | 16 | Not available |

| | | | | | |
|---|---|---|---|---|---|
| Sedan | 28 | 0.07 | 0.07 | 1.15 | 180 |
| Mini-van | 23 | 0.07 | 0.07 | 1.15 | 250 |
| SUV | 22 | 0.07 | 0.07 | 1.15 | 260 |
| Small bus | Not available | 4.50 | 2.90 | 7.40 | Not available |

*The bottom sub-table shows the average performance of non-hybrids in different vehicle classes

### 3.1.2 Hybrid Sales[24]

Increasing gasoline prices and growing choices are helping boost hybrid sales. As of 2003, 43,435 hybrid cars have been registered, and the average annual growth rate compared to 2000 levels is 88.6%.

Hybrid vehicle registration in 2003 by state is as follows: California, 11,425; Virginia, 3,376; Florida, 1,996; Washington, 1972; Maryland, 1,851; New York, 1,653; Texas, 1,651; Illinois, 1,502; Massachusetts, 1,335; and, Pennsylvania, 1,217.

## *3.2 Natural gas and LPG cars*

The natural gas car is a kind of internal combustion vehicle. Natural gas cars emit less toxic gases because they use natural gas instead of gasoline. Gasoline and diesel cars can be easily converted into natural gas cars by slightly modifying their fuel tanks. LPG cars have the same engine structure as the natural gas car, except that they use liquefied petroleum gas instead of natural gas. Natural gas and LPG cars have comparable performances.

### 3.2.1 Technology

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[24] Telegram & Gazette, "Hybrid sales grow: Gas prices, eco-issues fuel car trend," 04/22/04.

Natural gas cars use compressed, liquefied, or absorbed natural gas for their fuel. Natural gas cars are just as fuel efficient as diesel cars, which in turn are less efficient than hybrids but more efficient than gasoline cars. Natural gas cars are important because of their clean emissions. Toxic materials in tailpipe emissions are mainly nitrous oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM). Natural gas cars emit less $NO_x$, CO, and HC than other types of vehicles. There is almost no emission of PM.

Natural gas cars are much quieter and vibrate and shake less than other vehicles. Diesel cars are more efficient than gasoline cars, but they emit more tailpipe emissions (especially HC, $NO_x$, and PM,) and produce more motor and engine vibrations. So, natural gas cars take the place of existing diesel cars.

As mentioned earlier, it is easy to turn gasoline cars and diesel cars into natural gas cars. The only thing has to be done is to replace the fuel tank for natural gas. The conversion cost is about $2,000 to $3,000[25]. Therefore, it is a relatively simple task to introduce more natural gas cars into the market, as it does not require much further investment.

Initially, natural gas cars did not travel very far in one refill (about 200 miles per refill[26]). In recent years, lighter fuel tanks are developed recently. By installing more light fuel tanks, large natural gas cars that are capable of installing many fuel tanks can travel as far as diesel cars can per refill.

LPG cars have similar performance to natural gas cars. The only difference is that they use LPG as their fuel. LPG consists mainly of propane ($C_3H_8$) and butane ($C_4H_{10}$) whereas natural gas mainly consists of methane ($CH_4$). Because both natural gas and LPG are primarily hydrocarbons, they behave similarly upon combustion. Just as converting gasoline and diesel cars into natural gas cars is easy, converting them into LPG cars is simple. The conversion cost is average $2,500[27].

Natural gas and LPG cost about the same as gasoline. For the last three years, the nationwide average for gasoline prices was $1.439 per gallon. The price of compressed natural gas was $1.420 per GGE (Gas Gallon Equivalent) and the price of LPG was $1.599 per GGE[28]. The price of natural gas and LPG might go down further in the future if their use

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[25] http://www.afdc.doe.gov/afv/natural_gas.html
[26] http://www.gas.or.jp/ngvj/text/ngv_feat.html
[27] http://www.afdc.doe.gov/afv/propane.html
[28] http://www.afdc.doe.gov/documents/pricereport/pricereports.html

increases in popularity. Thus, fuel prices cannot be an issue when considering purchasing natural gas and LPG cars in place of conventional cars.

There were roughly 130,000 natural gas cars in the US in 2002[29]. LPG cars number at over 350,000[30]. These numbers are rising rapidly. The lower price of natural gas and LPG has attracted an increasing number of drivers for years. There are more than 3,500 LPG gas stations 1,300 for natural gas stations. Furthermore, home-fueling devices can be useful to refill normal gas cars from the home[31]. Therefore, natural gas and LPG cars have an advantage in terms of refueling infrastructure over other alternative vehicles.

Take for example the Honda Civic GX, a natural gas sedan that drives up to 235 miles per refill. Compared to gasoline Civic, Civic GX only travels half as much per refill. Home fueling devices can make this obvious disadvantage less noticeable. Also, fuel prices for natural gas and gasoline are similar. Regarding safety, Honda claims that there is no leakage of gas even if the car is hit by another car. If there is gas leakage for various reasons, it will spread into the atmosphere quickly, and explosions are highly unlikely. Figure 3.3 shows gas tank located in the trunk. It occupies some space in the trunk, but it will not take up too much space. The car is still a compact car. So, depending on the driver's needs, the Civic GX can perform just as well as the Civic.

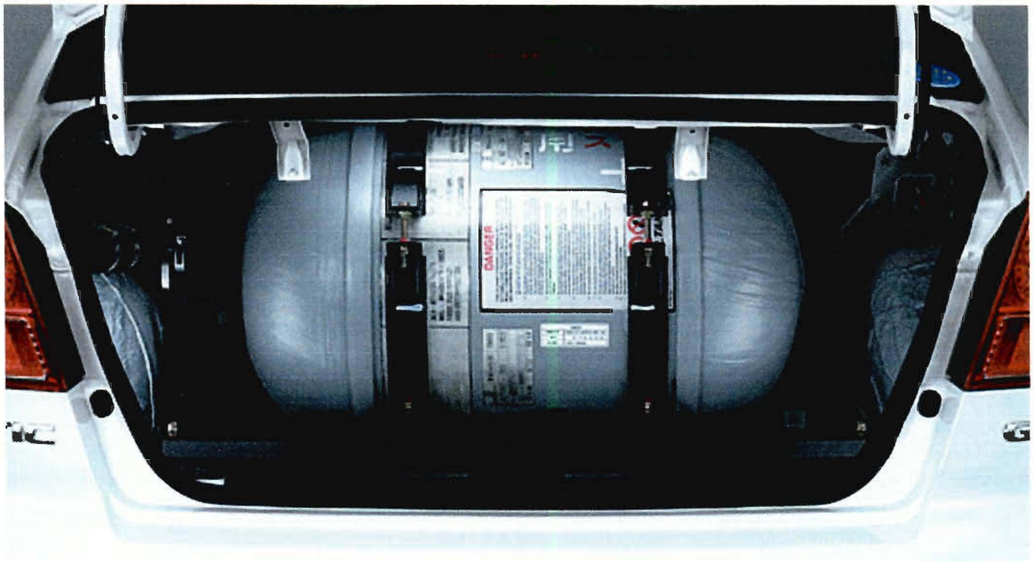

**Figure 3.3 Gas tank[32]**

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[29] http://www.eia.doe.gov/cneaf/alternate/page/datatables/table1.html

[30] http://www.afdc.doe.gov/altfuel/prop_market.html

[31] http://www.hotwired.co.jp/news/news/technology/story/20020716305.html

[32] http://www.honda.co.jp/auto-lineup/civic-gx/safety/fueltank/index.html

Figure 3.4 and Figure 3.5 compare LPG, CNG, gasoline and diesel cars[33,34]. PM emissions are not shown since LPG/CNG cars do not emit PM. CO emission from large vehicles is higher in LPG/CNG cars compared to diesel cars, but other emissions are much lower in LPG/CNG cars than in diesel cars.

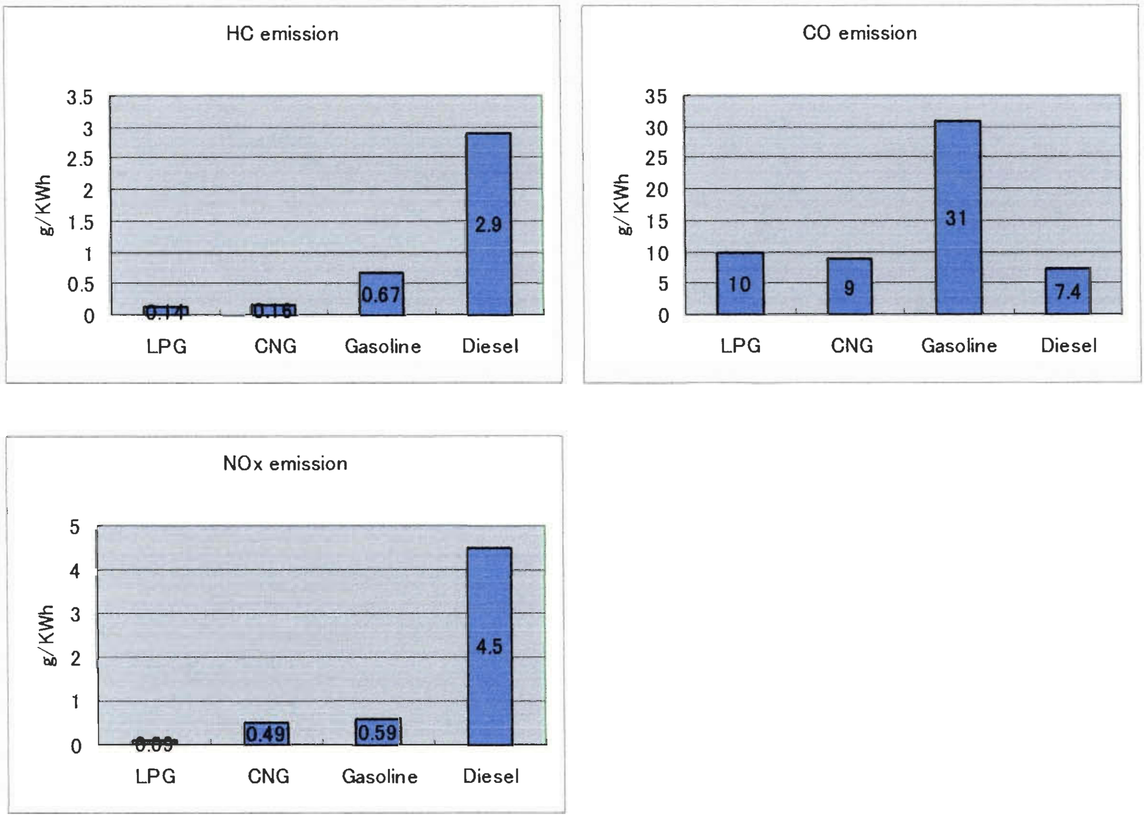
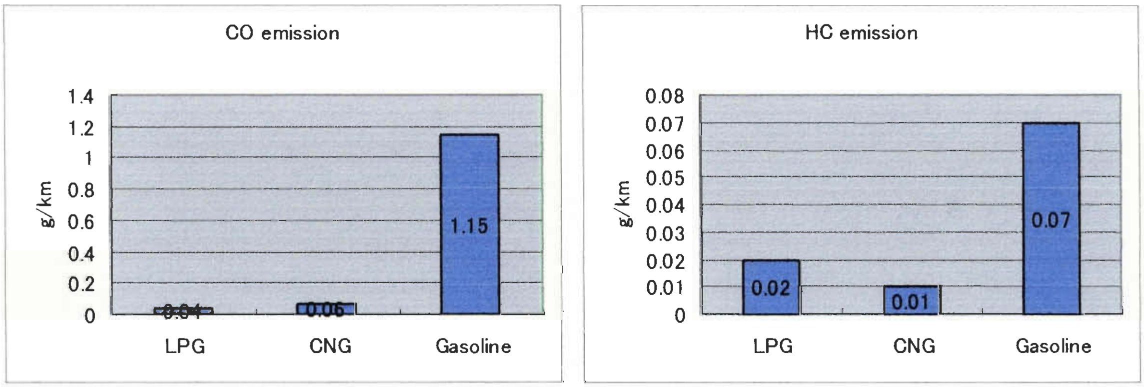


**Figure 3.4 Emissions from large vehicles**



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[33] http://www.j-lpgas.gr.jp/util/lgv/02.html

[34] Table 3.2

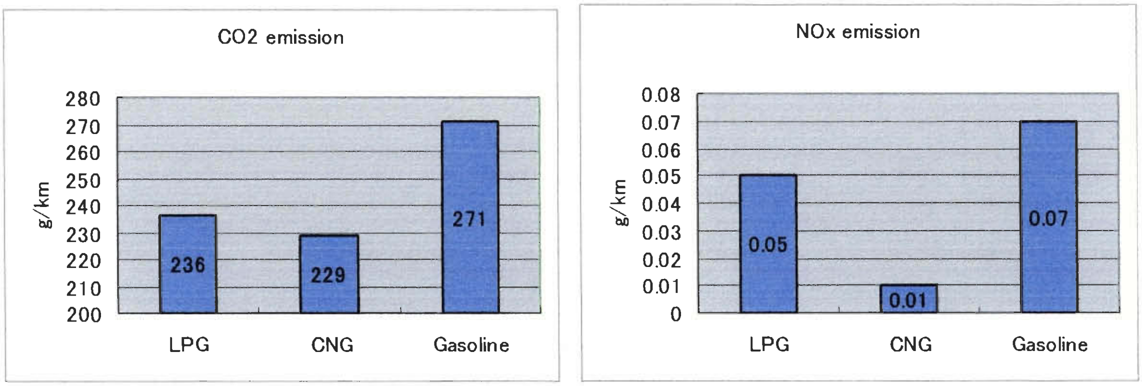

**Figure 3.5 Emissions from small vehicles**

## *3.3 Fuel cell cars*

Like electric cars, fuel cell cars fully operate on electric motors. The difference from electric cars is that the fuel cell cars generate electricity inside the car through the chemical reaction of hydrogen and oxygen. Fuel cell cars are as efficient as the electric motor they carry, and only emit water ($H_2O$). Hydrogen, either in pure form or reformed from gasoline or methanol is used for fuel. The difference between regular batteries and fuel cells will be discussed.

### 3.3.1 Brief history of batteries

The Italian inventor and physicist Alessandro Volta (1745-1827) initiated the study electrochemical cells, the old term for batteries. Many followed his footsteps during the 19th century, including English chemist John Daniel (1790-1845), French scientists G. Leclanche (1839-1882) and R.L.G. Plante (1834-1889), and Michael Faraday of England (1791-1867). The standard unit of electric potential was named the volt in honor of Volta; the farad, named after Faraday, is the unit of capacitance.[35]

### 3.3.2 Basic mechanism of batteries

Fuel cells and batteries are closely related devices, so it pays to first examine how batteries work. Figure 3.6 shows a typical battery.

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[35] General Chemistry, pp.232-237

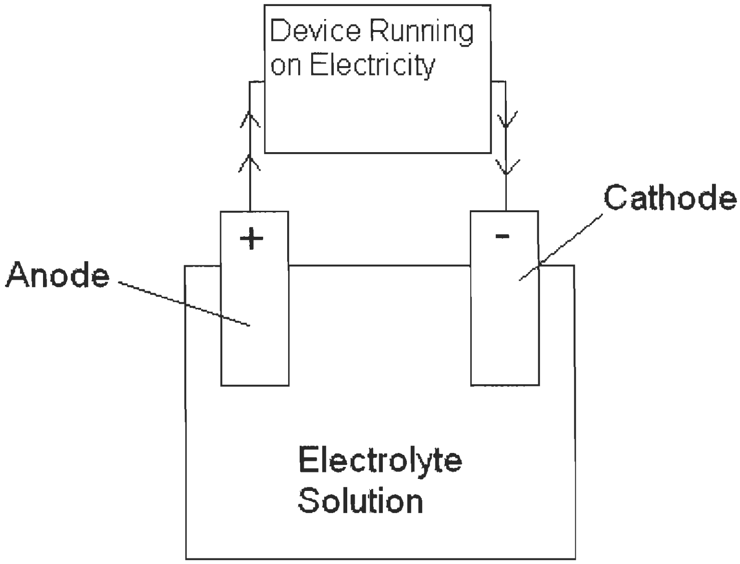

**Figure 3.6 Structure of a typical battery**

A typical battery consists of a liquid electrolyte solution, anode, and a cathode. The cathode is made of material that attracts electrons stronger than does the anode. When the anode and cathode are connected through copper wires, one of the best conductors available, a competition for electrons occurs between the anode and the cathode. In the current configuration, electrons will leave the anode, travel through the wires, and arrive at the cathode. The arrows in the diagram represent the direction in which the electrons flow, which by convention is opposite to the electric current. Regardless of any plus and minus signs or arrows, the basic principle is that electrons flow from the anode to the cathode.

The atoms or molecules at the anode lose electrons in this way. Conversely, the atoms or molecules at the cathode gain electrons. Transfer of electrons between anode and cathode occur naturally when a wire attaches the two electrodes to each other. This phenomenon is the cause of electric current through the wire, but unless some device that uses electricity is inserted into the circuit, the electric current is useless. Once a device, such as a lamp or a voltmeter is attached to the circuit, the electric current flows through it, turning it ‘on’.

Naturally, a battery cannot provide electric currents indefinitely. As electric current is generated, atoms or molecules in the anode are loosing electrons. Those that do lose electrons, are no longer a part of the anode, as their chemical identity has changed. Parts of the anode dissolve into the electrolyte solution, as they can no longer provide electrons without tremendous effort. Likewise, atoms or molecules in the cathode, as well as ions in the electrolyte solution, accept electrons; they too, change chemical identity. Consequently, the cathode’s capacity to accept electrons is saturated. The electrochemical process continues to the point where there is no voltage difference between the anode and cathode.

That is to say that the anode and cathode can no longer transfer electrons between each other to generate an electric current.

### 3.3.3 Common battery types

Table 3.7 gives a brief description of common batteries, as well as historically important ones.

**Table 3.7 Common battery types and their characteristics**[36]

| Type | Electrolyte | Cathode | Anode | Voltage | Additional Information |
|---|---|---|---|---|---|
| Voltaic | Dilute $H_2SO_4$ | Zn: $Zn \rightarrow Zn^{2+} + 2e^-$ | Cu: $2H^+ + 2e^- \rightarrow H_2$ | 1.1V | Primary (non-rechargeable) battery, historically significant |
| Daniel | Dilute $H_2SO_4$ | Zn: $Zn \rightarrow Zn^{2+} + 2e^-$ | Cu: $Cu^{2+} + 2e^- \rightarrow Cu$ | 1.1V | Primary battery, historically significant |
| Dry | $ZnCl_2$ and $NH_4Cl$ solution | Zn: $Zn \rightarrow Zn^{2+} + 2e^-$ | $MnO_2$ coated on C: $2NH_4^+ + 2MnO_2 + 2e^- \rightarrow 2MnO(OH) + 2NH_3$ | 1.5 V | Primary battery |
| Lead Acid | Dilute $H_2SO_4$ | Pb: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$ | $PbO_2$: $PbO_2 + 2e^- + SO_4^{2-} + 4H^+ \rightarrow PbSO_4 + 2H_2O$ | 2.0V | Secondary (rechargeable) battery |

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[36] General Chemistry, p.238

| Type | Electrolyte | Cathode | Anode | Voltage | Additional Information |
|---|---|---|---|---|---|
| NiCd | Dilute $H_2SO_4$ | Using:<br>$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$<br>Recharging:<br>$2Ni(OH)_2 \rightarrow 2NiO(OH) + 2e^- + 2H^+$ | Using:<br>$2NiO(OH) + 2e^- + 2H^+ \rightarrow 2Ni(OH)2$<br>Recharging:<br>$Cd(OH)_2 + 2 e^- \rightarrow Cd + 2OH^-$ | | Secondary battery |
| Lithium | | Inorganic Li compound | $F_2$ coated on C | 3.0V | Average lifetime around 10 years |

### 3.3.4 Brief history of fuel cells

The study of fuel cells occurred concurrently with the development of batteries. William Robert Grove of England (1811-1896) took fellow British men William Nicholson and Anthony Carlislie's idea of electrolyzing water into hydrogen and oxygen, and reversed it to develop crude prototypes of today's fuel cells. As time past, such chemists and physicists as Ludwig Mond (1839-1909), Carl Langer, and Friedrich Wilhelm Ostwald (1853-1932) from Germany, William W. Jacques (1855-1932), Emil Baur of Switzerland (1873-1944), and Francis Thomas Bacon of England (1904-1922) have added their names to the growing list of contributors. In more recent times, Thomas Grubb and Leonard Niedrach were instrumental in developing polymer electrolyte membrane technology at General Electric in the early 1960s.[37]

### 3.3.5 Basic mechanism of fuel cells

In many respects, fuel cells and batteries are similar. The most important difference is that hydrogen gas, the *fuel*, along with oxygen, has to be supplied from outside the fuel cell. Thus, the fuel cell is not self-contained. Figure 6.2 below portrays a typical fuel cell. It is important to note that other types of fuel cells, namely zinc fuel cells, do exist, but are not important in the discussion of fuel cell technology in automobiles.

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[37] http://fuelcells.si.edu/origins/origins.htm

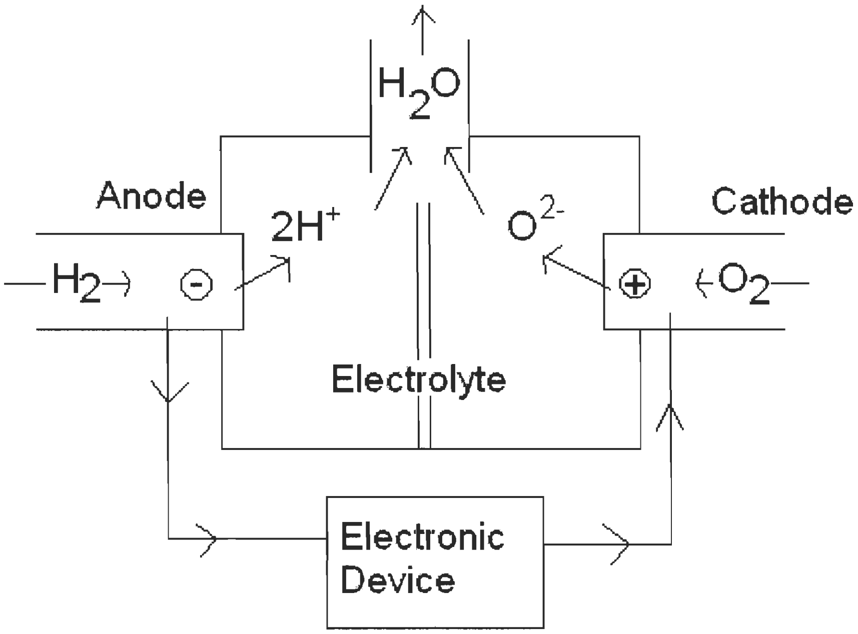

**Figure 3.8 Structure of a typical fuel cell**

In the chemist's parlance, there are two half-reactions that occur. $H_2$ introduced at the anode loses electrons, denoted $e^-$, to the circuit, and dissociates into $H^+$:

$$2\,H_2 \rightarrow 4\,H^+ + 4\,e^- \text{ (Anode).}$$

Next, the cathode acquires electrons. That is, electrons that have left the anode and have done useful work in the electronic device reach the cathode, and then, oxygen gas $O_2$ accepts electrons from the circuit, later dissociating into oxide ions $O^{2-}$:

$$O_2 + 4\,e^- \rightarrow 2\,O^{2-} \text{ (Cathode).}$$

The anode-cathode reaction pair is not special in and of itself, as similar reactions occur in batteries as well. What distinguishes fuel cells from batteries is the final product of the energy-generating reaction. In the case of hydrogen fuel cells, this is water vapor, $H_2O$. $H^+$ and $O^{2-}$ ions generated at the electrodes migrate through the electrolyte, and upon encounter, form $H_2O$. The net reaction that occurs is:

$$2\,H_2 + O_2 \rightarrow 2\,H_2O + \text{Energy.}$$

What happens to the water vapor that is released? It simply leaves through the exhaust. It is this lack of significant waste products that characterizes hydrogen fuel cells. No green house gases like carbon dioxide, $CO_2$, appear, and certainly no nitrogen oxides, the so-called $NO_x$, form.

### 3.3.6 Constraints on components of fuel cells

To accomplish this seemingly simple reaction, the electrolyte must meet some constraints. First, it must not degrade significantly under the operational temperature range. That is the minimal requirement for any such device. Second, the electrolyte must be selectively permeable, preventing impurities, usually trace gases that are present with the $H_2$ and $O_2$ used, from traveling through the electrolyte and then reacting with $H^+$, $O^{2-}$, or the electrodes to produce harmful products. More importantly, the electrolyte must be less conducting than the electric circuit; otherwise, electrons would flow across the solution, and no useful work will be done.

Another technical problem to circumvent is the storage of $H_2$. Hydrogen gas is the lightest of all gases, considerably less dense than the other gases. Hydrogen gas is also very reactive. These characteristics make handling hydrogen difficult at times. For on-board usage, such as in automobiles, hydrogen gas is either compressed at extremely high pressures or is liquefied at below-freezing temperatures to reduce the volume considerably. As handling containers in such extreme conditions can be quite dangerous, many research groups are developing metal alloys and other solids that adsorb $H_2$ well as a substitute for the compression and liquefication methods.

The advantages of fuel cells are not free in any sense of that word. Constructing efficient, feasible, and affordable fuel cells for use in homes and cars is a difficult task. To approach this problem, different types of fuel cells are used depending on the purpose and the conditions under which the fuel cells should operate. Table 3.9 outlines the existing categories of fuel cells.

**Table 3.9 Types of fuel cells and their characteristics**[38,39]

| Type | Electrolyte | Operational Temperature | Possible Fuels | Characteristic | Efficiency | Usage |
|---|---|---|---|---|---|---|
| Molten Carbonate | Molten $Li_2CO_3$ and/or $K_2CO_3$ | 600°C-700°C | Natural gas, petroleum, coal | No need of catalyst; large devices built | 45%-60% | Cogeneration; distributed power source; large-scale thermal power replacement |
| Solid Oxide | $ZrO_2 \cdot Y_2O_3$ | 900°C -1000°C | Natural gas, petroleum, coal | No need of catalyst; cogeneration can increase overall efficiency | Over 50% | Cogeneration; distributed power source; medium-scale thermal power replacement |
| Type | Electrolyte | Operational Temperature | Possible Fuels | Characteristic | Efficiency | Usage |
| Phosphoric Acid | $H_3PO_4$ | 150°C -220°C | Hydrogen, naphthalene, natural gas, methanol | Pt catalyst needed; CO reduces activity of catalyst | Up to 45% | Cogeneration; distributed power source; off-shore power source; for large-scale transportation |

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[38] Materials for fuel cells, p.24

[39] The Story of Fuel Cells, pp.66-69

| Type | Electrolyte | Operational Temperature | Possible Fuels | Characteristic | Efficiency | Usage |
|---|---|---|---|---|---|---|
| Alkali | KOH | 100°C -250°C | Hydrogen | Pt catalyst needed; CO reduces activity of catalyst | Up to 60% | Naval and space missions |
| Polymer Electrolyte (Proton Exchange) Membrane | Sulfonated polymers | Room temperature - 80°C | Hydrogen, naphthalene, natural gas, methanol | Pt catalyst needed; CO reduces activity of catalyst; high output per surface area ratio; many options for materials | Over 40% | Fuel Cell Vehicles, home use |

### 3.3.7 Barriers to widespread use

Auto manufacturers are gradually beginning to make fuel cell vehicles (FCV) available for promotion purposes. Table 3.10 below indicates that the Big Three, Toyota, Honda, and Nissan, have all begun to move from the proto-typing phase to leasing these vehicles to companies and government agencies.

**Table 3.10 Fuel cell vehicles by manufacturer**

| Company | Name | Maximum Speed | Range | Number of Passengers | Availability in the US |
|---|---|---|---|---|---|
| General Motors | HydroGen3 (mini-van) | 160 km/h | 400 km | 5 | |
| Daimler-Chrysler | F-Cell | 140 km/h | 150 km | 4 | Since late 2003 |
| Toyota | FCHV | 155 km/h | 300 | 5 | Since late 2002 |
| Honda | FCX | 150 km/h | 355 km | 4 | Since late 2002; first fuel cell vehicle to be approved by US EPA and CARB |

| Company | Name | Maximum Speed | Range | Number of Passengers | Availability in the US |
|---|---|---|---|---|---|
| Nissan | X-Trail FCV | 125 km/h | 200 km | 5 | |
| Ford | Focus FCV, P2000 | 128 km/h | 160 km | 5 | Focus FCVs planned to be available beginning 2004 |

These vehicles are far from being available, however, to the public.

In Japan, Toyota leases its fuel cell vehicles for roughly 1,200,000 yen per month (nearly $11,000 per month), while Honda leases its FCVs for roughly 800,000 yen per month ($7,400 per month). Likewise, in the US, Toyota and Honda are leasing very few FCVs, primarily to government agencies, academic institutions, and energy companies. Daimler-Chrysler leased its first F-Cell FCV ever to Tokyo Gas in October of 2003; it plans to introduce 60 F-Cell FCVs in the US, Germany, Singapore, and Japan between 2003 and 2004.

Aside from the lack of FCVs available to the public, there are problems of infrastructure. As of yet, there are very few hydrogen-fueling stations. Certain regions in California, Nevada, Michigan, Arizona, Pennsylvania, and Washington DC have fueling stations. Outside of the US, Australia, Belgium, Brazil, Canada, China, Denmark, Germany, Iceland, Italy, Japan, Mexico, Netherlands, Portugal, Singapore, South Korea, Spain, Sweden, and the United Kingdom are either building more fueling stations or are setting them up for the first time.

In states that do have fueling stations, the issue is how to transport hydrogen from production plants to fueling stations in a safe and cost-efficient manner. Unlike the case with fossil fuel, there are no hydrogen pipelines, nor are there any pumping stations. Gas suppliers directly distribute hydrogen using trucks and trailers.

To solve this issue, the industry is looking into fuel reformulation. Reformers, devices that convert natural gases to hydrogen, although at a cost, are becoming increasingly feasible. Steam reformers, which convert natural gases, such as methane, into hydrogen using nickel-based catalysts, are the most common type of reformers. In the short-term, it might be much less costly to set up reformers at gas stations so that one could produce a sufficient amount of hydrogen to run a FCV on demand. This way, the automotive and energy industries can continue to use the extensive distribution system for natural gases and gasoline that have been built beginning well over a century ago.

Establishing a distribution system for hydrogen is not enough to ensure the widespread use of FCVs. Automobile parts must operate under extreme conditions, in temperatures ranging from below freezing to way beyond. FCVs are no exception, and fuel cell parts are not quite at a level of dependability comparable to conventional vehicles.

All FCVs available now use stacks of proton exchange membrane (PEM) fuel cells. Many, if not all, PEM cells use Dupont's Nafion, a chemical 'relative' of Teflon, as the membrane. Such cells do not last more than a few thousand hours, when treated under laboratory conditions. That does not make for mileage in the 100,000-mile range.

## *3.4 Electric cars*

Electric cars fully operate with an electric motor. There is no emission and the electric motor is more efficient than the internal combustion engine. The common type of battery used for the cars is lead acid, nickel metal hydride, and lithium ion. The lead acid battery is the same type of battery as those used in regular cars, but because of the need for high performance, nickel metal hydride and lithium ion battery have been developed and used for electric cars.

### 3.4.1 Technology

Electric cars use electricity as fuel and electric motors as engines. Using electric motors enables cars to reduce noise and vibration considerably. Electric cars are ZEVs because they have neither tailpipe nor evaporative emissions. They generate electricity when they brake. Braking energy is converted into electricity by the motor as in hybrids. The combination of regenerative braking and electric motors make electric cars more efficient than internal combustion cars.

Since internal combustion engines do not assist electric cars, electric cars need more batteries than hybrid cars. The cost of batteries, which are still expensive, keep the price of electric cars higher than gasoline cars. For lead acid powered electric cars, the driving range is typically between 50 to 70 miles[40]. This is short compared to internal combustion vehicles because batteries cannot be charged beyond capacity. Another issue is that there is a limit to the rate of energy release by batteries. Thus, acceleration and driving uphill can be issues.

Nickel metal hydride and lithium ion batteries have been developed to improve upon lead acid batteries. Nickel metal hydride batteries are also used to power hybrid cars. These advanced batteries can power larger vehicles over longer distances. With the new technology, electric cars travel up to 100 miles per recharge.

Batteries on electric cars do typically take four to six hours to recharge. Considering that electric cars travel as far as gasoline cars, this is a clear drawback. Fast recharging technologies have been developed, enabling cars to recharge within fifteen minutes, but the equipment and facilities needed are not yet widely available.

At least for cars, electricity is cheaper than gasoline. In terms of *fuel*, electric cars cost $15 per month on average, whereas gasoline cars cost $50 per month[41]. Batteries in electric cars have to be replaced every two years, so electric cars are not necessarily cheaper to maintain than gasoline cars.

Although electric cars are ZEVs by definition, we must note that power plants emit various substances when generating electricity. If power plants are more polluting than gasoline cars in general, then adopting electric cars may actually harmful to the environment. Thus, whether or not electric cars become widely used depends, among other things, on clean methods of power generation.

Table 3.11 summarizes the performance and price of electric cars that are produced by major auto manufacturers.

**Table 3.11 Major electric cars**[42]

| | Battery | Driving range | Price of car | Time to recharge |
|---|---|---|---|---|
| GM EV1 | Lead Acid | 50-70 miles | $33,995 | 3~5 hours |

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[40] Zero Emission Vehicle Study
[41] Zero Emission Vehicle Study
[42] Zero Emission Vehicle Study

| Battery | Driving range | Price of car | Time to recharge | |
|---|---|---|---|---|
| GM EV1 | Nickel Metal Hydride | 80-120 miles | $44,000 | 3~5hours |
| Chevrolet S-10 | Nickel Metal Hydride | 50-70 miles | $32,995 | 2~3 hours |
| Honda EV Plus | Nickel Metal Hydride | 70-90 miles | $54,000 | 6~8 hours |
| Ford Ranger | Nickel Metal Hydride | 50-70 miles | $34,999 | 6~8 hours |
| Ford Ranger | Nickel Metal Hydride | 80-100 miles | $48,995 | 6~8 hours |
| Toyota RAV4 | Nickel Metal Hydride | 60-80 miles | $44,222 | 6~8 hours |
| DaimlerChrysler EPIC | Nickel Metal Hydride | 70-80 miles | $45,000 | 5 hours |
| Solectria Force | Lead Acid | 50 miles | $28,000 | 8 hours |
| Solectria Force | Nickel Metal Hydride | 80-100 miles | $35,000 | 8 hours |
| Nissan Altra | Lithium Ion | 60-80miles | Lease only | 5 hours |
| | | | | |

## *3.5 Diesel cars*

Diesel cars are a type of internal combustion cars. They differ from gasoline cars because they use lighter gases for fuel. Diesel cars are noisier, vibrate more, and emit much more $NO_x$ HC, and PM than other types of cars. As such, diesel cars can contribute significantly to inner-city photochemical smog. Recent breakthroughs have reduced emissions, giving further impetus for the adoption of diesel cars in Europe. Diesel cars are more efficient than gasoline cars, and the fuel is generally cheaper than gasoline. In this paper, we will not enter into a further discussion of diesel cars, since use of oil precludes them from being an alternative to gasoline cars.

## *3.6 Methanol cars and cars with other fuels*

Methanol cars have internal combustion engines, and they are a kind of internal combustion cars. The fuel used, methanol, is a renewable source of energy, and is produced in a variety of ways. Both gasoline and diesel cars can be converted into methanol cars. Emission levels of methanol cars are between those of diesel and natural gas cars. As other fuels that are renewable, ethanol and bio-diesel have been introduced into the market.

### 3.6.1 Technology

Methanol cars directly burn methanol ($CH_3OH$). Most methanol production uses natural gases, but new methods involving non-petroleum products such as biomass and coal, are being studied.

The first type, called M100, uses pure (100%) methanol as fuel. The second, called M85 runs on a mixture of 85% methanol and 15% gasoline. Methanol cars generally have 50% less $NO_x$ and no PM. From the emissions standpoint, methanol cars can replace diesel cars. Methanol, however, is toxic, so evaporative emissions from methanol cars are a problem. No company currently manufactures methanol cars because of this difficulty and because of the industries focus on other LEVs and ZEVs. The number of methanol cars on the road has been declining over the past few years.

On the contrary, ethanol cars are gaining popularity. Ethanol ($C_2H_5OH$) is an alcohol related to methanol, could be made from biomass, including corn and wheat. It hence is a renewable source of energy. Ethanol is a cleaner fuel than gasoline (25% less CO, 20% less $NO_x$, and almost no emission of PM[43]). It is usually mixed with gasoline: E10 fuel contains 10% ethanol and 90% gasoline; E85 fuel contains 85% ethanol. Ethanol as a fuel can be used in many of ordinary gasoline cars. Flexible fuel vehicles (FFVs) can use both E85 and gasoline in the same fuel tank. At least 3,000,000 FFVs have been sold in the US[44]. Considering that 12% of gasoline sold in the US is a mixture of gasoline and ethanol, a little effort by oil companies can make ethanol a much more popular choices of fuel.

Bio-diesel cars are diesel cars that use biomass fuel. Instead of using light oil, bio-diesel cars use plant-based oils that do not require changes to the diesel engine. Compared to light oil, bio-diesel has the same gas mileage, cleaner emission (93%, 50%, and 30% reduction of

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[43] http://journeytoforever.org/jp/ethanol.html

[44] http://journeytoforever.org/jp/ethanol.html

HC, CO, and PM respectively compared to gasoline[45]). Initially, bio-diesel cost two to three times as much as light oil, but prices have dropped quickly. Currently, 1 to 2% blend of bio-diesel is sold at the same price as light oil[46].

## *3.7 Comparison of major types of vehicles*

### 3.7.1 Comparison of general features of the major classes of automobiles

Table 3.12 compares major types of cars according to feature. The features are rated on a 1 to 5 scale, where gasoline cars take on the reference value 3. Numbers higher than 3 indicate an improvement over gasoline vehicles, while smaller numbers indicate that a given feature is generally inferior compared to gasoline cars.

**Table 3.12 Comparison of each vehicle**

| | NOx emission | CO and HC emission | PM emission | $CO_2$ emission | Efficiency of engine |
|---|---|---|---|---|---|
| Gasoline | 3 | 3 | 3 | 3 | 3 |
| Diesel | 1~2 | 4 | 1 | 4 | 4 |
| CNG | 4 | 4 | 3 | 4 | 3 |
| LPG | 4 | 4 | 3 | 3 | 3 |
| Methanol | 4 | 4 | 3 | 3~4 | 3 |
| Electric | 5 | 5 | 5 | 5 | 5 |
| Hybrid (Gasoline and Electric) | 3~4 | 3~4 | 3 | 4 | 4~5 |
| Fuel Cell | 5 | 5 | 5 | 5 | 5 |

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[45] http://journeytoforever.org/jp/biodiesel.html

[46] http://www.hotwired.co.jp/news/news/business/story/20031127105.html

| | Distance traveled per refill | Availability of refueling facilities | Time that takes to refill | Price of fuel | Replacement from oil |
|---|---|---|---|---|---|
| Gasoline | 3 | 3 | 3 | 3 | 3 |
| Diesel | 4 | 3 | 3 | 4 | 3 |
| CNG | 2~3 | 2 | 2 | 4 | 5 |
| LPG | 2~3 | 2 | 2 | 4 | 4 |
| Methanol | 3 | 1 | 3 | 2 | 5 |
| Electric | 1~2 | 2 | 1~2 | 3~4 | 5 |
| Hybrid (Gasoline and Electric) | 4 | 3 | 3 | 4 | 3 |
| Fuel Cell | 2 | 1~2 | 2~3 | 2~3 | 5 |

### 3.7.2 Number of LEVs and ZEVs

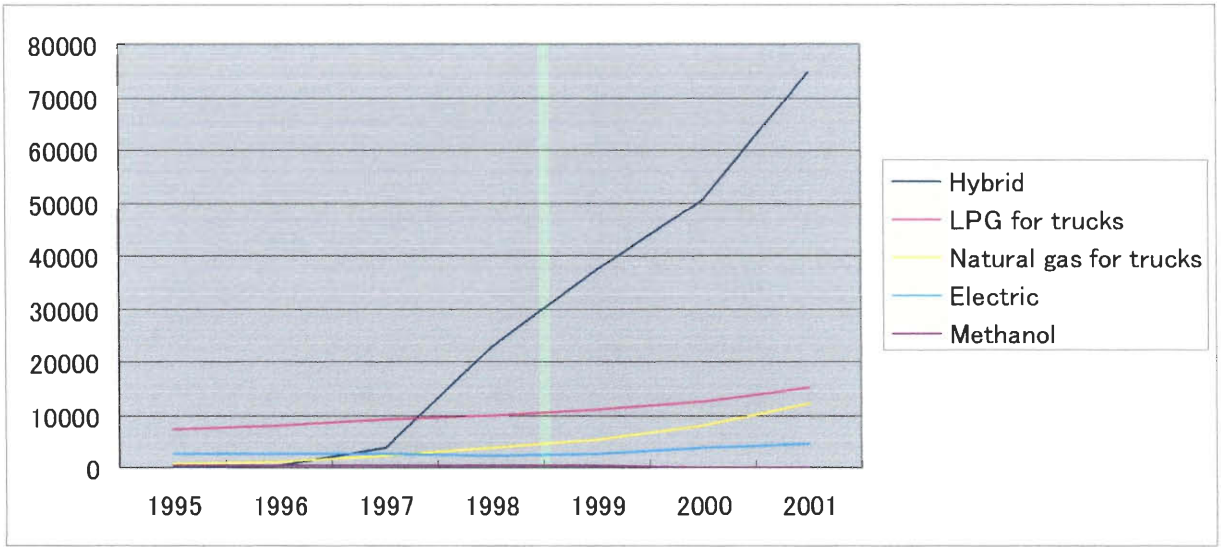

**Figure 3.13 Number of LEVs and ZEVs in Japan**[47]

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[47] http://www.jama.or.jp/eco/energy/table_02.html

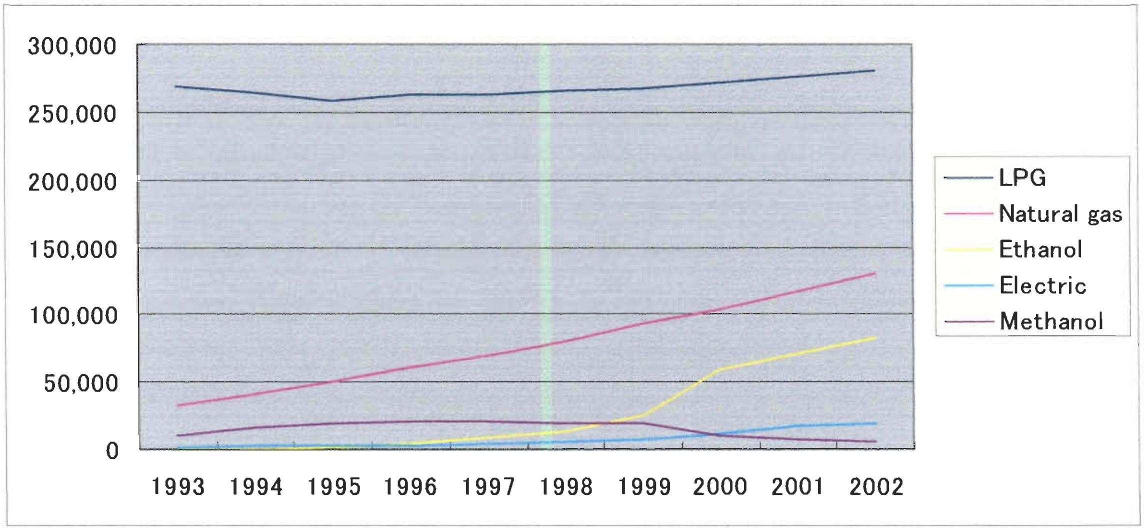

**Figure 3.14 Number of LEVs and ZEVs in the US**[48]

By looking at the change in the number of each LEVs and ZEVs in these years, it seems that natural gas, LPG, and especially hybrid cars gained popularity. There were over 10,000 hybrid cars around the world in 2002, and the number continues to grow rapidly. Unless ZEVs, namely electric and fuel cell cars, become commercially affordable, hybrids, natural gas and LPG, and biomass cars will be important alternative fuel cars.

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[48] http://www.eia.doe.gov/cneaf/alternate/page/datatables/table1.html

# Chapter 4: Current Products

Auto manufacturers, including the Big Three (Daimler-Chrysler, Ford, and GM), Toyota, and Honda, have announced that they will commit to the development of and introduction of alternative cars into the US market in the near future. What products are available as of today? Which concepts still need time? In this chapter, we will introduce alternative cars that are available already. We will compare cars from the same category, and in addition compare conventional vehicles with alternative cars that have similar configurations.

## *4.1 Hybrid cars*

As of January 2004, only Toyota and Honda have hybrid cars on market. Toyota's midsize Prius, first introduced in Japan in 1997, was the first hybrid car to be mass-produced. Honda was only a step behind in introducing its two-seater Insight, and it has recently brought a hybrid version of its Civic to the market.

The Big Three, and the previously mentioned Toyota and Honda, are working to put more hybrid vehicles into production, in terms of quantity and variety. In 2005 alone, Toyota will release the hybrid Highlander, while its branch company, Lexus, will start selling the RX Hybrid SUV; Ford will add Escape to this mixture; GM will release the Saturn VUE; and Daimler-Chrysler will make the first hybrid pickup, the Dodge Ram Pickup. The Chevy Equinox and the Mercedes S-class will join the lineup in 2006. In 2007, the Chevy Malibu and GMC SUVs will further diversify the list of hybrid cars. A full list of hybrid cars in planning is in Tables 4.1 and 4.2:

**Table 4.1 Release schedule of hybrid cars[49,50]**

| Manufacturer | Model | Type Vehicle | Hybrid Type | Expected Mileage | Expected Availability |
|---|---|---|---|---|---|
| Toyota | Highlander | SUV | Full | Not Available | 2005 |
| Lexus | RX330 | SUV | Full | Not Available | 2005 |

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[49] http://www.californialung.org/
[50] http://www.fueleconomy.gov/

**Table 4.2 Release schedules of hybrid cars**[51,52]

| Manufacturer | Model | Type Vehicle | Hybrid Type | Expected Mileage | Expected Availability |
|---|---|---|---|---|---|
| General Motors | 12 models | | | | 2007 |
| | GMC Sierra | Pickup | Mild | Small increase | 2003 (only to fleets) |
| | Chevrolet Silverado | Pickup | Mild | Small increase | 2003 (only to fleets) |
| | Saturn VUE | SUV | Full | 40 mpg | 2005 |
| | Chevy Equinox | SUV | Mild | Small increase | 2006 |
| | Chevy Malibu | Sedan | Mild | Small increase | 2007 |
| Ford | Escape | SUV | Full | 40 mpg | 2004 |
| Daimler-Chrysler | Mercedes S-class | Sedan | | | 2006 |
| Dodge | Ram | Pickup | Mild | Small increase | 2005 |

All data in Table 4.1 have been collected by the US Department of Energy, and is therefore expected to be necessarily less biased than data from manufacturers.

### 4.1.1 Toyota's hybrid cars

In its home, Japan, Toyota has already introduced a fleet of hybrid cars. The Prius is the typical, midsize car. Estima Hybrid, the world's first hybrid mini-van, along with Alphard Hybrid, has been available in addition to the Prius. For executives, there is the Crown Sedan Mild Hybrid. Toyota even has a hybrid bus, the Coaster, which they report is selling modestly. Only the Prius, however, is available in the US right now, but more are to come in the near future, depending on what classes of hybrid cars are in demand.

The Prius is a midsize 4- or 5- seater, and therefore, it is logical to compare it with the popular

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[51] http://www.californialung.org/
[52] http://www.fueleconomy.gov/

conventional same-sized car, the Corolla. For completeness, we will also note the features of the 2003 Prius. Table 4.3 compares the Prius and the Camry.

**Table 4.3 2003 Toyota Prius, 2004 Toyota Prius and Toyota Camry features**[53,54]

| | 2003 Toyota Prius | 2004 Toyota Prius | 2004 Toyota Corolla |
|---|---|---|---|
| Manufacturers suggested retail price (MSRP) | NA | \$20,510 | \$15,830 |
| Are there tax incentives? | NA | Possibly yes | No |
| Fuel type | Regular Gasoline | Regular gasoline | Regular gasoline |
| Mileage per gallon (City) | 52 | 60 | 29 |
| Mileage per gallon (Highway) | 45 | 51 | 38 |
| Combined mileage per gallon (45% highway and 55% city driving for 15,000 miles) | 48 | 55 | 32 |
| Annual fuel cost (regular gasoline at \$1.40 per gallon) | \$437 | \$382 | \$817 |
| Annual greenhouse gas emissions (tons) | 4.0 tons | 3.5 tons | 5.9 tons |
| EPA Size class | Compact cars | Midsize cars | Compact cars |
| Engine size (liters) | 1.5 liters | 1.5 liters | 1.8 liters |
| Number of cylinders | 4 | 4 | 4 |
| Transmission | Automatic | Automatic | Automatic |
| Drive | Front-wheel drive | Front-wheel drive | Front-wheel drive |
| Curb weight (lbs) | Unavailable | 2,890 lbs | 2,590 lbs |
| Passenger volume ($ft^3$) | 89 $ft^3$ | 96 $ft^3$ | 90 $ft^3$ |
| Luggage volume ($ft^3$) | 12 $ft^3$ | 16 $ft^3$ | 14 $ft^3$ |

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[53] http://www.fueleconomy.gov/

[54] http://www.toyota.com/

The 2004 Prius is a significant improvement over the original Prius. Since its introduction in 1997, over 120,000 have been sold worldwide. Toyota, nonetheless, revamped its onboard Toyota Hybrid System (THS). In THS II, found on every 2004 Prius, several notable advances have been made. These include, but are not limited to: electric motors that are 1.5 times more efficient than before; Atkins Cycle engines with improved efficiency; nickel hydride batteries with better delivery and charging capacities; generators that rotate faster; and, a higher-voltage power system[55].

Conventional wisdom says that there is a trade-off between the acceleration of a car and its fuel efficiency. The first Prius, with the THS, showed that that statement is not necessarily true, achieving fuel efficiency roughly double that of the best gasoline vehicles at the time. THS II will make the difference between riding a Prius and a gasoline car even less noticeable.

**Figure 4.4 2004 Toyota Prius ©2003-2004 Toyota Motor Sales**

### 4.1.2 Honda's hybrid cars[56,57]

Toyota introduced the world's first mass-produced hybrid vehicle in Japan, but Honda brought the first commercially available hybrid cars to the US market.

In 1999, Honda released its two-seater Insight to the Japanese and US markets. The first Insights achieved their incredible gas mileage – the Insight still remains to be the most efficient gasoline vehicle – thanks to a combination of aluminum-based light-weight bodies,

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[55] http://www.toyota.co.jp/
[56] http://world.honda.com/
[57] http://www.honda.co.jp/

improved aerodynamic design, and its IMA power unit, which combines one of the world's most efficient and lightest engines with equally efficient electric motor and batteries.

Honda only sells two types of two-seaters, the Insight and the S2000, both of them designed around different concepts, so that a comparison of the Insight and the S2000 is not entirely reasonable. Nonetheless, a comparison of the Insight and the S2000 is still necessary to make a rational choice between two-seaters. Table 4.5 compares the 2004 Honda Insight and the 2004 Honda S2000 in 15 aspects:

**Table 4.5 2004 Insight and S2000 features**[58]

| | 2004 Honda Insight | 2004 Honda S2000 |
|---|---|---|
| Manufacturers suggested retail price (MSRP) | $19,180 | $32,800 |
| Are there tax incentives? | Possibly yes | No |
| Fuel type | Regular gasoline | Premium gasoline |
| Mileage per gallon (City) | 57 | 20 |
| Mileage per gallon (Highway) | 56 | 25 |
| Combined mileage per gallon (45% highway and 55% city driving for 15,000 miles) | 56 | 22 |
| Annual fuel cost (regular gasoline at $1.40 per gallon, premium gasoline at $1.60 per gallon) | $376 | $1092 |
| Annual greenhouse gas emissions (tons) | 3.5 tons | 8.7 tons |
| EPA Size Class | Two-seaters | Two-seaters |
| Engine size (liters) | 1 liters | 2.2 liters |
| Number of cylinders | 3 | 4 |
| Transmission | Automatic | Manual (6 speed) |
| Drive | Front-wheel drive | Rear-wheel drive |
| Curb weight (lbs) | Unavailable | Unavailable |
| Passenger volume ($ft^3$) | NA | NA |
| Luggage volume ($ft^3$) | NA | NA |

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[58] http://www.fueleconomy.gov/

Honda began to sell the Honda Civic Hybrid, the hybrid version of the first car that Honda ever made, in Japan in 2001. Now, the Civic Hybrid, a compact 5-seater, is available in the US as well, broadening the range of hybrid cars for consumers. The 2004 Honda Civic Hybrid and the 2004 Honda Civic compare in the following way (see Table 4.7, 4.8):

**Figure 4.6 Honda Insight ©2004 American Honda Motor Co**

**Table 4.7 2004 Honda Civic Hybrid and Honda Civic features**[59]

| | 2004 Honda Civic Hybrid | 2004 Honda Civic |
|---|---|---|
| Manufacturers suggested retail price (MSRP) | $19,650 | $13,010 |
| Are there tax incentives? | Possibly yes | No |
| Fuel type | Regular gasoline | Regular gasoline |
| Mileage per gallon (City) | 47 | 35 |
| Mileage per gallon (Highway) | 48 | 40 |
| Combined mileage per gallon (45% highway and 55% city driving for 15,000 miles) | 47 | 37 |
| Annual fuel cost (regular gasoline at $1.40 per gallon) | $447 | $567 |
| Annual greenhouse gas emissions (tons) | 4.1 tons | 5.2 tons |
| EPA Size class | Compact cars | Compact cars |
| Engine size (liters) | 1.3 liters | 1.7 liters |

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[59] http://www.fueleconomy.gov/

**Table 4.8 2004 Honda Civic Hybrid and Honda Civic features**[60]

| | 2004 Honda Civic Hybrid | 2004 Honda Civic |
|---|---|---|
| Number of cylinders | 4 | 4 |
| Transmission | Automatic | Automatic |
| Drive | Front-wheel drive | Front-wheel drive |
| Curb weight (lbs) | Unavailable | Unavailable |
| Passenger volume ($ft^3$) | 91 $ft^3$ | 91 $ft^3$ |
| Luggage volume ($ft^3$) | 10 $ft^3$ | 10 $ft^3$ |

Tables 4.10 and 4.11 compare the 2004 Toyota Prius, 2004 Toyota Civic Hybrid, and the 2004 Honda Insight, to see how the hybrid cars, albeit in different vehicle classes, compare to each other.

**Figure 4.9 Honda Civic Hybrid ©2004 American Honda Motor Co**

**Table 4.10 2004 Toyota Prius, Honda Civic Hybrid, and Honda Insight features**[61]

| | 2004 Toyota Prius | 2004 Honda Civic Hybrid | 2004 Honda Insight |
|---|---|---|---|
| Manufacturers suggested retail price (MSRP) | $20,510 | $19,650 | $19,180 |
| Tax incentives? | Possibly yes | Possibly yes | Possibly yes |

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[60] http://www.fueleconomy.gov/
[61] http://www.fueleconomy.gov/

**Table 4.11 2004 Toyota Prius, Honda Civic Hybrid, and Honda Insight features**[62]

| | 2004 Toyota Prius | 2004 Honda Civic Hybrid | 2004 Honda Insight |
|---|---|---|---|
| Fuel type | Regular gasoline | Regular gasoline | Regular gasoline |
| Mileage per gallon (City) | 60 | 47 | 57 |
| Mileage per gallon (Highway) | 51 | 48 | 56 |
| Combined mileage per gallon (45% highway and 55% city driving for 15,000 miles) | 55 | 47 | 56 |
| Annual fuel cost (regular gasoline at $1.40 per gallon) | $382 | $447 | $376 |
| Annual greenhouse gas emissions (tons) | 3.5 tons | 4.1 tons | 3.5 tons |
| EPA Size class | Midsize cars | Compact cars | Two-seaters |
| Engine size (liters) | 1.5 liters | 1.3 liters | 1 liters |
| Number of cylinders | 4 | 4 | 3 |
| Transmission | Automatic | Automatic | Automatic |
| Drive | Front-wheel drive | Front-wheel drive | Front-wheel drive |
| Passenger volume ($ft^3$) | 96 $ft^3$ | 91 $ft^3$ | NA |
| Luggage volume ($ft^3$) | 16 $ft^3$ | 10 $ft^3$ | NA |

## *4.2 Electric cars*

Major auto manufacturers had begun selling small quantities of electric vehicles, but most of them have discontinued electric vehicles all together. By the end of 2003, Honda had discontinued its offerings; Daimler-Chrysler did not have anything available for the public, except for its low speed vehicle, GEM; General Motors completed recalling all electric vehicles it had leased to fleet users; Ford withdrew from TH!NK EV; and Toyota drew the

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[62] http://www.fueleconomy.gov/

plug to its electric RAV4 SUV.

### 4.2.1 Neighborhood electric vehicles[63]

Neighborhood electric vehicles (NEVs) are compact, rechargeable using ordinary AC outlets, and suited for traveling shorter distances at slower speeds than conventional vehicles. Several lesser known companies have offerings in this category. Drivers who live close to their school or workplace and commute for a short time, and those who need cars for occasional grocery shopping are among the prime target for NEVs. It is important to note that mileage information is not available.

**Table 4.12 NEVs by Big Man**

| | 2004 Barton | 2004 Shorty |
|---|---|---|
| Sticker Price | $10,500 | $10,500 |
| Estimated driving range (city) | 75 mi | 75 mi |
| Top speed | 25 mi/hr | 25 mi/hr |
| Battery type and number | Lead acid, 8 | Lead acid, 8 |
| Battery Life | Unavailable | Unavailable |
| Charge time at 110V | 10 hrs | 10 hrs |
| Maximum passengers | 5 | 2 |
| Drive | Rear-wheel drive | Rear-wheel drive |
| Gross vehicle weight | 2,250 lbs | 2,450 lbs |

**Table 4.13 NEVs by Colombia ParCar**

| | 2003 2-Passenger | 2003 2-Passenger LX | 2003 4-Passenger | 2003 4-Passenger LX | 2003 NEV Cargo Express |
|---|---|---|---|---|---|
| Sticker Price | $5,916 | $6,972 | $8,336 | $9,362 | $6,952 |
| Estimated driving range (city) | 50 mi | 50 mi | 50 mi | 50 mi | 50 mi |
| Top speed | 25 mi/hr | 25 mi/hr | 25 mi/hr | 25 mi/hr | 25 mi/hr |
| Battery type and number | Lead acid, 8 | Lead acid, 8 | Lead acid, 8 | Lead acid, 8 | Lead acid, 8 |

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[63] http://www.ccities.doe.gov/vbg/consumers/

**Table 4.14 NEVs by Colombia ParCar**

| | 2003 2-Passenger | 2003 2-Passenger LX | 2003 4-Passenger | 2003 4-Passenger LX | 2003 NEV Cargo Express |
|---|---|---|---|---|---|
| Battery Life | Unavailable | Unavailable | Unavailable | Unavailable | Unavailable |
| Charge time at 110V | 8 hrs | 8 hrs | 8 hrs | 8 hrs | 8 hrs |
| Maximum passengers | 2 | 2 | 4 | 4 | 4 |
| Drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive |
| Gross vehicle weight | 1,910 lbs | 1,910 lbs | 2,460 lbs | 2,460 lbs | 2,460 lbs |

**Table 4.15 NEVs by Dynasty Motorcar Corporation**

| | 2004 IT Sedan | 2004 IT Tropic | 2004 IT Van |
|---|---|---|---|
| Sticker Price | $13,000 | $13,000 | $13,000 |
| Estimated driving range (city) | 30 mi | 30 mi | 30 mi |
| Top speed | 25 mi/hr | 25 mi/hr | 25 mi/hr |
| Battery type and number | Lead acid, 6 | Lead acid, 6 | Lead acid, 6 |
| Battery Life | 3 yrs | 3 yrs | 3 yrs |
| Charge time at 110V | 6 hrs | 6 hrs | 6 hrs |
| Maximum passengers | 4 | 4 | 4 |
| Drive | Front-wheel drive | Front-wheel drive | Front-wheel drive |
| Gross vehicle weight | 2,601 lbs | 2,601 lbs | 2,600 lbs |

**Table 4.16 NEVs by Global Electric Motorcars**

| | 2004 2-Passenger NEV | 2004 4-Passenger NEV | 2004 Long-Back NEV | 2004 Short-Back NEV |
|---|---|---|---|---|
| Sticker Price | $6,995 | $8,995 | $8,695 | $7,595 |
| Estimated driving range (city) | 30 mi | 30 mi | 35 mi | 30 mi |
| Top speed | 25 mi/hr | 25 mi/hr | 25 mi/hr | 25 mi/hr |
| Battery type and number | Lead acid, 6 | Lead acid, 6 | Lead acid | Lead acid |
| Battery Life | 3 to 5 yrs | 3 to 5 yrs | 3 to 5 yrs | 3 to 5 yrs |
| Charge time at 110V | 6 to 8 hrs | 6 to 8 hrs | 6 to 8 hrs | 6 to 8 hrs |
| Maximum passengers | 2 | 4 | 2 | 2 |
| Drive | Front-wheel drive | Front-wheel drive | Front-wheel drive | Front-wheel drive |
| Gross vehicle weight | 1,600 lbs | 2,100 lbs | 2,300 lbs | 1,850 lbs |

**Table 4.17 NEVs by Neighborhood Electric Vehicle Company**

| | 2003 Gizmo |
|---|---|
| Sticker Price | $8,950 |
| Estimated driving range (city) | 45 mi |
| Top speed | 45 mi/hr |
| Battery type and number | Lead acid |
| Battery Life | 3 to 5 yrs |
| Charge time at 110V | 8 hrs |
| Maximum passengers | 1 |
| Drive | Rear-wheel drive |
| Gross vehicle weight | 1,000 lbs |

**Table 4.18 NEVs by Scooterteq**

| | 2004 EG-2023 | 2004 EG-2023 Security | 2004 EG-2024-2 | 2004 EG-2044-4 | 2004 EG-6041-4 | 2004 EG-6061-6 |
|---|---|---|---|---|---|---|
| Sticker Price | Purchase or lease | Unavailable | Unavailable | Unavailable | Unavailable | Unavailable |
| Estimated driving range (city) | 48 mi | 48 mi | 42 mi | 48 mi | 48 mi | 48 mi |
| Top speed | 15 mi/hr | 15 mi/hr | 13 mi/hr | 13 mi/hr | 15 mi/hr | 13 mi/hr |
| Battery type and number | Lead acid, 6 | Lead acid, 6 | Lead acid, 6 | Lead acid, 6 | Lead acid, 8 | Lead acid, 8 |
| Battery Life | Unavailable | Unavailable | Unavailable | Unavailable | Unavailable | Unavailable |
| Charge time at 110V | 8 to 10 hrs | 8 to 10 hrs | 8 to 10 hrs | 8 to 10 hrs | 8 to 10 hrs | 8 to 10 hrs |
| Maximum passengers | 2 | 2 | 2 | 4 | 4 | 6 |
| Drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive |
| Gross vehicle weight | 2,160 lbs | 2,160 lbs | 1,940 lbs | 1,190 lbs | 2,558 lbs | 2,558 lbs |

**Table 4.19 NEVs by Western Golf Cars**

| | 2004 Elegante | 2004 Lido Runabout | 2004 Lido Sedan | 2004 Model 100 | 2004 Model 300 | 2004 Model 400 |
|---|---|---|---|---|---|---|
| Sticker Price | $12,950 | $14,100 | $14,100 | $11,295 | $8,995 | $7,885 |
| Estimated driving range (city) | 35 mi | 40 mi | 40 mi | 35 mi | 35 mi | 35 mi |

**Table 4.20 NEVs by Western Golf Cars**

| | 2004 Elegante | 2004 Lido Runabout | 2004 Lido Sedan | 2004 Model 100 | 2004 Model 300 | 2004 Model 400 |
|---|---|---|---|---|---|---|
| Top speed | 25 mi/hr | 25 mi/hr | 25 mi/hr | 25 mi/hr | 25 mi/hr | 25 mi/hr |
| Battery type and number | Lead acid, 7 | Lead acid, 8 | Lead acid, 8 | Lead acid, 7 | Lead acid, 7 | Lead acid, 7 |
| Battery Life | Unavailable | 3 yrs | 3 yrs | Unavailable | Unavailable | Unavailable |
| Charge time at 110V | 7 hrs | 6 to 8 hrs | 6 to 8 hrs | 7 hrs | 7 hrs | 7 hrs |
| Maximum passengers | 2 | 4 | 4 | 2 | 2 | 2 |
| Drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive | Rear-wheel drive |
| Gross vehicle weight | 1,000 lbs | 1,470 lbs | 1,470 lbs | 1,000 lbs | 1,000 lbs | 1,000 lbs |

## *4.3 Fuel cell cars*

Fuel cell cars are still in the development phase, and as such, are not available commercially. The current administration, under President Bush's initiative, aims to have fuel cell vehicles become a viable option for the public by 2020[64]. Industry predictions are more optimistic, but deployment will be no earlier than 2005, hopefully before 2010.

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[64] http://www.whitehouse.gov/news/releases/2003/01/20030128-14.html

# Chapter 5: Policies and Tax Benefits

The current chapter focuses on approaches taken by the federal government and state governments, namely California, to make zero-emission and low-emission vehicles a viable choice for the public. We will examine the reasons for and how various government agencies and industry are cooperating to make alternative automotive technologies readily available. We will also summarize Kyoto protocol, which is an international environmental treaty.

## *5.1 Current Bush administration's approach*

Energy and environment have been key issues for the current administration, although other important issues such as national security and the economy have overshadowed these issues. President G. W. Bush has addressed these issues in every State of the Union Address since 2002:

In his 2002 State of the Union Address:

> Consumers and businesses need reliable supplies of energy to make our economy run -- so I urge you to pass legislation to modernize our electricity system, promote conservation, and make America less dependent on foreign sources of energy. (Applause.)[65]

In 2003:

> Our third goal is to promote energy independence for our country, while dramatically improving the environment. (Applause.) I have sent you a comprehensive energy plan to promote energy efficiency and conservation, to develop cleaner technology, and to produce more energy at home. (Applause.) I have sent you Clear Skies legislation that mandates a 70-percent cut in air pollution from power plants over the next 15 years. (Applause.) I have sent you a Healthy Forests Initiative, to help prevent the catastrophic fires that devastate communities, kill wildlife, and burn away millions of acres of treasured forest. (Applause.)
>
> I urge you to pass these measures, for the good of both our environment and our economy. (Applause.) Even more, I ask you to take a crucial step and protect our environment in ways that generations before us could not have imagined.

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[65] http://www.whitehouse.gov/news/releases/2004/01/20040120-7.html

> In this century, the greatest environmental progress will come about not through endless lawsuits or command-and-control regulations, but through technology and innovation. Tonight I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles. (Applause.)
>
> A single chemical reaction between hydrogen and oxygen generates energy, which can be used to power a car -- producing only water, not exhaust fumes. With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free. (Applause.)
> Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy. (Applause.) [66]

And, in 2004:

> Good jobs also depend on reliable and affordable energy. This Congress must act to encourage conservation, promote technology, build infrastructure, and it must act to increase energy production at home so America is less dependent on foreign oil. (Applause.)
>
> Members, you and I will work together in the months ahead on other issues: productive farm policy -- (applause) -- a cleaner environment -- (applause) -- broader home ownership, especially among minorities -- (applause) -- and ways to encourage the good work of charities and faith-based groups. (Applause.) I ask you to join me on these important domestic issues in the same spirit of cooperation we've applied to our war against terrorism. (Applause.)[67]

### *5.2 FreedomCAR and Fuel initiatives*[68,69,70]

President Bush presented the FreedomCAR Initiative in 2002, and in his 2003 State of the Union Address, he unveiled the Freedom Fuel Initiative. The two initiatives are aimed at

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[66] http://www.whitehouse.gov/news/releases/2003/01/20030128-19.html
[67] http://www.whitehouse.gov/news/releases/2002/01/20020129-11.html
[68] http://www.whitehouse.gov/news/releases/2003/02/20030206-2.html
[69] http://www.energy.gov/engine/content.do
[70] http://www.whitehouse.gov/news/releases/2003/02/20030206-2.html

making fuel cell vehicles available to the public at a reasonable price by 2020. It is hoped that the initiatives lead to higher energy independence for the United States, and also contribute to improve the environment.

The proposed five-year budget from 2003 to 2007 is in Table 5.1:

**Table 5.1 Freedom CAR and FUEL budget**

| | Budget | |
|---|---|---|
| Freedom FUEL | $1.2 billion annually for 5 years | Maximum additional funding of $720 million in 5 years |
| Freedom CAR | $500 million in 5 years | |
| Total | $1.7 billion annually, for 5 years | |

Note:
1) These figures represent spending by the federal government, and therefore it is not clear how much has been and will be spent by industry on related projects.
2) Although the total annual budget is $1.7 billion, additional investment amounts to $720 million in 5 years.
3) For FreedomCAR alone, the 2003 budget was $150 million, while the 2004 budget is $273 million.

### 5.2.1 FreedomCAR

In 1993, former President Clinton announced the Partnership for a New Generation of Vehicles (PNGV) to improve the fuel efficiency of conventional cars threefold. In 2002, President Bush effectively replaced PNGV with FreedomCAR, CAR being short for cooperative automotive research. FreedomCAR is a collaborative effort between the Department of Energy, which seeks to make hydrogen the primary fuel for cars and trucks, and American motor companies. Under FreedomCAR, research in fuel cell technology receives more funding than it had under PNGV.

### 5.2.2 FreedomFUEL

The main goal of the Freedom FUEL initiative is to develop technology and infrastructure for manufacturing, storing, and delivering hydrogen to and for fuel cell vehicles and power generation. Specifically,

1. Reduce the price of hydrogen produced from natural gases to a level that can compete with gasoline by 2010; currently, hydrogen costs 4 times as much as gasoline.
2. Improve current methods to extract hydrogen using renewable energy sources and nuclear energy and methods to extract hydrogen from coal.
3. Produce on-board hydrogen storage tanks that can meet the demands of consumers.

According to 2003 Department of Energy (DOE) figures, the United States imports roughly 10 to 11 million barrels of crude oil per day. DOE predicts that the initiatives will lead to lower demand for cruel oil, by approximately 11 million barrels per day, by 2040, and additionally, they expect yearly carbon dioxide production to be lower by 500 million tons by 2040.

## *5.3 California low-emission vehicles regulations*

In an effort to reduce vehicle emissions and pollution within the state, the California Air Resources Board (CARB) introduced the ZEV Mandate. The original 1990 mandate required that 10% of new vehicles sold in California must be ZEVs by 2003 (3% in 1998, 5% by 2001). Facing pressure from industry, CARB revised the mandate twice. In 1996, they removed the 1998 and 2001 requirements, leaving the 10% requirement by 2003. CARB changed the mandate incrementally in 1999 and 2001 to let manufacturers achieve the 10% by assigning credit points to various vehicle classes. Furthermore, as a result of a lawsuit by industry in 2003, the 10% will not come into effect until 2005.

### 5.3.1 Vehicle Categories

The four categories defined by the CARB are, in order of increasing stringency,

- Transitional low emission vehicles (TLEVs)
- Low emission vehicles (LEVs)
- Ultra low emission vehicles (ULEVs)
- Zero emission vehicles (ZEVs)

Details are shown below in Table 5.2:

**Table 5.2 Emission standards and time schedule**[71]

| Vehicle category | Emission standard (gram/mile) | | | New vehicle market penetration (year) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | 2% | 10% | 15% | 20% | 25% | 75% |
| TLEV | 0.125 | 3.4 | 0.4 | | 94 | | 96 | | |
| LEV | 0.075 | 3.4 | 0.2 | | | | | 97 | 03 |
| ULEV | 0.040 | 1.7 | 0.2 | 97 | | 03 | | | |
| ZEV | 0.000 | 0.0 | 0.0 | | 05 | | | | |

Currently, only electric cars fall under the ZEV category, which only admits cars that emit zero tailpipe or evaporative emissions.

## *5.4 CAFE standards*[72]

CAFE (Corporate Average Fuel Economy) standards strictly define minimum fuel efficiency for passenger cars, light trucks, and SUVs. The regulation was first adopted in 1975 in response to the oil crisis, aiming to double fuel efficiency by 1985.

For passenger cars, the required minimum fuel efficiency begat at 18.0 mpg in 1978, and rose to 27.5 mpg in 1990. Required minimum fuel efficiency for light trucks started at 18.2 mpg in 1979, reached 21.0 mpg by 2001, and will increase to 22.2 mpg in 2007.

Car manufacturers that fail to meet CAFE standards pay $5.00 for every 0.1 mpg short of the target, per car. For example, if a car manufacturer today produced 1,000,000 cars with an average fuel efficiency of 27.6 mpg, they are fined $5,000,000.

CAFE standards caused the average fuel efficiency to peak at 26.2 mpg in 1987, when light trucks made only 28.1% of the market. Yet, the average fuel efficiency dropped to 24.4 mpg by 2001 because light trucks had comprised nearly 50% of the market. The popularity of SUVs, which are generally inefficient compared to smaller cars, contributes to this trend

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[71] P167 of Natural Gas Vehicles

[72] http://www.ita.doc.gov/td/auto/cafe.html

## *5.5 Tax deductions*[73,74]

Under current legislation, the Toyota Prius, the Honda Civic Hybrid, and the Honda Insight are tax-deductible. Hybrid vehicles by other manufacturers, once available, will also be tax deductible. Congress, however, is considering changing the tax incentives for purchasing hybrid vehicles, so close attention must be paid.

**Table 5.3 Tax deductions on hybrid cars**

| Year of Purchase | Maximum Deduction per Vehicle |
|---|---|
| 1992-2003 | $2,000 |
| 2004 | $1,500 |
| 2005 | $1,000 |
| 2006 | $500 |

Similarly, electric cars, although not readily available, are tax deductible.

**Table 5.4 Tax deductions on electric cars**

| Year of Purchase | Credit (% of cost) | Maximum Deduction per Vehicle |
|---|---|---|
| 1992-2003 | 10% | $4,000 |
| 2004 | 7.5% | $3,000 |
| 2005 | 5% | $2,000 |
| 2006 | 2.5% | $1,000 |

## *5.6 Kyoto protocol*

The Kyoto protocol was adopted at the Conference of Parties 3 (COP3) in 1997. It aimed to reduce the production of six greenhouse gases to slow down global warming. The six greenhouse gases are $CO_2$, $CH_4$, $N_2O$, HFC, PFC, and $SF_6$. All countries that ratify the

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[73] http://www.irs.gov/pub/irs-news/ir-02-64.pdf

[74] http://www.fueleconomy.gov/feg/tax_hybrid.shtml

Kyoto protocol are required to reduce the emissions of the six greenhouse gases according to individual reduction goals. The reduction goals for some developed countries are[75]:

EU -8%　USA -7%　Japan -6%　Canada -6%　Russia 0%　New Zealand 0%
Norway +1%　Australia +8%

The reduction goals are relative to 1990 levels of $CO_2$, $CH_4$, and $N_2O$ emissions and 1995 levels of HFC, PFC, and $SF_6$. The goals have been set so that the developed countries can reduce greenhouse gas emissions by 5% by 2012. The US and Russia have yet to ratify the Kyoto Protocol. President Bush declared in 2001 that the US would not ratify the Kyoto Protocol on the grounds that

> Kyoto is, in many ways, unrealistic. Many countries cannot meet their Kyoto targets. The targets themselves were arbitrary and not based upon science. For America, complying with those mandates would have a negative economic impact, with layoffs of workers and price increases for consumers. And when you evaluate all these flaws, most reasonable people will understand that it's not sound public policy.[76]

The Kyoto Protocol requires that at least 55 countries ratify it and that the total $CO_2$ emission by those countries exceeds 55% of the world emission[77]. Since the US emitted 22% of manmade CO2 in 1990 and is still the largest emitter of CO2, the decision had a negative impact on the Kyoto Protocol. As such, whether or not the Kyoto Protocol goes into effect depends on Russia ratifying the Protocol.

Even if the Kyoto Protocol becomes reality, there are many loopholes in the treaty, namely the Kyoto mechanism. The Kyoto mechanism consists of three parts: joint implementation, clean development, and emissions trading. In joint implementation, developed countries can meet part of their reduction goals by helping to build and implement environmentally clean power plants and factories in other countries. Similarly, with clean development, developed countries can partially satisfy reduction goals by helping other countries with environmental projects (e.g., forestation for absorbing CO2). Finally, with emissions trading, countries that more than meet their reduction goals can sell excess reductions to other countries. Russia benefits the most from emissions trading. The Russian economy, despite its modest size in 1990, has shrunk significantly over since the collapse of the Soviet Union. Russia effectively has no reduction goal, and can sell reduction credits easily.

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[75] http://www.mofa.go.jp/mofaj/gaiko/kankyo/kiko/cop3/k_koshi.html
[76] http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html
[77] http://unfccc.int/resource/kppop.html

Using the Kyoto mechanism, developed countries can avoid reducing greenhouse-gas emissions domestically. Russia asked for economic favors in exchange for ratifying the Kyoto Protocol. Many countries did the same. Thus, the Protocol has been more economic diplomacy than environmental treaty. We must wait to see whether or not the Protocol will function as intended.

# Chapter 6: Analysis

In this chapter, we will examine the potential impact of the widespread acceptance of alternative fuel vehicles. We will make estimates and predictions to trace the possible outcomes of emissions regulation and the introduction of low emission vehicles. Our focus will be on economical, environmental, and health issues.

## *6.1 Reduction of oil consumption and emissions by hybrids*

### 6.1.1 Reduction of oil Consumption and $CO_2$

In 2001, there were roughly 222 million passenger cars in the US[78]. If all small and medium passenger cars in the US are replaced by corresponding hybrid cars, there will be some reduction in the gasoline consumption and $CO_2$ emission.

We begin our estimation using Table 3.2: we take the average gas mileage for hybrid sedan to be 51 mpg; for the hybrid mini-van, 37 mpg; and, 37 mpg for small and medium hybrid SUVs (this figure is based on our assumption that hybrids, on average, have 1.7 times the gas mileage of their conventional counterparts). For gasoline cars, we also refer to Table 3.2: sedans have 28 mpg; mini-vans have 23 mpg; and SUVs have 22 mpg. Of all US passenger cars, about 50% are sedans, 11% are mini-vans, and 10% are SUVs[79,80]. Hence, considering that the average person travels on a passenger vehicle 12,000 miles per year[81], 31.2 billion gallons of gasoline per year can be saved by replacing all conventional passenger vehicles with corresponding hybrids. This savings would amount to 10% of total US oil consumption, and the cost of oil that can be saved is $43.7 billion.

Next, we compare $CO_2$ emissions. We take 77 g/km (grams $CO_2$ per kilometer of run) for a hybrid sedan, 136 g/km for a hybrid mini-van, and 130 g/km for hybrid SUV (again, this third figure is based on an assumption - that $CO_2$ emission in hybrid cars is approximately half of their counterparts), 180 g/km for a conventional sedan, 250 g/km for a mini-van, and 260 g/km for an SUV. Replacing sedans, mini-vans and SUVs with their hybrid equivalents can reduce 308 million tons of $CO_2$ per year, which is 5% of total $CO_2$ emissions in the US in 2001.

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[78] Table 1-11 of National Transportation of Statistics 2003
[79] Table 1-19 of National Transportation of Statistics 2003
[80] Table 1-20 of National Transportation of Statistics 2003
[81] http://www.meti.go.jp/report/downloadfiles/g30808d7j.pdf

Reducing oil consumption by 10% is a significant step towards independence from foreign imported oil. Currently, 53% of all oil consumed in the US is imported. The Persian Gulf region is particularly important to the US, imports 12.6% of its oil from the region. Political instability, however, has been a recurrent issue for the Persian Gulf region; such political climate has ramifications for oil import, namely fluctuation in the supply and price of oil. Replacing passenger cars with equivalent hybrids can help minimize oil imports from the Persian Gulf region.

In this way, the US can focus political and financial resources on importing oil from more politically stable countries, while also moving stationed troops out of the region, an important source of fiscal burden. Furthermore, estimates say that domestic oil production will peak in 2008. In 2008, oil production will be 3% greater than in 2000, but by 2025, it will drop to 4.5% below the 2000 level. Meanwhile, oil consumption is expected to increase by 40% by 2025[82]. Therefore, a 10% reduction in US oil consumption by introducing hybrids is crucial in meeting energy needs.

According to the yet unimplemented Kyoto Protocol, the US must reduce $CO_2$ emissions by 7% in comparison to 1990 levels. Some 5 billion tons of $CO_2$ was emitted in 1990, and by 2001, annual emissions had reached 5.8 billion tons[83]. If the US decides to ratify the Protocol, the US must reduce annual $CO_2$ emissions by at least 1 billion tons. Replacing all passenger vehicles with hybrids alone can accomplish 28% of the reduction goal. The rest, 72%, needs to be achieved through other means. Replacing all passenger vehicles with hybrids is itself a daunting task, so unless we have a variety of ways to reduce $CO_2$ emissions, ratifying the Kyoto Protocol is at best unreasonable.

Replacing all small and medium passenger cars within the US is not an overnight task; the reduction goal. According to the Protocol, must be met by 2012; yet, auto manufacturers are just beginning to make hybrid vehicles available to the public. Therefore, if the US is to achieve reduction in $CO_2$ emission of the scale on Protocol goals, then a more concerted effort among industries and sectors is necessary.

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[82] http://www.eia.doe.gov/oiaf/aeo/gas.html

[83] http://www.eia.doe.gov/emeu/aer/txt/ptb1201.html

### 6.1.2 Comparability of emissions of NOx, HC, and CO

Today, hybrids and gasoline cars typically have similar NOx, HC, and CO emissions, the notable exception being the Toyota Coaster, specifically designed to further reduce emissions. The reason is simple – emissions of these gases are strictly regulated, and newer vehicles have to meet more stringent emission standards. Naturally, manufacturers must produce cleaner cars, cars that emit as little NOx, HC, and CO as possible. On the contrary, $CO_2$ emission is unregulated, save the unimplemented Kyoto Protocol. Correspondingly, $CO_2$ emission varies from company to company, from model to model.

Reducing harmful gases, such as NOx, HC, and CO, requires more ingenuity than changing the structure of the internal combustion engine, used in both gasoline cars and in hybrids. Manufacturers have devised and synthesized various catalysts to adsorb these gases. This method is used in gasoline cars as well as in hybrids, so emission levels for the three gases are usually comparable. On the other hand, $CO_2$ emission is tied with internal combustion and cannot be reduced by catalysis, so hybrids, which use the internal combustion engine less than a comparable gasoline vehicle, generally emit less $CO_2$.

## *6.2 Reduction of emissions by natural gas and LPG cars*

### 6.2.1 Reduction of emissions from large vehicles

Natural gas and LPG are used as replacement for diesel cars because they emit less PM, HC, and NOx, which cause air pollution. Currently, roughly 281,000 LPG cars and 130,000 natural gas cars are running on the road[84], comprising all trucks and buses in the US.

To calculate the reduction in emission by introducing LPG and natural gas cars, we say that all gasoline and diesel trucks and buses, which many of them run on diesel, are replaced by 50% LPG trucks and buses, and the rest by natural gas trucks and buses. Currently, there are twice as many LPG cars as natural gas cars, but natural gas cars are quickly gaining popularity[85]. Thus, we can safely assume that there will be just as many natural gas cars as LPG cars in the near future.

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[84] Table 1-11 of National Transportation of Statistics 2003

[85] Figure 3.13 and Figure 3.14

Compared to diesel trucks and buses, the replacement results in a 100% reduction of PM, a 90% reduction of HC, and an 87% reduction of $NO_x$. CO emission will increase by 28%, but this increase is much smaller than the 420% increase when replacing diesel trucks and buses by gasoline trucks and buses. Considering all US automobiles together, the replacement causes a 65% reduction of PM, a 50% reduction of HC, a 24% reduction of $NO_x$, and a 6% increase of CO[86,87]. The increase in CO is negligible since trucks and buses account for only 4% of US automobiles. By replacing only 4% of US vehicles, we can significantly reduce automotive air pollution in the US. This would have a large impact on reducing air pollution in urban and suburban regions. It is easy to introduce natural gas and LPG trucks and buses since gasoline and diesel automobiles can be easily and cheaply converted to their natural gas and LPG counterparts. Hence, the cost of converting only 4% of US automobiles to reduce air pollution is a small one to pay.

Natural gas cars consume 0.06% of all natural gas in the US while LPG cars consume 1.83% of LPG. If the replacement occurs, natural gas trucks and buses would consume 2% of natural gas and LPG trucks and buses would consume 11.7% of LPG. The percentage increase in LPG consumption is much higher than the percentage increase in natural gas consumption. As natural gas production is expected to rise, increased natural gas consumption is not a significant issue. The increase in LPG consumption can be compensated by producing more LPG from natural gas. Currently, 66% of LPG is produced from oil, and 34% is produced from natural gas[88]; thanks to projected increase in natural gas production, less oil and more natural gas can be used be used to produce more LPG. In addition, because natural gas and LPG trucks and buses replace diesel ones, oil used for diesel trucks and buses can be used to produce further LPG.

A smaller percentage of natural gas and LPG is imported from abroad compared to oil. Only 15.5% of natural gas and 5.8% of LPG are imported from foreign countries compare to 53% for oil[89,90]. The production of oil is expected to decrease in the US. So, it is certainly rational to depend more on natural gas and LPG and less on oil for energy. The replacement leads to an 8% decrease in US oil consumption, a significant reduction to say the least.

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[86] http://www.epa.gov/ttn/chief/efdocs/fugitivedust.pdf

[87] Section 3.2

[88] http://www.j-lpgas.gr.jp/intr/03/index.html

[89] http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2000/natgas_imports_exports_2000/fa082001.pdf

[90] http://www.eia.doe.gov/emeu/aer/txt/ptb0503.html

Consumers now pay roughly the same price for gasoline, natural gas, and LPG[91]. Prices seem to favor the use of natural gas and LPG.

### 6.2.2 Reduction of emissions from passenger cars

Natural gas and LPG can be introduced to small and medium passenger cars as well. Honda already is producing natural gas Civics[92]. There are 240,000 LPG taxies running in Japan[93]. As with the previous section, we will estimate the effect of replacing all gasoline and diesel passenger cars with natural gas and LPG ones.

In Figure 3.4, we estimate that we can reduce emissions of $NO_x$ by 57%, HC by 79%, CO by 96%, and $CO_2$ by 14%. It will reduce all automotive emission of $NO_x$ by 23%, HC by 35%, CO by 76%, and $CO_2$ by 1.3%. Natural gas and LPG cars emit less $NO_x$, HC, and CO even in comparison to hybrid cars, due to their use of different fuel. Replacing gasoline cars with natural gas and LPG cars does not reduce $CO_2$ emissions as much as replacing gasoline cars with hybrid cars (53% reduction if $CO_2$ from passenger cars, 5% reduction from automotive $CO_2$ emissions). This is because hybrids have internal combustion engines that are more efficient.

In this replacement plan, 35% of all natural gas consumed and 456% of all LPG must be reallocated for use in passenger cars. Thus, the replacement has to tale place gradually. In the short term, these demands can be met partially, due to a forecasted increase in natural gas production and the fact the oil can be used to produce LPG. Replacement with natural gas and LPG passenger cars can reduce US dependence on foreign oil, since gasoline passenger cars account for 42% of oil consumption in the US[94]. The switch seems a practical one.

Gasoline and diesel cars can be easily converted into natural gas and LPG cars for a few thousand dollars[95]. It is much easier than buying a new hybrid car, but we must keep in mind that the infrastructure for distributing natural gas and LPG is still limited. Hybrid cars do not need special infrastructure. A natural gas/electric or LPG/electric hybrid car would be cleaner and more efficient than natural gas, LPG, and hybrid cars. But, they do not exist yet. In the mean time, a mixture of natural gas, LPG, and hybrid cars will benefit the drivers, the environment, and the country.

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[91] Section 3.2

[92] http://www.honda.co.jp/auto-lineup/civic-gx/

[93] http://www.j-lpgas.gr.jp/lgv/index.html

[94] http://www.eia.doe.gov/cneaf/alternate/page/datatables/table10.html

[95] Section 3.2

### *6.3 Tax benefits*

Hybrid cars generally cost a few thousand dollars more than gasoline cars, but they are not as expensive in the long-run because of better mileage and tax benefits. Hybrid cars are tax deductible ($2,000 deduction in 2003)[96]. According to Table 4.6, choosing hybrid Civic over the gasoline Civic can help save $120 annually on fuel. Although other companies have not released hybrid versions of existing gasoline cars, for eight years, the average life time of a car in the US. Hybrid cars are not too expensive to maintain compared to gasoline cars also. The hybrid Civic effectively costs $3,680 more than the regular Civic. Highly fuel efficient to begin with, the difference in fuel cost between hybrid and gasoline Civics is not large. Also, the gasoline Civic is relatively cheap for its class. If we compare a Toyota Prius to a Corolla, it turns out that the Prius will effectively be $800 cheaper than Corolla. So the difference in the effective price depends from car to car, but as a general trend, hybrids are not competitive compared to cheap and fuel efficient gasoline cars.

Tax reductions for hybrids decrease every year. It is not clear as to why it should be so; perhaps budget is an issue. The annual budget for tax deductions stays the same while sales of hybrids are expected to rise; so that tax deductions per hybrid must fall. Currently, it is more economical for consumers to buy highly fuel efficient gasoline cars than to buy a hybrid. Then, if hybrids are to become more popular, tax deductions should not drop incrementally.

From a fiscal perspective, replacing all gasoline passenger cars with hybrids requires $315 billion worth of tax deductions. On the other hand, fuel costs saved only amount to $49.3 billion. There are hidden costs that justify further tax deductions. US military presence in the Persian Gulf costs $10 billion to $40 billion[97]. $CO_2$ emissions and their impact on the environment might have intangible costs. If the Kyoto protocol goes into effect, one ton of $CO_2$ can be sold at 10 to 20 euros ($11.69~$23.38). Introducing hybrids reduces US $CO_2$ emissions by 5%, which amounts to $3.6 billion to $7.2 billion worth of $CO_2$. What we cannot estimate is the environmental effects of $CO_2$ emission, such as the negative consequences of global warming. These costs are likely to be high. Therefore, spending $315 billion to replace gasoline cars with hybrids might be well worth the expenses.

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[96] Section 5.4

[97] Section 2.3

## *6.4 Regulations and their effects*

Air pollution has decreased significantly since emission regulations were adopted. Measurements show that there was a 48% reduction of CO, a 17% reduction of $NO_x$, a 51% reduction of HC, and a 34% reduction of PM in 2001 compared to 1970 levels[98]. The reduction was due to stringent regulations on emissions from both stationary and mobile sources. So regulations on car emissions certainly can be used to reduce emissions.

It is estimated that 1% of the US GNP comes from air pollution regulations. It amounts to $60 billion and more than 80% of that benefit is due to positive effects on human health. On the other hand, $32.7 billion is spent to control air pollution, and 56.7% ($18.5 billion) of the cost is spent to control mobile source emissions[99]. The net benefit of emissions regulation is $27.3 billion. The effects of stricter regulations are debatable, but available data shows that regulations generate benefits for the economy.

California ZEV mandate was initially intended to introduce 10% of ZEVs by 2003. The regulation was implemented in 1990 when both auto manufacturers and the state government expected that electric cars would be in the market as ZEVs in near future. However, when they came out from major auto manufacturers, there were problems with the car. The cost of car was much more expensive than gasoline one, the traveling range was short, it took longer time to refill electricity, and the replacement of batteries was also expensive. Even as the environmental consideration, it has been doubted that electric cars actually produce less emission. Since electricity is produced at generation sites and it is sent over a long distance, the energy loss can cause more emission. For these reasons, electric cars were not accepted by the public and major auto manufacturers stopped producing electric cars. So there is now no ZEV that is produced by major auto manufacturers.

While the failure of electric cars, other low emission vehicles have increased their number. Mainly, they are hybrid, natural gas, and LPG cars. They are not ZEVs, but they have fewer barriers to be used as a replacement of gasoline cars. So the state government decided to give partial ZEV credits to those low emission vehicles rather than forcing auto manufacturers to produce more electric cars. Auto manufacturers now can produce certain LEVs in order

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[98] http://www.epa.gov/airtrends/highlights.html
[99] P170 of Natural Gas Vehicle

to meet the requirement of ZEV mandate. In the future, fuel cell cars are the candidate of complete ZEVs. Fuel cell cars are expected to resolve problems electric cars had.

ZEV mandate was postponed until 2005 and there was still a lawsuit by auto manufacturers to discard the regulation completely, but in 2003, General Motors and Daimler-Chrysler cancelled the lawsuit. As a result, ZEV mandate will be in effect as it is planed after 2005[100]. Since auto manufacturers agreed upon the mandate, it is likely that they can produce ZEVs as required. In 2004, Toyota agreed to provide hybrid technology to Ford in order to enhance standardizing their hybrid technology in the market[101]. It seems that hybrid will be the major component of LEVs produced in order to meet the ZEV mandate.

Since the failure of electric cars and rise of other technology like hybrid and fuel cell were hard to predict, it was a reasonable thing to change the mandate. It was not totally caused by the auto manufacturers to protect their profits but rather technological improvement made the situation different. At this point, it is much better to introduce more hybrids than to introduce a few electric cars, which are not favorable economically and not even necessarily for the environment. So we would say that as long as auto manufacturers do not postpone the mandate any more, the change in the mandate is reasonable.

Because of CAFE standards, the fuel efficiency increased from 18.0 mpg to 27.5 mpg for passenger cars and 18.2 mpg to 21.0 mpg for light trucks in the last twenty years. We can estimate that we save 35.2 billion gallons of oil annually ($49.3 billion), which is 11% of total US oil consumption. If oil consumption had been 11% higher, we would have been more dependent on foreign oil imports. As discussed in Section 6.3, there are intangible costs other than the cost of oil itself. We might be able to eliminate military commitment in the Persian Gulf, and further reducing costs. Therefore, CAFE standards have positive effects on the US economy.

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[100] The Kyoto Newspaper, 8/12/03

[101] The Kyoto Newspaper, 3/9/04

# Chapter 7: Summary

Here, we outline the most important observation discussed in this work.

- Vehicle emissions are a leading source of US air pollution. Major air polluting emissions from cars are HC, $NO_x$, CO, and PM. $CO_2$, a greenhouse gas, is also emitted from cars.

- Cars are the major source of US oil consumption. The use of oil is not favorable economically and politically because oil is not a renewable energy source and because oil wells are concentrated in certain regions.

- Hybrid cars emit less $CO_2$ and approximately the same amount of HC, $NO_x$, CO, and PM compared to gasoline cars. Other alternative fuel cars (natural gas, LPG, methanol, and ethanol) emit significantly less HC, $NO_x$, CO, and PM and slightly less $CO_2$ compared to gasoline cars. Electric and fuel cell cars have no emissions.

- Among LEVs and ZEVs, hybrid, natural gas, and LPG cars have gained popularity. Not many methanol and electric cars are on the road. Fuel cell cars are not yet commercially available. Ethanol as a fuel is used as a mixture with gasoline.

- The US government will spend \$1.7 billion for the development of fuel cell cars and related infrastructures in the near future.

- By replacing all conventional small and medium-sized cars with hybrid cars, we can reduce US oil consumption by 10% and $CO_2$ emission by 5%.

- By replacing all conventional small and medium-sized cars with natural gas and LPG cars, we can significantly reduce air-polluting emissions. Hybrid natural gas/LPG cars reduce both air-polluting emissions and $CO_2$ emission.

- Hybrid cars, despite tax benefits, are not economically competitive against highly efficient gasoline cars. Larger tax deductions will encourage more users to consider hybrids.

- Air-pollution regulations and minimum fuel efficiency requirements have certainly contributed to reduced air pollution and oil consumption. Further regulations should be implemented as technology permits.

# Appendix

## Summary of interview 1

We interviewed Kazumasa Shiotani who is a director of the division of promotion of environmental policies within the department of environmental economy in Nagaokakyo City Hall in Kyoto, Japan.

*What is the type and number of LEVs and ZEVs?*

The city owns 9 garbage trucks and 7 trucks. Out of totally 16 large vehicles, 5 of them are natural gas cars. As a small vehicle, the city owns an electric car and the gymnasium in the city owns a Toyota Prius as a hybrid car. The electric car was introduced in 1994, Toyota Prius in 1998, and a natural gas car per year has been introduced for five years.

*What are the things you have noticed or learned after you started using LEVs and ZEVs?*

As the city uses those LEVs and ZEVs, they have seen some merits and weak points in each vehicle. For natural gas cars, they say that the vehicles make less vibration and noise compare to diesel cars. The emission is also cleaner ($CO_2$ 70-80%, NOx 10-30%, and 0% of black smoke compare to diesel cars). Natural gas cars can currently travel about as far as diesel cars with a refill. The problem of natural gas cars is that since there is no production line for the vehicle, there is no company that produces natural gas cars directly. Every natural gas car is converted from diesel or gasoline cars. Because of that, natural gas cars are about 20% more expensive compare to diesel cars. Another problem is that there are not yet enough gas stations for the vehicle. Natural gas cars have to travel far to be refilled, which makes the vehicle less efficient. For an electric car, they say that it is quiet and has no emission from the car. Since it makes much less noise, it can be dangerous for pedestrians because it is harder for them to know the car is close. The problem of an electric car is that it can go only 20 miles per refill. The acceleration is also slow. The battery has to be replaced every two years, and even before the replacement, the battery becomes less efficient as it is recharged many times. They also say that because there are not many companies that produce electric cars, the price of the car was relatively expensive because there was less competition among companies. Even after the purchase, the maintenance was more expensive. If we take into the consideration that electricity is produced in burning fossil fuel and that it is sent over a long distance before it is actually used, an electric car is not necessarily good for the environment. Because of these reasons, the city will not buy any more electric cars in the future. For a hybrid car, they just replaced the battery after they used it for five years. Because a hybrid car can be used in the same way as normal gasoline cars, it seems a hybrid car is more reasonable to use than an electric car.

*What is the future plan of introducing LEVs and ZEVs?*

As a future plan, the city will replace all trucks into natural gas cars. For normal size vehicles, the city will introduce the vehicles that pass the standard of ULEV (Ultra Low Emission Vehicle). As ULEV standard vehicles, the city plans to buy hybrid cars and light size vehicles.

*What kind of legislation is there to promote the use of LEVs and ZEVs?*

The purpose of introducing LEVs and ZEVs for the city is to fulfill the requirement of the Kyoto Protocol. The Kyoto Protocol requires Japan, the US, and EU to reduce respectively 6%, 7%, and 8% of six greenhouse gases ($CO_2$, $CH_4$, $N_2O$, HFC, PFC, and $SF_6$) compare to the emission level of 1990 by the year of 2012. By the introduction of LEVs and ZEVs, the city aims not only the reduction of greenhouse gases but also it is a part of promotion to make the civilians be aware of environmental issues. As a legislative aspect, the city has acquired ISO14001, which is an international standard on environmental policies. With ISO14001, the city is responsible for self-imposing environmental plans. The city has also made the plan for prevention of global warming.

*Is there any funding that helps purchasing LEVs and ZEVs?*

As the national policies that promote the use of LEVs and ZEVs for municipalities, the government gives financial aids on purchasing LEVs and ZEVs and has tax cuts on those vehicles. To help purchase LEVs and ZEVs, the government has the law which provides the financial aid for the people who wish to buy those vehicles. According to the law, the government pays the half of the difference in the price between conventional gasoline vehicles and LEVs and ZEVs. For example, if a natural gas car happens to cost $1000 more compare to a gasoline one, the government pays $500. For the tax cut, owners of LEVs and ZEVs are exempt from paying half amount of the car tax.

**Summary of interview 2**

We interviewed Prof. Arthur Gerstenfeld, who is a professor at Worcester Polytechnic Institute. He is a user of hybrid car Toyota Prius.

*What is the primary reason you chose to purchase a hybrid car?*

The first reason why he purchased a hybrid car was because of its cleaner emission. He was more concerned about the environment rather than the economical considerations. As a secondary reason, he brought the consideration of better gas mileage and saving of fuel.

*Has your decision to by a hybrid car affected the way you view environmental issue? If so, in what way has it influenced you?*

He said that since the car has less emission, he could think of himself reducing air pollution. He said he became more concerned about protecting plants and preserving better air that we can all breathe normally.

*Do you think your purchasing a hybrid car affected how others around you look at environmental issues?*

His wife liked the car and its idea, but his children were still more concerned about the design of the car. They did not like the car because of its design, therefore, they did not become more concerned about the environment because of the purchase.

*How did/does the price of your car compare to similar-sized cars?*

The price of the car was not much different from other same-size vehicles. Some of the cars in the same size were even more expensive than Prius.

*Is gas mileage as good as the manufacturer claims it to be?*

It has been claimed that Prius can travel at the mileage of 45 mpg, however, he said his car could only travel at the mileage of about 40 mpg. He said he might be because he used snow tires or because he drove the car in a less efficient manner.

*Can you tell when your car is running on entirely/mainly on electricity?*

He said he could not feel the difference clearly whether the car was operating with the electric motor or internal combustion engine. He could know it clearly only through the display in the car that shows the powering source.

*How is the driving experience compared to your previous car? Is it more comfortable?*

The acceleration was a little less than an ordinary gasoline car. He also said the car was a little noisier than his previous car. He assumed that it was because the car did not have enough insulators in order to increase the gas mileage.

*Have you had to replace the car batteries? How often do they have to be replaced?*

He has been using the car for three years, but he has not replaced them at all.

*How do maintenance costs compare to your previous vehicle?*

It was just the same as other gasoline cars. No extra maintenance costs were needed.

*Overall, do you feel that you financially/economically benefit from owning a hybrid car as opposed to a gasoline car?*

He said he was very satisfied with the car because there was not much difference in the price and maintenance costs, and he could still contribute to protect the environment.

Report of demonstration drive

We had a demonstration drive of the hybrid car for about ten minutes. The first thing I noticed was that the car shut off the engine completely while it is at stops. While at stops, it was quiet, and there was probably no emission. When it started moving, the display showed it was working with the electric motor. The motor was used much more times than we expected. Whenever the car was at slow speed or accelerating, the motor was used, and it was charged when the car was braked or even it was at constant speed. It was switched between operating with the motor and engine very often. The display could also show the gas mileage at each instance. It showed 100 mpg, which was the highest measurement, when the car operated fully with the motor. It is not obviously correct for the entire trip, so we had to look at the average gas mileage to know the value for the entire trip. The car performance was very similar to ordinary gasoline cars. We did not feel the much difference during the drive.

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