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The Clean Fuel/Vehicle Strategy for Hong Kong

An Interactive Qualifying Project Report
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by

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Abstract

This project, sponsored by Civic-Exchange, a non-profit "think tank" determined to improve Hong Kong's ecological infrastructures, explores possible solutions to air pollution in Hong Kong. The project helped Civic-Exchange to examine alternative fuels in replacing the usual fuel, diesel, in Hong Kong. The IQP analyzes the emission efficiencies of different types of alternative fuels and technologies by vehicle types and test cycles, as well as providing conclusions and recommendations based on the analyses of the data.

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Executive Summary

Civic-Exchange is a nonprofit "think tank" that has conducted a seven-month research project to help improve the ecological aspects of Hong Kong, funded by the Asia Foundation. The goal of the whole project is to find better advanced technologies to improve Hong Kong's air quality. The objective is to develop a clean fuel strategy for Hong Kong that focuses on comparing various fuel technologies. The scope of the whole project is to find feasible methods to utilize innovative technologies to improve the environment of Hong Kong.

Collected data was divided into three matrices of life-cycle stages for each alternative fuel technology and categorized by the types of vehicles. The life-cycle stages are emissions produced during the manufacture of the vehicle, the upstream (production) of the fuel and vehicle operation. The categories are passenger or light-duty vehicles, heavy-duty vehicles and transit buses. Each of the matrices was grouped into GHG (greenhouse gas) and pollutant emissions.

ES.1 Passenger Vehicles

Figure ES1 has the life-cycle emissions of all the alternative fuels and the main feedstock. The graph measured the life-cycle emissions on the upstream (production) of the fuel, the manufacture of a vehicle and the operation of the vehicle using the fuel. Observing the graph can clearly reveal hydrogen (hydroelectric) has the lowest CO_2 emission equivalent/mile out of all. Hydrogen vehicles only emitted water during combustion, therefore it produced no pollutants during vehicle operations, but it produced pollutions during the upstream of fuel and the manufacture of vehicles. On the other hand, petrol (300-ppm S) has the highest emissions of all.

E-85 produced from corn and cellulose has negative emission ratings for upstream of the fuel. The reason is because ethanol needs CO_2 in the production process to manufacture E-85, so the total emission of E-85 should be negative.

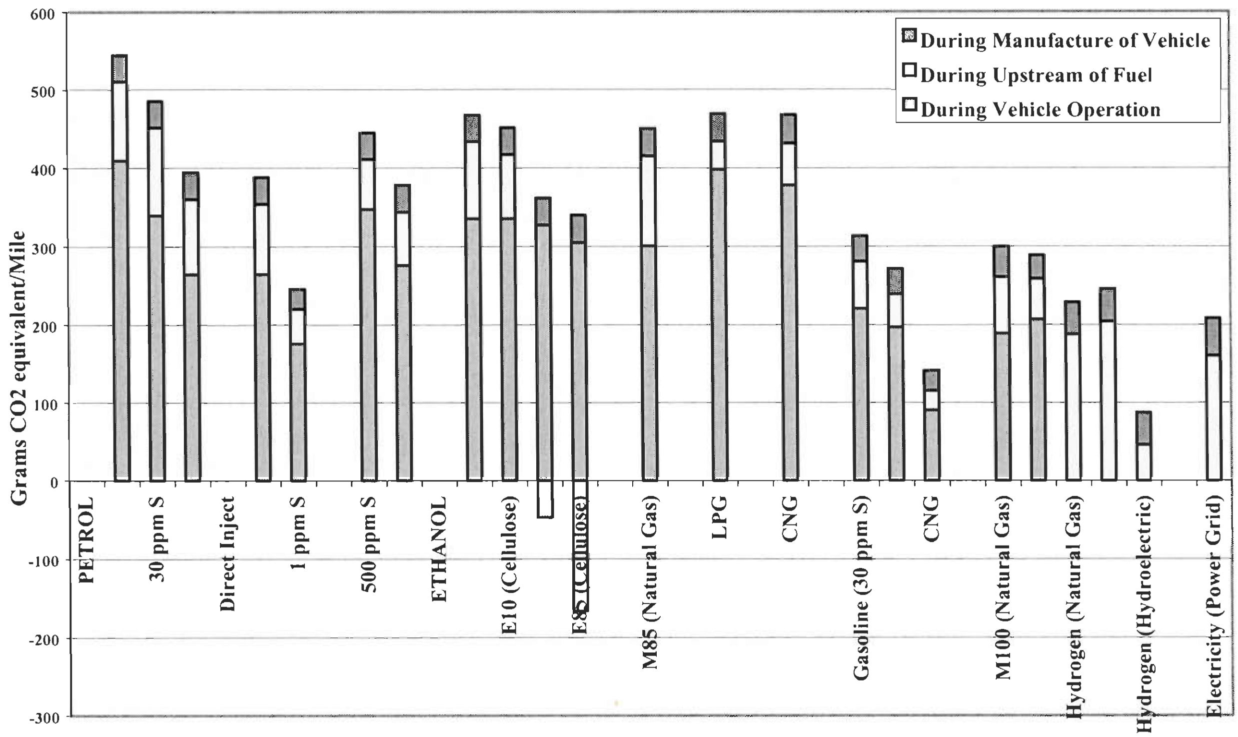

Figure ES1. The life-cycle GHG Emission for Passenger Vehicles

The analyses conclude that ethanol (E85) is very low in greenhouse gas (GHG) emissions but is very high for other pollutant emissions. Liquefied Petroleum gas (LPG) and compressed natural gas (CNG) have a very low particulate matter (PM) but high GHG emissions. Most of these technologies only benefit one stage of the life-cycle. The hybrid and fuel cell technology reduced most of the emissions, therefore they are the preferred solution out of all alternative fuel technologies for passenger vehicles.

ES.2 Heavy-duty Vehicles

Figure ES2 show the life-cycle emission of all alternative fuel technologies for heavy-duty vehicles. The result of biodiesel is similar to ethanol from Figure E1. It has a negative emission rate during the production of the fuel and has the overall lowest life-cycle GHG emission. On the other hand, conventional diesel (50-ppm sulfur) has the most emission rate for the life-cycle. Thus, conventional diesel is the worst fuel that a heavy-duty vehicle could use.

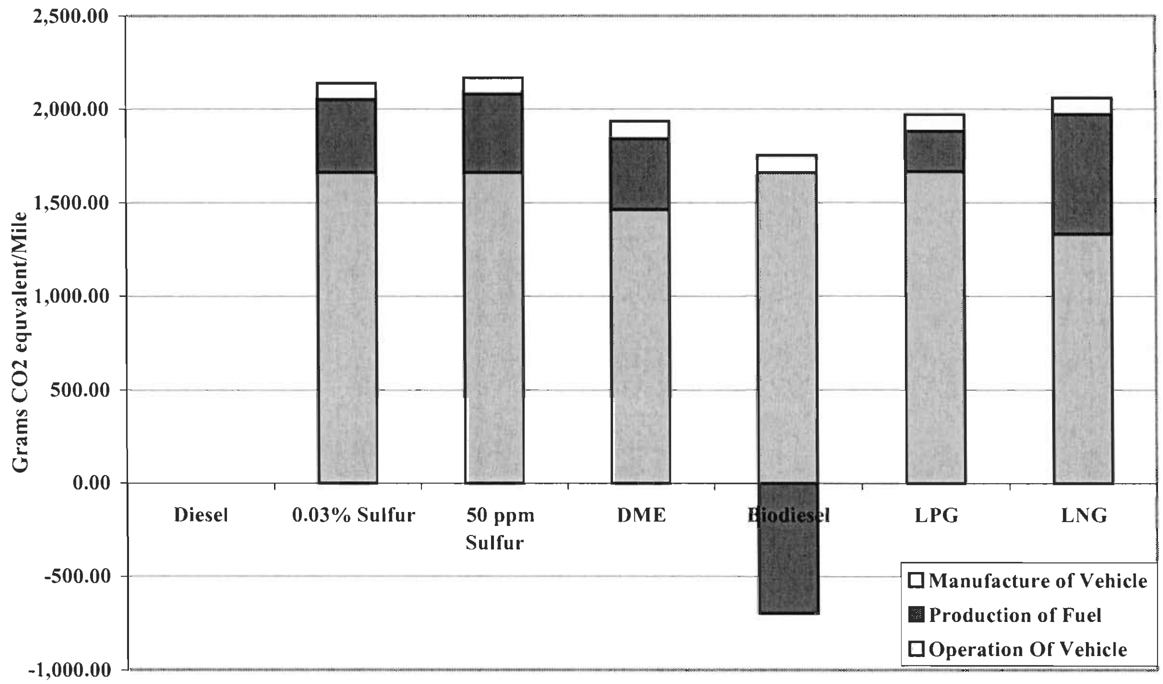

Figure ES2. Life-Cycle Emission For Heavy-Duty Vehicles

The stacked graph of the GHG and pollutant emission during vehicle operation illustrated that CNG has a better performance than biodiesel. Unfortunately, there was not enough data to analyze the emission of CNG for its life-cycle. However, it is possible for CNG to have an emission rate lower than biodiesel.

ES.3 Transit Buses

Figure ES3 illustrated another life-cycle analysis for alternative fuels of transit buses. Once again the graph has illustrated that biodiesel fuels have negative emission rate during the production of fuel. Even though hybrid technology has the lowest emission level of all the fuel technologies, it is not comparable to biodiesel during the production process. Still, hybrid is considered to be one of the best vehicle fuels for transit buses.

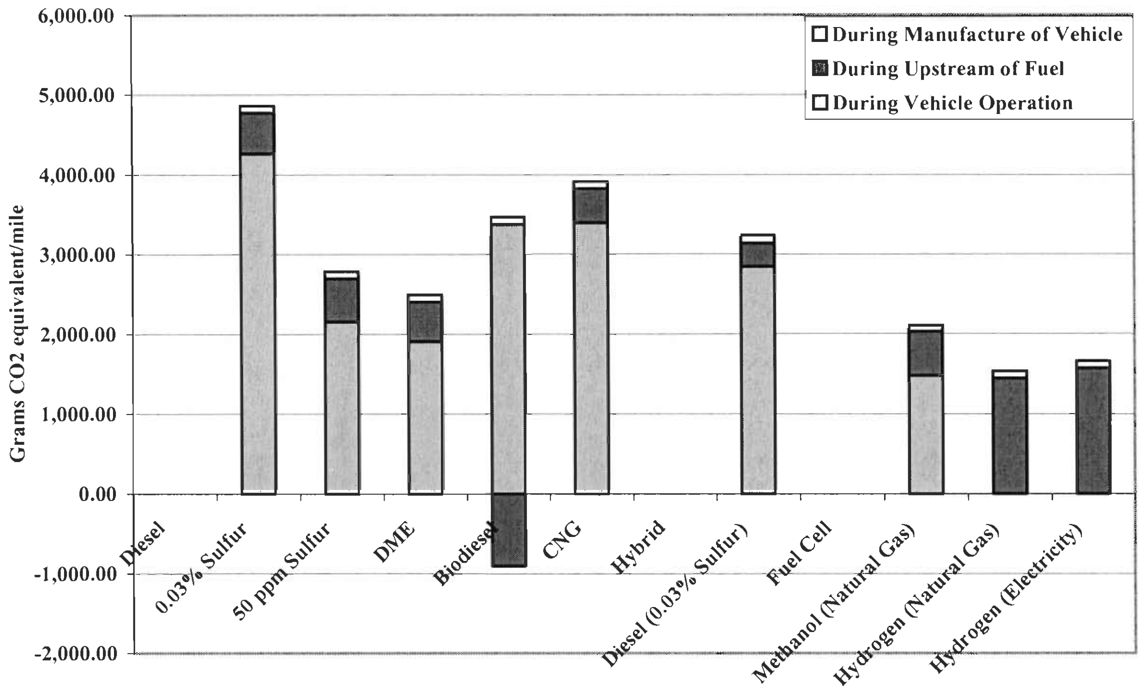

Figure ES3. Life-Cycle GHG Emission of Transit Buses

Focusing on the whole life-cycle determines the best fuel type and technologies because life-cycle demonstrates the emission efficiency from the manufacture of the vehicle to vehicle operation. Another point this report focused on is the different types of vehicles. Different vehicles such as heavy-duty trucks use different engines and types of fuels than passenger vehicles. Therefore, the emissions are also different.

ES.4 Conclusion

A list of short-term and long-term alternative fuels is provided for each type of vehicles from the analyses of this report. From the conclusions, the most efficient fuel for short and long-term has been chosen for recommendations.

- **Passenger or light-duty vehicles:** LPG has the best short-term solution and hybrid or fuel cell is the best long-term solution. Furthermore, low sulfur diesel fuel has the best overall output for both long and short terms.
- **Heavy-duty vehicles:** CNG has the best emission rate for short-term solutions and for long-term biodiesel is the most efficient.
- **Transit buses:** hybrid diesel with a low sulfur content of 0.03% is the best short-term solution and hydrogen fuel produced from electricity is the best long-term solution.

1 Introduction

The project focuses on the ecological aspects of Hong Kong. The main purpose of the project is to find an alternative fuel technology to replace the current diesel fuel system. To understand the importance of these projects, it is necessary to provide a brief background on the city of Hong Kong.

Hong Kong is one of the most well known cities in Asia. In fact, it is the most popular city destination in Asia. In 1998, 9.3 million entries to Hong Kong were recorded. The majority of those were visitors and about 32% were business travelers[1]. Because it was a British colony for almost a century (from 1898 to1997), Hong Kong's people have adopted many western values. They have much more freedom of speech and press, and have more influences in government issues compared to people of some other Chinese cities. Its western style brought Hong Kong many opportunities to establish connections with foreign countries. It plays a role as an international business center, providing first-class services globally and to Asia-Pacific regions. The service sector accounted for 85% of Hong Kong's GDP (Gross Domestic Product) in 1997[2]. Services include import, export, tourism, food industries, etc. Its GDP of 1997 was HK$1.344 trillion, and per capita GDP was HK$206,718[3]. From 1990 to 1997, Hong Kong had an average annual growth rate of 12.5% in nominal GDP[2]. Besides being one of the most prosperous Asian cities, its population density is also among the highest. Hong Kong has a land area of 1,096 square kilometers, and an average of 6,330 people per square kilometer. Not until recent years did environmental issues raise concerns for some government officials. As one of the busiest high-tech cities in the world, Hong Kong has plenty of resources and industrial

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[1] Source from: http://www.info.gov.hk/hkfacts/tourism.pdf
[2] Source from: http://www.info.gov.hk/hkfacts/servecon.pdf
[3] Source from: http://www.info.gov.hk/hkfacts/stat.pdf

pollutions. One of the biggest issues is air pollution. Most vehicles in Hong Kong use diesel as their primary fuel. Diesel fuel is relatively inexpensive and provides excellent mileage for most vehicles. However, diesel contains many organic compounds that, once they undergo the combustion process, will release harmful products such as carbon monoxide and sulfur oxide to the atmosphere, in turn causing air pollution. The liaison of the project, Civic-Exchange of Hong Kong, is a non-profit think-tank that primarily focuses on environmental issues in Hong Kong and China. The objective of the project is to assist Civic-Exchange in researching on a more environmentally friendly fuel technology for Hong Kong.

Civic-Exchange has conducted a seven-month project to develop a cleaner fuel and vehicle strategy for Hong Kong. It involved studies of various clean fuel technologies to develop a literature review, which provides basic information and the pros and cons of each type of alternative fuels. The literature review also comprised of different emission comparisons based on alternative fuels, different types of vehicles and test cycles, which the IQP primarily focused on.

This project is to develop a clean fuel strategy for Hong Kong by comparing the advantages and disadvantages of different alternative fuels and technologies. Based on the results of the analyses, the report provided a solution to the most emission efficient fuel for each type of vehicles.

2 Background

2.1 Hybrid

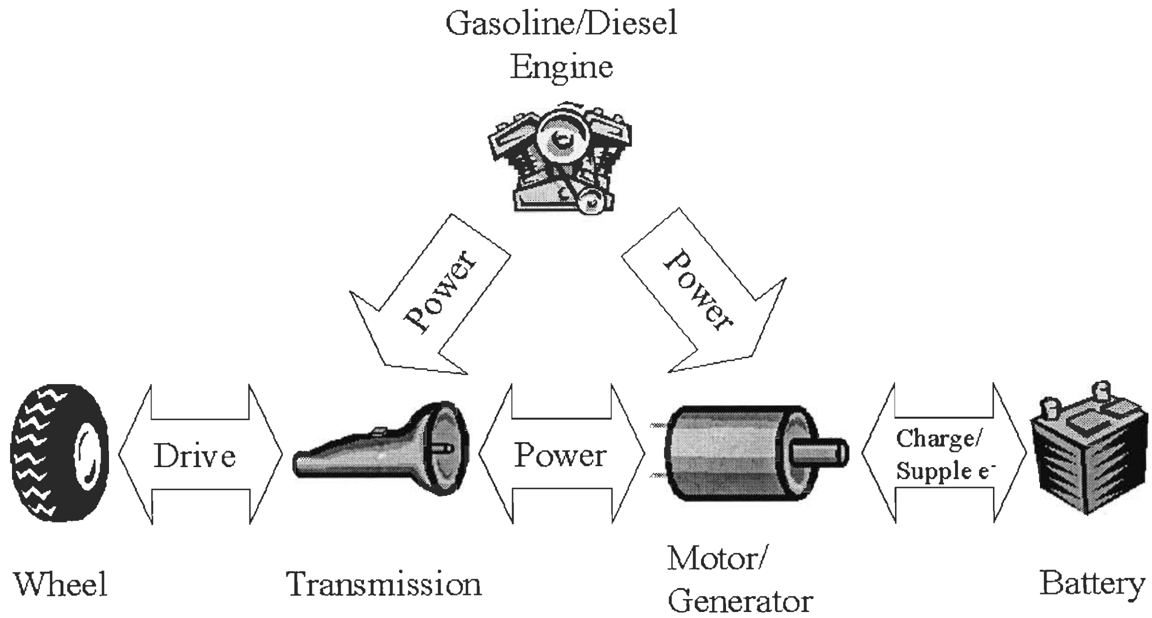

Figure LR1. Flow Chat of Hybrid System[4]

2.1.1 Description of hybrid system[4]

Hybrids use two or more energy conversion systems to drive a vehicle and one or more energy storage systems. Most of prototype and concept hybrid vehicles today use an internal combustion engine and electric motor as the energy conversion system. The idea of a Hybrid system first appeared during the fuel crises in the 70's[5]. The use of two power systems could improve fuel economy. But the automakers dismissed the idea after the fuel crisis was over. They were more interested in developing fast sport cars using turbo than slow passenger cars using a hybrid system. The technologies hybrid vehicles require such as light chassis, low drag body design, and high efficient batteries were not being fully developed until recently. There

[4] Source From: http://www.ott.doe.gov/oaat/hev.html
[5] Source From: **Car and Driver** December 2000 PP 233-235 Hybrid and Fuel Cell

were also other engine improvements such as changing from fuel condenser to fuel injection system to improve fuel economy. The idea of developing Hybrid vehicles was put aside[2].

There are two popular ways to combine an internal combustion engine with electrical motor. They are called Serial Hybrid Configuration (SHC) and Parallel Hybrid Configuration (PHC).

SHC is an older technology and use the internal combustion engine to drive the generator. The generator will charge up the battery while the vehicle does not require much power, during idling or hill descent. When the motor requires power, such as going up hill or picking up speed, it will draw power from the battery or directly from the generator. But while the vehicle is going down hill or breaking, the electrical motor will also charge up the battery. This configuration is widely used on 100+ ton haul truck[6] used in mining fields. These trucks are powered by 12 to 16 cylinder diesel engine and motor that is capable of moving weight up to 1 million lb. When this configuration is applied to smaller vehicles, the engine will shut down when the battery is charged up to a certain level and turn on after the battery is drained to a certain level. Since the engine operates independently from the wheels, the engine can remain in the most efficient range of speeds.

PHC use both internal combustion engine and electrical motor to drive the vehicle. The internal combustion engine turns the electrical motor. The electrical motor will act like a generator to charge the battery while idling, going down hill, and while driving. The electrical motor will assist the engine while driving and charge the battery while going down hill and breaking. A newly developed control system allows the transmission to switch between two power systems or use both at the same time. The system can choose the electrical motor during low speed and switch to the internal combustion engine at high speed. This configuration can get

[6] Source From: http://www.komatsueq.com/

the most out of both power systems since an electrical motor has more power at lower rpm while an internal combustion system is more powerful at high rpm. A hybrid vehicle can have a smaller engine but still achieve the same power rating of vehicle with a relatively larger engine.

When automakers advertise their hybrid vehicles[2], they always mislead customers to think the main reason of good fuel economy is because the battery is being charged during engine idling and breaking. But the real reason of good fuel economy is due to the small engine that's being used. A vehicle equipped with a 20-30 horsepower engine is enough to cruise at a speed of 60 mph. But due to our driving habit, more horsepower is required for the rapid acceleration, and more torque is required for our fast start up. More horsepower means a bigger engine, a bigger engine means more weight is added and in turn an even bigger engine is needed for the extra weight. The Hybrid system uses an electrical motor to assist the engine during acceleration and start up, which is the time when an internal combustion engine lags the power to do the work efficiently.

2.1.2 Current development by automakers

Currently there are two hybrid vehicles for sale in America. They are the Honda Insight and the Toyota Prius. Insight uses the parallel configuration. It is being classified as a two-seated coupe and can go for 74 miles per gallon. Prius uses serial configuration. It is being classified as a four-seated compact and can go for 54 miles per gallon. In 2003 Ford will introduce their first hybrid vehicle called Escape. The Escape uses the parallel configuration, it is a small SUV designed to carry four passengers. One other problem with these hybrid vehicles is the cost of using two power systems and a storage unit in a single vehicle. Honda Insight itself costs about

US$20,000. At this price range a consumer can get a fairly comfortable four-passenger mid-size vehicle.

2.1.3 Efficiency in reducing emission

Generally a hybrid vehicle has the range at least twice of a conventional vehicle. But since they still burn gas, they still produce pollution to the environment at half to two third of a conventional vehicle. But at the same time, since they use gasoline or diesel as fuel, they are very easy to adapt to current infrastructure.

2.2 Fuel Cell

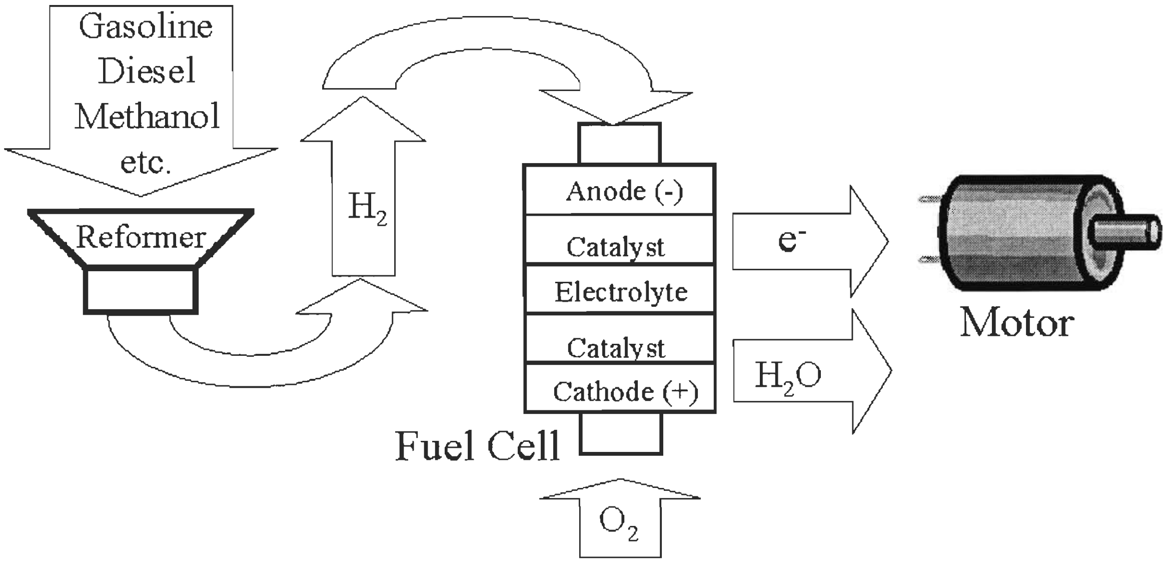

Figure LR2. Flow Chat of Fuel Cell System

2.2.1 Description of fuel cell[7]

The idea of fuel cells is to produce electricity by supplying just hydrogen and oxygen. The basic design of a fuel cell includes a stack consists of Anode – Catalyst – Electrolyte – Catalyst – Cathode. Hydrogen is fed to the anode and oxygen to the cathode. Following are the chemical formulas, anode $2H_2 \rightarrow 4H^+ + 4e^-$, cathode $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$. Chemical reactions in the catalyst at the anode side separate the nucleus and electron of the hydrogen atoms. The nucleus of hydrogen will travel though the electrolyte to react with oxygen atoms in the catalyst at the cathode side to form water (H_2O). But since the reaction require electrons and the electron separate from the hydrogen is blocked by the electrolyte, it requires an external path to reach the catalyst at the cathode side. The process of supplying of electron at the anode and draining of electron at the cathode work like a battery but the electron flow is very weak.

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[7] Source From: http://216.51.18.233/whatis.html

Therefore stacks of fuel cells are put together to produce a stronger current. Pure H_2O and heat are the only by-products from these reactions and it escapes the system as water vapor.

In 1839, Sir William Grove[8] introduced the original concept of a fuel cell. His idea came from the experiment on the electrolysis of water. He believed he could reverse the process and generate electricity with components of water, which are hydrogen and oxygen. However, lack of knowledge on electrochemistry and technology of manufacturing caused failure in early attempts of building fuel cells. Experiments on converting hydrogen and oxygen to electricity were unsuccessful until 1932, when Francis Bacon built the first working fuel cell. But extensive research on fuel cells was not carried out until the late 1950s. NASA's space program required a system that could produce electricity in space. Batteries were too heavy and short-lived, and a nuclear reactor was too dangerous. Solar panels and fuel cells were developed to be used on satellite and space probes. Solar panels were used on satellite stations, where fuel cells were used on space probes that carried astronauts. Fuel cells onboard were supplied with pure oxygen and hydrogen as fuel, and they in turn charged up the batteries that supplied electricity to the space probe. Fuel cells used on these spacecraft could achieve power efficiencies of 70% or higher compared to 30% on most conventional generator. A fuel cell was the ideal power generator for spacecrafts because beyond generating electricity, it also provided heat and water that sustained the life of astronauts.

The potential danger of a fuel cell system is the storage of hydrogen. When in contact with oxygen, hydrogen will cause explosions. One of the well-known accidents with the storage of hydrogen happened on the NASA spacecraft, Apollo 13. The hydrogen tank exploded. All the fuel for the fuel cell was lost, and the astronauts had to run the spacecraft with electricity left in the batteries. One way to address this problem is to install a reformer or converter, which will

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[8] Source Form: http://www.ttcorp.com/fccg/fc_what1.htm

extract the hydrogen from any hydrocarbon fuel including natural gas, methanol, gasoline, diesel, etc. In theory, a fuel cell can generate electricity without any organic material as long as the converter can extract hydrogen from these materials. But the byproduct in this process may vary.

There are many different families of fuel cells. The type used by NASA on spacecrafts is called alkaline. Others are phosphoric acid, proton exchange membrane, molten carbonate, solid oxide, and direct methanol to name a few. Until recently, most fuel cells are too expensive for commercial uses.

Alkaline fuel cells are only suitable for projects where expense is not a factor of consideration. Alkaline fuel cells can generate electricity of up to 70% efficiency. Companies are developing it to be applied to vehicles.

Phosphoric acid is suitable for heavy-duty vehicles. It generates a higher voltage compared to other families of fuel cells. It can achieve efficiency of 40% or higher, and up to 85% if steam produced by the fuel cell is utilized for cogeneration. This system is the most commercially developed. It is generally larger and is being used in stationary applications such as hospitals, hotels and schools.

Proton exchange membrane (PEM) fuel cells operate at temperatures around 200ºF, a relatively low temperature compared to other fuel cells. This technology can vary the output quickly to meet the power demand, which is suitable for use in light duty vehicles.

Solid oxide fuel cells can be used at high power applications such as power stations, industrial building, and possibly automobiles. Solid oxide fuel cells operate at temperature up to 1,800ºF and can achieve efficiency of up to 60%.

Molten Carbonate and direct methanol fuel cells are newly developed fuel cells. They are currently being tested on large applications such as buildings and power stations.

2.2.2 Current development by automakers[9]

Fuel cell technology is currently a hot research topic for carmakers and private development firms, including BMW, Ford, DaimlerChrysler, GM, and Energy Conversion Devices (ECD). BMW developed a storage system that's storing hydrogen as super-cooled liquid. Ford stores them as highly pressurized hydrogen. The problems with these two storage systems are the fire hazard and the need of hydrogen refilling stations. But this system also cuts cost and weight, and saves space by eliminating the reformer. DaimlerChrysler is experimenting with a vehicle-using methanol as the fuel. It reduces the fire hazard, but it still raises the problem of refilling, most gas stations do not provide methanol. The easiest way to adapt fuel cells to reduce air pollution is using gasoline as the fuel to power the fuel cell. GM and ExxonMobil are currently in partnership and have begun research on using gasoline. They have announced a breakthrough on the development of a reformer that turns gasoline into hydrogen. ECD developed an experimental storage device using an alloy called metal hydrides that can absorb hydrogen, which can be extracted to be used by a fuel cell. Hydrogen stored inside this device will not release in large quantity and cause damage. This device also cuts cost, weight, and saved space by eliminating the reformer. But it still has the problem of finding a refilling station. Out of these five companies, GM has the system that can integrate into current society without changes of the supporting infrastructure. But since gasoline will still be the primary fuel, future development and introduction of hydrogen fuel vehicles to the public will be much harder.

[9] Source Form: **Automobile Magazine** p 30 The Hard Cell

2.2.3 Efficiency in reducing emission and cost

Fuel cell technology is a very clean system. The emission of this system comes from the byproduct of the reformer and fuel cell. Efficiency and emissions depend on the type of the reformer and fuel cell. A fuel cell system runs on natural gas has water vapor and carbon dioxide as the emissions from the fuel cell. Carbon monoxide is the main emission from the reformer in very small amount compared to carbon monoxide emit form an internal combustion engine. Since there is no burning of fuels, a vehicle equipped with a fuel cell system that runs on gasoline would still be much cleaner than a conventional vehicle.

The cost of fuel cell is currently very high compared to conventional internal combustion engines. But the cost is expected to drop as new technologies are being developed and once mass production of vehicles is carried out.

2.3 Natural Gas

2.3.1 What is Natural Gas?

Natural gas is a common hydrocarbon gas that contains about 85-95% methane (CH_4). It is produced from gas wells or crude oil and is naturally colorless and odorless. The natural gas has an odor because gas companies add sulfur into the content for safety reasons. Natural gas is a fossil fuel that burns cleaner and more efficiently than other fossil fuels like oil and coal.

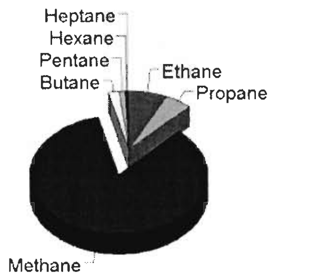

Figure LR3. Properties of Natural gas

Most natural gas is domestically produced in the United States. It is generated through a process that separates the gas from the oil and other contaminants after the drilling. The first step in the process of purifying natural gas is to separate the natural gas from crude oil, hydrocarbon condensate, water, and other components. Then another process needs to treat the natural gas to meet special requirements. For example, "natural gas for transmission companies must generally meet pipeline quality specifications with respect to water contents, hydrocarbon dew-point, heating value, and hydrogen-sulfide content."[10]

Natural gas is a very light gas and has storage difficulties due to the fact that it has a low volumetric energy density (the measure of available energy in terms of volume). Therefore, it has to be stored as either compressed natural gas (CNG) or liquefied natural gas (LNG). CNG is stored at high pressures and is preferred for most vehicles. Since CNG has low volumetric

[10] Source from: http://www.afdc.nrel.gov/altfuels/gas_general.html

energy density, vehicles need a tank four times the size of a conventional gasoline tank to have the same driving range.[11] On the other hand, it is less expensive and safer than LNG.

LNG is stored at low pressures and mostly used on heavy-duty vehicles. LNG has a unique characteristic that can increase its volumetric energy density by cooling it to -260°F.[12] Therefore, LNG vehicles do not need a large tank like CNG vehicles and can store up to two to four times more LNG fuel than CNG.

2.3.2 History

Natural gas has been discovered on earth since the 1800s. A former railroad conductor named Col. Edwin Drake discovered natural gas on August 27, 1859. He "struck oil sixty-nine feet below the surface of the ground in Titusville, Pennsylvania,"[13] and the discovery led to the development of the first gas transportation pipeline in the United States. Unfortunately, there were not enough transportation pipelines or any available mechanisms that could transport natural gas into homes for heating and other useful purposes such as producing electricity. Unless a home was lucky enough to have a natural gas seepage nearby, it did not have access to natural gas. Therefore, the use of natural gas during the 19th century was primarily for lighting city streets.

In 1885, Robert Bunsen invented the Bunsen Burner that utilized the thermal properties of natural gas. That was the beginning of extensive usage of natural gas. Gas producers turned their concentrations to using natural gas for other purposes like space and water heating and cooking at home. Unfortunately, there was a lack of supply of natural gas because transportation

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[11] Source from: Literature Review by Civic-Exchange
[12] Source from: Literature Review by Civic-Exchange
[13] Source from: http://www.naturalgas.org/HISTORY.HTM

pipelines were not fully implemented. Only after World War II did natural gas become widely obtainable because during the war, thousands of miles of pipelines were built.[14]

The federal government of the United States passed its first Natural Gas Act in 1938 to regulate the gas industry. The purpose of the bill was to enforce regulations on the price of natural gas to protect consumers from the monopoly of natural gas suppliers. The bill lasted until the late 1970's and 1980's when there was a shortage of natural gas supply. This indicated that government regulations in the oil industry needed to change. The government shifted away from price regulation during the 1980's to 1990's and as the gas supply went up, consequently, the price fell 50% from what it used to be. Also during this era, advanced technologies helped gas suppliers "transport natural gas with greater efficiency and less cost."[14]

2.3.3 Search for Natural Gas

Many geologists believed that natural gas, oil and other petroleum products came from decomposed bodies of plants and animals that lived at prehistoric time. Through the erosion process, the remains of the bodies were carried down streams and covered with layers of sediments. Eventually, the remains "were compressed by the weight of the sedimentary layers"[15] and transformed into petroleum products. That's why many gas and petroleum products are found under layers of sedimentary rocks today. Figure LR4 demonstrates the process of formation of gas.

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[14] http://www.naturalgas.org/HISTORY.HTM
[15] http://www.naturalgas.org/EXPLOR.HTM

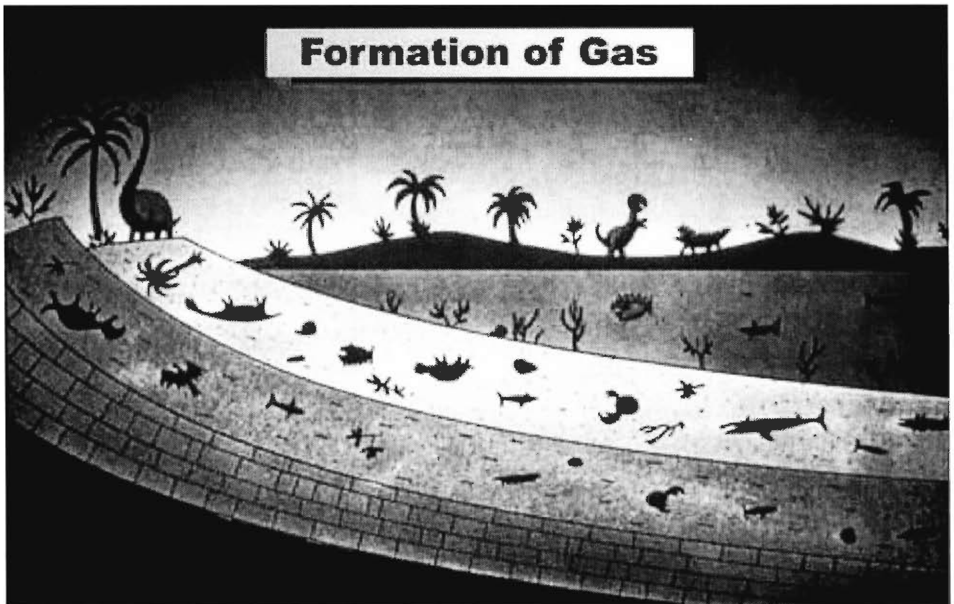

Figure LR4. The process of formation of gas[18]

Previously when technologies were not as advanced as today, people only knew to search for gas and oil on "surface evidence of formation" (layers of the earth crust that contained oil). But as advanced technologies and new research developed, techniques of finding natural gas and petroleum products improved. A device called "seismology" was invented to help geologists find areas that had natural gas and petroleum products. This device detects the "sound or seismic waves move through the earth's crust" that allow geologists to study the layers of the rocks to make an educated guess if petroleum products exist.[16]

Another great help to the geologist in finding an area to drill is knowledge of the rock formation. Geologists know that there are two categories of gas and oil traps: the structural traps and stratigraphic traps. Layers of rock trapping the oil from seeping through formed these traps. "Structural traps are caused by the folding or deformation of layers of rock," and composed of two types, anticlines and faults traps. Anticlines traps are formed in an arch shape and have gas

[16] Source from: http://www.naturalgas.org/EXPLOR.HTM

and oil remained at the highest point of the arch, while faults traps are "fracture layers of rock" which capture the oil and gas in it.[17]

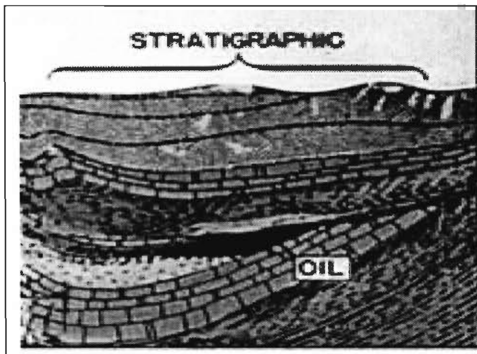

Figure LR5. Formation of stratigraphic traps.[17]

Stratigraphic traps referred to the reservoir layer that trapped the gas and oil. The stratigraphic trap allowed gas and oil to flow through pores until it hits a point where it cannot move anymore, due to tight compacts of the impermeable layer of rocks. By understanding the different forms of traps and with the help of the seismology, geologists are able to find natural gas faster with less time.

2.3.4 Efficiency

Using natural gas as a transportation fuel can improve the quality of air because it releases very little amounts of pollutants. It releases small amounts of carbon monoxide, oxide of nitrogen, and sulfur dioxide during combustion. Carbon dioxide and water vapor are mainly the products of the combustion process because natural gas contains mainly methane, which is composed mostly of hydrogen and carbon (a 4:1 atomic ratio). According to NGV (the Natural Gas Vehicle Coalition), using natural gas as fuel can lower 70% of carbon monoxide, 89% of non-methane organic gas and 87% of oxides of nitrogen emitted into the environment. Furthermore, the reduction of these pollutants can decrease greenhouse gases (GHG) and other environmental hazards.[18]

[17] Source from: http://www.naturalgas.org/EXPLOR.HTM
[18] Source from: http://www.ngvc.org/qa.html

Other benefits of natural gas include increase in job opportunities. According to a report from the National Defense Council Foundation, thousands of jobs were created to meet the demand of natural gas. In addition, using natural gas as vehicle fuel is very useful during cold weather. It resolves the cold-start problem because natural gas does not need heat to vaporize for combustion while other fuels like gasoline and diesel do.

Other fossil fuels such as oil and coal do not burn as cleanly as natural gas and produce ash particles from combustion that are passed into the atmosphere. They also released more sulfur dioxide (SO_2) and large amount of carbon monoxide (CO), nitrogen oxides (NO_x), reactive hydrocarbons and carbon dioxide (CO_2) during the combustion process. In contrast, the combustion process of natural gas produces very few pollutants. It practically produces no sulfur dioxide and a relatively small amount of nitrogen oxides. With the mixture of sulfur dioxide and carbon monoxide in the atmosphere, acid rain is generated and carbon dioxide will create more health hazards because it depletes the earth's ozone layer.

2.3.5 Safety

Natural gas fuel is less harmful than gasoline. In fact, many school buses use natural gas as fuels because it offers safety benefits to children. For example, spillage of natural gas would dissipate into the air because it is lighter than air, while spillage of gasoline may lead to an explosion when there is an accident. But vehicles using LNG have a high rate of causing fire or tank ruptures during refueling, therefore CNG are mostly used on vehicles.

2.3.6 Cost

Table LR1 illustrates the price of gasoline, natural gas, and propane or LPG (liquefied petroleum gas) from 1980 to 1991. The table demonstrates that natural gas has always been the cheapest alternative fuel. Unfortunately both CNG and LNG are very costly in two ways: (1) The high flow-rate, high pressure CNG compressor used for refueling natural gas is very expensive, along with the storage tanks that are made of aluminum or steel liners with fiberglass or Kevlar over-raps to minimize weight.[19] (2) The storage tanks for LNG are expensive because they are double-walled vessels with the inner vessel made of stainless steel according to the ASME Code requirements and the outer vessel made of carbon steel.

Table LR1. Average Fuel Costs For Gasoline, Natural Gas, and Propane
(Adapted from U.S. Energy Information Administration Data)

Year	Gasoline ($/gal)	Natural Gas ($/gal eq)	Propane ($/gal eq)
1980	1.22	0.41	0.68
1981	1.35	0.48	0.80
1982	1.28	0.58	0.83
1983	1.23	0.67	0.94
1984	1.20	0.67	1.04
1985	1.20	0.66	1.01
1986	0.93	0.61	1.06
1987	0.95	0.57	0.99
1988	0.97	0.54	1.00
1989	1.05	0.57	0.87
1990	1.22	0.58	1.06
1991	1.20	0.59	1.03

[19] Source from: Maxwells, Timothy T. and Jones Jesse C., *Alternative Fuels: Emissions, Economics, and Performance*, (p. 51-52)

2.4 Biofuels

2.4.1 What are biofuels?

Biofuels are alcohols, ethers, esters, and other chemicals made from biomass-renewable resources and waste products, such as agricultural and forestry residues, earth's vegetation and municipal and industrial wastes.[20] Biomass is the primary material to produce biofuels. The term biomass refers to all the "earth's vegetation and many products and co-products that come from it."[21]

Biofuels have the ability to reduce a large portion of emissions and clean up air pollution. Therefore, a better environment would be created for people's health. Using biofuels can decrease the amount of imported oil since they are produced domestically. When the cost of imported oil decreases, more money can be spent on economic growth, such as finding ways to produce alternative fuels. Another beneficial side effect of biofuels is that they could resolve some of the waste problems in the country because it uses biomass wastes such as industrial, agricultural, and municipal wastes for production.

2.4.1.1 Ethanol

Ethanol is an alcohol that is clear and colorless with a pleasant odor. It is usually combined with gasoline to reduce chemical emissions, although it can be used as neat ethanol (100% ethanol). Ethanol can be used in all types of engines with little need for modifications. Ethanol can be produced from any sources of starch or sugar. It is usually produced from the fermentation process of corn, or through a process like "brewing beer where starch crops are converted into sugars, the sugars are fermented into ethanol, and then it is distilled into its final

[20] Source from: http://www.ott.doe.gov/biofuels/what_are.html
[21] Source from: http://www.ott.doe.gov/biofuels/what_is.html

form."[22] Figures LR6 and LR7 described the processes of fermentation from crops and starch/sugar products to ethanol.

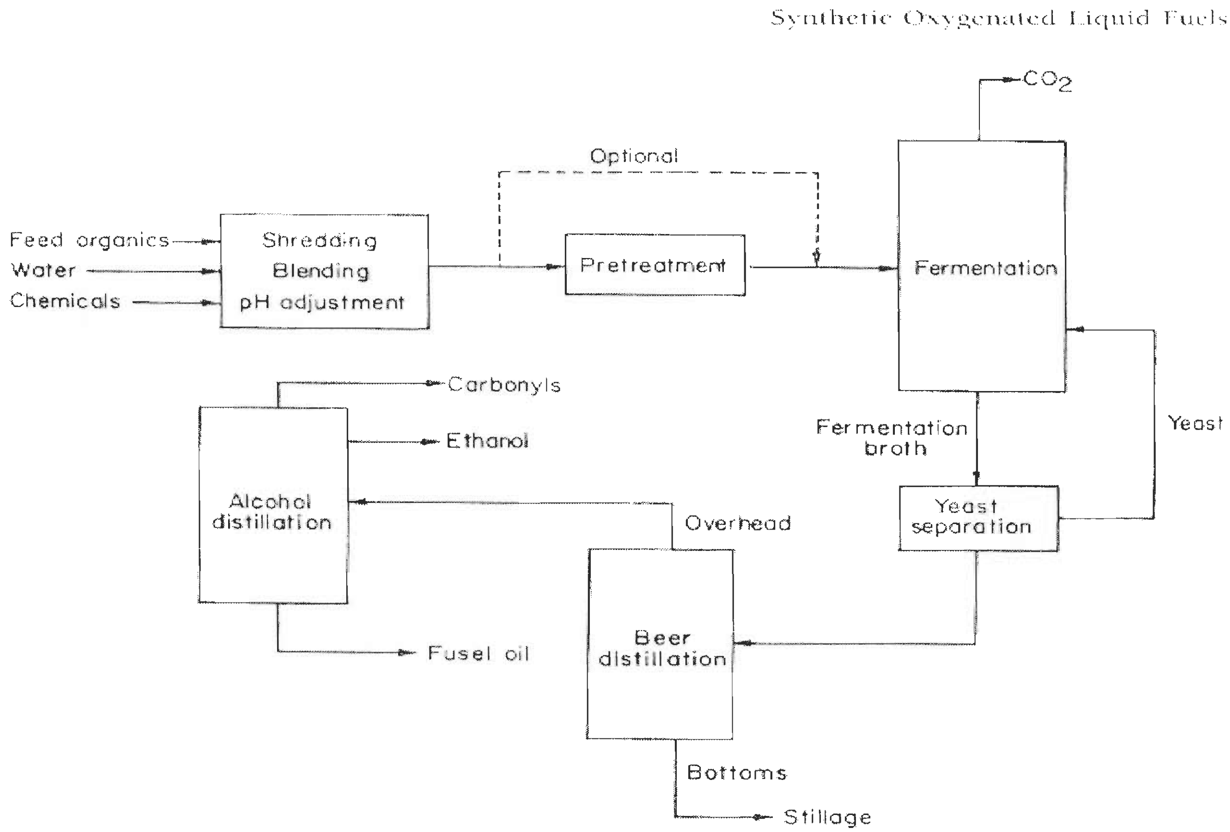

Figure LR6. Ethanol production by alcoholic fermentation.[23]

[22] Source from: http://www.ott.doe.gov/biofuels/what_are.html
[23] Source from: Klass, Donald L., *Biomass for Renewable Energy, Fuels, and Chemicals* (p.412)

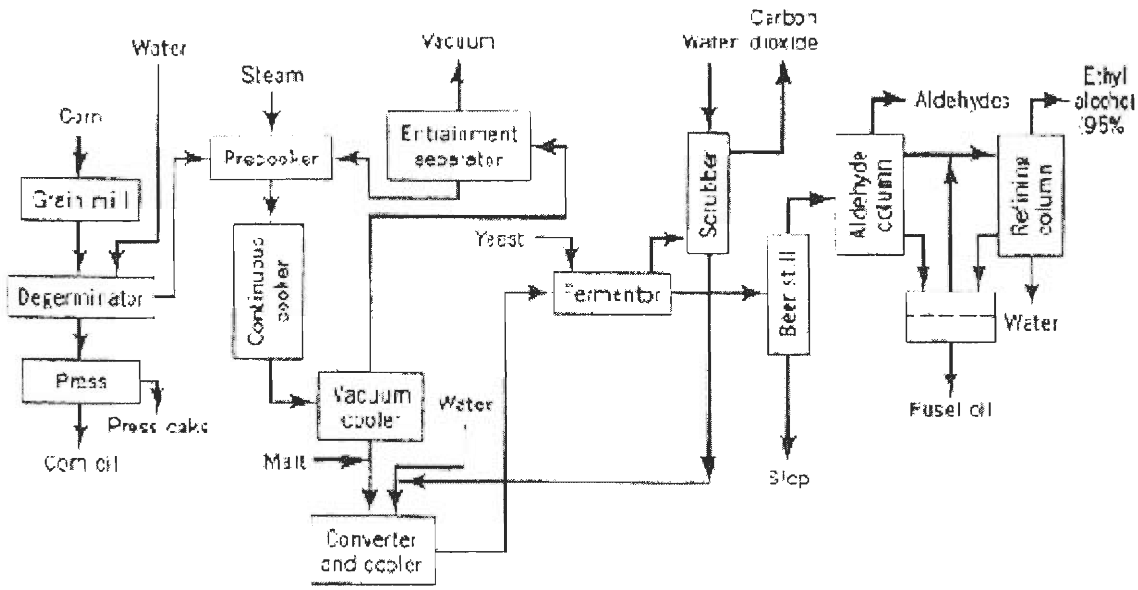

Figure LR7. Flow scheme for manufacture of ethanol from corn.[24]

Ethanol is used as a transportation fuel by blending with gasoline to reduce pollution, also to meet the requirements of the Clean Air Act. Until now, there are three main uses of ethanol: (1) Gasohol: 10% ethanol blended with 90% gasoline. (2) E85: 85% ethanol blended with 15% gasoline, mainly for light-duty vehicles. (3) E95: 95% ethanol blended with 5% gasoline, mainly for heavy-duty vehicles.

2.4.1.1.1 History

The idea of using ethanol for transportation fuels was started by Henry Ford when he designed the first Model T automobile back in 1908. He planned to use ethanol that was produced from biomass renewable resources, for "major fuel uses."[25] He and several other experts developed a fermentation plant to produce ethanol from corn. They called the biomass

[24] Source from: Klass, Donald L., *Biomass for Renewable Energy, Fuels, and Chemicals* (p.412)
[25] Source from: http://www.ott.doe.gov/biofuels/history_html

made fuel "gasohol." Unfortunately low petroleum prices closed the market for ethanol during the 1940s. As a result, ethanol was replaced by petroleum gas.

Eventually, in 1979 the market has adopted his idea once again to blend ethanol and gasoline together as fuels for transportation automotives. There was trouble with petroleum supply because the "oil supply disruption in the Middle East became a national security issue"[26] for the United States, and alternative fuels became the only solution to the energy resources. Also with the Clean Air Act Amendments of 1990, (all vehicle fuels required to reduce pollutions during combustion) there were even more demands on using ethanol to mix with gasoline to reduce pollutions.

2.4.1.1.2 Efficiency

Ethanol can reduce large amounts of pollutants from combustion and help improve air quality. Ethanol has a very low production of HC (hydrocarbon), CO (carbon monoxide) and NO_x (oxides of nitrogen). It also helps improve engine efficiency by 15%. Ethanol also produces a toxic substance during combustion, which is acetaldehyde, and may wear engines out sooner than regular gasoline.[27]

Ethanol has a drawback of low energy density. It requires 1.5 gallons of ethanol to equal one gallon of gasoline. Another disadvantage of ethanol includes emissions of formaldehyde and acetaldehyde. The two compounds are two types of toxic chemicals produced in large quantity during the combustion of ethanol, even worse than petroleum fuel.[28]

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[26] Source from: http://www.ott.doe.gov/biofuels/history_html
[27] Source from: Poulton, M.L. *Alternative Fuels for Road Vehicles*, (p.58, 67)
[28] Source from: Bechtold, Richard L., *Alternative Fuels Guidebook*, (p. 6)

2.4.1.1.3 Costs

Table LR2 illustrates the price for various fuel types, and once again natural gas has the lowest cost when compared to other fuels. Ethanol has the highest price out of all the fuels, ranging from $1.51 to $2.47 per Equivalent Gallon of Gasoline. The price of electricity is similar to ethanol during off peak at $1.51 per Equivalent Gallon of Gasoline.

Table LR2 Fuel Prices As Projected For 1993
(Source: California Energy Commission)

Fuel	Projected Price per Equivalent Gallon of Gasoline
Unleaded Gasoline	$1.07
Premium Unleaded Gasoline	$1.21
Natural Gas	$0.88
Propane	$1.07
Methanol	$1.44
Ethanol	$1.51 - $2.47
Electricity	$1.51 Off Peak

2.4.1.2 Biodiesel

Biodiesel is a cleaner burning diesel fuel that was produced from different types of vegetable oil such as soybean, rapeseed, and also animal fat. Biodiesel fuels are very similar to regular diesel fuels, so they can be used the same way as diesel fuels with no necessary engine conversions and can be stored in the same storage tank.

Biodiesel fuels are generated from a process called "transesterification," which is a transformation of the oil into fatty acid ethyl esters. Then the fatty esters can be blended with diesel fuels or used as 100% biodiesel.

2.4.1.2.1 History

Rudolf Diesel[29] came up with the idea of biodiesel when he invented his diesel engine and operated it with peanut oil a century ago. He "envisioned" that his diesel engine could run on any type of vegetable oil. When he had released his product, the biodiesel, the market welcomed it with satisfaction because it was cheap and efficient.

Then along with ethanol, biodiesel became an alternative fuel during the 1970s because of the oil supply problem. Since biodiesel is made from natural, renewable resources that take carbon dioxide from the atmosphere, it will help eliminate the pollutions in the air and help reduce greenhouse gases.

2.4.1.2.2 Efficiency

Biodiesel was estimated to reduce 50% of ozone pollution, 50% of CO, 30% of particulates, and 93% of HC compared to diesel fuel.[30] It also reduces acid rain and greenhouse gases and does not have any toxic aroma, however, biodiesel may increase or decrease NO_x compared to diesel fuel because of the combustion temperature. The higher the temperature, the more NO_x will be emitted into the atmosphere; but a proper catalyst can help control the amount of NO_x released.

A major benefit of biodiesel fuel is that it can run on regular diesel fuel engines without any modifications and does not need any special specification for storage or dispenses. Furthermore, because biodiesel use biomass renewable products as its main source for production it can help solve the waste problem in this world.

[29] Source from: http://www.ott.doe.gov/biofuels/history.html
[30] Source from: http://www.biodiesel.org/fuelfactsheet.htm

2.5 LPG

2.5.1 What is LPG?

Liquefied petroleum gas (LPG), sometimes referred to as propane or LP gas, is similar to natural gas. It is colorless, odorless and nontoxic, consequently an odor is added for leak detection. LPG composes mostly propane, along with other substances such as propylene, butane and butylenes in different mixtures.

LPG fuel sold in the United States composes about 90% propane while in Europe different proportion of propane exists within LPG fuels. Different countries produce diverse proportions of LPG fuel depending on available resources and surrounding environment. For example the propane content in Italy is as low as 20%, while it could be 35-60% in the Netherlands or as high as 90% in the UK or Germany.[31]

LPG can be turned into liquid when put under a pressure less than 300 psi. The tanks used to store LPG are pressure vessels made from low-carbon steel that is much cheaper than the storage tank for liquefied natural gas (LNG) and compressed natural gas (CNG). In order to have the same amount of energy as conventional gasoline, LPG needs a tank that is 45% larger.[31]

All LPG vehicles are converted from gasoline vehicles, approximately 75%[32] of them use LPG fuel only. The rest of them are bi-fuel that used both gasoline and LPG, but they do not work as well as the dedicated LPG fuel vehicles.

LPG has been used as vehicle fuels worldwide for the past sixty years. Back in 1992, about 220,000 to 370,000 vehicles used LPG fuel.[33] During 1994, about four million LPG vehicles were operating worldwide, approximately 400,000 in the United States, 700,000 in the

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[31] Source from: Poulton, M.L *Alternative Fuels for Road Vehicles*, (p. 83)

[32] Source from: Maxwell, Timothy T. and Jones Jesse C., *Alternative Fuels: Emissions, Economics, and Performance*, (p. 55)

[33] Source from: Bechtold, Richard L. *Alternative Fuel Guidebook*, (p. 24, 26)

Netherlands, 500,000 in Italy and 100,000 in Canada. Later, during 1995, there were about 10,000 LPG fueling facilities in the southwest and western states of America. Texas was the leading state that produced about 34% of the nation's supply of LPG and 57% were stored underground.[34]

2.5.2 Efficiency

LPG improves the efficient use of fuel because it lowers the emission of carbon dioxide (CO_2), particulates and hydrocarbons (HC) during the combustion process. Decreasing the emission of HC would also lower the likelihood of forming black smoke, particulates and toxic substances such as benzene. LPG has low unburned hydrocarbon emissions because unburned HCs (with the help of oxygen) are capable of oxidizing in the oxidization catalyst.

Tests conducted by the US Environmental Protection Agency (EPA) proved that LPG or propane vehicles could produce 30-90% less CO, 50% less toxic substances and other emissions than gasoline. It also reduced 87% total HC, 50% in NO_x and 40% in particulates.[35] Moreover, LPG does not produce any sulfur dioxide (SO_2) that contributed to acid rain because it contains a very small amount of sulfur.

Propane in LPG may contribute to the formation of smog because propane has ozone reactivity, and the emissions of NO_x could be higher than gasoline due to higher combustion temperature, but that could be controlled with suitable catalysts. Other than reducing air pollution it also reduced land pollutions because spillage of LPG is not harmful to soil and water.

[34] Source from: Maxwell, Timothy T. and Jones Jesse C., *Alternative Fuels: Emissions, Economics, and Performance*, (p. 263)
[35] Source from: http://www.npga.org/public/articles/details.html?id=166

2.5.3 Performance

LPG vehicles have less carbon built-up than gasoline vehicles do. Along with natural gas, it has a good cold-start performance that improves the engine's durability and extends the life of the exhaust system. On the other hand, it has a 5-10% reduction in power output (up to 30% if it is lean fuel). Since there is a decrease in energy, LPG vehicles need to store 15-20% more fuels compared to gasoline or diesel fuels.[36]

2.5.4 Safety

LPG fuel has a low range of flammability. For the fuel to ignite it must have a mixture of propane vapor between 2.2-9.6%. If it were less than 2.2%, it would be too lean to burn. If it were more than 9.6%, it would be too rich to burn.[37] Therefore, the range of ignition is very small. In addition, LPG would not ignite unless the source of ignition reaches at least 940°F. In the contrary, gasoline would ignite when the source of ignition reaches 430-500°F. Similar to natural gas, spillage of LGP will vaporize and dissipate into air.

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[36] Source from: Poulton, M.L. *Alternative Fuel for Road Vehicles*, (p.95-96)
[37] Source from: http://www.npga.org/public/articles/details.html?id=172

3 Literature Review

The data from the project was derived from five reports on emission testing. These reports have illustrated various greenhouse gas and pollutant emissions with different test methods. Each method produced distinctive results due to the different types of variations such as the weather, condition, altitude, etc.

The purpose of the literature review is to inform readers on the main information about each report that has been reviewed. Furthermore, providing the information on the reports would determine that these reports are non-biased based on the baselines and methods. This is the primary incentive of selecting these five reports because they are non-biased and had all the information to support their analyses. Most of these reports were studies provided by the governments of the US, UK and Canada that are more trustworthy than the studies conducted by private organizations. Private organizations tend to provide biased results due to their expectations, business, or other reasons that could alter the actual outcome. In contrast, government does not alter its results because it is not a profit organization; it is here to improve the life of the people.

3.1 Hybrid-Electric Drive: Heavy-Duty vehicle Testing[38]

The Heavy-Duty Testing Project was conducted by the Northeast Advanced Vehicle Consortium (NAVC) to test the energy efficiency and emission performance of hybrid-electric heavy-duty vehicles compared to conventional diesel heavy-duty vehicles and alternative fuel compressed natural gas (CNG) buses. The NAVC is a public-private partnership of public sector and private sector firms and agencies working together to promote advanced vehicle technology in the northeastern United States. The funding source of the project, Defense Advanced Research Projects Agency (DARPA), is the central research and development organization for the U.S. Department of Defense. It was established to ensure superior technology for the US military forces.

3.1.1 Types of Vehicles and Fuels

The vehicles involved in this project are two hybrid-electric vehicle models, three compressed natural gas bus models and one diesel bus model. Each bus is equipped with a recent model year 1997-1999 engine with moderately low mileage. Five of the buses were hybrid electric Orion VI buses from Orion Bus Industries equipped with Lockheed Martin Control Systems powerplants (Orion-LMCS), and one hybrid electric RTS bus from Nova Bus Incorporated (NovaBus) that is equipped with an Allison Transmission hybrid powerplant (Nova-Allison). Each bus is of series configuration and equipped with an integrated oxidation catalyst/regenerative particulate trap.

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[38] Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project, 2000, Northeast Advanced Vehicle Consortium, M. J. Bradley & Associates, Inc., and West Virginia University

The fuels that were used for the testing are CNG, grade D1 diesel fuel (~ 330-ppm sulfur on average), low sulfur diesel fuel (~20-ppm sulfur), and MossGas, (a synthetic diesel fuel with an essentially zero sulfur).

3.1.2 Methodology

Different types of heavy-duty buses and operators from Boston, Massachusetts and New York City were used for the testing. Six different emission test cycles were used for the testing with average speeds ranging from 3 to 17 mph and with duty cycles ranging from 4 to 18 stops per mile. Different fuel variations were also tested to determine the effects of sulfur in fuel on particulate emissions. The study was conducted during the spring and fall of 1999 in Boston, MA and Brooklyn, NY. The test lasted approximately a year and it was not a life-cycle study.

There were a total of six different types of drive cycles used for testing. The Central Business District (CBD) Cycle was used to evaluate transit buses and has 14 identical sections that contained acceleration of 20 mph, a cruise at 20mph, braking to a stop then dwell. The total test cycle for efficiency was 2 miles over 600 seconds. However the CBD cycle did have several drawbacks: the acceleration rate had a tendency to support buses with five speed transmissions and large engines because it was fixed.

The New York Bus Cycle was a statistically derived cycle that was developed using data collected from transit buses and trucks in New York City during the 1970's. It was used to evaluate greater variations in the rates of acceleration and deceleration and the overall speed. The total cycle had a range of 0.6 miles in 571 seconds with average speed of 3.7 mph, which was slower than normally used.

The Manhattan Bus Cycle was a further testing cycle of the CBD cycle that contained similar testing patterns of acceleration and deceleration rates. Its purpose was to reflect more accurate driving conditions in the Metropolitan area of New York. The testing range was similar to the New York Bus Cycle but with an average speed of 6.9mph.

The New York Composite Cycle reflected a wider range of variation on the acceleration and deceleration rates than the CBD cycle. It contained a mix of inner city and urban transit bus uses that allowed the bus to reach and maintain greater speeds. The test process was similar to the New York Bus Cycle with an average speed of 8.8mph.

The Route #22 and #77 Cycle was data based on buses in service along the two routes at Logan International Airport in Boston, Massachusetts. Route #22 was a road to and from the subway stations that involved different inter-terminals stop-and-go passenger service and two cruises at 30mph with an average speed of 13.9 mph. Route #77 was almost the same as Route #22 but contains highway cruises and inner city traffic at average speed of 16.8mph.

3.1.3 Analysis

The report describes tests of different types of buses including regular diesel buses, CNG buses, and Hybrid buses on different simulated drive cycles. These buses were taken off the road from NYC and Boston, all of them were used under similar driving conditions and equipped with relatively low mileage engines. They were all tested by independent teams of engineers under the same test conditions, with the same test equipment and same test cycle. Since all of the buses were used regularly and were shipped to the test center directly without being refitted for testing, the data collected should be accurate and non-biased.

If we compare the buses under the same test cycle, we can see that the buses equipped with a hybrid system always have a better fuel economy and lower emission rating than diesel buses. Although CNG buses have a lower fuel economy and produce more NO_x, CO and CH_4 than diesel buses, its CO_2 and particulate numbers are considerably lower. Since the main problem of air pollution and greenhouse gas came from CO_2 and particulates, CNG buses are still cleaner than diesel buses. When comparing the performance of the same bus in different test cycles, all buses performed poorly in the NY and Manhattan cycles. The CBD and NY composite cycles have the best performance over all. Out of the entire test cycles only the NY and Manhattan cycles were created by using real-world data recorded from buses in service in NY City and Manhattan. While NY City cycle contains more idle time for a longer period than Manhattan, it is better for simulating the traffic jam time frame in Hong Kong, which is between 7:30 am to 9:30 am and 4:30 pm and 6:30 pm. For the rest of the day, the frequent stop and quick accelerate/decelerate of Manhattan cycle is closer to simulating the aggressive driving behavior of a typical Hong Kong driver.

3.2 The Report of the Alternative Fuels Group of the Cleaner Vehicles Task Force[39]

The Alternative Fuels Group of the Cleaner Vehicles Task Force from UK wrote this report. It provides information regarding potential benefits related with the use of alternative fuels and technologies, the change in capital and operational costs and the necessary infrastructure and barriers to introduce them to the market.

The UK's Alternative Fuels Group was composed of members from the oil industry, motor vehicle manufacturers, fuel suppliers, transport executives and other organizations that have an interest in road transport issues. They had held a meeting during July 1998 and December 1999, which as a result, provided the contents in this report.

3.2.1 Types of Vehicles and Fuels

The types of vehicles involved in this project were passenger car or car derived van (1500-1800cc), the panel van (<3.5 tons GVW), the single-deck bus (12m, 44 seat), the rigid truck (17 tons GVW) and the articulated truck (38/40 tons GVW). For the testing, light-duty vehicles used petrol as the baseline and heavy-duty vehicles used Ultra Low Sulfur Diesel (ULSD) for the baseline.

The various types of fuel and systems used in the report were cleaner petrol (<50-ppm sulfur), cleaner diesel (<50-ppm sulfur), natural gas, Liquefied Petroleum Gas (LPG), Battery Electric Vehicle (BEV), Hybrid Electric Vehicles (HEV), Hydrogen or Fuel Cell Electric Vehicles (FCV).

[39] Source from: The Report of the Alternative Fuel Group of the Cleaner Vehicles Task Force, 2000, Jonathan Murray, Ben Lane, Ken Lillie, and Joshua McCallum

3.2.2 Methodology

The report was written based on assumptions. The following assumptions were made for the model to eliminate uncertainties because there was a wide range of analysis:

- Equal usage: assumed all vehicles had equal usage (same mileage) so the study group could compare it easily in the analysis.
- Equal survivability: to prevent extra replacement costs for the vehicles due to the first assumption.
- Concurrent introduction: assumed that all comparable vehicles were from the same year to keep similar comparisons.
- Equivalent location: assumed that all vehicles were used in similar locations to avoid variations with equal usage.

3.2.3 Analysis

This report used all real life examples and data for their analysis, which were more reliable and believable than using computer simulation. But they only included emissions on carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NO_x), and total hydrocarbons (THC). Total hydrocarbon (THC) included VOC and CH_4, while CH_4 was a greenhouse gas and VOC was a pollutant and there was no way to separate them. Data of total hydrocarbon (THC) were dropped. The results in the report were parentage difference between different scenarios. Most of the data retrieved from this report came from Tables E1-E4. The report also studied life-cycle emissions on CO2 and CH_4 but the raw data of them were also missing.

Table E1-E4 has divided the data into four categories, they are passenger vehicle and light duty truck, Panel van, buses and rigid truck. All data in each category were collected from cars from real life include specific test cycle and fuel being use. But most PM data from the tables were missing.

3.3 Alternative and Future Fuels and Energy Sources For Road Vehicles[40]

Levelton Engineering Ltd. has conducted a study to provide information on current and future alternative fuel technologies to reduce greenhouse gas emissions from light and heavy-duty vehicles and the infrastructure requirements that could reduce greenhouse gas emissions by 2010 to 2020. It focused mainly on the full fuel cycle of greenhouse gas emissions in total or as in segments. Additional materials reviewed by the report included the cost and barriers of each alternative fuel technology, plus predictions of greenhouse and nongreenhouse gas emissions.

Levelton Engineering Ltd. is a British Columbia and Alberta firm that delivers a variety of services throughout the world ranging from materials engineering, quality assurance, environmental, geotechnical, process and energy technology to construction science, and many more. The funding source of the project was the National Climate Change Process (NCCP), which provided information on studies of the government and other experts across Canada that were exploring the impact, costs and benefits relating to climate change.

3.3.1 Types of Vehicles and Fuels

Light duty vehicles, heavy-duty diesel trucks and city transit buses were involved in this study and fuels tested were gasoline, diesel, LPG, CNG, LNG, DME (Dimethyl Ether), methanol, ethanol, biodiesel, hydrogen and electricity.

[40] Source from: Alternative And Future Fuels and Energy Sources For Road Vehicles, 1999, Wayne Edwards, Bob Dunlop, and Wenli Duo

3.3.2 Methodology

For the fuel-cycle emission analyses, the report has used the Delucchi model to develop a partial Canadianized fuel cycle model to estimate greenhouse gas emissions for the complete life cycle of each alternative fuel for this study. The Delucchi model is a spreadsheet model based on Lotus software for Apple™ computers that has the capabilities to estimate full fuel cycle emissions of greenhouse gases and pollutants from combustion. The model was modified by Mark Delucchi himself in 1998 for the Natural Resources Canada to develop the partial Canadianized fuel cycle model to meet the proper analysis conditions for Canada. The model had the best analysis of greenhouse and nongreenhouse gases from alternative fuels and had the "advantage of incorporating functional capabilities and data for analysis of Canada specifically." In addition, this study also used the model to predict emissions for the past, present and future using historical data.

3.3.3 Analysis

This report contains lots of data on life-cycle emissions. Since these data are prediction for 2010, data must be scaled back, in order for them to be closer to 2000 value. This report use life cycle emission and concentrated on both greenhouse gas (GHG) and pollutant emissions. Life cycle emission includes the three stages of fuel life cycle. They are vehicle operation, production of fuel (upstream) and manufacture of vehicle. This is because some technologies might have a very low emission during the operation stage such as fuel cell, but the fuel production stage produces a very high emission. So looking at the life cycle of an alternative technology can draw a very different conclusion than looking at one emission alone. They used both grams of CO_2 equivalent per mile and grams per million BTU delivered as units. Grams of

CO_2 equivalent per mile was used for the final result and grams per million BTU delivered was used for individual studies.

3.4 ON THE ROAD IN 2020: A life-cycle analysis of new automobile technologies[41]

The research was conducted for approximately two years by members of MIT to review technologies for passenger vehicles that could be developed and commercialized by the year 2020. It was primarily a study on the attribution of new vehicle technologies that had the potential to reduce greenhouse gas emissions.

3.4.1 Types of Vehicles and Fuels

The various types of vehicles were1996 reference internal combustion engine (ICE), baseline evolved ICE, advanced gasoline ICE, advanced diesel ICE, gasoline ICE hybrid, diesel ICE hybrid, CNG ICE hybrid, gasoline fuel cell (FC) hybrid, methanol FC hybrid, hydrogen FC hybrid, and battery electric. Spark ignition internal combustion engines (SI-ICE), compression ignition (diesel) internal combustion engines (CI-ICE), ICE-hybrids (combined ICE and battery power plants), fuel cell hybrids (combined FC and battery power plants), and battery-powered electric vehicles were used in testing.

Fuels tested were gasoline from petroleum, diesel fuel from petroleum, Fischer-Tropsch synthetic diesel from remote natural gas (F-T diesel), methanol from remote natural gas, compressed domestic natural gas (CNG), hydrogen from domestic natural gas, and electric power from the US grid mix of primary energies.

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[41] On The Road in 2020, 2000, Malcolm A. Weiss, John B. Heywood, Elisabeth M. Drake, Andreas Schafer, and Felix F. AuYeung

3.4.2 Methodology

The analyses of the report were derived from the assumptions made for the study. One assumption for the report comprised of all the 2020 vehicles to meet the US EPA Tier 2 standards of 43.5mg/km for NO_x and 6.2 mg/km for PM10. To "assess and compare future technologies validly" the report contains three sections:

- Assessment of the total system over its entire life cycle: the life cycle involved the whole process of distribution of fuels from the manufacturer of the vehicle to operation and maintenance of the vehicle up to scrappage and recycling.
- Assessment of all the important characteristics (cost, environment, health, safety, performance, drivability, convenience, reliability, or familiarity) of the technology at the same future date
- Assessment of the impacts of each of the characteristics and transitional changes on each of the main stakeholder groups. The group included fuel manufacturers, vehicle distributors (including maintenance and repairs), customers for vehicles and fuels, and government officials that dealt with safety and environmental issues.

3.4.3 Analysis

This report concentrated on the life cycle GHG emission from light duty and passenger vehicles. Data from this report were generated from computer simulations that predicted the emission values of all alternative fuel technology for 2020. Data were extracted from Table 1.2, 1.5, 1.6, 1.7, 1.8, 1.14, 3.2, 3.4, 5.3, and 5.4 of this report. While the unit used by the report was gC/km, they must be converted to gC/mile before they could be compared with data from other reports. Since these data were predictions for technologies in 2020, technologies were expected to be more advanced, in turn produced a lower amount of emission. The data values from this report were always the smallest when compare to data from other reports. But since the data from this report were not going to affect the analysis, data from this report were used to be included in the matrix as reference for future studies only.

3.5 Alternatives to Traditional Transportation Fuels 1994 (Volume 2)[42]

The Energy Information Administration (EIA) provided the report with information on greenhouse gases as required by the Energy Policy Act (EPACT) of the United States.

3.5.1 Types of Fuels

Gasoline, methanol from natural gas, ethanol from corn, compressed natural gas (CNG), and liquefied petroleum gas (LPG) were the fuels tested for GHG emissions.

3.5.2 Methodology

All data in this report were derived from the unpublished version spreadsheet of the Argonne National Laboratory, Center for Transportation Research, *Emissions of Greenhouse Gases From the Use of Transportation Fuels and Electricity*, and ANL/ESD/TM-22 (Vol. 1 and Vol. 2) prepared by Dr.Mark Delucchi. Greenhouse gas emissions were estimated using the Delucchi fuel cycle and gasoline as a comparison.

3.5.3 Analysis

This report contains data for GHG produced during the upstream of fuel, CO2, CH4, N2O, CO, and NOx, during operation of vehicle. Data were extracted from Table 7, 8, 9, 10, 11, and 12 of this report, and is the first report reviewing the idea of using Global Warming Potential (GWP) to calculate the total GHG emission. The units used in this report are milligram/Vehicle Mile Travel (mg/VMT) and mill mole/Vehicle Mile Travel (mmol/VMT), which are equivalent to mg/mile and mmol/mile and can easily convert to g/mile for use in the matrix.

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[42] Alternatives to Traditional Transportation Fuels 1994 Volume 2 Greenhouse Gas Emission, 1996, Energy Information Administration Office of Coal, Nuclear, Electric and Alternate Fuels U.S. Department of Energy

4 Methodology

The project team reviewed unbiased reports on the effectiveness of the alternative fuels in reducing pollutions. The reports examined were mostly from governments of the US, UK, or Canada. The following tasks were accomplished to complete the project:

- Attended interviews with Civic-Exchange members and many stakeholders from various organizations to acquire factual information regarding cleaner fuels and technologies and the policies of Hong Kong
- Researched studies/reports focused primarily on emission testing for each alternative fuel, various types of vehicles and its test conditions to obtain unbiased data
- A literature review was conducted for each report, from which data were extracted for the analysis/conclusion of the project.
- Three matrices were developed using the maximum and minimum emission values from the reports:
  - Upstream (production of fuel)
  - Manufacture of vehicle
  - Vehicle operation
- The matrices were further broken down into vehicle types:
  - Passenger or light-duty vehicles
  - Heavy-duty vehicles
  - Transit bus vehicles
- Bar graphs were developed to illustrate the comparisons of emissions:
  - GHG (greenhouse gas) emissions
  - Pollutant emissions

5 Results and Analysis

All data collected from the reports are divided into three different life-cycle stages for each alternative fuel technology and categories by vehicle types. The stages are emission being produced during vehicle operation, emission during production of the fuel (upstream) and emission during manufacture of the vehicle. Categories are passenger vehicles or light-duty vehicles, heavy-duty truck, and transit buses. Most reports do not distinguish the difference between passenger vehicles and light-duty goods vehicles, therefore, light-duty trucks are included in the passenger vehicles' category.

The raw data collected from different reports are always in different units. Some of the reports use moles per mile, grams per BTU (British Thermal Units) delivered, or Joules per kilometer. Converting all the data to the same units of measurements is necessary before a comparison of the results can be made. Grams per mile were decided to be the unit of measurements.

When total greenhouse gas emission was needed for comparison, Grams of CO_2 equivalent per mile was used. The global warming potential (GWP)[43] of a greenhouse gas, which is defined as the ratio of global warming, or radioactive forcing (both direct and indirect) from one unit mass of greenhouse gas to one unit of mass of carbon dioxide (CO_2) over a period of time, was used to calculate the greenhouse gas emission. Table RA1 shows individual GWP value. Carbon dioxide has a value of one and is used as the baseline, the total value of all the greenhouse gases is represented by the total GWP, which can be regarded as the equivalent amount of carbon dioxide. In the emission there are 1000 grams of carbon dioxide, one gram of methane, and one gram of nitrous oxide, the total emission will be 1331 grams (1000 * 1 + 1 *

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[43] Source from: Northeast Advanced Vehicle Consortium, *Hybrid-Electric Drive Heavy Duty Vehicle Testing Project* February 15, 2000

21 + 1 * 310) CO_2 equivalent per mile, which is the same as the global warming potential of 1331 grams CO_2.

Table RA1. Greenhouse Gas and Their Value of Global Warming Potential Over 100 years

Greenhouse Gas (GHG)	Global Warming Potential (GWP) value
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310

With the data extracted from the reports, three main matrices were created based on the life-cycle emission (production of fuel, manufacture of vehicles and vehicle operation). Each matrix was grouped into GHG (greenhouse gas) and pollutant emissions. Then each matrix is divided based on the three types of vehicles. The final form of these matrices can be found in Table RA2-RA9. Tables of raw data can be found in appendix C. Columns for the fuel economy, reference vehicle, test cycle and comments are included for reference purposes. Even though all the available data from the reports were included, none was found to fill in all the information needed, therefore, gaps existed.

Table RA2. Worst Cast Life Cycle Greenhouse Gas (GHG) Emission For Passenger Vehicles

	During Vehicle Operation				During Upstream of Fuel				During Manufacture of Vehicle			
	GHG			Total GHG Emission	GHG			Total GHG Emission	GHG			Total GHG Emission
Engine/Fuel Type	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile
Petrol												
Conventional												
300 ppm Sulfur	384.55	0.16	0.07	409.61	78.00	0.95	0.01	101.05	34.00	0.01	0.00	34.21
30 ppm Sulfur	330.00	0.16	0.02	339.56	88.00	0.98	0.01	111.68	34.00	0.01	0.00	34.21
1 ppm Sulfur	259.00	0.12	0.01	264.62	76.00	0.79	0.01	95.69	34.00	0.01	0.00	34.21
Direct Inject												
30 ppm Sulfur	259.00	0.12	0.01	264.62	70.00	0.77	0.01	89.27	34.00	0.01	0.00	34.21
1 ppm Sulfur	172.19	0.08	0.01	175.92	35.20	0.39	0.01	44.88	24.78	0.01	0.00	24.99
Diesel												
0.03% Sulfur	337.89	0.01	0.03	347.40	48.00	0.73	0.00	63.33	34.00	0.01	0.00	34.21
50 ppm Sulfur	270.00	0.01	0.02	276.41	52.00	0.74	0.00	67.54	34.00	0.01	0.00	34.21
Ethanol												
E10 (Corn)	326.00	0.16	0.02	335.56	72.00	0.95	0.02	98.15	34.00	0.01	0.00	34.21
E10 (Cellulose)	326.00	0.16	0.02	335.56	58.00	0.97	0.01	81.47	34.00	0.01	0.00	34.21
E85 (Corn)	301.10	0.22	0.07	327.42	-91.00	0.64	0.10	-46.56	34.00	0.01	0.00	34.21
E85 (Cellulose)	288.00	0.22	0.04	305.02	-186.00	0.80	0.01	-166.10	35.00	0.01	0.00	35.21
Methanol												
M85 (Natural Gas)	277.00	0.10	0.07	300.80	91.50	0.96	0.01	114.76	35.00	0.01	0.00	35.21
LPG	373.29	0.16	0.07	398.35	25.00	0.51	0.00	35.71	35.00	0.01	0.00	35.21
CNG	316.97	1.89	0.07	378.36	32.00	1.01	0.00	53.21	36.00	0.01	0.00	36.21
Hybrid												
Gasoline (30 ppm Sulfur)	210.00	0.09	0.03	221.19	48.00	0.58	0.00	60.18	32.00	0.01	0.00	32.21
Diesel	194.00	0.01	0.01	197.31	32.00	0.49	0.00	42.29	32.00	0.01	0.00	32.21
CNG	74.02	0.63	0.01	90.41	15.03	0.47	0.00	25.00	25.96	0.01	0.00	26.17
Fuel Cell												
M100 (Natural Gas)	189.00	0.00	0.00	189.00	60.00	0.57	0.00	71.97	39.00	0.01	0.00	39.21
Hydrogen (Gasoline)				207.08				51.92				30.09
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.00	174.00	0.66	0.00	187.86	41.00	0.01	0.00	41.21
Hydrogen (Electricity)	0.00	0.00	0.00	0.00	190.00	0.41	0.02	204.81	41.00	0.01	0.00	41.21
Hydrogen (Hydroelectric)	0.00	0.00	0.00	0.00	46.02	0.00	0.00	46.02	41.00	0.01	0.00	41.21
Electircity (Power Grid)	0.00	0.00	0.00	0.00	158.92	0.08	0.00	160.66	48.00	0.01	0.00	48.21

Table RA3. Best Cast Life Cycle Greenhouse Gas (GHG) Emission For Passenger Vehicles

	During Vehicle Operation				During Upstream of Fuel				During Manufacture of Vehicle			
	GHG			Total GHG Emission	GHG			Total GHG Emission	GHG			Total GHG Emission
Engine/Fuel Type	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile
Petrol												
Conventional												
300 ppm Sulfur	265.00	0.08	0.04	279.08	58.42	0.71	0.01	76.46	28.91	0.01	0.00	29.12
30 ppm Sulfur	330.00	0.16	0.02	339.56	88.00	0.98	0.01	111.68	34.00	0.01	0.00	34.21
1 ppm Sulfur	259.00	0.12	0.01	264.62	76.00	0.79	0.01	95.69	34.00	0.01	0.00	34.21
Direct Inject												
30 ppm Sulfur	195.56	0.09	0.01	200.56	40.36	0.44	0.01	52.78	25.37	0.01	0.00	25.58
1 ppm Sulfur	172.19	0.08	0.01	175.92	35.20	0.39	0.01	44.88	24.78	0.01	0.00	24.99
Diesel												
0.03% Sulfur	266.29	0.01	0.02	272.70	48.00	0.73	0.00	63.33	34.00	0.01	0.00	34.21
50 ppm Sulfur	162.18	0.01	0.01	165.49	20.01	0.28	0.00	25.99	25.96	0.01	0.00	26.17
Ethanol												
E10 (Corn)	326.00	0.16	0.02	335.56	72.00	0.95	0.02	98.15	34.00	0.01	0.00	34.21
E10 (Cellulose)	326.00	0.16	0.02	335.56	58.00	0.97	0.01	81.47	34.00	0.01	0.00	34.21
E85 (Corn)	288.00	0.08	0.04	302.08	-91.00	0.64	0.10	-46.56	34.00	0.01	0.00	34.21
E85 (Cellulose)	288.00	0.22	0.04	305.02	-186.00	0.80	0.01	-166.10	35.00	0.01	0.00	35.21
Methanol												
M85 (Natural Gas)	270.40	0.08	0.04	284.48	82.00	0.86	0.01	103.16	35.00	0.01	0.00	35.21
LPG	246.50	0.08	0.04	260.58	19.51	0.40	0.00	27.91	35.00	0.01	0.00	35.21
CNG	204.70	0.90	0.03	232.90	25.78	0.81	0.00	42.79	36.00	0.01	0.00	36.21
Hybrid												
Gasoline (30 ppm Sulfur)	117.90	0.05	0.00	119.57	20.89	0.25	0.00	26.14	25.37	0.01	0.00	25.58
Diesel	110.40	0.01	0.01	113.71	12.05	0.18	0.00	15.93	25.96	0.01	0.00	26.17
CNG	74.02	0.63	0.01	90.41	15.03	0.47	0.00	25.00	25.96	0.01	0.00	26.17
Fuel Cell												
M100 (Natural Gas)	146.90	0.00	0.00	146.90	39.45	0.37	0.00	47.32	28.91	0.01	0.00	29.12
Hydrogen (Gasoline)				207.08				51.92				30.09
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.00	174.00	0.66	0.00	187.86	41.00	0.01	0.00	41.21
Hydrogen (Electricity)	0.00	0.00	0.00	0.00	161.24	0.35	0.02	173.81	28.91	0.01	0.00	29.12
Hydrogen (Hydroelectric)	0.00	0.00	0.00	0.00	31.00	0.00	0.00	31.00				0.00
Electircity (Power Grid)	0.00	0.00	0.00	0.00	96.00	0.05	0.00	97.05	30.09	0.01	0.00	30.30

Table RA4. Worst Case Life Cycle Pollutant Emission For Passenger Vehicles

	During Vehicle Operation					During Upstream of Fuel					During Manufacture of Vehicle					Total Pollutant emission				
	Non-GHG					Non-GHG					Non-GHG									
Engine/Fuel Type	CO	NO_x	VOC	SO_x	PM	CO	NO_x	VOC	SO_x	PM	CO	NO_x	VOC	SO_x	PM	CO	NO_x	VOC	SO_x	PM
PETROL																				
Conventional																				
300 ppm Sulfur	9.00	0.80	0.90	0.09	0.05	0.36	0.43	0.27	0.17	0.23	0.01	0.05	0.00	0.07	0.01	9.37	1.28	1.17	0.33	0.29
30 ppm Sulfur	6.18	0.63	0.68	0.03	0.05	0.37	0.44	0.25	0.19	0.24	0.01	0.05	0.00	0.07	0.01	6.56	1.12	0.93	0.29	0.30
1 ppm Sulfur	4.87	0.49	0.53	0.02	0.04	0.30	0.36	0.20	0.16	0.19	0.01	0.05	0.00	0.07	0.01	5.18	0.90	0.73	0.25	0.24
Direct Inject																				
30 ppm Sulfur	4.87	0.49	0.53	0.02	0.04	0.29	0.35	0.19	0.15	0.19	0.01	0.05	0.00	0.07	0.01	5.17	0.89	0.72	0.24	0.24
DIESEL																				
0.03% Sulfur	1.54	1.61	0.30	0.07	0.32	0.26	0.30	0.07	0.12	0.18	0.01	0.05	0.00	0.07	0.01	1.81	1.96	0.37	0.26	0.51
50 ppm Sulfur	1.54	1.22	0.30	0.03	0.19	0.26	0.31	0.08	0.13	0.18	0.01	0.05	0.00	0.07	0.01	1.81	1.58	0.38	0.23	0.38
ETHANOL																				
E10 (Corn)	6.06	0.63	0.66	0.03	0.04	0.40	0.51	0.31	0.18	0.23	0.01	0.05	0.00	0.07	0.01	6.47	1.19	0.97	0.28	0.28
E10 (Cellulose)	6.06	0.63	0.66	0.03	0.04	0.38	0.48	0.24	0.18	0.23	0.01	0.05	0.00	0.07	0.01	6.45	1.16	0.90	0.28	0.28
E85 (Corn)	9.00	0.80	0.52	0.03	0.02	0.62	1.05	0.83	0.10	0.11	0.01	0.05	0.00	0.07	0.01	9.63	1.90	1.35	0.20	0.14
E85 (Cellulose)	4.92	0.66	0.52	0.03	0.02	0.48	0.74	0.14	0.07	0.15	0.01	0.05	0.00	0.07	0.01	5.41	1.45	0.66	0.17	0.18
METHANOL																				
M85 (Natural Gas)	9.00	0.80	0.38	0.03	0.02	0.25	0.64	0.13	0.10	0.09	0.01	0.05	0.00	0.07	0.01	9.26	1.49	0.51	0.20	0.12
LPG	9.00	0.80	0.19	0.02	0.01	0.13	0.20	0.05	0.04	0.04	0.01	0.05	0.00	0.07	0.01	9.14	1.05	0.24	0.13	0.06
CNG	9.00	0.80	0.07	0.01	0.01	0.14	0.26	0.02	0.05	0.01	0.01	0.05	0.00	0.07	0.01	9.15	1.11	0.09	0.13	0.03
HYBRID																				
Gasoline (30 ppm Sulfur)	4.56	0.43	0.52	0.02	0.03	0.22	0.26	0.17	0.11	0.14	0.01	0.05	0.00	0.06	0.01	4.79	0.74	0.69	0.19	0.18
Diesel	1.13	0.90	0.22	0.05	0.14	0.17	0.20	0.05	0.08	0.12	0.01	0.05	0.00	0.06	0.01	1.31	1.15	0.27	0.19	0.27
FUEL CELL																				
M100 (Natural Gas)	0.00	0.00	0.06	0.03	0.00	0.14	0.48	0.06	0.06	0.02	0.01	0.06	0.00	0.08	0.01	0.15	0.54	0.12	0.17	0.03
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.03	0.00	0.12	0.27	0.02	0.09	0.02	0.01	0.06	0.00	0.08	0.01	0.13	0.33	0.02	0.20	0.03
Hydrogen (Electricity)	0.00	0.00	0.00	0.03	0.00	0.08	0.49	0.01	0.73	0.05	0.01	0.06	0.00	0.08	0.01	0.09	0.55	0.01	0.84	0.06
Hydrogen (Hydroelectric)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.08	0.01	0.01	0.06	0.00	0.08	0.01
Electircity (Power Grid)	0.00	0.00	0.00	0.00	0.00	0.01	0.23	0.00	0.38	0.02	0.01	0.07	0.00	0.09	0.01	0.02	0.30	0.00	0.47	0.03

Table RA5. Best Case Life Cycle Pollutant Emission For Passenger Vehicles

	During Vehicle Operation					During Upstream of Fuel					During Manufacture of Vehicle					Total Pollutant emission				
	Non-GHG					Non-GHG					Non-GHG									
Engine/Fuel Type	CO	NO_x	VOC	SO_x	PM	CO	NO_x	VOC	SO_x	PM	CO	NO_x	VOC	SO_x	PM	CO	NO_x	VOC	SO_x	PM
PETROL																				
Conventional																				
300 ppm Sulfur	1.01	0.16	0.90	0.09	0.05	0.36	0.43	0.27	0.17	0.23	0.01	0.05	0.00	0.07	0.01	1.38	0.64	1.17	0.33	0.29
30 ppm Sulfur	6.18	0.63	0.68	0.03	0.05	0.37	0.44	0.25	0.19	0.24	0.01	0.05	0.00	0.07	0.01	6.56	1.12	0.93	0.29	0.30
1 ppm Sulfur	4.87	0.49	0.53	0.02	0.04	0.30	0.36	0.20	0.16	0.19	0.01	0.05	0.00	0.07	0.01	5.18	0.90	0.73	0.25	0.24
Direct Inject																				
30 ppm Sulfur	4.87	0.49	0.53	0.02	0.04	0.29	0.35	0.19	0.15	0.19	0.01	0.05	0.00	0.07	0.01	5.17	0.89	0.72	0.24	0.24
DIESEL																				
0.03% Sulfur	0.53	0.84	0.30	0.07	0.06	0.26	0.30	0.07	0.12	0.18	0.01	0.05	0.00	0.07	0.01	0.80	1.19	0.37	0.26	0.25
50 ppm Sulfur	1.54	1.22	0.30	0.03	0.19	0.26	0.31	0.08	0.13	0.18	0.01	0.05	0.00	0.07	0.01	1.81	1.58	0.38	0.23	0.38
ETHANOL																				
E10 (Corn)	6.06	0.63	0.66	0.03	0.04	0.40	0.51	0.31	0.18	0.23	0.01	0.05	0.00	0.07	0.01	6.47	1.19	0.97	0.28	0.28
E10 (Cellulose)	6.06	0.63	0.66	0.03	0.04	0.38	0.48	0.24	0.18	0.23	0.01	0.05	0.00	0.07	0.01	6.45	1.16	0.90	0.28	0.28
E85 (Corn)	4.92	0.66	0.52	0.03	0.02	0.62	1.05	0.83	0.10	0.11	0.01	0.05	0.00	0.07	0.01	5.55	1.76	1.35	0.20	0.14
E85 (Cellulose)	4.92	0.66	0.52	0.03	0.02	0.48	0.74	0.14	0.07	0.15	0.01	0.05	0.00	0.07	0.01	5.41	1.45	0.66	0.17	0.18
METHANOL																				
M85 (Natural Gas)	4.99	0.65	0.38	0.03	0.02	0.25	0.64	0.13	0.10	0.09	0.01	0.05	0.00	0.07	0.01	5.25	1.34	0.51	0.20	0.12
LPG	0.03	0.21	0.19	0.02	0.01	0.13	0.20	0.05	0.04	0.04	0.01	0.05	0.00	0.07	0.01	0.17	0.46	0.24	0.13	0.06
CNG	0.29	0.13	0.07	0.01	0.01	0.14	0.26	0.02	0.05	0.01	0.01	0.05	0.00	0.07	0.01	0.44	0.44	0.09	0.13	0.03
HYBRID																				
Gasoline (30 ppm Sulfur)	0.48	0.10	0.52	0.02	0.03	0.22	0.26	0.17	0.11	0.14	0.01	0.05	0.00	0.06	0.01	0.71	0.41	0.69	0.19	0.18
Diesel	1.13	0.90	0.22	0.05	0.14	0.17	0.20	0.05	0.08	0.12	0.01	0.05	0.00	0.06	0.01	1.31	1.15	0.27	0.19	0.27
FUEL CELL																				
M100 (Natural Gas)	0.00	0.00	0.00	0.03	0.00	0.14	0.48	0.06	0.06	0.02	0.01	0.06	0.00	0.08	0.01	0.15	0.54	0.06	0.17	0.03
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.03	0.00	0.12	0.27	0.02	0.09	0.02	0.01	0.06	0.00	0.08	0.01	0.13	0.33	0.02	0.20	0.03
Hydrogen (Electricity)	0.00	0.00	0.00	0.03	0.00	0.08	0.49	0.01	0.73	0.05	0.01	0.06	0.00	0.08	0.01	0.09	0.55	0.01	0.84	0.06
Hydrogen (Hydroelectric)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.08	0.01	0.01	0.06	0.00	0.08	0.01
Electircity (Power Grid)	0.00	0.00	0.00	0.00	0.00	0.01	0.23	0.00	0.38	0.02	0.01	0.07	0.00	0.09	0.01	0.02	0.30	0.00	0.47	0.03

Table RA6. Total Emission During Operation of Vehicle For Heavy-Duty Vehicles

Engine/Fuel Type	GHG CO_2	CH_4	N2O	Total GHG Emission g CO_2 Equivalent/mile	Non-GHG CO	NO_x	VOC	SO_x	PM
Diesel									
0.03% Sulfur	1,629.00	0.10	0.07	1,662.00	16.37	20.55	2.71	0.43	0.58
50 ppm Sulfur	1,629.00	0.10	0.07	1,662.00	16.37	20.55	2.71	0.17	0.58
DME	1,426.00	0.05	0.07	1,463.00	21.28	10.27	7.35	0.13	0.12
Biodiesel	1,639.00	0.03	0.07	1,663.00	4.91	26.71	0.54	0.27	0.29
CNG	1,341.91	8.00	0.30	1,601.79	0.06	1.35	0.30	0.04	0.03
LPG	1,618.00	0.10	0.07	1,668.00	1.64	10.27	8.67	0.10	0.04
LNG	1,215.00	2.97	0.07	1,331.00	1.64	10.27	8.58	0.04	0.03

Table RA7. Life Cycle GHG Emissions For Heavy-Duty Vehicles

Engine/Fuel Type	Operation Of Vehicle	Production of Fuel	Manufacture of Vehicle	Total GHG Emission
Diesel				
0.03% Sulfur	1,662.00	389.00	90.00	2,141.00
50 ppm Sulfur	1,662.00	418.00	90.00	2,170.00
DME	1,463.00	381.00	92.00	1,936.00
Biodiesel	1,663.00	-696.00	92.00	1,059.00
LPG	1,668.00	215.00	90.00	1,973.00
LNG	1,331.00	641.00	90.00	2,062.00

Table RA8. Total Emission During Operation of Vehicle For Transit Buses

	Worst Case				Best Case			
	GHG	Pollutant			GHG	Pollutant		
Engine/Fuel Type	CO_2	CO	NOx	PM	CO_2	CO	NO_x	PM
Diesel								
0.03% Sulfur	4,268.00	7.00	40.30	0.48	2,156.00	0.34	20.16	0.03
50 ppm Sulfur	2,156.00				2,156.00			
DME	1,908.00				1,908.00			
Biodiesel	3,377.00	8.50	27.90	3.80	2,156.00	4.50	22.30	1.81
CNG	3,395.00	26.30	25.00	0.05	1,964.00	0.60	6.80	0.03
LPG	2,106.18	0.02	8.69	0.02	2,106.18	0.02	8.69	0.02
MossGas	2,816.00	2.00	32.20	0.10	2,386.00	1.00	26.90	0.09
Hybrid								
Diesel (0.03% Sulfur)	2,841.00	0.40	27.70	0.14	1,262.00	0.10	19.20	0.00
Diesel (no regen)	3,010.00	1.00	32.10	0.24	2,625.00	0.04	22.00	0.07
MossGas	2,218.00	0.10	18.50	0.02	2,218.00	0.10	18.50	0.02
Fuel Cell								
Methanol (Natural Gas)	1,479.00	0.00	0.00	0.00	1,479.00	0.00	0.00	0.00
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen (Electricity)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table RA9. Life Cycle GHG Emissions For Heavy-Duty Vehicles

Engine/Fuel Type	During Vehicle Operation	During Upstream of Fuel	During Manufacture of Vehicle	Total
Diesel				
0.03% Sulfur	4,268.00	505.00	87.00	4,860.00
50 ppm Sulfur	2,156.00	543.00	87.00	2,786.00
DME	1,908.00	497.00	89.00	2,494.00
Biodiesel	3,377.00	-903.00	90.00	2,564.00
CNG	3,395.00	429.00	89.00	3,913.00
Hybrid				
Diesel (0.03% Sulfur)	2,841.00	296.00	102.00	3,239.00
Fuel Cell				
Methanol (Natural Gas)	1,479.00	548.00	82.00	2,109.00
Hydrogen (Natural Gas)	0.00	1,445.00	88.00	1,533.00
Hydrogen (Electricity)	0.00	1,570.00	88.00	1,658.00

The matrix of emission during operation of a vehicle contained the most information, followed by the matrix of the upstream of fuel. The emission during manufacture of a vehicle had the least amount of data. Most of the reports focused only on vehicle operation and concentrated mainly on GHG emission of passenger vehicles. The reason why the whole life-cycle is important for the analysis is because one technology could perform very well on one stage but could do poorly on the others. Therefore, looking at the life-cycle emission of each technology is more important than focusing on a single stage alone. Since most reports dealing with heavy-duty vehicles and buses only focus on emission during operation of vehicles, data of upstream of fuel production and vehicle manufacture for both heavy-duty vehicles and buses are limited. Therefore, life cycle analysis for heavy-duty vehicles and buses could only be performed on total greenhouse gas emission.

It is necessary to develop a strategy so that comparing the values of emissions would be easier to understand for the readers. The average values of all the data collected were considered for the analysis, but maximum value of the data was believed to be more important, since most vehicles on the roads right now in Hong Kong are more than four years old. Most of them are poorly maintained, and the driving style of most drivers creates emissions far worse than the regulated idling value. Thus the maximum value would closely resemble the current on-road condition. Bar graphs were also created using minimum values because these values could be used to guide the future improvement of the technologies. The minimum value could be seen as the emission of a well maintained vehicle.

After the data were selected for the creation of the bar graphs, a graph style was chosen so it would be easier to compare and show the results. A stacked graph was the proper solution because it allowed comparisons of the total emission as well as individual pollutant at the same time. If the data range between different pollutants was big enough, the smaller pollutant might not show up in the graph at all. At that point we would need to use separate graphs to conduct further analysis.

5.1 Passenger Vehicles

This category contains most of the data found but mainly concentrates on CO_2 emission and most of these data do not contain N_2O and particulate matters. Table RA10 is an example of raw data for gasoline (petrol) vehicles using fuels containing 300 ppm Sulfur. Different rows in the table show data from different reports.

Table RA10. Raw data of petrol vehicle using 300 ppm Sulfur fuel (g/mile)

	GHG			Total GHG Emission	Non-GHG					Refence
Engine/Fuel Type	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO	NO_x	VOC	SO_x	PM	Report
Gasoline										
300 ppm S	327.00	0.16	0.04	347.00	7.73	0.74	0.90	0.09	0.05	Report 1
	272.40	0.08	0.07		9.00	0.80				Report 2
	267.58				1.48	0.16				Report 4
	265.00				1.67	0.16				Report 4
	288.98				1.01	0.27				Report 4
	384.55				1.66	0.42				Report 4
	376.51				1.51	0.24				Report 4

For most of the technologies, there are more than one set of data for CO_2, CO, and NO_x, but very few has data for all other emissions. Since we used maximum (worst case) and minimum (best case) value for our analysis, the fact that only one set of data is available should not affect our analysis. That one set of available data was used as both the minimum and maximum value. From these data, three tables were created. They are *Worst Case Life-Cycle*

GHG Emission for Passenger Vehicles (Table RA11), *Best Case Life-Cycle GHG Emission for Passenger Vehicles* (Table RA12), and *Best/Worst Case Life cycle Pollutant Emission for Passenger Vehicles* (Table RA13).

Table RA11. Worst case Life-Cycle GHG Emission for Passenger Vehicles (g/mile)

Engine/Fuel Type	Vehicle Operation	Upstream of Fuel	Manufacture of Vehicle	Total GHG Emission
PETROL				
300 ppm Sulfur	409.61	100.00	34.00	543.61
30 ppm Sulfur	341.00	111.00	34.00	486.00
1 ppm Sulfur	269.00	94.00	34.00	397.00
Direct Inject				
30 ppm Sulfur	268.00	88.00	34.00	390.00
1 ppm Sulfur	178.17	44.25	24.78	247.20
DIESEL				
500 ppm Sulfur	345.40	64.00	34.00	443.40
50 ppm Sulfur	276.00	69.00	34.00	379.00
ETHANOL				
E10 (Corn)	338.00	95.00	34.00	467.00
E10 (Cellulose)	338.00	83.00	34.00	455.00
E85 (Corn)	327.42	-47.00	34.00	314.42
E85 (Cellulose)	306.00	-167.00	35.00	174.00
METHANOL				
M85 (Natural Gas)	300.80	112.70	35.00	448.50
LPG	398.35	36.00	35.00	469.35
CNG	378.36	54.00	36.00	468.36
HYBRID				
Gasoline (30 ppm S)	222.00	61.00	32.00	315.00
Diesel	198.00	47.00	32.00	277.00
CNG	91.44	25.37	25.96	142.77
FUEL CELL				
M100 (Natural Gas)	189.00	70.00	39.00	298.00
Hydrogen (Gasoline)	207.08	51.92	30.09	289.09
Hydrogen (Natural Gas)	0.00	187.00	41.00	228.00
Hydrogen (Electricity)	0.00	203.00	41.00	244.00
Hydrogen (Hydroelectric)	0.00	46.02	41.00	87.02
Electricity (Power Grid)	0.00	162.23	48.00	210.23

Table RA12. Best Case Life-Cycle GHG Emission for Passenger Vehicles (g/mile)

Engine/Fuel Type	Vehicle Operation	Upstream of Fuel	Manufacture of Vehicle	Total GHG Emission
PETROL				
300 ppm Sulfur	279.08	74.90	28.91	382.89
30 ppm Sulfur	341.00	111.00	34.00	486.00
1 ppm Sulfur	269.00	94.00	34.00	397.00
Direct Inject				
30 ppm Sulfur	202.36	50.74	25.37	278.47
1 ppm Sulfur	178.17	44.25	24.78	247.20
DIESEL				
500 ppm Sulfur	272.21	64.00	34.00	370.21
50 ppm Sulfur	165.78	26.55	25.96	218.29
ETHANOL				
E10 (Corn)	338.00	95.00	34.00	467.00
E10 (Cellulose)	338.00	83.00	34.00	455.00
E85 (Corn)	302.08	-47.00	34.00	289.08
E85 (Cellulose)	306.00	-167.00	35.00	174.00
METHANOL				
M85 (Natural Gas)	284.48	101.00	35.00	420.48
LPG	260.58	28.10	35.00	323.68
CNG	232.90	43.50	36.00	312.40
HYBRID				
Gasoline (30 ppm Sulfur)	123.89	26.55	25.37	175.81
Diesel	112.68	17.70	25.96	156.34
CNG	91.44	25.37	25.96	142.77
FUEL CELL				
M100 (Natural Gas)	146.90	46.02	28.91	221.83
Hydrogen (Gasoline)	207.08	51.92	30.09	289.09
Hydrogen (Natural Gas)	0.00	187.00	41.00	228.00
Hydrogen (Electricity)	0.00	172.27	28.91	201.18
Hydrogen (Hydroelectric)	0.00	31.00		31.00
Electricity (Power Grid)	0.00	98.00	30.09	128.09

Table RA13. Best/Worst Case Life Cycle Pollutant Emission for Passenger Vehicles (g/mile)

	Worst Case					Best Case				
Engine/Fuel Type	CO	NOx	VOC	SOx	PM	CO	NOx	VOC	SOx	PM
PETROL										
300 ppm Sulfur	9.37	1.28	1.17	0.33	0.29	1.38	0.64	1.17	0.33	0.29
30 ppm Sulfur	6.56	1.12	0.93	0.29	0.30	6.56	1.12	0.93	0.29	0.30
1 ppm Sulfur	5.18	0.90	0.73	0.25	0.24	5.18	0.90	0.73	0.25	0.24
Direct Inject										
30 ppm Sulfur	5.17	0.89	0.72	0.24	0.24	5.17	0.89	0.72	0.24	0.24
DIESEL										
Conventional	1.81	1.96	0.37	0.26	0.51	0.80	1.19	0.37	0.26	0.25
50 ppm Sulfur	1.81	1.58	0.38	0.23	0.38	1.81	1.58	0.38	0.23	0.38
ETHANOL										
E10 (Corn)	6.47	1.19	0.97	0.28	0.28	6.47	1.19	0.97	0.28	0.28
E10 (Cellulose)	6.45	1.16	0.90	0.28	0.28	6.45	1.16	0.90	0.28	0.28
E85 (Corn)	9.63	1.90	1.35	0.20	0.14	5.55	1.76	1.35	0.20	0.14
E85 (Cellulose)	5.41	1.45	0.66	0.17	0.18	5.41	1.45	0.66	0.17	0.18
METHANOL										
M85 (Natural Gas)	9.26	1.49	0.51	0.20	0.12	5.25	1.34	0.51	0.20	0.12
LPG	9.14	1.05	0.24	0.13	0.06	0.17	0.46	0.24	0.13	0.06
CNG	9.15	1.11	0.09	0.13	0.03	0.44	0.44	0.09	0.13	0.03
HYBRID										
Gasoline (30 ppm S)	4.79	0.74	0.69	0.19	0.18	0.71	0.41	0.69	0.19	0.18
Diesel	1.31	1.15	0.27	0.19	0.27	1.31	1.15	0.27	0.19	0.27
FUEL CELL										
M100 (Natural Gas)	0.15	0.54	0.12	0.17	0.03	0.15	0.54	0.06	0.17	0.03
Hydrogen (Natural Gas)	0.13	0.33	0.02	0.20	0.03	0.13	0.33	0.02	0.20	0.03
Hydrogen (Electricity)	0.09	0.55	0.01	0.84	0.06	0.09	0.55	0.01	0.84	0.06
Hydrogen (Hydroelectric)	0.01	0.06	0.00	0.08	0.01	0.01	0.06	0.00	0.08	0.01
Electricity (Power Grid)	0.02	0.30	0.00	0.47	0.03	0.02	0.30	0.00	0.47	0.03

Three bar graphs were produced from the tables above, they are the *Best and Worst Case of CO_2 Emission for Passenger Vehicles During Vehicle Operation*, *Worst Case of GHG Emission for Passenger Vehicles (Stack Graph)*, and *Worst Case of Pollutant Emission for Passenger Vehicle (Stack Graph)*. Figure RA1 is the bar graph of the *Best and Worst Case GHG Emission for Passenger Vehicle.*

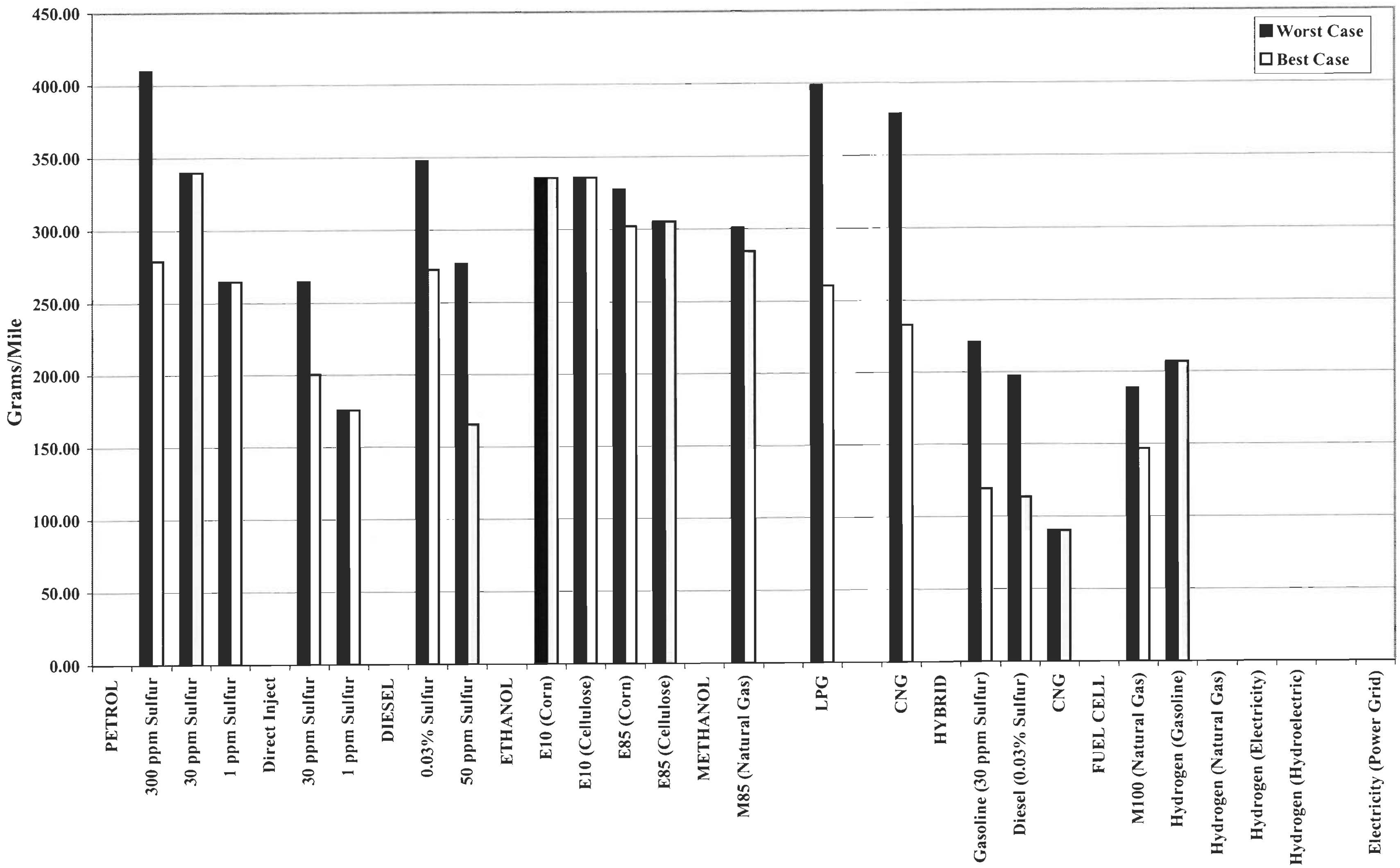

Figure RA1. Best and Worst Case CO_2 Emission for Passenger Vehicle During Vehicle Operation

CO_2 is one of the emissions in that most people are interested because it contributes about 90% of the total emission from an on-road petrol or diesel. The CO_2 emission during vehicle operation is also what most reports tend to focus on. Figure RA1 illustrates the difference between the maximum and the minimum value. Most technology has some difference between the maximum and the minimum value, but since the amount of available data is limited, some engine/fuel type only has CO_2 data available. Therefore, maximum and minimum values in this case would be the same. Figure RA1 can also illustrate one of the possible ways to create a biased report. If a company is trying to produce a report to promote their low sulfur diesel (50-ppm Sulfur), they can use the minimum value to compare to the maximum value of hybrid petrol or M100 fuel cell. The figure can also provide information on whether a vehicle received good maintenance. A poorly designed vehicle with good maintenance can have a better emission than a well designed vehicle with poor maintenance.

From Figure RA1, the emission of a diesel engine using low sulfur diesel has better performance than most of other fuels, with the exception of Hybrid and Fuel cell. In the best case value, the diesel vehicles (50-ppm Sulfur) produced a lower amount of CO_2 than petrol vehicles (30-ppm Sulfur) equipped with direct injection, while for the worst case, they have similar values. In the worst case value, LPG and CNG are the highest, while Hybrid has the best result out of all alternative fuel technologies. LPG and CNG has such a high emission rating due to the fact that most unburned LPG and CNG escape through the exhaust. When new technologies are developed to burn all the components in the fuel, LPG and CNG could be cleaner than hybrid vehicles. Fuel cells are supposed to produce nothing other than water and heat during operation. But as illustrated from the Figure RA1, the CO_2 emission of a fuel cell vehicle that is equipped with a methanol or gasoline reformer has higher emission than a diesel vehicle in the best-case value. This is not saying that the fuel cell technologies are not efficient, the fossil fuel used in the reformer of fuel cell vehicles still contains carbon. The amount of CO_2 being produced depended on the efficiency of the engine. Burning of fuel in an internal combustion engine causes carbon to react with oxygen, which in turn produces CO and CO_2. Since fuel cells are generally more efficient than an internal combustion engine. A fuel cell equipped with a gasoline reformer has a lower CO_2 emission than a conventional gasoline engine running on the same grade of gasoline because the fuel cell is more efficient.

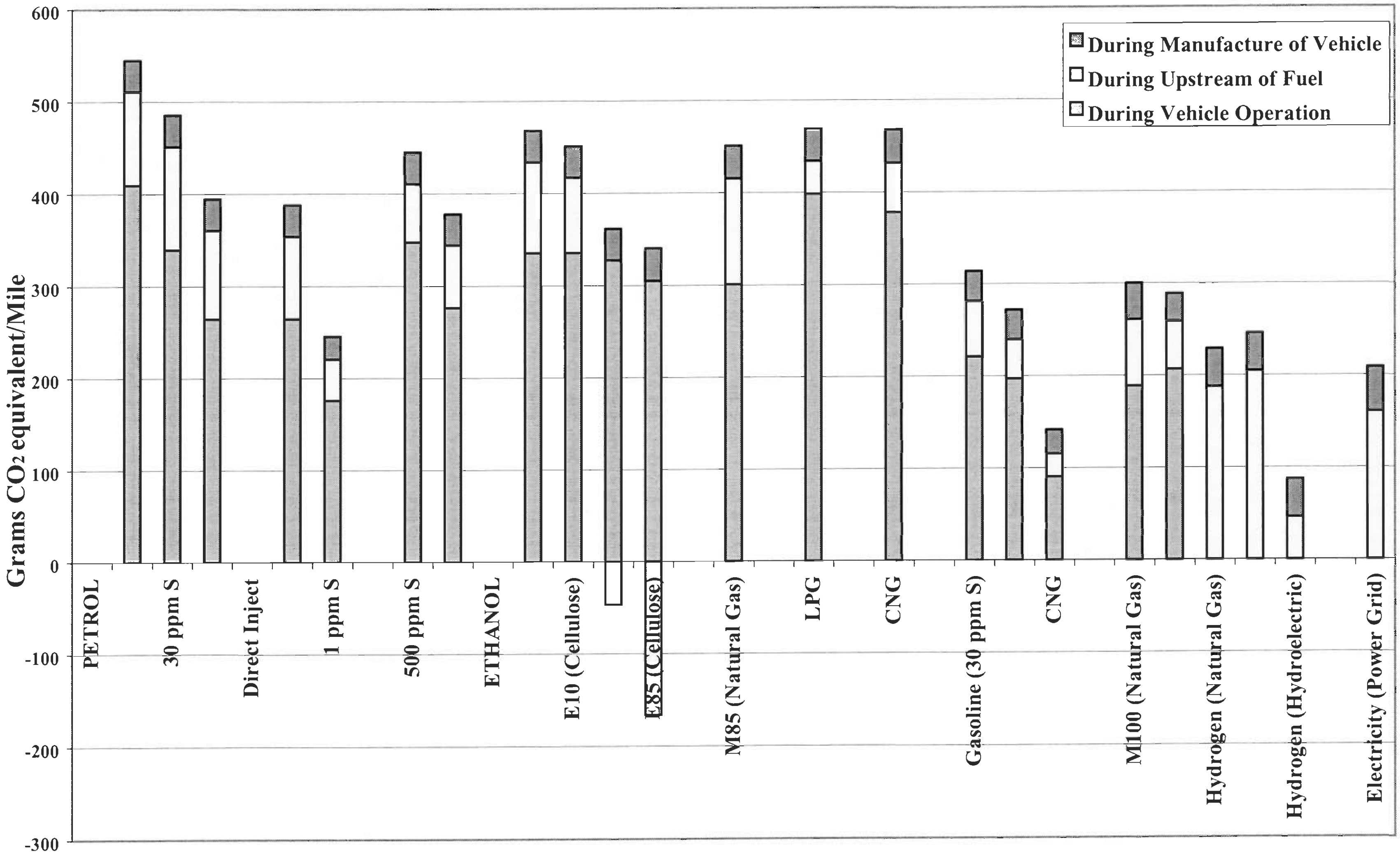

Figure RA2. Worst Case of GHG Emission for Passenger Vehicle

Figure RA2 shows the total GHG emission from the three stages of the life cycle of each alternate fuel. It includes the vehicle operation, production of fuel (upstream) and the manufacture of vehicle. The GHG emissions of each stage contain the total of CO_2, CH_4 and N_2O expressed in grams of CO_2 equivalent. Looking at the whole life cycle of the fuel reveals a different picture from the CO_2 emission during operation of a vehicle. As seen from the Figure RA2, E85 has negative emission ratings. The negative upstream means it uses CO_2 in the process to create E85, so the total emission of E85 should be lower. Instead of separating into different stages, Figure RA3 shows the total GHG emission of each alternative fuel. From Figure RA3 the maximum value of E85 (corn) is about 300 g CO_2 equivalent/mile and for E85 (cellulous) is less than 200 g CO_2 equivalent/mile.

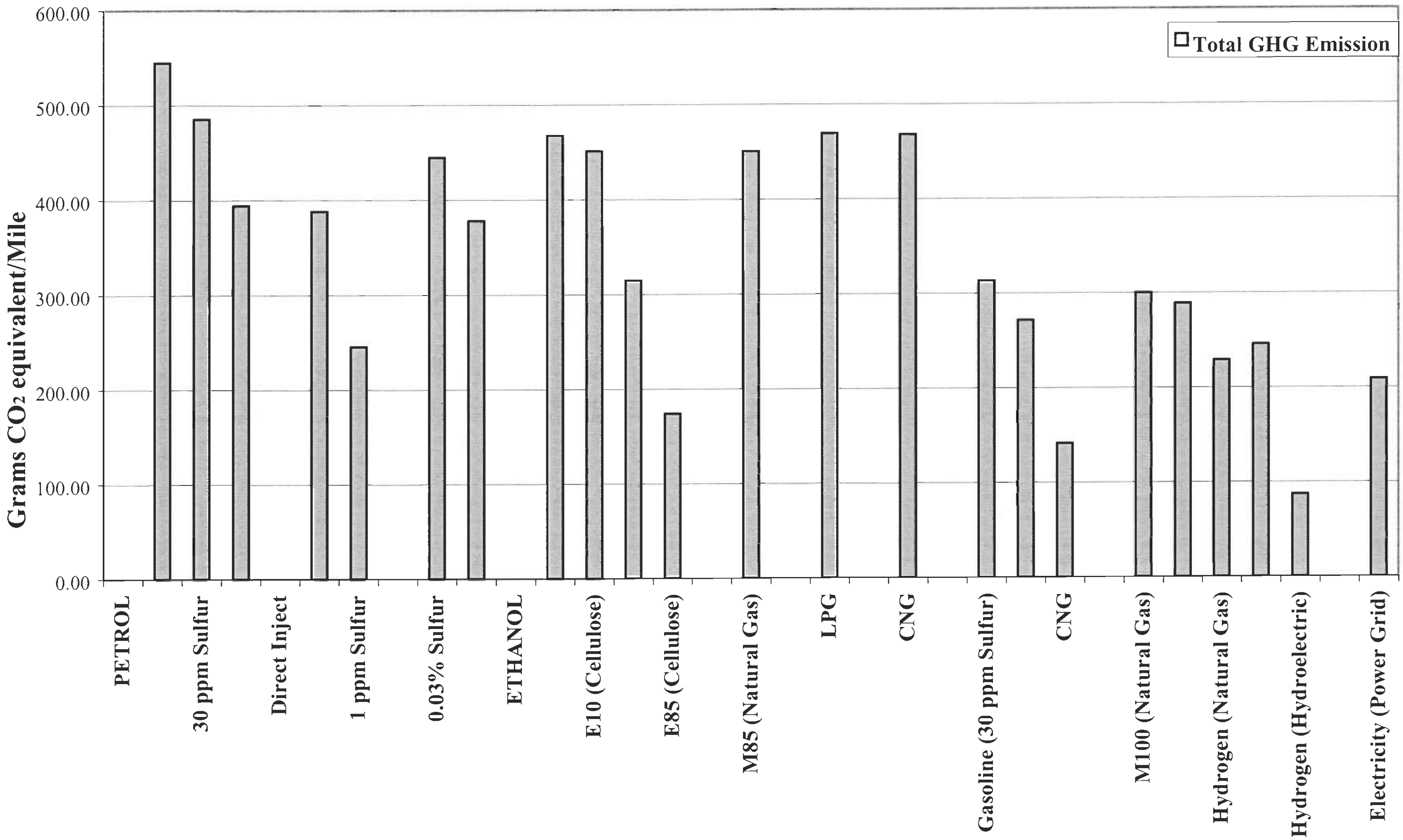

Figure RA3. Total Life cycle GHG Emission for Passenger Vehicles

Ethanol E85 has a lower emission rating than most hybrid technology or fuel cell technology. But comparing that with the analysis of Figure RA1, which concentrates on CO_2 emission during vehicle operation alone, E85 was rated as one of the highest emission technologies. The last four columns of Figure RA2 show the emission from electrical vehicles drawing power from the power grid, and fuel cell vehicle using hydrogen produced from natural gas, electricity, and hydroelectric. Although these fuel technologies produce zero emission at the vehicle operation stage, all of them except hydrogen produced from hydroelectric generate twice the amount of CO_2 during production of fuel than any other technologies. The emission is so high that the petrol vehicle using direct injection technology with ULSP (Ultra Low Sulfur Petrol) fuel has a similar or lower total emission rating than fuel cell vehicles using hydrogen produced from natural gas or electricity, as well as some hybrid vehicles. Therefore, an evaluation of Figure RA1 alone would give a wrong conclusion.

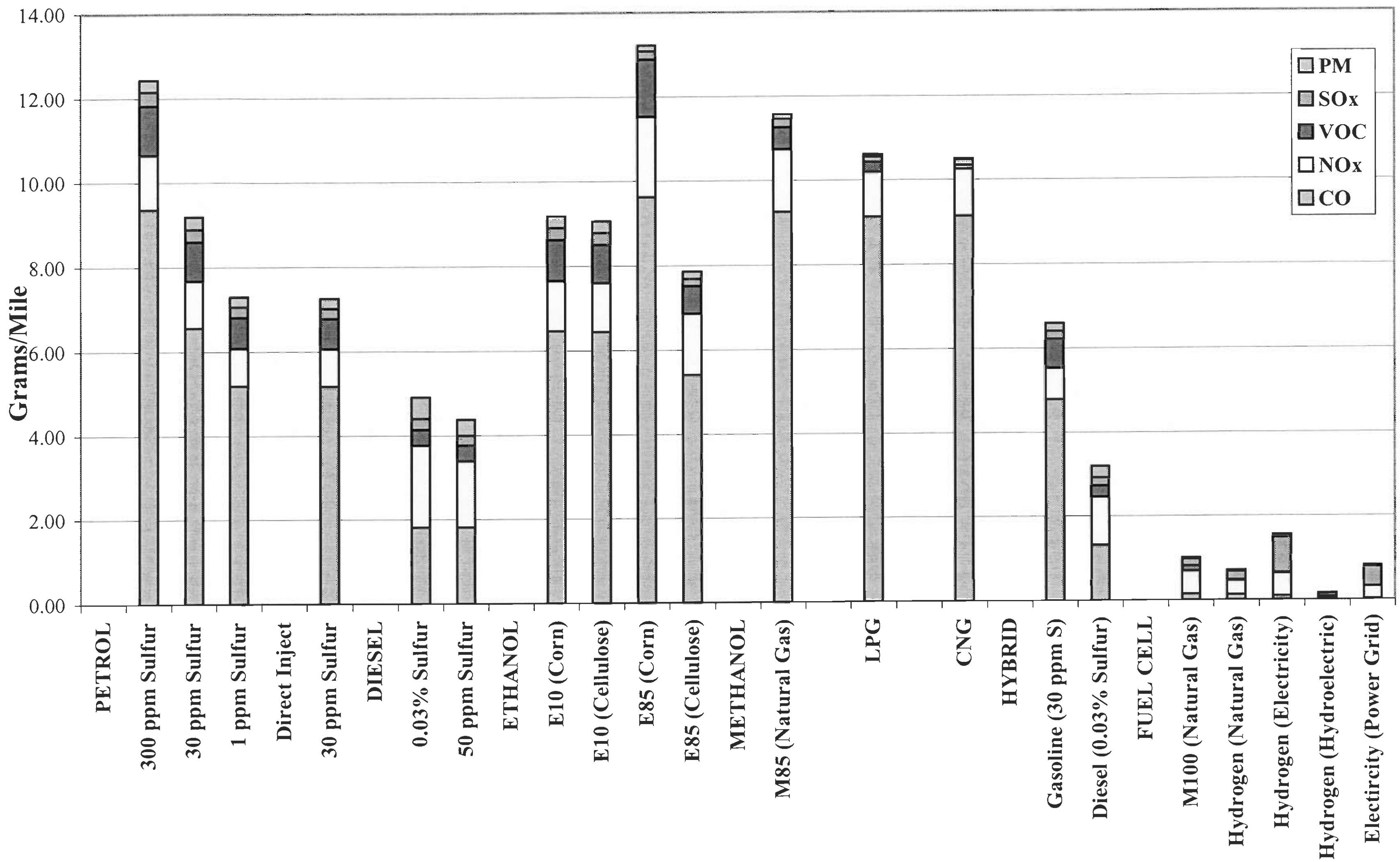

Figure RA4. Worst Case of Pollutant Emission for Passenger Vehicle

Figure RA4 shows the total pollutant emission over the life cycle of each alternative fuel. Most government decision-makers tend to focus on the amount of particulate matters (PM) because it is the main cause of black smoke and the black cloud that flows over the cities. Except fuel cell vehicles, LPG and CNG produces the lowest PM level among all alternative fuel vehicles, but both of them also have one of the highest pollution ratings. The emission of LPG and CNG may not affect human lungs like particulate matters do but they do produce four times more carbon monoxide than that produced by diesel vehicles. Figure RA4 illustrates that diesel vehicles produce the most PM out of all the present alternative fuel technologies but they have a lower total emission rating than most of them, except hybrid diesel and fuel cell. The total emission from diesel vehicle is less than half of the total of LPG or CNG. The pollutant produced by ethanol (E85), methanol (M85), LPG, CNG and petrol has the highest pollutant ratings of all alternative fuel vehicles.

5.1.1 Passenger Vehicle Conclusion

Figures RA1-RA3 illustrated the results obtained for GHG and pollutant emissions for passenger vehicles. Looking at one stage or one aspect of the fuel emission is not sufficient to determine a fuel's effectiveness in reducing pollutions. However the analysis of a single stage can be used to guide the short-term solution like reducing CO_2 emission from the population. On the other hand, bringing in an alternative technology to reduce one emission might result in creating more emission of another kind. The whole life-cycle determines a fuel's life emission, therefore, choosing the lowest emission alternative fuel based on the life-cycle would be more appropriate as a long-term strategy. Although most reports concentrated on the emission of CO_2

produced during the operation of vehicles, the analysis on Figure RA1 alone could reveal that the emissions from ethanol, methanol, LPG, and CNG produce more emission than other alternative technologies. But with the combination of Figures RA2, RA3 and RA4, it is certain that even though E85 has a very high pollutant emission, its GHG emission level is very low. LPG and CNG have a very low PM emission but both have a very high emission rating on GHG and pollutant emission. Ultra-Low Sulfur Petrol (ULSP) is comparable with hybrid technology but since ULSP can be used in hybrid technology, hybrid is still a cleaner technology than ULSP alone. It seems that hybrid vehicles are going to be the best replacement for passenger vehicles until fuel cells are cheap enough to become popular. With the exclusion of hybrid and fuel cell technology, diesel is actually the cleanest fuel of all.

5.2 Heavy-Duty Vehicle

This part of the analysis concentrates on heavy-duty vehicles, which include all vehicles over 2000 lbs except buses. This section of the report has the least amount of available data, only two reports being reviewed have a combined total of eight different technologies, each technology contains only one set of reliable data. There are no reliable data for pollutants and individual greenhouse gas for the production of fuels and production of vehicles. The life cycle analysis is only performed on total GHG Emission. Due to the lack of data for each technology, the maximum and minimum value method is dropped for this section. A table of *Total Emission During Operation of Heavy-Duty Vehicles* (Table RA14) and *Life Cycle GHG Emission For Heavy-Duty Vehicles* (RA6.1) were created.

Table RA14. Total Emission During Operation of Vehicle For Heavy-Duty Vehicles

	GHG			Total GHG Emission	Non-GHG				
	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO	NO_x	VOC	SO_x	PM
Engine/Fuel Type									
Diesel									
0.03% Sulfur	1,629.00	0.10	0.07	1,662.00	16.37	20.55	2.71	0.43	0.58
50 ppm Sulfur	1,629.00	0.10	0.07	1,662.00	16.37	20.55	2.71	0.17	0.58
DME	1,426.00	0.05	0.07	1,463.00	21.28	10.27	7.35	0.13	0.12
Biodiesel	1,639.00	0.03	0.07	1,663.00	4.91	26.71	0.54	0.27	0.29
CNG	1,341.91	8.00	0.30	1,601.79	0.06	1.35	0.30	0.04	0.03
LPG	1,618.00	0.10	0.07	1,668.00	1.64	10.27	8.67	0.10	0.04
LNG	1,215.00	2.97	0.07	1,331.00	1.64	10.27	8.58	0.04	0.03

Table RA15. Life Cycle GHG Emissions For Heavy-Duty Vehicles

Engine/Fuel Type	Operation Of Vehicle	Production of Fuel	Manufacture of Vehicle	Total GHG Emission
Diesel				
0.03% Sulfur	1,662.00	389.00	90.00	2,141.00
50 ppm Sulfur	1,662.00	418.00	90.00	2,170.00
DME	1,463.00	381.00	92.00	1,936.00
Biodiesel	1,663.00	-696.00	92.00	1,059.00
LPG	1,668.00	215.00	90.00	1,973.00
LNG	1,331.00	641.00	90.00	2,062.00

From Table RA14 and RA15, Four graphs were produced. They are *CO_2 Emission of Heavy-Duty Vehicles During Operation of Vehicles* (Figure RA5), *Total GHG emission of Heavy-Duty Vehicles During Operation of Vehicles (excluding CO_2)* (Figure RA6), *Total Pollutant emission of Heavy-Duty Vehicles During Operation* (Figure RA7), and *Life Cycle GHG Emission For Heavy-Duty Vehicles* (Figure RA8)

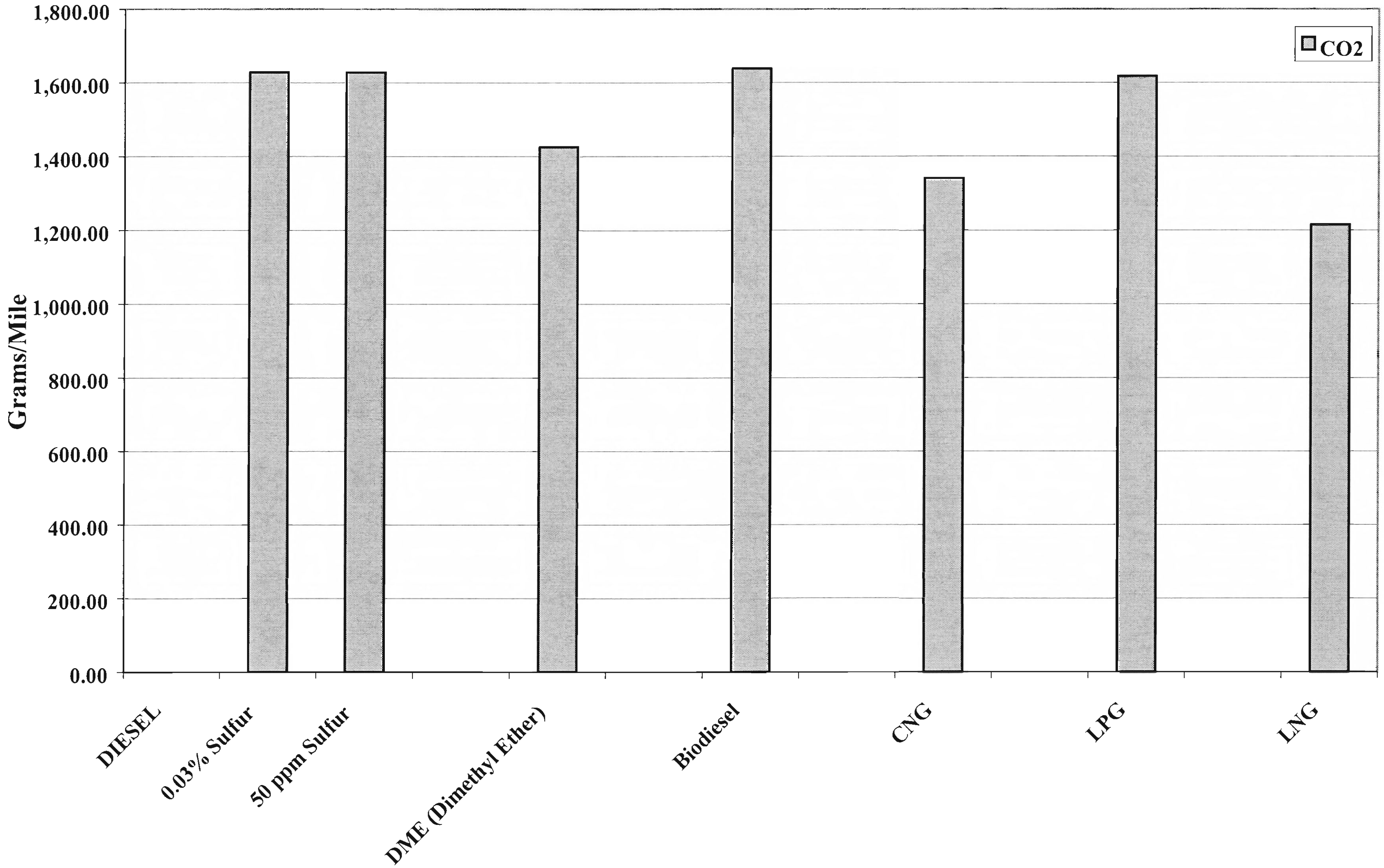

Figure RA5. CO_2 Emission of Heavy-Duty Vehicles During Operation of Vehicles

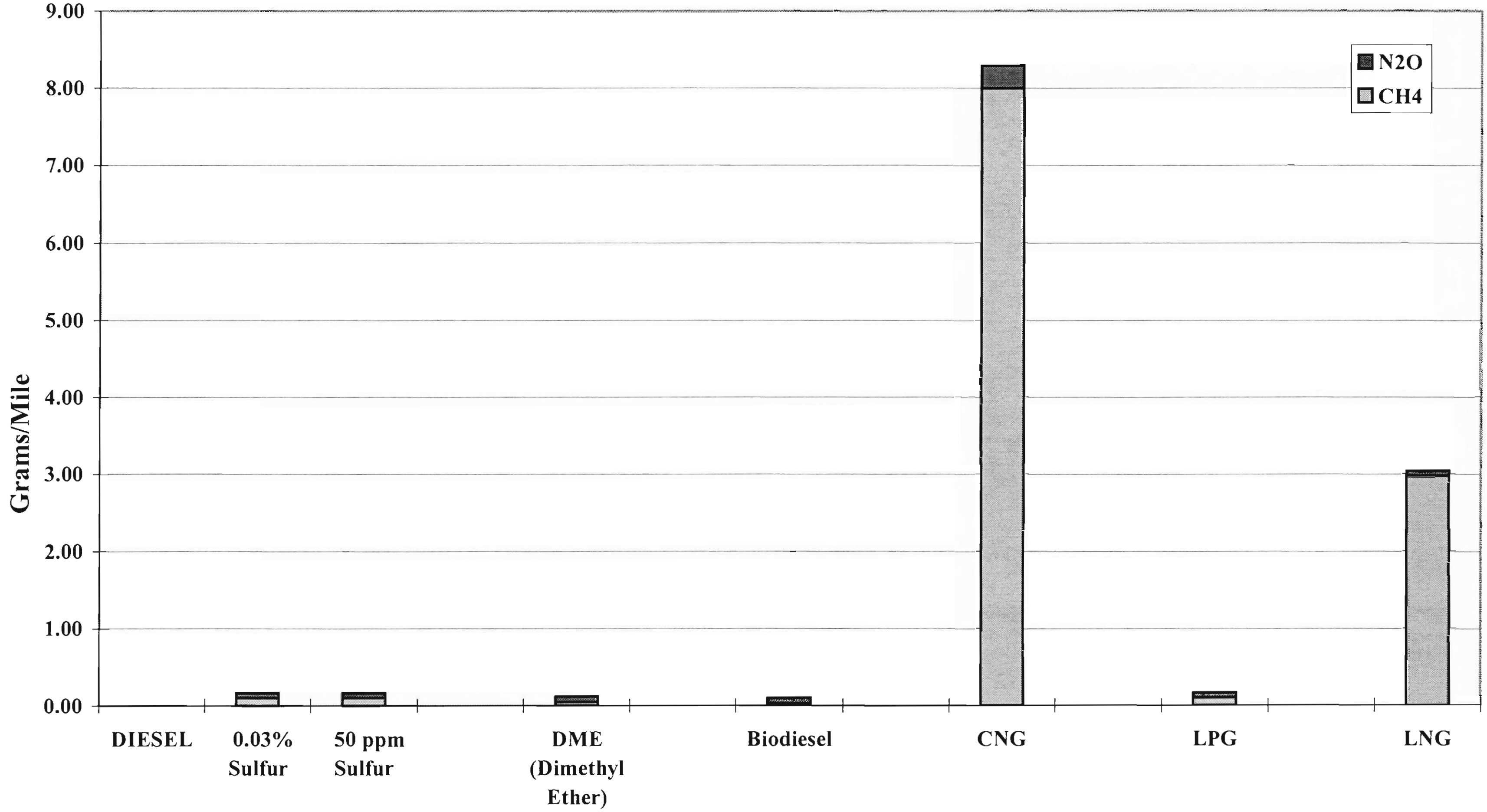

Figure RA6. Total GHG Emission of Heavy-Duty Vehicle During Operation (Excluding CO_2)

Due to the difference in the magnitude of data between CO_2, CH_4, and N_2O, the total GHG emission is divided into two different graphs. Figure RA5 shows biodiesel, diesel, and LPG produced the highest overall amount of CO_2 emission. Although CNG produced a lower emission of CO_2 than biodiesel or diesel, Figure RA6 and Table RA14 shows that CNG produced eighty times of CH_4 and four times of N_2O more than those produced by diesels. But since CH_4 and NO_x is only about 5% of the total emission, its effect on the total GHG emission is very small. Figure RA7 is the Pollutant Emission of Heavy-Duty Vehicles. It includes particulate matters, sulfur oxides, volatile organic compounds, nitro oxides, and carbon monoxide.

Figure RA7 and Table RA14 show that CNG and LNG produced a very small amount of pollutant compared to all other alternative technologies. Especially on particular matters, it is almost three times better than that from LPG, which has the next best emission value in these six different technologies. Although biodiesel has a particulate matters emission two times better than diesel, it has the highest nitro oxides emission. If the total pollutant emission value is used for the comparison, conventional diesel vehicle is the worst technology out of all technologies. Biodiesel produce more CO_2 and NO_x than conventional diesel, but any other emissions are half of what conventional diesel produces. CNG has the best value and it is about twenty times better than conventional diesel on pollutant emissions.

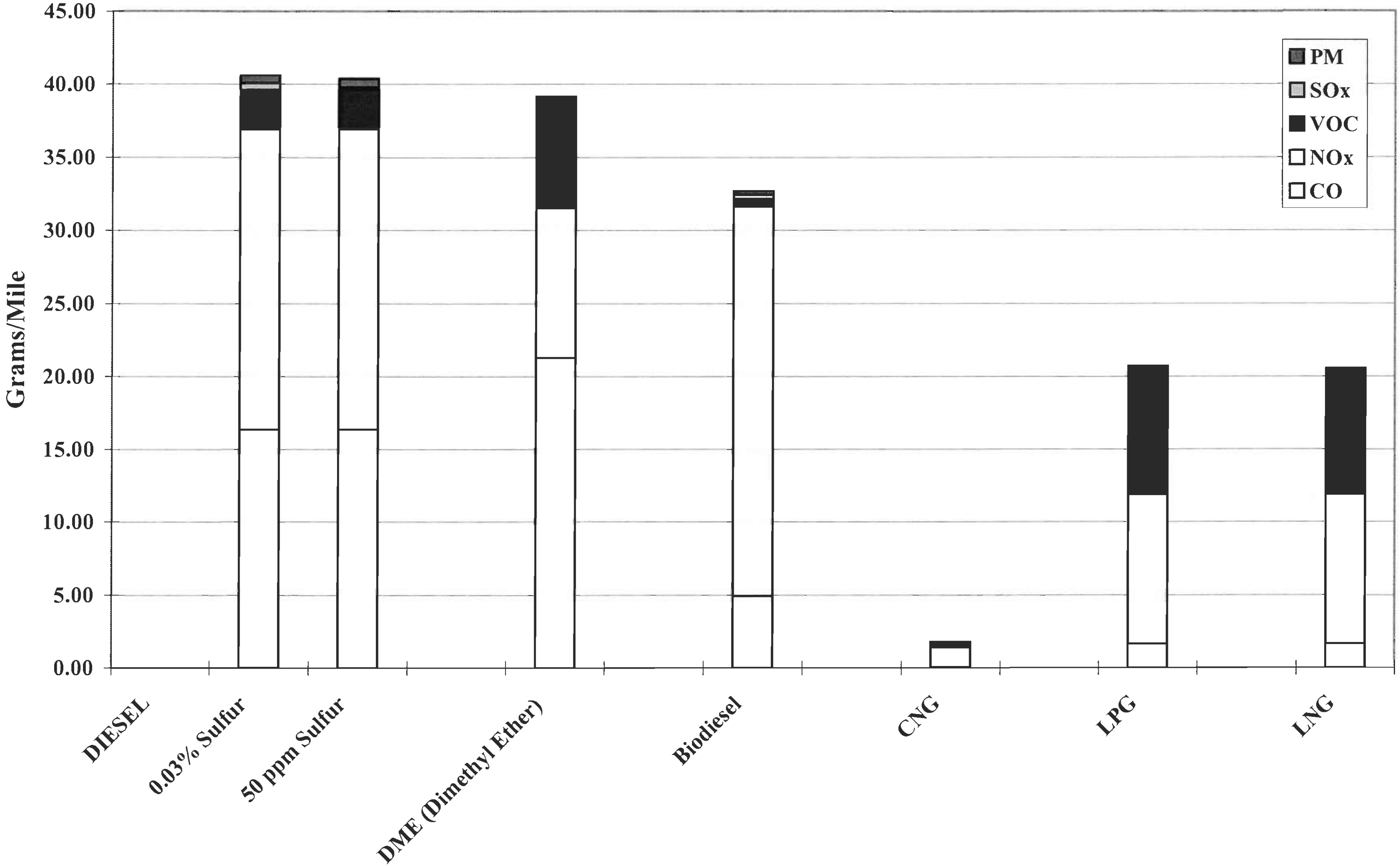

Figure RA7. Total Pollutant Emission of Heavy-Duty Vehicle During Operation

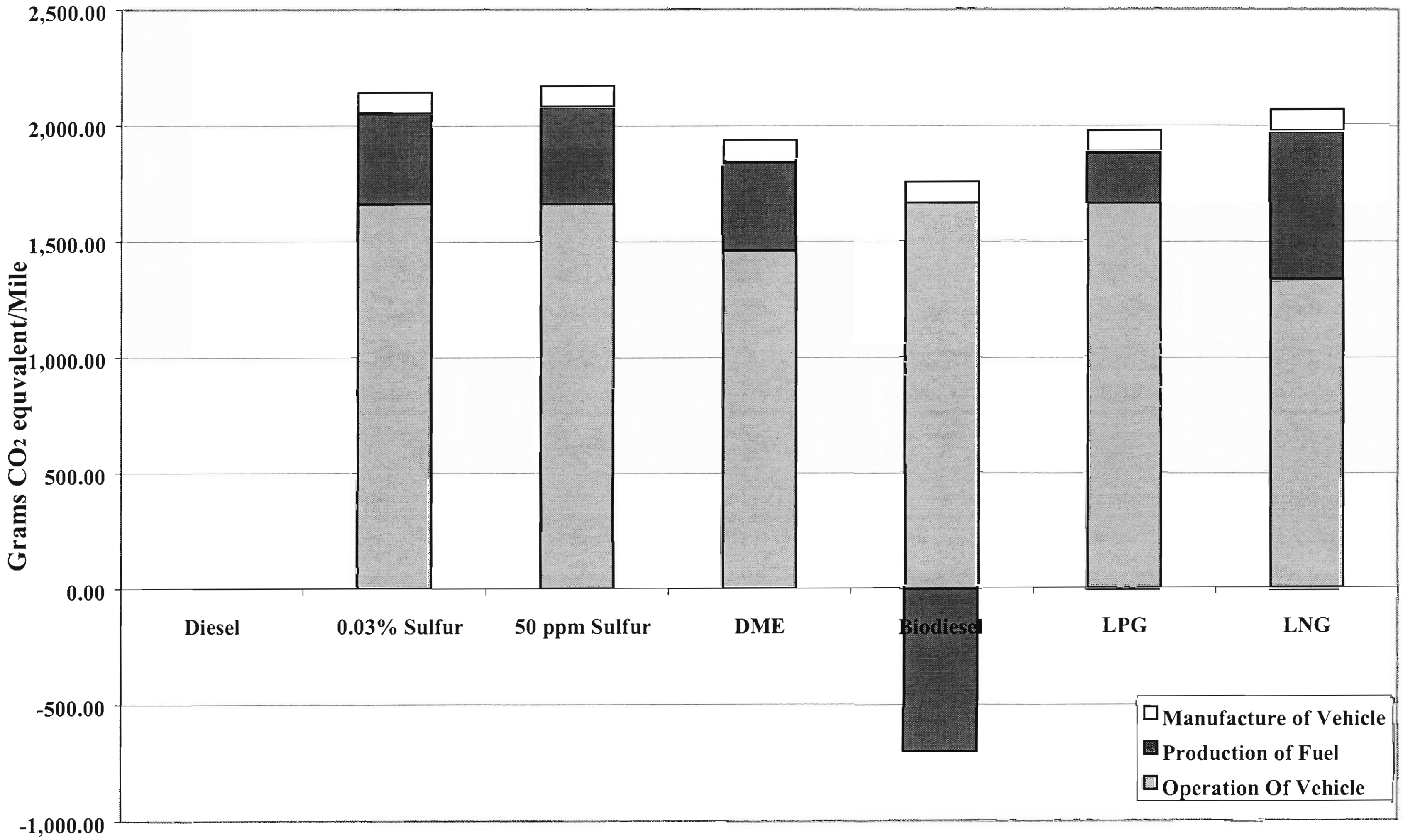

Figure RA8. Life Cycle GHG Emission For Heavy-Duty Vehicles

On the other hand, Figure RA8 shows that biodiesel produces the lowest overall life cycle GHG emission. Although there are insufficient data for CNG to be including in Figure RA8, Figure RA2 and Figure RA3 suggest that CNG should have a very similar total GHG emission as LPG. The CNG's life cycle emission should have a better performance than the conventional diesel, but worse than the biodiesel.

5.2.1 Conclusion of heavy-duty vehicle

From the standpoint of the GHG and pollutant emission during vehicle operation, CNG has the best performance and biodiesel has the worst. But the results from life cycle GHG emissions suggest the opposite. Although life cycle analysis result should have a bigger effect to the conclusion, the immediate need for Hong Kong should also take into consideration. One of the main reasons for Hong Kong to bring in alternative fuel vehicles is to lower the air pollution. CNG vehicles are the best short-term solution for lower air pollutions; pollutant emissions produced by a CNG vehicle are twenty times better than a biodiesel vehicle. For long-term solutions, biodiesel has the lowest life cycle GHG emission among all alternative technologies.

5.3 Transit Buses

One of the reports being reviewed was a study of buses. Figure RA9 contains the pollutant emission for one of the bus tested. This particular bus was tested under four different test cycles as shown in Figure RA9. (The definitions of these test cycles are in section 3.1.2)

As it shows in Figure RA9, this particular NoveBus, tested under the NY bus test cycle, produced about two and a half times the emission produced during CBD test cycle. After the test cycles were analyzed, data collected form the Manhattan test cycle was selected. This cycle models the aggressive, short idle time, and fast accelerate/decelerate driving style of most Hong Kong drivers. The NY bus cycle contains long idle time between stops and accelerations, which represent frequent and long stops. This type of driving pattern resembles rush hours in any major city including Hong Kong. Although rush hours are about four hours per day, the actual driving distances traveled are very short. Furthermore, since the measuring units for the data are grams per mile, the total emission during rush hours should be very close to the total emission for the rest of the day. From these assumptions, data collected from the Manhattan test cycle are believed to have a better resemblance to the bus emission in Hong Kong. If data for the Manhattan cycle are not available, the NY composite cycle can be use as an alternative since the test cycle is similar. With these guidelines, Table RA16 and Figure RA10 were created.

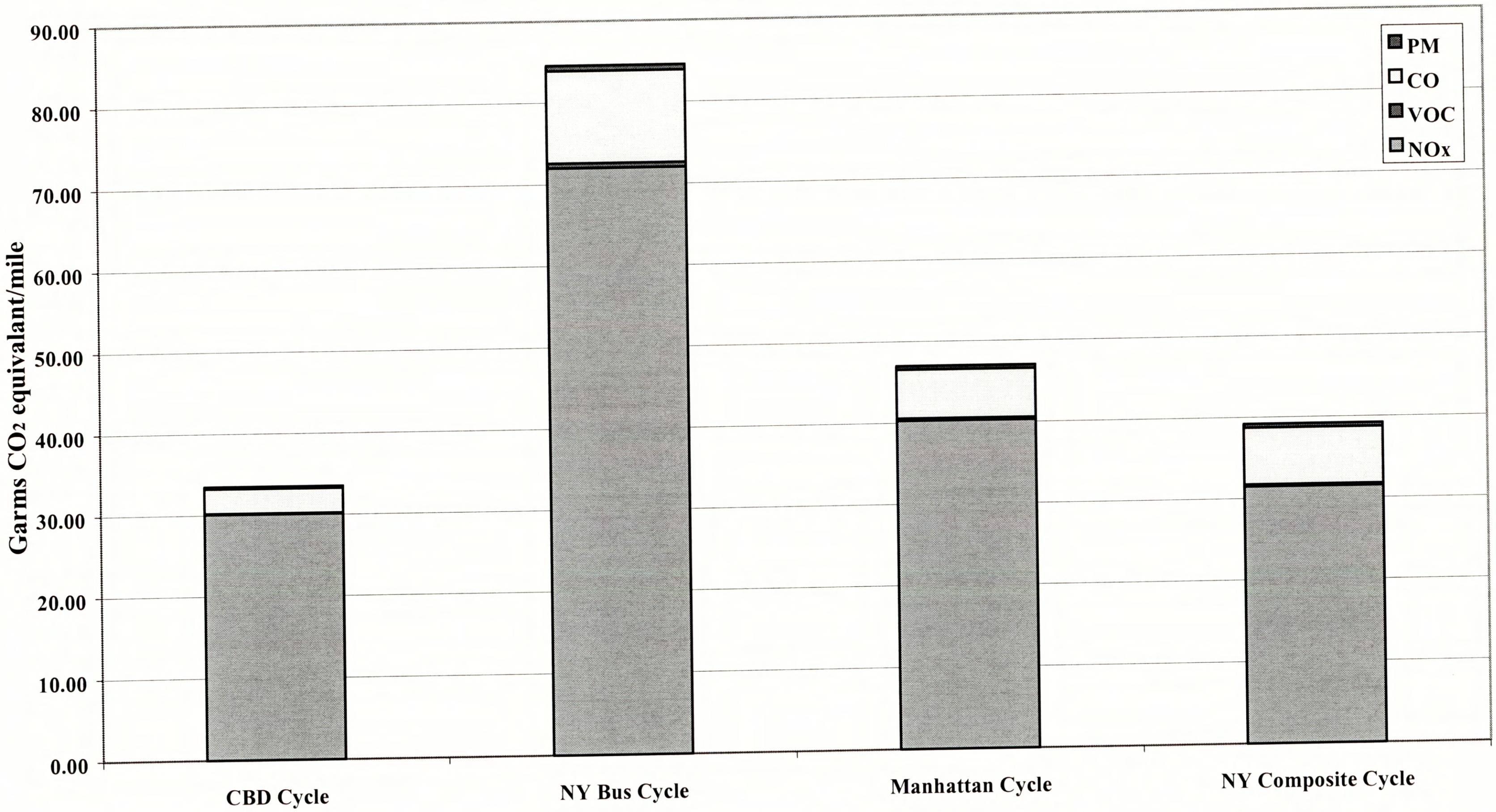

Figure RA9. NovaBus Pollutant Emission in Different Cycle

Table RA16. Total GHG Emission of Transit Buses During Vehicle Operation (g CO_2 Equivalent/mile)

	Worst Case	Best Case
DIESEL		
0.03% Sulfur	4,268.00	2,156.00
50 ppm Sulfur	2,156.00	2,156.00
DME (Dimethyl Ether)	1,908.00	1,908.00
Biodiesel	3,377.00	2,156.00
CNG	3,395.00	1,964.00
LPG	2,106.18	2,106.18
MossGas	2,816.00	2,386.00
HYBRID		
Diesel	2,841.00	1,262.00
Diesel (no regen)	3,010.00	2,625.00
MossGas	2,218.00	2,218.00
FUEL CELL		
Methanol (Natural Gas)	1,479.00	1,479.00
Hydrogen (Natural Gas)	0.00	0.00
Hydrogen (Electricity)	0.00	0.00

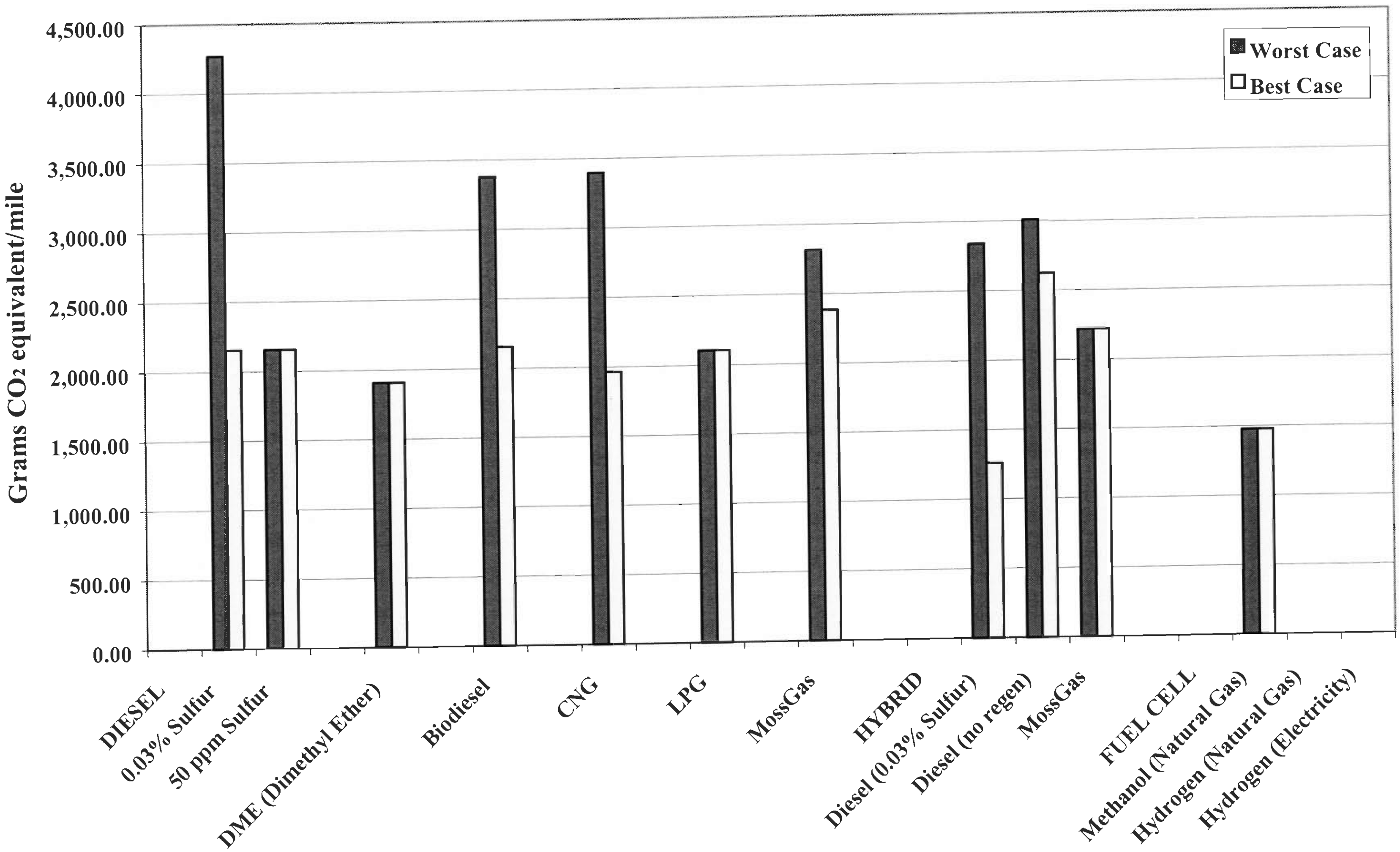

Figure RA10. Best/Worst case Total GHG Emission During Operation

Figure RA10 shows the difference between the best case and worst-case data. There is a 100% difference between the best and worst case data for 0.03% Sulfur diesel, as the result of including data from both newer and older engine designs. It should be noted that the hybrid diesel without regeneration has a similar emission level as diesel, because when there is no regeneration to charge up the batteries, there is not as much support from the motor to assist the diesel engine, which in turn depends more heavily on the diesel engine, thus, producing higher emissions. Therefore, the regeneration during the operation of the vehicle is a key point to low on-road emissions in heavy-duty vehicles. All the best-case emission data are very close to each other except hybrid diesel and hydrogen fuel cells. It should be noted that, in the worst-case, a diesel engine using low sulfur diesel has almost the same emission level as CNG or LPG. Figure RA11 and RA12 are graphs for life cycle GHG emission. Figure RA11 shows the life cycle GHG emission in different stages. Figure RA12 shows the total GHG emission of all three stages. From both figures, the total emission for diesel buses using low sulfur diesel is similar to biodiesel or DME but much lower than CNG. The emission from manufacture is similar for all technologies except hybrid diesel. But comparing to the magnitude of emission during the operation of a vehicle, the difference is insignificant. Biodiesel is the only technology that has a negative upstream value and its total emission is lower than hybrid diesel (Although the report where the data for this type of hybrid diesel were collected did not specify the type of diesel used, the data suggested this diesel was regular 0.03% Sulfur diesel). Some fuel cell technology has zero operation emission and extremely high upstream emission, but the total emission for both Fuel cell and hybrid are always the lowest. From these data, one can assume fuel cell technology has the lowest total emission, hybrid comes second, while CNG and old diesel technology has the worse performance overall.

Table RA17. Total Life-Cycle Emission of Transit Buses

Transit Bus	Vehicle Operation	Upstream of Fuel	Manufacture of Vehicle	Total
Diesel				
0.03% Sulfur	4,268.00	505.00	87.00	4,860.00
50 ppm Sulfur	2,156.00	543.00	87.00	2,786.00
DME	1,908.00	497.00	89.00	2,494.00
Biodiesel	3,377.00	-903.00	90.00	2,564.00
CNG	3,395.00	429.00	89.00	3,913.00
Hybrid				
Diesel	2,841.00	296.00	102.00	3,239.00
Fuel Cell				
Methanol (Natural Gas)	1,479.00	548.00	82.00	2,109.00
Hydrogen (Natural Gas)	0.00	1,445.00	88.00	1,533.00
Hydrogen (Electricity)	0.00	1,570.00	88.00	1,658.00

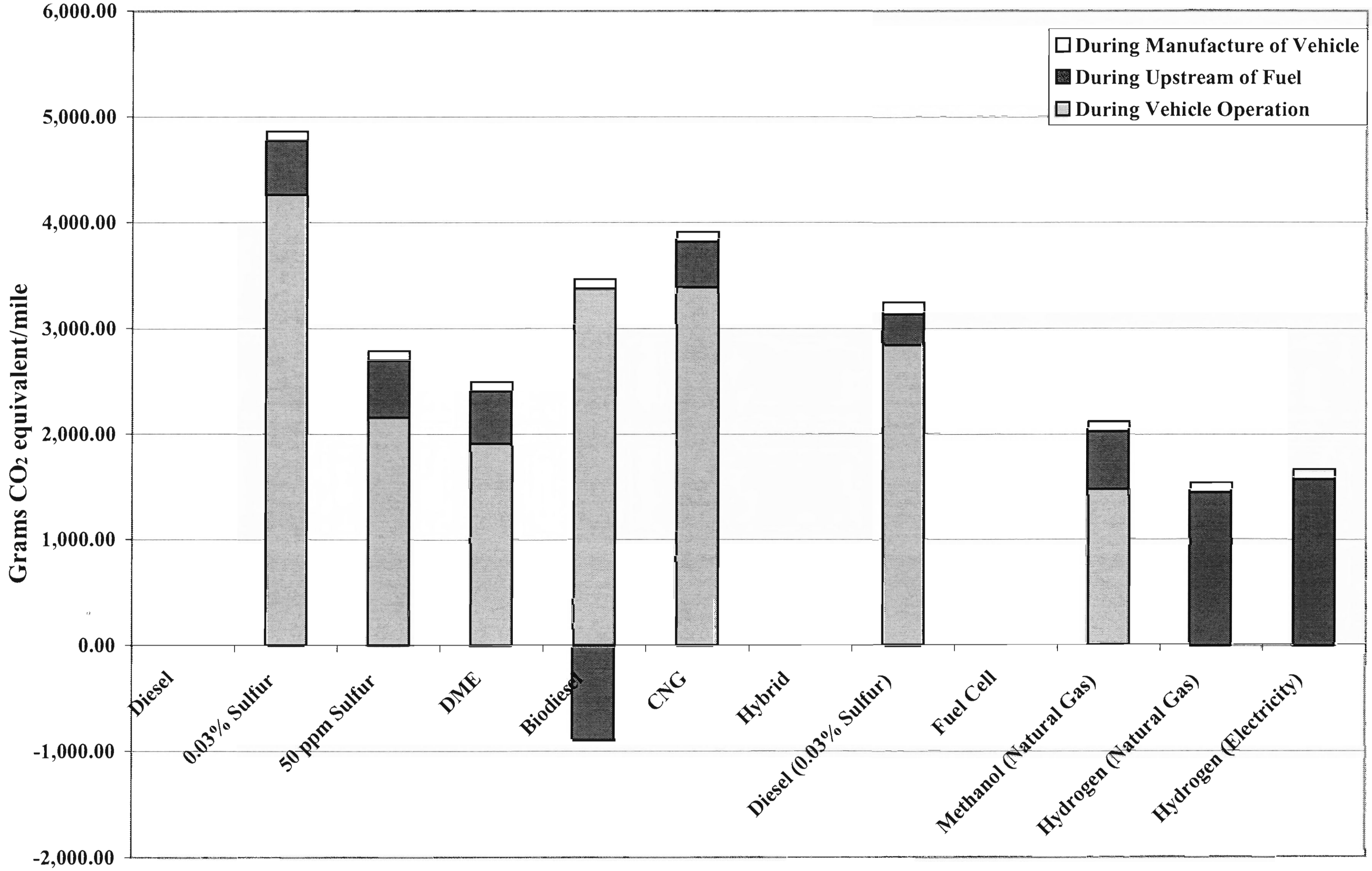

Figure RA11. Life-Cycle GHG Emission of Transit Buses

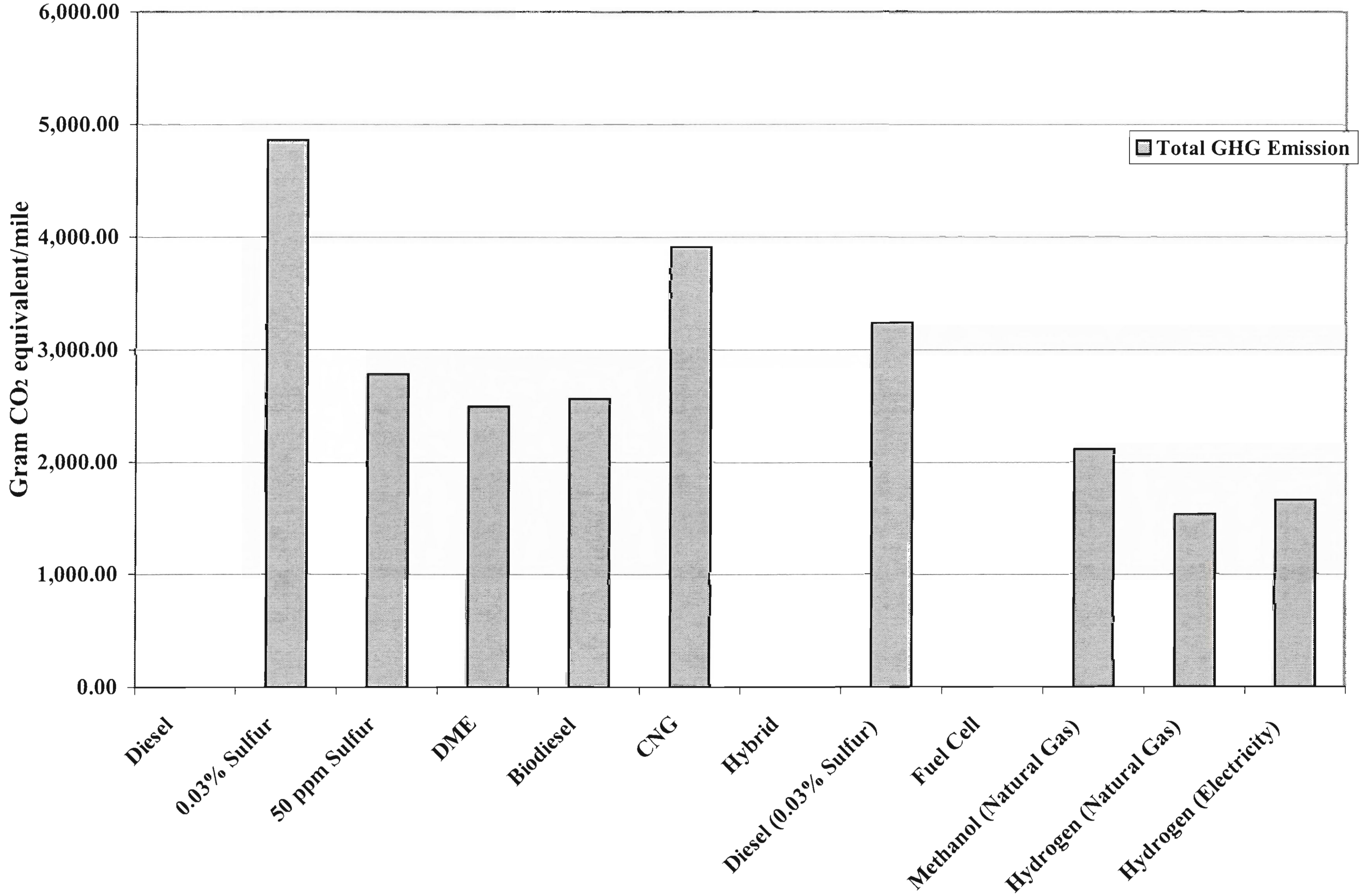

Figure RA12. Total Life Cycle GHG Emission of Transit Buses

Due to the insufficiency of the data for both LPG and Mossgas, the emission during the operation of a vehicle is the stage selected for final analysis in order to have a larger variety of technologies for comparison. Table RA18 includes data for both GHG emission (CO_2) and pollutants (CO, NO_x, and PM). Due to lag of data for CH_4, N_2O, VOC, and SO_x, they are not included in the table. But since CO_2 is about 95% of the total GHG emission and CO plus NO_x is about 90% of the total pollutant emission, the absence of CH_4, N_2O, VOC, and SO_x should have negligible effects on the total emission. Therefore Figure RA13 and Figure RA14 were created.

Table RA18. Greenhouse Gas and Pollutant of Transit Buses During Operation (Grams/Mile)

	GHG	Pollutant		
	CO_2	CO	NO_x	PM
Diesel				
0.03% Sulfur	4,268.00	7.00	40.30	0.48
50 ppm Sulfur	2,156.00			
DME	1,908.00			
Biodiesel	3,377.00	8.50	27.90	3.80
CNG	3,395.00	26.30	25.00	0.05
LPG	2,106.18	0.02	8.69	0.02
MossGas	2,816.00	2.00	32.20	0.10
Hybrid				
Diesel	2,841.00	0.40	27.70	0.14
Diesel (no regen)	3,010.00	1.00	32.10	0.24
MossGas	2,218.00	0.10	18.50	0.02
Fuel Cell				
Methanol (Natural Gas)	1,479.00	0.00	0.00	0.00
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.00
Hydrogen (Electricity)	0.00	0.00	0.00	0.00

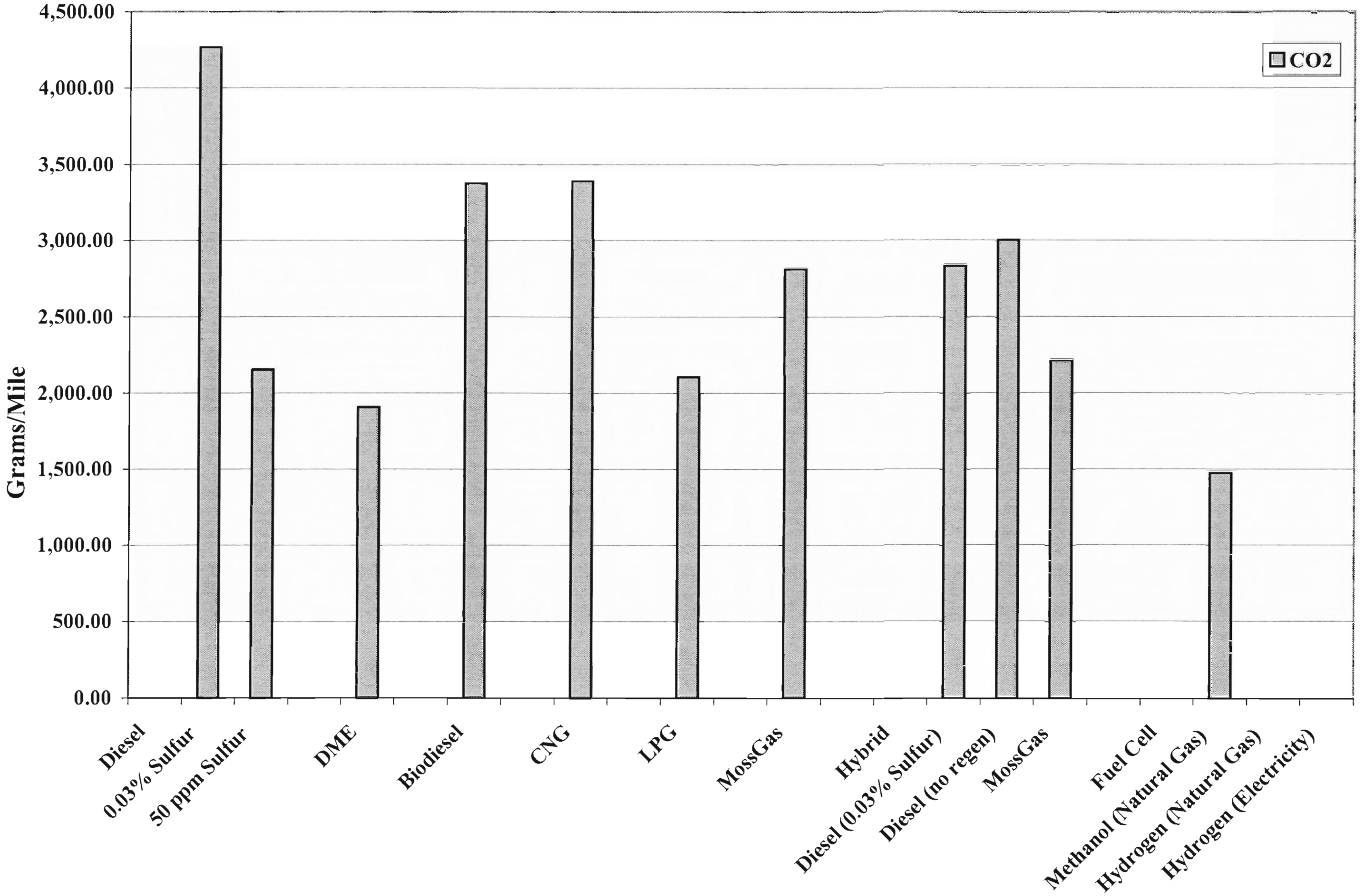

Figure RA13. CO_2 Emission for Transit Buses During Vehicle Operation

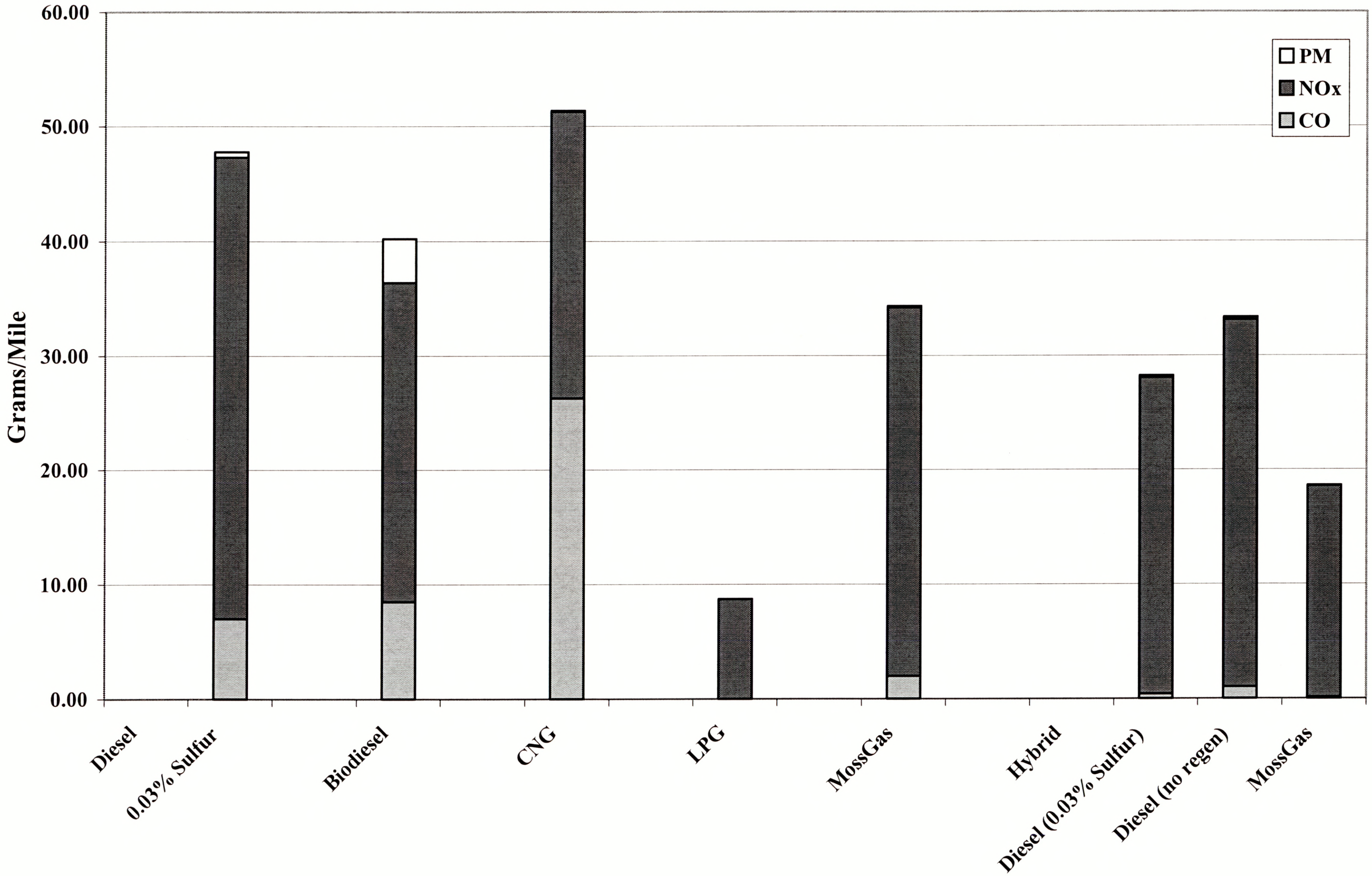

Figure RA14. Total Pollutant Emission of Transit Buses During Vehicle Operation

Figures RA13 and RA14 show that other than fuel cell technologies. LPG produced the lowest overall emission. It produced close to zero CO and PM emission, and a much lower NO_x emission than other technologies. LPG is second to the lowest on producing CO_2 emission. Hybrid technologies are next to the lowest, although they have a relatively higher emission than Mossgas, DME, and diesel using Low Sulfur Diesel (LSD). Hybrid technologies have a much lower CO and PM emission.

5.3.1 Conclusion of Transit Buses

Figures RA13 and RA14 suggest that LPG and CNG produces the least amount of on-road emission. It should be the ideal alternative technology for transit buses. However, from interviews with taxi drivers and government officials in Hong Kong, it became clear that in order for a LPG or CNG vehicle to retain the same distance per refilling, the fuel tank must be one and a half to two times the size of a gasoline tank. The fuel tank for any LPG or CNG vehicles larger than a light-duty goods vehicle would be so large that it will take up space inside the vehicle. A new method of carrying the fuel tank is to mount it on top of the buses. Although this method solve the problem of extra fuel tank spaces, but the double-decker buses used in Hong Kong already reaches the maximum height for the road system. For this reason, LPG and CNG buses are not going to be an ideal technology for transit buses in Hong Kong. Out of all the alternative technologies, fuel cell should be the ultimate solution, but it will take years until the technology becomes mature. In the meantime since hybrid, biodiesel, and low sulfur diesel only require minimum modification to the current fuel-distributing infrastructure, hybrid, biodiesel, or low sulfur diesel should be the short-term solutions for transit buses. If new ways of storage and distributing of LPG and CNG is developed, LPG and CNG will be the ideal technologies to both short and long term solutions for Hong Kong.

6 Conclusions

From the result and analysis section, lists of alternative technologies ranging from the best to the worst solution are drawn for each category and for both short and long terms.

6.1 Passenger Vehicle

6.1.1 Short Term Solution

- Hybrid Diesel (0.03% Sulfur)
- Hybrid Petrol (30-ppm Sulfur)
- LPG
- CNG
- E85 (Cellulose)
- E85 (Corn)
- E85 (Cellulose)
- E85 (Corn)
- M85 (Natural Gas)
- E10 (Cellulose)
- E10 (Corn)
- Diesel (50-ppm Sulfur)
- Diesel (0.03% Sulfur)
- Petrol (Direct Inject 30-ppm Sulfur)
- Petrol (1-ppm Sulfur)
- Petrol (30-ppm Sulfur)
- Petrol (300-ppm Sulfur)

Particulate matter (PM) emission is an issue Hong Kong Government tried to address right away. For short-term solution, low PM emission became a priority for ranking of the technologies. Although LPG and CNG have a very high overall emission, both of them have a near zero PM emission. Therefore, LPG and CNG received a very high ranking.

6.1.2 Long Term Solution

- Fuel Cell Hydrogen (Hydroelectric)
- Fuel Cell Hydrogen (Natural Gas)
- Electricity (Power Grid)
- Fuel Cell M100 (Natural Gas)
- Fuel Cell Hydrogen (Electricity)
- Hybrid Diesel (0.03% Sulfur)
- Diesel (50-ppm Sulfur)
- Diesel (0.03% Sulfur)
- Hybrid Petrol (30-ppm Sulfur)
- Petrol (Direct Inject 30-ppm Sulfur)
- Petrol (1-ppm Sulfur)
- E85 (Cellulose)
- Petrol (30-ppm Sulfur)
- E10 (Cellulose)
- E10 (Corn)
- CNG
- LPG
- M85 (Natural Gas)
- Petrol (300-ppm Sulfur)
- E85 (Corn)

Long-term solutions are ranked by the overall emission on both Pollutant and GHG emissions. For the long term solution, LPG ranked as one of the highest for all the alternative technologies and Diesel ranked as one of the lowest.

6.2 Heavy-Duty Vehicle

6.2.1 Short Term Solution

- CNG
- LNG
- Biodiesel
- Dimethyl Ether
- Diesel (50-ppm Sulfur)
- Diesel (0.03% Sulfur)
- LPG

Although LPG has very low PM and overall emission in this category, it is unsuitable for equipping heavy-duty vehicles.

6.2.2 Long Term Solution

- Biodiesel
- CNG
- LNG
- Dimethyl Ether
- Diesel (50 ppm Sulfur)
- Diesel (0.03% Sulfur)
- LPG

Biodiesel is quickly becoming a good long-term solution for heavy-duty vehicle. Biodiesel is a technology at its newborn stage, when this technology becomes mature, it will reduce problems produced by conventional diesel.

6.3 Transit Buses

6.3.1 Short Term Solution

- Hybrid Diesel (0.03% Sulfur)
- Hybrid Diesel (No Regeneration)
- Dimethyl Ether
- Diesel (50 ppm Sulfur)
- Mossgas
- Biodiesel
- CNG
- LPG
- Diesel (0.03% Sulfur)

The short-term solution of Hybrid Diesel is somewhat surprising, given the fact that some major cities in the U.S. (e.g. San Diego) are experimenting with the CNG. But in fact the double-decker buses usually used in Hong Kong make such use of CNG problematic in regard to the storage tank and the overall height of the vehicles.

6.3.2 Long Term Solution

- Fuel Cell Hydrogen (Natural Gas)
- Fuel Cell Hydrogen (Electricity)
- Fuel Cell Methanol (Natural Gas)
- Biodiesel
- DME
- Diesel (50 ppm Sulfur)
- CNG
- LPG
- Diesel (0.03% Sulfur)

7 Recommendations

The following recommendations were made based on the analyses of this report.

Passenger or Light-Duty Vehicles

- LPG is the best solution for short-term problems because it is very low in particulate matters and relatively cheaper than gasoline and diesel
- Hybrid or Fuel Cell is the best solution for the long-term, but are more expensive
- Diesel (50-ppm Sulfur) has the best overall output for both short-term and long-term

Heavy-Duty Vehicles

- CNG has the best emission efficiency for the short-term solution because CNG can produce more power than LPG and is cleaner than diesel
- Biodiesel is the best solution for the long-term but currently it is not popular enough, therefore, there is a shortage of supply

Transit Buses

- Hybrid Diesel (0.03% Sulfur) is the best short-term solution because it supplies the power that the buses need and generate low emission benefits from the hybrid systems
- Fuel Cell Hydrogen (Electricity) is the best long-term solution because transit buses have more idling time and are used more frequently than heavy-duty vehicles.

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Appendix A: Civic-Exchange

Civic Exchange is an independent and non-profitable "think tank". It is formed from different organizations, professionals, volunteers and interns, and Christine Loh is the Chief Executive. Their works cover many different fields and most of them are addressed to environmental and social and political problems. Their objectives are[44]:

- To promote civic education, public awareness and participation in governance by strengthening civic participation in public life.
- To undertake research and development of economic, social and political policies and practices to help shape the breath and depth of public policy debate and so to advance polices that are sustainable, resilient, non-violent, economically efficient, just, participatory, locally appropriate and spiritually rewarding.
- To integrate skills and experience across various disciplines including academic, business, politics, finance, technology and the non-profit sectors.

Established in September 2000, Civic- Exchange is now having three projects in hand. They are [45]"Developing a Clean Vehicle Strategy for Hong Kong", " Cross- board Environmental Law Research" and " Civic Exchange for the Environment". Besides these current projects, Civic Exchange had already published two publications[46]: " A Return of Sanity on Housing" and " A Comprehensive Review of Marine Policy" in late November. There are also some up coming publications which concerned on the pollutions and the disabled people in Hong Kong.

[44] Information Source: http://www.civic-exchange.org/main.asp
[45] Information Source: http://www.civic-exchange.org/main.asp
[46] For detail information, please visit: http://www.civic-exchange.org/publications.htm

In December 11th, Civic Exchange lunched a newly designed Webpage, which contained the "Environment Pilot Site[47]". This Pilot is a very informative source, and it main concern is the environmental issues. Inside the site, they provided a lot of information such as law and environment, political structure, and economics and the environment, etc. Civic Exchange is now getting feedbacks from schools and community groups so that they can develop the Pilot into a more advanced level. Civic Exchange hope the community could find it informative and useful, and people could get the greatest beneficial from the Pilot[48].

[47] Please visit: http://www.civic-exchange.org/enviro/politic_n_enviro/politics_n_envir_a01.htm

[48] Personally, I visited the site and I found out that it is very informative.

Appendix B: Interviews

Meeting: EMSD (Electrical and Mechanical Services Department)

Representatives: Lam, Kam-Kuen (Chief Engineer), Chow, Hau-Keung (Electrical & Mechanical Engineer), Tseng, Hing-Wah (Senior Electrical & Mechanical Engineer

Date: January 18, 2001

By: Lisa Hopkinson, Karen Zhu, Vivian Kwok and Edward Lo

1) Regulation of oil supply has been under the EMSD for a year. But the price of oil is regulated under its old owner, ESB (Environmental & Service Bureau).

2) Gas safety was first regulated during 1982 – focus mainly on natural gas and LPG (for use in buildings). In 1997, the first test trial of LPG conducted and was supported by the EMSD. It looks into operating cost, safety, and adequacy of supply filling stations.

3) 1998 – safety study on LPG vehicles were conducted. The studies proved that existing fuel terminals could support 18,000 taxis.

4) 2000 – they stretch the range of vehicle use in LPG from taxis to other vehicles. There are also studies of increasing the fuel tanks for minibuses from 65kg to100 kg (acceptable) or up to 400 kg (questionable).

5) The main constraint on LPG transportation is the lack of space for LPG fuel storage. Roads in Hong Kong are small and narrow to transport LPG fuel. Currently the capacity in Tsing Yi (a city in Hong Kong) has 5 LPG terminals, 15,000 tons. LPG fuel can be stored 20-30 days but when all taxis converted to LPG, consumptions will be great. Storage day will be drop to around 15-20 days, but if other transportation vehicles changed to LPG it will drop to 10 days. Therefore, more LPG facilities will be needed.

6) Not all existing refueling stations meet the requirement standards. There are 180 existing fueling stations and more are needed, and 40 more refueling stations are needed to refill LPG taxis. But they have to search for a site – government most likely will have to provide more land for it.

7) If hydrogen becomes a fuel, the Fire Service Department (FSD) will regulated and EMSD will help.

8) Vehicles only generate 25% greenhouse gases (GHG) in Hong Kong, 3% pollution economic growth is expected in ten years. Goods-vehicles are the main pollution problem.

9) EMSD expect diesel to be the future fuel. To look into alternative fuels, have to concern with security, availability, reliability, roadside pollution, and GHG (main concern).

10) Transport vehicles accounted for a quarter of Hong Kong's greenhouse gases.

11) European countries started an agreement where people pay more tax for using electricity vehicle than LPG to promote the use of LPG vehicles.

Meeting: IVE (Institute of Vocational Education)

Representatives: Iain Seymour-Hart (Head of Department of Automotive Engineering)

Date: January 22, 2002

By: Lisa Hopkinson, Vivian Kwok, Edward Lo and Karen Zhu

1) IVE is the only automotive engineering school in Hong Kong.

2) It offers courses for both crafts and technician apprentices. Craft course originate from form 3, 3-year course, employees of IVE realize the material they learned is deteriorating in work. Technician is in higher academic level and originates from form 5. They are in the process of developing a new technician program, but haven't got through yet.

3) For crafts apprentices, under the legal requirement of the Apprenticeship Ordinance, employees of companies can go to IVE one day per week to receive part-time day release complementary education that contains both theory and practices. If they get more apprentices than the class size, they will have to cancel other courses due to the requirement of the law (to support apprentices). For technician apprentices – they will not cancel any course if there is a large quantity of technicians (the Apprenticeship Ordinance is written for craftsmen, not for technicians).

4) Apprentice is a person who joins the company and four years received some kind of hierarchical training with other people who are practitioners in that field, which accounts for the complementary education.

5) Advanced craft course is a modular course for continuation of graduate craft course to go deeper into selective area of technology including LPG and others. It is also a course for return and learning for craftsmen who has a certificate of being in the field of working for a long period and the technology has gone pass them and they are struggling because vehicles are more sophisticated. But they have trouble filling the advanced courses because the industry has an economic downturn and they need a lot of educating themselves to try to work with them but the industry are focusing on profit, therefore education and training is not so important. They are looking for someone that works constant and cheap.

6) Under the ordinance, VTC actually runs the apprenticeship system. Attendance order – people between the age of 15-18 years old, if employed, they will have the privilege to attend class one day per week for complementary education. The department has staffs to make sure companies allow apprentices to attend the apprentice courses and was down size to 90% last year. Iian Seymour-Hart worried that there won't be much enforcement for Apprenticeship Ordinance because they don't have enough men power to do it.

7) IVE is going to introduce the high diploma – another full-time course that is 3-year, have taken form 5.

8) Also attempt to create a 2-year full-time craft course this year for people who wish to have a broader education in automotive engineering. It includes all the necessary components of the Certificate of Vocational Studies: include IT, English, Chinese Studies, math, etc. (accounts for 50% of the course). The other 50% is vehicle related: vehicle associated studies, science, electronics, technologies, etc.

9) About 2000 companies are in the field of land transport repair-tech; need to check that all apprentices actually attending course regularly is difficult.

10) The automotive engineer (AE) industry has trouble attracting form 5 leavers into the industry because it is not a popular field. There aren't many girls in this field due to their gender, but they do have beneficial influence to the class. The whole class change for the better than the worst.

11) Student intake – 1000 to 1100 total: ~ 40 advanced technicians, ~ 40 technicians, ~160-200 craftsmen, ~ 80 full-time 2-year students, ~ 80 full-time high diploma, ~ 200 trainees of which ~ 150 come form basic courses.

12) Iain Seymour Hart feel vehicle maintenance is the biggest problem because people in Hong Kong will not provide time and money for maintenance. They only worry about gaining profits. And time is money. He feels that maintenance is a great solution to reduce emission and keeping engine clean.

13) People also cheat the vehicle inspection by adjusting and changing the engine before the inspection. Then switch the old parts back after receiving the go sign in inspection.

Meeting: Yardway Limited

Representatives: James Rourke (Deputy General Manager) and Mike Hudson (Project Engineering Manager)

Date: February 5, 2001

By: Lisa Hopkinson, Edward Lo, and Karen Zhu

1) The company involves in providing supply to heavy-duty vehicles and airport needs.

2) Only imports (all near plant services) and customized parts do not manufactured.

3) Try to get into China market: involved in railways and airport supports in China.

4) All equipments are imported from the UK.

5) Currently service 140 double-deck buses, 30 new double-deck buses are imported from Germany (slightly more expensive but has more technology).

6) Currently all engines are Euro II standards. They try to bring in the Euro III standard engines but they are more expensive and not regulated by the government. Therefore no bus company will use them yet.

7) They look into the environmental aspect of Hong Kong: need facilities for heavy-duty vehicles testing.

8) The major problem of heavy-duty vehicles is maintenance in Hong Kong, which most people don't do.

9) They have provided a seminar with German experts to speak with decision makers the proper technologies to reduce air pollutions, and also provided illustrations of available technologies. Unfortunately, the environmental personnel of the government and other business related personnel were not very interested because of the price and some didn't even show.

10) James Rourke stated that it is difficult to get information from government officials. He had asked the government department of environment for the date of the Euro III engine implementation, still they conceive no answer but it gets the MTR (the train transportation service) into pressuring the government for it.

Meeting: First Bus (a double-deck bus company in Hong Kong)

Representatives: John Whitworth, Engineering Director

Date: February 5, 2001

By: Suzanne Skinner, Vivian Kwok, Karen Zhu, Lisa Hopkinson

1) First Bus (FB) have 750 buses of which 550 Euro II, some Euro III on order (their vehicle requirement is quite modest). They are committed to fit diesel oxidation catalysts to 200 of pre-Euro II buses. Commitment to fit CRTs to all fleet is towards the end of 2001 and even vehicles with oxidation catalysts (will remove and sell). The best that could be done is ULSD (Ultra-Low Sulfur Diesel) with Euro II and CRT. They have been using ULSD since end of Dec. 2000. This will cost a lot, FB one of 1st operators to apply for fare increases, and large part of justification is environmental improvements.

2) Currently testing 2 CRTs (continuously regenerative traps) – Johnson Matthey (more expensive but considered more effective) and Englehard. Testing operability for each vehicle type (a total of 11 types, will test for 3 months. Signed off 2 types, whole process will take until June 2002, which is final completion for fitting fleets (some slippage). CRT costs UK sterling 2500-3500.

3) Testing diesel/water emulsion – Purinox, emulsion of water/ULDS and chemical. Running on two vehicles and if works well will expand to 10-20 vehicles. They are interested because good impact on particulates and NOx. Water can be added up to 20% but FB went for 10%. 2.5% additive, 10% water and 87.5% ULSD. The company bought readymade additives from UK for trial. If enlarge size of trial (to 10 vehicles) will mix unit alongside bulk storage site. If beyond that will put mixing unit at oil terminal and deliver in mixed condition. They will announce trails in 4 weeks time. Don't know about the extra cost of maintenance. Sizeable trial as in UK/Italy. It has a 10% power loss but has chosen vehicles that can withstand that. Seems like most buses overpowered it anyway. ELF also markets Aquazole – running in France and Italy. John ran tests in UK and wasn't impressed. Constraints: lowers exhaust gas by 30 ºC, which works against CRT (which needs high temperature).

4) In UK, London Transport was issued with 1,000 free CRTs. Englehard (EH) won tender but not trouble free. What FB end up with partly depends on operability and partly on cost and what suppliers preferred. Volvo and Dennis prefer Johnson Matthey (fit and supply as OEM (original equipment manufacturer)) but won't recommend the EH CRT. Affects warranty (2-3 years).

5) John promised to send published results of CRT/ULSD. Results not as beneficially as in London – thinks its because of quality of testing – Dah Chong Hong Dyno, good for annual testing, designed to hold vehicle on load for few seconds, but need different cycle for reliable testing. Results underestimated.

6) They were invited to participate on biodiesel but decided to opt out.

7) Trolleybus – tour of trolleybus operators/manufacturers in Jan 2000. They see benefit and could apply, but it will add costs (10-20%). Manufacturing getting more sensible and less unnecessary sophistication. Substituting trolley for diesel won't generate more revenue, need to find application where added value e.g. dedicated road for trolley bus. NWFB (new world first bus) interested but also vested interest in that so many new buses, no keen on wholesale switch to trolleys.

8) Hybrids – Dennis (main bus supplier), Royth (large German power transmission company, supplies gearboxes) developing electric traction system. Many people in game (e.g. Siemens). Route 19 (Shau Kei Wan to Happy Valley, passes through C Bay) looked at hybrid operating through Causeway Bay for under 1km under electric power with SD bus. Hybrid always delivering electric power (series?) – need to recharge after Causeway bay because of a/c. Auxiliaries: air compressor, brake, and hydraulic system, adds extra complication and cost. Royth concluded concept not likely to be technical package that would prove viable. The weight of battery (2t) killed it.

9) Many companies not keen to run small-scale projects, especially 1000s km from home. Waiting for fuel cells – how long?

10) Natural gas - if commercial proposition to run with natural gas then will consider but don't think new technology is something to rush into. LPG is not so good in terms of greenhouse gases. CNG require whole new regime, and for not much benefit compared with Euro III and IV. Seriously reduce passenger space and not keen. CNG/LPG fuelling takes a lot of installation and labor. Initial added cost, maintenance and safety. It is not good having just few in fleet.

11) ULSD not much apparent premium but government holding oil companies to ransom. In UL, 1.5p/L premium for ULSD. Consume more because calorific value is less (0-5%), FB reckons 5%.

12) Diesel Euro III- Exhaust gas re-circulation emerging. Benefits pushing up to Euro IV in terms of particulates and NO_x. EGR (exhaust gas recirculation), bought from another Swedish company and retrofittable to Volvos and most of other vehicles.

13) Main constraints of alternative vehicles: (1) costs. (2) size of equipment. Buses tightly packaged. Quad catalyst, Seryx (US company), trap which reduces NO_x. EPD (Environmental Protection Department) sponsored trial with manufacturer paying for it; HK PolyUniversity used it for testing. The trap weighs a lot and huge, don't believe it will be successful.

14) Overcoming constraint – benefit to community, bus operators should front significant costs of anti-pollution measures.

Meeting: Exxon-Mobil

Representatives: Jane Tang (PA Manager), Yvonne Chan (PA Officer)

Date: February 16, 2001

By: Lisa Hopkinson, Vivian Kwok, and Edward Lo

1) Exxon and Mobil now merged. In HK primarily marketing org, research done by HQ in US. Still have Esso HK and Mobil HK plus Exxon Mobil Energy Ltd (power interests) – JV with CLP. Also have another company selling chemicals. Sell LPG – piped and bottled, petrol, diesel (all ULSD at filling stations), marine diesel, indicated diesel and aviation fuels.

2) E-M has 57 filling stations but no LPG. Still retrofitting, done feasibility study. With premium-free sites government has created an unleveled playing field – may consider possible refund. Last batch of sites acquired in 1996/97 – US$1 billion for 11 sites - premium based on formula linked to throughput. Some of that volume will be take away because of LPG, therefore industry negotiating to have premium refund. Lease usually 21 years.

3) Gasoline prices are high in HK because of premium plus high duty, which is government policy.

4) ULSD – government original plan to have 350ppm sulfur, but since Aug 200o tax incentive for ULSD – expect that to continue. Some confusion about tax concession because in 1998 government gave tax concession because of recession – also 89 cents. They now plan to reinstate that duty (from 98) not the ULSD concession.

5) Particulate traps – ME don't provide facilities for washing because of space and how to treat wastewater?

6) LPG – looking at retrofits to 12 possible stations to see if commercially viable (to compete with no-premium stations). Government announced 4 more premium free sites for tender.

7) ME would like to see general principle followed that government does not prescribe the solution and not interfere, rather have flexible policies that will encourage private sector. Lay out certain requirements eg by 2005 all vehicles have to meet certain emission standards. Gov there to provide level playing field. Performance based rather than prescriptive. ME is tech/science based org and will try to provide what's needed in the market. Working closely with different orgs to produce diff technologies.

8) Natural gas – if market here, would like to support. Infrastructure very expensive, though natural gas v cheap per BTU. If market is small then no incentive. Black

Point – saw environmental opportunity. CNG technology for large buses. Because they have the gas, can convert CLP fleet and then government fleet. Looking at large fleets. Under law only Towngas allowed to lay pipes – Mobil unable to supply LPG in pipes. CNG safer than LPG and costs lower. LNG plant in Shenzhen will make a big difference. If natural gas common carrier system will be piped in – easier to convert filling stations.

9) EM has a number of Joint Ventures with vehicle manufacturers:

- Ford/GM – to develop gasoline powered fuel cell vehicle. On board gasoline reformer, very light vehicle prototype.
- Toyota – next generation automotive systems to improve efficiency
- Ford on advanced diesel technologies.
- Toyota/GM -Hybrids – gasoline/electric. Lubricants very important because help to control temperature in engine and improve efficiency – especially for hybrid.
- Peugeot – relation to reduce NO2.
- Constraints to introduce cleaner technologies – economics – whether commercially viable or not. No problem in supplying it. Consideration is investment in infrastructure and who to bear costs? If there is a market EM will supply it.

Meeting: Taxi operators/drivers and vehicle repairers

Date: February 19, 2001

By: Lisa Hopkinson, Edward Lo, Vivian Kwok

Representatives:

Taxi operators/drivers	
Mr. Wong To (Consultant)	Rights of Taxi Owners And Drivers Association Limited
Mr. Lau Kin Man (President)	Rights of Taxi Owners And Drivers Association Limited
Mr. Yu Chui Kan (Entertainment Secretary)	Rights of Taxi Owners And Drivers Association Limited
Mr. CHAN Kim Fung (Vice Treasurer)	Rights of Taxi Owners And Drivers Association Limited
Vehicle repairers	
Mr. Ringo LEE Y.P. (Chairman)	Hong Kong Repair Merchants Assocation Ltd.
Mr. Casey MAN K. C. (Director)	Automatic Transmission Rebuilding Specialist

Taxi operator/drivers

1) A new product, called Fuelstar, is being tested on two taxies, which they claimed is much more effective than particulate trap in controlling vehicle emissions.

2) Fuelstar is a combustion catalyst that is housed in a canister. The canister contains metal alloy cones, the main ingredient of which is tin. The fuel line is cut, as close to the engine as convenient, and reconnected to the canister. As the fuel passes through the canister, minuscule particles of metallic tin are released into the fuel supply and are carried through to the combustion chamber, where they act as a catalyst in the combustion process. The tin changes the combustion characteristics of the fuel, giving a more complete and more prolonged fuel burn, and hence results in improved engine efficiency and performance. (For further information, visit the website of www.fuelstar.com)

3) The benefits of Fuelstar, based on the experiences of the taxi drivers testing it:
   - Reduction of smoke emission
     - Less than 30 HSU, as expected. A recent smoke test on Mr. Wong's taxi is 28 HSU, originally 50 HSU without Fuelstar.

- For Mr. Yu's taxi, before the installation of Fuelstar, his taxi (14 years old) got 57 HSU smoke emission, failing to pass the smoke test. With the Fuelstar installed, only taking 10 days, the smoke emission from his taxi has already been reduced to 43 HSU.

- Improve combustion
  - A more complete combustion, giving a more complete and more controlled fuel burn

- Reduction of carbon soot
  - A more complete carbon burning, reducing carbon soot emissions and exfoliating carbon deposits and other sticky substances. It helps keep the engine oil and the internal engine operating surfaces cleaner, which prolongs the life of both engine oil and the engine itself.

- Fuel saving
  - Improved engine efficiency results in better fuel economy, and hence helps on fuel saving. 10 to 15 % of fuel saving is claimed by the Fuelstar.

- Economical
  - Costs $2,000 (HKD) for 5 years of about 500,000 km

4) Both taxi drivers and repairers commented that Fuelstar is a better solution for the root problems, compared to the use of particulate trap, as Fuelstar is designed for improving the fuel combustion itself, which is the root source of vehicle emission problems.

5) In contrast, the weaknesses of particulate trap:

- Not a solution to the root. Only designed for trapping the pollutants. It hence brings out the problems of particulate trap washing. With insufficient proper facilities, dirty water is dumped into drains directly, arousing concerns on associated water problems.

- If not washed properly, supposed to be cleaned everyday according to the design of PolyU, the dirty particulate trap will be blocked and cannot function properly and adversely affect the vehicle engine as well. On the other way round, if the vehicle engine is dirty, the carbon soot emission can accumulate on particulate trap against its proper operation.

- A taxi driver, Mr. CHAN, has come across the breakdown of the particulate trap on his old diesel taxi, as the trap was blocked by dirty carbon soot. (Remark: Mr. CHAN has changed to LPG taxi for two months)

- Therefore, the taxi drivers comment that particulate trap is nearly useless, and even will bring more problems to the users. When PolyU first introduced the particulate trap, the taxi drivers have already foreseen the problems and known that it is not viable, but don't understand why the government still insisted on the retrofitting of particulate trap.

6) In contrast, the taxi drivers don't get any government support of the use of new products, let's say Fuelstar, even though they are proved to be efficient in reducing vehicle emissions. Today, the HKSAR government recognizes only two retrofitting products, one is particulate trap by (環保康) and another one is diesel catalytic converter by Dah Chong Hong. For the former, the government pays drivers for free retrofitting. For the latter, the government provides subsidy for installation. But except these two products, the government does not provide any financial assistance for the installation of other products. If the drivers want other products, they can do it by affording the costs themselves. The drivers feel not justifiable, as the government is subsidizing something not effective obviously, but denies other possible technologies. Fuelstar will be a key new product that the taxi drivers are keen to introducing to the government, and strive for government support as much as possible.

- Mr. Man and Mr. Wong have just introduced the Fuelstar to Guangzhou, and helped on three buses, from ‡ 一汽今廠 (one of the 4 biggest Guangzhou bus manufacturing companies), fitted in with Fuelstar.

7) About the taxi LPG switch, the fuel cost ($2 to $3/L LPG) is obviously cheaper than diesel (ULSD). But lots of hidden hurdles:

- Unknown maintenance costs (as LPG is still new, information on LPG vehicle maintenance is still insufficient)
- Unknown future cost of LPG (as now there is tax concession on LPG, but not known in the future)

8) The compulsory LPG switch among all taxis in Hong Kong is not absolutely necessary. There could be many possible cheaper options for improving the vehicle emissions, e.g. the installation of Fuelstar (only costs $2,000). The one-off grant of $40,000 for each taxi LPG switch can be used in a more cost-effective way.

9) The taxi drivers, already in harsh business environment, said government support for them is very crucial. They also want to contribute to a better environment. If only stricter legislation, let's say, $1,000 fine levied on excessive smoke emission, but without any assistance for the drivers to meet the more stringent requirements, it will only increase the burden on them. The main concern is the unclear picture of the future government policies on controlling vehicle emissions, for example, the tax concession on ULSD (89 cents). Be continued or be terminated? The unpredictable government action weakens the sense of security among the taxi drivers.

Vehicle repairers

10) Diesel doesn't mean "not good". Diesel engine could be a good engine. Indeed, clean diesel engine, e.g. EURO III & EURO IV, has been very widespread in other countries. So switch to LPG is not the only option available.

11) Superficially, LPG is good, in terms of black smoke reduction. But it is not a long-term solution for Hong Kong, as HK doesn't have its feedstock of LPG.

12) Hong Kong should find the solutions that are more focusing on the vehicle engine itself, developing a wide variety of quality vehicle engines, so as to improve vehicle emissions in long term. It is because no matter how sophisticated new product is retrofitted in vehicle, if the engine is in poor quality and dirty, the products can never function properly.

13) Major prerequisites for attaining quality vehicle maintenance:

- Open repairing information from vehicle agents, as transparent and detail as possible:
  - Incomplete availability of vehicle engine and repairing information is a main constraint for the repairers today to maintain a good quality of vehicle (as the vehicle agents, usually 1 agent for 1 brand in HK, always keep the details secret). Not only the conventional petrol/diesel engine, the repairers also face difficulties in repairing LPG vehicles. It will be a big hurdle introducing other alternative fuel/technology vehicle to HK, e.g. duel-fuel vehicle, as the repairers mentioned.

- Clear government policy direction on vehicle
  - Unclear government policy today results in inadequacies of supporting facilities for attaining a better quality vehicle maintenance field.

- Qualified mechanics
  - Qualified mechanics are very important, therefore, government is urged to set up a system to certify qualified mechanics, what doesn't exist now in Hong Kong.

Other interesting points

14) A new technology, called 南天t 技 introduced by a professor from Singapore, is being tested on two taxies (Mr. Wong's and Mr. Yu's) and one light bus. It is still at trail stage, but the taxi drivers already highly commented the effectiveness of this new technology. Both taxies will be brought for smoke and dynamometer test within three-week time, and press release on the results is expected.

15) Comparing diesel and LPG, diesel is more suitable for taxi. It is because taxi has long VKT, traveling over 400 km per day, plus the steep and narrow road features in HK. The use of LPG may not be able to go through these technical and physical constraints efficiently. Mr. Wong raised an example of a catalyst breakdown within a LPG taxi, leading to the increase in NO_x emission.

16) Comparing LPG taxi and LPG light bus, the taxi drivers find LPG is even more infeasible for light bus. One of the main reasons is the higher fuel consumption of light bus. To compensate the power loss associated with LPG switch, refueling will be more frequent, and hence will increase the operating costs for light-bus operators. Another main reason is the safety issue, as the LPG tank will be fitted in the middle part of light-bus, which will be very dangerous if any explosion.

17) About other alternative fuels, both taxi drivers and repairers don't hear too much. One of the better known is biodiesel. But it is still at a very infant stage. Moreover, the HKU biodiesel trail is not targeting at taxi, but mainly light bus and heavy-duty vehicle, according to Mr. WONG. But a main concern is the substances within biodiesel, which are claimed to be potentially toxic to humans.

18) The taxi drivers feel the unfair treatment from the HKSAR government. No consultation at all before any changes.

Extra information

19) One of the taxi operators, called 互助社 (Cooperative???), has also tried the combustion catalyst with a similar design as Fuelstar. But after running for 6 months, all broke down. Don't know the reasons clearly. Mr. Wong suggested that visit to Macau will also be interesting. Mr. Kwok from the Cooperative will be coming to Hong Kong on 25/2 according to Mr. Wong.

20) A HK taxi driver, Mr. Yeung, is intending to install Fuelstar. Mr. Wong gave us his contact number so that we can ask his feedback on the Fuelstar performance. (Mr. Yueng – 9201-5383)

Meeting: Guangzhou Municipal EPB

Representatives: Mr. He Rong You and Mr.Zhang Sheng Jian

Date: February 27, 2001

By: Lisa Hopkinson, Suzanne Skinner, Edward Lo, Karen Zhu, and Vivian Kwok

1) **Background information**

- 1.3 million vehicles in Guangzhou, with 0.45 million automobiles
- Vehicle proportion in Guangzhou: 75 % gasoline Vs 25 % diesel
- Vehicle emission contributes to about 70 – 80 % NO_x
- Unlike Hong Kong, diesel is not a major source of vehicle emissions. Heavy trucks run on diesel are not allowed to enter the Guangzhou during daytime.
- Main vehicle emissions in Guangzhou come from gasoline vehicles
- Both emission and fuel standards in China still lag behind, compared to Hong Kong and other developed areas

2) **Gasoline**

- Mainly refer to taxi and passenger van / minivan

- Ban on the sale of lead gasoline from October 1997 in Guangzhou. The whole program of replacing lead gasoline by unleaded gasoline (0.013 g/L lead) only took 9 months to finish. By 2002 all gasoline supply in China must be unleaded. Comparing the ambient lead concentration in 1997 with that in 1998, it was decreased by 71 %.

- From July 2000, use of clean gasoline of (0.005g/L lead, equivalent to EURO I standard), which is now only available in Beijing, Shanghai, and Guangzhou. As the supply of clean gasoline, distributed by the Central government, can only be guaranteed for these three cities today.

- Price of unleaded gasoline is standardized over the country. There is no economic incentive at all for the fuel quality improvement, just by the mandatory approach to regulate the change.

3) **Diesel**

- Mainly refer to the public transport and special-purposed vehicles

- The diesel quality standard is not as high as Hong Kong

- Still using the 1994 National Standard on diesel fuel, with three classes according to diesel sulphur content:
    - High-rate: 200-ppm sulfur
    - First-rate: 500-ppm sulfur
    - Qualified: 1000-ppm sulfur

- Same diesel-selling price among the three classes in the fuel market, which indirectly discourage the sale of low-sulfur diesel due to higher cost of supply involved.

- Guangzhou is implementing a more stringent requirement on fuel quality by mandatory approach, with no use of any economic incentive from the government.

- Realizing that sulfur content contributes to emissions, therefore Guangzhou is getting more stringent regulations on diesel quality. Finding that over 70 % of vehicles already run on the diesel of First-rate, starting from October 1, 2000 only First-rate diesel of 500-ppm sulfur content can be available for sale in Guangzhou. Diesel of lower quality than First-rate is banned now.

4) **LPG in Guangzhou**

- Only duel-fuel (LPG + Gasoline) vehicles are available in Guangzhou, but no dedicated ones.

- On road, there are around 1,000 (out of 15,000) taxies and 100 to 200 buses are running on duel-fuel.

- The gasoline taxi / bus is retrofitted to use both LPG and gasoline.

- However, as the vehicle is originally a petrol engine, when it is change to duel fuel, the setting of the vehicle such as fuel and air mix, and ignition timing must change. The setting will sacrifice some performance (horsepower, low fuel economy, etc.) and emission so both fuels will have a similar performance but still meet the emission requirement. Since most of these vehicles are old, the performance became very poor. Most drivers will adjust the setting so they will have the performance they want and these setting will cause a very high emission rating (such as NO_x and SO_2). Guangzhou EPB has done emission testing among 300 duel-fuel vehicles. Most of which failed to meet the emission requirements.

- It brings out the problem of duel-fuel. Single fuel should be a better option. Therefore, any new vehicle using LPG in Guangzhou should be a single –fuelled / dedicated one (but currently, there is no dedicated LPG vehicle in Guangzhou).

- Guangzhou is planning the first LPG-fuelled bus by October 2001, with LPG (50%) supply from the Central government distribution and 50 % from foreign import.

5) **Natural Gas**

- There is no natural gas vehicle now in Guangzhou because no natural gas supply to Guangzhou now.

- But foresee that natural gas vehicle will be available in Guangzhou within 5 years.

- In Beijing, there are both LPG-dedicated and NG-dedicated buses (single-deck) running on roads

6) **Control of New and In-used Vehicles**

- New vehicle must meet the EURO I standard

- For the in-use vehicles,
  - Annual examination, with pollutants emission testing;
  - Road Random Testing, with $200 fine on vehicles exceeding the limits, according to the city regulations;
  - Compliant hotline (requirement of vehicle testing 15 days after the notification), thereby normally, failed to sue as vehicle owners just re-fix their cars before going for inspection.

- Pollutants for emission testing:
  - Diesel: Smoke
  - Gasoline: NO_x and SO_2

- There is no vehicle growth control in Guangzhou. But there is a requirement that the new vehicle must meet the EURO I standard. As the old vehicle may already be in 1979 standard, the purchase of a new vehicle of EURO I standard (1992) will significantly reduce vehicle emissions. Therefore, control on vehicle growth is not very necessary, as the vehicle improvement can compensate the emission associated with vehicle growth.

- But there is vehicle-scrapping program: life limit of 15 years for motorcycles and 10 years for automobiles.

- 2/3 of on road vehicles in Guangzhou are motorcycles, no new motorcycle license has been issue since 1997, and motorcycle license cannot be renewed for another motorcycle.

7) **Use of Alternative Fuels**

- Unlike the developed countries, where emission standard is already up to EURO IV, China still have gap on emission standards (Just upgrade to EURO I from 1 January 2001 and will up to EURO II by 2004). Therefore, China doesn't have high pressure on developing alternative fuels, as there are many other legislative and fuel quality options available to China (e.g. more stringent requirements on emission standards, vehicle engine class, and fuel quality).

- The development of alternative fuels is not so urgent now in China. The alternative fuels, like electric, biodiesel, and ethanol, are still in laboratory stage.

- The Guangzhou EPB is considering fuel cell, and a trail is being planned among the automobiles which require smaller-sized battery.

8) **Retrofitting technologies (Particulate trap, Catalyst, Catalytic converter)**

- Both technically and economically, now is not an appropriate time for China to widely adopt the retrofitting technologies, until the China vehicle market is up to the EURO III standard.

- Major hurdles:
  - No government economic incentives, but not affordable for the drivers on such expensive products (Unlike Hong Kong, free or subsidized retrofitting in China supported by the government is impossible);
  - Poor vehicle maintenance and repairing standards, resulting in poor vehicle operation;
  - Already old vehicles;
  - Particulate trap washing problem (no facilities for washing and waste water treatment);
  - Poor driving quality

- About the particulate trap by PolyU, Mr. Zhang commented that for trapping coarse particulate matters, it could work. But he doubts if it can trap the fine particles efficiently as well. Moreover, regular washing is a must-be, which is the main weakness of particulate trap.

- Mr. ZHANG did also comment some on FuelStar (a combustion catalyst that is housed in a canister). He said Guangzhou EPB has tried lots of products, coming all over the world, for the past few years, but did not find any of which can really work properly, even though the products are claimed to be so advanced from the States. A similar product as FuelStar has also be tested, but the results are not very satisfactory. Mr. Zhang said that the root of the problem is fuel quality rather than any retrofitting on the vehicle engine. If the vehicle engine is already old, marginal benefits from retrofitting won't be very high. But in HK, the fuel quality is high (ULSD), burning of fuel itself is already clean. The addition of a retrofitting product will bring some extra emission benefits.

9) **I/M Program (2001)**

- According to US experience, I/M Program can help on achieving 60% emission reduction.

- "I" refers to Inspection, with qualified inspectors from the Police and Transport Department.

- "M" refers to Maintenance, with qualified mechanics. A traffic committee, coordinating all vehicle-repairing factories and workshops, hold meeting monthly to maintain the mechanics standards. Mechanics are required to pass a particular test for getting the qualification.

10) **Main Constraints Against and Requirements for Vehicle Control Emission**

- Complex government bureaucratic structure
  - Unlike Hong Kong, where the government can make its own policy and decision. Guangzhou is a city under Province and the State. Any suggestion of change, let's say more stringent emission and fuel standards, must need go through all government levels and get approval from the Central government. It thereby will slow down the whole process.
  - Indeed, there is an inter-affecting relationship between the Central and the Local government. The Central government sets up the national standards for the Local government to follow. On the other hand, if the Local government find any needs or rooms of improvement, it can propose to the Central government for consideration. So, the Local government is not static to wait for the commands from the Central government only.

- National planning and policy
  - Clear national policy planning on improving vehicle emissions is necessary, as it will be a guideline and standard for the future fuel supply and vehicle technologies development.
  - As fuel supply is centrally planned, it forms one of the constraints. For Guangzhou, when change from unleaded gasoline (0.05 g/L lead) to clean gasoline (0.013 g/L lead), it must need the guarantee from the Central government on the supply of such clean gasoline. Otherwise, Guangzhou cannot implement the program. As fuel supply is controlled, the current supply of clean gasoline is only restricted to Beijing, Shanghai and Guangzhou. Shengzhen does not have clean gasoline now because of the restricted / limited supply.

- Public consciousness
  - Low drivers' awareness resulting in poor driving habits cause poor vehicle operation and maintenance.
  - Raising public consciousness by education and promotion is crucial. Let the public, both drivers and pedestrians, understand the harms of pollutants on human health.
  - When public awareness is raised, willingness to obey the law among the public will be higher.

11) **Others**

- Transboundary air pollution
  - Wintertime, northerly wind Vs Summer time, southerly wind. The proportion of southerly wind is higher than northerly wind, so Mr. Zhang thought if Hong Kong affects Guangdong more.
  - Mr. Zhang commented that transboundary air pollution is not avoidable on high atmospheric level. The critical problem is the ground-level air pollution, which is directly affecting human health. It is seldom possible to have the ground-level pollutants to be dispersed in a transboundary scale. Most pollutants are generated by the city itself.

- Pedestrian Zone
  - Two streets with pedestrian zone within the designated time, one (Beijing Road) for every weekend and other one (上下九佃) every night.
  - Mainly for safety reasons, with the alleviation of road emissions as secondary purpose.

- International Funding Programs
  - 95' a funding from World Bank for a simulation model of vehicle emission at lab.
  - 97' a 8.35 million US funding for 4 items:
    (1) A air monitoring station
    (2) A noise monitoring station
    (3) Vehicle emission testing research center
    (4) I/M Program

Meeting: Shell

Representatives: Peter Robinson (Director) and Irene Hao (PA Manager)

Date: January 15, 2001

By: Lisa Hopkinson, Suzanne Skinner

1) Shell has a number of organizations including Shell hydrogen and researching fuel cells and hybrids – Shell has JV with Mercedes Benz. Could give introductions. Nothing on battery EVs.

2) PR thinks ULSD, LPG driven by government. LPG only successful where government policy because infrastructure/relative pricing and conversion issues. LPG technology stagnant. Non-auto LPG business in decline - 1.5%/y. Currently 25% domestic market. Consumer Council did 2 reports on LPG in 1998 and 1999. Taxi/minibus supply no problem on tankage. Tsing Yi capacity increased because of decline in domestic demand. Flexibility is there.

3) LPG filling stations. Shell plan to retrofit (technically feasible) 10 filling stations out of 60. Constraint is safety or replacing an existing product. HK Island stations too small or near residential buildings (need 50m setback). 180 filling station sites total in HK. EPD, EMSD (GSO), ESB, FSD all have different requirements. Rumors of 6 new dedicated sites. LPG not commercial proposition for Shell. Government changed rules on land and has gone for cheapest tender rather than highest bidder. US16 million for last site for filling station – cannot make enough $ to recoup that investment.

4) Natural gas – Shell has big push with all big investments in LNG. Shell energy profile used to be oil, large coal and some LNG. Woodside, Australian co, 35% owned by Shell has just discovered natural gas off NW shelf of Australia. LNG mainly aimed at domestic use. CNG for vehicles tried in NZ and US but didn't work. Lot of R&D needed on NGVs. Shell owns natural gas fields in Brunei and NW Australia. LNG plant in Shenzhen – shell or BP will win contract. Shell not thinking of LNG for NGVs.

5) Government – if make policy decisions, should be level playing field, including for all incumbents. Government has a lot of flexibility with duty.

6) Infrastructure constraints – problem in trying to deliver twin fuels. Biodiesel – don't have infrastructure. Had to choose between ULDS and normal diesel.

7) HK very small market. Cross border – Sandra Lee of ESB talking about common carrier. Sometimes the fact that it's a small market works in HK's favor. ULSD – such a premium market. Usually HK rides on the back of what happens elsewhere.

8) Concerns about other technologies. BEV – battery waste.

9) Illegal diesel. Retail sales of diesel have gone up by 13% - indicative of crack down. Shell now only sells ULSD, not normal diesel. Regulations on tax subsidy means that industrial customers (with fleets within their own area) now want to use ULSD. Marginal cost of 20-30cents to import ULSD compared to normal diesel. When first introduced it was 80cents. Singapore now supplies. If demand for ULSD increases then price might increase.

10) Reformulated fuels. Shell has policy not to use MTBE. Expect Euro IV spec in HK. Euro II for gasoline introduced 1/1/01. Australia already use Euro IV. Difficulties in going to better grades of fuel.

11) Shell renewables – by 2050 expect half world's energy will be from renewables. Xinjiang (?) 50,000 houses powered by solar. Driven by aid money, and Dutch government. Shell has 3 solar factories. In Australia – tax incentive to install solar panels. Shell working with solar company.

12) Note: Kyoto conference in HK 10/11 May. Risks and opportunities of Kyoto mechanism. PR asked to present paper on emissions trading.

Meeting: Citybus

Representatives: John Blay (Chief Engineer)

Date: January 15, 2001

By: Lisa Hopkinson

Fleet

1) Citybus have 960 buses:
   80 pre-Euro
   313 Euro I
   567 Euro II
   No plans to buy more.

Trolleybuses

2) Citybus are currently fitting overhead cables at site near Ocean Park for trial. Waiting for traction motor and inverter from Italy (expect end of Jan.) and Auxiliary power unit from Germany (mid Feb). Aim to start end of Feb. Will run for 6 months to check reliability, durability, performance, and costs.

3) Government consultancy expected end of Jan?? Nicholas Ng met CE of Stagecoach, not positive about trolleybuses. Consultancy indicates too difficult for urban areas, next stage route in Aberdeen.

4) Constraints: infrastructure – will Citybus have to negotiate with every private building owner or will government give them the authority?

5) Costs – new, low floor $3.7M compared to $2.3 M for standard bus. However lasts longer – 20 years. Operating costs slightly more than diesel costs Wellington – electricity costs minimal. With oil prices going up electricity will be relatively cheaper than diesel in 10 years. Maintenance costs on vehicle less. Maintenance on overhead wires would mean that overall maintenance costs more. For small route, not so much. When you have large network need team standing by. If choose right routes with high ridership, can spread extra costs.

[Marconi quoted $40M for wires for Aberdeen/Lei Tung route though Beijing co can probably do it for ½ cost]

6) Already have bus-bus interchange system where get discount on Octopus for 2nd bus ride. If interchange at Kennedy Town or East HKI – so passengers can switch to trolleybus. May be able to maintain same fare as normal buses. Duty refund on diesel encourages use of diesel.

7) Infrastructure consortium – KMB, HK Tramways, FirstBus – CB wouldn't object to o/h power lines used by other operators. Would like government corporation to build overhead wires and let companies use them. Main constraint – getting government to come up with policy that provides for it – and give provision for infrastructure. Substation sites – do power companies lease from government? Or get special provision? For TBs could use sites under flyover. Aberdeen to Lei Tung, 2 km would need 1 substation, max 2. This is long-term solution – for 50-100 years.

8) Still need mechanics for maintenance but need electricians. In Wellington, one person maintains all electrical wires and equipment for 60 buses. As it gets older, wearing, pushes maintenance curve below diesel.

9) For crossing, buses have passing bays at bus stops – or could have 2 lines with crossing wires.

10) Not as flexible as ordinary buses, does need coop from government. If mixed fleet and do have problem with lines or electrical system, could put diesel buses out and keep service running. Occasional operational problems when boom comes off wire – with auto boom raising equipment, driver just needs to get out of bus and reattach – takes a matter of seconds. If a problem with overhead pick up driver could use APU.

ULSD (Ultra-Low Sulfur Diesel)

11) For all buses from 1/2/01 – no incentives from government, absorbing costs, but prices now more reasonable.

12) All pre-Euro buses fitted with oxygen catalysts. Reduce PM and soot by 15%. Waiting for ULSD before use CRTs – getting in early Feb, trial for a few months. Budget for 200 in 1st year. CRT best one for next 5 years. Concentrate on Euro I and do Euro II later. In London, authorities give grants to bus companies to fit CRTs – should reduce particulates by 90%. De-NOx eg. Quad, not practical. Not trying Englehard DPX.

Natural Gas

13) Main problem is supply. Think could obtain DD NG bus but lose 12 seats or if 13.5m could maintain seating capacity. Biggest problem is refueling – for every 10 buses refueling would need tanker of gas every 15 mins, logistically impossible. 44 buses refueling over 2 hours. Wait for piped gas system.

14) With CNG (didn't look at LNG) without dedicated parking system at depot (temp parking spaces all over the place) cant have slow fuelling system. Need fast fuelling system.

Biodiesel

15) Where to source from? Not enough to guarantee bus co supply. Mix it so benefits not huge.

- Diesel/water – NWFB trying that.

- Hybrids – more efficient. Don't see benefits compared to TBs. Need lot of batteries, with a/c make very heavy Don't think viable for DD bus. Wouldn't get much mileage with engine shut down. If suburban area feeding in then reasonable option, however most of HK already v. urban – from Aberdeen to Central, where would you run diesel portion?

- H2/Fuel Cells – where to get hydrogen from? How to distribute it? Where to put it on the bus? Not an option for 10 years. Fuel cell seminar last week – German chamber of commerce. Daimler Chrysler – senior person said 'marathon not a sprint' – may get some private vehicles out of it.

For other vehicles

- LNG for trucks reasonable option as long as cheaper than diesel.

- Government – 3 grants to change taxis to LPG – bus companies not getting anything. Government can push bus cost but need carrots for others.

- TD & EPD – split responsibilities, none combining 2. EPD trying hard.

Diesel

- China – Green Diesel Initiative – main vehicle manufacturers and JV partners created fund to do publicity on green diesel. Suggestion to do the same in HK.

- Auckland – have LPG buses, government grant to put in fuelling system and buses. Co won't buy more buses unless government gives assistance. In London city authority gives grant to local operator.

Testing – EMSD don't even have testing facilities.

Meeting: CLP

Representatives: Richard Entwistle

Date: January 19, 2001

By: Lisa Hopkinson

Fuel Cells

- CLP part of venture to put in 30ft 300kw fuel cell (natural gas) to run on Towngas (250kw) to provide part of the energy requirements at Science Park. The H2 would be stripped out of Towngas. This would be combined with absorption chiller and microturbine, waste heat would go to chiller to provide 100kw of free a/c. If get microturnbine to run on waste heat can also recoup more energy. This is part of US DOE fuel cell commercialization process. Uses molten carbonate fuel cell, produced by company "fuel Cell energy". DOE sponsor it and provide 20% funding. 5 other fuel cells coming to Asia Pacific as a part of this program. CLP provide $5 million set up and maintenance support. Japanese co sole agent for the 5 fuel cells.

- EMSD HQ planning to install fuel cell (Westinghouse) –retrofit old Haeco buildings at Kai Tak in 2 years time, fed with Towngas.

Hypercar

- UK car co part of consortium. CLP interested to be involved. Looking at fleet vehicles. CLP's primary input would be in designing end product and customizing vehicles for Asia. BP verbally committed. Can plug fleets in to generate power when not being used.

- Wave, and ocean current energy

- Ma Wan – solar project, 50kw for Tsing Ma Bridge.

- MTR electric/solar city at Tseung Kwan O (area 85). Transport 20-30% energy demand so makes sense to have dream electricity source. Check MTR website. Makes more sense than having filling stations.

- Natural gas – government (Kim Salkeld) not interested, don't want to get locked into old technology. More ironmongery, people need to make it pay. Nat gas can be used for fuel cells, hybrids.

- EV – HK perfect for EVs because flat routes. KCR or MTR feeder buses should be electric or hybrid. What's wrong? Based on older technologies, manually assembled battteries and quality not good. Battery no longer a problem but need to design from scratch, can't retrofits. Select routes in HK – minibuses. Need to keep it simple. Toyota Prius complicated.

- Get book "EVS are profitable" by Peter Harrop, Footnote publications
- Design problems with CLP EVS- bus, chassis too heavy. Vicmax bus put together cheaply, lack of attention to detail. 2nd hand parts, reliability questionable. Andrew Ng – Solectria/Goldpeak batteries. EV – drivers have to drive differently

- Hydrogen – H2 economy 15 years away. New fuel cell hybrids 2003/2005. Natural gas will phase out LPG.

- MGVs/HGVs may be able to take some freight by rail but will take 10 years. Can use Prius engine for MGVs.

- Hybrids – still need storage system until fuel cells.

- Transport & power sections are converging. Next 5-10 yrs, leading systems for batteries. HEC EV designed to swap batteries. If buses – fuel cells. If idle then could park and become generators. Don't see utilities becoming transport cost but can see transport cost becoming utilities. Only certain proportion of fleet used at any one time.

- Trolley buses – not keen because of wires.

- Main players – utilities, MTR. Needs group of people collaborating on vision. Need to get main players involved. Gov legislators, lobby groups – need consensus.

- Gasoline FCVs – option to get people used to idea.

- Biodiesel – CLP looking at that with Hednesford.

Other people to talk to – Swires, Sun Hung Kai, ASD, MTR
Should include people movers, travellators, robotic systems like airport shuttle train.

Meeting: Towngas

Representatives: Sam Shum, Technology Development Manager

Date: January 22, 2001

By: Lisa Hopkinson, Vivian Kwok

Trials of NGV

1) Towngas have introduced HK's 1st NGV, a CNG Volkswagen Transporter (light goods van) – over next 12 months will do trial run with EPD/EMSD. This is a bi-fuel (petrol/natural gas) vehicle used in Germany, but EMSD won't allow bi-fuel so requested VW to modify before importing.

2) Have assigned small part of plant at Tai Po and installed Vehicle Refilling Apparatus from Canada – slow filling. Approved to be used by domestic users in Canada. Compress to 200 bar and fill up tank. Built cabinet to house cylinders in the vehicle at request of Transport Dept. Took 1 year to get type approval. Bought EMSD/EPD/FSD to Germany for factory visit. Promised to send manufacturers spec.

3) To get type approval – gas system, components spec, certification (especially for gas cylinder), and materials specification. Germany already done risk assessment. Energy content of 2 cylinders less than LPG so assumed safer than LPG. Also characteristics of NG – lighter than air, disperse quickly. LPG tank 90L energy content one third of NG. NGV has 280L tanks i.e. 160L with volume of 32 cubic meters. 250 km range

4) Using internally for operations – need to refuel twice a day. Empty tank takes 8 hours to fill, with VRA 4 cubic meters/hour so 32 cubic meters takes 8 hours.

5) Trial will look at emissions – CO, HCs and NOx. Also feedback from drivers and performance under different loads.

Sources of NG

6) Using methane cylinders bought from other sources – agent in HK, imported from US, but very expensive because of transport costs. Looking for cheaper gas – trying to source from PRC

7) Shenzhen LNG plant -- not sure if can utilize NG for vehicles but need infrastructure – NG filling stations more expensive than LPG. Heard FSD/Disney looking at NGVs? NGVs will only become commercial after piped gas available. Not allowed to use CLP natural gas because of scheme of control.

8) Landfill gas (50% methane) – Towngas in negotiation with operators/EPD to try and use SENT. Collect LFG and convert to high concentration CH4 and pump into Refuse collection vehicles. Closed loop system. Still in negotiation. Small amount of gas already used for power gen. Dedicated RCV available from MAN, in Munich. Don't have fuel costs for RCV but environmental benefits and technically feasible.

9) LFG – to clean – use pressure swing absorption, several steps. Investment expensive. SENT gas lasts about 20 years. One project is to use for RCV. Another project is to reform landfill gas to natural gas, blend to form Towngas and pump into existing supply system. SENT has 10 million cubic feet per day of NG, could serve Tseung Kwan O. Worth investing over so many years. Benefits – not using fossil fuels in Tai Po, using waste material. LFG from Shuen Wan landfill already used – Towngas extract natural gas for use in boilers. Need to get approval from EMSD and other departments for the reforming plants. Hope to start building plant end 2001, operating at end year 2002. Government has 20 vehicles to SENT. NENT too far, and doesn't use RCS – brings waste from Refuse Collection Stations using containers. Expensive to buy new container vehicles.

Costs

10) NG cheap but compared to diesel, price is similar. In Germany pump price of NG similar to diesel. If drive over 20,000 miles per year, prefer diesel. Mainly for heavy-duty vehicles. Using methane cylinders bought from other sources – agent in HK, imported from US, but very expensive because of transport costs. Looking for cheaper gas – trying to source from PRC. VW transporter 15-20% higher than diesel or petrol because of conversion – main cost is cylinder. RCV 20% higher costs. Lifetime costs – some sacrifice on payload.

Performance

11) May be some issues because of amount of stop start driving in HK so consumption may be higher. Maintenance – have agreement with VW agent – Dah Chong Hong who will do maintenance. Not as complicated as LPG so similar maintenance.

Availability

12) No car agent who can import a dedicated NGV. Honda Civic passenger car – Honda Japan will not sell to HK because no maintenance workshop. Honda agent – Reliance – wiling to do service but have no say in matter. HK$400,000 for Civic Honda (2 million yen in Japan). Civic designed in US – US Honda will sell Left hand drive. Other EC manufacturer have dedicated vehicles mostly bi-fuel. In Europe prefer bi-fuel because not many filling stations.

Infrastructure

13) When NG transported by pipe, not same as LPG/diesel etc because no need for underground tanks. Pressure little lower because using compressor to fill. Can use any filling station. Proximity to station still an issue because still have dispenser. In Japan still have 4 m boundary from dispenser.

Long term plans

14) Depends on government. If import passenger NGV – government prefers not – try to avoid complicated issue. Push LPG taxis and testing minibus. Tax is main issue. Gov focus on LPG minibus first. LPG interim solution because of safety. LNG also possible for heavy-duty vehicles.

Hydrogen

15) Talked to EPD about FCVS – contact with Daimler Chrysler. Mr. Shum met Daimler Chrysler. EPD would like to introduce prototype and approached HKCG to get the H2. Work with other industrial gas companies to produce. HKCG use H2 for cooling. When do processing will generate H2.

16) When government wants common carrier system, competitor will not use Towngas so NG is main future gas. NG main source for FCV or transport. Don't need pure H2 for vehicles. Combined cycle power generation – produce heat and electricity. Depends on commercial viability – FCs will drop in price in future. Toshiba has done pioneer research on fuel cells. When electricity costs drop to US$2000/kWh then viable. Internally Towngas interested in power generation.

17) Applications – new development areas – South East Kowloon, Science Park etc. Fuelcells for power gen and also heat recovery.

18) In future NG will be fuel of future – especially in PRC.

Main drivers for change

19) Government priority. Seminar in Yokohama – many countries – without government initiative cannot do anything. Education – promote public to be aware of issues.

Main competitor

20) CLP – lot of financial support, can spend a lot on R&D.

Other technologies

21) Good opportunity to have test/research on different kinds of fuel. Interested in ethanol – produce from veg matter. Interested in other transport. Working on green fuel – mixture of naphtha, ethanol and alcohol compounds. Used in Japan. Problem – will car manufacturer maintain warranty? Patented mixture – can manufacture in different countries. Liquid, cleaner than petrol. Similar in safety and can distribute at petrol filling stations. Exluding gov tax, will costs a bit higher than petrol. Tax free in Japan. Can mix with petrol. CO and HCs less than petrol. No NOx data.

Meeting: Transport Department

Representatives: Mr. Alan S Y Lui (Asst. Commissioner Transport/Ferry/Paratransit), Y. W Chiu (Senior Engr, VehExam division), Larry Y M Li (Snr. Eng Vehicle Regn & Stds), and Benjamin Mok (Asst. Sec. for transport)

Date: February 15, 2001

By: Suzanne Skinner and Lisa Hopkinson

1) Mr. Lui is in charge of vehicle examination, Mr. Chiu day-to-day vehicle inspection and Mr. Li legislation.

Emissions testing

2) TD have 4 testing centers – 2 in Kowloon Bay (1 is contracted out to Dah Chong Hong), 1 at Tok Ko Wan and one at Sheung Kai Cheung?. A latter test NT taxis so no need for Dyno. They have 1 chassis Dyno. Test HGVs and LGVs at random – 10% of vehicles tested. However machine broken down after 30 vehicles. Dah Chong Hong center inspects vehicles over 1.9t to 16t. All goods (2 axle) vehicles. Government testing centers inspect taxis, light buses, public service vehicles, mainly for safety reasons. For franchised buses they send TD inspectors to the bus depots. Franchised bus depots do not have Dynos.

3) Private cars – testing done by private sector – TD designated 23 centers over the SAR. Cars over 6 years have to go through annual inspection. Monitoring team visits car-testing centers regularly to recheck vehicle and watch inspections being carried out. ICAC also monitors inspection fees. Private testing center fee scale normally the same as government - TD authorizes any fee rises.

4) For petrol vehicles TD measures emissions of CO – follows EU standards which vary according to age of vehicle. Very old vehicles are exempt. LPG follows Japanese standards and measure CO and Hydrocarbons.

5) Costs – if want to install more Dynos need to increase fees. Costs >$2M for installation of Dyno at K Bay and 3 additional staff to operate it. Plan to install one more Dyno in Kowloon Bay and one at To Ko Wan (many non franchised buses).

6) Once a vehicle has failed test, TD issues repair order until it passes. Usually owner has incentive to get it repaired so it can go on the road.

7) TD emission check. EPD has ad hoc spotter scheme. Police do roadside checkpoints. Discrepancy in standard used – TD use 60 HSU standard for smoke, Police follow TD but EPD use 50HSU. EPD coordinating action to standardize but trade argues older vehicles cannot meet 50 HSU.

Vehicle licensing

8) For new vehicles imported into HK – before registration/licensing need to go through type approval or pre registration procedures. If a vehicle dealer brings the first vehicle of its type to HK need to get type approval – check against vehicle regulations. For private cars once type approval is obtained can import same model without further inspections.

9) Other models – goods vehicles, bus, taxi etc, even if type approval obtained, need to go through individual pre registration approval to ensure every vehicle in good condition.

10) A vehicle can be registered before licensed – latter means it can drive on the road. Registered means it can be kept in workshop. If don't license for 2 years then registration is deleted.

11) For new vehicle brought to HK need to submit noise and exhaust emission details to EPD for approval, and stipulating that it meets legal requirements. With that certificate, if gas vehicle need to submit to GSO/EMSD to examine gas/fuel system. EMSD will issue approval letter to state it complies. Finally it's brought to TD for overall safety check. After TD inspection can submit documentation to confirm it complies with regulations.

Legislation

12) Road Traffic Construction and Maintenance of Vehicles (Cap 374) – stipulates all technical requirements for petrol/diesel vehicles.

13) TD carry out pre registration inspection – if authorized vehicle from dealer then type approval. If not from OEM need to carry out inspection on individual vehicles. If all conditions met then issue letter for registration.

Alternative technologies

14) For CNG, LPG, EV, FCVs – at present no specific legal requirements but international standards to assess whether cleaner. E.g. LPG – Japan has auto type approval handbook standards. Also use Australian/US/ED standards.

15) TD developing type approval for LPG – drafting legal provisions to incorporate in existing regulations – complete in 2002/2003. For EVs/hybrids – also prepared to consider regulations.

16) Priority – LPG, then EVs, CNG…FCVs last. New legislation will apply to newly imported vehicles. Objectives are (1) to update regulation taking into account new

policies (2) to make more efficient in terms of subsequent amendment. At present all the schedules are included in the present regulations – very cumbersome to update (3) to make more user friendly for commercial sector. Hope to effect law amendment next year. Technical schedules and standards will be added to new regulation in incremental/batch manner. Thus when any new standard being applied elsewhere can adopt.

17) In 1999 TD reviewed the Road Traffic Vehicle Regulations – outdated, based on UK 80's standards. Try to enhance vehicle safety. Will base on well recognized national standards. Will keep old regulations for in use vehicles – will die a natural death at some point.

18) In adopting standards, TD uses judgment – generally uses EC/Japan and Us as main standards. Japanese vehicles dominate HK. In proposed type approval use Japan and EC standard to build up framework. Consultation document in preparation to consult manufacturers.

19) For emissions/noise – standard still based on EPD but in new regulations the standard will be stated there in coordination with EPD. Trying to adopt a one stop shot approach with single point of contact.

20) Hydrogen – gas vehicles under EMSD but can cover under new regulations.

Environmental protection

21) For environmental protection – EFB main bureau but TB also trying to develop more environmental friendly transport system. EFB come to TB for expert advice. TD/TB help to reflect concerns of the trade. TD undertook trolleybus study because of impact on transport modes/operators.

22) May give environmental friendly vehicles exemptions e.g. light bus, but can consider relaxing for EVs. Case by case basis but never compromise on safety.

Appendix C: Raw Data

Table C1. Emission Table for Passenger Vehicles

Engine/Fuel Type	Emission During Operation of Vehicle: GHG CO_2	GHG CH_4	GHG N_2O	Total GHG Emission g CO_2 Equivalent/mile	Non-GHG CO	Non-GHG NO_x	Non-GHG VOC	Non-GHG SO_x	Non-GHG PM	Refence Vehicle	comment	Fuel Economy	Test Cycle	Refence Report
Gasoline/Petrol														
Conventional														
300 ppm Sulfur	327.00	0.16	0.04	347.00	7.73	0.74	0.90	0.09	0.05					Report 1
	272.40	0.08	0.07		9.00	0.80						30 mpg		Report 2
	267.58				1.48	0.16				Vauxhall Astra 1.4l	Unleaded petrol RF 08	32.82 mpg		Report 4
	265.00				1.67	0.16				Vauxhall Astra 1.4l	City' Petrol	32.72 mpg		Report 4
	288.98				1.01	0.27				Vauxhall Combo 1.4l	Unleaded petrol EN 228	31.21 mpg		Report 4
	384.55				1.66	0.42				Transit Van 2.01 Catalyst	Unleaded petrol RF 08	22.20 mpg		Report 4
	376.51				1.51	0.24				Transit Van 2.01 Catalyst	City' Petrol	22.84 mpg		Report 4
				315.63						1996 Toyota Camry	Auto Transmission	27.8 mpg		Report 5
30 ppm Sulfur	330.00	0.16	0.02	341.00	6.18	0.63	0.68	0.03	0.05					Report 1
1 ppm Sulfur	259.00	0.12	0.01	269.00	4.87	0.49	0.53	0.02	0.04					Report 1
Direct Inject														
30 ppm Sulfur	259.00	0.12	0.01	268.00	4.87	0.49	0.53	0.02	0.04					Report 1
				202.36						2020 Evolutionary	Auto-Clutch Transmission	43.2 mpg		Report 5
1 ppm Sulfur				178.17						2020 Advanced	Auto-Clutch Transmission	49.1 mpg		Report 5
Diesel														
0.03% Sulfur	270.00	0.01	0.02	276.00	1.54	1.22	0.30	0.07	0.19					Report 1
	266.29				0.53	0.84			0.06	Vauxhall Combo 1.7l	Diesel EN 590	37.59 mpg		Report 4
	337.89				1.45	1.61			0.32	Transit Van 2.5.1 turbo	Diesel RF 73	29.12 mpg		Report 4
50 ppm Sulfur	270.00	0.01	0.02	276.00	1.54	1.22	0.30	0.03	0.19					Report 1
				165.78						2020 Advanced	Auto-Clutch Transmission	56.0 mpg		Report 5

Ethanol														
E10 (Corn)	326.00	0.16	0.02	338.00	6.06	0.63	0.66	0.03	0.04					Report 1
E10 (Cellulose)	326.00	0.16	0.02	338.00	6.06	0.63	0.66	0.03	0.04					Report 1
E85 (Corn)	288.00	0.22	0.04	306.00	4.92	0.66	0.52	0.03	0.02					Report 1
	301.10	0.08	0.07		9.00	0.80						30 mpg		Report 2
E85 (Cellulose)	288.00	0.22	0.04	306.00	4.92	0.66	0.52	0.03	0.02					Report 1
Methanol														
M85 (Natural Gas)	277.00	0.10	0.04	293.00	4.99	0.65	0.38	0.03	0.02					Report 1
	270.40	0.08	0.07		9.00	0.80						30 mpg		Report 2
LPG	267.00	0.16	0.04	285.00	4.64	0.66	0.19	0.02	0.01					Report 1
	235.40	0.08	0.07		9.00	0.80						30 mpg		Report 2
	246.50				0.58	0.21				Vauxhall Combo 1.4l	LPG bi-fuel Calor 90-95%	23.41 mpg		Report 4
	373.29				0.03					Transit Van 2.01 Catalyst	LPG bi-fuel	15.47 mpg		Report 4
CNG	221.00	1.89	0.03	273.00	4.64	0.66	0.07	0.01	0.01					Report 1
	204.70	0.90	0.07		9.00	0.80						30 mpg		Report 2
	229.77				0.53	0.18				Vauxhall Combo 1.4l	CNG bi-fuel 93% methane	30.49 mpg		Report 4
					0.40	0.16				Honda Civic OE conversion				Report 4
	316.97				0.29	0.13				Transit Van 2.01 Catalyst	CNG bi-fuel	17.1 mpg		Report 4
Hybrid														
Gasoline (30 ppm S)	210.00	0.09	0.03	222.00	4.56	0.43	0.52	0.02	0.03					Report 1
	196.46				0.48	0.10				Toyota Prius	30kW motor 20 kWh NiMH Battery	50.6 mpg		Report 4
				123.89						2020 Advanced	Continuously Variable Tranmission	70.8 mpg		Report 5
Diesel	194.00	0.01	0.01	198.00	1.13	0.90	0.22	0.05	0.14					Report 1
				112.68						2020 Advanced	Continuously Variable Tranmission	82.3 mpg		Report 5
CNG				91.44						2020 Advanced	Continuously Variable Tranmission	73.4 mpg		Report 5
Fuel Cell														
M100 (Natural Gas)	189.00	0.00	0.00	189.00	0.00	0.00	0.06	0.03	0.00					Report 1
	0.00	0.00	0.00		0.00	0.00	0.00		0.00	Ford P2000	Estimate	59.88 mpg		Report 4
				146.90						2020 Advanced	Direct	56.9 mpg		Report 5
Hydrogen (Gasoline)				207.08						2020 Advanced	Direct	42.3 mpg		Report 5
Hydrogen (Natural Gas)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00					Report 1

Hydrogen (Electricity)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00					Report 1
				0.00						2020 Advanced	Direct	94.1 mpg		Report 5
Hydrogen (Hydroelectric)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					Report 1
	0.00				0.00	0.00			0.00	Ford P2000		67.29 mpg		Report 4
Electircity (Power Grid)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					Report 1
	0.00	0.00	0.00		0.00	0.00	0.00		0.00	Peugeot 106	35 kW motor 28 kWh NiCd battery	81.24 mpg		Report 4
				0.00						2020 Advanced	Direct	149 mpg		Report 5
Production of Fuel														
Gasoline/Petrol														
Conventional														
300 ppm Sulfur	78.00	0.95	0.01	100.00	0.36	0.43	0.27	0.17	0.23					Report 1
				74.9								30 mpg		Report 2
				79.05						1996 Toyota Camry		27.8 mpg		Report 5
30 ppm Sulfur	88.00	0.98	0.01	111.00	0.37	0.44	0.25	0.19	0.24					Report 1
1 ppm Sulfur	76.00	0.79	0.01	94.00	0.30	0.36	0.20	0.16	0.19					Report 1
Direct Inject														
30 ppm Sulfur	70.00	0.77	0.01	88.00	0.29	0.35	0.19	0.15	0.19					Report 1
				50.74						2020 Evolutionary		43.2 mpg		Report 5
1 ppm Sulfur				44.25						2020 Advanced		49.1 mpg		Report 5
Diesel														
0.03% Sulfur	48.00	0.73	0.00	64.00	0.26	0.30	0.07	0.12	0.18					Report 1
50 ppm Sulfur	52.00	0.74	0.00	69.00	0.26	0.31	0.08	0.13	0.18					Report 1
				26.55						2020 Advanced		56.0 mpg		Report 5
Ethanol														
E10 (Corn)	72.00	0.95	0.02	95.00	0.40	0.51	0.31	0.18	0.23					Report 1
E10 (Cellulose)	58.00	0.97	0.01	83.00	0.38	0.48	0.24	0.18	0.23					Report 1
E85 (Corn)	-91.00	0.64	0.10	-47.00	0.62	1.05	0.83	0.10	0.11					Report 1
				24.40								30 mpg		Report 2
E85 (Cellulose)	-186.00	0.80	0.01	-167.00	0.48	0.74	0.14	0.07	0.15					Report 1
Methanol														

M85 (Natural Gas)	82.00	0.86	0.01	101.00	0.25	0.64	0.13	0.10	0.09					Report 1
				112.70								30 mpg		Report 2
LPG	25.00	0.51	0.00	36.00	0.13	0.20	0.05	0.04	0.04					Report 1
				28.10								30 mpg		Report 2
CNG	32.00	1.01	0.00	54.00	0.14	0.26	0.02	0.05	0.01					Report 1
				43.50								30 mpg		Report 2
Hybrid														
Gasoline (30 ppm S)	48.00	0.58	0.00	61.00	0.22	0.26	0.17	0.11	0.14					Report 1
				26.55						2020 Advanced		70.8 mpg		Report 5
Diesel	32.00	0.49	0.00	47.00	0.17	0.20	0.05	0.08	0.12					Report 1
				17.70						2020 Advanced		82.3 mpg		Report 5
CNG				25.37						2020 Advanced		73.4 mpg		Report 5
Fuel Cell														
M100 (Natural Gas)	60.00	0.57	0.00	70.00	0.14	0.48	0.06	0.06	0.02					Report 1
				46.02						2020 Advanced		56.9 mpg		Report 5
Hydrogen (Gasoline)				51.92						2020 Advanced		42.3 mpg		Report 5
Hydrogen (Natural Gas)	174.00	0.66	0.00	187.00	0.12	0.27	0.02	0.09	0.02					Report 1
Hydrogen (Electricity)	190.00	0.41	0.02	203.00	0.08	0.49	0.01	0.73	0.05					Report 1
				172.27						2020 Advanced		94.1 mpg		Report 5
Hydrogen (Hydroelectric)				31.00										Report 1
Electicrity (Power Grid)	96.00	0.05	0.00	98.00	0.01	0.23	0.00	0.38	0.02					Report 1
				162.23						2020 Advanced		149 mpg		Report 5
Vehicle Manufacture														
Gasoline/Petrol														
Conventional														
300 ppm Sulfur	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
				28.91						1996 Toyota Camry		27.8 mpg		Report 5
30 ppm Sulfur	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
1 ppm Sulfur	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
Direct Inject	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
30 ppm Sulfur				25.37						2020 Evolutionary		43.2 mpg		Report 5

1 ppm Sulfur				24.78						2020 Advanced		49.1 mpg		Report 5
Diesel														
0.03% Sulfur	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
50 ppm Sulfur	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
				25.96						2020 Advanced		56.0 mpg		Report 5
Ethanol														
E10 (Corn)	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
E10 (Cellulose)	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
E85 (Corn)	34.00	0.01	0.00	34.00	0.01	0.05	0.00	0.07	0.01					Report 1
E85 (Cellulose)	35.00	0.01	0.00	35.00	0.01	0.05	0.00	0.07	0.01					Report 1
Methanol														
M85 (Natural Gas)	35.00	0.01	0.00	35.00	0.01	0.05	0.00	0.07	0.01					Report 1
LPG	35.00	0.01	0.00	35.00	0.01	0.05	0.00	0.07	0.01					Report 1
CNG	36.00	0.01	0.00	36.00	0.01	0.05	0.00	0.07	0.01					Report 1
Hybrid														
Gasoline (30 ppm S)	32.00	0.01	0.00	32.00	0.01	0.05	0.00	0.06	0.01					Report 1
				25.37						2020 Advanced		70.8 mpg		Report 5
Diesel	32.00	0.01	0.00	32.00	0.01	0.05	0.00	0.06	0.01					Report 1
				25.96						2020 Advanced		82.3 mpg		Report 5
CNG				25.96						2020 Advanced		73.4 mpg		Report 5
Fuel Cell														
M100 (Natural Gas)	39.00	0.01	0.00	39.00	0.01	0.06	0.00	0.08	0.01					Report 1
				28.91						2020 Advanced		56.9 mpg		Report 5
Hydrogen (Gasoline)				30.09						2020 Advanced		42.3 mpg		Report 5
Hydrogen (Natural Gas)	41.00	0.01	0.00	41.00	0.01	0.06	0.00	0.08	0.01					Report 1
Hydrogen (Electricity)	41.00	0.01	0.00	41.00	0.01	0.06	0.00	0.08	0.01					Report 1
Hydrogen (Hydroelectric)	41.00	0.01	0.00	41.00	0.01	0.06	0.00	0.08	0.01					Report 1
				28.91						2020 Advanced		94.1 mpg		Report 5
Electicrity (Power Grid)	48.00	0.01	0.00	48.00	0.01	0.07	0.00	0.09	0.01					Report 1
				30.09						2020 Advanced		149 mpg		Report 5

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Report 4: Report of the Alternative Fuels Group of the Cleaner Vehicles Task Force (gm/km)
Report 5: On The Road In 2020 (From MIT)

Table C2. Emission Table for Heavy-Duty Vehicles

	Emission During Operation of Vehicle													
	GHG			Total GHG Emission	Non-GHG					Refence	comment	Fuel	Test	Refence
Engine/Fuel Type	CO_2	CH_4	N_2O	g CO_2 Equivalent/mile	CO	NO_x	VOC	SO_x	PM	Vehicle		Economy	Cycle	Report
Diesel														
0.03% Sulfur	1,629.00	0.10	0.07	1,662.00	16.37	20.55	2.71	0.43	0.58					Report 1
	1,250.19				1.93	9.49			0.47	Scania 94L 310 'Safeway'	City' Diesel	8.09 mpg	Typical Heavy Truck Cycle	Report 4
50 ppm Sulfur	1,629.00	0.10	0.07	1,662.00	16.37	20.55	2.71	0.17	0.58					Report 1
DME	1,426.00	0.05	0.07	1,463.00	21.28	10.27	7.35	0.13	0.12					Report 1
Biodiesel	1,639.00	0.03	0.07	1,663.00	4.91	26.71	0.54	0.27	0.29					Report 1
CNG	1,341.91				0.06	1.35			0.03	ERF EC 12 'Safeway'		7.42 mpg	Typical Heavy Truck Cycle	Report 4
LPG	1,618.00	0.10	0.07	1,668.00	1.64	10.27	8.67	0.10	0.04					Report 1
LNG	1,215.00	2.97	0.07	1,331.00	1.64	10.27	8.58	0.04	0.03					Report 1
	Emission During Production of Fuel													
Diesel														
0.03% Sulfur				389.00										Report 1
50 ppm Sulfur				418.00										Report 1
DME				381.00										Report 1
Biodiesel				-696.00										Report 1
LPG				215.00										Report 1

Engine/Fuel Type	CO_2	CH_4	N_2O	Total GHG Emission g CO_2 Equivalent/mile	CO	NO_x	VOC	SO_x	PM	Refence Vehicle	comment	Fuel Economy	Test Cycle	Refence Report
LNG				641.00										Report 1
Emission During Vehicle Manufacture														
Diesel														
0.03% Sulfur				90.00										Report 1
50 ppm Sulfur				90.00										Report 1
DME				92.00										Report 1
Biodiesel				92.00										Report 1
LPG				90.00										Report 1
LNG				90.00										Report 1

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Table C3. Emission Table for Transit Buses

Engine/Fuel Type	Emission During Operation of Vehicle: GHG CO_2	GHG CH_4	GHG N_2O	Total GHG Emission g CO_2 Equivalent/mile	Non-GHG CO	Non-GHG NO_x	Non-GHG VOC	Non-GHG SO_x	Non-GHG PM	Refence Vehicle	comment	Fuel Economy	Test Cycle	Refence Report
Diesel														
0.03% Sulfur				2,156.00										Report 1
	2,779.00	0.00			3.00	30.10	0.14		0.24	NovaBUS RTS Series 50		3.5 mpg	CBD Cycle	Report 3
	7,076.00	0.00			11.30	72.00	0.60		0.70	NovaBUS RTS Series 50		1.4 mpg	NY Bus Cycle	Report 3
	4,268.00	0.00			6.00	40.30	0.25		0.48	NovaBUS RTS Series 50		2.3 mpg	Manhattan Cycle	Report 3
	3,227.00	0.00			7.00	31.50	0.22		0.46	NovaBUS RTS Series 50		3.0 mpg	NY Composite Cycle	Report 3

	2,230.00				2.17	24.14			0.23	Volvo Olympian double deck	Diesel Euro 2	4.51 mpg	London Bus Route	Report 4
	2,173.76				2.22	22.85			0.16	Volvo Olympian double deck	City' Diesel	4.63 mpg	London Bus Route	Report 4
	2,160.89				0.34	20.16			0.03	Volvo Olympian double deck	City' Diesel + CRT	4.67 mpg	London Bus Route	Report 4
50 ppm Sulfur				2,156.00										Report 1
DME				1,908.00										Report 1
Biodiesel				2,156.00										Report 1
	3,377.00	0.00			8.50	27.90	3.04 (THC)		3.51	TMC Biodiesel Bus		3.0 mpg	CBD Cycle	Report 3
	7,153.00	0.00			16.90	78.30	9.22 (THC)		4.50	TMC Biodiesel Bus		1.4 mpg	NY Bus Cycle	Report 3
	2,819.00	0.00			4.50	22.30	2.59 (THC)		1.81	TMC Biodiesel Bus		3.6 mpg	Route #22 Cycle	Report 3
	2,964.00	0.00			5.20	23.60	2.73 (THC)		3.80	TMC Biodiesel Bus		3.4 mpg	Route #77 Cycle	Report 3
CNG				1,964.00										Report 1
	2,392.00	14.60			0.60	25.00	0.60		0.02	Ncoplan AN400T L10 280G		3.1 mpg	CBD Cycle	Report 3
	6,090.00	65.40			29.00	113.20	4.84		0.14	Ncoplan AN400T L10 280G		1.2 mpg	NY Bus Cycle	Report 3
	1,889.00	11.90			2.80	24.80	0.87		0.03	Ncoplan AN400T L10 280G		3.9 mpg	Route #22 Cycle	Report 3
	1,973.00	11.40			2.70	23.10	0.69		0.05	Ncoplan AN400T L10 280G		3.7 mpg	Route #77 Cycle	Report 3
	2,343.00	17.40			12.70	14.90	3.15		0.02	New Flyer C40LF Series 50g		3.1 mpg	CBD Cycle	Report 3
	5,610.00	75.10			37.20	26.20	4.35		0.00	New Flyer C40LF Series 50g		1.3 mpg	NY Bus Cycle	Report 3
	3,395.00	62.30			26.30	21.40	2.10		0.00	New Flyer C40LF Series 50g		2.1 mpg	Manhattan Cycle	Report 3
	2,785.00	23.70			10.80	9.70	2.36		0.02	Orion V Series 50G		2.6 mpg	CBD Cycle	Report 3
	6,535.00	66.70			31.70	15.30	6.64		0.11	Orion V Series 50G		1.1 mpg	NY Bus Cycle	Report 3
	3,165.00	50.50			25.70	12.40	4.57		0.03	Orion V Series 50G		2.2 mpg	NY Composite Cycle	Report 3
	2,225.00	17.20			8.90	6.80	1.80		0.03	Orion V Series 50G		3.3 mpg	Route #22 Cycle	Report 3
	2,160.89				1.06	15.96			0.05	Volvo B10L single deck	CNG	3.2 mpg	London Bus Route	Report 4
LPG	2,106.18				0.02	8.69			0.02	DAF GG 170	LPG	2.74 mpg	London Bus Route	Report 4
MossGas	2,816.00	0.00			1.00	32.20	0.05		0.09	NovaBUS RTS Series 50		3.3 mpg	CBD Cycle	Report 3
	7,272.00	0.00			6.60	72.30	0.15		0.37	NovaBUS RTS Series 50		1.3 mpg	NY Bus Cycle	Report 3
	2,386.00	0.00			2.00	26.90	0.15		0.10	NovaBUS RTS Series 50		3.9 mpg	Route #22 Cycle	Report 3
Hybrid														
Diesel				1,262.00										Report 1
	2,262.00	0.00			0.10	19.20	0.08		0.12	Orion-LMCS VI		4.3 mpg	CBD Cycle	Report 3
	4,251.00	0.00			5.00	40.50	0.08		0.16	Orion-LMCS VI		2.3 mpg	NY Bus Cycle	Report 3

	2,841.00	0.00			0.10	22.60	0.18		0.00	Orion-LMCS VI		3.4 mpg	Manhattan Cycle	Report 3
	2,250.00	0.00			0.20	19.90	4.57		0.14	Orion-LMCS VI		4.2 mpg	NY Composite Cycle	Report 3
	2,472.00	0.00			0.40	27.70	0.00		0.00	Nova-Allison RTS		3.9 mpg	CBD Cycle	Report 3
	5,430.00	0.00			0.60	58.90	0.00		0.00	Nova-Allison RTS		1.7 mpg	NY Bus Cycle	Report 3
Diesel (no regen)	2,625.00	0.00			0.04	22.00	0.12		0.24	Orion-LMCS VI		3.7 mpg	CBD Cycle	Report 3
	5,500.00	0.00			3.00	50.00	0.12		0.00	Orion-LMCS VI		1.5 mpg	NY Bus Cycle	Report 3
	3,010.00	0.00			1.00	32.10	0.03		0.07	Nova-Allison RTS		3.1 mpg	CBD Cycle	Report 3
MossGas	2,218.00	0.00			0.10	18.50	0.03		0.02	Orion-LMCS VI		4.2 mpg	CBD Cycle	Report 3
	3,930.00	0.00			0.10	32.00	0.03		0.00	Orion-LMCS VI		2.4 mpg	NY Bus Cycle	Report 3
Fuel Cell														
Methanol (Natural Gas)				1,479.00										Report 1
Hydrogen (Natural Gas)				0.00										Report 1
Hydrogen (Electricity)				0.00										Report 1
Emission During Production of Fuel														
Diesel														
0.03% Sulfur				505.00										Report 1
50 ppm Sulfur				543.00										Report 1
DME				497.00										Report 1
Biodiesel				-903.00										Report 1
CNG				429.00										Report 1
Hybrid														
Diesel				296.00										Report 1
Fuel Cell														
Methanol (Natural Gas)				548.00										Report 1
Hydrogen (Natural Gas)				1,445.00										Report 1
Hydrogen (Electricity)				1,570.00										Report 1
Emission During Vehicle Manufacture														
Diesel														
0.03% Sulfur				87.00										Report 1
50 ppm Sulfur				87.00										Report 1
DME				89.00										Report 1

Biodiesel				90.00										Report 1
CNG				89.00										Report 1
Hybrid														
Diesel				102.00										Report 1
Fuel Cell														
Methanol (Natural Gas)				82.00										Report 1
Hydrogen (Natural Gas)				88.00										Report 1
Hydrogen (Electricity)				88.00										Report 1

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