Environmental Effects of Vehicle Exhausts, Global and Local Effects – A Comparison between Gasoline and Diesel

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Abstract

Since 1970, vehicleôs exhaust pollutions have received increasing attention as a source of air pollution at both local (human health concerns) and global (global warming) scales. This study mainly discusses diesel and gasoline vehicles because, today, over 90% of vehicles on the road use gasoline and diesel fuels. The major concerns of gasoline exhaust contaminants are carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2) and polycyclic aromatic hydrocarbons (PAHs); the major concerns of diesel exhaust emissions contaminants are nitrogen oxides (NO_X) and particulate matter (PM). The aim of this study is mainly to compare gasoline and diesel fuels, and to determine which fuel and its developed forms are less harmful to humans, and which are most suitable for the natural environment at both a local and global level. The results show that burning gasoline fuels will emit less PM and NO_X emissions than burning diesel fuels, but it will generate about 50% more CO_2 than diesel fuels, and it also emit about ten times more CO, PAHs and around five times more HC than diesel fuels; burning diesel fuels will produce less CO_2 emissions than gasoline fuels, but will emit around ten times more NO_X and PM than gasoline fuels. Consequently using a gasoline car in urban areas might help to reduce the human health effects; using a diesel car on motorways or in rural areas might help to reduce the greenhouse gas (GHG) emissions and minimize the global warming effects. Biofuels, biodiesel and ethanol, have the potential to minimize the vehicle exhaust emissions and adverse effects. Nonetheless, there are still many debatable issues around biodiesel, such as insufficient fuel supply and health concerns (especially, ultrafine particles (UFPs)). In the future, there remains a need to continue the further studies of vehicle exhaust emissions, and to improve the understanding of all vehicle exhaust emissions and all of their impacts, especially the vehicle exhaust health research.

Keywords: Vehicle exhaust; emissions; gasoline; diesel; human health

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Abbreviations

CO: Carbon Monoxide;
CO_2: Carbon Dioxide;
HC: Hydrocarbon;
NO_X: Nitrogen Oxides;
NO: Nitrogen Monoxide;
NO_2: Nitrogen Dioxide;
SO_2: Sulfur Dioxide;
O_3: Ozone;
THC: Total Hydrocarbon;
NMHC: Non-methane Hydrocarbon;
PM: Particulate Matter;
PAHs: Polycyclic Aromatic Hydrocarbons;
FPs: Fine Particles;
UFPs: Ultrafine Particles;
DFVs: Diesel Fueled Vehicles;
GFVs: Gasoline Fueled Vehicles;
TWC: Three-way Catalytic Converters;
WFPF: Wall Flow Particulate Filter;
SCR: Selective Catalytic Reduction;
EU: European Union;
SUVs: Sport Utility Vehicles
GHG: Green House Gas

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1. Introduction

Since 1970, transportations, in particular the combustion of gasoline and diesel in vehicles, have received increasing attention as a source of air pollution at both local and global scales.

Over 95% of motorized transport depends on petroleum and accounts for nearly 50% of world use of petroleum (Woodcock et al., 2007). For the amount of car use, in the OECD (Economic Cooperation and Development) countries, the average car ownership figures at over 450 cars per 1000 persons; and in some developed countries there are more cars per persons, This trend is still increasing in such nations as the United States (Patrick and Damon, 2008). For the past few decades, fuel consumption has been increasing rapidly. It has mainly been caused by increasing amounts of vehicle use, the growth of heavy duty fleet use, and a shift from personal passenger cars to personal light-duty trucks, vans, and SUVs (sport utility vehicles) (Sawyer et al., 2000). Nowadays, the diesel vehicles market is expanding globally. Light duty diesel vehicles with advanced direct injection engines are predicted to capture about six percent of the new light duty vehicle US market in 2030 (Energy Information Administration, 2007). In Europe, light duty diesel vehicles cover about half of the light duty market (Coelho et al., 2009).

The main kinds of vehicles we are using today are diesel cars and gasoline cars. There is an increasing trend in fuel consumption - especially gasoline and diesel ï because, today, over 90% vehicles on the road use gasoline and diesel fuels. Each kind of fuel has its benefits and weak aspects. Diesel engines of motor vehicles make a considerable contribution to both gaseous and particular air toxics in the urban atmosphere. These toxic pollutants have been associated with serious adverse health effects, including premature death, respiratory symptoms, impaired lung function and cardiovascular diseases (Karavalakis et al., 2011). For gasoline cars, the fuel produces more CO_2, CO, HC and PAHs emissions than diesel cars but it creates less PM. NO_X are caused by both diesel cars and gasoline cars (Morten, 1998). CO_2 also has large effects on the atmosphere and contributes to global warming.

This steady growth in vehicular populations will put huge environmental stress on local and global scales in various forms, particularly causing poor air quality (Suresh et al., 2009). This is due to large amount of vehicle exhaust emissions. The exhaust emissions contain a variety of toxic components, such as NO, CO, PAHs, HC and PM. Through the chemical transformation process, some compounds may cause higher concentrations of O_3, especially during the period of higher temperature. Also, some small aerosol particles (FPs and UFPs) are likely to be injurious to death during human respiration (Corsmeier et al., 2005); some compounds such as CO_2 are considered to contribute to global warming and makes a major increasing contribution to the total anthropogenic greenhouse effect (Elmar et al., 2010).

As the amount of fossil fuel decreases, some alternative fuels have already been established on the market and some of these are still in experimental forms, such as biogas and methanol. These alternative fuels can minimize the dependence on fossil fuels, and by using alternative fuels we can reduce some environmental problems, for example through use of electric vehicles which have no emissions. Overall, the world will have to rely on alternative modes of transport (various forms of public transport, walking and cycling), and, for much of the industrialized world, much-reduced levels of vehicle use as well.

This thesis focuses on the use of diesel cars and gasoline cars, because those two kinds of fuels are commonly used nowadays. There is a growing concern about the disadvantages and advantages and also the future developing trends of these two. In the below part, this work also discusses some alternative forms of fuel to diesel and gasoline, such as biodiesel and ethanol.

This thesis mainly discusses the local (human health) and global (global warming) effects of vehicle exhausts. However, there also be adverse effects on the local environment (wildlife, plants and so on) and global environment (atmosphere pollution, acid rain, eutrophication and so on), however those factors will not discussed here.

2. Aim of study

The aim of this study is mainly to compare gasoline and diesel fuels and to determine which fuel and its developed forms are less harmful to humans, and which are most suitable for the natural environment at both a local and global level. Then, I would like to put forward some suitable suggestions, which are not only to warn people that we should reduce fossil fuel use immediately and be aware of the effect of using fossil fuel, but also to select a proper kind of fuel for different area uses to minimize the effect of fossil fuel use.

3. Problem formulation

As we know that the major problems of gasoline cars are the release of CO_2, CO and the variety of HC and PAHs. The modern diesel cars are mainly concerned with the emission of NO_X and PM. Nowadays, the diesel vehicles market is expanding globally and different countries have different policies relating to the diesel cars. For instance, the United States just began to accept light duty diesel cars. In Europe, the light duty diesel vehicles have almost taken over 50% of the light duty market. According to this fact and compared to the conventional gasoline cars, does it mean that the modern light duty diesel cars will be less harmful to the environment, emit less harmful substances, have less adverse effects on human health? In the future, will the diesel fuel be more suitable for modern passenger cars or not?

4. Background

4.1 Effects of vehicle exhausts on global and local scales

We know that vehicle emissions have a variety of negative effects on public health and the environment. So if we want more in-depth understanding the impact of vehicle exhausts, we can divide this large problem into two major areas: the global scales and the local scales:

Local effects

Traffic represents one of the largest sources of primary air pollutants in urban areas. Large amount of vehicle exhaust emissions will have seriously adverse effects on human health.

Assessing the effects of air quality management strategies in urban areas is a major concern worldwide. In addition, worldwide epidemiological studies show a consistent increase in cardiac and respiratory morbidity and mortality from exposure to vehicle exhaust pollution. Both in urban and residential regions, this has become the main areas of toxic compound emissions from the unrestrained use of vehicles burning fossil fuels. In these areas, the population is very sensitive to vehicular pollution.

Global effects

On a global scale, people are more concerned about air pollution and global climate change which are contributed to by vehicle exhausts. Combustion engines contribute to greenhouse gas accumulation in the atmosphere. There are many climate researchers who support the view that emissions of heat trapping gases into the atmosphere, particularly CO_2, from the combustion of fossil fuel, cause global warming. The concentration of CO_2 are currently rising by 2 ppm (parts per million) annually (Patrick and Damon, 2008).

Transport contributed to an estimated 19% of global GHG (greenhouse gas) emissions in 1971, but rose to 25% in 2006. Reductions of CO_2 emissions from transport can be achieved by using energy saving vehicle technologies, which relies on cleanly produced biofuels, such as biodiesel and ethanol (Kockelman et al., 2009).

4.2 Emission standards

Different countries have different emission standards, like the United States, the United Kingdom, Germany and China, while the emission standard of the EU is the most commonly used standard worldwide. The vehicles exhausts emissions standard provides the limitation of vehicles exhausts which can be directly released into the atmosphere.

As the European Union (EU) Emission Standards for exhaust emissions limit the amount of new vehicles sold in EU member states (Diesel net, 2008), the EU also has very restricted standards for emission test system (ECE R49 as the old test cycle and ESC (European steady Cycle) since 2000) (Coelho et al., 2009). The EURO II, EURO III, EURO IV and EURO V emission standards are progressively more stringent and apply to all passenger vehicles that were built between January 1996 and January

2000, January 2000 and January 2005, January 2005 and September 2009, and from September 2009, respectively (Margarida et al., 2009).

According to the history of the EU standards which were adopted for new gasoline-fuelled cars in the early 1990s, (called Euro I standards) these have been gradually tightened in several steps: Euro II in 1996, Euro III in 2000 and Euro IV in 2005. In conjunction with the tightening of vehicle standards, fuel quality improvements were also introduced. In some cases, the fuel modifications are necessary to allow the introduction of vehicle technologies that are required to meet the new vehicle emissions standards (EU legislation, 1992-2009; Vehicle emission standards, 2010).

Table 1 European emission standards for passenger cars, mg/km (EU legislation, 1992-2009)

Tier	Date	CO	THC	NMHC	NO_X	$HC+NO_X$	PM
Gasoline (Gasoline)							
Euro I	July 1992	2720	-	-	-	970	-
Euro II	January 1996	2200	-	-	-	500	-
Euro III	January 2000	2300	200	-	150	-	-
Euro IV	January 2005	1000	100	-	80	-	-
Euro V	September 2009	1000	100	68	60	-	5
EuroVI (future)	September 2014	1000	100	68	60	-	5
Diesel							
Euro I	July 1992	2720	-	-	-	970	140
Euro II	January 1996	1000	-	-	-	700	80
Euro III	January 2000	640	-	-	500	560	50
Euro IV	January 2005	500	-	-	250	300	25
Euro V	September 2009	500	-	-	180	230	5
EuroVI (future)	September 2014	500	-	-	80	170	2.5

EU vehicle emission standards became effective and required further reductions in the tailpipe emissions of carbon monoxide (53%), hydrocarbons (67%), and nitrogen oxides (68%) relative to the Euro I Standard that became effective in 1992. This also required catalytic converters on all cars (Department for Transport, 2003). The Euro IV Standard that became effective on January 1, 2006 required further tailpipe

emissions reductions (relative to Euro III) in carbon monoxide (43%), hydrocarbons (33%), and nitrogen oxides (50%).

The EU also sets standards for fuel composition to require successively cleaner fuels. Thus, the EU seeks to reduce transport related air pollution not only by requiring cleaner and more efficient engines and catalytic converters but also by requiring cleaner fuels.

4.3 Automotive fuels

4.3.1 Traditional fuels

A huge amount of energy is used for passenger travel and cargo transport in modern and mobile societies. The energy used by human transport is about 25% of total energy consumption. With regards to transportation energy, 95% of energy is produced by petroleum (Zecca & Chiari, 2010). Different petroleum products are created from different distillation processes. Different products are obtained and recovered at different temperatures when the distillation unit heats the crude oil; at the lowest temperature, the lighter products are obtained like LPG, Naphtha and gasoline; at the middle temperature, aviation gasoline, kerosene and gas/diesel oil are generated; at higher temperatures, heavier products are recovered such as fuel oil (OECD, 2004).

Table 2 Typical petroleum Products and Calorific Values (OECD, 2004)

Product	Density (kg/m^3)	Liters per ton	Net-calorific value (GJ/T)
Ethane	366.3	2730	47.51
Propane	507.6	1970	46.33
Butane	572.7	1746	45.72
LPG(1)	522.2	1915	46.15
Naphtha	690.6	1448	45.34
Aviation gasoline	716.8	1395	45.03
Motor gasoline(2)	740.7	1350	44.75
Aviation turbine fuel	802.6	1246	43.92
Gas/diesel oil	843.9	1185	43.38
Fuel oil, low ï sulfur	925.1	1081	42.18
Fuel oil, high ï sulfur	963.4	1038	41.57

(1) Assumes a mixture of 70% propane and 30% butane by mass.

(2) An average for motor gasoline octane number is between 91 and 95.

The common petroleum forms used today are gasoline and diesel as shown below:

- Gasoline

Gasoline is primarily used as a fuel in internal combustion engines. This kind of fuel is a liquid mixture made from petroleum. The main compositions of gasoline are hydrocarbons which are generated by the distillation of petroleum, such as aromatic, alkenes and aliphatic HC. In order to increase its octane rating, the MTBE (methyl-tertiary-butyl ether; $(CH_3)_3COCH_3$) and Ethanol (C_2H_5OH) are added in.

Common gasoline consists of hydrocarbons with between four and twelve carbon atoms per molecule (C_4-C_{12}) (US EPA, 2008).

Commercial gasoline is a complex blend of many hydrocarbons and oxygen containing compounds which are mixed to provide combustion characteristics compatible with the engines in which the gasoline is burned. The most important characteristics affecting combustion are vapor pressure and octane number. These and other parameters, such as aromatic, olefin, sulfur, and additive content and distillation temperatures affect emissions (Sawyer et al., 2000). Since the 1920s, tetra-ethyl lead ($Pb(CH_3CH_2)_4$) has been used as an additives in gasoline fuel, it can modify the knocking behavior from gasoline engine. However, at present in the most worldwide countries nearly all gasoline consumed is unleaded.

- Diesel

In a diesel engine, diesel fuel is used as energy source. Generally, diesel consist of saturated hydrocarbons (mainly paraffin including n-, iso-, and cyclo-paraffins), 1-2% olefin hydrocarbons and 25-35% aromatic hydrocarbons (including naphthalene and alkyl benzenes). The components of diesel fuel range from $C_{10}H_{20}$ to $C_{15}H_{28}$, though the average chemical formula of common diesel fuel is $C_{12}H_{23}$. The primary advantage of diesel fuel is better fuel economy and less CO_2 emission compared to gasoline fuelled cars. However, diesel fuel also has many disadvantages, such as the higher cost of the engines, poor acceleration, noise and more NO_X and PM emissions compared to gasoline cars.

Normally, diesel emissions standards are the same as those of gasoline vehicles. Diesel cars are required to meet some specific PM emission standards, whereas gasoline vehicles are usually not required to, because gasoline cars have comparatively low levels of PM emissions (Sawyer et al., 2000).

Current diesel cars have improved a lot for NO_X and PM control, through processes such as the design of new diesel combustion engine, the ability to operate at lower speeds, the use of higher fuel injection pressures, the use of fuel injection rate shaping, electronic controls for improved timing, and use of turbo-chargers with waste gases (Sawyer et al., 2000).

4.3.2 Alternative fuel

In considering efficiency and environment, some fuels are considered as alternative transportation fuels, such as alcohols, gaseous fuels, renewable fuels, and electricity. Many alternative fuels have the potential to reduce the emissions of toxic chemicals, greenhouse gases and other pollutants. Compared with traditional fuels, some alternative fuels are similar to traditional ones, and with little or no modification they can be used in conventional vehicles. So here we mainly discuss the uses of biodiesel and ethanol.

- Biodiesel

Biodiesel is produced from plant oils (soybean oil, cottonseed oil, canola oil), recycled cooking greases or oils (yellow grease), or animal fats (beef tallow, pork lard) (NREL, 2009). The advantages of biodiesel are as follows (NREL, 2009):

- It displaces petroleum - derived diesel fuel.
- It can be used as a 20% blend in most diesel equipment with no or only minor modifications.
- Biodiesel is biodegradable (Sun et al., 2010);
- It can reduce global warming gas emissions by 41% compared with diesel (Hill et al, 2006).
- It has potential to reduce tailpipe emissions and may be more suitable for sensitive environments.

The most outstanding advantage of biodiesel is that it is quite similar to conventional diesel fuel. Therefore, it can be used directly in common diesel engines (Brent, 2005).

Biodiesel still has disadvantages, according to the EPAôs (Environmental Protect Agency) review, the NO_X emissions tend to increase with the use of B20 (conventional diesel with 20% biodiesel) by 2% compared to petroleum diesel use. Biodiesel can be used in existing diesel engines with few or no engine modifications. Using B20 or higher concentrations B100 has potential to reduce the emission of common exhaust compounds (NREL, 2009). However, it also has potential to increase certain toxic compounds such as aldehydes and ketones (Karavalakis et al., 2011).

- Ethanol

Ethanol (ethyl alcohol) is a kind of alcohol generated by fermenting simple sugars. Ethanol is a renewable fuel which is made from various plant materials which are usually called "biomass". The chemical formula of ethanol is C_2H_5OH (EERE, 2010).

Nowadays, ethanol is commonly used as an additive in gasoline; it has potential to reduce some of exhaust emissions, such as CO_2. Ethanol in its pure form can also be used as an alternative to gasoline. It is often mixed with gasoline at a ratio of 85% ethanol (E85) (Brent, 2005).

Overall, the cost per kilometers for ethanol is comparable to gasoline, but cars need higher amount of ethanol fuel per kilometer compared with the need of conventional gasoline fuel. The use and storage of E85 will also lead to the emission of regulated pollutants, and GHGs. The emissions are mainly released by fuel evaporation and combustion from vehicles (Boyce, 2010). Use of ethanol as addition to gasoline fuel can reduce GHGs emissions by 12% compared with conventional gasoline (Hill et al, 2006).

- Other alternative fuels
  - Propane (LPG)

LPG (liquefied petroleum gas) is usually derived from fossil fuel sources. LPG consists of propane (C_3H_8), propylene (C_3H_6), butane (C_4H_{10}), and butylene (C_4H_8). The components of LPG are gases at normal temperature and pressure, so the mixture must be liquefied for use in vehicles (Brent, 2005). Nowadays, LPG plays a greater role in fuel supply, because it is available commercially, which most alternatives is not (Johnson, 2003)

  - Natural Gas

Natural gas is a product of petroleum production and a fossil fuel gas. It consists of hydrocarbons; mainly methane (CH_4), but it also contains amounts of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}) and pentane (C_5H_{12}) (Brent, 2005). Natural gas is one of the most promising alternative fuel (Cho & He, 2007). CO_2 emissions of natural gas can be reduced by 20% compared with gasoline. There is also less PM emission than diesel, because natural gas does not contain aromatic compounds such as benzene (C_6H_6) (Cho & He, 2007).

  - Methanol

Methanol, the simplest alcohol, it is usually derived from natural gas, but can also be derived from coal or biomass. As a fuel, methanol is most often used as a blend with gasoline called M85 (85% methanol, 15% gasoline). The fuel can, however, also be used in an almost pure form called M100 (Brent, 2005).

  - Electricity

An electric vehicle is powered by an electric motor, as opposed to an internal combustion engine. Energy is supplied to the motor by a set of rechargeable batteries. Because no fuel is burned, there are no emissions from the vehicle, making it a zero emissions vehicle. However, there are emissions from electricity production associated with electric vehicles (Brent, 2007).

  - Hybrid Electric Vehicle

A type of vehicle that can address some of the problems associated with electric vehicles is a hybrid electric vehicle. It combines an electric motor and battery pack with an internal combustion engine to improve efficiency. The efficiency of the hybrid drive system allows a significant increase in fuel economy compared to conventional vehicles, cutting fuel costs (Brent, 2007).

4.4 Exhausts treatment devices

4.4.1 Catalytic converters for gasoline exhaust

Catalytic converters are widely used to reduce the vehicle emissions from the combustion engines, and are usually placed in the vehicle exhaust pipe. Since 1981, three-way catalytic (TWC) converters have been used in gasoline vehicle emission

control systems. Today, almost all of new cars sold in worldwide scales are fitted with catalytic converters.

The main task of the TWC is to convert the harmful compounds, those toxic compounds contained in the exhausts. There are many precious metals used in TWC, such as metals of the platinum group and so on. TWC use oxidation catalysts (Pt/Pd) to control HC and CO emissions and combined with an upstream Pt/Rh catalyst to control NO_X emissions at the same time. Because of those three exhaust pollutants were treated within one catalyst, so this kind of catalyst was christened the ñthree way catalystò (Twigg, 2011).

The three catalysis processes are described in the list below (Reduction in emissions with Catalytic Converters, 2009):

- Reduction of NO_X to O_2 and N_2: 2NOx Ÿ $xO_2 + N_{2;}$
- Oxidation of CO to CO_2: $2CO + O_2$ Ÿ $2CO_{2;}$
- Oxidation of unburned hydrocarbons (HCs) to CO_2 and H_2O:
  $C_X H_{(2X+2)} + [(3x+1)/2] O_2$ Ÿ $xCO_2 + (x+1) H_2O$.

A gasoline operated car (with TWC) converts over 90% of HCs, CO and NO_X from the engine into less harmful CO_2, N_2 and H_2O (Hromadko et al., 2010). The key factors of catalysis processes were to control the ratio of air and gasoline fuel at the point of 14.6 (±0.05). The stoichiometric point can be measured by a gasoline engine closed loop control microprocessor (Farrauto and Heck, 1999; Twigg, 2011).

4.4.2 Catalytic converters for diesel exhaust

Today, over 50% of all new European light duty vehicles operate by use of diesel fuel. The technical development requires more effective exhaust after-treatment devices for modern diesel cars. However, the use of TWC to heavy duty diesel engines has not been possible, because the excess air used during diesel fuel combustion. It is not possible to reduce NO_X in presence of excess air (Sawyer et al., 2000).

Before 1993, only the fitting of Pt monolithic oxidation catalyst has been used in diesel cars, it removed the odour of diesel exhaust and controlled the HC and CO emissions. This kind of traditional Pt based oxidation catalysts have faced a major challenge with the lower temperatures of diesel exhaust compared to their gasoline counterparts. Today, the introduction of zeolites into the catalyst has greatly improved the conversion process at low exhaust temperature. With zeolite, the efficacy of conversion rate of oxidation catalysts converters was increased over 30% during low temperature conditions (around 120℃, Cold start) (Twigg, 2011).

Considering the PM emission of diesel car exhausts, the most successful and commonly used particulate filter is Porous Ceramic WFPF (Wall Flow Particulate

Filter). Its application has introduced the process of filter regeneration. This process means re-burning / re-oxidizing the PM in particulate filters.

Available information indicates that using the diesel WFPF can effectively reduce diesel PM emissions over 90%. This high efficiency was measured for all sizes of PM, including fine and ultrafine PM (range from 0.023εm to 2.5εm) (Kumar et al,2010; Bergmann et al., 2009).

At present, there are two possible catalytic control treatment methods for diesel cars NO_X emissions. These are the NO_X trapping and the SCR (selective catalytic reduction). The NO_X trapping is commonly used in modern diesel cars, it converts the NO_X to N_2 by an alkaline Pt based catalyst process (Twigg, 2011). The most common and that being actually used on heavy duty diesel cars is NH_3 selective catalytic reduction for NO_X abatement from diesel exhausts. Currently the majority of European heavy duty diesel vehicles equipped the commercialize SCR able to meet Euro IV and Euro V emission standards (Ciardelli et al., 2007), however the NO_X emissions still higher than gasoline exhausts.

5. Methods

5.1 Literature Selection criteria

The articles included in the present review were those describing:

- The review and original articles of gasoline and diesel fuels exhaust emissions;
- The emission control methods of gasoline and diesel exhausts;
- The health effects of toxic compounds found in vehicle exhaust, especially those generated by burning gasoline and diesel fuels.
- The number of contaminants in gasoline and diesel exhaust emissions.

Numerous publications covering other issues related to fossil fuels emissions and air pollution were not included, and only articles written in English were included.

5.2 Selection process

The main method I used is searching for the relevant literature, a total of 149 articles published between 1976 and 2011 were initially selected from databases and only 48 articles uses as references. By comparing those scientific articles, I obtained the relevant data and arguments to support my thesis more scientifically and comprehensively.

The databases I searched: ISI (web of science), Science Direct and the reports from energy or environmental agencies (organizations) of U.S.A and EU especially the USEPA; Energy Efficiency & Renewable Energy (EERE); Energy Information Administration (EIA); diesel technology forum and so on.

The keywords I used: transport fuels; diesel; gasoline; vehicle exhausts; global and local effect; exhaust emissions effect; alternative fuels; human health effects; biodiesel; ethanol etc.

The process of searching articles from databases:

- Searched the relevant keywords at databases and the keyword of review was used to limit the searching results.
- Carefully read those review articles (and original articles), then found the most interesting and relevant references.
- Searched the databases again with the new references as keywords or relative information.
- Collected the most relevant arguments and data from the figures and tables of present articles and gave my own comments of that information.

6. Result

6.1 Adverse effects of vehicle exhaust generated by burning of gasoline and diesel fuels

Before describing the individual exhaust components, we should know what is emitted by burning the fossil fuels, especially diesel and gasoline fuels. According to a report from the car industries (Volkswagen and Audi), N_2, CO_2, H_2O and O_2, are the major components of vehicle exhaust emissions (Motor Vehicle Exhaust Emissions, 2005). The toxic exhaust components, the terms which used repeatedly are: CO, NO_X, SO_2, O_3, heavy metals, HC and Diesel PM. These pollutants have very serious and irreversible impacts on both human health and the environment in which we live (Amer, 2007). The pollutants with various human health effects were highlighted in the table 3 below.

Table 3 Key pollutants and their effects on human health (Colin and Michael, 2005; Amer, 2007)

Name of pollutant	Symbol	Effects on human health
Carbon monoxide	CO	Have great effect on the oxygen delivery to the bodyôs organs and tissues, and may cause death.
Nitrogen dioxides	NO_X	Linked to a wide range of respiratory problems; cough and sore throat.
Ozone	O_3	Can cause chest pain, coughing and shortness of breath.
Heavy metals	e.g. Pb	Exposure will lead to irreversible damage to brain and in some cases, also lead to premature deaths.
Particulate matter	PM	Acute exposure will cause death, increased respiratory symptoms, decreased lung function, and pulmonary inflammation. Chronic exposure will increased mortality

		rates, chronic cardiopulmonary disease, and reduce lung function.
Hydrocarbons	HC	HC, NO_X and sunlight can generate the photochemical smog. Some hydrocarbon compounds caused irritation to eye and damage lungs such as benzene (C_6H_6). At high concentration it causes asthma and death.
Polycyclic aromatic hydrocarbons	PAHs	mutagenic and carcinogenic.

6.1.1 Carbon monoxide (CO)

Carbon monoxide is produced when a fuel does not burn completely. The United States environmental protection agency has estimated as much as 95% of carbon monoxide comes from vehicles. A high level of carbon monoxide is harmful to human health, because CO has great effect on the oxygen delivery to the bodyôs organs (e.g. heart and brain) and tissues (e.g. skin). Normally CO will cause headaches and even visual impairment. At comparatively high levels, CO can directly cause death, especially to people with heart diseases (Motor Vehicle Exhaust Emissions, 2005; HEI 2010; US EPA, 2006).

6.1.2 Hydrocarbons (HC)

Hydrocarbons are produced from incomplete fuel combustion and from the evaporation of fuels. HC is an essential part of photochemical smog, and HC is considered as a serious air pollutant especially in urban areas. Surroundings with a comparatively high level of HC may cause cancer, and some HC also can cause harmful effects on tissues and the human immune system, such as benzene (C_6H_6) (Motor Vehicle Exhaust Emissions, 2005; HEI 2010; US EPA, 2006). Modern vehicles with catalytic converters will help to reduce the HC emissions, however, HC emissions are still as a major problem of vehicle exhausts.

6.1.3 Nitrogen oxides (NO_X)

Nitrogen oxides (NO, NO_2, N_2O etc.) are the compounds of N_2 and O_2. NO_X is produced when fuels burn at high temperatures, high pressures and excess oxygen in the engine combustion chamber. Almost half of NO_X emissions are caused by vehicles utilizing spark and compression ignition engines burning gasoline and diesel respectively. Diesel vehicles are the dominant exhaust source of NO_X (Sawyer et al., 2000). NO_X causes O_3 and smog which can travel long distances and causing all kinds of health and environmental problems. Therefore, O_3 control strategies require that we pay more attention to reducing NO_X from diesel vehicle sources (Sawyer et al., 2000). There are a lot of adverse health effects associated with NO_X such as an increase in total mortality, cardiovascular deaths, and infant mortality (Colvile et al., 2001). NO_X reacts with ammonia and other compounds to form small particles. These small

particles worsen respiratory diseases, such as emphysema and bronchitis (US EPA, 2006). NO_2 is more harmful than NO, especially considering the potential of toxicity and ozone effects. Short term NO_2 exposure, ranging from 0.5 to 24 hours, will cause many adverse respiratory effects including respiratory passage inflammation in healthy people. Also NO_2 may increase respiratory symptoms in people with asthma (Motor Vehicle Exhaust Emissions, 2005; HEI 2010).

6.1.4 Particulate matter (PM)

The commonly found PM is coarse particles with a size around of 10 µm (PM_{10}). The coarse particle is the major part of PM and it can be easily found in mineral dust. Moreover, it is also important to measure the FPs (fine particles) with the size below 2.5µm ($PM_{2.5}$) and UFPs (ultrafine particles) with size of 0.1µm ($PM_{0.1}$). FPs are often produced from fuel combustion especially in the diesel exhaust emissions. Table 4 shows an example of comparison of fine and coarse particles (WHO, 2006). PM can travel long distances and has great health impact on human health, such as asthma, chronic bronchitis and difficult painful breathing. The epidemiological studies have shown that FPs are responsible for and/or aggravating respiratory problems such as asthma (Johnson, 2003). FPs and UFPs will cause the greatest problems, because they can get deep into peopleôs lungs, and the UFPs (0.1µm) may get into the bloodstream as well. Exposure to such kinds of particles can affect both lungs and heart functions (Jes, 2009).

Table 4 comparison of fine and coarse mode particles (WHO, 2006)

	Fine (< 2.5µm)		Coarse (2.5µm-10µm)
	Ultrafine (< 0.1µm)	Accumulation (0.1µm - 1µm)	
Formation process	Combustion, high temperature process and atmospheric reactions		Break up of large solids.
Sources	Combustion; Atmospheric transformation of SO_2 and organic compounds; High temperature process.	Combustion of gasoline fuels, diesel fuels, coal, oil, wood; Atmospheric transformation products of NO_X, SO_2 and organic carbon; High temperature process.	Industrial dust; Construction and demolition; Uncontrolled coal and oil combustion.
Atmospheric half	Minutes to hours	Days to weeks	Minutes to days

life			
Travel distance	Less than 10km	100 to 1,000 km	Less than 100 km

EPA (environmental protect agency) estimated the main health effects of particle pollutions which include:

- Increased respiratory symptoms, such as irritation of the respiratory passages, coughing, or difficulty breathing;
- Decreased lung function;
- Aggravated asthma;
- Development of chronic bronchitis;
- Heart attacks;
- Premature death in people with heart or lung disease.

Children and older people, especially people with heart or lung diseases are more likely to be affected by particle pollution (US EPA, 2006).

6.1.5 Polycyclic aromatic hydrocarbons (PAHs)

PAHs were known as poly-aromatic or poly-nuclear aromatic hydrocarbons, it commonly occurs in crude oil and other fossil fuels. The vehicle exhausts contained a lot of PAHs compounds, some of those compounds have been identified as mutagenic and carcinogenic, such as anthracene, fluorene, phenanthrene, and their benzo compounds. Exposure to PAHs is associated with many human health problems, like heart disease, reducing the lung functions, and may cause asthma and cancer (US EPA, 2006).

6.1.6 Ozone (O_3)

O_3 is formed when NO_X and volatile organic compounds react in the presence of heat and sunlight. Children, older people, people with lung diseases such as asthma, and people who work or exercise outside are at risk of adverse effects from O_3. These include reduction in lung function, increased respiratory symptoms, and possibly premature deaths (US EPA, 2006).

6.1.7 Heavy metals

For heavy metals, there is much concern about Pb, because tetra-ethyl lead has been used as an anti-knock additive, mixed with conventional gasoline fuels. Leaded gasoline exhaust with microscopic Pb particles not only infects the air we breathe, but also be responsible for adding the Pb content to the environment. In addition, the Pb in the atmosphere will contaminate water and soil, even drinking water and food. Once Pb comes into human body, it will distribute throughout the body and accumulate in the bones. Pb can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system and Pb also affects the oxygen carrying capacity of blood (US EPA, 2006).

Johansson et al., (2009) reported that there was a significantly decreasing trend of the air concentration of Pb with 9.1ng/m^3 in 1995-1996 compared to 3.4ng/m^3 2003-2004 in urban areas (Johansson et al., 2009). This is likely due to the improvement quality of fuels (unleaded gasoline fuels). The introduction of catalytic converters to control the exhausts from gasoline cars also required to removal of lead from the fuel. Today, only a few developing countries still use leaded gasoline fuels, such as Afghanistan, Iraq, Jordan, Mongolia, North Korea, Serbia, Yemen and so on (HEI, 2010).

6.1.8 Carbon dioxide (CO_2)

CO_2 is the most important greenhouse gas. It is mainly produced by the combustion of fossil fuels. The discussions about global warming and CO_2 effect have increased peopleôs awareness on the subject of CO_2 emissions. As a GHG, CO_2 absorbs the emitted heat, and heats in the atmosphere, causing widespread climate change. After industrial revolution, the concentration of CO_2 in the world has risen by over 30% (Motor Vehicle Exhaust Emissions, 2005; HEI 2010). In 2005, the transport contributed to 25% of all the world anthropogenic CO_2 emissions released into the atmosphere. Approximately 80% of those emissions are from road transport, of which 60% is from automobiles, SUVs and pick-up trucks (Silva et al., 2009).

6.2 How much exhausts are emitted by burning gasoline and diesel fuels?

There is an old review article by Stupfel (1976), In the report it mentions that there is an immense complexity of vehicle exhaust emissions due to the different fuel compositions, different engines (gasoline and diesel) and different operating conditions. Table 5 is the list of the automotive exhaust levels of common toxic components.

Table 5 Summary of automotive exhaust levels (Stupfel, 1976)

Gases and particles	Gasoline exhaust	Diesel exhaust
Regulated emissions (mg/m^3)		
Oxygen,%	1-14	1-20
Nitrogen, %	76-90	
Carbon dioxide%	5-15	1-14
Carbon monoxide%	2-6%	0-0.1%
NO_X	60-8000	60-4000
NO_2 (ε g/m^3)		0.94-75.2
SO_2 (ε g/m^3)	0-212	265-795

Lead	70-80% of the lead in gasoline	0
Particles	0.2-3 mg/g of burned gasoline	150-450

From an analysis of the above table 5 we can draw a conclusion that because of after-treatment devices were not been used in 1976, the toxic components from gasoline and diesel cars exhausts reached high levels, especially the Pb emissions in gasoline exhausts and the PM emissions in diesel exhausts. In early 1970, tetra-ethyl Pb was used as an octane enhancer in gasoline fuels (Poulopoulos & Philippopoulos, 2000). The most frequently used oxygenate additives in gasoline today are MTBE and ethanol, and pure ethanol also can be used as fuel. Within the last three decades the use of catalytic converters and diesel particle filters has led to a significant reduction in toxic components and PM emissions (Vouitsis et al., 2009). At present, there are more and more restricted standards for vehicle exhaust emissions than 30 years ago. Although this review is quite outdated, and it would be interesting to compare with newer data, but unfortunately it has not been possible to find an update data.

Recently, Bergvall and Westerholm, (2009) determined the exhausts from different vehicles:

- Two diesel fueled vehicles (DFVs): D1 (Opel Astra KO 1.7 CDTI C), D2 (Skoda Octavia EL 1.9 TDI); they followed the Euro IV standards;
- Two gasoline fueled vehicles (GFVs): G1 (Audi A2 1.4), G2 (SAAB 9-3 SE 5D 2.0T M1); G1 and G2 followed the Euro III and II emission standards, respectively;
- Those vehicles were operated in: the Urban (AU), Rural Road (AR) and Motorway (AM) following ARTEMIS driving cycles;
- The fuels followed Swedish Environmental Class 1 (MK1) quality and were obtained from local fuel stations (Bergvall and Westerholm, 2009).

The results of regulated exhaust emissions, CO_2 emissions and fuel consumptions are shown as table 6.

Table 6 the comparison of regulated exhaust emissions, CO_2 emissions and fuel consumption of two GFVs and two DFVs (Bergvall and Westerholm, 2009)

Vehicle	G1 AU	G2 AU	D1 AU	D2 AU	G1 AR	G2 AR	D1 AR	D2 AR	G1 AM	G2 AM	D1 AM	D2 AM
Regulated emissions (mg / km)												
CO	12	660	26	5	209	155	1	2	6058	466	5	13
HC	34	29	7	14	17	8	3	5	139	14	2	8
NO_X	28	52	765	624	15	119	466	329	10	135	800	612
Particulates	1.9	1.6	28	69	3.0	3.3	12	43	15	22	19	44
PAHs concentrations (ng/mg)	124	197	26	31	936	966	19	19	305	354	13	11
CO_2 (g / km)	209	322	190	221	133	178	110	119	191	230	137	154

Fuel consumption (L / 100km)	8.5	13.7	7.4	8.6	5.6	7.6	4.2	4.6	8.5	9.8	5.3	6.0

From table 6 we can draw the conclusion that the GFVs emit around ten times higher amount of CO and PAHs, and around five times higher amount of HC than the DFVs on the both urban roads, rural roads and motorways (except for G1 in the motorway driving cycle). On the contrary, the DFVs emit around ten times higher NO_X and PM than GFVs on the both urban roads, rural roads and motorways. In addition, GFVs emit around 50% more CO_2 than DFVs on the both urban roads, rural roads and motorways, and GFVs consume more fuels than DFVs.

US EPA report indicates that due to the use of after-treatment devices (particle filter and oxidative catalytic converter) and the introduction of more restricted emission standards, the regulate pollutions from the diesel vehicles have been clearly reduced within last three decades. Nevertheless, the changes of diesel NO_X emissions were relatively small. The engine deterioration is a possible reason for the constancy of diesel NO_X emissions, it will causes higher diesel PM and NO_X emissions.

At present, modern diesel cars with particle filter and oxidative catalytic converter will effectively limit diesel smog emissions, and a better fuel injector rate may effectively decrease the NO_X emissions as well (US EPA, 2002). In order to get higher diesel fuel efficiency, modern diesel engines are required to a higher pressure, higher temperature and extra air conditions, however, these factors will lead to a rise in NO_X emissions. Because of NO_X are produced by the conditions of a higher pressure, higher temperature and excess O_2. Therefore, a more effective combustion process will generate a higher pressure, higher temperature and extra oxygen engine operating conditions; those factors will cause more NO_X emissions (Motor Vehicle Exhaust Emissions, 2005).

Vouitsis et al., (2009) estimated the PM emissions by testing two Euro IV vehicles:

- The diesel car was equipped with an oxidation pre catalyst and a oxidation catalyst;
- Test the same diesel car by replacing the catalyst with a silicon carbide catalyzed diesel particle filter;
- The gasoline car was equipped with TWC (Vouitsis et al., 2009).

Results list as table 7.

Table 7 PM emission rate over the different vehicles (Vouitsis et al., 2009)

Different type of vehicles with different after-treatment devices	PM emissions (mg/km)
Diesel with oxidation catalyst	30-35
Diesel with particle filter (silicon carbide)	3-5
Gasoline car with TWC	1-3

From table 7 we can draw the conclusions that diesel cars with a silicon carbide catalyzed particle filter can effectively reduce the PM emission rates around seven times compared to diesel cars with an oxidative catalyst converter. Gasoline cars with TWC converter can effectively control the PM emission rate around 1 mg/km. As expected, the PM emissions of the gasoline car were lower than the diesel car with a particle filter, in the range of 1-3 mg/km.

Todayôs diesel technologies have made the diesel engines cleaner than ever before. Clean diesel systems have combined with more advanced engine technologies:

- Turbocharging: through a turbine wheel forcing more and more extra air into the diesel engine combustion cylinder, increasing the engine performance;
- Fuel injection time control: using an electronic fuel injection time controller to give the accurate amount of fuel at the time of highest engine compression rate, increasing the fuel efficiency.
- Better configuration of diesel engine combustion chamber: a better engine configuration will supply the better and accurate space of combustion chamber, and let the fuel burn more effectively at the right fuel and air mix rate.

Clean diesel systems have combined with more effective exhaust after-treatment devices:

- WFPF: wall-flow diesel particulate filter has the relatively highest efficiency of PM reduction. The use of WFPF can effectively reduce over 90% of PM emissions.
- NO_X trapping system: is a catalyst technology for reducing the NO_X concentration in diesel vehicle exhaust emissions.
- Oxidation catalyst converter: the use of oxidation catalyst converter in diesel vehicles can effectively reduce the odour of diesel exhaust and remove the HC and CO emissions.

Those new diesel engine and after-treatment devices technology might be able to supply the better efficiency of diesel fuel burning and less toxic exhaust components emissions.

From table 8 we also can see that the gasoline car equipped with catalytic converters has significantly reduced the exhaust emissions. Compared to non-catalyst converter gasoline vehicles, the use of a TWC converter can effectively reduce the CO, NO_X, HC and O_3 by a factor of six, four, five and ten times, respectively.

Table 8 the emissions of CO, NO_X, HC and O_3 in gasoline exhaust from vehicles without catalysts, with oxidative catalyst and three-way catalytic converter (Schifter et al., 2011a).

Gasoline exhaust	No catalyst	Oxidative catalyst	Three-way catalytic converter
Regulated emissions (mg / km)			
CO	1800	1300	300

NO_X	3.46	2.16	0.82
HC	1560	700	220
Ozone	4190	3950	312

Considering the diesel fuel exhaust emissions, NO_X and PM are the two major problems. CO_2, CO, and HC of diesel fuel exhaust emissions are much lower than gasoline counterparts. Due to the higher fuel economy and less the emissions, diesel vehicles take a more and more important role in world automobile market, especially in Europe. That is also why European countries have introduced increasing strict diesel emission standards. These standards also required the use of fatty acid methyl esters (e.g. biodiesel) as substitutes of conventional diesel fuels.

Nowadays, many countries have legislations that require and/or encourages the use of alternative fuels, and there is no doubt that ethanol is the most important one of those alternative fuels. Also the most commonly application of ethanol is used as gasoline additive to suppress the engine knocking problem. In Europe many countries supply the E85 (85% anhydride ethanol, 15% gasoline) gasoline blend fuels (Garcia et al., 2010). From the research by Schifter et al. (2011b), we can draw the conclusion that the increase of ethanol content in conventional gasoline fuels will help to reduce the CO and HC emissions, but it also will increase the NO_X emissions as well. The highest reduction in emissions is 52% and 19% for CO and HC respectively, with a corresponding increase of 60% in NO_X emissions. There are possible reasons for NO_X increasing, that is the higher exhaust temperatures. Using the ethanol blended gasoline fuels in a conventional gasoline engine will cause elevated exhaust temperatures (Schifter et al., 2011b). Using ethanol as a fuel also produced more O_3 than conventional gasoline, because burning ethanol blend fuels may generate more NO_X emissions compared with conventional gasoline fuels (Ginnebaugh et al, 2011).

Karavalakis et al. (2009) measured and compared the regulated emissions and fuel consumption of conventional diesel fuel and biodiesel fuels. They estimated that the conventional diesel fuels blend with biodiesel has shown a tendency for lower HC, CO and PM emissions. However, the fuel consumption will increase around 10% and NO_X emissions might be increase when operated by conventional diesel fuels blend with biodiesel (Karavalakis et al., 2009). Those conclusions about the decrease of CO PM and HC emissions and the tendency of increase of NO_X were also can be found in a US EPA report, shown as table 9.

Table 9 Emission impacts of B20 (20% biodiesel + 80% convertional diesel) (US EPA, 2002)

Contaminants	Emission changes in percentage
NO_X	+2.0%
CO	-11.0%
PM	-10.1%
HC	-21.1%

7. Discussions and conclusions

Diesel cars have higher energy efficiency and produce better performance than gasoline cars. Diesel cars emit about 2/3 amount of CO_2 compared to gasoline cars; a higher proportion of diesel cars will help to reduce the global warming effects. Today diesel exhaust treatment devices have improved substantially compared to 30-years ago, and we also have increasing stricter emission standards, which are forcing diesel and gasoline to meet the same emission levels. Nonetheless, modern diesel cars still emit about ten times higher NO_X and PM compared to gasoline cars.

Gasoline cars are expected to emit less NO_X and PM compared with diesel cars. A higher proportion of gasoline cars may help to minimize the human health effects However, when we takes more consideration on global warming and climate changes, gasoline cars seems have no advantages anymore, because gasoline cars emit 50% more CO_2 than diesel cars. In addition, gasoline cars emit about ten times more CO, PAHs and five times more HC than diesel cars.

Today, the use of a TWC converter with gasoline engines can effectively reduce the CO, NO_X, HC and O_3 by a factor of six, four, five and ten times, respectively (Schifteret al., 2011a); the use of a diesel WFPF can effectively reduce over 90% of diesel PM emissions; this quite high efficiency was determined for all dimensions of PM emissions, which include fine and ultrafine PM (range from 0.023εm to 2.5εm) (Kumar et al,2010; Bergmann et al., 2009).

Todayôs diesel technologies have made the diesel engines cleaner than ever before. Clean diesel systems have combined with more advanced engines (turbocharging system, fuel injection time control and better configuration of diesel combustion), more effective exhaust after treatment devices (oxidation catalyst converter, wall flow particulate filter and NO_X trapping system) and clean diesel fuels (biodiesel). Clean diesel system might be able to supply the better efficiency of fuel burning and less GHG emissions than conventional diesel.

In the future, diesel cars may play an important role in reducing the global warming effects and the dependency on fossil fuels. It might be that the diesel hybrid electric car is the best choice, because it may provide the highest fuel efficiency and the greatest reduction in GHG emissions. However, the greatest challenge is whether modern diesel cars can meet the same level of toxic emissions (NO_X and UFPs) as todayôs gasoline cars.

There are some suggestions for car use:

- In urban areas, using a gasoline car will be better than diesel cars, because gasoline vehicles emit less PM and less NO_X, which are harmful to human beings;
- When we have a long distance travel, on motorways or rural areas, using a diesel car will be a better choice because diesel vehicles emit less CO_2 and may slow down the global warming rate.

Use of biodiesel may reduce GHG emissions by over 40% compared to the conventional diesel. Also, it has the potential to reduce other exhaust contaminants such as CO, HC and PM. Consequently, the use of biodiesel instead of conventional diesel will help to reduce the exhaust effects on human and environmental health. Nonetheless, there are no very big differences between the biodiesel blends and conventional diesel. Also, there are still many debatable issues around biodiesel, such as insufficient fuel supply and health concerns (especially, UFPs) (Kumar et al, 2010).

Use of ethanol has less potential to reduce the GHG emissions compared with biodiesel. However, burning ethanol will increase the NO_X emission by over 60%. Therefore, burning ethanol will increase the O_3 level as well. As such, ethanol has more adverse effects on human and environmental health.

When we talk about the CO_2 emissions from biofuels, we should be aware that the CO_2 emissions from the biofuels are not the exactly new CO_2. This CO_2 is harvested from the biomass (plants). This is a CO_2 recycling process, and therefore there is no change in total atmosphere CO_2 concentrations. However, burning fossil fuels obviously add the new CO_2 to atmosphere. So, the biofuels, biodiesel and ethanol, have the potential to reduce the CO_2 emissions compared to conventional diesel and gasoline fuels.

In times of the expansion of food and energy demand, there is a great need for some clean energy sources, which will not harm the environmental and human health. Biofuels (ethanol and biodiesel) are made from agricultural products. So, the production of biofuels might effect on food supply and the price of food. Therefore, in the future, the biofuels which are produced from residues have great potential to provide for the demands for energy, and have the less human and environmental adverse effects than fossil fuels. Especially the residues come from agricultural or agricultural industrial, because the agricultural residues were not directly associated with food supply and the price of food.

Generally, the health effects of conventional fuels and biofuels have not yet been evaluated accurately. In the future, there remains a need to continue the further studies of vehicle exhaust emissions, and to improve the understanding of all vehicle exhaust emissions and all of those impacts. Future health research should be integrated with vehicle exhaust studies because there is a great need for studies of the effects of vehicle exhausts in metropolitan areas.

Finally, it can be concluded that:

- From the information that is available, it appears that burning gasoline fuels will produce less PM and NO_X emissions than burning diesel fuels, but it will generate around 50% more of CO_2 than diesel fuels. Use of gasoline cars in urban areas might help to reduce the human health effects.

- From the information that is available, it appears that burning diesel fuels will produce less CO_2 emissions than gasoline fuels, but will emit around about ten times higher NO_X and PM compared with gasoline cars. Use of diesel cars in motorways or rural areas might help to reduce the GHG emissions and minimize the global warming effects.
- Biofuels - biodiesel and ethanol - are potentially less harmful to the environment and human health than gasoline and diesel fuels. Burning biofuels produce less CO_2 emissions than burning fossil fuels. In the future, biofuels have a great potential to replace conventional fuels. In addition, there is also a need for more health impact studies on biofuel emissions.

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