The Role of Petroleum Based and Alternative Transport Fuels in Reducing Emissions in the APEC Region

Energy Working Group Project EWG 04/99

Prepared for:

APEC Expert Group on Clean Fossil Energy

Asia-Pacific Economic Cooperation Secretariat
438 Alexandra Road
#14-01/04 Alexandra Point
Singapore 119958

Prepared by:

Levelton Engineering Ltd.
in association with
(S&T)^2 Consultants, Inc. and
Malaysian Environmental Services SDN. BHD.

December, 2000

THE ROLE OF PETROLEUM BASED AND ALTERNATIVE TRANSPORT FUELS IN REDUCING EMISSIONS IN THE APEC REGION

ENERGY WORKING GROUP PROJECT EWG 04/99

Prepared for:

APEC Experts' Group on Clean Fossil Energy

Asia-Pacific Economic Cooperation Secretariat
438 Alexandra Road,
#14-01/04 Alexandra Point
Singapore 119958

By:

Levelton Engineering Ltd.
150 - 12791 Clarke Place
Richmond, British Columbia
Canada, V6V 2H9
(www.levelton.com)

in association with:

(S&T)^2 Consultants Inc.
Delta, British Columbia, Canada

and

Malaysian Environmental Services SDN. BHD.
Johor Bahru, Malaysia

December, 2000 File: 499-0756

APEC Secretariat
438 Alexandra Road
#14-01/04 Alexandra Point
Singapore 119958

Email: info@mail.apecsec.org.sg
Website: http://www.apecsec.org.sg
Published by Levelton Engineering Ltd., Richmond, BC, Canada (www.levelton.com)
for APEC and the APEC Expert's Group on Clean Fossil Energy.

APEC Publication # 00-RE-01.14
ISBN: 0-9688327-0-9

ACKNOWLEDGEMENTS

Levelton Engineering Ltd. and the authors of this report wish to extend their thanks to the following individuals for their valued guidance and assistance during the completion of this study:

- Dr. Sun Chun, Chair, APEC Expert's Group on Clean Fossil Energy, Energy Working Group and Senior Executive Advisor, US Department of Energy, Office of Fossil Energy;
- Mr. Kenneth Leong Hong, Secretariat for the APEC Expert's Group on Clean Fossil Energy;
- Dr. Lowell Miller, Director, Office of Coal Fuels and Industrial Systems, US Department of Energy;
- Dr. Frank Mourits, Mineral and Metal Policy Branch, Natural Resources Canada
- Dr. Charles Johnson, then Coordinator, Environmental Studies Research Program, East-West Center.

The authors would also like to thank the many individuals, agencies, industry organizations and companies in the APEC member economies, who are too numerous to list individually, for the time and effort they contributed in order to provide data and information that was used in preparing this study. Mr. Saengroaj Srisawaskraisorn of the East-West Center, Hawaii, very kindly assisted by preparing the front cover design and assembling the photographs that were used.

EXECUTIVE SUMMARY

This study examined the options for petroleum-based and alternative transportation fuels and the contribution they could make towards reducing emissions and air quality impacts associated with transportation in the APEC region. The study facilitates sharing information on transportation energy options, information that can be used to assist in improving economic and environmental conditions in the APEC region. The transportation sector is complex, involving different modes of transport, a variety of engines and vehicle types within each transport mode and the use of numerous fuels of different types and compositions. For this study, the transport sector was considered to include vehicles used to transport people and goods by road, air, rail and water.

Transportation Energy Use and Vehicle Population

Of the total 3,796,973 ktoe of oil equivalent of energy consumed in the APEC region, 43.5% is used by industry, 27.1% is used for transportation and 29.4% is used for other purposes. The APEC economies having the five largest shares of total transportation energy use are the United States (58.9%), Japan (8.4%), Russia (5.4%), Canada (5.1%) and PR China (4.7%), which, in aggregate, equal 82.5%.

The average distribution of energy used for transportation by all modes of travel for the 12 economies that provided data for this study is 47.3% gasoline, 38.8% diesel fuel and 13.9% other fuels.

On-road vehicles are the predominant consumer of transportation energy in APEC, with this energy demand comprising an average of 84% of the energy used by this sector in the surveyed economies. The modes of travel having the next largest shares of energy use were air travel at 11%, marine vessels at 4.3% and rail travel at 1.1%. Petroleum based fuels provide the vast majority of the energy used for road transportation, varying from 96% to essentially 100% in the economies that provided a breakdown of the energy used according to the type of fuel.

The number of passenger cars and commercial vehicles per person in the APEC economies increases in proportion to the gross domestic product per capita raised to the 1.23 power. In developing economies, where significant growth in GDP per capita is anticipated to occur, this relationship suggests that such growth will likely be accompanied by a faster growth in the number of road vehicles. Measures will need to be implemented to reduce, or off-set the effects of growth in vehicle population on road transportation energy consumption, traffic congestion and vehicle emissions. In 1995, the number of passenger cars and commercial vehicles varied from 9 to 849 per thousand people in the APEC region, with developed economies in the range of about 530-760. Motor cycles are in addition to these values and can equal the number of passenger cars in some Asian economies.

The fleet average fuel economy of light duty vehicles has declined in the United States and a similar trend is occurring in Canada as a result of an increase in the market share of new light and medium duty trucks, at the expense of passenger cars. These vehicles have lower fuel economies than passenger cars. The shift in new vehicle sales to heavier and less fuel efficient vehicles now occurring in the developed economies could be a future issue for the developing economies. Developed economies project the fuel economy of passenger cars and light duty trucks will improve gradually through to 2020, though this gain as noted above will largely be off-set by the increased weight and horsepower desired by purchasers of new vehicles.

Emissions and Air Quality Effects Associated with Transportation

Combustion of fuels by transportation vehicles produces a range of gaseous and particulate emissions, which directly, or as precursors to the formation of other gases and particles in the atmosphere, can result in adverse impacts to human health and the environment. Emissions from the combustion of fuels are typically grouped as follows:

- Greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O);
- Criteria (also called “common”) air contaminants: carbon monoxide (CO), nitrogen oxides (NO and NO_2 expressed as NO_2), sulphur oxides (SO_2 and other oxidized forms of sulphur expressed as SO_2), volatile organic compounds (VOC, excludes methane), and particulate matter (total, PM10 and PM2.5); and
- Toxic or hazardous air contaminants: lead, aldehydes, polyaromatic hydrocarbons (PAH), benzene and 1,3-butadiene.

The approximate contribution of on-road vehicles to national emissions of criteria pollutants and carbon dioxide in the surveyed APEC economies are summarized in Table S-1. The contribution of on-road vehicles to emissions is significantly higher in urban areas than on a national basis, as shown by data for both developed and developing APEC economies reviewed in this study.

Table S-1 Reported Contribution of On-Road Vehicles to Total National Emissions

Contaminant	Contribution Range
Nitrogen Oxides	30-52%
Sulphur Oxides	2-8%
Volatile Organic Compounds	16-90%
Carbon Monoxide	32-95%
Particulate Matter (PM10)	2-10%
Carbon Dioxide	20-40%

Based on the air quality data available for the APEC region from this and other studies, trends in fuel and vehicle technologies, and concerns about future greenhouse gas emissions, the most important changes to petroleum fuels and reductions in emissions for road vehicles in many economies in APEC are:

- Elimination of leaded gasoline and reduction in lead emissions (also required for catalytic emission control on gasoline motor vehicles);
- Reduction in gasoline and diesel fuel sulphur content (to improve the performance of emission control systems and reduce SO_2 and particulate emissions);
- Reduction in primary particulate emissions of PM10 and PM2.5;
- Reduction in NO_x, VOC and CO emissions, which are of concern as contaminants and as precursors of secondary particulate and ozone formation in the atmosphere;
- Reduction in air toxic emissions;
- Reduction in greenhouse gas emissions.

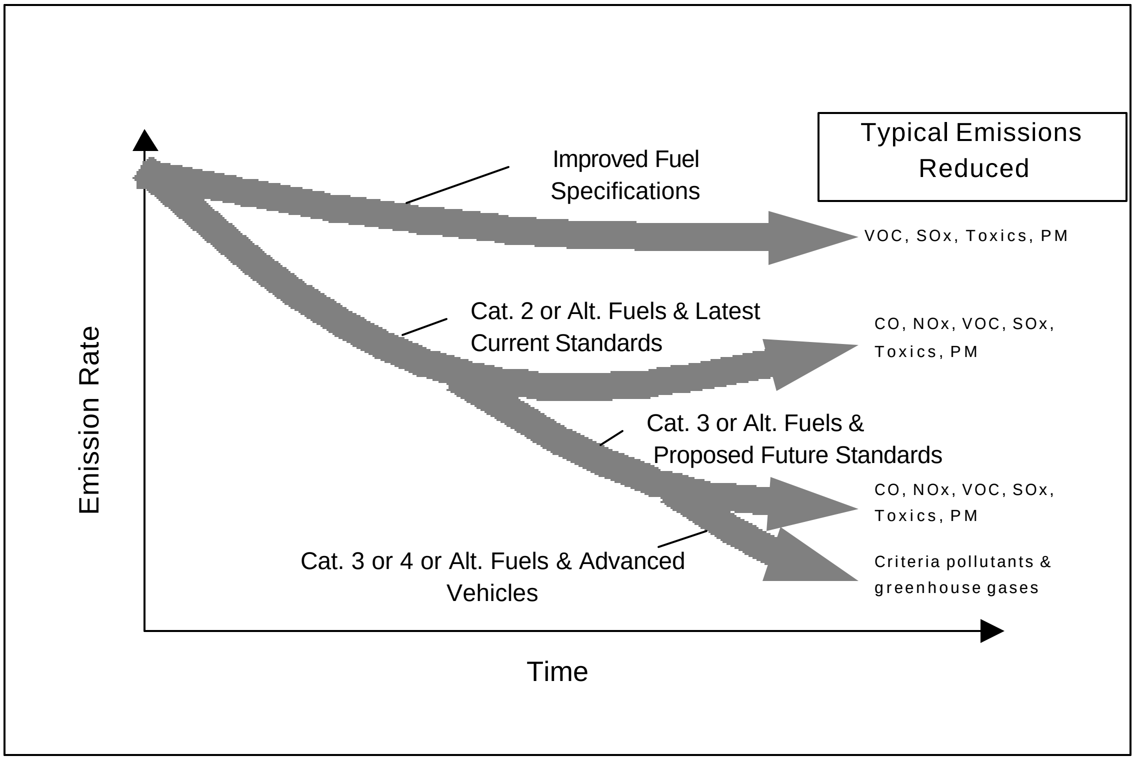
Petroleum-based and Alternative Fuel Options

The emission behaviour of motor vehicles is intimately related and partially dependent on the fuel used. Options for reducing emissions from on-road motor vehicles are best developed considering the fuel and vehicle as an integrated system. The options for reducing emissions from motor vehicles and fuels fall into three overlapping options, as follows:

- Changes in the fuel to reduce emissions without requiring implementation of new vehicle technology;
- Moderate changes in the fuel in concert with improved commercially available vehicle emission control technology that can achieve lower emission standards;
- Substantial changes in fuel specifications from current levels to enable implementation of advanced vehicle emission controls and/or commercialisation of emerging vehicle technologies.

Figure S-1 illustrates these concepts, which apply to both spark ignition and compression ignition vehicles. The categories used in the figure refer generically to the World-Wide Fuel Charter developed as a guideline to improve petroleum based fuels.

Figure S-1 Conceptual Fuel and Vehicle Emission Reduction Options



The study reviewed the main fuel options for light and heavy duty vehicles, including commercially proven fuel/vehicle technologies and potential fuel/vehicle technologies that may be of future interest in the APEC region. Substantial reductions in emissions of criteria and toxic pollutants from motor vehicles are possible in developing and developed economies with the use of unleaded gasoline, moderate fuel reformulation and the latest commercial vehicle emission control technology. Low-sulphur and reformulated gasoline and diesel fuel are needed to support the use of advanced emission controls meeting proposed US EPA and EURO emission standards. Several alternative vehicle fuels were also identified that have been used in the APEC region and can achieve lower criteria and greenhouse gas emissions than vehicles using gasoline or diesel fuel. Commercial petroleum-based and alternative fuel options identified and reviewed in the study for light and heavy duty vehicles are shown in Table S-2. Emerging and future fuels of potential interest in the APEC region were also identified, and include:

- ultra-low sulphur liquid fuels, principally diesel fuel, produced using Fischer Tropsch synthesis and syngas derived from natural gas or via gasification of solid fuels;
- dimethyl ether produced from natural gas via methanol dehydration for compression ignition (diesel) engines;
- liquid fuels derived from coal.

Table S-2 Commercial Fuel Options Studied for Light and Heavy Duty Vehicles

Light Duty Vehicles	Heavy Duty Vehicles
Low-sulphur and reformulated gasoline	Low-sulphur and reformulated gasoline
Low-sulphur and reformulated diesel fuel	Low-sulphur and reformulated diesel fuel
Natural gas	Natural gas
LPG	LPG
Ethanol-gasoline blends (10%, 85%)	Biodiesel
Methanol (gasoline blends and 100%)	

Reduction of the sulphur content of gasoline yields substantial improvements in the efficiency of catalytic emission control systems on existing and new vehicles. A sulphur content approaching about 30 ppm is needed to enable future motor vehicles to meet the most stringent US and EURO emission standards. The US, Canada and Australia have planned to reduce sulphur content of gasoline to 30 ppm.

Benzene contents of gasoline are relatively high in some economies (5-6 volume percent) and reduced to low levels near 1 volume percent in others. Significant reductions in emissions and exposure to benzene, which is carcinogenic, could be achieved by reducing benzene in gasoline to 1 volume percent.

Reductions in the sulphur content of diesel fuel would help reduce emissions in APEC economies. The sulphur content of diesel fuel will need to be reduced to 15-50 ppm to enable implementation of the most stringent emission standards now proposed for heavy duty vehicles.

A number of alternative fuels are being used in the APEC region. Natural gas and LPG are the two most widely used alternative fuels in the APEC region and are attractive options when there are indigenous resources, air quality problems exist and there is favourable regulatory and economic environment. The most popular and cost effective applications of these fuels appear to be for dedicated fleets. Natural gas and LPG fuelled vehicles are capable of lower emissions of criteria pollutants and greenhouse gases and higher fuel economies if they are dedicated OEM vehicles optimized for these fuels, rather than converted or dual fuel vehicles.

Methanol is a potentially attractive future fuel for production in APEC economies with abundant natural gas or coal resources. Interest in M85 methanol fuelled vehicles has declined, but methanol is now being advocated as a good candidate for fuel cell vehicles.

Opportunities exist for expanded manufacturing of ethanol from renewable resources in the APEC economies and increased use of ethanol in gasoline to add octane and oxygen content and to reduce emissions of criteria and greenhouse gases.

Biodiesel is a potentially attractive fuel for displacement of diesel fuel as it is compatible with existing engine technologies and can be produced from renewable resources. Moderate to large reductions in criteria emissions can be achieved with 20-100% biodiesel blends.

Dimethyl ether (DME) is a potentially attractive alternative to diesel fuel because of its excellent combustion characteristics and the large reduction in emissions that can be achieved. It can be produced from natural gas, which makes it a potentially viable means of converting and transporting energy from stranded natural gas resources.

Fuel/Vehicle Options and Impacts on Emissions and Air Quality

Fuels used for road vehicles have more affect on urban air quality than fuels used for other modes of transportation and should be the priority in the transportation sector for emission reduction strategies. Improvements to road transportation fuels can be extended to yield benefits as well for emissions from rail and marine sources. The air pollutants from motor vehicles that appear to be having the most impact on human health in the APEC economies are PM10 and PM2.5, ground-level ozone formed in the atmosphere from emissions of NO_x, VOC and CO, and air toxics. Also significant are emissions of SO_2 which contribute to respiratory problems and acid rain.

APEC economies can achieve large reductions in emissions from motor vehicles by implementing, as quickly as socially and economically acceptable, emission standards achievable with current catalytic emission control systems on light duty vehicles. Because of the time needed to displace older high emitting vehicles from the existing vehicle fleet, combined with the growth rates projected for developing economies, consideration should be given in these economies to accelerating the introduction of improved petroleum fuels and implementation of the most stringent emission standards presently proposed in developed economies.

Alternative fuels should be considered carefully for individual APEC economies as an effective means of reducing reliance on petroleum fuels and achieving reductions in emissions and the associated adverse health impacts. A range of alternative fuel options were identified in this study, enabling APEC economies to select the individual, or a combination of options that best suit their energy supplies and environmental priorities.

Harmonization of fuel and vehicle standards in the developing economies with those in the developed economies in the APEC region could be beneficial in future as it would avoid redundant efforts to develop standards for individual economies and help streamline implementation of fuel/vehicle options to achieve emission reductions more effectively.

Opportunities exist for reducing emissions of greenhouse gases, as well as some criteria pollutants by increasing the average fuel economy of the on-road vehicle fleet. For significant improvement in the average fleet fuel economy in developing economies, vehicles having improved fuel economy will need to increase their penetration of the vehicle fleet and off-set the trend to purchase heavier, less fuel efficient vehicles.

Obstacles and Data Gaps

Obstacles to improving petroleum based fuels or to switching to alternative fuels and vehicles exist, however, there is experience with many of these fuel/vehicle options in the APEC region that can be applied to help plan for, and minimize the impact of these obstacles. APEC economies will need to evaluate the viability of fuel/vehicle options with careful consideration of their own priorities and situation. Ratings of the fuels were developed to provide guidance regarding the merits of a range of fuel/vehicle technologies.

Improved and more complete emission inventory data is needed for the evaluation of emission control strategies for transportation and other emission sectors in some of the developing economies. Improved data on the characteristics of the vehicle fleet and fuel specifications in some APEC economies would also be beneficial to future assessments of fuel/vehicle options.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Abbreviations

APEC	Asia Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Center
ASTM	American Society for Testing and Materials
BBL	Barrel; equal to 42 US gallons
bhp-h	Brake horsepower-hour
BTU	British Thermal Units Energy. To convert to kJ multiply BTU by 1.055
CH_4	Methane
CI	Cetane index
CIE	Compression ignition engine
CN	Cetane number
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide greenhouse gas equivalent based on 100 year global warming potential factors. Equal to the mass of CO_2 plus 21 times the mass of methane plus 310 times the mass of nitrous oxide.
Driveability	The response of a vehicle to the throttle. Good driveablity requires smoothness at idle, ease of hot or cold starting, smoothness during acceleration and constant performance while cruising.
E10 & E85	10% and 85% ethanol with balance gasoline by volume, respectively
ETBE	Ethyl tertiary butyl ether
EV	Electric vehicle
EWG	Energy Working Group of APEC
FCC	Fluid catalytic cracking unit in a petroleum refinery
GDP	Gross Domestic Product
g	Gram
gal	US gallon (1 US gal=3.785 L)
GHG	Greenhouse gases
GJ	Gigajoule
GWP	Global warming potential over a 100 year period: CO_2, 1; CH_4, 21; N_2O, 310
HC	Total hydrocarbons
HHV	Higher heating value of a fuel (combustion moisture as liquid)
Hybrid	Hybrid combustion engine and battery electric vehicle
k	Prefix for thousand
km	kilometre
ktoe	Thousand tonnes of oil equivalent. One ton of oil equivalent energy is defined as 41.868 gigajoules. This is approximately equal to the net heat content of one ton of crude oil (APEC, 1998)
L	Litre
lb	Pound (0.4536 kg)
LDV	Light duty vehicle, which includes passenger cars, light duty trucks and sport Utility vehicles with a gross vehicle weight under 3856 kg as defined by the US EPA.
LDT	Light duty trucks, which includes trucks up to 3856 kg, as defined by the US EPA.
LNG	Liquified natural gas
LPG	Liquified petroleum gases (principally propane and butane)
M	Prefix for million, when used with metric unit
M85	85% methanol with balance gasoline by volume

M100	Neat methanol (100%)
mi	Mile (1.609 km)
MCF	Thousand cubic feet of gas at 15C temperature
MM	Million when applied to an imperial unit of energy
MMBTU	Million BTU (1 MMBTU= 1.055 GJ)
MON	Motor octane number (ASTM method D2700)
mpg	Mile per United States gallon (1mpg=0.4251 km/L)
MTBE	Methyl tertiary butyl ether
N_2O	Nitrous oxide
NGV	Natural gas vehicles
NLEV	US national low emission vehicle emission standards
NMHC	Non-methane hydrocarbons, as defined by the US EPA
NMOG	Non-methane organic gases, as defined by the US EPA
NO_x	Oxides of nitrogen
OEM	Original equipment manufacturer of motor vehicles
PAH	Polyaromatic Hydrocarbons
%, v/v	Percent by volume
PJ	Petajoule (10^{15}J)
PM	Particulate matter
PM10	Particulate matter having an aerodynamic diameter of 10 microns or less
PM2.5	Particulate matter having an aerodynamic diameter of 2.5 microns or less
POM	Polyorganic matter
ppm	Parts per million by volume
psi	Pounds per square inch of pressure (6.895 kPa)
RON	Research octane number for gasoline (ASTM method D2699)
R+M/2	Average of the RON and MON octane numbers
RVP	Reid vapour pressure. A measure of the vapour pressure of a liquid measured by the ASTM D323 procedure. Usually applied to gasoline or gasoline components.
S	Sulphur
SO_2	Sulphur dioxide
SOx	Oxides of sulphur
SUV	Sport utility vehicle
t	Metric tonne (1000 kg)
ton	Imperial ton (2000 pounds) (1 ton=0.9072 tonnes)
THC	Total hydrocarbon
T10	Temperature at which 10% of a gasoline distills
T90	Temperature at which 90% of a gasoline distills
ULEV	Ultra low emission vehicle standard
UN EP	United Nations Environment Programme
US EIA	United States Environmental Information Administration
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compounds, excluding methane and ethane
WHO	World Health Organization
WWFC	World-Wide Fuel Charter proposed by a consortium of automobile manufacturers.

1. INTRODUCTION

1.1 BACKGROUND

Current and projected data on energy use indicates that transportation vehicles are a major consumer of energy world-wide and that oil is the predominant source of transportation fuels. Approximately 49% of the world-wide oil demand in 1997 was for transportation, and this share is projected to increase to 55% by 2020, with transportation energy use growing at an average annual rate of 2.5% over this period (US EIA, 2000). The data for 1997 also shows that about 65% of the world's transportation energy is used in APEC member economies and that this consumption, approximately 23 million bbl/day, amounts to 50% of the total oil consumption in the APEC region.

Road vehicles consumed about 74.2% of the total world-wide transportation energy in 1997, followed next by aircraft at 11.5% and marine and other modes of travel at 14.3 %. By 2020, road vehicles are projected to still consume about 74.2% of world-wide transportation energy use, while air travel will increase to 14.9% of the total and marine and other modes of travel will decrease to 10.2%.

Emissions from transportation sources contribute to air quality concerns, particularly in urban areas, where emissions from on-road vehicles in particular can have adverse health and environmental impacts. Emissions from on-road vehicles have the most significant adverse impacts on air quality in highly populated urban areas where the cumulative emission rate exceeds the ability of the air shed to disperse and assimilate these emissions. The transportation sector is also a large component of global emissions of greenhouse gases, because of the carbon dioxide emissions when fuel carbon is burnt, methane emissions from combustion inefficiencies and nitrous oxide emissions from the engine and as a by-product of some catalytic pollution control systems for exhaust gases. The projected substantial growth in the consumption of oil for transportation fuels will result in a parallel growth in greenhouse gas emissions.

The Expert's Group on Clean Fossil Energy (hereafter referred to as the "Expert's Group"), under the theme of energy and the environment, promotes both the use of clean fossil fuels and advanced conversion technologies that will increase energy efficiency and reduce environmental impacts of fossil fuel use. It recognizes the different energy resource bases and economic development status of member economies and promotes energy options that are suited to their individual energy, economic and environmental situations. Increasingly, environmental factors influence energy and technology choices, with coal and natural gas likely to play major roles in the future energy supplies for most member economies.

This study on the role of petroleum based and alternative transport fuels in reducing emissions in the APEC region is a further step by the Expert's Group to address environmental issues associated with energy use. The study furthers APEC objectives by sharing information on energy options amongst APEC economies, information which can be used to assist in improving economic and environmental conditions in the APEC region. The issues of how to expand and improve the transportation sector in the most efficient and economic manner consistent with available resources, while reducing to a minimum any associated adverse environmental impacts are of key importance and common to many APEC economies.

The Expert's Group retained Levelton Engineering Ltd. to undertake this study with the voluntary assistance of many participants in APEC member economies who provided information on transportation energy use, the motor vehicle fleet, fuel composition, energy resources and emissions. Technical review and direction was provided by a steering committee with representatives from the United States and Canada. The East-West Center in Honolulu, Hawaii was very helpful in providing information and assistance over the course of the study.

1.2 SCOPE OF WORK

This APEC study was initiated in September, 1999 and focuses on fuels and vehicles used by the transportation sector in of the APEC economies. The objectives of this project were:

- to obtain, with the use of a questionnaire distributed to the APEC economies and supplemental public sources of information, data on current and forecast transportation energy use, size and characteristics of on-road vehicles, composition and characteristics of motor fuels, and emissions of air contaminants and greenhouse gases from major economic sectors;
- to prepare a data report containing the raw data provided by the APEC economies together with results of correlation, analysis of trends and assessment of the data;
- to present a paper at the APEC 7th Technical Seminar on Clean Fossil Energy held in Chinese Taipei on March 6-9, 2000 discussing the status of work on the project;
- to identify potential options for reducing emissions and improving air quality by the use of reformulated petroleum fuels or alternative fuels; and
- to assess the reduction in emissions of criteria and greenhouse gas emissions that could potentially be achieved by future fuel/vehicle options.

2. METHODOLOGY AND SOURCES OF DATA

2.1 OVERALL APPROACH

The transport sector is complex, involving different modes of transport, a variety of engines and vehicle types within each transport mode and the use of numerous fuels of different types and compositions. For this study, the transport sector was considered to include vehicles used to transport people and goods by road, air, rail and water. All major fuels presently used in the transport sector were included in the study, namely, gasoline, diesel fuel, natural gas, liquified petroleum gases and electricity.

A good foundation of data was required for the study and had to be developed, at least in part, by direct contact with government agencies and fuel companies in the APEC economies via questionnaire. The data needed for the study covers a wide range of different aspects of the transport sector, including energy supply and demand; characteristics of the vehicles used for transportation of people and goods; composition and characteristics of fuels and emissions of air contaminants and greenhouse gases. Once collected, the data on these aspects of the transport sector in each APEC economy was used to assess the potential role reformulated or alternative fuels could play in helping to reduce emissions to the atmosphere and associated impacts on air quality.

A review of fuel technologies was conducted to identify current and future fuel and associated vehicle options for the transport sector in the APEC region. These could also be applied in other jurisdictions. Because on-road transportation is the predominant energy user and corresponding source of emissions in the APEC region, emphasis was given to fuels and vehicles that could reduce emissions from this segment of the transportation sector. Some of these same fuels can also be applied to vehicle used for marine and rail transport, though the impacts of such applications were not addressed explicitly. The purpose of the review of fuel/vehicle technologies was to describe the fuel production process, summarize the characteristics of petroleum-based fuels presently used in the APEC region and to discuss the effects of key fuel characteristics on vehicle emissions and, where appropriate, on vehicle performance.

A suite of fuel/vehicle options are available to reduce emissions from the transport sector and the mix of these options is optimal for a region depends on many factors, such as the available energy resources and refining capability, the economics of the fuel options, security of energy supply, and air quality priorities, among others. This study used information on reformulated petroleum and alternative fuels in combination with data describing the transport sector in APEC economies to develop a guideline for selecting fuels that would reduce emissions and to estimate the nominal reduction in emissions that could be achieved with the penetration of these technologies in the market place.

2.2 QUESTIONNAIRE DEVELOPMENT AND CONTENT

The study team designed a questionnaire in consultation with the project steering committee to collect data for the study. The questionnaire consisted of five worksheets in an Excel™ workbook file requesting information on transportation energy demand, characteristics of the on-road vehicle fleet, characteristics of fuels, energy resource options and barriers and emissions. The type and nature of the data requested in the questionnaire is outlined below:

- Transportation Energy Demand - requests current and forecast transportation energy demand for transportation by road, air, rail, marine transportation and, for each mode, by type of fuel.

- Vehicle and Fuel Economy Data for a Representative Urban Area (or nationally) - requests data on the number of passenger cars, motorcycles, light duty trucks and heavy duty trucks by fuel type, the fuel economy of new and existing vehicles in each category, typical city and highway vehicles speeds, the age distribution passenger cars and emission standards of gasoline passenger cars.
- Fuel Parameters and Prices - requests data on the key current and future quality parameters for gasoline and diesel fuel affecting engine performance and emissions, and on the range of typical fuel prices for gasoline, diesel fuel, natural gas, liquified petroleum gases and electricity.
- Fuel Resources and Barriers - requests qualitative rankings of the energy resources utilized and potentially available to meet transportation energy demand and the respondent's ranking of potential barriers to use of reformulated or alternative fuels.
- National Emissions - requests data on the magnitude of emissions of regulated air pollutants (nitrogen oxides, sulphur oxides, volatile organic compounds, particulate matter and carbon monoxide) and carbon dioxide from transportation, energy production and other major source sectors.

A complete copy of the questionnaire is provided in Appendix A of this report.

2.3 Distribution of Survey Questionnaire

An initial distribution list for the questionnaire was prepared starting with a list of people working in the energy sector and related fields provided by the East-West Centre in Honolulu, Hawaii. This data base contains names and contact information for many individuals in government energy and environment agencies in all APEC economies that were compiled from lists of attendees at APEC conferences and meetings. A distribution list was created from this data base and used to distribute the initial batch of questionnaires in November, 1999 by email, facsimile and mail, as the contact information allowed. The initial distribution list included 133 individuals distributed in all of the APEC economies. Subsequently, the questionnaire was also distributed to additional contacts identified using updated lists of the Expert's Group for Clean Fossil Energy and officials of the Energy Working Group, or that were suggested by recipients of the questionnaires.

The distribution list used for tracking the survey includes 177 individuals that have received the questionnaire. Others have been contacted for information as well, bringing the total number approached for information to about 200.

2.4 Data Collected by Visits to APEC Economies

A member of the project team based in Kuala Lumpur met with government representatives in Malaysia, Singapore, Indonesia and Thailand to fill data gaps in responses to the survey sent by email and other means. These meetings and subsequent follow-up generated some additional information that was added to produce the survey questionnaire responses included in this report.

Data gathering efforts were also conducted while one of the authors of this report attended the APEC 7th Technical Seminar held in Taipei, Chinese Taipei and the APEC 6th Coal Flow Seminar held in Kyongju, Korea, both held in March, 2000. Obtaining data for Chinese Taipei was facilitated through meetings held with representatives of the Energy

Commission, the Ministry of Transportation and Communications and the Environmental Protection Agency.

2.5 OTHER SOURCES OF DATA FOR THE STUDY

The following sources were searched to identify and obtain information to supplement the data obtained using the survey questionnaire:

- APEC, APERC and Energy Working Group web sites;
- APEC project listings on their web site;
- US Energy Information Administration, International Energy Agency and Organization for Economic Cooperation and Development web sites;
- United Nations, World Bank and World Health Organization web sites;
- Industry sources
- Internet web sites identified by key word searches;
- Web sites maintained by energy and environmental agencies in APEC economies when they existed and could be found;
- Computerized literature data bases.

Relevant electronic data from these searches was downloaded. Almost all of the most relevant APEC documents were only available in hardcopy form and these were purchased from their office in Singapore.

3. TRANSPORTATION DATA IN APEC ECONOMIES

3.1 INFORMATION COMPILED FOR THE STUDY

As described in Section 2 of this report, government agencies and other sources of data were contacted to obtain information describing the transport sector and the contribution of this sector to air quality issues in each of the APEC economies. The questionnaire survey conducted specifically for this study generated data for over one-half of the APEC economies. Additional information was acquired where possible from internet web sites, APEC publications and a variety of other sources to fill gaps in the data available from the questionnaire survey. Not all of the data gaps could be filled within the scope and duration of this study.

This section of the report describes the current conditions in the APEC economies that are relevant when considering current and potential future impacts of transportation sector on air quality and greenhouse gas emissions, and the fuel and vehicle technology options to reduce these impacts. Data from the questionnaire survey and supplemental data sources are summarized and trends are examined, with a focus on transport energy demand, on-road vehicle fleet characteristics and fuel economy, emissions and air quality. Section 4 of the report extends this discussion in detail to include fuel quality for petroleum and alternative fuels, energy sources for producing motor fuels and petroleum refining capacity in the APEC economies.

3.2 POPULATION AND ECONOMIC DATA

Table 3-1 summarizes population, land area, gross domestic product and reported energy reserves for 1998 as compiled by APERC (APERC web site). In 1998, the APEC region had a combined population of about 2.5 billion people and a combined GDP of close to US$ 21 trillion. The GDP/capita varies from a low of US$ 1,764 in Viet Nam to a high of US $30,259 in the United States of America, with an overall average of US$ 12,345. The economies reporting significant oil reserves, in order of decreasing size, are: Russia, Mexico, Canada (including oil sands), United States and Indonesia. Note that energy resource data was not reported for PR China in the APERC summary information.

3.3 TRANSPORTATION ENERGY DEMAND

The energy consumption data compiled for 1998 by APERC (2000) indicates that the total energy consumption in the APEC region for all purposes is approximately 3,796,973 ktoe. Of this total energy consumption, 43.5% is for industrial operations, 27.1% is for transportation and 29.4% is for other purposes. The available data suggests transportation's share of total energy consumption varies widely in the APEC region from a low of 8.5% in PR China to a high of 48.3% for Thailand, depending on local conditions.

The total energy used in 1998 for transportation in the APEC region is 1,027,159 ktoe. Figure 3-1 presents the transportation energy consumption distribution among the APEC economies in sorted order. The transportation energy requirement is largest in the United States and constitutes 58.9% of the total transportation energy consumption in the APEC region. The four next largest, in order of decreasing magnitude, are Japan at 8.4%, Russia at 5.4%, Canada at 5.1%, and PR China at 4.7%. Taken together, these five economies consume 82.5% of the total transportation energy in the APEC region. A figure summarizing the energy consumption data by end-use for the APEC economies is included in Appendix B.

Table 3-1 Key Data and Economic Information for APEC Economies (1998)

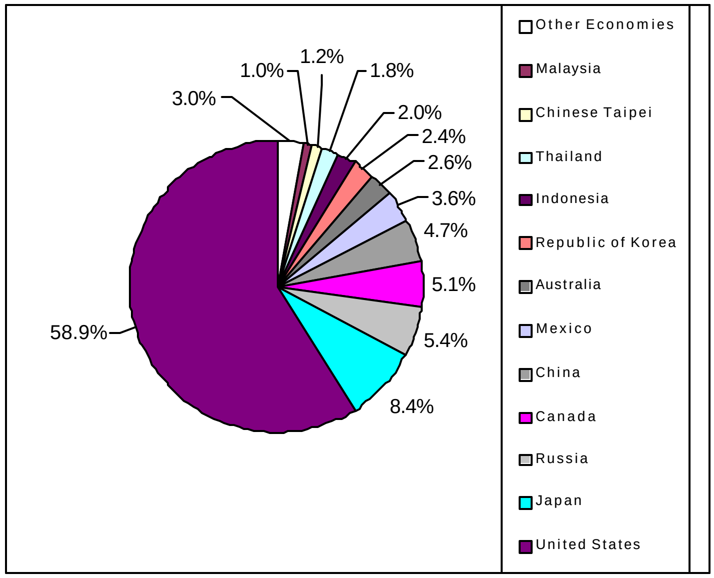
Economy	Area	Population	GDP	GDP/Capita	Energy Reserves		
					Oil	Gas	Coal
Units	Square km	Million	Billion US $	US $/person	MCM	BCM	Mt
Australia	7,600,000	18.75	432.41	23,062	233*	555*	90,940*
Brunei Darussalam	5,765	0.32	5.4	16,878	223**	329	-
Canada	9,984,670	30.30	733.41	24,205	646 6855+	1,651	7,110*
Chile	757,000	14.82	128.11	8,644	4.8**	45	155
China	960,000,000	1248.1	3,955.8	3,169	-	-	-
Chinese Taipei	36,000	21.87	271.51	12,414	-	-	-
Hong Kong, China	1,097	6.69	142.45	21,292	-	-	-
Indonesia	1,937,179	204.42	545.5	2,669	1,590**	4,670	38,000*
Japan	377,800	126.41	3,014.83	23,850	9.4**	39.6	785*
Malaysia	329,750	21.39	181.65	8,492	572*	2,430	1,025**
Mexico	1,964,375	100.24	758.30	7,565	7,600*	1,797	1,211**
New Zealand	268,680	3.79	67.33	17,764	20.5*	154.8	8,600**
Papua New Guinea	462,000	4.21	11.13	2,643	61.1*	39.7	-
Peru	1,285,216	24.8	112.23	4,526	49.2*	246.3	56.0**
Philippines	300,000	75.15	273.86	3,644	37-45*	82-130	297**
Republic of Korea	99,408	46.43	641.29	13,812	-	-	646**
Russia	17,000,000	146.91	974.39	6,632	7,808*	48,140	157,010**
Singapore	647.5	3.87	78.44	20,268	-	-	-
Thailand	513,115	61.20	348.62	5,696	12.7*	419	2,276** (lignite)
United States	9,372,610	270.56	8,186.94	30,259	3,339*	4,646	249,567**
Viet Nam	331,111	76.52	135.00	1,764	390*	617	3,325**
Totals	1,012,626,424	2506.75	20998.6	-	-	-	-

Source: APERC, 2000 web site: http://www.ieej.or.jp/aperc/

* Recoverable resources; ** Proven; + Oil sands

Transportation energy demand data was received from 12 APEC economies in response to the survey conducted in this study. Of these, one did not report an energy split by mode of travel, namely: air, marine, rail, and road, though total energy demand data was provided and has been included in the analysis.

Figure 3-1 1998 Transportation Energy Use in the APEC Region by Economy



Transportation energy demand data from the survey are summarized in Table 3-2. The modal split of transportation energy demand, as illustrated in Figure 3-2, shows the dominance of energy demand for on-road vehicles for developed and developing economies. On-road vehicles account for 79-89% for all reporting economies, with an average of 84%. Air travel, the second largest energy-use transportation sector, accounts for 7% to 18%, or an average of 11%, of the total transportation energy demand for the reporting economies. Marine transport accounts for an average of 4.3% of energy transport energy demand, while rail travel accounts for an average of 1.1%.

Figure 3-2 Distribution of Transportation Energy Demand by Mode

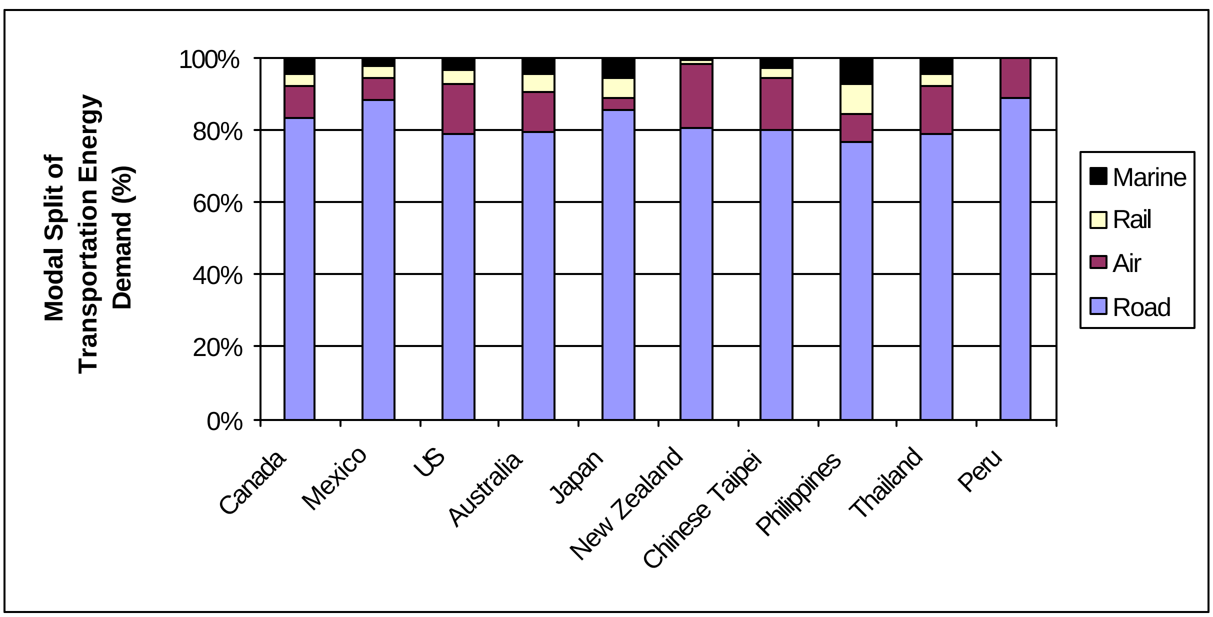


Table 3-2 Transportation Energy Demand Reported in Survey

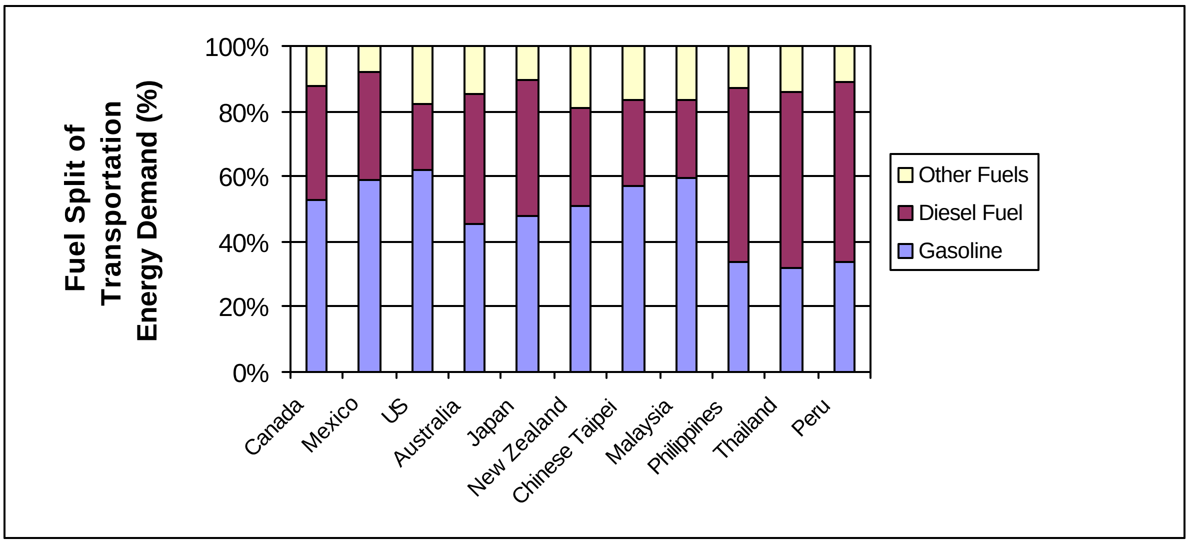
	Canada PJ	Mexico PJ	US PJ	Australia PJ	Japan PJ	New Zealand PJ	Chinese Taipei PJ	Malaysia PJ	Thailand PJ	Peru PJ	Philippines PJ
Year	1997	1999	1998	98/99	1997	1999	1998	1998	1998	1999	1999
Sector:											
Road	2,004	1,532	20,682	1,172	3,586	148	444	0	681	129	317
Air	212	113	3,587	168	134	33	80	0	115	16	32
Rail	80	25	589	0	79	2	4	0	5	0	0
Marine	101	49	969	68	239	2	16	0	36	0	33
Total	2,397	1,719	26,091	1,408	4,038	185	544	427	837	145	382
Fuel Type (all sectors):											
Gasoline	1,269	1,011	16,227	639	1,937	94	311	255	265	49	130
Diesel	834	571	5,218	564	1,684	56	142	101	452	80	203
Other Fuels	293	137	4,646	205	417	35	91	71	119	16	49
Total	2,397	1,719	26,091	1,408	4,038	185	544	427	837	145	382
Fuel Type (on-road):											
Gasoline (leaded)	0	0	0	166	0	0	42	0	0	49	102
Gasoline (unleaded)	1,265	1,011	16,182	469	1,937	93	269	0	247	0	27
Diesel	711	498	4,417	496	1,577	52	132	0	430	80	188
Other Fuels	28	23	83	41	73	2	1	0	4	0	0
Total	2,004	1,532	20,682	1,172	3,586	148	444	0	681	129	317

Figure 3-3 illustrates gasoline is a major transportation fuel in many APEC economies. The split between gasoline and diesel fuel for the economies shifts from a preference for gasoline in the developed economies to a preference for diesel fuel in many of the developing economies. Fuel price is likely an important influence on this fuel choice.

For the 12 economies which provided data, the average distribution of total transportation energy use is gasoline 47.3%, diesel fuel 38.8% and other fuels 13.9%. The reported data falls into the ranges summarized below:

	Percent Transportation Energy Use	
	Gasoline	Diesel fuel
North America	53-62%	20-35%
Australia, Japan and New Zealand	45-51%	30-40%
Chinese Taipei, Malaysia	57-60%	24-26%
Thailand, Philippines, Peru	32-34%	53-55%

Figure 3-3 Distribution of Transportation Energy Demand by Fuel Type



Ten economies provided data on the energy demand for road transportation by fuel type. Canada provided data including on-road and off-road combined. The present share of on-road transportation energy provided by fuels other than gasoline and diesel fuel is small (Table 3-2). The share of on-road energy provided by alternative fuels in the developed economies that provided data was 0.4% for the United States, 1.4% for Canada, 2% for Japan, 1.5% for New Zealand and 3.5% for Australia. For the developing economies, The Philippines was zero, Chinese Taipei was 0.2% and Thailand was 0.6%. Data reported for on-road transportation in Canada's Energy Outlook (NR Can, 1997) indicates alternative fuels provided 2.7% of the road transportation energy demand in 1995 and this was projected to increase slightly to 2.8% in 2000.

The latest International Energy Annual (US EIA, 2000) reports the apparent consumption of refined petroleum products for each continental area and worldwide. The estimates of gasoline and jet fuel are almost exclusively for transportation fuel use and applicable to this study. However, the US EIA estimates of the consumption of diesel fuel, kerosene, LPG and other fuels apply to both stationary sources and mobile sources and, therefore, can not be compared directly with the data obtained in this study. The estimates reported by the US EIA for gasoline are consistent with the data obtained in this study. The survey data shows a lower percentage of jet fuel usage and higher percentage of diesel fuel usage for the transportation sector than reported by the US EIA for 1997. Differences in values between the different economies are directionally similar in the survey results.

3.4 ON-ROAD VEHICLE CHARACTERISTICS

The questionnaire requested data on the vehicle fleet by class of vehicle, such as numbers of vehicles, new and existing fleet fuel economies, the average distance driven, the age distribution of vehicles and the local vehicle emission standards. Ten APEC economies provided data for this part of the questionnaire.

3.4.1 Level of Motorization

The number of vehicles in operation in an economy is a key determinant of the emissions from on-road transportation. As illustrated in Figure 3-4, the total number of passenger cars and commercial vehicles per capita correlates well with GDP per capita in the APEC economies. Excluding the results for Japan, Hong Kong China and Singapore, which appear to differ in the relationship from the balance of the economies, the remaining data correlate well using the formula:

Vehicles per 1000 people = $0.0034\ G^{1.2285}$,

where Vehicles = 1995 total of passenger cars and commercial vehicles,

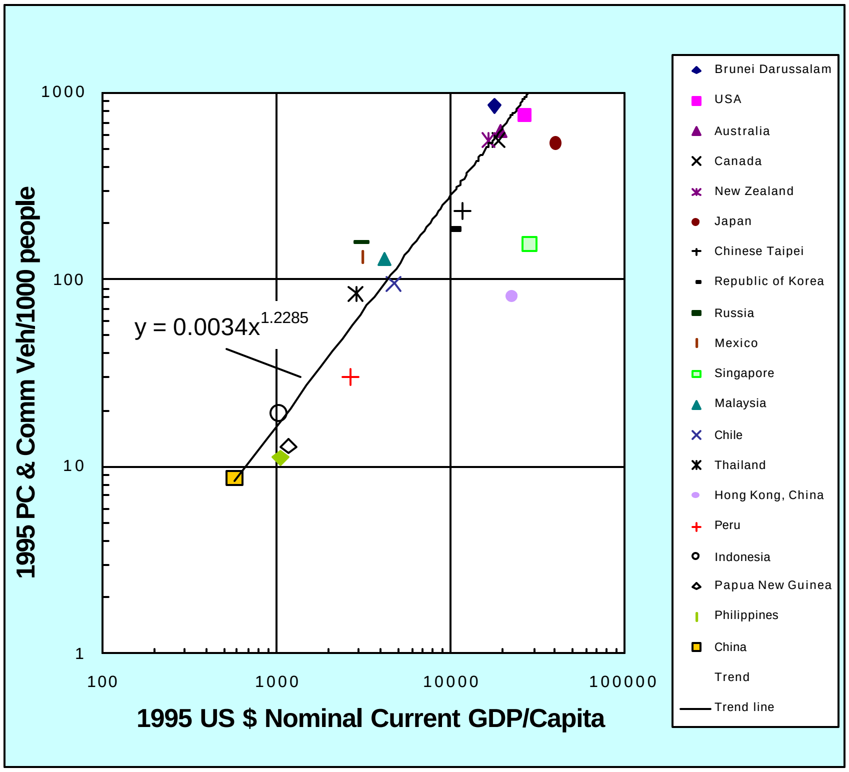
G = 1995 nominal GDP per capita expressed in US dollars/capita.

The elasticity coefficient of 1.2285 determined in this study is similar to the value of 1.59 found for 21 Latin American and Caribbean countries (World Bank, 1997). Results for Singapore and Hong Kong China show that their compact land area and use of public transit lead to lower motorization levels compared to others with similar GDP per capita.

If the historical trend in motorization continues for the developing economies from their present levels, increased personal income, combined with increases in population will lead to significant growth in the total number of vehicles and the potential for substantial increases in mobile source emissions with existing commercial vehicle technologies. Using the motorization levels and population predicted for the APEC region by the US EIA (2000), there will be roughly 640 million vehicles in the APEC region by 2020, an increase of 72% over the 372 million registered in 1995.

Table 3-3 presents the motor vehicle data ranked in decreasing order by motorization level in terms of total passenger cars and commercial vehicles per thousand people. The motorization level decreases from a high of about 849 for Brunei Darussalam to a low of about 9 for PR China. Developed economies have the highest motorization levels. The number of passenger cars per 1000 people decreases from a high of 513 in the US to a low of 3 in PR China, with the highest levels occurring in the developed economies.

Figure 3-4 Passenger Cars and Commercial Vehicles in APEC Economies in 1995



3.4.2 On-road Vehicle Fleet Types and Ages

The survey of APEC economies generated information on the distribution of numbers of vehicles by class of vehicle in the existing vehicle fleet. All the reported results apply to national vehicle profiles except for Thailand, which provided data specific to Bangkok. Substantial differences exist between the percentage of the fleet comprised of passenger cars, with results of 79% in Australia, 62-63% in the US and Canada, 37% in Malaysia and 23% in the Philippines (Table 3-4 and Figure 3-5) . The percentage of motorcycles in the vehicle fleet is lowest in North America, at only 2%, and highest in southeast Asia. For example, motorcycles are 46.5% of the fleet in Chinese Taipei, similar in magnitude to that for passenger cars, while they are 57.2% of the fleet in Malaysia, exceeding that for passenger cars. Passenger cars fuelled by diesel fuel or other fuels comprise less than about 3% of the fleet in all economies, except Japan where the value increases to about 6%.

Light duty trucks comprise 29-33% of the North American vehicle fleet, and this share has been increasing gradually with fleet turn-over because of the increase in sales of light trucks, such as sport utility vehicles and vans, at the expense of passenger cars. About 50% of the new purchases of light duty vehicles in the US and Canada are now in the light duty truck category, typically with a lower fuel economy and higher horsepower compared to an average passenger car. The proportion in the light duty truck class is 15% in Australia and New Zealand, 22% in Japan, 4-6% in Chinese Taipei and Malaysia, and 15% in Singapore.

Gasoline and diesel fuelled heavy duty vehicles comprise about 1-8% of the fleet for the economies that responded to the questionnaire. Almost all of the heavy duty vehicles were reported to be fuelled by diesel fuel for the surveyed economies outside North America.

A recent World Bank report (1997) provides some additional data for Mexico and Chile. The composition of the fleet of 3 million vehicles in Mexico City is reported to be 76.6% passenger cars and taxis, 19.7% heavy duty trucks and buses, 1.1% government vehicles and 2.6% other vehicles. In the Santiago Metropolitan Area of Chile, 74.5% of the vehicles in 1992 were passenger cars and taxis, 17.5% were light duty trucks and 8% were heavy duty trucks and buses.

Table 3-3 1995 Motor Vehicle and Motorization Levels in the APEC Economies

Economy	Population	Nominal GDP	Registered Vehicles**			GDP/Capita	Total Vehicles per 1000 people
	Million	Billion US $	Passenger Cars	Commercial Vehicles	Total Vehicles	US$/person	
Brunei Darussalam	0.29	5.22	115,377	130,919	246,296	18,000	849
USA	262.89	7029.6	134,981,000	65,465,000	200,446,000	26,740	762
Australia	18.06	350.68	9,010,000	2,197,000	11,207,000	19,417	621
Canada	29.62	560.01	13,182,996	3,484,616	16,667,612	18,906	563
New Zealand	3.59	59.75	1,658,175	352,635	2,010,810	16,643	560
Japan	125.44	5134.3	44,680,037	22,173,463	66,853,500	40,930	533
Chinese Taipei	21.3	252.78	4,100,000	850,000	4,950,000	11,868	232
Korea	45	456.36	6,006,290	2,462,611	8,468,901	10,141	188
Russia*	147.1	450	13,638,600	9,856,000	23,494,600	3,059	160
Mexico	91.61	286.28	8,400,000	3,750,000	12,150,000	3,125	133
Singapore	2.99	85.43	324,026	136,836	460,862	28,572	154
Malaysia	20.1	85.31	2,559,672	35,224	2,594,896	4,244	129
Chile	14.21	67.3	888,645	469,142	1,357,787	4,736	96
Thailand	59.4	168.36	1,350,000	3,650,000	5,000,000	2,834	84
Hong Kong, China	6.16	140.2	300,000	200,000	500,000	22,760	81
Peru*	24.37	65	472,000	264,000	736,000	2,667	30
Indonesia	193.98	201.18	1,900,000	1,850,000	3,750,000	1,037	19
Papua New Guinea	4.3	5.03	20,000	35,000	55,000	1,170	13
Philippines	70.27	74.13	572,766	207,388	780,154	1,055	11
China	1203.32	697.61	4,178,964	6,221,065	10,400,029	580	9
Viet Nam*	76.55	26	-	-	-	340	-

* Population and GDP data for these economies applies to 1997, as 1995 data was unavailable.

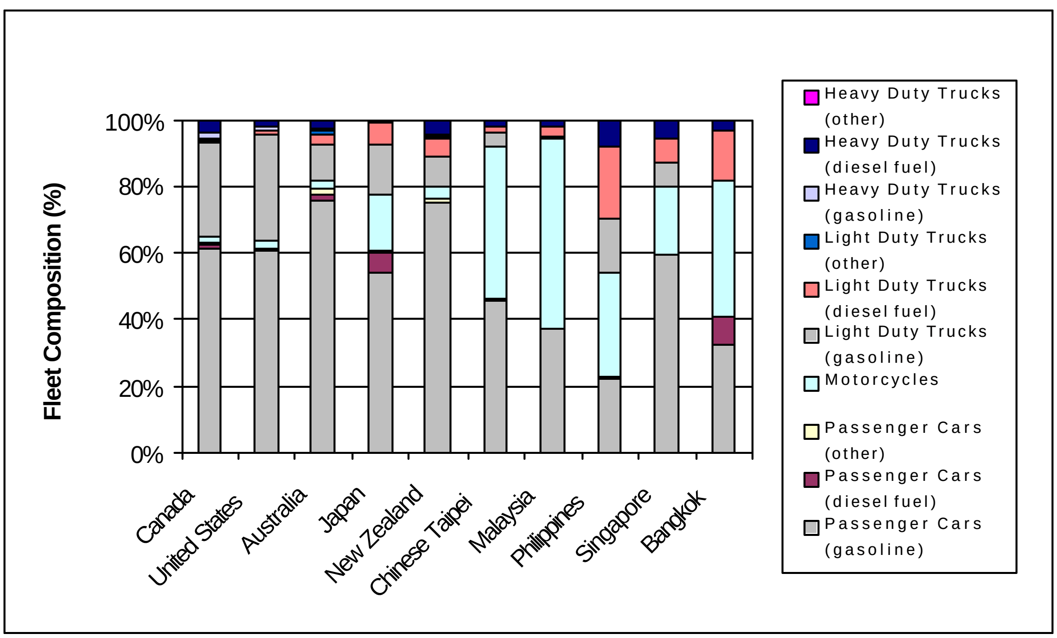
** Excludes the number of motor cycles, which can exceed the number of passenger cars in some economies Asian economies.

Sources: APEC, 1998; AAMA, 1997.

Table 3-4 Current Vehicle Fleet Profile by Vehicle Type in Percent

	Canada	United States	Australia	Japan	New Zealand	Chinese Taipei	Malaysia	Philippines	Singapore	Bangkok
Passenger Cars (gasoline)	61.7	60.8	75.7	54.1	74.9	45.6	36.9	21.9	59.3	32.6
Passenger Cars (diesel fuel)	0.6	0.6	1.8	5.8	0.5	0.9	0.2	0.9	0.0	8.0
Passenger Cars (other)	0.5	0.2	1.5	0.3	0.9	0.1	0.0	0.0	0.0	0.0
Subtotal	62.9	61.6	79.0	60.2	76.4	46.5	37.2	22.8	59.3	40.5
Motorcycles	1.9	1.9	2.7	17.2	3.4	45.4	57.2	31.4	20.6	41.3
Light Duty Trucks (gasoline)	28.4	32.0	10.8	14.9	9.1	4.3	1.1	16.0	7.5	0.0
Light Duty Trucks (diesel fuel)	0.2	1.1	3.5	6.7	5.8	1.9	2.4	21.8	7.2	14.9
Light Duty Trucks (other)	0.7	0.2	0.6	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Subtotal	29.3	33.3	14.8	21.7	15.5	6.2	3.5	37.8	14.7	14.9
Heavy Duty Trucks (gasoline)	2.1	1.2	0.7	0.0	0.5	0.0	0.0	0.2	0.0	0.0
Heavy Duty Trucks (diesel fuel)	3.9	1.9	2.8	0.9	4.2	1.9	2.1	7.8	5.4	3.2
Heavy Duty Trucks (other)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	6.0	3.1	3.5	0.9	4.7	1.9	2.2	8.0	5.4	3.2
Total Vehicles	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

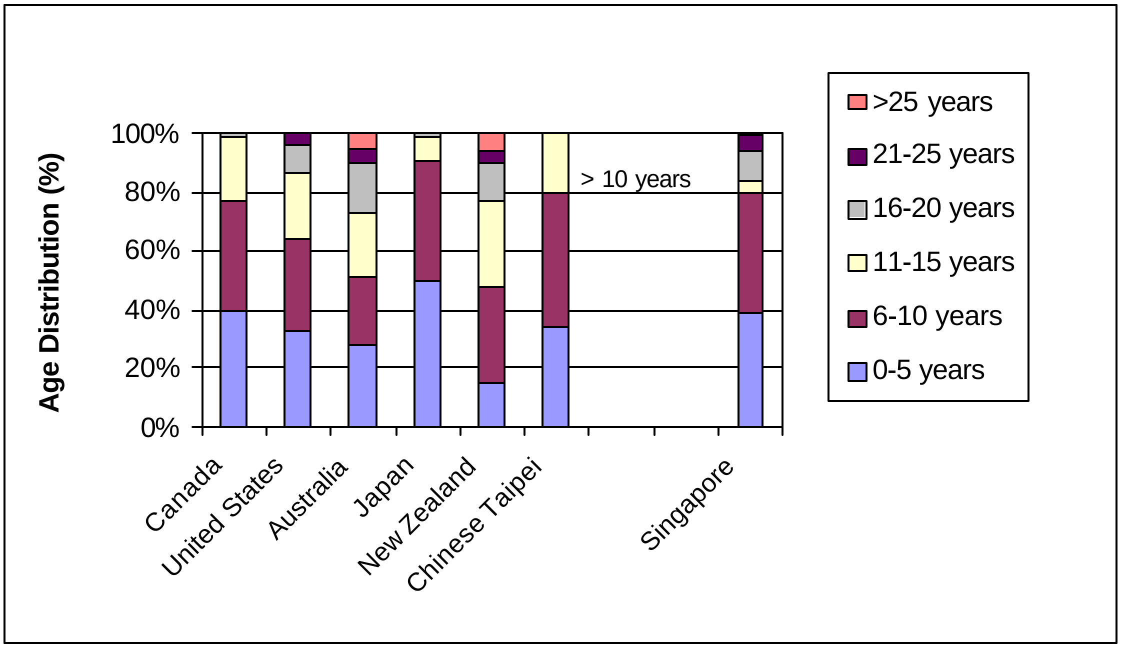
Figure 3-5 Fleet Composition by Type of Vehicle



The age distribution of the passenger car fleet was reported for only seven APEC economies, as shown in Figure 3-6, limiting the analysis of trends and comparison that is possible. The data on the age profile of the passenger car fleet suggests there is a higher percentage of older vehicles on the road in Australia and New Zealand than in North America. Japan reported the highest percentage of vehicles in the 0-5 year age range. As older vehicles tend to meet less stringent emission standards and the performance of emission controls, if present on the vehicle, deteriorate with increasing age and mileage, older vehicles usually make a disproportionately high contribution to total emissions from on-road vehicles.

In Mexico City about 42% of the vehicle fleet is more than 10 years old, 26% is 6-10 years old and 32% is 0-5 years old, at the time of a 1996 study (World Bank, 1997). Sixty-eight percent of the light duty vehicle fleet were then not equipped with catalytic converters.

Figure 3-6 Vehicle Fleet Age Distribution



3.4.3 Vehicle Fuel Economy

3.4.3.1 Existing and New Vehicle Fleet

Eight APEC economies provided complete or partial data on the on-road fuel economy of the existing vehicle fleet of passenger cars, light duty trucks and heavy duty trucks by fuel type. These results are shown in Figure 3-7.

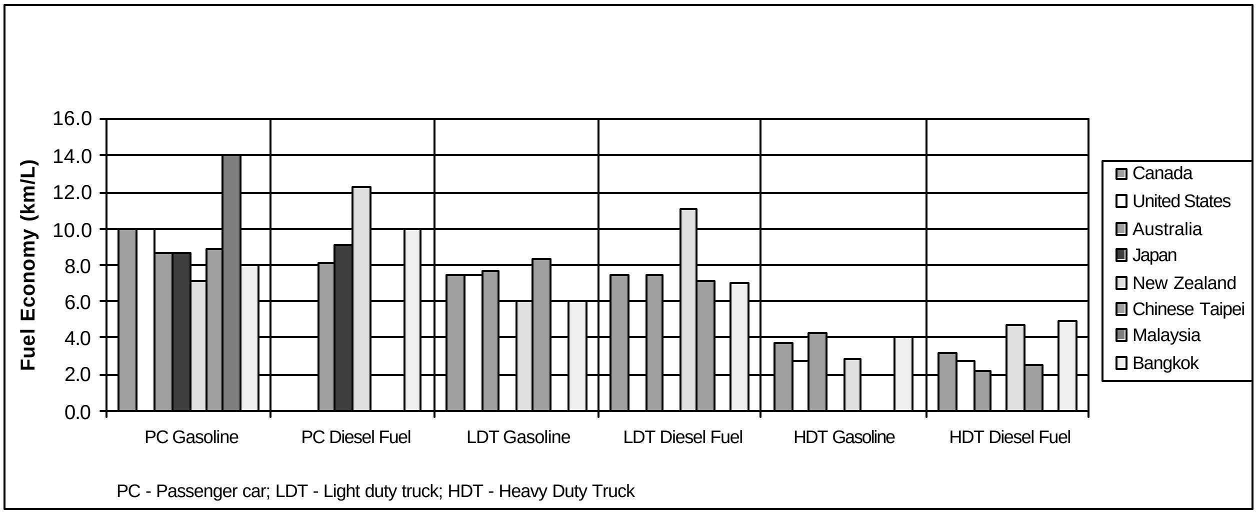
Most fuel economy values for gasoline passenger cars are between 7 and 10 km/L. Fuel economies provided for the survey tended to be higher in North America economies than in Asian economies. Malaysia reported 14 km/L for the fuel economy of the existing gasoline passenger car fleet. This value is unusually high for the on-road vehicle fleet and, for this reason, could be in error. For comparison, the fuel economies for gasoline passenger cars in Japan and Chinese Taipei are 8.7 km/L and 9 km/L, respectively.

Diesel engines have a higher thermodynamic efficiency than gasoline engines and diesel fuel contains 11% greater net heating value. However, for the economies that provided both diesel and gasoline fuel economies, diesel passenger cars have only a 6% advantage in fuel economy over gasoline passenger cars. A study in Canada estimated that diesel passenger cars have a 40% higher theoretical fuel economy than an equivalent gasoline fuelled vehicle (Levelton et al, 1999).

The existing fuel economy of light duty gasoline fuelled trucks are in the range of 6-8 km/L for all economies. The fuel economies of diesel fuelled light duty trucks were 7-11 km/L. Diesel fuelled light duty trucks should typically have a better fuel economy than a comparable gasoline fuelled vehicle because of the higher engine efficiency. The average fuel economy of gasoline fuelled light duty trucks is 19% lower than that for gasoline fuelled passenger cars.

Heavy duty vehicle fuel economy is reported to be slightly lower for diesel fuel than gasoline in spite of the higher engine fuel economy that can be attained with diesel engines. Fuel economies were reported to be 2.9-4.3 km/L for gasoline and 2.2-5.0 km/L for diesel fuel.

Figure 3-7 Fuel Economy of Existing Vehicle Fleet



A recent US EPA report (1999c) provides a detailed review of motor vehicle fuel economy and technology trends that shows trends relevant to the North American economies specifically and to the APEC region in general. The new vehicle test fuel economy of the combined passenger car[1] and light duty truck[2] fleet sold in the United States has declined about 8 % from a high of 11.0 km/L (25.9 mpg) in 1987/88 to a low of 10.1 km/L (23.8 mpg) in 1999. For the North American driver, the on-road fuel economy of light duty vehicles is typically about 85.4% of the test fuel economy. On this basis, the 1999 on-road fuel economy of the new light duty vehicle fleet in the United States was 8.6 km/L (20.3 mpg). Because of harmonisation of motor vehicle standards between Canada and the United States, the new passenger car fleet fuel economy in Canada is becoming close to that for the United States.

The fuel economies of passenger cars and light duty trucks have been relatively stable over the past decade, as shown in Figure 3-8. In 1999, the passenger car and light truck test fuel

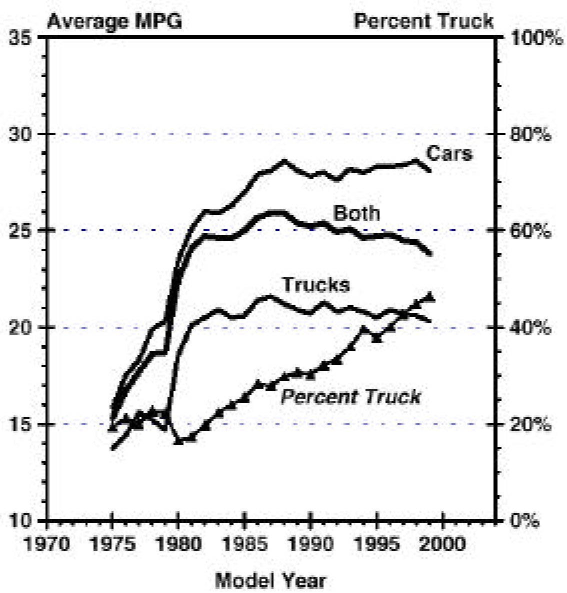
[1] Passenger cars include two-seater cars, sedans and station wagons.

[2] Vehicles with a gross vehicle weight rating of up to 8,500 lbs, including pickup trucks, vans, minivans and sport utility vehicles.

economies were 11.94 km/L (10.2 km/L on-road) and 8.63 km/L (7.37 km/L on-road), respectively. Manufacturer's vehicles are to meet the Corporate Average Fuel Economy (CAFE) standards established by Congress under the Automotive Fuel Economy Program (US DOT, 2000). The CAFE fuel economy standard for passenger cars over the 1990-2001 period is 27.5 mpg (11.7 km/L), while the standard for light duty trucks is 20.7 mpg (8.8 km/L) for the period 1996-2001. Over the period 1990 - 1996 in Canada, the new car fleet fuel economy improved 8.5% from 9.7 km/L to 10.5 km/L (NR Can OEE, 1998).

The fuel economy of the light duty vehicle fleet has declined as light duty trucks, with a lower fuel economy relative to passenger cars, have captured an increasing share of the sales of light duty vehicles. Light duty trucks were about 46% of the light duty vehicle sales in 1999, and their share of sales continues to grow. Light duty vehicle sales in 1999 consisted of 51.8% passenger cars, 1.7% station wagons, 10.3% vans, 19.9% sport utility vehicles and 16.3% pickup trucks.

Figure 3-8 US Test Fuel Economy by Model Year



Since 1990, new passenger car fleet curb weight has increased 7.2% from 1319 kg to 1413 kg and horsepower per vehicle weight has increased 15% from 4.53 hp/100 lb to 5.21 hp/100lb, while fuel economy remained fairly constant (1% increase). Substantial technology improvements have been accomplished to provide increased vehicle performance and features while meeting more stringent vehicle emission standards and existing CAFE fuel economy standards. Figure 3-9 Illustrates the passenger car fleet inertia weight (curb weight plus 300 lb) and improved acceleration time to 60 mph which have been achieved and the associated fleet fuel economy since 1975.

The EPA (1999c) estimated that higher passenger car fleet fuel economies could have been achieved if vehicle acceleration and weight had remained the same as in 1986. Under this scenario, model year 1999 passenger cars could have had a test fuel economy of 14 km/L, or an on-road fuel economy of 12 km/L. This level is about 20% higher than presently exists. Similarly, light duty trucks could have an average test fuel economy of 10.6 km/L, or on-road fuel economy of 9.1 km/L, exceeding the current fleet average by 23%.

Passenger cars made by manufacturers based in Asia have consistently had higher fleet fuel economies relative to domestic US passenger cars, which in turn have slightly higher fuel economies relative to European manufacturers (Figure 3-10). In 1999, Asian passenger cars sold in the US had a test fuel economy of 12.8 km/L (on-road 11.0 km/L), or 7.5% higher than the passenger car fleet average for all manufacturers.

Figure 3-9 US Passenger Weight and Acceleration Time

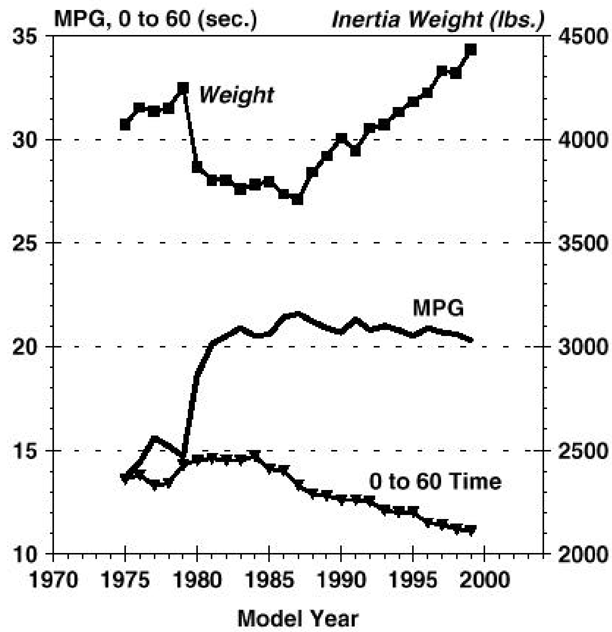
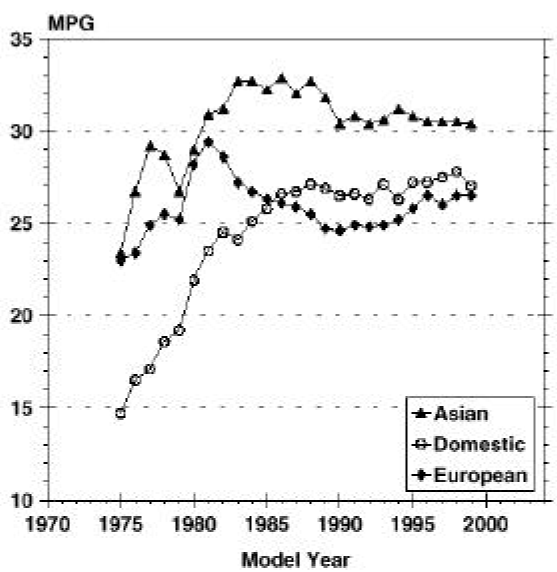


Figure 3-10 Passenger Car Fuel Economies for Domestic and Imported Vehicles



3.4.3.2 Future Vehicles

A very limited number of responses were received from the surveyed APEC economies regarding the future fuel economy of the existing vehicle fleet. The responses received or developed from provided data were as follows:

- Canada (percent of fuel economy (km/L) change by 2020 relative to 1997):
  - 19% improvement in existing passenger car fleet.
  - 12% improvement in new light duty truck fleet.
  - 5.5% improvement in new heavy duty truck fleet.
- United States (percent fuel economy (km/L) change by 2010 relative to 1998):
  - 8.2% improvement in existing passenger car fleet.
  - 1% improvement in existing light duty truck fleet.
  - 7.4% improvement in existing heavy duty truck fleet.

The US EIA Annual Energy Outlook (2000) has estimated a gradual improvement in the fuel economy of light duty vehicles over the period from 2000 to 2020. The fuel economy of new passenger cars is project to improve by 1.2 km/L (10%), while the fuel economy of new light duty trucks is projected to improve by 0.9 km/L (4.3%). This improvement is based on gradual introduction of advanced and alternative engine and vehicle technologies and lower weight vehicle materials, combined with the off-setting effects of increases in the average horsepower and weight of motor vehicles.

- Japan

Under Articles 18 and 20 of the Law concerning the Rational Use of Energy, MITI and the Ministry of Transport (1999) have established standard energy efficiency levels for gasoline and diesel fuelled passenger motor vehicles shipped to the Japanese market which shall be attained beginning April, 2010.

Nine categories of gasoline motor vehicles by weight and seven categories of diesel motor vehicles by weight have specified standard efficiency levels. For a 1,266 kg to 1,516 kg gasoline passenger car the standard efficiency is 13.0%, while the value for the same size of diesel fuelled car is 13.2%. Japan has established a "Top Runner" program as a means to encourage energy savings for 12 categories of products, which includes gasoline and diesel fuelled passenger cars and freight vehicles. The Top Runner program establishes a target energy efficiency as the highest energy efficiency of all the products in an equivalent group. If the energy efficiency of a manufacturer's product is unable to rise to the Top Runner efficiency by a specified target date such measures as recommended by MITI will be imposed.

The energy efficiency (fuel economy) improvements for motor vehicles projected as a result of implementation of the Top Runner program are as follows relative to 1995:

- Gasoline fuelled passenger vehicles: 23% by 2010.
- Gasoline fuelled freight vehicles (2.5 tonne or below): 13% by 2010.
- Diesel fuelled passenger vehicles: 15% by 2005.
- Diesel fuelled freight vehicles (2.5 tonne or below): 7% by 2005.

- Australia

A study by the CSIRO for Australia (Manins, 2000) projected an improvement in the fuel economy of the new passenger car fleet in Australia from 11.1 km/L (9L/100km) in 1992/93 to perhaps 15.6 km/L (6.4 L/100km) by 2015 if the shift to higher engine sizes ceases. The new car fuel economy (as km/L) is presently poorer in Australia than in the US and Japan, but is forecast to approach the levels in these economies by 2005. The existing and forecast fuel economies for passenger cars from this study are as follows:

Year	Fleet Average		New Vehicle	
	km/L	L/100km	km/L	L/100km
1985	8.3	12	8.9	11.25
1990	8.3	12	9.5	10.5
1995	8.5	11.75	9.6	10.4
2000	9.1	11.0	10.3	9.75
2005	9.5	10.5	10.8	9.25

– The business as usual projection for improvement in the fuel efficiency of new passenger cars has been estimated to be 1% per year for 2000-2010 (Environment Australia, 1999)

3.4.4 Vehicle Emission Standards

Recent and planned emissions standards for gasoline fuelled passenger cars were compiled for 17 of the APEC economies from responses to the questionnaire survey, together with public supplemental sources of information, and are presented in Table 3-5, along with the current and proposed standards for the European Union. These focus specifically on gasoline passenger cars, however, there are standards in all the economies for other classes of vehicles as well. The main sources of vehicle emission standards are the European Union and the US EPA, with lesser reference currently to Japanese standards. Many economies are implementing or planning to implement lower emission standards for passenger cars and other vehicles though these vary significantly.

Table 3-5 shows the existing US Tier 1 standards and the proposed US Tier 2 standards. There is also bridging national low emission vehicle (NLEV) standards that apply in the continental US for the period from 2001 through 2003. The NLEV standards for passenger cars at 80,000 km are 2.1 g/km CO, 0.124 g/km NO_x (equal to 50% of the Tier 1 standard) and 0.05 g/km for NMOG (same as the Tier 2 standard). California has implemented stage I of its low emission vehicle standards (LEV I) and will implement LEV II emission standards for new vehicles. These standards are lower than required under US EPA regulations and have been adopted in some states and regions of the US outside California. The NLEV standards where made equal to the LEV standards already used on commercial vehicles under the LEV I program. The LEV II program has similar NO_x standards, but lower nonmethane organic gas (NMOG) standards than proposed under the Tier 2 program.

The US Tier 2 emission standards for passenger cars are lower than emission standards proposed to be met in all other APEC economies except Canada where the vehicle standards are harmonized. Achieving the US Tier 2 standards requires lowering of the sulphur content of gasoline to 30 ppm, which as been legislated. A unique feature of the Tier 2 standards is the requirement that all light duty vehicles up to a GVWR of 3,856 kg comply with the standards by 2009. This will help combat the adverse affect on fleet emissions of the continuing growth in the proportion of light duty trucks in the on-road vehicle fleet. The EURO IV has a significantly higher NO_x standard and a lower CO standard than that included in the US Tier 2 standards.

The new emission standards for passenger cars proposed in several of the developing APEC economies by the middle of the decade will reduce combined NO_x and hydrocarbon emissions from new vehicles by 50%, or more. The continued introduction of these cleaner new vehicles will decrease the emissions per kilometer traveled by the on-road vehicle fleet, however, rapid growth in the number of vehicles and greater distances traveled per vehicle has historically led to renewed growth in fleet emissions in many areas. Introduction of ever more stringent emission standards is required under these circumstances to maintain air quality at a desired level, thus counteracting the effects of growth in vehicle travel.

Current and proposed emission standards for heavy duty diesel vehicles are summarized in Table 3-6 for the US EPA and Table 3-7 for the European Union. Neglecting the effect of the different test cycles used for these two sets of emission standards, the EURO I to IV standards have similar NO_x emission levels, but lower hydrocarbon and particulate matter and much lower CO emission levels than the US EPA standards in similar model years. The proposed US EPA 2007 standard has significantly lower limits than EURO V for all parameters.

Table 3-5 Light Duty Gasoline Vehicle Emission Standards

Economy	Effective Date	Name	CO g/km	NOx g/km	HC g/km	NMOG g/km	PM g/km	Comments
Australia	1997/99	ADR 37/01**	2.1	0.63	0.26	-	-	At 80,000 km. Same as US 1981.
	Western AU 2001 All AU, 2005/06	Euro 3	2.3	0.15	0.20	-	-	Full harmonisation with UNECE standards.
Canada	1988	US Tier 0	2.1	0.62	0.25	-	-	Same as US, but later introduction
	1998	US Tier 1	2.1	0.25	0.16	-	0.05	Same as US, but later introduction.
	2004-07	US Tier 2	2.1	0.03	-	0.05	0.01	Same as US Tier 2
Chile	1995		2.1	0.62	0.25	-	-	Same as US Tier 0.
China	2000		2.72	0.97		-	-	PM 0.14 for diesel. Same as EC 93
	2002 or 2005		2.2	0.50				Option to subscribe to 91/441 (2000), 94/12 (2005) or 94/12 (2002) for PC
Chinese Taipei	1995	Stage II-3	2.1	0.62	0.26	-	-	Same as US Tier 0
	1999	Stage III	2.1	0.25	0.16	-	-	Same as US Tier 1
	Not determined	Stage IV				-	-	Considering adoption of next stage of US, EU or Japan as Stage IV.
Hong Kong, China	1995		2.1	0.62	0.25	-	-	Same as US Tier 0
	1999		2.2	0.5				Same as EC 96/69/EC#
	2001		2.3	0.15	0.20			Same as EURO III
Indonesia	2003		2.72	0.97		-	-	PM 0.14 for diesel. Same as EC 93
Japan	CO & HC, 1975 NO_x 1978		2.7/2.1	0.48/0.25	0.39/0.25	-	-	PC & LDV < 1,700 kg. Maximum/average emission rates. 10-15 Mode test cycle.
Korea	1998		2.1	0.42	0.25	-	-	
	2000		2.1	0.25	0.16			Same as US Tier 1
Malaysia	1997		2.72	0.97		-	-	PM 0.14 for diesel. Same as EC 93
	2003		2.2	0.50				Same as EC 96/69/EC#
Mexico	1997		2.1	0.62	0.25	-	-	Same as US Tier 0. Moving to harmonisation with US & Canada.
Philippines	2000		2.72	0.97		-	-	PM 0.14 for diesel. 91/441 EEC#
	2003		2.2	0.5		-	-	Same as EC 96/69/EC
Russia	1999		2.2	0.5		-	-	ECE R 83/02
Singapore	1994		2.72	0.97				PM 0.14 for diesel. Same as EC 93
	2000		2.2	0.50		-		Same as 96/69/EC
Thailand	2000		2.72	0.97		-	-	PM 0.14 for diesel. Same as EC 93
	2003		2.3	0.15	0.20	-	-	Same as EURO III
United States	1981	Tier 0	2.1	0.62	0.25			At 80,000 km.
	1994-96	Tier 1	2.1	0.25	0.16	-	0.05	At 80,000 km.
	PC & LLDT: 2004-07* HLDT : 2008-09*	Tier 2	2.1	0.03	-	0.05	0.01*	At 80,000 km. Uniform phase-in. PM std. shown is at 120,000 mi. Std. shown applies to Bin 5 used as average.
	PC & LLDT: 2004-07	Interim std.	2.1	0.12	-	0.05	0.04	At 80,000 km. Applies to vehicles not meeting Tier 2 during phase-in.
	HLDT: 2008-09	Interim std.	2.1	0.09	-	0.08	0.01	At 80,000 km. Applies to vehicles not meeting Tier 2 during phase-in.
Viet Nam	2003		2.72	0.97		-	-	PM 0.14 for diesel. Same as EC 93
EU	1992	EURO I	4.05	0.49	0.66	-	-	#
EU	1996	EURO II	3.28	0.25	0.34	-	-	#
EU	2000	EURO III	2.3	0.15	0.20	-	-	#
EU	2005	EURO IV	1.0	0.08	0.10	-	-	#

* US Tier 2: PC, passenger car seating up to 12; LLDT, light light duty truck <2,722 kg GVWR; HLDT, heavy light duty truck 2,722-3,856 kg.

** Australia: ADR 37/01applies to light commercial vehicles up to 2,700 kg gross vehicle weight, though values shown are for passenger cars. Euro 3 for gasoline vehicles covers passenger cars and light commercial vehicles. Only the values for passenger cars and for light commercial vehicles up 1,350 kg gross vehicle weight are shown.

Light duty vehicles less than 3,500 kg gross vehicle weight. Test method ECE 15+EUDC.

Sources: Survey responses, Automotive Industries (ai-online.com), European Commission DG Environment, 2000, World Bank, 1997.

Table 3-6 US EPA Emission Standards for Heavy-Duty Vehicles

Model Year	NO_x‡ g/bhp-h	NO_x+NMHC grams/bhp-h	PM‡ (g/bhp-h) Trucks	PM‡ (g/bhp-h) Buses	HC g/bhp-h	CO g/bhp-h
1990	6.0	-	0.6	0.6	1.3	15.5
1991	5.0	-	0.25	0.1	1.3	15.5
1993	5.0	-	0.25	0.1	1.3	15.5
1994	5.0	-	0.1	0.07	1.3	15.5
1996	5.0	-	0.1	0.05**	1.3	15.5
1998	4.0	-	0.1	0.05**	1.3	15.5
2004	-	2.4* or 2.5* & NMHC of 0.5 g/hp-hr	0.1	0.05**	see NO_x+NMHC	15.5
2007‡ proposed	0.2	-	0.01	-	0.14 as NMHC	-

* Options: 2.4 for NO_x+NMHC; or 2.5 for NO_x+NMHC and 0.5 for NMHC.

** The in-use emission rate allowed is 0.07 g/bhp-hr.

‡ Phase in of new standard 25% in 2007, 50% in 2008, 75% in 2009 and 100% in 2010.

Source: US EPA, 1997

Table 3-7 European Union Emission Limits for Heavy-Duty Vehicles

Year	EURO	Test Cycle	NO_x[a]		HC[a]		NMHC[a]		PM[a]		CO[a]	
			g/kW	g/bhp-h	g/kW	g/bhp-h	g/kW	g/bhp-h	g/kW	g/bhp-h	g/kW	g/bhp-h
1993	I	13-mode	8.0	5.96	1.10	0.82	-	-	0.612 0.36[b]	0.456 0.27	4.5	3.4
1996	II	13-mode	7.0	5.22	1.10	0.82	-	-	0.15[c]	0.11	4.0	3.0
2000	III	ESC[e]	5.0	3.73	0.66	0.49	-	-	0.10 0.13[d]	0.07	2.1	1.6
		ETC[f]	5.0	3.73	-	-	0.78	0.58	0.16 0.21[d]	0.12 0.16	5.5	4.1
2005	IV	ESC[e]	3.5	2.61	0.46	0.34	-		0.02	0.015	1.5	1.1
		ETC[f]	3.5	2.61	-	-	0.55	0.41	0.03	0.022	4.0	3.0
2008	V	ESC[e]	2.0	1.49	0.46	0.34	-		0.02	0.015	1.5	1.1
		ETC[f]	2.0	1.49	-	-	0.55	0.41	0.03	0.022	4.0	3.0

a Original units of standard are g/kWh. Values in g/bhp-h are rounded.

b For engines greater than 0.85 kW.

c Until 30/11/98 the particulate limit for engines< 700 cc per cylinder and with a rated power speed of more than 3000 rpm was 0.25 g/kWh.

d For engines <750 cc per cylinder and with a rated power speed greater than 3000 rpm.

e Measured on the European Standard Cycle (ESC).

f Measured on the European Transient Cycle (ETC).

Source: After Marsh et al, 2000.

3.5 EMISSIONS

National emission inventory data was requested in the questionnaire to help assess the contribution being made by the transportation sector to total criteria contaminants and greenhouse gas emissions, and to form a preliminary basis for assessing the associated affects on air quality. Seven APEC economies provided national emissions. Emission data for the large Metropolitan Region in the vicinity of Santiago, Chile and for Chile as a whole were obtained independently from the CONAMA and World Bank web sites. These results are included in the discussion in this section.

The reported emission inventory data were converted to consistent units, checked for reasonableness then used in this study. There are gaps in the emission data provided and more complete data sets could possibly be compiled for the participating APEC economies, and others, with additional time and effort. Outside of this preliminary data review, the emission data was used as provided. The emission inventories provided vary in the scope of emission sources included, use a variety of different emission source categories and are based on emission calculation methods that likely differ. Consequently, the emission inventory results presented in this section are considered suitable for gaining a general sense of the contribution of the transportation sector to total emissions in a region and investigating similarities and differences between the results for different economies, but should be used with discretion and the understanding that the underlying methodologies are not consistent across the APEC economies.

Figure 3-11 presents the distribution of NO_x emissions from transportation and stationary sources for eight APEC economies and the Santiago Metro Region of Chile. The percent of national emissions for these economies that arise from transportation sources ranges from 30% to 52%. The proportion of NO_x from transportation sources is higher in urban settings than nationally, as shown for the Metro Region of Santiago, Chile, where 70% of the NO_x emissions are from on-road sources and 71% are from transportation. This is similar to the situation in the Lower Fraser Valley area surrounding Vancouver, British Columbia, Canada, where light duty-duty, heavy-duty, off-road and other (rail, marine and air) mobile sources contributed 36%, 11%, 7% and 23% to the 1998 regional total NO_x emissions, for a total of 77% from transportation sources (GVRD, 1999). On-road vehicles contributed 70% of the total 1994 NO_x emissions in Mexico City (World Bank, 1997). The higher contribution of on-road vehicles in urban areas needs to be considered when trying to extend national NO_x emission information to urban areas having a significant motor vehicle population.

The contribution of transportation sources to national SO_x emissions is relatively small, ranging from 0.3% in Chile to 18% in Australia (Figure 3-12). The significance of the contribution of SO_x from transportation sources is very dependent on the types of industrial sectors present in the economy, some of which can be significant sources of SO_x. In Canada and the US where average gasoline and diesel fuel sulphur contents are currently about 350 ppm, the transport sector contributes 5-7% of the national SO_x emissions. As observed for NO_x, the contribution of the transport sector in densely populated urban areas is higher than it is nationally and is also very dependent on the contribution from local industrial sources. The contribution of the transport sector to emissions was 15% in the Santiago Metro Region in 1997 and 56% in the Lower Fraser Valley region near Vancouver, British Columbia in 1998. Note that the contribution from the transport sector is high in the Lower Fraser Valley because of low sulphur emissions from industrial sources.

The contribution of on-road vehicles to national emissions of SO_x was 2% in the US and Canada, 7% in Australia, 6% in Hong Kong and 8% in Thailand. In the Santiago Metro Region, 14% of SO_x emissions were reported to come from on-road vehicles. Higher fuel sulphur levels in gasoline and diesel increase the SO_x from on-road vehicles and their potential contribution to total regional SO_x emissions.

The share of emissions of volatile organic compounds (VOC) from transportation sources is strongly affected by the completeness of the inventory and what categories are included. This affects the interpretation of the survey results. The contribution of transportation sources to total VOC emissions is similar for Canada, US, Japan, Chinese Taipei and Chile, ranging from 12-31 % (Figure 3-13). In Australia, Hong Kong and Thailand, the contribution of transportation to total VOC emissions is reported to be from 90-98%. Such high levels are unlikely and probably arise because of the chosen range of emission sources included and the methodologies applied in these economies.

The contribution of on-road vehicles to total national VOC emissions was 16% in Canada, 31% in Chinese Taipei and 27% in the United States. High contributions from on-road vehicles were reported by Australia (83%), Hong Kong (84%) and Thailand (99%). Typically the contribution from on-road vehicles will be higher in urban areas, as illustrated by data for the Lower Fraser Valley near Vancouver, British Columbia, where on-road sources contribute 27% of the VOC emissions compared to a national average of 16%. The contribution of on-road vehicles to total VOC emissions in an urban are is site dependent.

Particulate matter emitted by combustion engines is 90%, or more, PM10. Particle emissions from other combustion sources, if burning clean fuels or equipped with advanced emission control systems also are predominantly under 10 microns in size. A mix of total and PM10 particulate emission inventory data is presented in Figure 3-14. Excluding road dust emissions, which can be a significant contributor to particulate emissions, the transport sector is usually a relatively small contributor to particulate emissions. The United States and Canada reported 2.2 and 1.8% of PM10 emissions, respectively, were from the transport sector. Chinese Taipei reported 9% of PM10 was from the transport sector. Data from the national emission inventory for Canada (Environment Canada, 2000) indicates only 0.6% of total particulate is from the transport sector in Canada, while data available for Australia indicates 16%, perhaps because of differences in assumptions and sources.

For urban areas, on-road vehicles contributed 7% of the total PM10 emissions in the Lower Fraser Valley region of British Columbia in 1998, substantially higher than the national Canadian result of 1.8%. On-road vehicles contributed 31% of the PM10 in the Santiago Metro Region in 1997, based on a regional emission inventory.

Figure 3-15 shows the distribution of CO emissions from the transport sector for APEC economies. Transportation contributes 39% of the CO emissions in Canada (65% if CO emissions from forest fires are excluded as for the US), 40% in Chile, 54% in Japan, 77% in the United States and 79% in Chinese Taipei. Higher contributions are reported for Australia, Hong Kong, and Thailand, which are in the range of 88-97%.

Motor vehicles have historically been a major source of carbon monoxide emissions. The CO emissions from this source segment has declined significantly in North America and any other areas where catalytic control equipment has been required on motor vehicles for a prolonged period. The contribution of on-road vehicles to total CO emissions in Canada is 52% (excluding forest fire emissions) and 58% in the United States. Higher contributions of on-road vehicles are reported by Chinese Taipei (79%), Australia (83%), Hong Kong (83%) and Thailand (97%). In the Santiago Metro Region, on-road vehicles contribute 92% of the CO, while the contribution is similar (84%) in the Lower Fraser Valley region of British Columbia, Canada.

NO_x, VOC and CO are precursors to formation of ground-level ozone, an important air quality issue throughout the APEC region. NO_x and SO_x and ammonia emissions are precursors to atmospheric formation of secondary PM10 and PM2.5, which have become significant concerns because of the growing body of knowledge about their adverse health effects. Formation of ozone and secondary particulate matter from precursor emissions should be considered in conjunction with the direct effects of the precursor emissions on ambient air quality.

Figure 3-16 shows the results for seven comprehensive national CO_2 emission inventories. The contribution of CO_2 from all transportation sources are in a fairly narrow band of 23-34% of the total national CO_2 emissions. The contribution to national CO_2 emissions from on-road vehicles is 23-25% in Canada and the United States, 19% for Hong Kong and Australia and 37% for Thailand. In the Lower Fraser Valley of British Columbia, on-road vehicles contributed 33% of the total CO_2 emissions from all sources in 1998, which is 1.43 times the national share in Canada. The contribution to total CO_2 emissions from on-road vehicles is typically higher in urban areas having a high motor vehicle population than it is on a national level.

On-road vehicles contribute a high proportion of the emissions of CO_2 from the transportation sector alone. From the survey data for CO_2 emissions, the ratio of on-road vehicle emissions to total transportation emissions is 83% in Canada, 79% in the United States, 77% in Australia, 83% in Hong Kong and 93% in Thailand. Clearly the on-road segment is the predominant source of CO_2 for the transportation sector.

Figure 3-11 Distribution of Annual NO_x Emissions

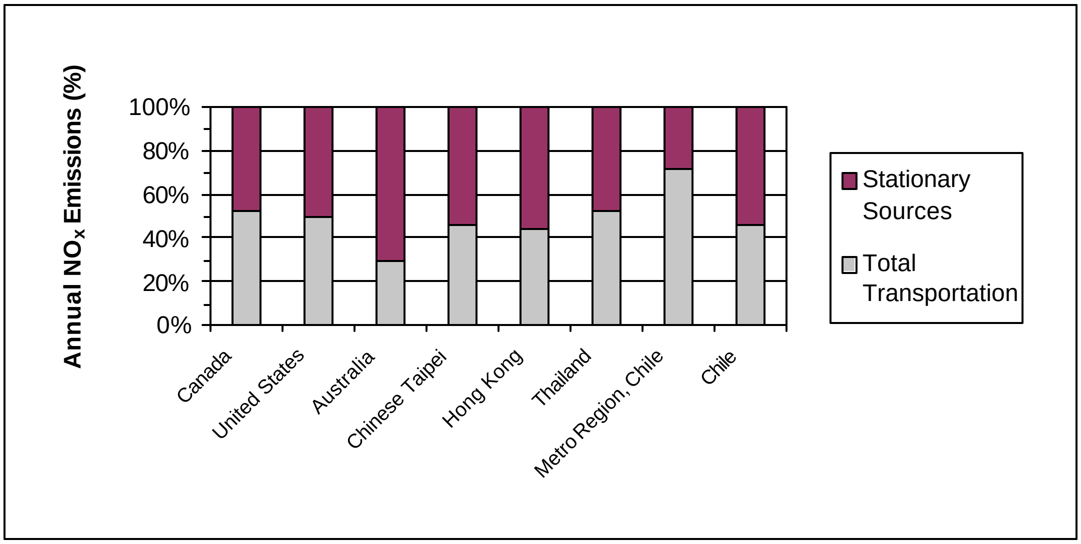


Figure 3-12 Distribution of Annual SO_x Emissions

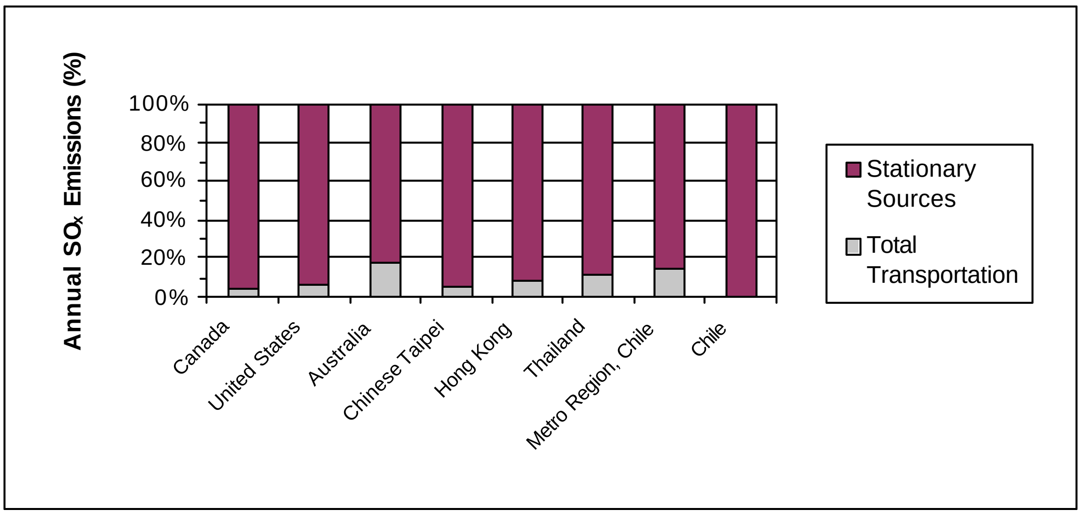


Figure 3-13 Distribution of Annual VOC Emissions

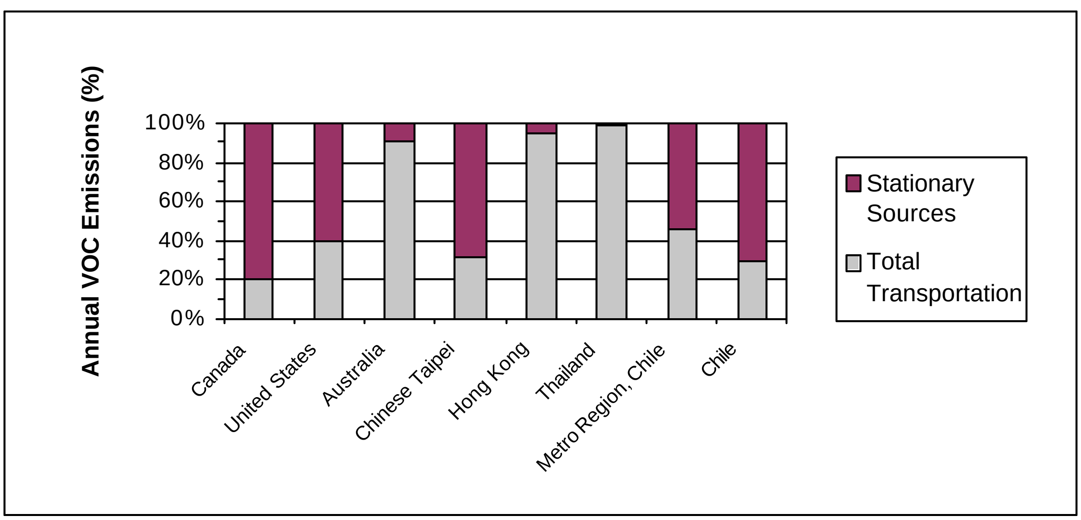


Figure 3-14 Distribution of Annual CO Emissions

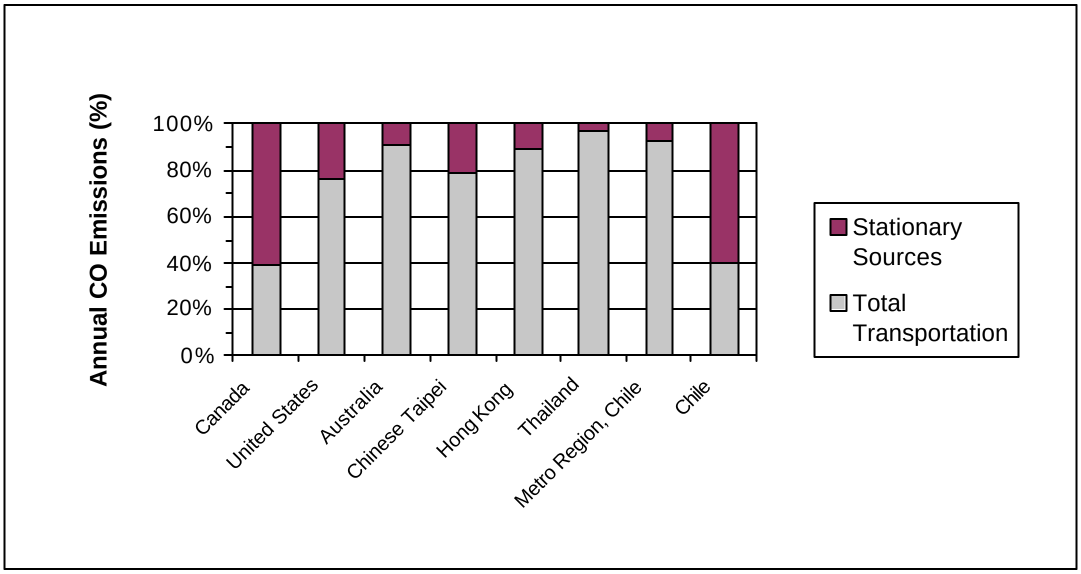


Figure 3-15 Distribution of Annual Particulate Emissions

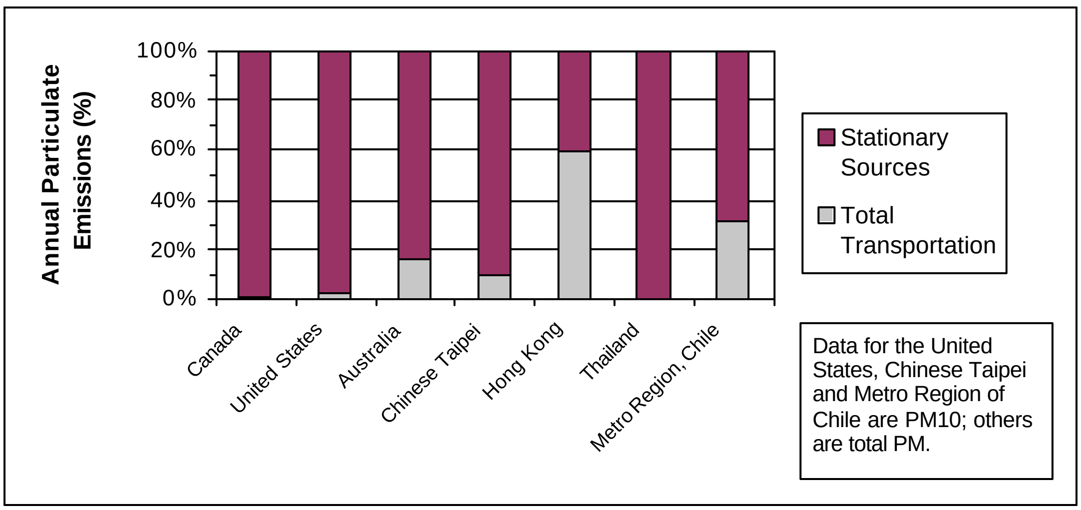
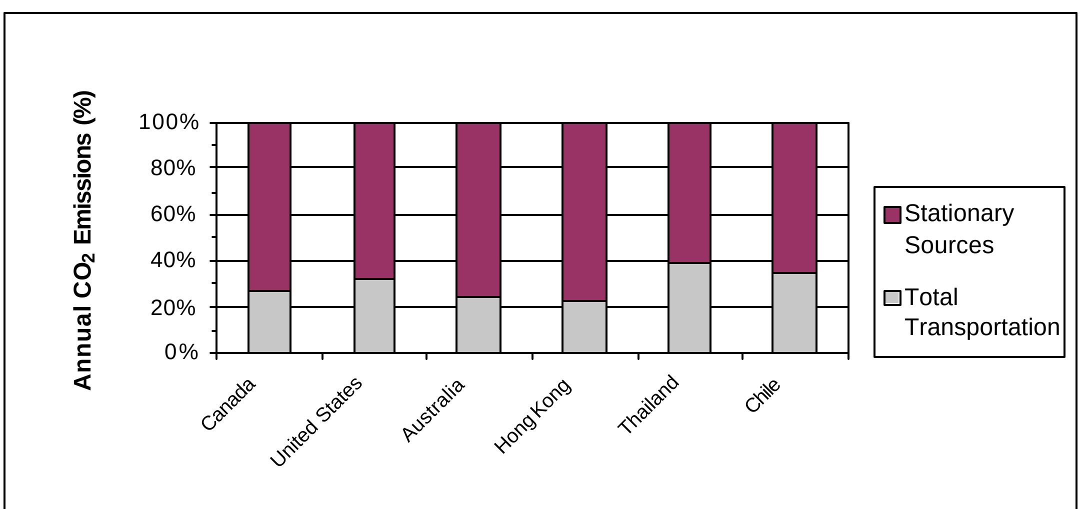


Figure 3-16 Distribution of Annual CO_2 Emissions



4. REVIEW OF FUELS OPTIONS AND THEIR INFLUENCE ON EFFICIENCY AND EMISSIONS

4.1 PETROLEUM FUELS

The petroleum based fuels, gasoline and diesel account for the majority of the transportation fuels consumed by the APEC economies. The petroleum resources for the APEC economies are shown in Table 4-1(US EIA). A negative sign in the exports column indicates net oil imports in the country. Oil demand includes crude oil and refined petroleum products. Only seven of the 21 countries are net exporters of petroleum.

Table 4-1 Petroleum Production, Demand and Exports.

Economy	1998 Oil Production	1998 Oil Demand	1998 Oil Exports Net
Units	Thousand BBL/Day	Thousand BBL/Day	Thousand BBL/Day
Australia	544	831	-287
Brunei Darussalam	157	16	141
Canada	1,981	1,873	108
Chile	8	245	-233
China	3,198	4,110	-912
Chinese Taipei	1	789	-788
Hong Kong, China	0	184	-184
Indonesia	1,518	970	548
Japan	9	5,512	-5,503
Malaysia	733	455	278
Mexico	3,070	1,950	-1,120
New Zealand	47	133	-86
Papua New Guinea	79	16	63
Peru	116	170	-54
Philippines	1	361	-360
Republic of Korea	0	1,995	-1,995
Russia	5,854	2,460	3,394
Singapore	0	580	-580
Thailand	75	685	-610
USA	6,252	18,917	-12,665
Viet Nam	246	175	71

Most but not all of the economies have petroleum refineries that supply their transportation fuel needs. All of the economies are involved in the import or export of refined petroleum products. In Table 4-2 a brief overview of the refined products production capacity and the level of imports and exports is shown for each of the economies (US EIA). Six of the countries are net exporters of refined petroleum products with the remainder all requiring some refined product imports to meet the local transportation fuel requirements. A negative sign in the table indicates product imports.

Table 4-2 Refined Products Production, Imports and Exports.

Economy	1999 Refining Capacity	1997 Product Net Exports
Units	Thousand BBL/Day	Thousand BBL/Day
Australia	807	24
Brunei Darussalam	9	-3
Canada	1,873	548
Chile	205	-49
China	4,347	-247
Chinese Taipei	770	-106
Hong Kong, China	0	-124
Indonesia	930	-35
Japan	5,069	-1,178
Malaysia	474	-71
Mexico	1,525	-206
New Zealand	98	-26
Papua New Guinea	0	-14
Peru	182	-6
Philippines	389	-6
Republic of Korea	2,540	121
Russia	6,745	1,136
Singapore	1,172	466
Thailand	713	46
USA	16,261	-1,040
Viet Nam	0	-159

Only three of the economies (Hong Kong, Papua New Guinea and Viet Nam) do not have a significant refining industry in relation to the refined product demand in those countries. Construction commenced on a refinery in Viet Nam in 2000 (World Fuels Today). The gasoline and diesel fuel quality is therefore largely internally driven in each region.

4.1.1 Gasoline

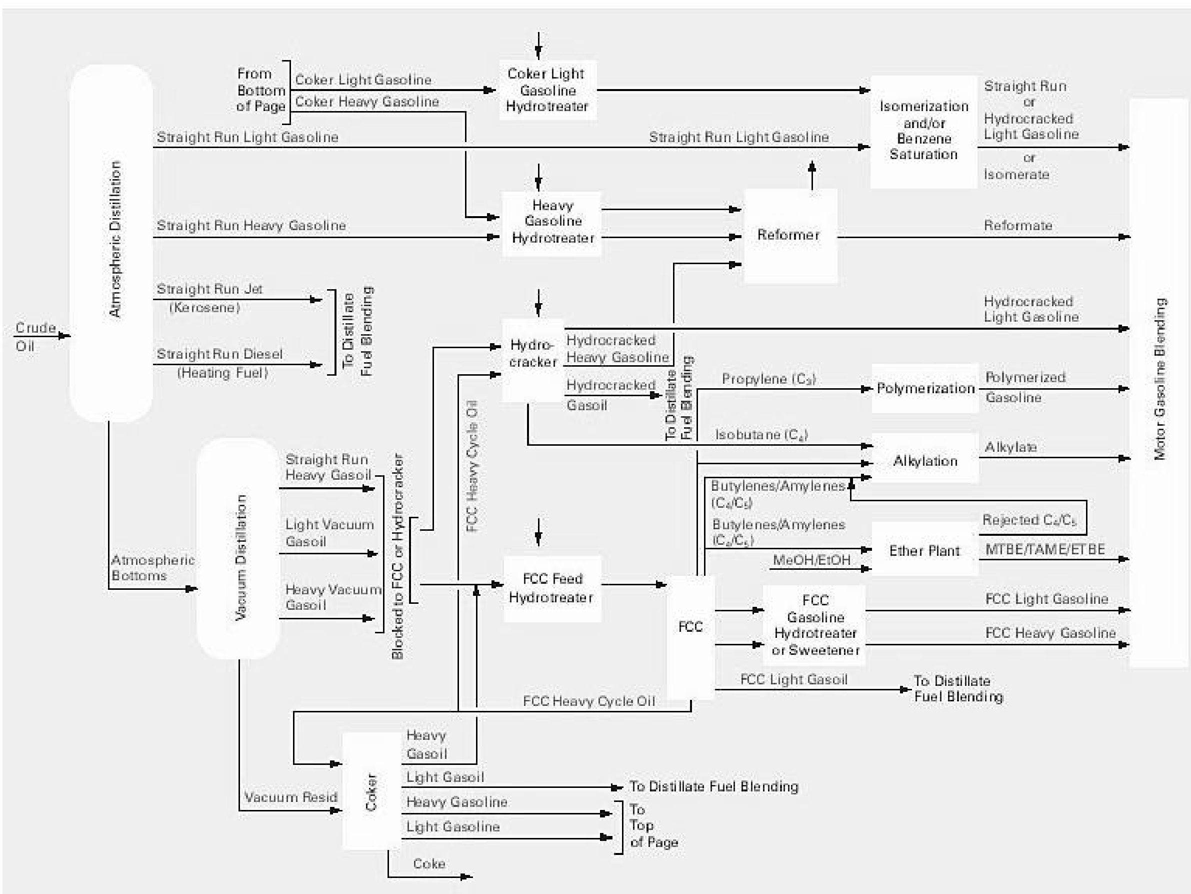
Gasoline and diesel fuels are complex mixtures of hydrocarbons that are produced from refining crude oil. These two fuels provide the majority of the energy requirements of the transportation sector. Traditionally the fuels have been blended to meet the performance requirements of the vehicles they are used in and to balance the production at the refinery. Refiners increasingly have to blend fuels to meet environmental requirements, allowing vehicles to operate with lower exhaust emissions.

Not only are fuels complex mixtures but the refineries that produce them are also complex manufacturing processes that combine many individual process operations to obtain the required yield of fuels demanded by the market in the most efficient and cost effective manner. The schematic layout of a typical refinery is shown in Figure 4-1 (Chevron, 1996).

Crude oil is fed to the distillation column where straight run light and heavy gasoline, jet and diesel are separated at atmospheric pressure. Whereas straight-run jet and diesel are usually acceptable as is, the straight-run gasolines typically require more processing to convert them into gasoline blending components. The straight run light gasoline may be isomerized to increase octane, hydrotreated to convert benzene to cyclohexane so that the final gasoline blend will meet a benzene specification limit, or both. The straight run heavy gasoline is hydrotreated to remove sulphur and then reformed to improve octane and generate hydrogen for the hydrotreaters.

The bottoms from the atmospheric column is vacuum distilled to obtain gas oils for FCC or hydrocracker feed. The gasoils are hydrotreated to reduce sulphur and nitrogen to levels which will not interfere with the FCC process. Even though the feed is desulphurized, the FCC product must be sweetened to convert reactive sulphur compounds (mercaptans) to more innocuous ones, otherwise the gasoline blend will be malodorous and unstable. In the future with tighter restrictions on the sulphur content of finished gasoline, the FCC product must be further desulphurized.

Figure 4-1 Gasoline Processing in a Modern Refinery.



Vehicle emissions are a function of not only vehicle characteristics but also fuel composition. The Auto/Oil Air Quality Improvement Research Program (AQIRP) was initiated in North America in the late 1980's to develop a better understanding of the relationships between gasoline composition and fuel parameters and vehicle emissions. The AQIRP program, efforts of the US EPA and California and similar programs undertaken in Europe throughout the 1990's has lead to a much better understanding of the impact of gasoline parameters on vehicle exhaust emissions.

A recent presentation from the California Air Resources Board (1999) summarized the emissions response to gasoline parameters. That summary is shown in Table 4-3.

Table 4-3 Summary of Emission Response to Fuel Parameter Changes

Decreasing Fuel Parameter	Leads to
RVP	Reduced evaporative VOC's
Sulphur	Reduced VOC's, NO_x, Toxics, SOx
Benzene	Reduced Toxics
Aromatics	Reduced VOC's, NO_x, Toxics
Olefins	Reduced NO_x, Toxics, Increased VOC's
T50 and T90	Reduced VOC's, Toxics, Increased NO_x
Oxygen	Increased VOC's, Toxics, CO, Reduced NO_x

Gasoline is formulated to meet many quality parameters including octane, volatility, driveability, and energy content. In addition a refiner must simultaneously meet the quality specifications of the other products being produced. The result is that it is extremely difficult to change only one parameter at a time. For example aromatics are a good source of octane, so lowering aromatics to reduce VOC's, NO_x and toxics must be offset by increasing another component that will increase octane.

Adding an oxygenate to gasoline such as ethanol or MTBE, not only reduces VOC's, CO, and toxics and increases NO_x it also adds octane so the aromatics can be reduced. A refiner that takes full advantage of the properties of the oxygenate can therefore reduce VOC's and toxics further and offset at least some of the NO_x increase usually associated with oxygenates. The oxygenate will also dilute some of the other gasoline parameters such as benzene and sulphur leading to further small improvements in air quality.

Automobile manufacturers around the world in recent years (AAMA 1998, Alliance of Automobile Manufacturers, 2000) have published their recommendations for gasoline and diesel fuel quality. These recommendations have been issued in part in response to emerging needs and in some cases regulations for more stringent vehicle emission control and reduced fuel consumption. Fuel specifications can impact directly on emissions and fuel economy as shown above and they can also act as technology enablers for new advanced emission control strategies. A review of the key elements of the newest proposed World-Wide Fuel Charter (WWFC) is an appropriate way to consider the gasoline and diesel fuel options and their influence on vehicle emissions and efficiency.

4.1.1.1 World-Wide Fuel Charter

In April 2000, the Alliance of Automobile Manufactures in conjunction with the European Automobile Manufacturers Association, the Engine Manufacturers Association and the

Japan Automobile Manufacturers Association issued a revised World-Wide Fuel Charter to address the need for more stringent standards on fuel sulphur that will be necessary to enable future vehicle technology to meet emerging requirements for vehicle fuel economy and vehicle emissions. This new proposal adds a fourth category for both gasoline and diesel fuel. The gasoline categories are summarized in Table 4-4.

Table 4-4 Summary of World-Wide Fuel Charter for Gasoline.

Property	Units	Category 1	Category 2	Category 3	Category 4
Octane[3]	MON	82.0	82.5	82.5	82.5
	RON	91.0	91.0	91.0	91.0
	R+M/2	86.5	86.75	86.75	86.75
Sulphur	ppm	1000	200	30	Sulphur-free[4]
Lead	g/L	0.4[5]	Non-detectable (n.d.)	n.d.	n.d.
Phosphorus	g/L	No spec	n.d.	n.d.	n.d.
Manganese	g/L	Not added[6]	n.d.	n.d.	n.d.
Silicon	g/L	No spec	n.d.	n.d.	n.d.
Oxygen	% wt	2.7[7]	2.7[5]	2.7[5]	2.7[5]
Olefins	% v/v	No spec	20.0	10.0	10.0
Aromatics	% v/v	50.0	40.0	35.0	35.0
Benzene	% v/v	5.0	2.5	1.0	1.0
Volatility End Point	C	215	195	195	195
Density	Kg/m^3	715-780	715-770	715-770	715-770
Inlet Valve Cleanliness	mg/valve	Requires additive	50	30	30
Combustion Chamber Deposits	mg/engine	No spec	3500	2500	2500

Gasoline specifications for any country rarely follow exactly all the requirements for a category. Many of the industrialized countries are in the process of moving their specifications toward Category 3.

The technical background for the limits are described in the following sections with particular emphasis on the property's impact on efficiency and emissions.

[3] Lowest grade shown here.

[4] 5-10 ppm based on available data. To be more specific when more data is available.

[5] Where legally permitted. Otherwise 0.013 g/L.

[6] Not intentionally added.

[7] Ethers preferred, but up to 10% ethanol where permitted. No methanol.

4.1.1.2 Octane

Gasoline octane is a measure of its ability to resist auto-ignition. Vehicles are designed to operate on a certain octane gasoline. Gasoline with a lower value than the vehicle was designed for may result in engine damage and reduced power and fuel economy. Octane level requirement is a function of engine compression ratio, which in turn impacts engine efficiency. High compression, high efficiency engines require high-octane gasoline. High-octane gasoline requires more processing and consumes more energy in the refinery, which offsets some or all of the vehicle efficiency gains. It is apparent from Table 4-5 that higher octane gasoline is not a priority for the world's automobile manufacturers.

The survey data for gasoline octane is shown in Table 4-5. The survey data has been augmented with additional data from industry sources. Most countries have more than one grade of gasoline. The data is for the lowest grade of gasoline. Most countries reported octane levels that met the category 4 level for unleaded gasoline. The octane requirements of the World-Wide Fuel Charter are such that fuels are likely to meet the requirements of level four or fail to meet the requirements of level one. Gasoline octane has been increasing in the Asia region (Yamaguchi) with the average refinery octane level of 88.5 RON in 1991 increasing to a projected 91.6 RON in 2000. In the People's Republic of China it is reported (Guoming) that in 1997 over 70% of the gasoline was over 90 octane and that in 1998 the production of 70 octane gasoline was stopped. Between 1988 and 1998 there was a 10 unit increase in gasoline octane.

The World Bank is leading efforts to harmonize fuel specification in Latin America and the Caribbean. The APEC countries in South America, Peru and Chile, are participating in this process. It is proposed that gasoline octane will be 86.5 (R+M/2) for regular unleaded and 90 for premium unleaded by the year 2005.

4.1.1.3 Sulphur

Sulphur occurs naturally in crude oils. Some is normally removed in the refining process and essentially all sulphur in gasoline can be removed if desired. Sulphur has a significant affect on vehicle emissions as it reduces the efficiency of vehicle catalysts. The quantity of the impact is dependent on the change in fuel sulphur and the type of emission control system installed on the vehicle. The US EPA (1999) has proposed the following sulphur impacts for inclusion in the new US EPA Mobile 6 motor vehicle emission model.

For all types of emission controlled vehicles reducing fuel sulphur reduces emissions. The newer Low Emission Vehicles exhibit the greatest impact from fuel sulphur. There are similar results reported in the World-Wide Fuel Charter for European and Japanese test programs.

Auto manufacturers are working on future technologies for improving fuel efficiency and reducing emissions of greenhouse gases. One of the technologies being pursued is operation at lean air-fuel ratios. This produces a challenge for NO_x control. Lean NO_x traps appear to be very sensitive to fuel sulphur and sulphur free gasoline may be required to maintain high NO_x conversion efficiencies. This is the reason for the addition of Category Four gasolines in the latest World-Wide Fuel Charter.

The trend in cleaner burning gasoline is for reduced sulphur content. The Category 3 limit is 30 ppm in the Charter. Category 4 is expected to be sulphur free.

Table 4-5 Gasoline Octane

Economy	Typical Values R+M/2	WWFC Category for Typical Value
Australia	87.0[8]	4
Brunei Darussalam	97 RON[9]	4
Canada	87	4
Chile	93 RON	4
China	85	<1
Chinese Taipei	92 RON	4
Hong Kong, China	90 RON	4
Indonesia	88 RON	<1
Japan	89 RON	<1
Malaysia	92 RON	4
Mexico	87	4
New Zealand	86.5	1
Papua New Guinea		
Peru	90 RON[10]	<1
Philippines	81 RON	<1
Republic of Korea	87	4
Russia		
Singapore	90	4
Thailand	81.5	<1
USA	87	4
Viet Nam		

Table 4-6 Emission Effects from Varying Sulphur Levels.

Pollutant	% Increase in Emissions When Sulphur is Increased from 30 ppm to:											
	75 ppm			150 ppm			330 ppm			600 ppm		
	Tier 0	Tier 1	LEV	Tier 0	Tier 1	LEV	Tier 0	Tier 1	LEV	Tier 0	Tier 1	LEV
HC	5.77	3.69	16.7	10.4	10.1	31.1	15.8	27.3	49.8	20.1	34.8	65.6
NMHC	5.17	3.30	13.7	9.26	9.05	25.3	14.1	24.2	39.9	17.9	30.7	52.1
CO	7.21	2.87	24.3	13.0	7.85	46.5	20.0	20.8	76.7	25.6	26.6	103.6
NO_x	2.86	1.44	38.3	5.08	3.89	76.8	7.66	10.0	133.6	9.66	12.6	188.7

[8] Unleaded gasoline. www.environment.gov.au/epg/fuel/transport.html.

[9] Unleaded gasoline.

[10] Regular unleaded grade. Lower octane (84 RON) leaded gasoline is being phased out.

The data for gasoline sulphur content is shown in Table 4-7. Some of the responses are the specification maximum and not the average level. There are some economies that are moving to lower sulphur levels, which will reduce emissions from vehicles equipped with catalytic converters.

Table 4-7 Gasoline Sulphur Contents.

Economy	2000 Sulphur Content ppm	2005 Sulphur Content ppm
Australia	150 (average)	
Brunei Darussalam	1000 max	
Canada	350 (average)	30
Chile	300 (typical)	
China	1000 max	
Chinese Taipei	275 max	
Hong Kong	500 max	150 max
Indonesia	2000 max	
Japan	100 max	
Malaysia	1500 max	
Mexico	500 max	
New Zealand	500 max	
Republic of Korea	200 max	
Peru	200 (average)	
Philippines	1000 max unleaded	
Singapore	130	
Thailand	1000 max	
United States	340	30

4.1.1.4 Lead

Lead additives have been used since the 1920's to inexpensively increase the octane of gasoline. Concerns with lead emissions and their impact on human health have resulted in many markets removing lead from gasoline. Unleaded gasoline is also required to support emission control technologies such as catalytic converters. Lead free gasoline is inevitable in all markets.

Removing lead from gasoline does lower the energy efficiency of the total fuel cycle as the replacements for lead, typically higher aromatic content of gasoline consumes more refining energy and results in a lower gasoline yield in the refinery.

The trend for cleaner burning gasoline is to be lead free. The current situation within the APEC economies with respect to lead is shown in Table 4-8. This information was assembled from the survey, from the International Lead Management Centre (ILMC, 2000) and the US Energy Information Administration.

Table 4-8 Leaded Gasoline Availability within APEC Economies.

Economy	Leaded Gasoline Available	Comments
Australia	YES	Phase out likely by 2002
Brunei Darussalam	NO	
Canada	NO	
Chile	YES	Phase out likely by 2005. Unleaded share 65% in 2000.
China	NO	
Chinese Taipei	NO	
Hong Kong, China	NO	
Indonesia	YES	Phase out expected by 2004
Japan	NO	
Malaysia	NO	
Mexico	NO	
New Zealand	NO	
Papua New Guinea	YES	Imports all gasoline
Peru	YES	Phase out expected by 2004
Philippines	YES	Phase out January 2001
Republic of Korea	NO	
Russia	YES	
Singapore	NO	
Thailand	NO	Since January 1, 1996
USA	NO	
Viet Nam	YES	Phase out by 2010

4.1.1.5 Phosphorus, Manganese and Silicon

Phosphorus, manganese and silicon will form metallic ashes in the combustion process. These ashes can adversely affect the components in the emission control system and result in an increase in exhaust emissions.

MMT (methylcyclopentadienyl manganese tricarbonyl) is a controversial octane boosting additive. It has been used in a number of countries where lead in gasoline has been reduced or eliminated. It is allowed in unleaded gasoline in Canada and the United States by the regulatory authorities but several automobile manufacturers indicate in their owners manuals that damage caused by MMT may not be covered by warranty.

There is some data available that indicates that MMT can lower emissions of NO_x from the vehicle. The use of MMT does reduce the energy requirements in the refinery for producing gasoline.

The trend in cleaner burning gasoline is for no ash forming additives.

4.1.1.6 Oxygenates

Ethers and alcohols can be used as gasoline blending components to increase octane and add oxygen to the gasoline. The oxygen leans the air-fuel ratio resulting in a reduction in carbon monoxide and hydrocarbon emissions and, depending on the level of oxygenate addition, an increase in nitrogen oxides. The effects are reduced with newer vehicles using sophisticated electronic feedback mechanisms as part of the emission control equipment.

The only alcohol permitted in the World-Wide Fuel Charter is ethanol. The most common ether used is MTBE (methyl tertiary butyl ether), although other ethers such as ETBE and TAME are sometimes used.

MTBE use in the United States is under attack. The State of California is in the process of eliminating it from gasoline in the state and the Federal EPA has also announced a legislative agenda that would result in the elimination of MTBE from gasoline. The primary driving force behind these changes is the discovery of MTBE in drinking water sources across the US. The MTBE is believed to have come mainly from leaking underground storage tanks.

An analyses of the impact of ethanol and oxygenates on vehicle emissions ($S\&T^2$, 1999) concluded that oxygen reduced the emissions of CO and HC from the vehicle. The review included a large number of papers published by the US EPA on the subject (EPA 1998; EPA 1999; Rao, 1997, 1998 and 1999; National Science and Technology Council, 1997)

Table 4-9 Impact of Oxygen on Vehicle Emissions.

Pollutant	Emission Reductions per Percent Fuel Oxygen		
	US Tier 0 and prior Vehicle Technology	US Tier 1 Vehicle Technology	US LEV Technology
CO	-3.1 to –9.4	-3.1	Insufficient data
HC	-2.9 to –6.6	-4.0	Insufficient data
NO_x	Deemed zero	Deemed zero	Deemed zero

Oxygenates lead to reduced exhaust emissions. They are treated as a voluntary component of cleaner burning gasoline in the World-Wide Fuel Charter.

4.1.1.7 Olefins

Olefins are unsaturated hydrocarbons. In most cases olefins have high octane values. Olefins are thermally unstable and they may lead to deposit formation in the engine's intake manifold. Increased olefins increase emissions of NO_x and air toxics. They are reactive compounds that readily contribute to ozone formation in the atmosphere.

The trend in cleaner burning gasoline is for lower olefin content. Categories 3 and 4 have a limit of 10% in the Charter.

Five countries reported olefin contents limits or actual average values. That data is shown in Table 4-10. None of the reported values would meet the Category 3 and 4 values of the Charter.

Table 4-10 Reported Olefin Content of Gasoline.

	Reported Value	Comment
Australia	17.1%	Average unleaded
Canada	10.6%	Average
Chile	15.3-34.6 (typical)	
China	35% max	From 2003 or 2000 in large cities
Hong Kong	18%	Limit in 2001
Japan	20% max	
Mexico	15%	Limit. 10% in Mexico City.
Republic of Korea	23% max	
United States	10.8%	Average

4.1.1.8 Aromatics

Aromatics are hydrocarbon components that contain at least one benzene ring. They have generally good octane values and are often used to replace lead in gasoline. They have a high density and can lead to better volumetric fuel economy, however they have a lower energy content per unit of carbon in the molecule and thus lead to increased emissions of CO_2 per distance travelled.

Aromatics are linked to combustion chamber deposits and increased aromatic content leads to increases in emissions of VOC's, NO_x and air toxics. Aromatics are also a precursor to exhaust benzene emissions.

The trend in cleaner burning gasoline is for lower aromatic content with a maximum value of 35% in Category 3 and 4 fuels.

4.1.1.9 Benzene

Benzene is a known carcinogen. It is a naturally occurring component of crude oil, a product of the catalytic reforming of gasoline, and is produced in the combustion process in an engine. The control of the benzene level in gasoline has been recognized by regulators as one of the most effective ways of limiting human exposure to benzene.

The trend in cleaner burning gasoline is towards lower benzene levels in gasoline. The reported survey data for benzene levels is shown in Table 4-11.

4.1.1.10 Volatility

Gasoline volatility is characterized by its vapour pressure and distillation curve. Gasoline volatility can directly impact evaporative emissions from the vehicle and indirectly through ensuring good cold start and warm-up performance which will minimize exhaust emissions.

Gasoline vapour pressure needs to be set in relation to the expected ambient temperatures of the location where the fuel will be used. It is expected that there will be a wide variety of gasoline vapour pressures across the APEC economies.

The temperature at which 10, 50 and 90% of the gasoline evaporates defines the distillation curve. Various driveability indexes, which are a function of the T10, T50 and T90 points, are also used to define and control gasoline volatility. Gasoline volatility must be high enough to provide good starting and driveability characteristics but not too high to cause vapour lock, hot starting problems and high evaporative emissions.

Lowering the T90 and end point temperatures of the gasoline tends to reduce VOC and air toxics emissions, but increase NO_x emissions.

The trend in clean burning gasoline is to lower T90 and end points and lower driveability indexes at the same time as gasoline vapour pressure is lowered.

Table 4-11 Gasoline Benzene Content

Economy	% Volume	WWFC Category for typical value
Australia	2.6 unleaded average	1
Brunei Darussalam		
Canada	1.0 max	4
Chile	1.4-1.8	1
China	2.5	2
Chinese Taipei	1.0 max	4
Hong Kong, China	5.0 max[11]	1
Indonesia		
Japan	1.0 max	1
Malaysia	5.0 – 6.0%	1
Mexico	1.0 – 4.9 max [12]	2
New Zealand	5.0 max	1
Papua New Guinea		
Peru	2.5 max	2
Philippines	4.0 max, 2.0 max 2003	1
Republic of Korea	2.0	2
Russia		
Singapore	5.0 max	1
Thailand	3.5 max	1
USA	1.6 average	2
Viet Nam		

4.1.1.11 Deposit Control Additives

Deposits in the engine can lead to higher exhaust emissions and affect vehicle performance. Even good quality gasoline can produce deposits. To control these deposits gasoline deposit control additives are required. A variety of test procedures are used to measure deposits in an engine. The most effective deposit control additives control fuel injection deposits, intake valve deposits and combustion chamber deposits.

[11] 1.0% max from 2001.

[12] Depends on location and grade.

The trend in cleaner burning gasoline is towards more advanced deposit control systems.

4.1.2 Diesel Fuel

Diesel fuel is widely used throughout all of the APEC economies for heavy-duty truck transport, rail, marine, off-road and in some areas for light duty automobile applications. Diesel engines generally are more efficient than gasoline engines and thus produce fewer greenhouse gas emissions. Emissions of NO_x and particulate matter are higher which is an undesirable characteristic for urban air quality.

The four categories of diesel fuel in the World-Wide Fuel Charter are shown in Table 4-12. The Category 4 sulphur free fuel was added with the latest revision.

Table 4-12 Summary of World-Wide Fuel Charter-Diesel Fuel.

Property	Units	Category 1	Category 2	Category 3	Category 4
Cetane Number	-	48	53	55	55
Cetane Index	-	45	50	52	52
Density	kg/m^3	820-860	820-850	820-840	820-840
Sulphur	% m/m max	0.50	0.030	0.003	Sulphur free
Total aromatics	% m/m max	na	25	15	15
T90	C max	na	340	320	320
T95	C max	370	355	340	340
FBP	C max	na	365	350	350
Carbon residue	% m/m max	0.30	0.30	0.20	0.20
Water content	mg/kg max	500	200	200	200
Injector cleanliness	% air flow loss	na	85	85	85

4.1.2.1 Cetane

Cetane is a measure of the compression ignition behaviour of a fuel. It influences startability, exhaust emissions and combustion noise. The cetane Index is calculated from measured fuel properties. It only reflects the natural cetane of a fuel and not the impact of any cetane improvers. The cetane number is measured on an engine test stand and reflects the addition of any cetane improver additives. Vehicle performance and emissions may respond differently to the two measures.

Increasing the cetane number is known to decrease the cranking time necessary to start the engine. The European Automotive Manufacturers Association's follow-up European Program on Emissions, Fuels and Engine Technology (EPEFE) found that cranking time could be reduced by up to 40% with an increase in cetane number from 50 to 58.

Cetane also impacts exhaust emissions and fuel consumption. The EPEFE found that for heavy duty engines increasing cetane from 50 to 58 reduced HC emissions by 30-40%, and at low loads emissions of NO_x were reduced by up to 9%. At high loads (more than 65%) up to 1% increases in NO_x were observed. For light duty vehicles EPEFE concluded that emissions of HC and CO would be reduced as cetane increased. Reductions of 26% were observed as the cetane number was increased from 50 to 58.

Natural cetane is known to improve fuel consumption. An increase from 50 to 58 can reduce brake specific fuel consumption (BSFC) by 0 to 2%. Similarly Schaberg et al (1997) report BSFC improving on a mass basis as the cetane was increased from 40 to 60. Total improvement over this range was 3.4%. Lange et al (1997) also found improvements in BSFC of 0.21% per cetane unit over the range of 51 to 59 cetane.

The effects of cetane on performance are engine dependent. A recent industry/EPA workgroup evaluated the incremental impact of changes in diesel fuel properties on NO_x and hydrocarbon emissions. The study employed advanced technology heavy-duty diesel engines that are expected to be used to meet the US 2004 standard. The engines used exhaust gas recirculation and optimized engine design but not advanced aftertreatment. The EPA (1999b) has reported that the results of the study showed that these new engines are mostly insensitive to changes in fuel density, aromatics content and cetane number. Contrary to studies on older technology engines, increasing the cetane number had no impact on emissions. This study did not report on fuel economy.

The cetane quality of diesel fuels sold within the APEC economies as determined by the survey and the Paramins World-Wide Diesel Fuel Quality Survey (typicals) are shown in table 4-13. Diesel fuel cetane values are lowest in North America. Many of the APEC economies have excellent cetane quality.

Table 4-13 Diesel Fuel Cetane Values.

Economy	Specification Minimum	Typical Values	WWFC Category for typical value
Australia	45	52 (C.I.)	4
Brunei Darussalam			
Canada	40	41 (C.N.)	<1
Chile	45 (C.N.)		1
China	45	50 (C.N.)	2
Chinese Taipei		47 (C.N.)	<1
Hong Kong, China	50	54 (C.N.)	2
Indonesia[13]	45	48 (C.N.)	1
Japan	45	52 (C.N.)	2
Malaysia	45	63 (C.N.)	4
Mexico	48	57 (C.N.)	4
New Zealand	45		1
Papua New Guinea			
Peru	45		1
Philippines	45-47		1
Republic of Korea	45	50 (C.N.)	2
Russia		47 (C.N.)	<1
Singapore		54 (C.N.)	4
Thailand	46	55 (C.N.)	4
USA	40	43-50 (C.N.)[14]	<1 - 1
Viet Nam			

[13] 1995 data

[14] Depending on region.

4.1.2.2 Density

The European EPEFE program found that fuel density could influence emissions of NO_x and particulate matter. Light duty vehicles exhibited particulate matter reductions of up to 18% when the density was reduced from 855 to 828 kg/m^3. Heavy-duty engines showed almost no impact from the same change. NO_x emissions increased in light duty applications and decreased in heavy duty engines from this change in density.

Density is also related to fuel economy, lower density fuels exhibit lower volumetric fuel economy. This does not translate into increased greenhouse gas emissions as the lower density fuels typically have a higher hydrogen to carbon ratio. The EPEFE found that CO_2 emissions were about 1% lower with the low density fuels.

Typical fuel densities and their relation to the WWFC are shown in Table 4-14.

Table 4-14 Diesel Fuel Density Values.

Economy	Typical Values	WWFC Category for Typical Value
Australia	840	4
Brunei Darussalam		
Canada	840	4
Chile	830-870	
China		
Chinese Taipei	843	2
Hong Kong, China	834	4
Indonesia	857	1
Japan	836	4
Malaysia	857	1
Mexico	836	4
New Zealand		
Papua New Guinea		
Peru		
Philippines		
Republic of Korea	830	4
Russia	815	Too low for WWFC
Singapore	844	2
Thailand		
USA	840-850[15]	2
Viet Nam		

4.1.2.3 Sulphur

Diesel fuel sulphur contributes to particulate emissions and some new emission control technologies are impaired or permanently contaminated by high fuel sulphur levels. The

[15] Depending on location.

degree of contribution of fuel sulphur to sulphate and thus particulate emissions varies from engine to engine. With engines that have an oxidation catalyst the conversion rate can approach 100% making fuel sulphur a very important contributor to particulate emissions.

NO_x emissions from diesel engines will have to be significantly reduced to meet new emission standards being introduced in many regions. It is anticipated that diesel after-treatment systems will play a major role in allowing engines to meet these new standards. These systems are very sensitive to fuel sulphur. They will require sulphur free fuels to operate effectively. The diesel fuel sulphur levels derived from the survey data and other sources are shown in Table 4-15. Diesel fuel sulphur levels will be decreasing in many of the countries of APEC over the next five years as the trend is for lower sulphur contents.

Table 4-15 Diesel Fuel Sulphur Levels.

Economy	Sulphur Content Maximum Wt %	Typical Values wt%	WWFC Category for Typical Value
Australia	0.5	0.13	1
Brunei Darussalam			
Canada	0.05	0.027	2
Chile	0.2 Santiago 0.3 elsewhere		1
China	0.5	0.035-0.15	1
Chinese Taipei	0.05		1
Hong Kong, China	0.05[16]	0.033	1
Indonesia	0.5	0.24	1
Japan	0.05[17]	0.03	1
Malaysia	0.1	0.08	1
Mexico	0.05	0.021	2
New Zealand	0.3		1
Papua New Guinea			
Peru	0.7	0.2	1
Philippines	0.3[18]		1
Republic of Korea	0.1[19]	0.062	1
Russia		0.057	1
Singapore	0.5[20]	0.25	1
Thailand	0.05		1
USA	0.05	0.03	1
Viet Nam			

[16] 0.035% for 2001. 0.005% in practice.

[17] 0.005% in 2005.

[18] 0.05 % in 1999, 0.02% in 2001 and 0.005% in 2004.

[19] 0.05% for 2001.

[20] 0.05% in 2000.

4.1.2.4 Aromatics

Aromatics are fuel molecules that contain at least one benzene ring. The fuel aromatic content affects the combustion properties of the fuel and impacts on exhaust NO_x and the formation of particulate matter.

A higher aromatic content will increase the flame temperature and lead to an increase in NO_x emissions. Testing in Europe showed that lowering the aromatic content from 30% to 10% reduced NO_x emissions by 5% in light duty vehicles and by almost 4% in heavy duty engines (Alliance of Automobile Manufacturers, 2000).

Polyaromatic (PAH) content can influence the particulate emissions and the exhaust emissions of PAH. Reducing the polyaromatic (di+) content of diesel fuel from 9% to 1% reduced particulate emissions by 6% in light duty vehicles and by 4% in heavy duty vehicles. The PAH (tri+) content of the fuel is directly proportional to the PAH emissions.

The aromatic content of diesel fuel was not included in the fuel survey.

4.1.2.5 Distillation Characteristics

The distillation characteristics of a fuel relate to what fraction of the fuel will boil off at a given temperature. The heavy end of the fuel has been studied with respect to its impact on exhaust emissions. The results of these studies are inconclusive. Data from the Paramins survey is compared to the WWFC in Table 4-16.

Table 4-16 Diesel Fuel Distillation Characteristics.

Economy	Typical Values		WWFC Category for Typical Value
	T90 C	T95 C	
Australia		349	2
Brunei Darussalam			
Canada	304		4
Chile			
China	258-342		1-2
Chinese Taipei	329		2
Hong Kong, China		359	1
Indonesia[21]	347		1
Japan	333		2
Malaysia	357		1
Mexico	336		2
New Zealand			
Papua New Guinea			
Peru			
Philippines			
Republic of Korea	338		2
Russia	307		4
Singapore	362		1
Thailand	347		1
USA	317		4
Viet Nam			

[21] 1995 data

4.1.2.6 Injector Cleanliness

Deposits can be formed on many parts of an engine as it is used. These deposits can interfere will the proper operation of the engine and results in an increase in emissions. One of the most important areas of the engine to keep deposit free is the fuel injector. In diesel engines the tip of the injector is in direct content with the combustion process and is very susceptible to deposit formation. These deposits can increase fuel consumption, reduce power and increase emissions. Detergent additives are available to help control deposit formation and minimize the deleterious effects of deposits.

A number of jurisdictions around the world specify detergent additives for gasoline very few have the same requirement for diesel fuel. Some companies voluntarily add detergent additives to their diesel fuel.

4.2 NATURAL GAS

Natural gas in its natural state is a colourless, odourless gas which is widely used as a heating fuel in residential, commercial and industrial applications. It is also used as a feedstock for chemical processes and can be used as a feedstock for other fuel options such as methanol, dimethyl ether or various gas to liquid fuel processes. The 1998 natural gas reserves, production rates and net exports for each country are shown in Table 4-17 (US EIA). A negative net exports indicates that the country is an importer of natural gas.

All but three countries have natural gas reserves and two additional countries have reserves, but do not have significant levels of production. Natural gas for vehicles is potentially applicable to nineteen of the countries with reserves.

Table 4-17 Natural Gas Production.

Economy	Natural Gas Reserves	1998 Dry Natural Gas Production	1997 Natural Gas Net Exports
Units	Trillion Cubic Feet	Trillion Cubic Feet	Trillion Cubic Feet
Australia	44.6	1.10	0.34
Brunei Darussalam	13.8	0.32	0.29
Canada	64	6.04	2.84
Chile	3.5	0.07	-0.024
China	48.3	0.78	0
Chinese Taipei	2.7	0.03	-0.15
Hong Kong, China	0	0	0
Indonesia	72.3	2.24	1.246
Japan	1.4	0.08	-2.242
Malaysia	81.7	1.44	0.77
Mexico	64	1.27	-0.026
New Zealand	2.5	0.17	0
Papua New Guinea	5.4	0	0
Peru	7.0	0.02	0
Philippines	2.9	0	0
Republic of Korea	0	0	-0.54
Russia	1,700	20.87	6.73
Singapore	0	0	-0.05
Thailand	12.5	0.57	0
USA	164	18.86	-2.84
Viet Nam	6.8	0.02	0

Natural gas has been used as a vehicle fuel in some parts of the world since the 1930's. Interest in natural gas vehicles (NGV) was renewed after the two oil price shocks of the 1970's. Today there are approximately 1.2 million vehicles operating on natural gas around the world. This is about 0.18% of the world's fleet.

Natural gas can be used as vehicle fuel without any further refining or chemical processing beyond that required for heating applications. It is composed primarily of methane with very small amounts of higher hydrocarbons that have not been completely removed at the gas processing plants. It is essentially sulphur free with only a very low residual sulphur content from processing plus a few parts per million of mercaptans added to provide an odour for safety purposes. As a vehicle fuel it is most often compressed to between 3000 and 5000 psi (CNG) to provide a higher energy density; but sometimes liquefied (LNG is a cryogenic liquid at –159 C) to provide even higher energy densities.

Natural gas has an octane rating of 130, making it suitable for use in very high compression engines. High compression engines have a higher efficiency and the potential for lower greenhouse gas emissions. Few of the existing original equipment manufacturers (OEM) take full advantage of the octane rating due to economic limitations imposed by the small number of vehicles being sold. The carbon content of natural gas (0.75) is lower than gasoline, resulting in the fuel having inherently lower greenhouse gas emissions.

The LNG market is not as well developed as the CNG market anywhere in the world. The major advantage of LNG is the higher energy density of the fuel, which allows a larger vehicle range. LNG can be transported as a liquid and can be used at locations that are not connected to a gas pipeline. The applications of the fuel have tended to be heavy-duty trucks rather than light duty vehicles. There are several LNG refuelling sites in the United States including public sites that allow for self-serving the fuel. Interest in LNG as a vehicle fuel for heavy-duty applications is starting to increase in parts of North America.

Natural gas has a low cetane number. When the fuel is used in diesel type engines it requires an ignition source or the pilot injection of diesel fuel to ignite the natural gas. These converted diesel engines often are less efficient when operated on natural gas and some of the greenhouse gas benefits are lost. A Canadian company, Westport Innovations Inc, is developing natural gas engines with pilot diesel injection systems. These engines retain the high efficiency of the diesel engine when operated on natural gas.

The driving forces behind the development of NGV in the countries where its use is growing have been;

- Abundant natural gas resources.
- The need to address air quality issues caused by transportation emissions.
- A favourable regulatory and economic environment for alternative transportation fuels.

These conditions exist in many of the APEC economies.

In Table 4-18 the state of use of NGV's in the various economies is summarized. The data was sourced from the International Association for Natural Gas Vehicles and has information that was current in late 1996.

Natural gas production and use is less carbon intensive that gasoline and diesel fuel. Full cycle greenhouse gas emissions were estimated to be 25% less than conventional gasoline in the year 2010 in Canada (Levelton, 1999). This study assumed that the engines were designed to take full advantage of the high octane rating of natural gas. If this is not the case the GHG emission benefit for natural gas vehicles drops to 20%.

The exhaust emissions from converted natural gas powered vehicles are dependent on the quality of the conversion. They can be better or worse than the original gasoline vehicle. Factory built natural gas vehicles have lower exhaust emissions than their gasoline counterparts.

In North America most OEM light duty natural gas vehicles are certified to more strict emission standards than Tier 1 gasoline vehicles. The DaimlerChrysler, dedicated Ford, and California Honda Civic vehicles are certified to ultra low emission vehicle standards (ULEV). The bi-fuel Fords and GM vehicles are TLEV vehicles.

The US DOE has tested some of the OEM alternative fuel vehicles and the similar gasoline vehicles for comparison. The Ford F-250 pickup truck and the Honda Civic dedicated natural gas vehicles have been tested. Both the natural gas vehicles meet the ULEV standards. For the Ford the natural gas vehicle had 97% lower non-methane hydrocarbons (NMHC), 63% lower carbon monoxide, 81% lower NO_x, and 99% lower air toxics. Carbon dioxide emissions from the vehicle were 17% lower. The gasoline used for testing was the US industry average fuel. The Honda exhibited similar reductions, a 96% reduction in NMHC, 90% less CO, 69% lower NO_x and 97% lower air toxics. The Honda levels on natural gas were 1/10 th the ULEV standards. The Honda has an engine optimized for natural gas with a higher compression ratio, which accounts for excellent CO_2 reduction. The CO_2 emissions measured in these tests are for the vehicle only and are not full cycle emissions. This data is summarized in Table 4-19.

Table 4-18 Natural Gas Vehicle Statistics.

Economy	Number of Natural Gas Vehicles	Number of Refuelling Stations
Australia	1,000	35
Brunei Darussalam		
Canada	17,220	120
Chile		
China	2,000	10
Chinese Taipei		
Hong Kong, China		
Indonesia	3,000	12
Japan	1,211	42
Malaysia	975	8
Mexico	1	3
New Zealand	25,000	190
Papua New Guinea		
Peru		
Philippines		
Republic of Korea	4	1
Russia	205,000	187
Singapore		
Thailand	82	1
USA	89,600[22]	1,265[12]
Viet Nam		

[22] 1999 Energy Information Administration.

Table 4-19 Emissions Comparison Between Gasoline and Natural Gas Vehicles.

	Honda Civic			Ford F250		
	Natural Gas	Gasoline	Reduction (%)	Natural Gas	Gasoline	Reduction (%)
Units	g/mile	g/mile		g/mile	g/mile	
NMHC	0.003	0.079	96	0.004	0.14	97
CO	0.16	1.595	90	0.48	1.29	63
NO_x	0.02	0.065	69	0.06	0.31	81
CO_2	219.25	296	26	548.7	660.75	17

The tests on a bi-fuel GMC Sierra pickup truck were quite different illustrating the compromises that must be made for bi-fuel operations. On natural gas the vehicle had 67% lower NMHC, 34% lower NO_x, 83% lower air toxics, but it had CO emissions 68% higher than the gasoline version.

Methane emissions from CNG vehicles are higher than from gasoline vehicles. Some tests on older vehicles have shown methane emissions to be an order of magnitude higher. This was factored into the greenhouse gas emissions for CNG reported earlier.

Evaporative emissions are very low from natural gas, as the fuel system is pressurized and not open to the atmosphere. A small amount of gas that is trapped in the fuelling nozzle is released at the end of the refuelling process.

Natural gas is also used in heavy-duty engines. These engines are usually modified diesel engines that have been converted to spark ignition. These engines offer much lower particulate emissions and lower NO_x emissions than diesel engines but sacrifice some of the efficiency normally associated with diesel engines. Carbon monoxide and NMHC emissions are also usually higher with natural gas engines compared to equivalent diesel engines. Full cycle greenhouse gas emissions are the same to 10% lower than a diesel engine (Levelton, 1999). New technology such as that being developed by Westport Innovations Inc. provided the same efficiency as a diesel engine in addition to the lower particulate and NO_x emissions. This technology will offer greenhouse gas emissions reductions in the 20 to 25% range compared to diesel engines.

A number of APEC economies have recognized the benefits of natural gas vehicles and have active development programs underway. The following programs were identified (Clean Fuels Report, 2nd Asia Pacific NGV Co-operation Meeting, US EIA Country Environmental Issues);

- Taxis operating in the city of Jakarta are required to use natural gas. All new buses in Indonesia must be NGV's.
- In Australia natural gas for vehicles is exempt from federal excise tax. Most States offer a similar incentive.
- Japan offers an incentive for the purchase of NGV's. Generally the government pays one-half of the cost differentials to gasoline. NGV refuelling stations have their capital costs subsidized.
- Malaysia reduces the road tax for natural gas by 50% compared to gasoline. The retail price of natural gas is fixed at one half of gasoline.

- Russia has passed a resolution that provides natural gas at no more than one half the price of the lowest grade of gasoline.
- Thailand plans to increase the number of refuelling stations to 30 and the number of vehicles to 25,000 by 2005. Buses and passenger cars are targeted. The program is driven by concerns regarding air quality, especially particulate emissions.
- China has increased the number of propane and natural gas vehicles from 5000 in 1997 to 10,000 in 1999. City officials in Beijing have vowed that by 2000 3,600 buses and 14,000 taxis in the city will run on these two fuels. Public concern about air quality is cited as the driver for the program. Tianjin Municipality has announced plans for 10,000 natural gas buses, taxis and postal service vehicles.
- The Korean government is using a package of fiscal incentives, including exemptions from value-added and acquisition taxes, to promote the substitution of 20,000 diesel buses with buses run on natural gas by the year 2007.

4.3 LPG

Liquid Petroleum Gases (LPG) are ethane, propane, butane, and pentane or a mixture of those gases. The most important gases from a transportation perspective are propane and butane. There are two sources of LPG's, oil refineries and natural gas plants. There are more than 4 million LPG fuelled vehicles in use in the world today in 38 countries (World LP Gas Association). There are over 21,000 dispensing stations in these countries.

In oil refineries propane and butane are produced though fractionation at several stages in the refinery. There is a limited ability to vary the production of LPG in the refinery, as it is primarily a co-product of other production processes.

Propane and butane from gas plants are by-products of natural gas production. The production of LPG depends on the composition of the raw natural gas. The LPG's are stripped from the gas to produce specification natural gas. LPG's are produced both at field gas plants and at larger straddle plants that perform a final clean up of the natural gas before it is sent to market.

Total world production rate of LPG's in 1997 was 9 million barrels per day (US EIA). Approximately 330,000 bbls/day of this was used for transportation applications. The LPG resources for the APEC countries are shown below.

Table 4-20 LPG Resources in APEC Economies

Economy	1997 LPG Refinery Production	1997 Natural Gas Plant Liquids Production	1997 LPG Exports	1997 LPG Imports
Units	Thousand BBL/Day	Thousand BBL/Day	Thousand BBL/Day	Thousand BBL/Day
Australia	28	71	34	9
Brunei Darussalam	0	15	0	0
Canada	84	636	361	8
Chile	15	7	0	16
China	198	0	37	117
Chinese Taipei	27	1	8	25
Hong Kong, China	0	0	0	5
Indonesia	18	85	23	0
Japan	162	5	21	599
Malaysia	13	50	46	25
Mexico	343	388	5	74
New Zealand	0	7	0	0
Papua New Guinea	0	0	0	2
Peru	7	1	0	3
Philippines	15	0	14	2
Republic of Korea	61	0	110	157
Russia	172	195	32	0
Singapore	32	0	150	0
Thailand	74	50	3	0
USA	691	1,817	57	205
Viet Nam	0	0	0	4

Eight countries are exporters of LPG. They are Australia, Canada, Indonesia, Malaysia, Philippines, Russia, Singapore and Thailand.

LPG has a high octane rating. When the fuel is predominately propane the octane is 104 R+M/2. This makes the fuel well suited to spark ignition engines, but not for compression ignition engines that require a high cetane number. LPG is a liquid under moderate pressure and is thus stored as a liquid but easily vapourizes at atmospheric pressure making for a more uniform air fuel ratio in the engine. The vapourization characteristics and the simple molecular structure can lead to lower exhaust emissions in well designed conversions or factory built propane powered vehicles.

LPG production and use is less carbon intensive that gasoline and diesel fuel. Full cycle greenhouse gas emissions were estimated to be 26% less than conventional gasoline in the year 2010 in Canada (Levelton, 1999). This study assumed that the engines were designed to take full advantage of propane's high octane. If this is not the case the GHG emission benefit for LPG vehicles drops to 19%.

In North America only Ford offers OEM light duty propane powered vehicles. They are dual fuelled F Series pickup trucks and Econoline vans. GM does have a number of medium duty trucks with a propane option. The testing performed by the US DOE on an F-250 truck showed that on propane the NMHC emissions were 55% lower, the CO emissions were 96% higher and the NO_x emissions were 160% higher than when the vehicle was tested on gasoline. The vehicle did meet ULEV standards on both propane and gasoline. The emissions of air toxics were 98% lower on propane than on gasoline. The DOE did not test a gasoline powered truck for comparison. Ford has introduced a LPG version of the Ford Excursion for testing. This vehicle meets the super ultra low emission vehicle (SULEV) standards in California.

A number of APEC countries with significant LPG vehicle programs have been identified. These include;

- Australia. There are almost 500,000 vehicles operated on LPG in Australia. This represents 5% of the vehicle fleet. There are 3,300 refuelling stations in the country. The fuel is tax free which accounts for the lower price than gasoline and the high growth rate.
- Canada. There are approximately 135,000 propane powered vehicles in Canada today. The size of the market has been declining in recent years. There are an estimated 3500 refuelling stations for automotive propane.
- United States. There are estimated to be 270,000 LPG vehicles operating in the United States and the number are growing by 2.5% per year. These vehicles consumed 240 million gallons (gasoline equivalent) of LPG.
- Japan. Nissan and Toyota produce OEM dedicated LPG fuelled taxis. 90% of all taxis are powered by LPG and 45,000 new vehicles are produced each year to replace existing taxis. Fiscal incentives are offered for vehicles and for refuelling stations.
- Chinese Taipei. Fiscal incentives are available for the purchase of new LPG vehicles as well as the conversion of gasoline vehicles. Incentives are also available for the establishment of LPG refuelling stations.
- Hong Kong, China. To deal with air pollution problems the government is offering fiscal incentives of $40,000 HK for taxi conversions to LPG. The territories 18,000 taxis and 6,000 buses are being targeted. Fuel taxes are also being reduced on LPG and land is being made available for LPG service stations.
- China. Taxis and buses are being converted to LPG and natural gas.

4.4 ALCOHOLS

Two alcohols, methanol and ethanol have been used as transportation fuels either as blends with gasoline or diesel or as neat fuels in some parts of the world. Both are primary alcohols with similar but not identical properties. For most applications they are not interchangeable and must be considered separately.

4.4.1 Methanol

Methanol is often referred to as wood alcohol but is usually made from natural gas. It is a liquid fuel with the chemical formula CH_3OH. It has a high octane rating of 100 R+M/2 and contains about 50% by weight oxygen. The high oxygen content results in a low energy density.

Methanol can and is also manufactured from coal. The counties with significant natural gas and coal reserves and production are shown in Table 4-21. The countries with large coal reserves also have significant natural gas reserves.

Table 4-21 Natural Gas and Coal Resources

Economy	Natural gas Reserves	1998 Dry Natural Gas Production	Coal Reserves	Coal Production 1998
Units	Trillion Cubic Feet	Trillion Cubic Feet	Billion short tons	Million short tons
Australia	44.6	1.10	99.6	314
Brunei Darussalam	13.8	0.32	0	0
Canada	64	6.04	9.5	83
Chile	3.5	0.07	1.3	1.3
China	48.3	0.78	126.2	1,351
Chinese Taipei	2.7	0.03	0	0.1
Hong Kong, China	0	0	0	0
Indonesia	72.3	2.24	5.8	66
Japan	1.4	0.08	0.9	4
Malaysia	81.7	1.44	0	0.2
Mexico	64	1.27	1.3	11
New Zealand	2.5	0.17	0.6	3.6
Papua New Guinea	5.4	0	0	0
Peru	7.0	0.02	1.2	0.04
Philippines	2.9	0	0.3	1.0
Republic of Korea	0	0	0.1	4.8
Russia	1,700	20.87	173.1	272
Singapore	0	0	0	0
Thailand	12.5	0.57	2.2	22
USA	164	18.86	275.1	1,119
Viet Nam	6.8	0.02	0.2	11.8

In the early 1980's methanol was used with a co-solvent as a gasoline blending component in low level (5% or less methanol) blends. These blends were sold in the United States, Canada and Europe. With the widespread use of MTBE as a gasoline blending component the popularity of methanol blends diminished and there are no low level commercial blending programs in North America and Europe today. Low level methanol blends are not permitted in the World Wide Fuel Charter.

In the early 1990's M85, a blend of 85% methanol and 15% gasoline was introduced in some parts of North America, particularly California and Western Canada. Some auto manufacturers introduced flexible fuel vehicles that operated on gasoline, M85 or any combination of the fuels. By 1997, 21,000 of these flexible fuel vehicles were in operation in the United States. They consumed about 2 million gallons of methanol annually. These vehicles are no longer being produced and M85 is no longer being actively promoted as a vehicle fuel. Both the number of vehicles in operation and the methanol consumed are dropping.

The attributes of M85 were lower exhaust emissions than the gasoline powered vehicles of the day, energy security and diversity benefits due to the large natural gas resources around the world as well as the potential to produce methanol from coal and biomass. The vehicles offered excellent power and performance.

Increases in the price of methanol in 1994 and 1995 combined with advances in gasoline engine technology, reformulated gasoline and the difficult task of introducing a new fuel and vehicle combination led to a decline in vehicle sales and the eventual elimination of the offering.

Methanol was used neat (M100) in diesel type engines in North America in the late 1980's and early 1990's. These programs had mixed success and only a few buses are still in operation today. There have been trials of methanol diesel blends in a number of countries around the world over the past several years. These have not led to any commercial programs. These programs require an emulsification agent to provide a stable blend of methanol and diesel. The blended fuel offers reductions in particulate emissions and NO_x.

Methanol today is being advocated as the fuel for fuel cell vehicles. It is the easiest liquid fuel to reform to hydrogen onboard the vehicle. The infrastructure required for the introduction of the new fuel is relatively inexpensive. Some companies are working on the development of direct methanol fuel cells, which would simplify the onboard fuel system and make methanol powered fuel cell vehicles very attractive. Methanol fuelled fuel cell vehicles will be included in the California Fuel Cell Partnership demonstration programs beginning probably in 2002.

Fuel cell vehicles offer very low exhaust emissions of criteria air pollutants (zero NO_x and CO with very low VOC) and about a 40% reduction in greenhouse gas emissions when methanol is produced from natural gas and reformed to hydrogen onboard the vehicle. The production of methanol from coal is more carbon intensive than from natural gas due to the process efficiency and the carbon contents of the raw materials. A fuel cell vehicle with methanol produced from coal is likely to have about a 15% reduction in GHG emissions compared to a gasoline powered internal combustion engine powered vehicle.

4.4.2 Ethanol

Ethanol is a liquid with the chemical formula C_2H_5OH. It is made from ethylene and sugar feedstocks today and is widely used as a fuel in Brazil and the United States with more limited use in Canada and some European countries. In the United States approximately 4.8 billion litres were used in 1998 mostly for 10% ethanol blends. There is a small but growing market for high level blends (E85) for flexible fuels vehicles developing in the United States.

Ethanol has a high blending octane value, a high blending vapour pressure and a high oxygen content. It is soluble in gasoline when water is not also present. When ethanol is added to gasoline at the 10% level it will increase the octane of the fuel by up to 3 octane numbers. It will increase the vapour pressure by approximately 1 psi and will reduce the emissions of carbon monoxide and unburned hydrocarbons. The magnitude of the emission reductions is dependent of the vehicle technology.

All of the transportation fuel uses sugar or starch containing materials as the feedstock. Ethanol produced from ethylene finds applications as an industrial solvent, in cosmetics and pharmaceuticals and in some food processes. The final product is identical irrespective of its origin.

Ethanol can also be produced from lignocellulosic materials such as straw and wood or municipal solid waste. The commercial feasibility of these new production methods has not been demonstrated in modern facilities. Most of the processes under development involve hydrolysing the cellulose to sugars and then fermentation of the sugars to ethanol. There are several alternative routes being investigated including the gasification of the lignocellulosics to syngas and then either a chemical or biological synthesis of the syngas to ethanol.

The potential resources available for the production of ethanol either from sugar and starch crops with proven technologies or from lignocellulosic materials with one of the developing technologies is not readily available as are the more traditional hydrocarbon resources. This is in part due to the renewable nature of these resources where the availability of the annual resources can vary from one year to the next depending on the weather.

Ethanol can be used in gasoline in low level blends according to the World Wide Fuel Charter. The accepted volume is 7.3% unless local regulations permit up to 10% such as in North America. The addition of oxygenates such as ethanol to the gasoline reduces vehicle emissions of carbon monoxide and volatile organic compounds.

Ethanol can also be used in high level blends such as E85. These vehicles are similar in concept to the M85 flexible fuel vehicles described in the previous section. The E85 are still produced in North America and for some vehicles and engine families it is the only engine available. It is offered at the same or slightly higher price than a gasoline powered vehicle. This is made possible by a fuel economy credit available under the US Corporate Average Fuel Economy regulations. Hundreds of thousands of vehicles are being produced by Ford and DaimlerChrysler under this program. Most of these vehicles are being operated on standard gasoline as the refuelling infrastructure is not developed for E85.

The US DOE has tested two of these E85 vehicles on both ethanol and gasoline as well as a comparable gasoline powered vehicle. The results of those emission tests for E85 and the comparable gasoline only vehicle are shown in Table 4-22. All vehicles met the required emissions standards. The E85 vehicles had lower carbon dioxide emissions and lower potency weighted air toxics but higher emissions of criteria air contaminants.

Table 4-22 Emissions from E85 Flexible Fuel Vehicles

	Ford Taurus			Dodge Caravan		
	E85	Gasoline	% change	E85	Gasoline	% change
Units	g/mile	g/mile		g/mile	g/mile	
NMHC	0.10	0.10	0	0.16	0.13	23
CO	1.48	1.13	31	2.13	0.88	142
NO_x	0.12	0.09	33	0.40	0.31	29
CO_2	396.4	439.7	-9.8	469.8	512.5	-8.3
Potency weighted Toxics			-55			-54

There are demonstrations taking place in the US with ethanol diesel emulsions in heavy-duty applications. Emissions of particulates and NO_x are reduced with this fuel.

The feedstock for ethanol production, whether it is a sugar, starch or lignocellulosic crop absorbs carbon dioxide from the atmosphere to grow. When the ethanol is finally produced and combusted the carbon dioxide that is released is not counted in a countries emissions inventory since the carbon originally came from the atmosphere. The energy, fertilizer requirements and changes in soil carbon resulting from the crop production and ethanol production are counted in the emission inventory. The overall impact of the production and use of ethanol on GHG emissions can be very crop and country dependent.

Levelton (1999b, 1999c) in studies performed for Agriculture and Agri-Food Canada studied the GHG emissions from ethanol produced from corn and ethanol produced from lignocellulosic materials. The results from those studies are shown in the following table.

Table 4-23 Greenhouse Gas Emission Reductions for Ethanol

Feedstock	E10		E85	
	% Reduction in CO_2 Equivalent Emissions		% Reduction in CO_2 Equivalent Emissions	
Year	2000	2010	2000	2010
Corn	3.9	4.5	38.2	45.4
Corn Stover	5.8	6.2	61.3	63.9
Wheat Straw	5.4	5.9	57.4	60.4
Switchgrass	6.7	6.9	71.0	71.6
Hay	6.4	6.7	68.3	69.1

The table recognizes that the technology is still developing for ethanol production in Canada and hence looked at the near term case as well as a medium term case. All scenarios produced reductions in emissions but the reduction was greater for the lignocellulosic crops since the ethanol plants were self sufficient in energy by utilizing the lignin from the crop as the fuel for the plant. The corn cases utilized natural gas for ethanol plant energy requirements.

In addition to the United States and Canada, ethanol is under consideration as a vehicle fuel in Thailand and Australia. Thailand recently approved measures that would extend tax incentives to the private sector for the construction of ethanol plants using sugarcane and other agricultural products. The government plans to form an ethanol committee to oversee ethanol production, distribution and standards. In addition, the government will ask state agencies to use ethanol to fuel fleet vehicles for the next two years.

Thailand's Ministry of Finance plans to implement a small excise tax on ethanol-based fuels. The country's Board of Investment will offer ethanol companies a duty exemption on the import of ethanol machinery as well as an eight-year exemption from corporate taxes.

Australia's Federal government will fund a study into the commercial viability of increasing ethanol fuel production by the sugar industry. Some sugar mills are already producing ethanol from waste cane, most of it used to meet their own fuel needs or to produce a variety of speciality products. Ethanol produced from grain is blended with gasoline in some parts of New South Wales.

4.5 BIODIESEL

Biodiesel is the methyl or ethyl ester of vegetable or animal fats. It can be used in its pure form or as a blend with petroleum based diesel fuels, the most common blend being 20%

biodiesel. It can be made from a variety of products, including animal fats and virgin and recycled vegetable oils derived from crops such as soybeans, canola, corn and sunflowers. Oil of low quality oil seeds, used restaurant oil, and tall oils produced from pulp waste are also potential feedstocks.

The technology for using biodiesel has been available for over a century, but it is only recently been used for commercial production. Biodiesel is receiving attention as an alternative fuel and fuel additive because of growing interest in environmental issues and through the development of more cost-effective processing techniques. It is produced and distributed in Europe to large extent and has also been produced and used in the United States.

The production of biodiesel is well known. Methanol and ethanol can both be used as the alcohol. There are three basic routes to ester production from oils and facts:

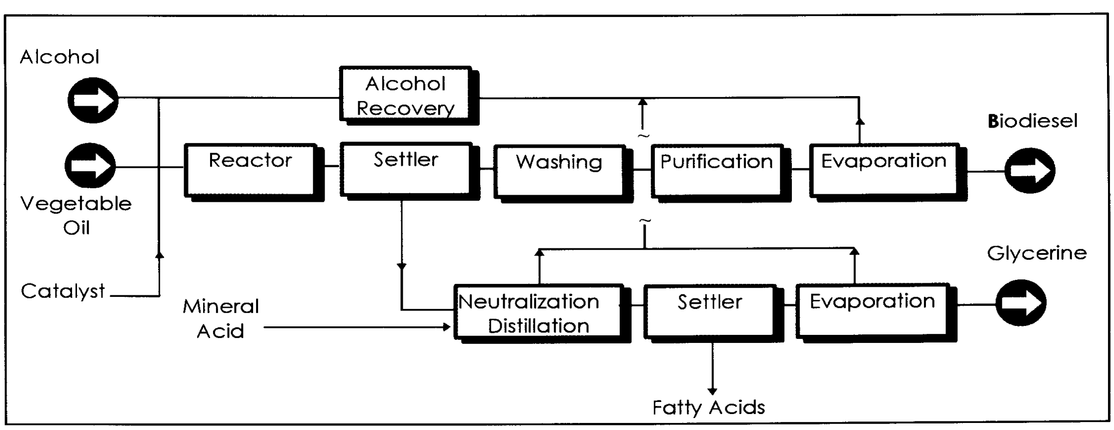
- based catalyst transesterification of the oil with alcohol,
- direct acid catalyzed esterification of the oil with alcohol,
- conversion of the oil to fatty acids, and then to esters with acid catalysis.

The majority of the esters produced today are done with the base catalyzed reaction using methanol because it is the most economic for several reasons:

- it is low temperature (65C) and pressure (1.35 atm),
- it yields high conversion (98%) with minimal side reactions and reaction time,
- it is a direct conversion to methyl ester with no intermediate steps,
- methanol is the lowest cost alcohol,
- exotic materials of construction are not necessary.

The general process is depicted in Figure 4-2. A fat or oil and is reacted with an alcohol, like methanol, in the presence of a catalyst to produce glycerine and methyl ester or biodiesel. The methanol is charged in excess to assist in quick conversion and recovered for reuse. The catalyst is usually sodium or potassium hydroxide, which is already been mixed with the methanol.

Figure 4-2 Biodiesel Production Process.



One kilogram of oil produces one kilogram of methyl ester or 1.13 litres of biodiesel. The total world production of vegetable oils is projected to be 85 million tonnes for the 1999/2000 crop year (USDA, 2000). Of this total only 31.3 million tonnes is available for export. Malaysia is one of the larger exporters in the world with exports projected to be 8.8 million tonnes. The United States and Canada are also exporters of oils. Malaysian exports of oil could produce 9.9 billion litres of biodiesel if it was available for non food uses. Of course the majority of it is consumed today in food applications.

The following table highlights the impact of biodiesel on exhaust emissions from diesel engines when the fuel is used either as a blend with diesel fuel or as a neat fuel. The wide variation in the data is evidence of the influence of engine design on the emissions.

Table 4-24 Impact of Biodiesel on Exhaust Emissions

Parameter	20% Biodiesel	100% Biodiesel
Particulate Matter	-5 to -15%	+27 to -68%
Total hydrocarbons	-15 to -20%	-37 to -63%
Nitrogen oxides	+1 to +5%	-8 to + 8%
Carbon monoxide	-2 to -16%	-33 to -46%
Sulphur oxides	-20%	-100%
Power	0 to -2%	0 to -5%

Biodiesel is not presently commercially available in Canada. It is commercial in Europe and has some niche markets in the United States. It has been widely tested and much is known of its properties. Biodiesel has many similar properties to conventional diesel. The table below compares the properties of the diesel, soy methyl ester and canola methyl ester as reported by Peterson et al (1994).

Table 4-25 Typical Properties of Diesel Fuel and Biodiesels

Property	Diesel	SME Soy	CME Canola
Heating Value kJ/kg	45,000	40,000	40,000
Cetane number	40-45	60	58
Specific Gravity	0.85	0.88	0.88
Pour Point C	-40 to -10	2	-7
Flash Point C	60	180	160
Viscosity CS @ 40C	2-3	4-5	4-5
Sulphur % mass	<0.05	<0.01	<0.01
Oxygen % mass	0	9-11	9-11
Aromatics % volume	25	0	0
Olefins % volume	15	0	0

The positive attributes of biodiesel are higher cetane, the oxygen content, the higher viscosity, and the lower sulphur. The lower pour point is a problem for cold climates that can be partially overcome with the use of pour point depressants and by using biodiesel as a blend with petroleum diesel fuels. The 10% lower energy content will impact refuelling frequency or fuel tank size in a commercial application.

Biodiesel is rated non-toxic to humans and aquatic life. It biodegrades about four times faster than petroleum diesel. Blends of biodiesel and diesel biodegrade about twice a fast as diesel fuel. It has a much higher flash point than diesel. These characteristics have lead to niche applications such as marine fuels, and fuels for underground mines. Emissions are lower than petroleum diesel, tests have shown that ozone forming potential is about one half that of diesel. Emissions of polycyclic aromatic hydrocarbons (PAH) and nitrated PAH compounds are much lower, most PAH's are reduced by 75-80% and nPAH's by 90%.

Biodiesel's renewability, higher cetane, generally lower emissions, lower toxicity, and biodegradability and better lubricity are attractive marketing propositions. These have been demonstrated in countries such as Germany and Austria, which have seen rapid growth in production and marketing in recent years. Market penetration has been aided by favourable tax considerations that have made the fuel economically comparable to petroleum diesel in those countries.

Biodiesel has the potential to reduce greenhouse gas emissions due to its consumption of carbon dioxide from the atmosphere during the growing stage of the oilseed. The magnitude of the reduction is dependent on the energy and fertilizer requirements for production and the value of the co-products in animal rations. Levelton (1999) studied the production of biodiesel from Canola oil in Canada and found that GHG emissions were reduced by 44% with the use of 100% biodiesel. In a study of biodiesel from soybean oil in the United States Delucchi (1998) reported reductions in GHG emissions of 41% for heavy duty applications of 100% biodiesel.

4.6 FISCHER TROPSCH FUELS

Fischer Tropsch synthesis was developed in Germany in the 1920's. It was commercially applied in Germany in the 1930's and 40's using coal as the source of syngas. It has been used in 1955 in South Africa again using coal as the feedstock. In 1993 Shell in Malaysia commissioned a natural gas to liquids (GTL) facility. That plant has experienced some operational difficulties but is now back in operation. The concept is to produce syngas, a combination of hydrogen and carbon oxides and then using a catalyst convert the syngas to liquid hydrocarbons, which can include diesel fuels and high value speciality chemicals. There is considerable interest in the technology around the world as a means of monetizing stranded gas reserves.

There are quite a number of process options for producing the syngas and for the synthesis steps and a wide variety of processes are being promoted by various process developers. The processes are capital intensive and a successful project depends on an accessible market for the products at a suitable product value and /or low cost gas reserves. The two commercial operations have been made possible by special circumstances.

The products produced by GTL processes have attractive properties. They are sulphur free and the distillates have a high cetane usually around 70. They can be used directly as a fuel or as a blending component to upgrade conventional diesel fuels. The benefits of cetane and sulphur free diesel were described in an earlier section of the report.

The same resources that were identified for methanol are applicable for GTL projects, either natural gas or coal.

The GTL processes are still in relatively early stages of development and the overall process efficiency is relatively low. This results in GHG emissions that are usually higher than for conventional oil products. Levelton (1999) reported that GHG emissions for a Fischer Tropsch diesel fuel were 95% higher than conventional diesel fuel in Canada. This was using natural gas as the plant feedstock. The use of coal as a feedstock will result in even higher GHG emissions. The higher cetane of the fuel has the potential to offset only a small portion of the higher GHG emissions. The degree of offset will be dependent on the quality of the conventional diesel fuel.

In addition to the Shell plant operating in Malaysia there are GTL projects proposed or under development in Indonesia and Australia. The Indonesia facility would have a capacity of 70,000 bpd and the Australian plant would have a 10,000 bpd capacity.

4.7 DIMETHYL ETHER

Dimethyl ether (DME) has received attention in the 1990's as a potential alternative fuel for diesel engines and as a fuel for fuel cells. DME has a cetane number higher than 55 and can produce lower emissions of particulate matter and NO_x. It is used today as an aerosol propellant. Current world production is about 150,000 tonnes per year.

The existing DME production is made via methanol dehydration. This two step non-integrated process is costly and relatively inefficient from an energy perspective and the Danish firm Haldor Topsøe has developed and piloted an alternative integrated process based on reforming of natural gas. This technology is very similar to that of methanol production. There have not yet been any plants built using these new technologies.

Like methanol, DME is a potential way to recover remote gas reserves that do not have access to market. It is thus more likely that the first DME plants would be built using low cost remote gas and the product then transported to markets.

Levelton (1999) analyzed the greenhouse gas emissions for DME production and use. The total greenhouse gas emissions for the upstream fuel cycle were 10.9% lower than conventional diesel in Canada.

DME is not a commercially available fuel today. The interest in DME as a potential fuel has been driven primarily by its ability to lower emissions in a diesel engine. In fuel cell applications it could be reformed at relatively low temperatures due to its lack of a carbon-carbon bond.

DME's physical properties are similar to LPG. It is a liquid at ambient temperature only under moderate pressure. It can be stored in equipment designed for LPG with one exception in that the elastomers have to be converted to Teflon. DME is non-corrosive to metals. DME's properties are compared to other fuels in Table 4-26.

Table 4-26 Comparison of DME Fuel Properties.

	Units	DME	Diesel	Propane
Lower Heating Value	MJ/kg	28.8	42.7	46.3
Density	Kg/m^3	667	831	500
Auto Ignition Temp	C	235	250	470
Cetane Number		>55	40-55	-
Vapour Pressure 20C	kPa	530	<1	830

The testing and limited demonstration that has been done on DME indicates that it has excellent combustion properties. The low auto ignition temperature combined with the almost instantaneous vapourization in the combustion chamber allows the injection event to be rate shaped. This results in low peak pressures and temperatures and consequently low NO_x and noise. Particulate emissions are also low due to the lack of a carbon-carbon bond in the molecule and the rapid vapourization of the fuel. Emissions of NO_x and particulates are comparable to those of lean burn LPG and Natural Gas engines. Methane emissions are about half those of diesel fuel. Other emissions are similar to diesel engines.

The fuel has a very low viscosity that has caused problems with wear in the injection systems when standard equipment was used. Additives have been shown to be effective in overcoming this high rate of wear as has redesigned parts.

One test reported by Kajitani et al (1997) reported a 10-15% improvement in specific energy consumption when DME was tested in a direct injection diesel engine. Most other researchers report similar engine efficiencies to diesel fuel. Given that some engine optimization is required to take full advantage of DME's properties and that work on this fuel has only been happening for the last five years there is still much to learn about DME.

Distribution and marketing of DME will require the development of a complete new infrastructure system. This system would be almost identical to the existing propane network in terms of technical specifications and cost of equipment. DME will suffer from the chicken and egg scenario in market development. There is no existing demand and no fuelling infrastructure. DME has the additional problem of no efficient manufacturing capacity.

4.8 LIQUID FUELS FROM COAL

Many APEC countries have significant resources and production of coal as shown in Table 4-27. These coal resources could be converted to transportation fuels via gasification to syngas and utilize a GTL process or conversion of the syngas to methanol. The coal to syngas to transportation fuels pathway is practised commercially in South Africa and the coal to methanol route is being demonstrated on a significant scale in the United States.

Table 4-27 Coal Reserves, Production, Trade and Consumption.

Economy	Coal Reserves	1997 Coal Production	1997 Coal Imports	1997 Coal Exports	1997 Coal Consumption
Units	Million Short Tons	Trillion BTU	Trillion BTU	Trillion BTU	Trillion BTU
Australia	99,649	5,378	0	3,832	1,471
Brunei Darussalam	0	0	0	0	0
Canada	9,505	1,703	380	1,004	1,075
Chile	1,302	29	91	0	125
China	126,215	24,985	44	788	24,466
Chinese Taipei	1	3	981	0	974
Hong Kong, China	0	0	154	0	173
Indonesia	5,754	1,474	12	1,122	404
Japan	865	87	3,039	72	3,065
Malaysia	4	3	64	0	66
Mexico	1,335	172	63	0	215
New Zealand	629	75	0	33	53
Papua New Guinea	0	0	0	0	0
Peru	1,168	0	15	0	13
Philippines	330	20	95	0	112
Republic of Korea	90	81	1,206	0	1,278
Russia	173,074	4,751	301	472	4,663
Singapore	0	0	0	0	0
Thailand	2,205	297	91	0	378
USA	274,156	23,211	239	2,214	21,466
Viet Nam	165	249	1	93	170

The fuels that are produced from coal have desirable properties when used in diesel engines, spark ignited engines or fuel cells. The production processes are not generally considered economic or energy efficient. The United States Department of Energy, Office of Fossil Energy has authored a Vision 21 plan. The plan envisions a future where fossil energy is converted in "21st Century Zero Emissions Energy Plants" into Electricity, Fuels and Chemicals. These plants would have near zero emissions of traditional pollutants, carbon dioxide emissions reduced by 40 – 50% by efficiency improvements or reduced to zero if coupled with carbon sequestration and capable of producing transportation fuels for $20/bbl or less. The key technologies that will have to be developed for these advanced plants include higher strength, corrosion resistant and more durable materials: improved catalysts and sorbents; instrumentation with artificial intelligence; and cost effective carbon sequestration techniques.

The US DOE has supported the commercial scale demonstration of the Liquid Phase Methanol Process where methanol is produced from syngas derived from coal. This project has been successfully producing 80,000 gal/day of methanol since 1997. The demonstration unit receives the coal syngas from an adjacent facility and thus the overall material balance is not reported in the project reports.

The challenge facing coal to fuel facilities with respect to greenhouse gas emissions is significant and largely a function of the carbon content of the coal compared to other resources such as natural gas. Delucchi (1998) modeled the greenhouse gas emissions of a coal to methanol plant and a natural gas to methanol plant. The energy efficiency of the gas to methanol plant was 65.7 % and the coal plant was 62.7%. The greenhouse gas emissions for just the fuel production step of the life cycle were 18,350 g CO_2 eq/million BTU methanol for the natural gas based process versus 89,973 g CO_2 eq/million BTU methanol for the coal feedstock. Adjusting for equal thermal efficiency, the coal plant would still have emissions of 82,170 g CO_2 eq/million BTU methanol. If this coal derived methanol were used in an advanced methanol powered fuel cell vehicle there would be a reduction in full cycle greenhouse gas emissions of about 13% compared to a gasoline powered internal combustion engine driven vehicle. There would be a 44% reduction in greenhouse gases for the natural gas derived methanol powered fuel cell vehicle.

5. ASSESSMENT OF FUEL OPTIONS AND IMPACTS ON EMISSIONS AND HEALTH EFFECTS

5.1 POLLUTANTS AND HEALTH ISSUES ASSOCIATED WITH TRANSPORTATION

Combustion of fuels in the engines of transportation vehicles produces a range gaseous and particulate emissions, which directly, or as precursors to the formation of other gases and particles in the atmosphere, can result in adverse impacts to human health and the environment. Emissions from the combustion of fuels are typically grouped as follows:

- Greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O);
- Criteria (also called "common") air contaminants: carbon monoxide (CO), nitrogen oxides (NO and NO_2 expressed as NO_2), sulphur oxides (SO_2 and other oxidized forms of sulphur expressed as SO_2), volatile organic compounds (VOC, excluding methane), and particulate matter (total, PM10 and PM2.5);
- Toxic or hazardous air contaminants: lead, aldehydes, polyaromatic hydrocarbons (PAH), benzene and 1,3-butadiene.

Extensive literature exists regarding the health and environmental effects of direct emissions and secondary atmospheric reaction products of fuel combustion and will not be repeated in any detail here. However, an overview of the key characteristics and health concerns associated with criteria and toxic air contaminants are provided.

5.1.1 Carbon Monoxide

Carbon monoxide is a clear, odourless gas that reduces the blood's capacity to carry oxygen to tissues in the body. At low levels CO impairs perception and judgement, with effects worsening to include drowsiness or headaches and general discomfort as levels rise, leading ultimately to convulsions and coma at high concentrations. CO also participates to a minor extent in photochemical smog reactions that lead to increased ground-level ozone formation.

5.1.2 Nitrogen Dioxide

Nitrogen dioxide is a brownish gas that causes irritation of mucous membranes in the respiratory tract and increased risk of respiratory irritation and infection, particularly for children and asthmatics, and reduced lung function a high levels. Also, NO_2 is an important precursor to ground-level ozone formation through photochemical reactions involving volatile organic compounds. NO_2 causes a brown colour in the atmosphere at elevated concentrations and reacts in the atmosphere with ammonia to form fine particulate salts, which reduce visibility and increase PM2.5 concentrations.

5.1.3 Sulphur Dioxide

Sulphur dioxide is a colourless gas with a strong odour. It is absorbed by the mucous membranes in the respiratory system, leading to irritation, coughing, chest discomfort, reduced lung function, respiratory diseases and increased risk of morbidity and mortality. SO_2 has been investigated extensively in epidemiological studies and is thought to worsen the effects of inhalation of particulate matter and to correlate with chronic bronchitis. It reacts with ammonia in the atmosphere to form fine particulate salts, which reduce visibility and increase PM2.5 concentrations.

5.1.4 Volatile Organic Compounds

As defined by the US EPA, volatile organic compounds are gaseous organic compounds, excluding those with negligible photochemical reactivity, such as methane, ethane and other copounds. VOCs are reactive in the atmosphere and can lead to increased formation of ground-level ozone through complex reactions with NO_x in the presence of sunlight. The composition of VOCs in downtown Vancouver, Canada was measured in 1993 to be 60% alkane, 22% aromatics (excluding benzene), 12% alkene, 3% benzene and 3% alkyne. NMOG is defined as nonmethane organic gases (GVRD, 1993).

5.1.5 Particulate Matter

The evidence relating to the effects of particulate matter on human health is primarily epidemiological. Particulate matter includes mineral, carbonaceous and other types of particles, as well as a mix of chemical compounds that may be adsorbed or adhered to the particle, depending on its origin. At elevated levels particulate matter can cause respiratory irritation, coughing, increased risk of respiratory illnesses such as pneumonia, asthma and bronchitis, reduced lung function, reduced pulmonary function and increased mortality. Particles over 10 microns are deposited in the upper respiratory tract and are of less concern than PM10 (less than 10 microns) and PM2.5 (less than 2.5 microns). PM2.5 can penetrate deep within the lung leading to increased morbidity and mortality and, for this reason, is considered to be the particulate size range of primary concern. PM10 and PM2.5 also reduce visibility. This year, PM10 was declared toxic in Canada under the Canadian Environmental Protection Act and targets with timetables for reduction of emissions have to be submitted by key industrial sectors.

5.1.6 Ozone

Ozone is a colourless, reactive oxidant gas that is formed at ground-level from photochemical reactions involving principally NO_x, VOC and CO. Ozone is one of the main concerns in urban smog because of the adverse effects on human health that can arise from both short-term and long-term exposure to elevated concentrations. Ozone also causes deterioration of a wide range of building materials. Short term effects include eye, nose and throat irritation, chest discomfort, increased risk of respiratory illnesses and asthma attacks, as well as decreased pulmonary function. The young and elderly are most susceptible to adverse effects.

5.1.7 Lead

Lead is emitted as particles less than 10 microns in size. Adverse effects of lead have been observed in children and adults, with newborns and young children being most vulnerable. No threshold level for adverse effects has been identified. Health effects include reduced IQ in children, increased blood pressure, increased risk of heart attack and increased mortality.

5.1.8 Benzene

Benzene has a strong, unpleasant odour and is noticeable at 2 ppm. It is considered a known carcinogen for humans, with toxic effects being associated with the central nervous system, the hematological system and the immunological system.

5.1.9 Aldehydes

The main aldehyde of concern is formaldehyde, which is regulated in some jurisdictions for light duty and heavy duty vehicles. Formaldehyde is absorbed in the respiratory system. Adverse effects of human exposure to formaldehyde include irritation of mucous membranes, coughing, chest tightness, and it is considered a probable human carcinogen.

5.1.10 1,3-Butadiene

Butadiene has a mild aromatic odour that is noticeable at about 1 ppm. It is considered a probable carcinogen based on the weight of evidence.

5.1.11 Diesel particulate matter

Diesel particulate is a complex mixture of particles composed of porous elemental carbon, sulphate, nitrate, and a range of organic compounds that are adsorbed on the surface or within the solid particles. The major organic constituents are hydrocarbons, polyaromatic hydrocarbons and nitro-polyaromatic hydrocarbons. Typically, 90% of the particles are less than 2.5 microns in diameter. A review of the health effects literature for diesel exhaust by the California Air Resources Board (1998a, 1998b) concluded that it was carcinogenic and assigned a cancer risk factor and a chronic non-cancer health risk exposure level below which adverse human health effects were unlikely to occur. The US EPA (2000) finalized a diesel exhaust health risk assessment in July, 2000 and concluded that diesel exhaust is likely to be carcinogenic, but concluded the available data was insufficient to assign a unit cancer risk estimate, contrary to the California Air Resources Board. The US EPA concluded that diesel particulate matter causes a small increase in the risk of cancer and that the hazard applies to ambient exposures as well as occupational exposures.

5.2 AIR QUALITY ISSUES IN THE APEC REGION

Air pollution is expected by the United Nations Environment Program (UNEP) to increase substantially in the Asia-Pacific region over the next three decades as a result of a three-fold increase in NO_x emissions and a four-fold increase in SO_x emissions (UNEP, 2000). The World Health Organization (WHO) has reported that 12 of 15 cities with the highest particulate, and 6 of 15 with the highest sulphur dioxide are located in Asia. Of the cities for which data was reported, most have annual particulate concentrations that exceed the WHO standards, as shown in Table 5-1. As noted above with regard to particulate matter, exposure to particulate matter, specifically, PM10 and PM2.5 at elevated levels can lead to significant adverse health outcomes and increased health related costs.

Table 5-1 Ambient Particulate and Sulphur Dioxide Concentrations in Asia

Economy	City	Particulate matter (Annual mean micrograms/m^3)	Sulphur Dioxide (Annual mean micrograms/m^3)
China	Beijing	370*	115*
India	Calcutta	393*	54*
Indonesia	Jakarta	271*	-
Japan	Tokyo	50	20
Malaysia	Kuala Lumpur	119*	24*
Philippines	Manila	90*	34
Thailand	Bangkok	105*	14

* Exceeds World Health Organization guidelines.
Source: AIT, 2000

The UNEP Geo-2000 study concluded that transportation contributes the largest share of air pollution in the urban environment of Asia and the Pacific region. Their study found that 10 of 11 cities in Asia exceed WHO guidelines for particulate matter by a factor of at least three. Tokyo was found to have low particulate pollution levels, generally meeting the guideline. They also concluded that problems with lead pollution existed in Bangkok, Jakarta, Karachi and Manila, and problems with CO existed in Jakarta. The introduction of unleaded motor fuels is reducing average lead levels, but the rate of decline is slower than elsewhere.

Air pollution is also a very serious problem in Chile and Mexico. Santiago was concluded by the World Bank (1997) to have very high air pollution levels caused to a major degree by emissions from urban transportation and industries. This pollution, including ozone, particulate matter and criteria pollutants, is causing severe respiratory problems and higher rates of pneumonia and other respiratory diseases. Mexico city is having similar problems with adverse effects of transportation on air quality and human health. Lead emissions are also of concern.

Major cities in Canada and the United States and other developed economies have made substantial progress in reducing emissions from motor vehicles, with associated improvements in air quality. The benefits realized by implementing lower emission standards for gasoline and diesel fuelled vehicles and requirements to reduce the emissions associated with the distribution and use of motor fuels has been positive for the fuels and vehicles industries and supported by the public. Further efforts to reduce the emissions per distance travelled are seen to be necessary for motor vehicles to ensure air quality continues to improve in spite of the projected growth in motor vehicle usage and urban population. Health research and cost benefit studies continue to support setting of more stringent ambient air quality and emission standards to prevent adverse health effects from pollutants strongly associated with fuels and motor vehicles, with NO_x, VOC, ozone, PM10/PM2.5, and diesel particulate matter being presently of highest priority (BC MELP, 1995; CTAP, 2000).

Long-term average ambient pollutant concentrations in an air shed generally vary in proportion to the rate of emissions from all sources in the air shed. This applies very well to gases and particles emitted directly to the atmosphere and with more uncertainty to contaminants formed in the atmosphere from precursor emissions. Problems with elevated ground-level ozone concentrations are largely episodic and seasonal in nature, lasting hours or days during an episode that is initiated under emission levels, ambient precursor concentrations, meteorology and climatology that promote the reaction chemistry. Modeling of ambient ozone formation and evaluation of the contribution of precursor emissions from local sources can be undertaken to calculate the level of emission reduction needed to prevent ozone episodes. This approach is costly and requires extensive study and modeling data. To avoid delay, regulatory authorities in some APEC economies have implemented measures to reduce emissions in advance of, or in parallel with, modeling studies attempting to predict the effects of emission reduction strategies.

Short-term ambient concentrations of contaminants are partly a function of the emission rate and partly dependent on the local meteorology and the discharge characteristics of the source. Reducing emissions in such cases will reduce ambient concentrations, but pollutant concentrations may still exceed air quality guidelines if conditions affecting dispersion are unfavourable.

5.3 Applications in APEC Regions

The APEC regions are very different in terms of the development of the fuels and transportation sectors. Some regions have developed as diesel fuel dependant and others as gasoline dependant. Even within fuel types there are vast differences in the development of the fuels. In North America, gasoline fuel quality is becoming very constrained by government set fuel quality criteria with the elimination of lead and restrictions on components such as benzene, sulphur, aromatics and olefins. In other APEC economies there are few, if any, restrictions on gasoline composition. There are similar, although not as extensive, differences with diesel fuel quality between the economies.

The results of the survey of APEC economies found that 84% of the total energy used for transportation is used in on-road vehicles, as discussed in Chapter 3. In-line with this result, the data from the survey also indicates that the on-road vehicle sector is also a major source of many pollutant emissions of potential concern. The approximate contribution of on-road vehicles to national emissions of criteria pollutants and carbon dioxide in the surveyed economies are summarized in Table 5-2. The contribution of on-road vehicles in urban

Table 5-2 Reported Contribution of On-Road Vehicles to Total National Emissions

Contaminant	Contribution Range
Nitrogen Oxides	30-52%
Sulphur Oxides	2-8%
Volatile Organic Compounds	16-90%
Carbon Monoxide	32-95%
Particulate Matter (PM10)	2-10%
Carbon Dioxide	20-40%

areas tends to be significantly higher than reported in Table 5-2 for national emissions.

Considering the significant share of national emissions that are from on-road vehicles, together with the large number of people that are potentially exposed to these emissions in densely populated areas, it is clear that motor vehicle emissions have more potential to adversely affect human health in the urban environment than the other transportation modes considered in this study. Emissions from the other source sectors are also important and can have significant local impacts on air quality and human health under certain situations. For example, emissions from marine vessels can have NO_x and particulate emission levels at dockside or underway that are very significant in busy port areas. Diesel particulate emissions from locomotives can potentially have significant effects adjacent to busy railway lines.

As a result of their potential impact on emissions, air quality and human health, on-road vehicles are the focus of the balance of this chapter, which addresses fuel/vehicle options. The following sections discuss the fuel options, and the associated vehicle options that are enabled by implementation of improvements in fuel quality, that can lead to reduced emissions in APEC economies. The sections are organized by type of air quality concern rather than by fuel type as the previous section. The decision process developed is applicable to all economies regardless of their stage of development. Also, the options can be applied to some fuel uses in non-road segments of the transportation sector, namely rail and marine transport, as well as off-road vehicle applications, to also achieve emission reductions.

Based on the air quality data available for the APEC region from this and other studies, as well as consideration of the future issues associated with climate change, the priority emission reductions in many areas are as follows:

- lead emissions (to enable use of catalytic converters)

- gasoline and diesel fuel sulphur content (to enable better emission control)
- primary particulate emissions of PM10 and PM2.5;
- NO_x, VOC and CO, which are of concern as contaminants and as precursors of secondary particulate and ozone formation in the atmosphere;
- air toxics
- greenhouse gases

Options to achieve these emission reductions and the technologies that could be used are discussed in the following sections.

5.4 Criteria Air Contaminants

5.4.1 Emission Reduction Strategies and Planning Considerations

The vehicle emission rates of contaminants are dependent on the vehicle technology and on the fuel used. In many APEC economies the emission rates for motor vehicles have been reduced as governments have set more stringent standards that new vehicles must meet. The typical emission rates or standards that have been applied in most of the APEC economies are summarized in Section 3.4.4 earlier in this report and demonstrate the advances in emission control possible with improved engine design and emission control systems, as well as the status of implementation of the latest level of emission standards.

Vehicle and engine technologies are continually changing in response to government regulations, consumer demand, technological capabilities and other factors. These changes have resulted in exhaust emissions from new vehicles being over 90% less than emissions from vehicles of the 1960's.

The emission behaviour of motor vehicles is intimately related and partially dependent on the fuel used. Options for reducing emissions from on-road motor vehicles are best developed considering the fuel and vehicle as an integrated system. The options for reducing emissions from motor vehicles and fuels fall into three overlapping options, as follows:

- Changes in the fuel to reduce emissions without requiring implementation of new vehicle technology;
- Moderate changes in the fuel in concert with improved commercially available vehicle emission control technology that can achieve lower emission standards;
- Substantial changes in fuel specifications from current levels to enable implementation of advanced vehicle emission controls and/or commercialisation of emerging vehicle technologies.

Figure 5-2 illustrates these concepts, which apply to both spark ignition and compression ignition vehicles. The categories used in the World-Wide Fuel Charter have been used in the figure as examples of the fuel changes contemplated.

The first level of reduction achieves moderate overall reductions or highly focused reductions on target contaminants and is labelled "Improving fuel specifications". This applies to conventional motor fuels and can be done for the existing vehicles in the APEC region. Many economies have proceeded with this approach to reduce VOC, lead, SO_x and toxic emissions. These reductions can be significant in a local air shed, but are moderate compared to the next level that can be achieved using more advanced emission controls on the vehicle.

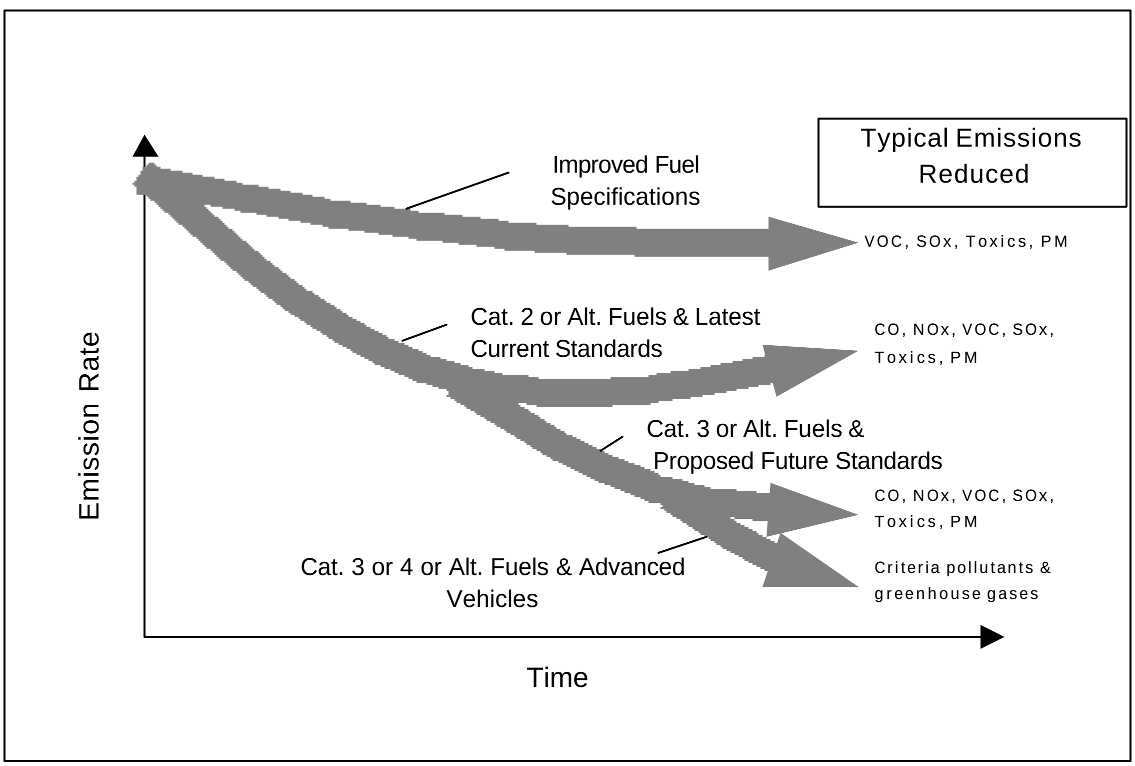
Moving fuel specifications in a direction similar to Category 2 of the World-Wide Fuel Charter (WWF) or using alternative fuels together with implementation of the latest commercially available catalytic emission controls can lead to large emission reductions relative to uncontrolled emissions. At some future time, growth in vehicle kilometers travelled will likely overwhelm the benefits achieved with the lower emission standards, causing emissions once again to rise (Figure 5-1).

Further emission reductions can be achieved by implementing WWF Category 3 petroleum based fuels or switching to alternative fuels to enable implementation of Tier 2 or EURO IV emission standards. As shown in Figure 5-1, this can be timed to achieve progressively lower emission levels as the new vehicles gradually displace older technology vehicles in the fleet.

The greatest emission reductions will be achieved with WWF category 3 and 4 petroleum based fuels or clean alternative fuels and emerging hybrid and fuel cell vehicles.

Important to the success of these emission reduction options is achieving a high level of penetration of the low emission vehicles and fuels in the on-road vehicle fleet. The survey data in this study and experience in Europe suggest 20-40% of the fleet is renewed in 5 years and 40-80% of the fleet is renewed in 10 years. Slower turn-over of the fleet is possible in some economies because of the comparatively high cost of new vehicles. The remaining older vehicles are high emitting vehicles and contribute a disproportionate amount of total emissions. As a result of slow turn-over of the on-road fleet with new vehicles, the full extent of vehicle emission reductions are not realized until 10-15 years after lower vehicle emission standards and enabling fuel specifications have been implemented.

Figure 5-1 Conceptual Approach for Fuel and Vehicle Emissions Reduction Options



5.4.2 Fuel and Vehicle Technologies

Most North American cars today are equipped with catalytic converters. Catalytic converters are pollution control devices installed directly in the exhaust system of vehicles to reduce harmful emissions. First used in 1975, oxidation (or two-way) catalytic converters take hydrocarbons (HC) and carbon monoxide (CO) and convert them into carbon dioxide (CO_2) and water vapour, which are then released into the air. Three-way catalytic converters were implemented in the United States in the early 1980s to meet the then new Tier 0 emission standards. This type of control oxidizes carbon monoxide and hydrocarbon (HC) emissions into carbon dioxide and water vapour, and chemically reduce nitrogen oxides (NO_x) into nitrogen and oxygen over a catalyst and with appropriate engine controls. Table 5-3 illustrates the emission reductions that can be achieved with the use of catalytic controls on a gasoline fuelled vehicle, assuming the gasoline does not significantly inhibit the performance of the catalyst because of poisoning with lead or sulphur.

Table 5-3 Approximate Reductions Achieved by the Use of Catalytic Exhaust Controls on a Baseline Uncontrolled Passenger Car

Type of Catalyst	CO		NO_x		THC		VOC	
	g/km	Change %	g/km	Change %	g/km	Change %	g/km	Change %
Uncontrolled	42.67	0	2.7	0	5.81	0	5.62	0
Non-catalyst control	27.7	-35	2.04	-24	3.24	-44	3.09	-45
Oxidation catalyst	22.37	-48	1.84	-32	2.59	-55	2.49	-56
Early 3-way catalyst	6.86	-84	0.66	-76	0.84	-86	0.79	-86
Advanced 3-way catalyst	6.2	-86	0.52	-81	0.71	-88	0.67	-88

Based on Mobile 5a runs assuming 24 C temperature, 31 km/h vehicle speed, gasoline RVP 9 psi and no inspection and maintenance program.

Source: World Bank, 1997

Many APEC economies and other countries could benefit from the adoption of current commercially available vehicle emission reduction technology to reduce emissions and improve air quality. In many of the developing economies the on-road vehicles either do not include emission control systems or the penetration of this emission control technology is low because insufficient time has elapsed to replace the older technology vehicles. Even in Europe, the share of the fleet of gasoline fuelled vehicles equipped with catalytic emission controls was just approaching 50% in 1997 from 10% in 1990, four years after the EURO I standard requiring such equipment came into force (European Environmental Agency, 2000). It is illustrative to observe that penetration of this technology varies widely from 22% in Spain to 75% in Austria and Portugal, depending on the member state. Also, only 23% of the heavy duty trucks comply with the EURO I standard.

An example of implementation of more stringent emission standards for light duty vehicles is the program for the Mexico City Metropolitan Area. Gasoline passenger cars were uncontrolled up to 1989, then more stringent standards were initiated for the 1991 model year and the US Tier 0 emission standards were required for the 1994 model year. Lower emission standards were also required for light duty gasoline commercial vehicles and diesel fuelled vehicles. This transition was enabled by phase-out of leaded gasoline. Three way catalytic controls were required on all new light duty gasoline vehicles and are reported to have achieved a 90% reduction in CO and hydrocarbons, and a 65% reduction in NO_x

emissions relative to emissions from a typical car without catalytic controls (World Bank, 1997). The inspection and maintenance program that was implemented would have helped to maximize these reduction levels. The sulphur level of unleaded gasoline at that time was 350-700 ppm for the "quality" grade. Some problems with using leaded fuel in vehicles equipped with catalytic controls were encountered during the phase-out of lead because of the higher cost of the unleaded fuel. This price differential was later reduced.

New gasoline passenger cars in Santiago, Chile were required to meet the US Tier 0 standards starting in 1992. By 1995, 95% of registered new vehicles were equipped with catalytic converters. Unleaded gasoline was introduced in 1992 and was expected to reach 65% by 2000 and be eliminated by 2005/6 (World Bank, 1997). Compared to emissions from a typical 1991 gasoline passenger car or taxi, the new standards were estimated to reduce emissions of CO by 68%, NO_x by 6% and hydrocarbons by 52%.

Introduction of US Tier 0 and Tier 1 standards or comparable European Union standards can achieve substantial emission reductions with potentially little change in fuel quality. The reduction in emission factors from 1985 levels that resulted for the light duty gasoline vehicle fleet in the Lower Fraser Valley, British Columbia, Canada as US Tier 0 standards were phased-in from 1980 to full implementation in the 1987 model year and as the US Tier 1 standards were phased in from 1994 to full implementation in 1997 are shown in Table 5-4. This data demonstrates the large reduction in NO_x, VOC and CO with replacement of higher emitting vehicles in the fleet and how long it takes for such benefits to be realized. The results were determined using a Canadianized version of the US Mobile 5b model that incorporates early Canadian emission standards and other national data, as well as vehicle age distribution, gasoline vapour pressure, ambient temperature and vehicle speed assumptions appropriate to the Vancouver area. The results pre-date the work on developing the new Mobile 6 model, which will include new emission estimation methodologies that more accurately estimate the effects of fuel sulphur on catalysts, deterioration with accumulated miles, Tier 1 and Tier 2 standards, aggressive driving behaviour and other factors.

Table 5-4 Reduction in Light Duty Gasoline Vehicle Emission Factors as a Result of US Tier 0 and Tier 1 Emission Standards in Vancouver, Canada

Year	NO_x		VOC Exh & Evap.		CO		SO_x		PM10	
	g/km	Change %	g/km	Change %	g/km	Change %	g/km	Change %	g/km	Change %
1985	2.19	0	3.48	0	32.01	0	0.08	0	.079	0
1990	1.70	-24	2.78	-24	25.30	-23	0.06	-25	.032	-60
1995	1.36	-38	1.87	-48	18.21	-44	0.05	-38	.013	-83
2000	1.15	-47	1.51	-57	15.47	-52	0.03	-63	.009	-89
2005	1.06	-51	1.35	-61	14.42	-55	0.03	-63	.009	-89
2010	1.04	-52	1.31	-62	14.23	-55	0.02	-75	.008	-90
2015	1.03	-53	1.29	-63	14.14	-55	0.02	-75	.008	-90
2020	1.03	-53	1.29	-63	14.14	-56	0.02	-75	.008	-90

Note: Results are from forecasting of emissions in the Lower Fraser Valley area of British Columbia, Canada, with Mobile 5C and PART 5 assuming continuation of Tier 1 standards. Vehicle age distribution assumed constant at 31.1% 0-4, 37% 5-9, 20.5% 10-14, 8.4% 15-19 and 3% >19 years old. SO_x emissions are adjusted for gasoline sulphur content: 1985 & 1990, 350 ppm; 1990, 300 ppm; 2000-2020,175 ppm. Vehicles up to 3,856 GVWR.

Source: Levelton, 1998

Other than the removal of lead from gasoline to enable the deployment of catalytic converters in the 1970's these improvements in exhaust emissions in the US and Canada have been accomplished without significant fuel composition changes. Average emission factors were developed by the US EPA for the "49 state" area on an annual basis and for May-September in selected major cities of the Unites States as the baseline to assess the proposed US Tier 2 emission standards. The latest knowledge on the effects of sulphur in gasoline on catalysts, off-cycle emissions, the rate of deterioration of emission control equipment and gasoline reformulation were included. The baseline results for Tier 1 are given in Table 5-5. The nation-wide average emission factors for the US are low relative to other jurisdictions because of the progressive high penetration of catalytic emission controls on vehicles first meeting the Tier 0 then the Tier 1 standards. These results can not be compared with the Canadian Tier 1 values because of differences in methodology and assumptions, but they do again show the reduction in emissions as new standards are implemented and the flattening off of the reduction when a high level of penetration is achieved in 10 to 15 years.

Starting with the Auto Oil program in the United States in the 1980's a better understanding of the impact of fuel composition on vehicle emissions has been gathered. Starting in 2004 gasoline sulphur content in North American gasoline will be limited to 30 ppm in order for the vehicles to meet Tier 2 emission standards. These new, low gasoline sulphur levels enable new vehicle technology to meet and maintain the low Tier 2 standards without deterioration of the performance of the emission control equipment from poisoning with sulphur. The Tier 2 standards will further reduce US 49 State average emission factors for all light duty vehicles (passenger cars and light duty trucks up to 3856 kg GVWR) relative to the Tier 1 baseline. The reduction in SO_x is proportional to the change in fuel sulphur. The largest absolute emission reduction will be achieved for NO_x with a considerably smaller reduction in VOC emissions. These emission reductions would not be achievable without the associated reduction in gasoline sulphur content and use of unleaded gasoline.

Table 5-5 Light Duty Vehicle Emission Factors Without and With Implementation of Tier 2 Emission Standards and 30 ppm Sulphur Gasoline in the US 47 State Area

Year	NOx			VOC (Exh & Evap)			SOx			PM10		
	Tier 1	Tier 2	Reduct'n	Tier 1	Tier 2	Reduct'n	Tier 1	Tier 2	Reduct'n	Tier 1	Tier 2	Reduct'n
	g/km	g/km	%	g/km	g/km	%	g/km	g/km	%	g/km	g/km	%
1990	1.68	1.68	0	3.64	3.64	0	0.052	0.052	0	0.014	0.014	0
2000	1.01	1.01	0	0.98	0.98	0	0.050	0.050	0	0.009	0.009	0
2005	0.81	0.67	17	0.65	0.62	4	0.051	0.005	90	0.009	0.004	57
2010	0.66	0.40	39	0.48	0.45	8	0.052	0.005	90	0.009	0.004	57
2015	0.59	0.24	59	0.40	0.36	11	0.053	0.006	89	0.009	0.003	63
2020	0.57	0.18	69	0.37	0.32	15	0.053	0.006	89	0.009	0.003	67

Note: Results are from modeling done in support of the proposed Tier 2 and gasoline sulphur standards in the United States. Emission factors determined using Mobile 6 methods and apply to 49 states excluding California, Alaska and Hawaii. Baseline is Tier 1 plus NLEV and supplemental test procedure as per full Tier 1 standards. The Tier 2 case is NLEV plus Tier 2, supplemental test procedure and 30 ppm sulphur. LDV includes gasoline and diesel passenger cars and trucks up to 3,856 kg GVWR.

Source: US EPA, 1999

The minimum fuel specification requirement in APEC economies to reduce emissions would be unleaded gasoline with sulphur levels of less than 1000 ppm and preferably less than 300 ppm. All APEC economies would benefit from the reduction of sulphur in gasoline to a level of 30 ppm or less.

After extensive consultation, Australia has proposed to meet the following specifications for gasoline:

By January, 2002

Octane: regular unleaded: 91 RON; premium unleaded: 95 RON.
Olefins: all grades 18% v/v pool average over 6 months with a cap of 20%.
Aromatics: all grades 45% v/v pool average over 6 months with a cap of 48%.
Benzene: no standards proposed.
Lead: all grades: 5 mg/L
Sulphur: unleaded: 500 ppm maximum; premium unleaded: 150 ppm.
Oxygen content: 2.7% maximum with exemption for ethanol blends up to 10%.
Phosphorous: unleaded and premium unleaded: 1.3 mg/L maximum

By January, 2005

Olefins: all grades: 18% v/v maximum.
Aromatics: all grades: 42% v/v maximum.
Benzene: all grades: 1% v/v maximum.
Sulphur: all grades: 150 ppm.

By January, 2007

Sulphur: all grades: 30 ppm or lower.

The use of alternatives fuels can result in significantly reduced emissions if they are properly executed. The emission results for factory built alternative fuelled vehicles was shown in earlier sections of the report. Table 5-6 shows the estimated impact on criteria air contaminants from lower sulphur gasoline and from various alternative fuels. Included in this table is the nominal reduction in emissions achievable with the use of a gasoline electric hybrid passenger car and is based on tests reported by the US EPA for a Japanese version of a Toyota Prius not optimized to meet US EPA standards (US EPA, 1998). The fuel economy of this vehicle was 33% better than a Toyota Corolla having a similar weight (1247 kg compared to 1361 kg for the Prius).

Beyond lead and sulphur other formulation changes can impact vehicle emissions. Many APEC economies are moving their fuel specifications towards the Level 3 criteria of the World Wide Fuel Charter. These higher quality fuels will lead to reductions in emissions of all criteria air contaminants.

A substantial part of the problem with fine particulate matter and ozone precursors in urban areas of developing economies is diesel particulate and NO_x from heavy duty and light duty diesel vehicles. Chile implemented lower emission standards for buses in 1993, and for heavy duty diesel trucks in 1994 to a level equivalent to the 1991/92 US emission standard of 15.5 g/bhp-h CO, 1.3 g/bhp-h HC, 5.0 g/bhp-h NO_x and 0.25 g/bhp-h particulate matter (World Bank, 1997). This was followed in 1996 for buses and 1998 for heavy duty trucks by the 1994/95 US standard, which reduced the particulate matter emission level to 0.10 g/bhp-h and did not change the levels of the other parameters. In coordination with this, the diesel fuel sulphur was reduced to 0.3 wt % in 1995 and 0.2 wt % in 1998 in the Santiago area. The lower standards were estimated to reduce emissions from a bus by 45% for CO, 68% for hydrocarbons, zero for NO_x and 72% for particulate matter. In the case of heavy duty trucks the emission reductions were: CO, 83%, hydrocarbons 52%, NO_x, 37% and particulate matter 69%.

Table 5-6 Nominal Emission Reductions for Gasoline and Alternative Fuels

Fuel	Change in Emissions per Distance Travelled				
	NO_x	SO_x	CO	NMHC	PM
Passenger Cars	% Relative to 300 ppm S Gasoline in US Tier 1 Vehicle				
30 ppm S gasoline	-10	-65	-15	-15	0
30 ppm S gasoline hybrid	-60	-80	-60	-65	-40
Natural Gas	-50	-80	-50	-90	-80
LPG	-10	-80	-40	-80	-80
10% Ethanol	+5	-10	-10	-15	-25
Methanol Fuel Cell	-98	-100	-99	-80	-100
Diesel Fuel	+25	-20	-80	-70	+400
Heavy Duty Vehicles	% Relative to 300 ppm S Diesel Fuel in 2000 Model-Year US Vehicle				
CNG/LNG	-40	-90	-20	-60	-95
LPG	-30	-85	-20	-60	-95
20% Biodiesel	+3	-20	-9	-15	-10
100% Biodiesel	0	-100	-40	-50	-50
Dimethyl ether (DME)	-60	-100	-80	-80	-90

Reduction in the sulphur content of diesel fuel reduces particulate and SO_2 emissions from diesel fuelled vehicles and is required to reach the most stringent proposed emissions standards for heavy duty vehicles. The world-wide fuel charter suggests 300 ppm for current emission standards and 30 ppm to zero sulphur to enable the technologies needed to meet the stringent future emission standards. The program proposed by Australia for improving the specifications of diesel fuel are:

By January, 2002
Sulphur: 500 ppm.
Cetane Index: 46 minimum.
Density: 820 to 860 kg/m^3
Distillation T95: 370 C.

By January, 2006
Sulphur: 50 ppm.
Density: 820-850 kg/m^3
Distillation: 360 C maximum.
Polyaromatic hydrocarbons: 11% m/m maximum.

By January 2008/10
Sulphur: 30 ppm or lower depending on a review in 2002/03.

Table 5-6 presents estimates of the nominal emission reduction that can be achieved in modern heavy-duty compression ignition engines fuelled with natural gas, LPG, biodiesel and dimethyl ether, relative to emissions from a year 2000 diesel fuelled vehicle designed for the US market.

5.5 AIR TOXICS

There are a number of components of vehicle emissions that are known to, or considered to cause adverse human health effects. The main air toxics are lead, benzene, particulate matter, 1,3-butadiene, formaldehyde and acetaldehyde and have the health effects described earlier in Section 5.1. The US EPA has recently identified 21 mobile source air toxics as lists in Table 5-7.

Table 5-7 US EPA Mobile Source Air Toxics

Acetaldehyde	Diesel Exhaust	MTBE
Acrolein	Ethylbenzene	Napthalene
Arsenic compounds	Formaldehyde	Nickel compounds
Benzene	n-Hexane	POM (sum of 7 PAHs)
1,3-Butadiene	Lead	Styrene
Chromium compounds	Manganese compounds	Toluene
Dioxin/furans	Mercury compounds	Xylene

The US EPA estimates that mobile (car, truck, and bus) sources of air toxics account for as much as half of all cancers attributed to outdoor sources of air toxics. This estimate is not based on actual cancer cases, but on models that predict the maximum number of cancers that could be expected from current levels of exposure to mobile source emissions. The models consider available health studies, air quality data, and other information about the types of vehicles and fuels currently in use. Non-road mobile sources (such as farm tractors) emit air toxics as well.

Some toxic compounds, such as benzene, are present in gasoline and are emitted to the air when gasoline evaporates or passes through the engine as unburned fuel. Cars emit small quantities of benzene in unburned fuel, or as vapour when gasoline evaporates. A significant amount of automotive benzene comes from the incomplete combustion of aromatic compounds in gasoline such as toluene and xylene that are chemically very similar to benzene. Like benzene itself, these compounds occur naturally in petroleum and become more concentrated when petroleum is refined to produce high octane gasoline.

Formaldehyde, acetaldehyde, diesel particulate matter, and 1,3-butadiene are not present in fuel but are by-products of incomplete combustion. Formaldehyde and acetaldehyde are also formed through a secondary process when other mobile source pollutants undergo chemical reactions in the atmosphere.

Lead emissions from leaded gasoline is the most serious air toxic in some of the APEC economies. Lead is one of the least expensive means available to increase the octane of gasoline. It was widely used from the 1920's to the early 1970's when it began to be phased out first because of its poisoning effect on catalytic converters that were being introduced and then due to its toxic nature. Most of the APEC regions have either removed lead from gasoline, or announced plans to do so. In some cases the scheduled date for elimination of leaded gasoline has been delayed due to economic pressures.

A number of APEC economies have begun to limit the amount of benzene allowed in gasoline. A few have also imposed limits on the aromatic content of gasoline. The most common limitation on benzene is to a value of 1% v/v, or slightly less. The survey data indicated that some economies have gasoline benzene levels as high as 5-6%, which is essentially an uncontrolled level. Benzene and the other aromatic components are good sources of gasoline octane and often increase when lead is removed from gasoline. This is as a result of the catalytic reforming process in a refinery often being the next lowest cost option for increasing octane after lead.

Particulate matter is formed from the incomplete combustion of gasoline or diesel fuel. It is primarily carbonaceous material but it can also be a carrier for other contaminants such as benzene or polyaromatic hydrocarbons. Particulate matter emissions are greatest from diesel engines, particularly if they are poorly maintained or do not meet recent European or US EPA standards.

The emissions that come out of a vehicle depend greatly on the fuel that goes into it. Consequently, programs to control air toxics pollution have centred around changing fuel composition. Many of the APEC economies have begun programs to improve fuel quality and thus reduce air toxics emissions.

In addition to eliminating or reducing the use of lead and benzene in gasoline some of the other fuel options for reducing air toxics include:

- Limits on gasoline volatility

  Volatility is a measure of how easily a liquid evaporates. Toxics such as benzene are present in gasoline and are emitted when gasoline evaporates. Limits on gasoline volatility could be imposed to control evaporative emissions of both hydrocarbon and toxic compounds. Implementation of the recommendations in the World Wide Fuel Charter (WWFC) would be appropriate.

- Limit gasoline aromatics

  Incomplete combustion of aromatic compounds increases benzene exhaust emissions. The WWFC provides guidance on suitable levels of aromatics, some areas of the United States have reduced aromatic levels even further.

- Limit gasoline sulphur

  Reducing gasoline sulphur content improves the efficiency of catalytic converters and reduces air toxic emissions. Canada and the United States are moving towards sulphur levels in gasoline of 30 ppm by 2004/5.

- Limits on diesel sulphur

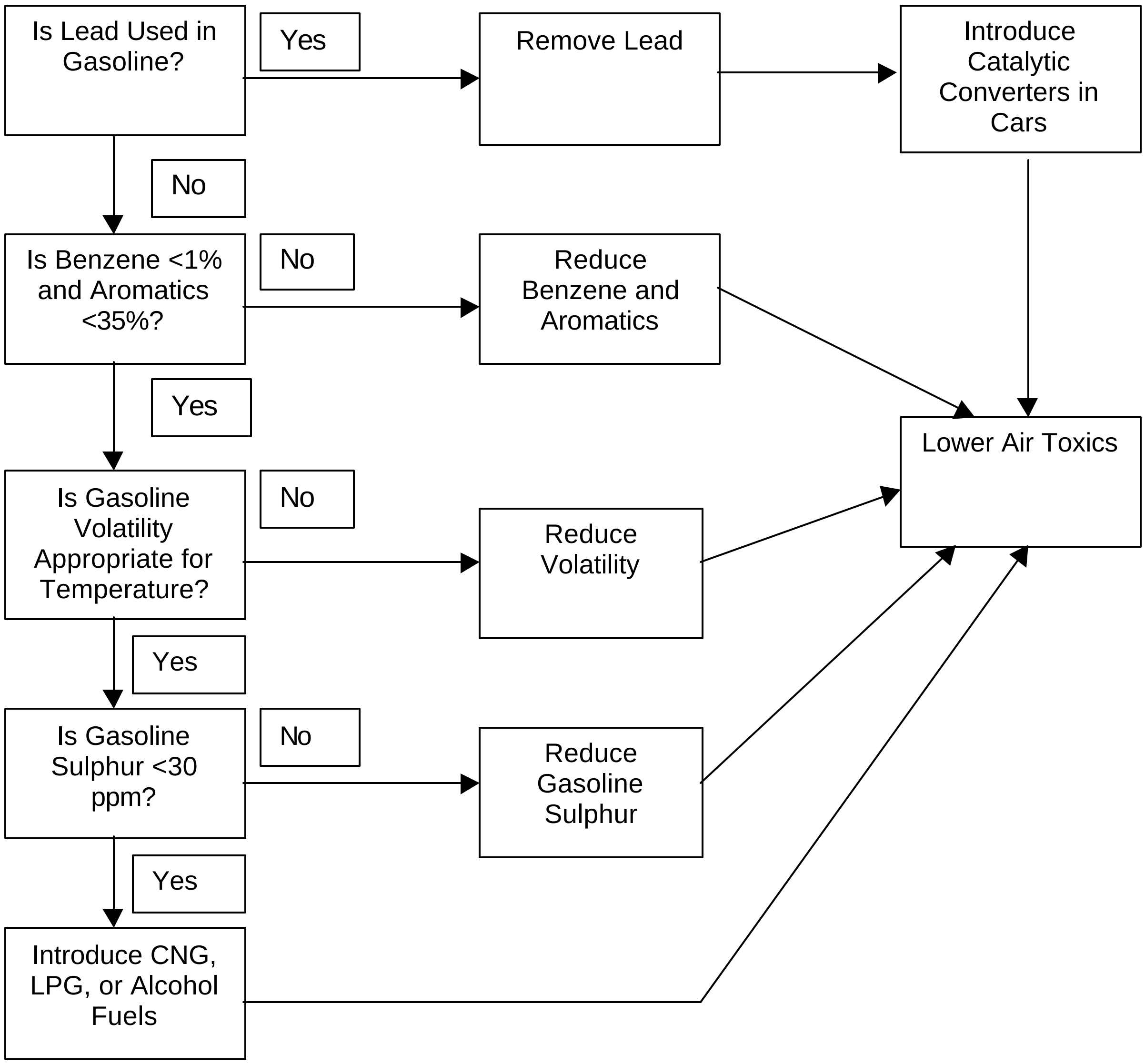
  The sulphur in diesel fuel has a significant impact on the emissions of particulate matter. Reducing diesel sulphur from 500 ppm to 30 ppm will reduce diesel particulate emissions from heavy duty engines by 6 to 9% (ACEA, 2000), and substantially reduce SO_2 emissions, the primary form in which the sulphur is emitted. In addition, the reduced sulphur in the exhaust gas enables the use of catalytic after-treatment devices to reduce particulate for the latest and future engine designs. Reduction of diesel sulphur is an effective means of reducing particulate emissions.

- Alternative Fuels

  A switch to alternative, non-petroleum fuels offers another strategy for reducing air toxics. Choices include alcohols, natural gas, and propane. These fuels are inherently cleaner than conventional gasoline and diesel because they do not contain toxics such as benzene. In addition, they are made of simpler chemical compounds, which yield lower levels of complex combustion by-products such as 1,3-butadiene.

North American Tier 1 cars today are capable of emitting 90% less air toxics on a per-mile basis than the uncontrolled models of 1970; new trucks and buses are designed to emit less than half the air toxics of their 1970 counterparts. The options for reducing air toxics from gasoline is shown in Figure 5-2. A combination of the measures could also be used.

Figure 5-2 Options for Air Toxics Reductions from Gasoline



The options for diesel fuel air toxic reductions are fewer. The sulphur content of the fuel can be reduced, the density can be lowered and the polyaromatic content can be reduced. These three options will all result in lower particulate matter emissions and, thus, lower air toxic emissions.

5.6 GREENHOUSE GASES

Greenhouse gases are emitted from the production and use of transportation fuels. The principal greenhouse gases in this context are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). There are other greenhouse gases, but they are not significant in the transportation sector. Greenhouse gas emissions are reported for individual gases (CO_2, CH_4 and N_2O) as well as in terms of equivalent emissions of CO_2. Mass emissions of methane are converted to CO_2 equivalent by multiplying by 21, using the 100 year global warming potential multiplier recommended by the International Panel for Climate Change. A global warming potential of 310 is used for nitrous oxide.

Fuel/vehicle options for reducing emissions of greenhouse gases from the transportation section include improving fuel economy, switching to lower carbon or renewable fuels and reducing transportation demand. Options for reducing transportation demand are outside the scope of the study and were not considered.

Emissions of CO_2 from a motor vehicle burning petroleum fuels are proportional to the fuel consumed. Therefore, improvements in fuel economy will result in a corresponding reduction in CO_2 emissions. On a full cycle basis, including emissions from resource production through to delivery of fuel to the vehicle, as well as CO_2 equivalent emissions of methane and nitrous oxide introduces a slight non-linearity. In a study for Canada (Levelton et al, 1999), the relationship for full cycle greenhouse gas equivalent emissions from a passenger car burning gasoline containing 30 to 300 ppm sulphur is approximately:

GHG emission = 37.2 (L/100 km) $^{0.95}$ grams CO_2 equivalent/km travelled,

where the fuel consumption rate of the vehicle is input into the equation in units of L/100 km travelled. The improvement in fuel economy needed to achieve a range of reductions in full cycle greenhouse gas emissions is shown in Table 5-8 from the study for Canada, and similar trends will apply generally to most other APEC economies assuming all steps in the fuel production, refining, distribution and use chain are included.

Table 5-8 Improvements in Fuel Economy Required to Achieve a Desired Reduction in Greenhouse Gas Emissions from a Passenger Car in Canada

Target Reduction in GHG Emissions (%)	Fuel-Cycle GHG Emission Rate * (g CO_2 Equivalent/mile)	Fuel Economy (US mpg)	Fuel Consumption (L/100km)	Reduction Required in Vehicle Fuel Consumption (%)
0	485	26.0	9.0	0
10	436	29.1	8.1	10.6
20	388	32.9	7.2	20.9
30	340	37.8	6.2	31.2
40	291	44.5	5.3	41.5
50	243	53.8	4.4	51.7

* Global warming potentials: CO_2 1; CH_4 21; N_2O 310. Reference year 2010.

As evident from the data presented in Section 3.4.3.2 on the fuel economy of new passenger cars in the United States, only a very minor improvement in fuel economy has been achieved in the last 15 years as a result of changes that have increased the weight and the performance of vehicles. The US EIA has forecast a 0.5 %/year improvement in the average new passenger car fleet fuel economy, increasing from 28.2 mpg in 1998 to 31.6 mpg in 2020, based on the projected mix of conventional and alternative technology vehicles (US EIA, 2000). Canada has forecast a 0.7%/year improvement fuel economy of new passenger cars for the period from 2000 to 2020 (NR Can, 1997), while Australia has predicted a 1%/year improvement. At the highest of these forecasts, a 10% reduction in greenhouse gas emission rates for a passenger car would be achieved after ten years. Over this same period there would be growth in the distance travelled per vehicle, an increase in the number of vehicles and likely an increase in the average weight of light duty vehicle, all of which will act to off-set improvements in fuel economy over the same time period.

Greenhouse gas emissions over the full fuel cycle include all significant sources of these emissions from production of the energy source (i.e. crude oil, biomass, natural gas, etc.), through fuel processing, distribution, and onward to combustion in a motor vehicle for motive power. A full fuel cycle analysis can also include greenhouse gas emissions from vehicle material and assembly as these emissions are affected by the choice of alternative fuel/vehicle technology. A wide range of emission sources are involved in the production and distribution of fuels, and these vary depending with the type of fuel.

The greenhouse gas emissions associated with a specific fuel cycle are country specific since the methods of production can vary from country to country. It is beyond the scope of this study to investigate these regional differences. An in-depth study of greenhouse gas emissions of various fuel cycles was recently performed in Canada (Levelton, 1999). The greenhouse gas emission data presented here is drawn mostly from that work performed on Canadian fuel production and use cycles. It should be generally representative of emission trends in other economies. The results for the year 2000 are shown in Tables 5-9, 5-10 and 5-11.

As is evident from the tables, the near term options for light duty vehicles (commercially available in 2000) that produce greenhouse gas emission reductions compared to a gasoline-powered vehicle are diesel-powered vehicles, CNG and LPG vehicles and fuels from renewable resources, such as ethanol. High efficiency hybrid electric vehicles can reduce full cycle greenhouse gas emissions significantly. Biodiesel and, to a lesser extent, LPG and DME can reduce greenhouse gas emissions from heavy duty vehicles compared to conventional vehicles using diesel fuel. The alternative fuelled vehicles also offer reductions in emissions of criteria air contaminants and air toxics.

For all of the fuel cycles shown in the tables, carbon dioxide is the dominant greenhouse gas. In most of the cycles, over 90% of the total CO_2 equivalent greenhouse gas emission is carbon dioxide. The exceptions to this are ethanol from cellulose, and natural gas. In the case of ethanol the lower percentage of carbon dioxide is due to the nature of the fuel cycle where biomass derived carbon is not counted by the Intergovernmental Panel on Climate Change (IPCC) and in the case of natural gas higher emissions of methane contribute to a portion of the global warming potential.

For most of the fuel cycles the majority (about 75%) of the carbon dioxide comes from vehicle operation. This means that the emissions are distributed and carbon sequestration is not a feasible alternative. The one exception shown in the table is hydrogen production from natural gas for a fuel cell powered vehicle. In this case most of the carbon dioxide is produced during hydrogen manufacturing and if this was done on a large scale at a central plant it may be possible to sequester the carbon dioxide.

The Canadian study did not consider coal-derived transportation fuels nor the effects when alternative fuels are introduced into a fleet designed using less advanced vehicle technology. Both of these issues are potentially of interest to APEC economies; the coal cycles because of the vast coal reserves in many economies, and the vehicle technology because in some economies the vehicle technology is less advanced than it is in North America. The greenhouse gas emission model used for the Canadian study is capable of analyzing coal to methanol cycles. For comparison purposes a preliminary review of this cycle was made and the results for M85 in the year 2000 are shown and compared to natural gas to methanol in Table 5-12. With the quantity of carbon dioxide produced at a coal to methanol facility there is a need for carbon sequestration with this fuel cycle.

For a conventional gasoline vehicle, the greenhouse gas emissions are a function of the fuel economy of the vehicle. The fuel economy in turn is a function of the efficiency of the engine. The overall engine efficiency is influenced by the engine compression ratio and the combustion efficiency. The maximum compression ratio that is feasible for an engine is determined by the gasoline octane rating. There are a number of APEC economies where the gasoline octane is less than 87 (R+M/2) or 91 RON and there is the potential to improve the fuel economy of new vehicles by raising the gasoline octane and enabling the introduction of more fuel efficient engines. These engines would also likely be cleaner burning and thus produce other air quality benefits.

Some of the options shown in Tables 5-9 and Table 5-10 are longer term options for many of the APEC regions. These longer term options include fuel cell cycles, electric vehicles and ethanol from cellulose. The year 2000 is not the appropriate year to consider for these fuel cycles since the processes or the vehicles are either not yet commercialised, or optimized. A study of fuels for fuel cell vehicles was prepared for Methanex Corporation ($(S\&T)^2$, 2000) that considered methanol, gasoline, Fischer Tropsch fuels in a fuel cell vehicle with on board reforming and various hydrogen pathways. The analysis was done for the 2010 when it was assumed that the vehicles had been optimized. The results were analyzed for both Canada and the United States to determine potential regional differences. A summary of these results is shown in Table 5-13. A comparison of the results in 2000 with those expected in 2010 indicates the rate of improvements expected in the development of fuel cell vehicles in the next decade.

A potential decision process for a region considering means to reduce greenhouse gas emissions from the transportation sector is shown in Figure 5-3. Combinations of the measures are also feasible.

Table 5-9 Fuel Cycle CO_2 Equivalent Emissions for Passenger Cars in 2000 (g/mile)

Fuel / Vehicle Option ->	300 ppm S Gasoline	30 ppm S Gasoline	30 ppm S Gasoline Hybrid	E10 (Corn)	E10 (Cellulose)	E85 (Corn)	E85 (Cellulose)	M85 (Natural Gas)	LPG	CNG	M100 Fuel Cell	H2 (Natural Gas) Fuel Cell	H2 (Electricity) Fuel Cell	EV	300 ppm S Diesel	50 ppm S Diesel	300 ppm S Diesel Hybrid
Vehicle operation	371	362	275	370	370	361	361	345	336	318	262	0	0	0	295	295	222
Fuel dispensing	1	1	1	1	1	1	1	1	1	7	1	14	14	0	0	0	0
Fuel storage and distribution	7	7	5	7	7	6	6	24	7	16	24	1	1	0	5	5	4
Fuel production	55	67	38	60	53	113	37	49	10	7	38	217	256	92	25	30	19
Feedstock transport	1	1	1	2	2	7	8	8	0	0	9	12	0	1	1	1	1
Feedstock and fertilizer production	29	29	20	34	30	85	36	23	12	9	17	12	0	1	23	23	18
Land use changes and cultivation	n/a	n/a	n/a	6	0	69	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CH_4 and CO_2 leaks and flares	17	17	12	16	16	4	4	20	14	26	17	19	0	3	14	14	10
C in end-use fuel from CO_2 in air	n/a	n/a	n/a	-24	-24	-271	-271	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Emissions displaced by coproducts	0	0	0	-6	-1	-64	-8	0	0	0	0	0	0	0	0	0	0
Sub total (fuelcycle)	480	484	351	465	453	311	174	469	379	382	368	275	271	97	363	368	274
% changes (fuelcycle)	--	1	-27	-3	-6	-35	-64	-2	-21	-20	-23	-43	-44	-80	-24	-23	-43
Vehicle assembly and transport	6	6	5	6	6	6	6	6	6	6	6	7	7	6	6	6	5
Materials in vehicles (incl.storage)	30	30	28	30	30	31	31	31	31	31	34	37	37	56	30	30	27
Grand total	516	520	384	501	489	347	210	506	416	419	408	319	315	159	398	403	307
% change (grand total) Relative to conv. gasoline	--	1	-26	-3	-5	-33	-59	-2	-19	-19	-21	-38	-39	-69	-23	-22	-41
% change Rel. to 30 ppm gasoline		--	-26	-4	-6	-33	-60	-3	-20	-19	-22	-39	-39	-69	-23	-22	-41

Source: Levelton, 1999

Table 5-10 Fuel Cycle CO_2 Equivalent Emissions for Heavy Duty Compression Ignition Trucks in 2000 (g/mile)

Fuel / Vehicle Option ->	300 ppm S Diesel	50 ppm S Diesel	LNG	LPG	Biodiesel	DME
Vehicle operation	1715	1715	1377	1742	1718	1510
Fuel dispensing	3	3	295	4	3	4
Fuel storage and distribution	27	28	87	38	36	97
Fuel production	149	178	33	52	710	122
Feedstock transport	5	5	0	1	25	48
Feedstock and fertilizer production	137	138	41	63	480	91
Land use changes and cultivation	n/a	n/a	n/a	n/a	665	n/a
CH_4 and CO_2 leaks and flares	81	81	306	72	0	92
C in end-use fuel from CO_2 in air	n/a	n/a	n/a	n/a	-1676	n/a
Emissions displaced by coproducts	0	0	0	0	-807	-10
Sub total (fuelcycle)	2118	2147	2139	1972	1152	1954
% changes (fuelcycle)	--	1	1	-7	-46	-8
Vehicle assembly and transport	15	15	15	15	15	15
Materials in vehicles (incl.storage)	77	77	76	77	79	79
Grand total	2209	2239	2230	2064	1246	2049
% changes (grand total)	--	1	1	-7	-44	-7

Source: Levelton, 1999.

Table 5-11 Estimated Full Cycle Emissions of Greenhouse and Criteria Pollutants from Passenger Car in 2000 (g/mile)

Fuel	300 ppm Gasoline	30 ppm S Gasoline	E10 Ethanol	E10 Ethanol	E85 Ethanol	M85 Methanol	LPG	CNG	M100 Methanol	Hydrogen	Diesel	50ppm Diesel
Feedstock	Crude Oil	Crude Oil	Corn	Cellulose	Cellulose	Nat. Gas.	Nat. Gas	Nat Gas	Nat. Gas	Nat. Gas	Crude Oil	Crude Oil
Engine Type	Spark Ignition	Spark Ignition	Spark Ignition	Spark Ignition	Spark Ignition	Spark Ignition	Spark Ignition	Spark Ignition	Fuel Cell	Fuel Cell	Compression Ignition	Compression Ignition
CO_2												
Vehicle Operation	344	348	343	343	334	321	312	259	262	0	288	288
Upstream	84	95	67	58	-209	103	29	36	90	255	50	54
Veh. Mat'l & Assembly	36	36	36	36	37	37	37	37	40	44	36	36
Total	464	479	446	437	162	461	378	333	392	299	373	378
Percent total CO_2 Equiv.	90%	93%	90%	90%	77%	91%	91%	80%	95%	93%	94%	94%
CH_4												
Vehicle Operation	0.17	0.17	0.17	0.17	0.23	0.10	0.17	2.01	0.00	0.00	0.01	0.01
Upstream	1.11	1.14	1.08	1.10	1.02	1.08	0.65	1.28	0.86	1.04	0.85	0.86
Veh. Mat'l & Assembly	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	1.29	1.31	1.26	1.28	1.26	1.19	0.82	3.29	0.87	1.05	0.87	0.88
Percent total CO_2 Equiv.	5%	5%	5%	6%	13%	5%	4%	17%	4%	7%	5%	5%
N_2O												
Vehicle Operation	0.06	0.02	0.06	0.06	0.06	0.06	0.06	0.05	0.00	0.00	0.02	0.02
Upstream	0.01	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Veh. Mat'l & Assembly	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.07	0.03	0.08	0.08	0.07	0.07	0.06	0.05	0.01	0.01	0.02	0.02
Percent total CO_2 Equiv.	4%	2%	5%	5%	11%	4%	5%	4%	0%	1%	2%	2%
Total CO_2 Equiv.	513	517	498	487	211	508	415	417	412	322	398	403
% Change from Gasoline		+0.8	-2.9	-5.1	-58.9	-1.0	-19.1	-18.7	-19.7	-37.2	-22.4	-21.4

Source: Levelton, 1999.

Table 5-12 Comparison of Natural Gas and Coal to Methanol Fuel Cycles (g/mile)

Fuel / Vehicle Option ->	300 ppm S Gasoline	M85 From Natural Gas	M85 From Coal
Vehicle operation	371	345	345
Fuel dispensing	1	1	1
Fuel storage and distribution	7	24	24
Fuel production	55	49	311
Feedstock transport	1	8	5
Feedstock and fertilizer production	29	23	11
CH_4 and CO_2 leaks and flares	17	20	21
Emissions displaced by coproducts	0	0	0
Sub total (fuelcycle)	480	469	718
% changes (fuelcycle)	--	-2	+50
Vehicle assembly and transport	6	6	6
Materials in vehicles (incl.storage)	30	31	31
Grand total	516	506	755
% change (grand total) Relative to gasoline	--	-2	+39

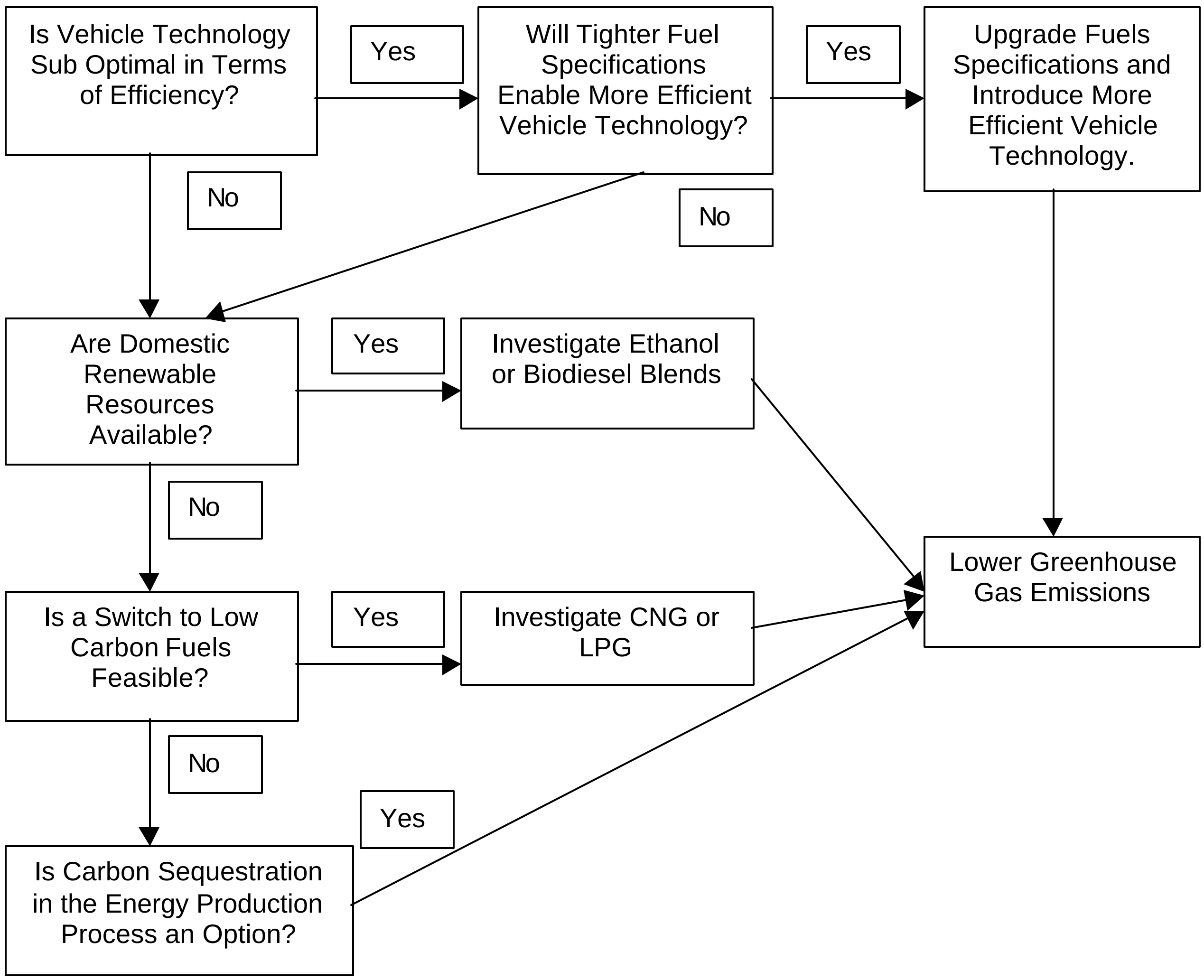
Table 5-13 Fuel Cell Vehicle Greenhouse Gas Emissions in 2010

Fuel	Source	% Reduction in GHG in Canada	% Reduction in GHG in the US
Compressed Hydrogen	Natural Gas SMR*	51.8	44.5
Methanol	Natural Gas	43.5	41.7
Liquid Hydrogen	Natural Gas SMR	44.3	22.5
Gasoline	Crude oil	27.5	25.8
Compressed Hydrogen	Natural Gas POX**	25.0	8.5
Fischer Tropsch	Natural Gas	22.5	21.9
Compressed Hydrogen	Electricity from Natural Gas Cogeneration	15.5	13.8

* Steam methane reforming.

** Partial oxidation.

Figure 5-3 Options for Greenhouse Gas Reduction in Transportation



6. OBSTACLES AND DATA GAPS

6.1 OBSTACLES TO GREATER USE OF IMPROVED OR ALTERNATIVE FUELS

The potential obstacles an economy may face regarding improvement of petroleum fuels for conventional and emerging vehicles are fairly well understood, as programs with this objective have either been implemented or are in the process of being implemented in the APEC region. Experience with these programs can be shared, helping others avoid, mitigate and plan for problems that may be encountered when moving ahead with a similar program in their own economy. Obstacles to greater use of alternative fuels, and the associated vehicle technology are much more complex and uncertain technically, economically and socially in the diverse economies of the APEC region. There is collective experience with many of these alternative fuels/vehicles in the APEC region, but it is also more limited and may be more sensitive to effects from differences between the economies.

This section provides an overview of the main obstacles with introducing reformulated petroleum fuels and/or switching to alternative fuels and vehicles. Site specific analysis should be undertaken for the design and implementation of programs to introduce major changes in fuels and vehicles in an APEC economy and such work should include careful consideration and planning to address obstacles that may exist.

6.1.1 Lower Emission Petroleum Based Fuels

Vehicle emission standards have a major influence on the introduction of improvements to petroleum fuels, or the introduction of alternative fuels. When lower emission standards are set for new motor vehicles, changes in fuels specifications are often needed to enable the proper and efficient operation of new vehicle emission control or engine technology. Examples of these types of changes are:

- Elimination of leaded fuel and introduction of catalytic emission control technology on vehicles;
- Removal of sulphur from gasoline and diesel fuel to improve the efficiency of catalytic controls on gasoline vehicles and enable the addition of catalytic after-treatment technologies on heavy duty diesel vehicles;
- Reformulation of gasoline to meet lower emission standards for toxic emissions, such as benzene and other aromatics;
- Introduction of ultra-low sulphur fuels to enable the use of fuel cell vehicles.

Major and minor obstacles can be encountered in the complex process of implementing a program to reformulate existing fuels. Consensus needs to be developed amongst the range of stakeholders affected by such programs, including the government, the motor fuel producers, automobile manufacturers, environmental organizations and the public. Once decisions have been made on the fuel specifications required and the time frame for implementation, obstacles are usually encountered during implementation pertaining to public education to explain the changes and motivate support, implementation of new processes for fuel refining, economic impacts, miss-use or unanticipated use of the new fuel and associated negative effects, lower than anticipated or desired penetration of the product in the market place.

The experience and lessons learned from the successful program to eliminate leaded gasoline in Thailand for on-road vehicles (Wangwongwatana, 1999) and other economies in the APEC Region (World Bank, 1997) are illustrative of the types of obstacles that can be encountered when making substantial changes to petroleum fuel specifications. The obstacle encountered with phase-out of leaded gasoline in developing economies include:

- Resistance of stakeholders to reaching consensus on the design and timing of the program.
- Long lead times were needed to allow for program development, refinery process changes and penetration of the new product in the market place.
- Alternative supplies of unleaded gasoline were needed to off-set temporary delays in supplies from local refiners.
- Unleaded fuel created some wear problems in older engines and the significance of this for the existing vehicle fleet had to be determined and practical and inexpensive alternatives for owners of these vehicles had to be developed.
- Unintentional and intentional miss-fuelling of vehicles having catalytic controls with leaded fuel was a problem and increased if the price of unleaded fuel was too much more than the leaded fuel.
- Problems were encountered with low octane levels in the unleaded gasoline and the increased use of aromatics to increase octane, which adversely affected operation of the older engines, emissions and public acceptance of the fuel.
- Displacement of leaded gasoline with unleaded gasoline initially proceeded more slowly than expected and this was followed by a rapid displacement over a relatively short period just prior to the total phase-out of leaded gasoline.
- Education and convincing of the motoring public regarding the merits of, and proper use of, unleaded gasoline in their vehicles was an on-going requirement and a difficult process.
- Problems with miss-information were encountered from suppliers of fuel additive products adversely affected by the displacement of leaded gasoline with unleaded gasoline.

The proposal to reduce the sulphur content of gasoline in the United States and Canada to meet the fueling requirements of vehicles designed for Tier 2 emission standards has involved extensive consultation between government, fuel producers, vehicle manufacturers and other stakeholders. Reduction of the sulphur content would be beneficial throughout the APEC region because of the reduction in emissions that could be achieved with existing and, more particularly, future catalytic emission control systems used on vehicles. Economies in the APEC Region interested in reducing the sulphur content of gasoline and diesel fuel to the 30-50 ppm range could encounter some or all of the same issues and obstacles to such programs that have been raised in North America and Australia.

Experience exists in Australia, the United States and Canada on the issues associated with reducing the sulphur content of gasoline and diesel fuel to low levels. The major concerns by the fuel producers about producing 30 ppm gasoline are the high cost of desulphurization with the currently available technologies and the potential for development of less expensive technologies in future, the impact of the higher desulphurization costs on product selling price, the method to phase in lower sulphur levels (should it be done in one step or a series of steps), harmonization of the gasoline sulphur requirement between trading economies, mechanisms to accommodate refiners unable to meet the sulphur reduction schedule, and the socioeconomic impact of the potential shut-down of some refineries unable to compete economically under the new requirements. These and other issues will need to be addressed in economies wanting to proceed with strategies to reduce gasoline sulphur levels.

6.1.2 Alternative Fuels to Reduce Emissions

Commercial acceptance and market growth for alternative fuels is dependent on the ability of these technologies to displace current petroleum-based fuels and vehicle technologies. There are examples of successful alternative fuels/vehicles in the market place in the APEC region and elsewhere in the world. These have been achieved with the aid of government policies and economic instruments to provide incentives for users to switch to the alternative fuels and with the support of the vehicle manufacturers to provide vehicle systems that offer attractive performance levels.

The share of the total energy demand of on-road transportation in developed APEC economies from alternative fuels (other than gasoline and diesel fuel) ranged in the survey from 0.4% to 3.5% at the present time. For the developing economies, two economies provided complete data which indicated 0.2% to 0.6% of on-road energy demand was currently being provided from alternative fuels. The United States Energy Information Administration (2000) has forecast that by 2020 alternative fuels will provide about 3% of the energy consumption by light and heavy duty vehicles in the United States, up significantly from a level of 0.4% in 1998, though still a small share of the total energy demand for this sector. Canada has forecast that in 2020 alternative fuels will provide about the same share of on-road energy as at present, amounting to about 2.7%. It is evident from the data for the APEC economies that alternative fuels have a small share of the market for on-road transportation fuels, in spite of considerable efforts by government and industry to promote their use in developed economies.

A range of advantages and disadvantages exist for alternative fuels and vehicles compared to conventional petroleum fuels and vehicles. The factors affecting the acceptance of alternative fuels in the market can be grouped into four areas: the characteristics of the alternative fuel and vehicle technology (real and perceived); communication of the technology to potential purchasers; the time for potential purchasers to become aware, understand and be persuaded to buy a new technology; and the social system and its influence on the potential buyer of the technology. Models have been developed to predict the penetration of alternative fuels into the market place, such as the sophisticated US DOE Alternative Fuels Trade Model (AFTM). However, models of this type are limited in their ability to model the wide range of factors that influence buying preferences and are weakest with regard to the influence of subjective attributes that can not be easily quantified. The main objective fuel and vehicle attributes of importance are:

- Fuel cost;
- Range of travel of the vehicle with its design fuel capacity;
- Refueling time and convenience;
- Vehicle and repair costs;
- Vehicle performance;
- People and cargo capacity;
- Whether it has dual fuel capability;

Subjective attributes perhaps of equal or greater importance are:

- Fuel availability;
- Availability of qualified repair and maintenance services and parts;
- Fuel quality and the impact on performance, reliability and safety;
- Appearance and aesthetics;

- Emissions relative to other options;
- Social appeal and acceptance;
- Vehicle reliability and durability.

At a screening level of detail, rankings of the merits of future and alternative fuels have been developed for the main options of potential interest for light duty and heavy duty vehicles compared to conventional petroleum-based fuels and vehicles. Tables 6-1 and 6-2 present these ranking for light duty and heavy duty vehicles, respectively, focusing on a short list of key attributes of the various technologies. Ease of communication refers to the communication of the technology to the prospective purchaser. These are subjective rankings and could vary from economy to economy because of cultural difference, as well as the influence of government policies and incentives.

A helpful illustration of the issues associated with promoting greater use of alternative transportation fuels in a developing economy is the program by the Thailand government to expand the use of natural gas vehicles (Eamrungroj, 2000). The motivating factors for proceeding with this program are the serious problem with air pollution from motor vehicles in Bangkok, natural gas for motor vehicles at US$ 4.90/GJ is 40% of the retail price of gasoline and 50% of the retail price of diesel fuel (US$ 0.36/L), natural gas processing and gathering pipeline infrastructure is in place, conversion kits and original equipment manufacturers equipment is available for the vehicles, and greater use of natural gas for transportation fuel will reduce the economy's reliance on imported petroleum. At a crude oil price of US$25/bbl, dedicated and dual fuel (diesel) natural gas buses were estimated to have payback periods of 5-10 years and 2-3 years, respectively. Payback periods for a dual fuel (gasoline) taxi and personal car are 3-7 months and 2-5 years, respectively.

The natural gas vehicle program being implemented in Thailand includes:

Short-term Plan:

- Use existing refueling station at Rangsit;
- Convert 100 taxis by November, 2000;
- Purchase 70 dedicated natural gas/diesel dual fuel buses;
- Add one mobile refueling station;
- Construct a main refueling station and five local refueling facilities at gasoline service stations;
- Promote use of natural gas by taxis by providing conversion kits and cylinders to 1,000 taxis in Bangkok at no charge.

Long-term Plan:

- Construct 30 NGV refueling stations along the existing and a future natural gas pipeline by 2005/06 in areas north, east and west of Bangkok and in the surrounding metropolitan area.

Some of the issues discussed above that influence the penetration of alternative fuels in the transportation sector have been considered in developing and promoting the plan for Thailand. The disadvantages of natural gas vehicles have been identified as the price of the natural gas vehicles and conversions, the added weight of the fuel storage cylinder, the lower vehicle range; lower fuel efficiency of a converted gasoline or diesel engine; and the limited number of refueling stations that can be installed because of their cost. The Thai government is promoting the switch to natural gas vehicles through a tax reduction on the equipment, providing financial support to the public and private sector for fleet conversions and new vehicles, revising laws to suit the program, developing national safety codes and regulations, providing investment privileges to private investors and promoting use of natural gas in State-owned public transit and garbage collection trucks. A public education and awareness program is being implemented. Participation of an OEM of natural gas vehicles for the Thai market is seen as essential to the long-term success of the program and is hoped to be stimulated by the government's commitments.

Table 6-1 Subjective Ratings of Merits of Alternative Fuels for Light-Duty Vehicles

	Gasoline Hybrid	Light Duty Diesels	E10 Blends	E85 Dedicated Vehicles	LPG	CNG	M100 Fuel Cells	Electric Vehicles	Hydrogen Fuel Cells
Relative advantage:									
performance	+	–	+	+	–	–	+	–	+
cost	–	0	–	–	–	–	– –	– –	– –
environment	+ +	0	+	+	+	+	+ +	+	+ +
convenience	0	0	0	–	–	–	–	–	–
prestige	0	–	0	0	–	0	+	0	+
Compatibility	0	0	0	–	–	–	–	–	–
Complexity	0	0	0	0	0	0	–	–	–
Ease of Communication	+	+	+	–	–	–	–	–	–
Time	+	+	+	– –	–	–	– –	– –	– –

Legend: +, positive; 0, neutral; and –, negative relative to a conventional gasoline vehicle.

Table 6-2 Subjective Ratings of Merits of Alternative Fuels for Heavy-Duty Vehicles

	Diesel 50 cetane 50 ppm S	LPG	LNG	Biodiesel	DME	FT Diesel
Relative advantage						
performance	+	–	–	+	+	+
cost	–	–	–	– –	– –	– –
environment	+	+	+	+ +	+ +	+
convenience	0	–	–	0	–	0
prestige	0	0	0	0	0	0
Compatibility	0	–	–	+	–	+
Complexity	0	–	–	0	–	0
Ease of Communication	+	–	–	+	–	+
Time	+	–	–	+	–	+

Legend: +, positive; 0, neutral; and –, negative relative to a conventional diesel fuelled vehicle.

A section of the survey questionnaire asked respondents to subjectively rank the barriers (1 for low, up to 5 for high) to improving gasoline and diesel fuel quality specifications and using alternative fuels of potential interest. The barriers to be ranked were regulatory, fuel cost, fuel production technology, user acceptance and vehicle technology, which are the main obstacles to successful introduction of fuels in the market place. Although the survey did not canvas a cross section of people who influence the production and use of these fuels, it did obtain a sense of the likely obstacles to these fuels and how these vary within the APEC region. Figure 6-1 presents the results for Canada, Malaysia and Mexico, while Figure 6-2 presents the results for Singapore, Thailand and Peru.

The lowest concern about barriers to changes in fuels was indicated consistently for improved petroleum-based fuels, which is not unexpected considering the well established infrastructure and user-acceptance for these fuels.

The ratings of barriers to changes in motor fuels is very dependent on the energy supply and demand in each economy, its state of development and access to energy sources for manufacture of transportation fuels. With the diverse range of circumstances in the APEC economies for transportation fuels, variability in the subjective rankings of barriers is to be expected and is evident in the survey results. For natural gas and propane, which are widely applied alternative fuels in the APEC region and relatively mature vehicle technologies, the most significant barriers appear in most cases to be user acceptance, vehicle technology and fuel production technology. In the case of alcohol fuels, all of the issues were ranked highly in at least one of the economies and more than one barrier was often significant. The rankings of barriers tended to be similar for ethanol and methanol. In Peru and Malaysia, most of the identified types of barriers were of high ranking.

Figure 6-1 Plot of Subjective Barrier Ratings for Canada, Malaysia and Mexico

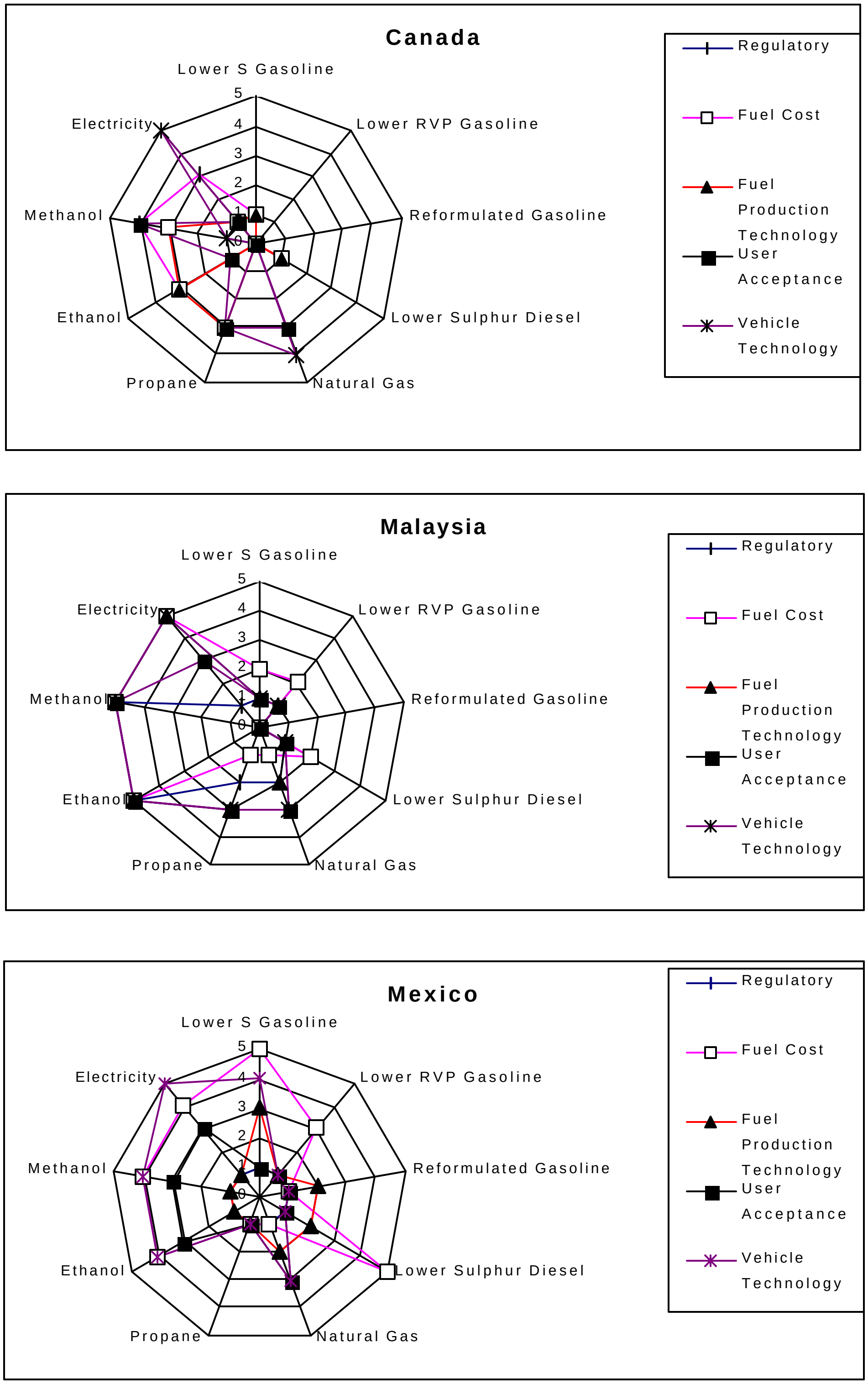
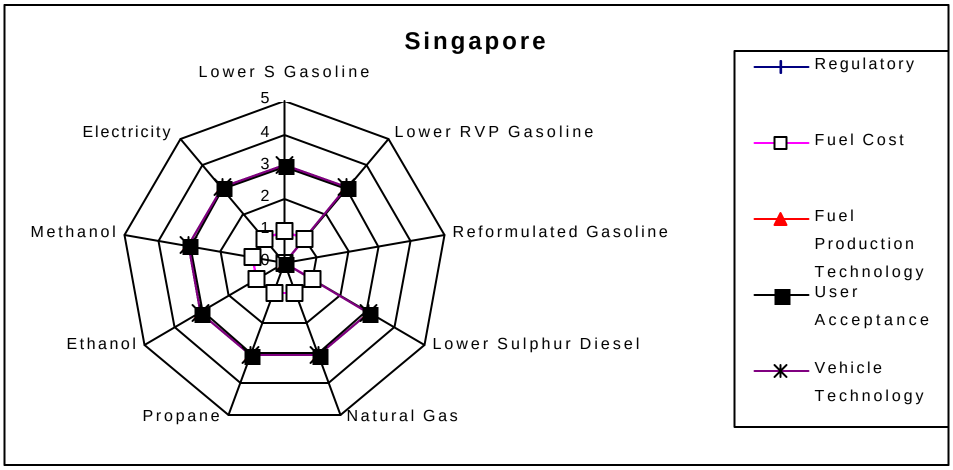
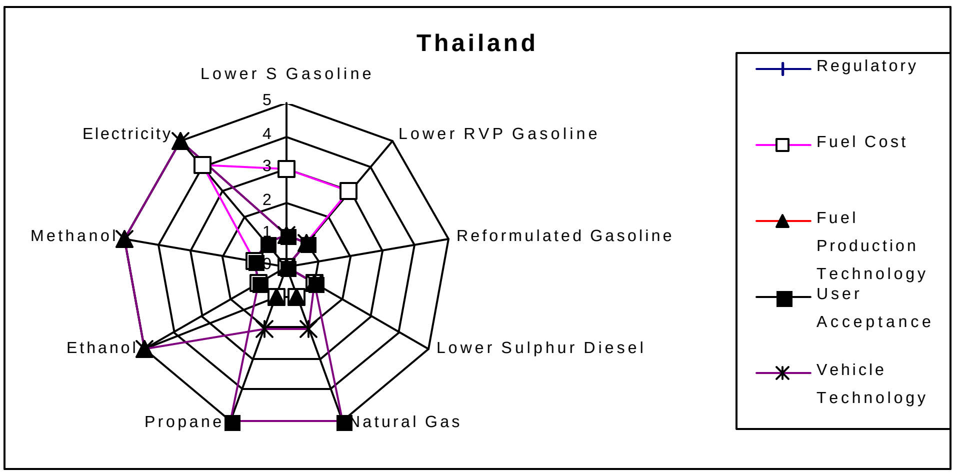
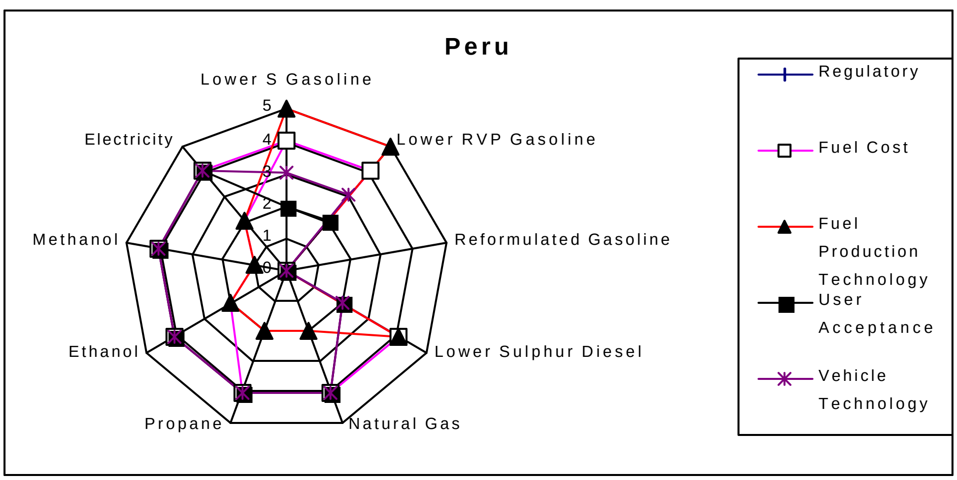


Figure 6-2 Plot of Subjective Barrier Ratings for Singapore, Thailand and Peru







6.2 DATA GAPS

This study compiled a substantial amount of data from APEC economies on existing fuel use, motor vehicles, energy supplies and emissions to the atmosphere that pertain to the transportation sector and on-road motor vehicles. The data was developed from many sources, with a significant amount from direct contact with the economies and the balance from web sites and published documents. The data tables presented in this report show the data that was collected and it is apparent from these tables what data gaps exist.

Further information in the areas identified below would be beneficial to APEC in general for studies of strategies that help reduce the air quality impacts of transportation fuels, and to individual economies when moving forward with their own programs:

- Emission inventory data for criteria and greenhouse gas emissions from all sectors was lacking for many of the developing economies and when data was available it applied to only selected emission source sectors. The developed economies, as well as developing economies that are experiencing problems with the poor air quality in major cities, tended to have the most complete emission inventories and to have developed and continued to improve them over a number of years. Reliable emission inventories for urban areas and on a national basis are beneficial to all economies for air quality management planning, selecting priority sectors of reduction of emissions and monitoring of the effects of implemented control measures.
- Data on the characteristics and activity levels of the existing stock of vehicles and new vehicles was not obtained from many of the developing APEC economies in response to the survey instrument that was used. More complete data on the vehicle fleet, as requested in the survey, would be beneficial for evaluating emission reduction strategies and the effect on emissions of implementing fuel/vehicle emission reduction options. The data would also provide a basis for monitoring and extrapolating the effects of growth, changes in the composition of the fleet and the introduction of new vehicles on emissions.
- There is interest and support from government and industry in some of the APEC economies for harmonization of fuel quality and motor vehicle standards. Data gaps exist on the quality and specifications of motor fuels in the APEC economies that, if remedied, would likely be of benefit to the APEC region. Filling of these data gaps and sharing of this data would help economies better understand the options for improving petroleum based motor fuels and the effects of fuel specifications on emissions from handling and use.
- Very limited information was available on renewable energy sources for production of motor fuels. More information on this subject would help identify the potential for development of sustainable renewable motor fuels supplies and use of these products as alternative fuels or for reformulation of current petroleum based fuels.
- More information is needed on the quality and production cost of liquid motor fuels that could be produced from coal resources, the full cycle greenhouse gas emissions from this fuel cycle and the performance and emission characteristics of coal-derive liquid fuels in motor vehicles.

7. CONCLUSIONS

Transportation Energy Use and Vehicle Population

- Of the total 3,796,973 ktoe of energy consumed in the APEC region, 43.5% is used by industry, 27.1% is used for transportation and 29.4% is used for other purposes. Transportation's share of total energy consumption varies from a low of 8.5% in PR China to a high of 48.3% in Thailand, based on the data available for this study. The economies having the five largest shares of total transportation energy use in APEC are the United States (58.9%), Japan (8.4%), Russia (5.4%), Canada (5.1%) and PR China (4.7%), which in aggregate equals 82.5% of the transportation energy use in APEC.
- Gasoline consumption for transportation exceeds diesel fuel consumption on an energy basis in the developed and some developing economies, while in other economies diesel fuel consumption exceeds gasoline. The average distribution of energy used for transportation by all modes of travel for the 12 economies that provided data is 47.3% gasoline, 38.8% diesel fuel and 13.9% other fuels.
- On-road vehicles are the predominant consumer of transportation energy in APEC, with this energy demand comprising an average of 84% of the energy used by this sector in the surveyed economies. The modes of travel having the next largest shares of energy use were air travel at 11%, marine vessels at 4.3% and rail travel at 1.1%. Petroleum based fuels provide the vast majority of the energy used for road transportation, varying from 96% to essentially 100% in the economies that provided a breakdown of the energy used according to the type of fuel.
- The number of passenger cars and commercial vehicles per person in the APEC economies increases in proportion to the gross domestic product per capita raised to the 1.23 power. This indicates that under a current trends scenario the number of vehicles and associated road transportation energy consumption, traffic levels, and problems with congestion and air pollution are likely to increase at a faster rate than the growth in an economy's GDP per capita. The number of motor vehicles in the APEC economies was estimated to grow to about 640 million vehicles by 2020 based on US EIA forecasts of growth in motorization and population, a 72% increase in the number of vehicles compared to 1995. The number of motor cycles used for transportation are in addition to the estimated number of passenger cars and commercial vehicles, which is very significant in some Asian economies where the number of motor cycles can equal the number of passenger cars.
- The fleet average fuel economy of light duty vehicles has declined in the United States and a similar trend is occurring in Canada as a result of the increasing share of the light duty vehicle sales that are light and medium duty trucks. These vehicles have lower fuel economies than passenger cars. This shift in purchases to heavier and less fuel efficient vehicles in some of the developed economies could be a future issue for developing APEC economies. Developed economies project the fuel economy of passenger cars and light duty trucks will increase gradually through to 2020, though this gain as noted above will largely be off-set by the increased weight and horsepower desired by purchasers of new vehicles.
- US EPA and European Union vehicle emission standards are used throughout the APEC region. Future vehicle emission standards are moving in a similar direction and stringent proposed standards will required the sulphur content of gasoline be reduced to about 30 ppm. This specification will be met in United States and Canada by 2004/05.

Much lower emission standards are also proposed for heavy duty diesel vehicles and these will require diesel fuel sulphur also be reduced to 15-50 ppm.

- On-road vehicles are significant contributors to emissions nationally and contribute higher proportions in urban areas. The survey data indicates road vehicles contribute 30-52% of NO_x, 2-8% of sulphur oxides, 16-90% of VOCs, 32-95% CO, 2-10% of direct PM10 and 20-40% of CO_2 on a national basis in many of the APEC economies. In addition, motor fuels are significant sources of certain toxic air contaminants present in petroleum fuels and formed during the combustion process. The share of emissions from road vehicles is significantly higher in urban areas than nationally.

Reformulated and Alternative Fuels and Energy Sources

- The APEC region imported about 50% of its crude oil demand in 1998 and is also a net importer of some of refined petroleum products to meet transportation fuel requirements.
- Gasoline specifications influence emissions from a motor vehicle. The formulation of gasoline can be adjusted to satisfy performance requirements while minimizing vehicle emissions. Assuming the gasoline is unleaded and a catalytic emission control system is used on the vehicle, changes in fuel parameters have the following general effects on vehicle emissions behaviour:

Decreasing Fuel Parameter	Leads to
RVP	Reduced evaporative VOC's
Sulphur	Reduced VOC's, NO_x, Toxics, SOx
Benzene	Reduced Toxics
Aromatics	Reduced VOC's, NO_x, Toxics
Olefins	Reduced NO_x, Toxics, Increased VOC's
T50 and T90	Reduced VOC's, Toxics, Increased NOx
Oxygen	Increased VOC's, Toxics and CO; Reduced NO_x

- Unleaded gasoline is needed to enable the use of catalytic emission control technology on gasoline vehicles. Eight economies continue to offer leaded gasoline and all have schedule phase out of this product by 2000-2010.
- Reduction of the sulphur content of gasoline yields substantial improvements in the efficiency of catalytic emission control systems on existing and new vehicles and would help reduce emissions in the APEC region. A sulphur content approaching about 30 ppm is needed to enable future motor vehicles to meet the most stringent US and EURO emission standards. The US, Canada and Australia have proposed to reduce sulphur content of gasoline to 30 ppm and other economies are considering this approach.
- Benzene contents of gasoline are relatively high in some economies (5-6 volume percent) and reduced to low levels near 1 volume percent in others. Significant reductions in emissions and exposure to benzene, which is carcinogenic, could be achieved in APEC economies by reducing benzene in gasoline to 1 volume percent.
- Further reductions in the sulphur content of diesel fuel would help reduce emissions in APEC economies. The sulphur content of diesel fuel will need to be reduced to 15-50

ppm to enable implementation of the most stringent emission standards now proposed for heavy duty vehicles.

- Natural gas and LPG are the two most widely used alternative fuels in the APEC region and are attractive options when there are indigenous resources, air quality problems exist and there is a favourable regulatory and economic environment. The most popular and cost effective applications of these fuels appear to be for dedicated fleets. Natural gas and LPG fuelled vehicles are capable of lower emissions and higher fuel economies if they are dedicated OEM vehicles optimized for these fuels, rather than converted or dual fuel vehicles. These fuels can yield a reduction in full cycle greenhouse gas emissions.
- Methanol is a potentially attractive future fuel for production in APEC economies with abundant natural gas or coal resources. Interest in M85 methanol fuelled vehicles has declined, but methanol is now being advocated as a good candidate for fuel cell vehicles. The viability of this fuel path in the APEC region will depend on the evolution of fuel cell technology.
- There appears to be opportunities for expanded manufacturing of ethanol from renewable resources in the APEC economies and increased use of ethanol in gasoline to add octane and oxygen content. Ethanol at 10% concentration in gasoline reduces emissions of criteria contaminants from light duty vehicles, except NO_x which may increase, and yields a reduction in full cycle emissions of greenhouse gases.
- Biodiesel is a potentially attractive fuel for displacement of diesel fuel as it is compatible with existing engine technologies and can be produced from renewable resources. Moderate to large reductions in criteria emissions can be achieved with 20-100% biodiesel blends.
- DME is a potentially attractive alternative to diesel fuel because of its excellent combustion characteristics and the large reduction in emissions that can be achieved. It can be produced from natural gas, which makes it a potentially viable means of converting and transporting energy from stranded natural gas resources. DME can yield a small reduction in full cycle greenhouse gas emissions.

Fuel Options and Impacts on Emissions and Health

- Transportation fuels are acknowledged by many economies to be major contributors to urban air quality problems that have adverse health impacts. Road transportation fuels have the most effect on urban air quality and should be the priority fuels for related emission reduction strategies. The air pollutants from motor vehicles that appear to be having the most impact on human health in the APEC economies are PM10 and PM2.5, ground-level ozone formed in the atmosphere from emissions of NO_x, VOC and CO, and air toxics. Also significant are emissions of SO_2 which contributes to respiratory problems and acid rain.
- APEC economies can achieve large reductions in emissions from motor vehicles by implementing as quickly as socially and economically acceptable emission standards achievable with current catalytic emission control systems on light duty vehicles. Because of the time needed to displace older high emitting vehicles from the existing vehicle fleet, combined with the growth rates projected for developing economies, consideration should be given in the these economies to accelerating the introduction of improved petroleum fuels and implementation of the most stringent emission standards presently proposed in developed economies.

- Alternative fuels should be considered carefully for individual APEC economies as a means of reducing reliance on petroleum fuels and achieving reductions in emissions and the associated adverse health impacts. A suite of alternative fuel options exist, enabling APEC economies to selection the individual, or a combination of options that best suit their energy supplies and environmental priorities.
- Harmonization of fuel and vehicle standards in the developing economies with those in the developed economies in the APEC region could be beneficial in future as it would avoid redundant efforts to develop standards for individual economies and help streamline implementation of fuel/vehicle options to achieve emission reductions more effectively .

Obstacles and Data Gaps

- Obstacles to improving petroleum based fuels or to switching to alternative fuels and vehicles exist, however, there is experience with many of these fuel/vehicle options in the APEC region that can be applied to help minimize the impact of these obstacles. APEC economies will need to evaluate the viability of fuel/vehicle options with careful consideration of their own priorities and situation. Subjective factors are very important to the successful acceptance and subsequent growth of alternative fuels and these are the most difficult to assess. Ratings of the fuels have been developed to provide guidance regarding the merits of a range of fuel/vehicle technologies.
- Improved and more complete emission inventory data is needed for the evaluation of emission control strategies for transportation and other emission sectors in some of the developing economies. Limited data was available on emissions in developing economies. Improved data on the characteristics of the vehicle fleet and fuel specifications would also be beneficial.

8. REFERENCES

2nd Asia Pacific NGV Co-operation Meeting. Sydney, Australia April 1999.

American Automobile Manufacturers Association. 1997. World Motor Vehicle Data. Washington, D.C.

APEC, 1998. APEC Energy Statistics 1996. Energy Working Group, prepared by the Energy Data and Modelling Centre, The Institute of Energy Economics, Japan. October.

ACEA, 2000, European Automobile Manufacturers Association, Alliance of Automobile Manufacturers, Engine Manufacturers Association, Japan Automobile Manufacturers Association. World Wide Fuel Charter. April. www.acea.be/acea/index.html

ACEA, 1998 European Automobile Manufacturers Association, American Automobile Manufacturers Association, Engine Manufacturers Association, Japan Automobile Manufacturers Association. World Wide Fuel Charter. December.

AIT. 2000. Alternative Policy Study: Reducing Air Pollution in Asia and the Pacific. Report prepared by the Asian Institute of Technology, Thailand and the National Institute of Environmental Studies, Japan. www.grida.no/geo2000/aps-asiapacific/index.htm

APERC, 2000, Asia Pacific Energy Research Centre. www.ieej.or.jp/aperc/

BC MELP, 1995, Economic Analysis of Air Quality Improvement in the Lower Fraser Valley, Report prepared for the British Columbia Ministry of Environment, Lands and Parks, November.

Environment Australia.1999. Review of Fuel Quality Requirements for Australian Transport. Report prepared by Coffey Geosciences Pty

California Air Resources Board. Office of Environmental Health Hazard Assessment. 1998a. Proposed Identification of diesel Exhaust as a Toxic Air Contaminant. May.

California Air Resources Board. Office of Environmental Health Hazard Assessment. 1998b. Proposed Identification of diesel Exhaust as a Toxic Air Contaminant. Statement of Reasons for Rule Making. June.

California Air Resources Board. 1999. What is California Cleaner-Burning Gasoline and why is Flexibility required in California? Presentation to EPA Blue Ribbon Panel on the use of MTBE and other Oxygenates in Gasoline. March 1999.

Chevron Products Company, Motor Gasolines – Technical Review, 1996

Clean Fuels Report. March 2000. Pages 178-184. Published by Energy Futures Inc.

CTAP. 2000. BC Clean Transportation Analysis Project. Report prepared for the Clean Transportation Project Steering Committee. Funding partners lead by the British Columbia Ministry of Environment, Lands and Parks, Canada

Delucchi, M.A., 1998, "Lifecycle Energy Use, Greenhouse Gas Emissions, and Air Pollution from the Use of Transportation Fuels and Electricity", Institute of Transportation Studies, University of California, Davis, December.

Eamrungroj, S., 2000, Clean CNG Transportation in Bangkok, paper presented at the Joint Eighth APEC Clean Fossil Energy Technical Seminar and Seventh APEC Coal Flow Seminar, Bangkok, Thailand, Oct 30-Nov 3.

European Environment Agency. 2000. Are We Moving in the Right Direction?. Term 2000. ISBN 92-9167-206-8. Copenhagen. Denmark.

Environment Canada. 2000. 1995 Criteria Air Contaminant Emissions in Canada. Table of emission results from www.ec.ca/pdb/cac/cacdoc/1995e/canada95.htm.

Guoming, Chen. China Petro-Chemical Group Corporation. www.eetpc.org/air%20quality/papers.air/chen_gu.htm.

GVRD, 1993. GVRD and Lower Fraser Valley Ambient Air Quality Review. Report prepared for the Greater Vancouver Regional District, Canada. June.

GVRD, 1999. 1998 Emission Inventory for the Lower Fraser Valley Airshed. Report prepared by the Greater Vancouver Regional District and the Fraser Valley Regional District, Canada. July.

International Association for Natural Gas Vehicles. www.iangv.org/ngv/stats.html.

International Lead Management Centre. 2000. Lead in Gasoline Phase-Out Report Card. www.ilmc.org/rptcard.pdf

Kajitani, S., Chen, Z.L., Konno, M., Rhee, K.T. 1997. Engine Performance and Exhaust Characteristics of Direc-Injection Diesel Engine Operated with DME. SAE Paper 972973.

Levelton Engineering. 1998. Forecast and Backcast of 1995 LFV Emission Inventory. Report prepared for the Greater Vancouver Regional District. May.

Levelton Engineering Ltd. 1999. Alternative and Future Fuels and Energy Sources for Road Vehicles. Prepared for Transportation Issue Table, National Climate Change Process. Canada. July 1999.

Levelton Engineering Ltd. 1999b. Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Southern Ontario. Prepared for Agriculture and Agri-Food Canada. August 1999.

Levelton Engineering Ltd. 1999c. Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Canada: Lignocellulosic Feedstocks. Prepared for Agriculture and Agri-Food Canada. December 1999.

Manins, P. 1997. Transport: The Future is Clearer. CSIRO, Atmospheric Research, PMB1 Aspendale 3195 Australia. Presented at Outlook '97. Canberra.

Marsh, G., N. Hill and J. Sully. 2000. Consultation on the Need to Reduce the SulphurContent of Petrol and Diesel Fuels Below 50 ppm: A Policy Makers Summary. Report prepared for the European Commission DG Environment. November.

MITI and Ministry of Transport. 1999. The Law Concerning the Rational Use of Energy. Law N. 49, Amended 1998. Notification No. 2 of the Ministry of International Trade and Industry and the Ministry of Transport (1999). Japan

National Science and Technology Council. 1997. Interagency Assessment of Oxygenated Fuels.

NR Can. 1997. Canada's Energy Outlook 1996-2020. Natural Resources Canada. Energy Forecasting Division. Energy Policy Branch. April.

NR CAN OEE. 1998. Energy Efficiency Trends in Canada 1990 to 1996. Natural Resources Canada, Office of Energy Efficiency. ISBN 0-662-26826-1. June

Paramins. 1999. Worldwide 1998 Winter Diesel Fuel Quality Survey.

Peterson, C.L., Reece, D.L., Hammond, B.L., Thompson, J., Beck, S.M, Processing, Characterization, & Performance of Eight Fuels from Lipids, University of Idaho, 1994

Rao, T. 1997. Effects of Oxygen on Exhaust CO Emissions, a Summary of a Draft Proposal for Mobile6. US EPA. Office of Mobile Sources.

Rao, T. 1998. Fuel Oxygen Effects on Exhaust CO Emissions. M6.FUL.002. US EPA. Office of Mobile Sources.

Rao, T. 1999. Effects of Oxygen on Exhaust CO Emissions. Presentation to Mobile6 Workshop, June 29-30, 1999.

$(S\&T)^2$ Consultants Inc. 1999. Assessment of Emissions from Ethanol-Gasoline Blends. Prepared for Environment Canada. October 1999.

$(S\&T)^2$ Consultants Inc. 2000. Assessment of Emissions of Greenhouse Gases from Fuel Cell Vehicles Blends. Prepared for Methanex Corporation. June 2000.

UNEP. 2000. GEO-2000 Global Environmental Outlook. United Nations Environmental Program. ISBN 1 85383 588 9. www.grida.no/geo2000/english/0250.htm.

USDA. 2000. Oilseeds: World Markets and Trade. May 2000. www.fas.usda.gov/oilseeds/circular/2000/00-05/toc.htm

US Department of Energy. Office of Fossil Energy, Federal Energy Technology Centre. Clean Energy Plants for the 21st Century

US DOE. 1998. Dodge Caravan Fact Sheet. http://www.ott.doe.gov/otu/field_ops/nve/.

US DOE. 1998. Ford F-250 Fact Sheet. http://www.ott.doe.gov/otu/field_ops/nve/.

US DOE. 1998. Ford Taurus Fact Sheet. http://www.ott.doe.gov/otu/field_ops/nve/.

US DOE. 1998. Honda Civic Fact Sheet. http://www.ott.doe.gov/otu/field_ops/nve/.

US DOT. 2000. Twenty-Fourth Annual Report to Congress Calendar Year 1999. www.nhtsa.dot.gov/cars/problems/studies/fuelecon/index.html

US Energy Information Administration. 1999. Table 34 Transportation Sector Energy Use by Fuel Type Within Mode. www.eia.doe.gov/

US Energy Information Administration. 2000. APEC: Energy Issues and Trends. May 2000.

US Energy Information Administration. 2000. Annual Energy Outlook 2000 - Transportation Sector Energy Demand.

US Energy Information Administration. China: Environmental Issues. www.eia.doe.gov/emeu/cabs/chinaenv.html

US Energy Information Administration. Petroleum Data. www.eia.doe.gov/emeu/international/petroleu.html

US Energy Information Administration. South Korea: Environmental Issues. www.eia.doe.gov/emeu/cabs/skoren.html

US Energy Information Administration. 2000. International Energy Outlook 2000, March. www.eia.doe.gov/oiaf/ieo/index.html

US EPA. 1997. Emission Standards Reference Guide for Heavy-Duty and Nonroad Engines. Report EPA420-F-97-014. September.

US EPA. 1988. Derivation of Technology Specific Effects of the Use of Oxygenated Fuel Blends on Motor Vehicle Exhaust Emissions. October 1988. US Environmental Protection Agency.

US EPA. 1998b. AP-42: Compilation of Air Pollutant Emission Factors, Mobile Sources. Pending fifth edition. Appendix H: Highway Mobile Source Emission Factor Tables.

US EPA. 1998. Evaluation of a Toyota Prius Hybrid System (THS). Report EPA420-R-98-006. August.

US EPA. 1999. Fuel Sulfur Effects on Exhaust Emissions. EPA 420-P-99-008.M6.FUL.001. March 1999.

US EPA. 1999. Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rule Making for Tier 2 and Sulfur Standards. Report EPA420-R-99-005.. March.

US EPA. 1999b, “Advanced Notice of Proposed Rulemaking, Control of Diesel Fuel Quality”.

US EPA. 1999c. “Light-Duty Automotive Technology and Fuel Economy Trends Through 1999. EPA420-R-99-018. September.

US EPA. 2000. Health Assessment Document for Diesel Exhaust. Report EPA/600/8-90/057E. July.

Wangwongwatana, S. 1999. Unleaded Air in Bangkok: A Story of Success. Paper presented at the Workshop on Energy-Related Pollution in Urban Areas of the Asia-Pacific Region. Sponsored by the East-West Center. Hawaii. June 17-18.

World Bank. 1997. Vehicular Air Pollution, Experiences from Seven Latin American Urban Centers. Technical paper No. 373 prepared by B. Onursal and S. Gautam. ISBN 0-8213-4016-6.

World Bank. 1998. Elimination of Lead in Gasoline in Latin America and the Caribbean. Clean Air Initiative – The Launching Workshop. December 3, 1998.

World Fuels Today. October 19, 2000. Hart Publications.

World LP Gas Association. www.worldlpgas.com/auto/d_auto.htm

Yamaguchi, N.D. 2000. Asian Fuel Demand and Quality. Intertech's Clean Fuel 2000 Conference. February 2000. San Diego, California.

APPENDIX A SURVEY QUESTIONNAIRE

ASIA-PACIFIC ECONOMIC COOPERATION (APEC)
ENERGY WORKING GROUP
EXPERT'S GROUP ON CLEAN FOSSIL ENERGY

QUESTIONNAIRE FOR THE STUDY OF THE ROLE OF PETROLEUM BASED AND ALTERNATIVE TRANSPORT FUELS IN REDUCING EMISSIONS IN THE APEC REGION (EWG 04/99)

Introduction

The APEC Expert's Group on Clean Fossil Energy promotes the use of clean fossil fuels and advanced conversion technologies that will increase energy efficiency and reduce environmental impacts of fossil fuel use. This questionnaire has been developed to gather data from APEC member economies that will be used to study the use of petroleum-based and alternative fuels in the transport sector, opportunities for reducing associated emissions and energy consumption, and related issues. The APEC contact to obtain additional background information for this study is Mr. Kenneth Leong Hong, who can be reached by email using the address: Kenneth.Hong@HQ.DOE.GOV

The participation of the APEC member economies and the assistance of individuals providing data in response to this questionnaire are gratefully acknowledged. Organizations which respond to this questionnaire will be provided with a complimentary copy of the study report.

General Instructions to participants:

The questionnaire consists of five worksheets, with individual tabs below. Each worksheet is focused on different information. The worksheets are: Transportation energy demand; Vehicle & fuel economy; Fuel parameters & prices; Fuel resources & barriers; National Emissions. Please make a copy of this Excel file, then enter your economy's data directly into the shaded areas in each worksheet. When done, email the file back to us at the address below. This will speed distribution and processing. If this form of distribution is not suitable for you, it can also be printed and faxed or mailed.

We want to involve the most appropriate organizations and individuals in providing the information requested in this questionnaire, and this may require the questionnaire to be circulated to a number of people. Please assist us with this objective as follows:

If you will complete all parts of the questionnaire:	*Please email a message indicating you will respond.*
If you can complete part of the questionnaire:	*Please provide the data you can. Also, please email names and coordinates of people you suggest we contact to obtain the balance of the information. Forward this questionnaire to them, if possible.*
If you can not complete this questionnaire:	*Please email a message that you cannot respond and identify any alternate organizations and individuals we should contact.*

Return or Clarification of Questionnaire

Please enter data into this file and return the completed questionnaire by email (preferred), fax, or mail to:

Wayne Edwards, P.Eng.
email address: apec@levelton.com
Telephone : (604) 278-1411 Fax : (604) 278-1042

Levelton Engineering Ltd., 150-12791 Clarke Place
Richmond, British Columbia, CANADA, V6V 2H9

If you have any questions about the data requested, please contact Wayne Edwards by email or fax and answers will be provided promptly.

For timely completion of the study, it is important that all questionnaires be completed and returned by January 5, 2000.

Checklist and notes for filling in the Worksheets

Please enter information about the name of the APEC economy and the person providing the data at the top of each worksheet. We need this to properly report the data and to follow-up any questions we have about the data.

1. Transportation Energy Demand	- You may use any units of measure that are convenient. - Specify the year of the data at the top of each column.
2. Vehicle & Fuel Economy Data	- This data characterizes the on-road vehicle fleet. - Please enter the best data available for a large urban area, or, if this is not available, enter national data.
3. Fuel Parameters & Prices	- The requested information defines typical fuel quality. - Please enter values in the forecast column for future changes that are required by regulation. - If fuel prices cannot be given in US $/Litre, please enter price data in the local currency.
4. Fuel Resources and Barriers	- This information is needed to understand the constraints on use of reformulated or alternative fuels. Please enter your own rating of priorities for future development and of barriers to alternative fuels. - Please enter other fuel options if they are not listed.

APEC Economy:
Respondent: _______ Email _______
Organization: _______ Telephone No. _______
Address: _______ Fax No. _______

1. Transportation Energy Demand

Sector	Units Used	Current Data Year =	Forecast Data Year=
1 Road Transportation			
Motor Gasoline (Leaded)			
Motor Gasoline (Unleaded)			
Electricity			
Diesel Fuel			
Propane (LPG)			
Compressed Natural Gas			
Liquified Natural Gas			
Other Fuels			
Sub-Total			
2 Aviation Transportation			
Aviation Gasoline			
Jet Fuel			
Sub-Total			
3 Rail Transportation			
Diesel Fuel Oil			
Electric			
Sub-Total			
4 Marine Transportation			
Motor Gasoline			
Light (Distillate) Fuel Oil			
Heavy (Residual) Fuel Oil			
Sub-Total			
5 Totals (in consistent units)			
Total Transportation			
Total Motor Gasoline			
Total Diesel Fuel			

Notes: (please state assumptions or add comments about the data provided)

APEC Economy:

Respondent:		Email	
Organization:		Telephone No.	
Address:		Fax No.	

2. Vehicle and Fuel Economy Data for a Representative Urban Area

The impacts of emissions on air quality are usually greatest in urban areas. To examine the opportunities for alternative fuels to reduce impacts in each economy, please provide the following data for a large city. If this data is not available, provide national data.

Enter City: **Enter State:**

Parameter	Current Data Year=	Forecast Data Year=
1 Vehicle Fleet Profile		
Passenger Cars		
Number of Vehicles		
Gasoline		
Diesel Fuel		
Natural Gas		
Other:		
New Fleet Fuel Consumption (km/litre)		
Gasoline		
Diesel Fuel		
Existing Fleet Fuel Consumption (km/litre)		
Gasoline		
Diesel Fuel		
Average Distance Driven (km/year)		
Motor Cycles		
Number of Vehicles: 2-cycle		
4-cycle		
New Fuel Consumption (km/litre)		
Existing Fleet Fuel Consumption (km/litre)		
Average Distance Driven (km/year)		
Light Duty Trucks (< 3,850 kg)		
Number of Vehicles		
Gasoline		
Diesel Fuel		
Other:		
New Fleet Fuel Consumption (km/litre)		
Gasoline		
Diesel Fuel		
Existing Fleet Fuel Consumption (km/litre)		
Gasoline		
Diesel Fuel		
Average Distance Driven (km/year)		
Heavy Duty Trucks (> 3,850 kg)		
Number of Vehicles		
Gasoline		
Diesel Fuel		
Other:		
New Fleet Fuel Consumption (km/litre)		
Gasoline		
Diesel Fuel		
Existing Fleet Fuel Consumption (km/litre)		
Gasoline		
Diesel Fuel		
Average Distance Driven (km/year)		
2 Typical Vehicle Speeds (km/h)		
City During Peak Rush Hour		
Off-Peak		
Highway		
Are these national average or or city specific?		

3 Age Distribution of Passenger Cars (% of number of passenger cars in age category) Age (years)		
1-5		
5-10		
10-15		
15-20		
20-25		
>25		
4 Gasoline Passenger Car Emission Standards (gram/kilometer) Give National and State values.		
Carbon Monoxide (national)		
(for city if different)		
Nitrogen Oxides (national)		
(for city if different)		
Total Hydrocarbons (national)		
(for city if different)		
NMOG* (national)		
(for city if different)		
Particulate Matter (national)		
(for city if different)		
Other:		

* NMOG is non-methane organic gases

Notes: (please state assumptions or add comments about the data provided)

APEC Economy:			
Respondent:		Email	
Organization:		Telephone No.	
Address:		Fax No.	

3. Fuel Parameters and Prices

Fuel Parameter	Units Used	Current Year =	Forecast Year =
1 Motor Gasoline			
Volatility			
Standard Test Method	-		
Summer			
Ambient Temperature	C		
Reid Vapour Pressure	kPa		
Winter			
Ambient Temperature	C		
Reid Vapour Pressure	kPa		
Octane :			
Regular			
Minimum	(RON+MON)/2		
Maximum	(RON+MON)/2		
Premium			
Minimum	(RON+MON)/2		
Maximum	(RON+MON)/2		
Sulphur content:			
Average	% by weight		
Maximum	% by weight		
Lead content (average)	grams/litre		
Oxygen content			
Average	% by weight		
Maximum	% by weight		
Olefins Content (maximum)	% by volume		
Aromatics Content (maximum)	% by volume		
Benzene Content (maximum)	% by volume		
2 Diesel Fuel			
Cetane Number (minimum)	-		
Sulfur content - Average	% by weight		
Sulphur content - Maximum	% by weight		
3 Typical Fuel Prices			
Gasoline (give range) no taxes	US $/Litre		
Gasoline (give range) with taxes	US $/Litre		
Diesel fuel (give range) no taxes	US $/Litre		
Diesel fuel (give range) with taxes	US $/Litre		
Natural gas: Circle: CNG, LNG, Pipeline	US $/GJ		
LPG (propane)	US $/Litre		
Electricity	US $/kWh		

Notes: (please state assumptions or add comments about the data provided)

APEC Economy:			
Respondent:		Email	
Organization:		Telephone No.	
Address:		Fax No.	

4. Fuel Resources and Barriers

1 Source of supply of liquid petroleum fuels

Approximate percent manufactured from:	
Domestic crude oil:	
Imported crude oil:	
Approximate percent imported as finished products	
Total (should total 100%)	

2 Domestic resources available for manufacturing transportation fuels

Type of resource	Resource Under utilized (Yes/No)	Resource Fully Exploited (Yes/No)	Priority for future development (1 Low; 5 high)	Comments
Crude Oil				
Natural gas				
Coal				
Oil shale				
Oil sand				
Solution gas				
Biomass (state type):				
Other:				

3 Comment on Reformulated Petroleum or Alternative Transportation Fuels

	Rate the Barriers to Increasing the Use of Alternative Fuels Listed (Indicate rating from 1 for low to 5 for high)				
Fuel Options	Regulatory	Fuel Cost	Fuel Production Technology	User Acceptance	Vehicle Technology
Gasoline:					
Lower sulphur					
Lower volatility					
Reformulated (specify)					
Lower Sulphur Diesel Fuel					
Natural Gas					
Propane					
Ethanol					
Methanol					
Electricity					

4 Please suggest areas of APEC cooperation on alternative fuels that would be most useful.

5 Please insert or email a list of studies of alternative fuels relating to your economy, giving author, year, title, report number and source where it may be obtained.

APEC Economy:

Respondent:

Organization:

Address:

Email

Telephone No.

Fax No.

5. National Emissions

Sector	National Emissions (kilotonnes)											
	Nitrogen Oxides*		Sulphur Oxides*		Volatile Organic Compounds*		Particulate		Carbon Monoxide		Carbon Dioxide	
	Current	Forecast	Current	Forecast	Current	Forecast	Current	Forecast	Current	Forecast	Current	Forecast
Enter Year->												
Transportation												
On-Road Transportation												
Automobiles & motor cycles												
Light Duty Trucks+												
Heavy Duty Trucks+												
Sub-Total On-road												
Air Transportation												
Rail Transportation												
Marine Transportation												
Sub-Total Transport												
Upstream Oil & Gas												
Petroleum Refining												
All Other Sectors												
Total Emissions												

Notes: (please state assumptions or add comments about the data provided)

* Volatile organic compounds: Equivalent to total hydrocarbons, excluding methane and ethane.

* Nitrogen oxides: as nitrogen dioxide

* Sulphur oxides: as sulphur dioxide.

+ Light duty < 3,850 kg; Heavy duty > 3,850 kg.

APPENDIX B DATA TABLES FROM SURVEY

Figure B-1 Total Final Energy Consumption as Percent and ktoe for APEC Economies in 1998

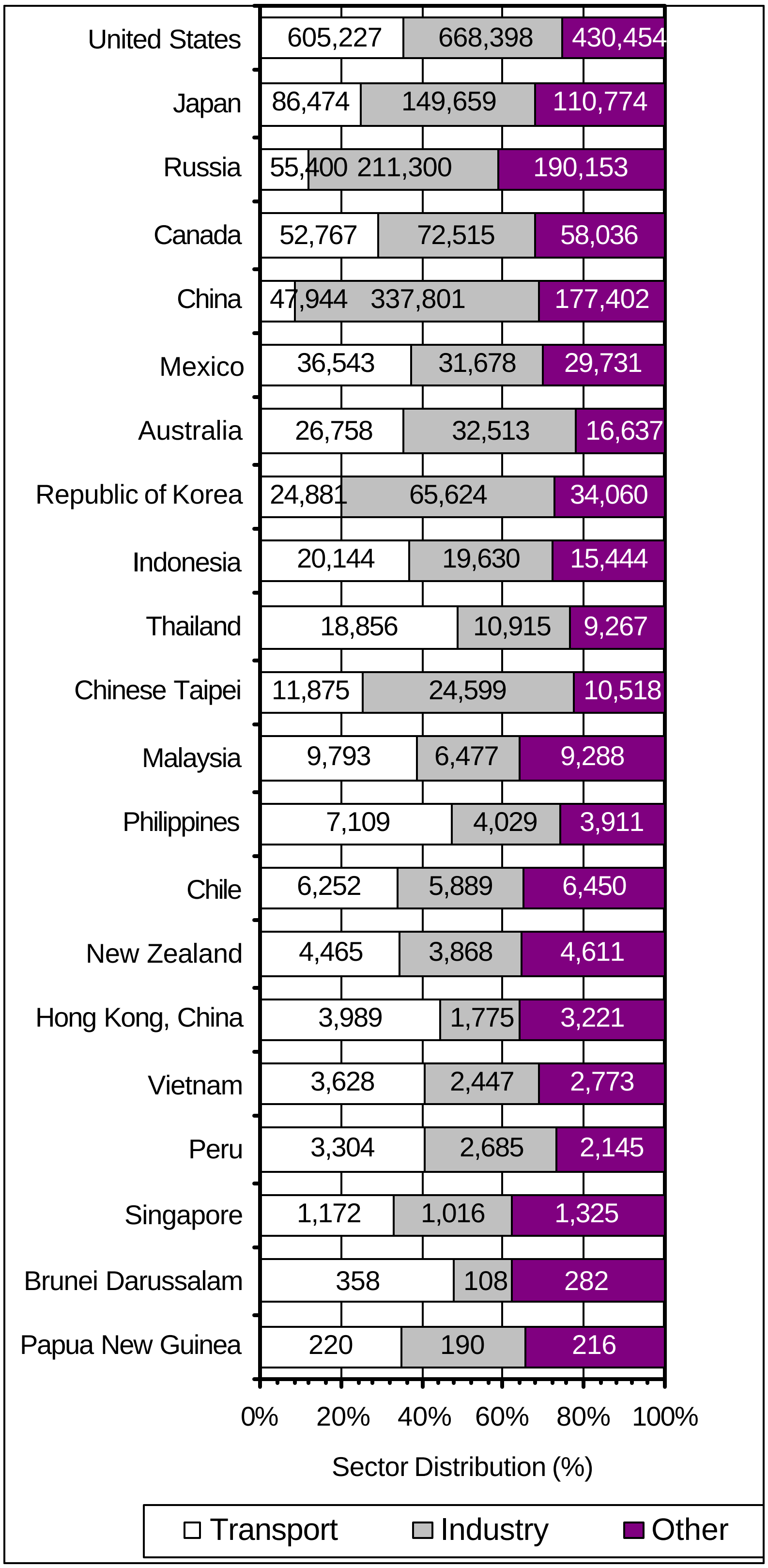


Table B-1 Questionnaire Responses for Vehicle Fleet Distribution

	Canada 1997		United States 1998		Australia 1998		Japan 1998		New Zealand 1998		Chinese Taipei 2000		Malaysia 1999		Philippines 1999		Singapore 1999		Bangkok 1998	
	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)	Vehicles	(%)
Reference Year	1997		1998		1998		1998		1998		1999/2000		1999		1998		1999		1998	
Number of Vehicles																				
Passenger Cars (gasoline)	10,542,605	61.7%	120,630,000	60.8%	9,133,119	75.7%	44,882,911	54.1%	1,756,000	74.9%	4,496,595	45.6%	3,265,743	36.9%	719,649	21.9%	382,937	59.3%	1,298,000	32.6%
Passenger Cars (diesel fuel)	107,382	0.6%	1,150,000	0.6%	213,460	1.8%	4,808,621	5.8%	12,400	0.5%	86,948	0.9%	21,867	0.2%	29,555	0.9%	4	0.0%	317,013	8.0%
Passenger Cars (other)	90,034	0.5%	470,000	0.2%	180,154	1.5%	276,617	0.3%	22,000	0.9%	10,000	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Subtotal	10,740,021	62.9%	122,250,000	61.6%	9,526,733	79.0%	49,968,149	60.2%	1,790,400	76.4%	4,593,543	46.5%	3,287,610	37.2%	749,204	22.8%	382,941	59.3%	1,615,013	40.5%
Motorcycles	318,990	1.9%	3,826,400	1.9%	328,845	2.7%	14,257,853	17.2%	79,000	3.4%	4,477,198	45.4%	5,054,961	57.2%	1,032,594	31.4%	133,358	20.6%	1,646,738	41.3%
Light Duty Trucks (gasoline)	4,847,004	28.4%	63,530,000	32.0%	1,305,647	10.8%	12,396,408	14.9%	213,000	9.1%	425,016	4.3%	94,541	1.1%	527,840	16.0%	48,314	7.5%	0	0.0%
Light Duty Trucks (diesel fuel)	41,762	0.2%	2,200,000	1.1%	418,348	3.5%	5,558,923	6.7%	135,000	5.8%	183,717	1.9%	212,432	2.4%	716,179	21.8%	46,526	7.2%	594,617	14.9%
Light Duty Trucks (other)	112,197	0.7%	340,000	0.2%	67,903	0.6%	12,957	0.0%	16,000	0.7%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Subtotal	5,000,963	29.3%	66,070,000	33.3%	1,791,898	14.8%	17,968,288	21.7%	364,000	15.5%	608,733	6.2%	306,973	3.5%	1,244,019	37.8%	94,840	14.7%	594,617	14.9%
Heavy Duty Trucks (gasoline)	352,953	2.1%	2,310,000	1.2%	78,559	0.7%	187	0.0%	12,000	0.5%	1,311	0.0%	4,057	0.0%	7,614	0.2%	173	0.0%	0	0.0%
Heavy Duty Trucks (diesel fuel)	670,453	3.9%	3,810,000	1.9%	336,548	2.8%	763,039	0.9%	98,000	4.2%	189,146	1.9%	188,248	2.1%	255,534	7.8%	34,741	5.4%	129,519	3.2%
Heavy Duty Trucks (other)	0	0.0%	80,000	0.0%	4,185	0.0%	277	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Subtotal	1,023,406	6.0%	6,200,000	3.1%	419,292	3.5%	763,503	0.9%	110,000	4.7%	190,457	1.9%	192,305	2.2%	263,148	8.0%	34,914	5.4%	129,519	3.2%
Total Vehicles	17,083,380	100%	198,346,400	100%	12,066,768	100%	82,957,793	100%	2,343,400	100%	9,869,931	100%	8,841,849	100%	3,288,965	100%	646,053	100%	3,985,887	100%
Total Vehicles (excluding motorcycles)	16,764,390		194,520,000		11,737,923		68,699,940		2,264,400		5,392,733		3,786,888		2,256,371		512,695		2,339,149	
Transport Energy Use (ktoe)	52,767		605227		26758		86474		4465		11875		9793		7109		1172		18856	
Transport Energy Use (GJ)	2,209,249		25,339,644		1,120,304		3,620,493		186,941		497,183		410,013		297,640		49,069		789,463	
Ratio Road Energy to Total Transport	0.836		0.793		0.832		0.888		0.799		0.816		0.839		0.83		0.839		0.813	
Approx. Road Vehicle Energy (GJ)	1,846,932		20,094,338		932,093		3,214,998		149,366		405,701		344,001		247,041		41,169		641,833	
Road Energy/Total Vehicles (MJ/Vehicle)	108		101		77		39		64		41		39		75		64		-	
Population (1998, million)	30.3		270.56		18.75		126.41		3.79		21.87		21.39		75.15		3.87		61.2	
Total vehicles/person	564		733		644		656		618		451		413		44		167		65	

Table B-2 Questionnaire Responses for Vehicle Fleet Age and Fuel Economy

Vehicle Fleet Characteristics	Canada 1997	United States 1998	Australia 1998	Japan 1998	New Zealand 1998	Chinese Taipei 2000	Malaysia 1999	Philippines 1999	Singapore 1999	Bangkok 1998
Age Distribution (%)										
0-5 years	40.2	32.7	28.4	50.3	15.0	34.4	0.0	0.0	39.4	0.0
6-10 years	36.4	31.3	23.1	40.0	33.0	45.6	0.0	0.0	40.0	0.0
11-15 years	21.6	22.0	21.9	8.6	29.0	20.1*	0.0	0.0	4.7	0.0
16-20 years	1.8	10.2	16.3	1.2	13.0	0.0	0.0	0.0	10.3	0.0
21-25 years	0.0	3.6	5.0	0.0	4.0	0.0	0.0	0.0	4.6	0.0
>25 years	0.0	0.2	5.3	0.0	6.0	0.0	0.0	0.0	1.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	0.0
Existing Fleet Fuel Economy (km/L)										
Passenger Cars										
- Gasoline	10.0	10.0	8.7	8.7	7.2	9.0	14.0	0.0	0.0	8.0
- Diesel Fuel	0.0	0.0	8.1	9.1	12.2	0.0	0.0	0.0	0.0	10.0
Light Duty Trucks										
- Gasoline	7.5	7.4	7.7	0.0	6.0	8.3	0.0	0.0	0.0	6.0
- Diesel Fuel	7.4	0	7.4	0.0	11.1	7.0	0.0	0.0	0.0	7.0
Heavy Duty Vehicles										
- Gasoline	3.8	2.8	4.3	0.0	2.9	0.0	0.0	0.0	0.0	4.0
- Diesel Fuel	3.2	2.7	2.2	0.0	4.7	2.5	0.0	0.0	0.0	5.0

*20.1 is for >10

Table B-3 Questionnaire Responses for Emissions in APEC Economies

Pollutant and Sector	Annual Emissions (kilotonnes)								
	Canada 1995	United States 1997	Australia 1997	Japan 1997	Chinese Taipei 1997	Hong Kong 1997	Thailand 1998	Santiago Metro Region Chile 1997	Chile 1994
Nitrogen Oxides									
On-road vehicles	787	6385	363		172.5	39	372	31	
Aircraft	34	163	52			4	0.03	1	
Railway	116	862	34				0.01		
Marine Vessels	119	218	100			10	0.09		
Other Mobile Sources	235	2893							
Total Transportation	1,290	10,521	549	1020	172.5	53	372	32	78
Stationary Sources	1,174	10,867	1294	966	202.5	66	342	13	91
Total	2,464	21388	1844	1,986	375	119	714	44	169
Sulphur Oxides									
On-road vehicles	51	290	47		22.3	5	62	3	
Aircraft	2	9	2			0		0	
Railway	7	100	3				1		
Marine Vessels	58	227	70			1	30		
Other Mobile Sources	17	626							
Total Transportation	136	1,252	122	99	22.3	7	93	3	6
Stationary Sources	2,518	17,224	561	697	350.1	71	709	18	1,962
Total	2,654	18476	683	796	372.4	78	802	21	1968
Volatile Organic Compounds									
On-road vehicles	564	4744	439		245.3	16	438	28	
Aircraft	12	172	9			1		0	
Railway	6	45	2						
Marine Vessels	37	45	27			1			
Other Mobile Sources	116	1942							
Total Transportation	734	6,948	475	229	245.3	17	438	29	74
Stationary Sources	2,841	10,484	53	1,687	546	1	5.7	34	182
Total	3,575	17432	528	1,916	791.3	19	444	62	256
Particulate	**PM**	**PM10**	**PM**	**PM**	**PM10**	**PM**	**PM**	**PM10**	
On-road vehicles	42	244	13		45.3	7		3	
Aircraft	2	36	0			0		0	
Railway	19	30	0						
Marine Vessels	8	27	1			1			
Other Mobile Sources	26	325							
Total Transportation	98	662	15		45.3	8		3	
Stationary Sources	15,587	29,795	75		457.9	5	2772	6	
Total	15,684	30457	90		503.2	13	2772	9	

Note: All emission results apply to national emissions, except for the Santiago Metro Region of Chile.

Table B-3 Questionnaire Responses for Emissions in APEC Economies (Continued)

Pollutant and Sector	Annual Emissions (kilotonnes)								
	Canada	United States	Australia	Japan	Chinese Taipei	Hong Kong	Thailand	Santiago Metro Region Chile	Chile
Carbon Monoxide									
On-road vehicles	5,427	45587	2472		1052.1	90	1961	226	
Aircraft	62	916	97			2	0	1	
Railway	22	109	5				0		
Marine Vessels	103	82	128			3	0		
Other Mobile Sources	1,094	14084							
Total Transportation	6,708	60,778	2,702	2009	1052.1	95	1961	227	378
Stationary Sources	10,420	18,542	262	1,742	279.7	13	61	19	568
Total	17,128	79320	2963	3,751	1331.8	108	2022	246	947
Carbon Dioxide									
On-road vehicles	118,220	1366852	59885			6308	49852		
Aircraft	12,600	235211	11574			1156	8.10		
Railway	5,660	35240	1548						
Marine Vessels	5,810	73898	4499			175	3470.00		
Other Mobile Sources	0	24599							
Total Transportation	142,290	1,735,800	77,506	251376		7,642	53330		12,695
Stationary Sources	377,710	3,729,100	234164	979,455		25739	81057		24,402
Total	520,000	5464900	311670	1,230,831		33,381	134387		37097