Acronyms

3C	Three-way catalytic converter
ABARE	Australian Bureau of Agricultural and Resource Economics
ACTION	Australian Capital Territory Internal Omnibus Network
ADR	Australian Design Rule
AFCP	Alternative Fuel Conversion Program
AGA	Australian Gas Association
AGO	Australian Greenhouse Office
AIP	Australian Institute of Petroleum
ALPGA	Australian Liquefied Petroleum Gas Association
ANGVC	Australasian Natural Gas Vehicles Council
AQIRP	Air Quality Improvement Research Program
BD	Biodiesel
BD100	100% Biodiesel
BD20	20% Biodiesel
BRS	Bureau of Resource Science
BTCE	Bureau Of Transport and Communications Economics
CAD	California Diesel
CBD	Central Business District
CEE	Canola Ethyl Ester
CFC	Chlorofluorocarbons
CH_4	Methane
CME	Canola Methyl Ester
CMU-ET	Carnegie Mellon University Equivalent Toxicity
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CRPT	Continuous Regenerating Particulate Trap
CUEDC	Composite Urban Emissions Drive Cycle
DAFGS	Diesel and Alternative Fuels Grants Scheme
DOC	Dissolved Organic Carbon
DOE	Department of Energy (United States)
E100	Ethanol
E10P	10% Ethanol dissolved in petrol (petrohol)
E15D	15% Ethanol dissolved in diesel fuel
E93	93% Ethanol
E95	95% Ethanol
ELR	European Load Response
EPA	Environmental Protection Agency (US)
	Environment Protection Authority (NSW & VIC)
EPEFE	European Programme on Emissions, Fuels and Engine Technologies
ERDC	Energy Research and Development Corporation
ESC	European Stationary Cycle
ETC	European Transient Cycle
ETSU	Energy Technology Support Unit

FAMAE	Fatty Acid Mono Alkyl Ester
FAME	Fatty Acid Methyl Ester
FFC	Full Fuel Cycle
FQR	Fuel Quality Review
FT	Fischer-Tropsch
FTD	Fischer-Tropsch Diesel
GCV	Gross Calorific Value
GJ	Gigajoule; unit of energy; 1 GJ = 1 x 10^9 J
GHG	Greenhouse Gases
GMO	Genetically Modified Organisms
GTL	Gas to Liquid
GVM	Gross Vehicle Mass
GWP	Global Warming Potential
HC	Hydrocarbons. In this report, HC is used for non-methanic hydrocarbons.
HD5	Standard for LPG such that it is primarily propane.
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicle
IANGV	International Association for Natural Gas Vehicles
IEA	International Energy Agency
IEA/AFIS	International Energy Agency/Alternative Fuels Information System
LCA	Life Cycle Analysis
LCV	Light Commercial Vehicle
LDV	Light Duty Vehicle
LEV	Low Emission Vehicle
LNG	Liquid Natural Gas
LPG	Liquefied Petroleum Gas
LSD	Low Sulfur Diesel
MJ	Megajoule; unit of energy; 1 MJ = 1 x10^6 J
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NG	Natural Gas
NGGIC	National Greenhouse Gas Inventory Committee
NGV	National Gas Vehicle
NMHC	Non-methanic Hydrocarbon
NMVOC	Non-methanic Volatile Organic Compound
N_2O	Nitrous Oxide
NO_2	Nitrogen Dioxide
NO_x	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
NSW	New South Wales
OEM	Original Equipment Manufacturer
OEHHA	Office of Environmental Health Hazard Assessment (of the Californian EPA)
OXC	Oxidation Catalyst
OHS	Occupational Health and Safety
PAH	Polycyclic Aromatic Hydrocarbons

PM	Particulate Matter
PM10	Particulate matter below 10 μm diameter
PULP	Premium Unleaded Petrol
REE	Rapeseed Ethyl Ester
RME	Rapeseed Methyl Ester
RMIT	Royal Melbourne Institute of Technology
RTA	Roads and Traffic Authority (NSW)
SAE	Society of Automotive Engineers
SO_2	Sulfur Dioxide
SO_x	Oxides of Sulfur
SOF	Soluble Organic Fraction
SULEV	Super Ultra-Low Emission Vehicle
THC	Total Hydrocarbons, being the sum of NMHC and methane.
TSP	Total Suspended Particles
TTVS	Trans Tasman Vehicle Standards
ULS	Ultra-Low Sulfur Diesel
US	United States of America
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
VOME	Vegetable Oil Methyl Ester
WVU	West Virginia University

Glossary of Terms

Acetaldehyde

CH_3CHO emission component of the exhaust gases of combustion engines; an air toxic, presumably carcinogenic.

Additive

additives are added to the fuel in small amounts to improve the properties of the fuel. For instance, anti-sludge additives prevent the deposits of carbon and tar on the inlet valves and other engine parts.

Air/fuel ratio

Mass ratio of air to fuel inducted by an engine. See also stoichiometric ratio.

Alcohol

Group of organic compounds, derived from hydrocarbons, which one or more hydrogen atoms replaced by hydroxyl (OH) groups.

Biodegradability

the capability of a substance to decompose into harmless elements

Biodiesel

automotive fuel consisting of esterified vegetable oils such as rapeseed methyl ester and soybean methyl ester

Catalyst

1. Substance that influences the speed and direction of a chemical reaction without itself undergoing any significant change.

2. Catalytic reactor which reduces the emission of harmful exhaust gases from combustion engines.

Canola Oil

A vegetable oil made from canola. It is similar to rapeseed oil but with less crucic acid and glucosinolates.

Cetane number

A measure of the ignition quality of diesel fuel based on ignition delay in an engine. The higher the cetane number the shorter the ignition delay and the better the ignition quality. The cetane number is based on the ignition quality of cetane ($C_{16}H_{34}$) and heptamethylnonane.

Compression ratio

The ratio of the volume of the combustion chamber at the beginning of the compression stroke and the volume of the chamber at the end of the compression stroke.

Compression ignition engine

Internal combustion engine with an ignition caused by the heating of the fuel-air mixture in the cylinder by means of compression. This compression causes a rise in temperature and pressure which make possible the spontaneous reaction between fuel and oxygen. Also called a diesel engine.

Crude; crude oil

crude mineral oil. Naturally occurring hydrocarbon fluid containing small amounts of nitrogen, sulphur, oxygen and other materials. Crude oils from different areas can vary enormously.

DI-engine
: direct injected engine; combustion engine with a direct injection of fuel into the combustion chamber.

Diesel engine
: 1. Combustion engine running on diesel oil;

: 2. other name for a combustion engine with compression ignition (named after Rudolf Christian Carl Diesel (1858-1913), one of the founders of the combustion engine principle).

Diesel (oil)
: 1. A mixture of different hydrocarbons with a boiling range between 250º and 350ºC;
: 2. A fuel for compression ignition or diesel engines.

Diesohol
: A blend of diesel fuel, hydrated ethanol and proprietary emulsifier.

Dual-fuel vehicle
: Vehicle fitted with one engine and two fuel systems. The engine can operate on both fuels. An example is an LPG/Gasoline dual-fuel vehicle.

Embodied energy
: The upstream processing energy required to produce an item. This term is widely used in life-cycle analysis

Exbodied emissions
: emissions associated with the cumulative life-cycle of the fuel including its combustion.

Evaporative emission
: Emission of hydrocarbons of a vehicle from sources other than the exhaust pipe. Important sources are the venting of the fuel tank and the carburettor. Evaporative losses are subdivided into:
- running losses
- diurnal losses
- hot soak losses

FFV
: Flexible-Fuelled Vehicle. Vehicle able to drive on any mixture of alcohol and gasoline up to 85% alcohol.

Formaldehyde
: Aldehyde compound; HCHO; very toxic; probably carcinogenic.

IDI-engine
: Indirect-Injection Engine; internal combustion engine (usually a diesel engine) with indirect fuel injection, for instance by way of a pre-combustion chamber or a swirl chamber.

Ignition delay
: Expression usually used in connection with compression ignition engine, defined as the time between the start of the injection and the start of the ignition.

Lean mixture
: mixture of air and fuel in a cylinder of a combustion engine containing less fuel than could be burnt by the oxygen present.

Liquefaction
: The conversion of a gas to a fluid by lowering the temperature and or raising the pressure. LPG is a liquefied gas; natural gas and hydrogen are sometime liquefied.

Methylester
: An ester which results from the esterification of oil with methanol, a known as biodiesel.

PAH
: Polycyclic Aromatic Hydrocarbon(s). Aromatics of which the molecules contain several, linked benzene rings; in several cases carcinogenic.

PM10
: Particulate matter with a size range (measured by the aerodynamic diameter) of less than 10 μm.

Pilot injection
: method to ignite fuels that are difficult to ignite. A more easily ignitable fuel is injected into the engine, next to a amount of the real fuel. The added fuel will ignite first and subsequently ignite the real fuel. An example is diesel pilot injection in alcohol engines.

Reformulated fuel
: A fuel (especially gasoline or diesel) blended to minimise undesirable exhaust and evaporative emissions.

Rich mixture
: An air-fuel mixture in a combustion engine that contains more fuel than can be combusted by the air in the cylinder.

Spark ignition engine
: Internal combustion engine with an ignition of the fuel/air mixture by means of a spark; also called otto engine.

Stoichiometric air/fuel ratio
: The exact air/fuel ratio required to completely combust a fuel to water and CO_2.

Tailpipe emissions
: Emissions of a combustion engine after the catalyst (as distinct from engine-out emissions which are measured before the catalytic converter).

Three-way catalyst
: Catalytic reactor for combustion engines which oxidises volatile organic compounds (VOC) and CO, as well as reduces nitrogen oxides.

Vkm
: vehicle kilometre

VOC
: Volatile Organic Compound(s). Collective noun for hydrocarbons which are emitted in the volatile phase by vehicles. Usually described as HC-compounds.

Executive Summary

This report responds to a brief from the Australian Greenhouse Office to undertake:

- a comparison of road transport fuel emissions through a full fuel-cycle analysis of greenhouse gas emissions and emissions affecting air quality; and
- for each fuel, an assessment of current and near future (i.e., to 2006):
  - health-related issues (including occupational health and safety issues);
  - viability and functionality; and
  - environmental issues (including ecologically sustainable development) not related to greenhouse or air quality issues.

STRUCTURE

The report consists of three main parts. Part 1 consists of 15 chapters, each of which provides a *summary* of the salient points of each fuel, with a graphical representation of the emissions from the fuel, the reference fuel, and similar fuels, together with a representation of the uncertainty associated with the emissions. There is no summary description of low sulfur diesel because it is the reference fuel against which all subsequent heavy vehicle fuels are examined. The first chapter of Part 1 provides information on the background of the study.

Part 2 consists of *detailed* chapters on each fuel. These provide a literature review for each fuel, a description of the upstream and tailpipe emissions along with an explanation of the assumptions made in the quantitative modelling, the numerical results on which the graphical information in Part 1 is based, as well as the uncertainty estimates. In addition, each chapter provides details of the viability and functionality, health effects, environmental issues and expected future emissions associated with each fuel.

Part 3 consists of supporting chapters that discuss possible weighting methodologies for examining air quality emissions, and the modelling approach for the estimates of future emissions.

METHODOLOGY

Stakeholder consultation was an essential part of this study. Some ninety stakeholders were invited to comment on the study. These included fuel producers, vehicle manufacturers, government stakeholders, and environmental groups. Two stakeholder forums were held – one in Canberra and one in Melbourne – and these were followed by focussed roundtables for detailed discussion and comments on the exposure draft.

The study, completed over a five-month period from March to July 2001, consists of a literature review and a desk analysis of existing Australian and overseas studies that assess the emissions characteristics of 15 fuels. Three classes of emissions are considered: greenhouse gases, air pollutants, and air toxics. International tailpipe results were used to supplement the small amount of available local data on tailpipe emissions for the majority of the fuels studied. Substantial Australian data was available for calculating the upstream emissions of most of the fuels.

The study adheres to the international standards framework for conducting life-cycle analysis contained in the ISO14040 series (International Standards Organisation, 1998). A full life-cycle analysis of emissions takes into account not only direct emissions from vehicles but also those associated with the fuel's: extraction; production; transport; processing; conversion and distribution. Key issues addressed in the report include the system boundaries for the analysis, and the allocation of emissions for co-products, by-products and waste products.

Many of the feedstocks for fuels used in this study are either co-produced with other products or are from by-products and wastes from other production processes. Two options available for dealing with co-production are to split emissions between product streams - known as allocation - or to expand the study to take into account potential flow-on effects of providing a new use for the co-products and on systems currently using the co-products - known as system boundary expansion. The study follows the international standard on life-cycle assessment, which states that allocation should be avoided where possible. However alternative allocations have also been examined to determine whether there is a significant difference between the results.

SimaPro 5.0 life-cycle analysis software was used during the study. The software has an extensive Australian database of manufacturing energy input and emissions. Process trees outlining emissions from the production of fuels are produced by SimaPro and are included in the report. Other software packages are available but these are generally based on US emissions scenarios that are often not relevant to Australia. Further information about SimaPro is in Appendix 2.

Fuels are compared on the basis of both the mass of emissions per unit of energy used (g/MJ), and the mass of emissions per kilometre of distance travelled. The mass of emissions per kilometre travelled is the environmentally more meaningful figure, though it is subject to greater variability than the mass per unit energy. The mass of emissions per tonne-kilometre and the mass per passenger-kilometre are also calculated for trucks and buses respectively. Both upstream (pre-combustion) emissions and downstream (tailpipe, or combustion emissions) were considered. Emissions were also divided between those in urban and non-urban areas. We use the term "exbodied emissions" to refer to the cumulative upstream and downstream full fuel-cycle emissions.

The fuels examined were:

Diesel fuels: low sulfur (LS) diesel (the reference fuel for heavy vehicles), ultra-low sulfur (ULS) diesel, and Fischer-Tropsch diesel.

Biodiesel and canola oil: five upstream sources for biodiesel were examined, namely the crops: canola, soy, and rape; tallow and waste cooking oil. Tallow and waste cooking oil were treated both as waste products and as economic commodities.

Gaseous fuels: compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG) as autogas, and LPG as propane gas (HD5). Two modes of gas compression (gas and electric) were examined for CNG. Three modes of transport were examined for LNG.

Hydrated ethanol-based fuels: Diesohol, which is a blend of 15% ethanol with low sulfur diesel and an emulsifier (E15D), and hydrated ethanol produced by seven upstream processes.

Hydrogen.

Light vehicle fuels: Premium unleaded petrol (PULP), PULP blended with 10% anhydrous ethanol (E10P) and anhydrous ethanol blended with 15% PULP (E85P). Again, seven upstream ethanol production processes were examined.

LS diesel was chosen by the Australian Greenhouse Office as the reference fuel against which other fuels are compared because it will be the mandated diesel standard from 2002 to 2006 and Euro4 standard vehicles designed for ULS diesel will not achieve significant market penetration for some time after the introduction of ULS diesel. It is recognised that for some analyses a different reference fuel may be required. Data to facilitate such analyses is provided in Part 2 of this study.

Projections, based on a study commissioned by the European Commission Directorate-General for Energy, are made about the ability of vehicles using the different fuels to meet Australian Design Rules for vehicle emissions.

RESULTS

The results of the analysis are summarised in Table 1. This table is derived from data in Part 1 of this report, which in turn is derived from the information in Part 2 of the report. The structure of the results given in this report is:

- Executive summary – Table 1 summarises the material in Part 1.
- Part 1 – Bar charts (incorporating a measure of the uncertainty of the data) of Part 2 material.
- Part 2 – Detailed quantitative information in the form of tables and process trees.

The relative emissions performance of each fuel is determined using information in Part 2, which is analysed to determine whether the difference between LS diesel and each fuel is statistically significant.

The viability and functionality, and environmental issues relating to each fuel are mentioned in Table 1 only if there are issues to be noted. Thus, all fuels except canola oil are viable and functional. Noteworthy environmental and ecologically sustainable development issues are referred to if they have a significant impact on the analysis of the fuel. For example, biodiesel made from tallow has to allow for significant methane emissions from the upstream beef cattle industry. In addition, ethanol made via ethylene from a fossil fuel emits large quantities of greenhouse gases because the ethanol is no longer from a renewable fuel.

The last column of Table 1 uses the estimates of Arcoumanis (2000) developed for the European Auto-Oil II program to determine the likelihood of the fuel meeting future Australian Design Rule emission limits. As the future Australian Design Rule emission limits are based on the European standards, the comparison is given against Euro3 and Euro4. These results indicate that some ethanol-based fuels may have difficulty meeting Euro3 and Euro4 limits for total hydrocarbons, and that 100% biodiesel may have difficulty meeting Euro 3 limits for particulate matter (PM), but improvements in vehicle technology are expected to enable 100% biodiesel to meet Euro 4 limits for particulate matter. Arcoumanis notes that a blend of 20% - 30% biodiesel with diesel in heavy vehicles is expected to meet all Euro 4 standards. With respect to diesohol, the higher THC and CO emissions reflected in the Arcoumanis' report can be overcome according to APACE Research. Consequently diesohol made from low sulfur diesel should be able to meet all future ADRs.

The heavy vehicle fuel results from Table 1 are summarised below:

Diesel fuels

The removal of sulfur from diesel produces a fuel that emits less important criteria pollutants and air toxics. Tailpipe emissions of particulate matter and hydrocarbons from ULS diesel are less than LS diesel, and emissions of these pollutants from Fischer-Tropsch diesel are less than those from ULS diesel. Tailpipe emissions of NOx for Fischer-Tropsch diesel and ULS diesel are similar to each other but are less than LS diesel.

The greater processing energy involved in the removal of the sulfur means that exbodied greenhouse gas emissions are similar for LS diesel and ULS diesel, but higher in the case of Fischer-Tropsch diesel.

Lower sulfur fuels permit more efficient operation of emission control devices such as exhaust gas recirculation, oxidation catalysts, and particulate traps. Consequently the use of ULS diesel (50ppm sulfur) will lead to improved performance of these devices when compared with LS diesel, and Fischer-Tropsch diesel with a very low sulfur content will perform better than ULS diesel.

A significant advantage for the ULS diesel and Fischer-Tropsch diesel is that they can be used by current refuelling infrastructure and in existing engines.

It is to be expected that once diesel vehicles routinely use ultra-low sulfur fuels and are equipped with such emission control devices then they will meet Euro4 standards.

There are no operational Australian gas to liquids plants producing Fischer-Tropsch diesel and so data from overseas plants has been considered in the course of this study. One issue raised in the course of the study was the energy source for the production of Fischer-Tropsch diesel. About 70% of energy is assumed to be derived from natural gas and the remainder from hydrogen produced in the gas shift reaction used as part of the Fischer-Tropsch process. A review should be undertaken when information about emissions from the production of Fischer-Tropsch diesel in Australia becomes available.

Biodiesel and canola oil

Canola oil is not presently a viable heavy vehicle fuel. Major alterations to heavy vehicle engines are needed to make it a viable fuel.

All forms of biodiesel are more climate-friendly than diesel. In other words, biodiesel emits less exbodied greenhouse gases than diesel. The emissions involved in upstream activities for biodiesel are less than the emissions involved in diesel combustion and upstream activities. Biodiesel made from tallow is less climate-friendly (i.e. it emits more exbodied greenhouse gases) than biodiesel made from vegetable oil because of the upstream methane emissions from cattle.

As in the case of ethanol, biodiesel made from a waste product has lower emissions than the same fuel made with a product that has to be purchased. This comes about because the rules associated with life cycle analysis specify that in such situations the upstream emissions in generating the waste product do not have to be debited to the final product. Biodiesel made with waste cooking oil is thus the best form of biodiesel on a life-cycle basis.

Biodiesel made from vegetable oils is comparable to diesel in its exbodied emissions except for oxides of nitrogen and particulate matter. Provided that the emissions from diesel-operated agricultural machinery are properly controlled then exbodied emissions of particulate matter from biodiesel are lower than those of diesel. However, it appears that exbodied emissions of NOx from biodiesel are higher than those of diesel. The major disadvantage of 100% biodiesel is related to concerns about its ability to meet Euro3 standards for PM, and to meet both Euro3 and Euro4 standards for NOx.

The growth of crops for biofuels should be monitored to ensure that principles of ecologically sustainable development are upheld.

Gaseous fuels (Natural Gas - Dedicated OEM)

There have been major advances in natural gas engines in recent years that mean that the present generation of natural gas vehicles have significantly lower emissions than the present generation of diesel vehicles such that some of the present generation of natural gas engines can already meet Euro4 standards. The emissions based on use in original equipment manufacture (OEM) vehicles are lower in all categories – greenhouse gases, important criteria pollutants, and air toxics. The lower particulate emissions and noise levels compared with diesel make it particularly attractive for urban areas.

The major uncertainty relates to leakage. There are many studies, based on earlier estimates of upstream and in-service methane leakage, which claim that natural gas vehicles emit more greenhouse gases than conventional fuel heavy vehicles. Based on our analysis of present day vehicles we believe that upstream and in-service leakage has been sufficiently reduced that the present generation of OEM natural gas vehicles have lower exbodied greenhouse gas emissions than the equivalent diesel vehicles.

This study used a value of 0.1% for fugitive emissions from distribution and compression, which is based on information provided by stakeholders. If Australian fugitive emissions were to be significantly higher (at approximately 4%) then the full fuel-cycle greenhouse gas emissions from CNG and LNG would exceed those from diesel.

Table 1
Summary of the results of the analysis per tonne-kilometre and per passenger-kilometre

Fuels	GHG	PM	NOx	Toxics[1]	Health	V&F	ESD	Future ADR
LS diesel (Aus)	Reference fuel for heavy vehicles							
ULS diesel (Aus)	=	~	~	~	√			
ULS diesel (100% hydroprocessing)	=	~	~	~	√			
Fischer-Tropsch diesel	+	-	=	-	√			
100% Biodiesel (canola)	- -	~	+	=	=			PM>E3; NOx>E3,E4
100% Biodiesel (soybean)	- -	~	+	=	=			PM>E3; NOx>E3,E4
100% Biodiesel (rape)	- -	~	+	=	=			PM>E3; NOx>E3,E4
100% Biodiesel (tallow-expanded sys. boundary)	- -	~	+	=	=		{CH_4	PM>E3; NOx>E3,E4
100% Biodiesel (tallow-eco.allocat.)	- -	~	+	- -	√		{upstream	PM>E3; NOx>E3,E4
100% Biodiesel (waste oil)	- -	~	+	- -	√			PM>E3; NOx>E3,E4
100% Biodiesel (waste oil 10% original oil value)	- -	~	+	- -	√			PM>E3; NOx>E3,E4
Canola			No data			XX		
[2]CNG (Electric compression)	- -	- -	- -	- -	√			
[2]CNG (NG compression)	- -	- -	- -	- -	√			
[2]LNG (from existing pipeline)	- -	- -	- -	- -	√			
[2]LNG (Shipped from north west shelf)	- -	- -	- -	- -	√			
[2]LNG (Road transport to Perth)	- -	- -	- -	- -	√			
[2]LPG (Autogas)	-	- -	- -	-	√			
[2]LPG (HD5)	-	- -	- -	-	√			
LSdiesohol	~	~	=	=	=			??THC>E3,E4
Ethanol azeotropic (molasses-expanded sys.bound.)	- -	-	=	-	√			THC>E3,E4
Ethanol azeotropic (molasses-economic allocation)	~	-	~	-	√			THC>E3,E4
Ethanol azeotropic (wheat starch waste)	- -	=	~	-	=			THC>E3,E4
Ethanol azeotropic (wheat)	-	=	=	=	=			THC>E3,E4
Ethanol azeotropic (wheat) fired with wheat straw	- -	+	=	++	X			THC>E3,E4
Ethanol azeotropic (woodwaste)	- -	=	-	++	X			THC>E3,E4
Ethanol azeotropic (ethylene)	+	-	=	++	X		fossil-fuel based	THC>E3,E4
Hydrogen (from natural gas)-upstream only	=	- -	- -	- -	√			
PULP	Reference fuel for light vehicles							
PULP e10 (molasses-exp.sys.bound.)	=	=	=	=	=			
PULP e10 (molasses-eco.allocat.)	=	=	=	=	=			
PULP e10 (wheat starch waste)	=	=	=	=	=			
PULP e10 (wheat)	=	=	=	=	=			
PULP e10 (wheat WS)	=	=	=	=	=			
PULP e10 (wood waste)	=	=	=	=	=			
PULP e10 (ethylene)	=	=	=	=	=			
PULP e85 (molasses-exp.sys.bound.)	- -	=	=	=	=			THC>E3,E4
PULP e85 (molasses-eco.allocat.)	-	=	=	=	=			THC>E3,E4
PULP e85 (wheat starch waste)	- -	=	=	=	=			THC>E3,E4
PULP e85 (wheat)	-	=	++	=	=			THC>E3,E4
PULP e85 (wheat WS)	- -	+	++	++	X			THC>E3,E4
PULP e85 (wood waste)	- -	=	-	++	X			THC>E3,E4
PULP e85 (ethylene)	++	=	++	++	X		fossil-fuel based	THC>E3,E4

GHG: greenhouse gases; PM: particulate matter; NOx: oxides of nitrogen; V&F: viability and functionality; ESD: ecologically sustainable development.

Symbols: - -, significantly lower (than the reference fuel); -, lower; ~, slightly lower; =, much the same; +, higher; and ++, significantly higher. Health effects are based on the rankings for toxics and PM. √ indicates improvement (compared with the reference fuel); X, worse. The symbol XX indicates very poor.

Significantly lower/higher means two standard deviations difference; higher/lower means more than one standard deviation difference.

[1] Due to limited air toxics data THC was used as a proxy. Thus these results are only a rough guide.
[2] CNG, LNG and LPG results apply only to OEM dedicated gas vehicles.

The major disadvantages of natural gas are the lack of sufficient refuelling stations, and the perceptions of safety problems that arose from fires in improperly maintained earlier generation natural gas vehicles. The extra weight of CNG fuel tanks leads to slightly higher fuel consumption, or loss of payload in the case of buses. This is less of a problem with LNG vehicles due to the higher energy density.

Gaseous vehicles (LPG - dedicated OEM)

A dedicated LPG bus produces significantly lower emissions of important criteria pollutants, and lower exbodied emissions of greenhouse gases. Air toxics from tailpipe emissions of LPG vehicles are much lower than those of diesel vehicles, but the greater upstream emissions of air toxics results in the exbodied emissions of air toxics from LPG being much the same as those from diesel.

LPG HD5 has minimum propane content of 90% whereas the ratio of propane and butane varies widely in autogas LPG. When compared with autogas, HD5 LPG emits more NOx but less particulate matter. Emissions of hydrocarbons are similar. The main benefit of HD5 compared with autogas is that the compression ratio can be altered to suit this higher-octane fuel.

The lower particulate emissions and lower noise levels compared with diesel make it attractive for use in urban areas.

The major disadvantage of LPG is the lack of market penetration of dedicated heavy LPG vehicles.

Gaseous vehicles (Converted vehicles and dual fuel)

The emissions performance of converted Australian CNG vehicles is known to be significantly worse than OEM CNG vehicles. However there is little data on CNG conversion configurations that are currently available. It is possible that the difference in emission levels between converted vehicles and OEMs will decrease as the heavy-duty vehicle conversion industry becomes more firmly established.

Diesel vehicles converted to LPG are less successful at reducing tailpipe emissions than OEM LPG vehicles. At best one could consider converted LPG vehicles as equal to their diesel counterparts except for HC, which appears to be higher, and PM, which remains significantly lower. The Australian LPG conversion industry for heavy vehicles is at an early stage in its development and the data available, from only two tests, may not reflect the emissions performance of converted vehicles in the longer term.

Hydrated ethanol based fuels

The nature of the upstream feedstock for the production of ethanol is crucial in determining whether ethanol-based fuels are superior or inferior to diesel regarding greenhouse gas emissions.

The use of renewable feed-stocks such as molasses, wheat, or wheat starch appears to produce lower exbodied emissions of greenhouse gases and emissions affecting air quality than LS diesel provided that wheat straw is not used as the energy source in which case there are increased emissions of hydrocarbons and possibly air toxics, as is also the case with the use of woodwaste. The growth of crops for biofuels should be monitored to ensure that principles of ecologically sustainable development are upheld.

Ethanol made from a non-renewable source via ethylene produces greater exbodied emissions of greenhouse gases than diesel fuel.

The major disadvantage of ethanol is that present estimates indicate that it may have difficulty meeting Euro3 and Euro4 standards in relation to the emissions of hydrocarbons.

In the case of diesohol, the manufacturers are confident that a combination of cetane improver and fuel injection modifications (to avoid vapour locks) will enable diesohol to meet Euro3 and Euro4 standards for hydrocarbons and carbon monoxide. Table 1 indicates that greenhouse emissions and particulate matter from diesohol are slightly lower than LS diesel. NOx and emissions of air toxics are similar to LS diesel. Benzene levels should decrease when ethanol concentrations increase which means that tailpipe emissions for these air toxics should be lower. Acetaldehyde and formaldehyde emissions will increase. Special measures are needed to control evaporative emissions from vehicles using alcohol fuels.

Hydrogen
Hydrogen fuel cells offer the possibility of offering significant potential improvements in emissions. Due to the experimental nature of this technology little is known of the in-service performance but there are assumed to be no tailpipe emissions apart from water vapour. The operation of three fuel cell buses in Perth by late 2002 will provide such information. It is known that hydrogen fuel cells are currently very expensive and very heavy in terms of weight per kilowatt output.

Hydrogen manufactured using natural gas is very energy intensive and lifecycle emissions are similar to those of LS diesel. Production of hydrogen by low-pressure water electrolysis would be an ecologically sustainable method of production provided that the electricity used to undertake electrolysis is based on renewable energy.

Light vehicle fuels
The addition of 10% ethanol to premium unleaded petrol to produce petrohol does not significantly alter the emission characteristics of the petrol, especially when the uncertainties and the variability of emission estimates are taken into account. Higher evaporative emissions may present problems with petrol/ethanol blends.

In an E85 blend of 15% petrol and 85% ethanol, the use of anhydrous ethanol (less than 1% water by volume) from a renewable source significantly reduces exbodied greenhouse gas emissions, as may be expected. However, there are doubts about the ability of 85% ethanol used in light vehicles to meet Euro3 and Euro4 emission standards for hydrocarbons.

Ethanol fuels made from a fossil fuel, such as ethylene, have higher exbodied emissions (than from premium unleaded petrol) for greenhouse gases, important criteria pollutants, and air toxics with one exception (aldehydes). The exbodied emissions of particulate matter are reduced.

UNCERTAINTIES

This study compares fuels on a statistical basis using the mean value and standard deviation for each fuel to address the variability present in emissions data. Uncertainties are calculated for each fuel by emission type. The smallest uncertainties for tailpipe emissions are associated with carbon dioxide followed by hydrocarbons, oxides of nitrogen, carbon monoxide and particulate matter. Standard deviations for each fuel are provided in each chapter in Part 2 of the report.

The use of the standard deviation in Table 1 minimises the impact of statistical variation inherent in emissions data and provides a greater level of confidence in the findings. The use of the terms significantly higher or lower in Table 1 refers to a two standard deviation difference. Higher or lower, as expressed by – or + signs, refers to one standard deviation difference. In some cases emissions data have a difference of less than one standard deviation but it is clear that the emissions are consistently less than those of low sulfur diesel. In this case a tilde sign "~" has been used in Table 1.

RECOMMENDATIONS

Insufficient is known about the emissions of air toxics from vehicles, and the appropriate Australian risk-weighted factors to use in examining their relative effects. It is expected that these issues will be examined as part of the work on a National Environment Protection Measure (NEPM) on air toxics.

When the NEPM work on air toxics is finalised, the air toxics issues examined in this report should be reviewed.

The sensitivity analysis revealed the importance of fugitive emissions in determining whether CNG and LNG are more, or less, climate friendly than diesel fuel. We recommend a study be conducted that combines measurement with an audit of fuel use to determine the level of fugitive emissions

Many of the gaseous fuel vehicles to be used in Australia are likely to be converted vehicles or dual fuel vehicles. Consequently it is important to ensure that the emissions from such vehicles are no worse than those of the unconverted vehicle. The collection and collation of emissions information from such vehicles needs to be systematically undertaken.

It follows that if the data produced herein are to be used in guiding initiatives that lead to alternative fuels implementation, the data should be reviewed periodically in two ways.

Firstly, an analysis such as the one in this report has a limited life. In some cases (such as hydrogen and Fisher-Tropsch diesel) there are no operational plants producing transport fuels presently in existence in Australia. Because it is to be expected that operational plants will be in place within a few years, the study will need to be repeated such that a re-analysis focuses on production processes that are actually in place at the time of the re-analysis.

Secondly, validation of the values established here through experimental tests would ensure that the technology being used in Australia is recognised in the allocation of environmental benefits accruing from the use of alternative fuels. A measurement program that surveys a significant proportion of alternative fuel vehicles should be undertaken in order to support this recommendation. Such an experimental program should ensure that the vehicles that are tested vary with engine and vehicle type; and the emission results are compared with the existing SAE-A truck fuel consumption model as described in Part 3 of this report.