Appendix 1. Terms of Reference for Comparison of Transport Fuels – Stage 2

A1.1 Background

The Australian Greenhouse Office (AGO) supported the development of the Diesel and Alternative Fuels Grants Scheme (DAFGS) which maintains price relativities between diesel and alternative fuels following the reduction in the diesel fuel excise rate and the provision of grants for diesel used for on-road transport from July 2000.

The Scheme is administered by the Australian Taxation Office (ATO) but the Chief Executive of the AGO is responsible for certifying additional alternative fuels as being eligible under DAFGS. This analysis will assist in determining the eligibility of several fuels currently not eligible under the Scheme. The study will also provide a profile of emissions for a broad range of conventional and alternative fuels under Australian conditions that will inform future policy for transport fuels.

Further information about DAFGS can be found using the search facility on the ATO website www.ato.gov.au and information about the AGO transport programs are available from www.greenhouse.gov.au/transport

The Stage 1 study (referred to in section 4) was based on the assessment of existing studies of transport emissions. Stage 2 builds on this work and requires extensive liaison with industry, government and other key stakeholders when developing the emissions profile.

A1.2 Definition

For the purpose of this study, "full fuel cycle emissions" are emissions of a fuel product generally from when a raw material is extracted (for fossil fuels) or planted (for renewable fuels) to when the fuel is combusted. The study of full fuel cycle emissions would include the following processes:

- extraction
- production;
- transportation and storage;
- fuel processing;
- conversion;
- fuel transportation, storage and distribution; and
- vehicle operations that involve fuel combustion or other chemical conversions.

The processes that precede vehicle operations are generally referred to as upstream activities; and vehicle operations are referred to as downstream activities.

A1.3 Objectives

The objective of Stage 2 is to examine the emissions and other characteristics of transport fuels that will assist the Chief Executive of the AGO to determine which additional alternative fuels should be considered for eligibility under the DAFGS, and to provide a profile of each transport fuels' emissions (both current and projected to 2006).

The objective will be achieved through:

1. a comparison of road transport fuel emissions through a full fuel cycle analysis of greenhouse gas emissions and emissions affecting air quality; and,

2. for each fuel, an assessment of current and near future (ie to 2006):

- viability and functionality;
- health related issues; and
- environmental issues (including ecologically sustainable development) not related to greenhouse or air quality issues.

A1.4 Scope

Stage 1 Analysis

The analysis of alternative fuels is being conducted in two stages. Stage 1 was limited to an overview of Australian and overseas studies that assess the emissions characteristics of alternative and conventional fuels that are or may be suitable for use in road vehicles from 4.5 tonnes gross vehicle mass (GVM).

The fuels assessed in Stage 1 were compressed natural gas (CNG), liquefied petroleum gas (LPG), liquefied natural gas (LNG), recycled waste oil, canola oil, ethanol, as well as a range of blends of these fuels, including biodiesel and conventional fuels such as low and ultra low sulfur diesel.

The greenhouse gases assessed in the Stage 1 analysis included carbon dioxide, nitrous oxide, and methane. Air pollutants assessed were carbon monoxide, oxides of nitrogen (the NOx group), oxides of sulfur (SOx), non-methane volatile organic compounds (NMVOCs), visible smoke and particulates. The analysis also examined greenhouse gas emissions and air pollutants in the upstream activities of a fuel's life cycle. Stage 1 has been completed and a copy of the report is on the AGO website at: www.greenhouse.gov.au/transport/pdfs/lifecycle.pdf

Requirements for Stage 2

Stage 2 will:

- conduct a full fuel cycle analysis of emissions for onroad transport fuels;
- determine whether any fuel has significant potential to compromise vehicles' compliance with gazetted ADR standards for the period to 2006 (inclusive);
- examine the viability and functionality of the fuels;
- examine significant health related issues from the use of the fuels; and
- examine other significant environmental issues resulting from the use of the fuels including ecologically sustainable development.

Stage 2 will include the following.

Full Fuel Cycle Analysis

1. Collect data on emissions for the specified fuels from production to combustion in onroad vehicles taking into account Australian conditions for fuel production.

2. Objectively assess the emission characteristics of the specified fuels.

3. Determine whether any fuel has significant potential to compromise vehicles' compliance with gazetted ADR standards for the period up to and including 2006.

Low sulfur diesel (ie 500ppm or less) will be used as an emissions benchmark against which other fuels are compared. Section 5 *Full Fuel Lifecycle Analysis* describes in detail the requirements for the analysis.

Viability and functionality

4. Taking into account existing and emerging technologies* examine:

- handling, transport, storage and safety issues focussing on significant risks associated with the use of the fuel;
- engine manufacturers' acceptance of the fuel for warranty purposes;
- the functionality of the fuel under the full range of Australian conditions (eg consider: the significance of problems associated with the cloud point temperature or the fuel's affinity for water; the effect of fuels on engine seals; and engine and other components' longevity);
- fuel energy density and vehicle operational range;
- refuelling requirements;
- issues affecting the availability of fuel and;
- other issues (except for price/excise/grant/cost related issues) that may affect the viability or functionality of the fuel.

* Refer to *Review of Fuel Quality Requirements for Australian Transport* Chapter 2 (commissioned by Environment Australia) for a definition of existing and emerging technologies applying to diesel engines. A copy can be found at: http://environment.gov.au/epg/fuel/transport.html

Health Issues

5. Examine key health issues resulting from the production, transport and use of the fuel. Among other issues, special attention should be paid to: occupational health and safety issues; particulates; vapour pressure (the main concern being evaporative emissions) and the following air toxins:

   - benzene;
   - 1,3 butadiene;
   - formaldehyde;
   - acetaldehyde;
   - polycyclic aromatic hydrocarbons (PAH);
   - toluene; and
   - xylene

Environmental Impact and Benefits

6. Examine significant environmental impacts not included under the fuel cycle analysis resulting from the production, transportation or use of each fuel. This section of the study will include, but not be limited to an examination of:

   - the use of technologies or additives associated with the fuel;
   - whether any of the principles of ecologically sustainable development are at risk of being compromised through the production, distribution and use of the fuel (refer to section 3A of the Environment Protection and Biodiversity Conservation Act 1999 for the definition of ecologically sustainable development - copy attached)
   - the sustainability of fuel production and use (eg impact on land used for biofuels); and
   - spillage issues including groundwater contamination.

A1.5 Fuel Types

The fuels to be examined and their specifications are:

- Low sulfur diesel (LSD) meeting either Euro II fuel specifications or the fuel specifications for LSD proposed by the Commonwealth for implementation in 2002. Refer to http://www.environment.gov.au/epg/fuel/pdfs/fuel0900.pdf *
- Ultra-low sulfur diesel (ULSD) meeting either Euro IV specifications or the fuel specifications for ULSD proposed by the Commonwealth for implementation in 2006. Refer to http://www.environment.gov.au/epg/fuel/pdfs/fuel0900.pdf
- Compressed natural gas (CNG) as defined in Australian standards.
- Liquefied petroleum gas (LPG) autogas grade from any source meeting the voluntary ALPGA specification or European standard EN589.
- LPG - HD5 grade from any source. Refer to Californian Air Resources Board specifications http://www.arb.ca.gov/regact/lpgspecs/lpgspecs.htm
- Ethanol - hydrated - from renewable sources (wheat, sugar cane, molasses and wood) and one source of ethanol from a non-renewable resource.
- Ethanol - anhydrous - from renewable sources (wheat, sugar cane, molasses and wood) and one source of ethanol from a non-renewable resource.
- Diesohol from APACE Research. The fuel is known as E15 and consists of 84.5% diesel, 15% hydrated ethanol (ethyl alcohol containing approximately 5% water) and 0.5% emulsifier.*
- Liquefied natural gas (LNG) as defined by European or US standards.
- Canola oil (ie not biodiesel).
- Biodiesel. Examine biodiesel meeting either of two major fuel specifications - European DIN V 51606 standard or the US standard ASTM PS121. Consider biodiesel produced from a range of feedstocks including tallow, recycled waste cooking oil, canola, rapeseed and soybean.*
- Synthetic diesel derived from natural gas using the Fischer Tropsch method.
- Hydrogen derived from a range of production methods and feedstock sources likely to be used in Australia. It is acknowledged that hydrogen is an energy carrier rather than a fuel but for the purposes of this study it will be described as a fuel. The study would only examine the upstream emissions.
- Premium Unleaded petrol (PULP) (95 RON) meeting either the Euro II specification for unleaded petrol or the fuel specifications for PULP proposed by the Commonwealth for implementation in 2002. Assume that this fuel does not contain ethanol and that it is used in light vehicles as defined in ADR 79/00 and 79/01. Refer to http://www.environment.gov.au/epg/fuel/pdfs/fuel0900.pdf
- PULP (95 RON) as specified above but with 10% ethanol. Assume that it is used in light vehicles.
- A-55. The fuel consists of 30-55% water, 45% naphtha, and small amounts of a blending agent. Developed in the USA in 1994 by Rudolph Gunnerman *of Clean Fuels Technology Inc* and is being promoted in Australia by *A-55 Australia*. **(Note: this fuel may be deleted from the list at any time up to 30 April 2001 and so should be considered last.)**

* Asterisked fuels will be examined first to enable a decision to be made about their possible inclusion under the Diesel and Alternative Fuels Grants Scheme. LSD will also be examined in the first group as it will be the emissions benchmark.

Where testing is undertaken by the consultant, the following information must be provided:

- for biodiesel, a certificate of analysis for the batch that identifies its density and cetane number or index, sulfur content and distillation point (degrees Celsius T90 and T95);
- for diesel or diesohol, a certificate of analysis for the batch that identifies its density and cetane number or index, sulfur content, polyaromatics and distillation point (degrees Celsius T90 and T95); and
- for gaseous fuels, a certificate indicating that they meet specifications as outlined above.

The successful tenderer will be responsible for managing and meeting all costs associated with sourcing the fuels required for any testing deemed to be necessary. A large-scale emission-testing program is not expected to be undertaken as a part of this project.

A1.6 Full Fuel Cycle Analysis

Upstream

The consultant is required to collect Australian data associated with all upstream activities of fuel cycle emissions for the fuels listed above. The derivation of the data should be clearly explained in a highly detailed manner utilising fuel cycle process trees and all assumptions must be fully explained. The data and data sources should be documented in a report that incorporates a comprehensive analysis of uncertainties regarding the data and how these uncertainties were resolved in order to determine values for the variables. All data collected will be made available in appendices and in electronic format.

To ensure the relevance of the upstream study to Australian conditions, it is crucial that extensive consultation be conducted with key Australian industry stakeholders involved in upstream activities associated with the fuel.

Where fuels have a range of production methodologies, the more common approaches used for fuels produced in, or imported into, Australia should be modelled. For example, biodiesel can be produced from an oilseed, recycled waste cooking oil and tallow. The greenhouse and air quality emissions from these approaches should be examined. A similar approach should be adopted for ethanol (which can be produced from sugar cane, molasses, wood, wheat and coal), LPG, hydrogen, LNG and other fuels which have more than one main upstream source.

For each fuel type with more than one upstream source, an indication of the likely Australian market share from each source within that fuel type will be indicated. The emissions from each upstream source will be modelled and combined with downstream emissions.

Downstream - Current and Future

A range of reputable and recent Australian and overseas studies will be considered in order to determine the relative downstream emissions of each fuel. Where possible, reports from sources using identical or similar testing methods should be used to enable the emissions to be compared. Allowances should be made for improvements in technology if reference is made to studies more than three years old.

It is important the Consultant collect certified emissions data produced by independent testing/measurement organisations using certified equipment/facilities following internationally recognised test methods/cycles. Collection of such data will have priority over collection of emissions data produced and/or funded by fuel producers, fuel users and industry associations.

Following consultation with key industry stakeholders, the consultant will comment about likely improvements in emissions from vehicles using each fuel in the near future as a result of improved fuels or technologies. This information will be included in a separate series of downstream emissions calculations. The consultant will also use this information as the basis for determining whether any fuel has significant potential to compromise vehicles' compliance with gazetted ADR standards for the period up to and including 2006 for both light and heavy duty vehicles.

Emissions

The nominated emissions to be considered in the analysis are:

- key transport greenhouse gases ie carbon dioxide, nitrous oxide, methane;
- oxides of nitrogen;
- oxides of sulfur (including a calculation of oxides of sulfur emitted following combustion);
- particulate matter less than 10 microns (also considering matter less than 2.5 microns and less than 1 micron if available);
- carbon monoxide;
- total hydrocarbons;

Emission measurements will be provided in:

- grams of emission type per megajoule.
- grams per tonne-kilometre for freight vehicles; and
- grams per passenger-kilometres for passenger transport.

All emissions affecting air quality will be weighted and combined into a single measure of air quality. The quantity of upstream emissions affecting air quality not produced in metropolitan areas will be included and will also be separately noted. This task involves the development of a weighting scheme for air quality. The consultant is required to develop and submit the weighting methodology to the Steering Committee for approval as soon as possible after the commencement of the project. No preliminary reports indicating weighted air quality results are to be discussed outside of the project team prior to the approval of the weighting methodology.

Greenhouse gas emissions will be weighted using IPCC 100 year global warming potentials.

New Models for Calculating Downstream Emissions

The AGO wishes to explore alternative approaches for approximating downstream emissions involving fuel and technology combinations (eg comparing the emissions from a CNG Euro II standard engine with a diesel Euro III standard engine). It is not considered that a large scale tailpipe emissions testing program is warranted. In addition, it is extremely difficult to arrange statistically valid samples for a broad range of fuel and technology combinations. Consequently such an approach is not being considered.

The consultant is required to identify and describe approaches that would enable the downstream emissions from fuel and technology combinations to be approximated without conducting a large scale tailpipe emissions testing program.

Information Required for a Downstream Model Using ADR Specified Emissions

The consultant is also required to undertake additional research outlined later in this section associated with a method for calculating emissions under which downstream emissions affecting air quality are deemed to be equal to the maximum emissions allowable under the ADRs to which vehicles have been certified.

It may be possible to calculate downstream greenhouse gas emissions from some ADR emission standards because they refer to key greenhouse gas emissions. For example:

- methane is referred to in ADRs 80/00 and 80/01 for gas fuelled heavy vehicles under the Euro III and IV European Transient Cycle (ETC) test emission limits;
- nitrous oxide is present in NO_x referred to under ADR emissions standards;

- the light duty vehicle emission test in ADR 37/01 provides the basis for calculating CO2 emissions provided that the carbon content of the fuel is known. (Carbon dioxide emissions for heavy vehicles should also be calculated.)

To assist with the exploration of this approach, the consultant is required to:

1. determine whether each fuel is likely to yield Euro standard "X" emissions when used in a Euro "X" designated engine for both light and heavy vehicle ADR emissions standards (without additional after treatment adopted for the specific fuel in question);
2. comment on the feasibility of reasonably approximating N_2O emissions from NO_x levels referred to in the Euro standards for both heavy and light vehicles across the specified fuel types. (If feasible, the calculations will be made and the margin of error indicated.);
3. determine the value of the CO_2 emission factor for each fuel (in grams per megajoule) which would be used to determine CO_2 emissions from the fuel (ie not the CO_2 *equivalent* emissions). (In order of preference the sources are to be used are: existing Australian Greenhouse Office data, IPCC data or primary data obtained from laboratory analysis of the carbon content of the fuel.); and
4. determine an average "grams of emission per megajoule" equivalent for both greenhouse emissions and air quality emissions for both light and heavy vehicle Euro Standards I to IV. (The light vehicle Euro Standards are measured in grams per kilometre and each of the light vehicle Euro standards has three vehicle categories.)

A1.7 References

The following references, among others, should be considered:

- *A Full Fuel Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas* (US Department of Energy report dated December 1999) www.transportation.anl.gov/ttrdc/publications/pdfs/esd-40.pdf
- *Effects of Fuel Ethanol Use on Fuel Cycle and Energy and Greenhouse Gas Emissions* (US Department of Energy report, January 1999) - an electronic version is available from the AGO
- *Health and Environmental Assessment of the use of Ethanol as a Fuel Oxygenate* (US Department of Energy report, December 1999) http://www-erd.llnl.gov/ethanol
- *Air Quality Impacts of the Use of Ethanol in California Reformulated Gasoline* (California Environment Protection Agency, December 1999) http://www.arb.ca.gov/cbg/ethanol/ethfate/airq/mainf.pdf
- US EPA and National Biodiesel Board reports on biodiesel. Tier I (emissions) report completed March 1998 and Tier II (health) report produced mid 2000 (approximately May - June).
- reports from the *Diesel National Environment Protection Measure* which can be obtained through Environment Australia website http://www.environment.gov.au/
- *Alternatives to Traditional Transportation Fuels 1994 Greenhouse Gas Emissions* by the US Dept of Energy www.eia.doe.gov/cneaf/pubs_html/attf94_v2/exec.html#head4
- test results on diesohol will be available from APACE Research
- US EPA Tier I and Tier II and US DOE test results for other fuels should also be considered.

ATTACHMENT

Ecologically Sustainable Development

As indicated in these Terms of Reference, the consultant will be required to broadly consider the principles of ecologically sustainable development which are outlined section 3A of the Environment Protection and Biodiversity Conservation Act 1999.

Section 3A of the Environment Protection and Biodiversity Conservation Act 1999

3A Principles of ecologically sustainable development

The following principles are principles of ecologically sustainable development:

(a) decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations;

(b) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;

(c) the principle of inter-generational equity—that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;

(d) the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making;

(e) improved valuation, pricing and incentive mechanisms should be promoted.

Appendix 2. The GREET model and the SIMAPRO model

The GREET model, available at http://www.transportation.anl.gov/ttrdc/greet/ , or http://greet.anl.gov is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model developed by Michael Q. Wang at Argonne National Laboratories in the United States.

GREET was developed as a multidimensional spreadsheet model in Microsoft Excel. The first version of GREET was released in 1996. Since then, Argonne has continued to update and expand the model.

For a given engine and fuel system, GREET separately calculates the following:

- Consumption of total energy (energy in non-renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal), and petroleum
- Emissions of CO_2-equivalent greenhouse gases - primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
- Emissions of five criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micron (PM10), and sulfur oxides (SOx).

GREET includes more than 30 fuel-cycle pathways. It also includes these vehicle technologies

- Conventional spark- ignition engines
- Direct-injection, spark- ignition engines
- Direct injection, compression ignition engines
- Grid-connected hybrid electric vehicles
- Grid-independent hybrid electric vehicles
- Battery-powered electric vehicles
- Fuel-cell vehicles.

To address technology improvements over time, GREET separates fuels and vehicle technologies into near- and long-term options. The latter are assumed to have improved energy and emission performance compared with the former.

The version of GREET that is available is GREET 1.5, though a test version of GREET 1.6 was made available on 14 August 2001. In addition there is a heavy vehicle module, known as the GREET 3 series that is designed to estimate fuel-cycle energy use and emissions of heavy-duty trucks and buses. This is not available outside of Argonne.

The GREET model combines spreadsheet calculations with US specific life-cycle data for light vehicles. SIMAPRO was considered to be more suitable for use in the Australian context for the following reasons.

The GREET model is based on US data. Thus, for example, ethanol assumes production from corn, woody biomass and herbaceous biomass not grain and molasses, Biodiesel assumes production from soybean not canola, tallow, waste oil etc. Electricity production includes nuclear power in its assumptions.

The GREET 1 series is designed to estimate fuel-cycle energy use and emissions for passenger cars and utility vehicles only. The GREET 3 series (which is not yet available) is designed to estimate fuel-cycle energy use and emissions of heavy-duty trucks and buses.

In a number of cases Australian practice is sufficiently different (e.g. widespread pipeline transport of CNG) that substantial modification would have been needed to make GREET relevant to Australian conditions.

SIMAPRO has an extensive Australian database of manufacturing energy input and emissions available for it.

SIMAPRO is able to provide embodied energies and exbodied emissions from a greater range of pollutants than GREET presently does.

In the preparation of this report there has been widespread use of the technical information that underlies the GREET model. The work of Wang (1999), Wang and Huang (1999) and Wang et al. (1997, 1999, 2000) was used to estimate values for those input variables or parameters that were not quantified in the Australian database, and to provide a check on our results.

A great advantage of SIMAPRO is its ability to produce process trees. Figure A2.1 indicates a process tree obtained from the SimaPro software used to undertake the quantitative life-cycle components of the study. These trees indicate, in an abbreviated form, the upstream components used to evaluate each component of the life-cycle.

To interpret the process tree, one starts at the top. Thus, in Figure A2.1, the values in the box refer to the mass (in kg) of CO2-equ. To travel 1 km using LSD, there is a total of 0.926 kg emitted, as shown in the top box and summarised in Table 1.21 of Chapter 1 (Part 2). The fuel energy expended in travelling this 1 km is 10.8 MJ, as depicted in the second box down. The box below, which we shall call the fuel box, indicates that prior to combustion, the fuel tank contained 0.251 kg of fuel and that the upstream emissions of CO2-equ to manufacture this fuel amounted to 0.207 kg CO2-eq., as shown in Table 1.22 of Chapter 1 (part 2).

Two separate process trees are depicted below the fuel box. The left hand side shows the upstream emissions involved in refining crude oil to produce diesel fuel. The process tree on the right shows the upstream emissions involved in hydro-processing to reduce the sulfur content of the fuel. For clarity, not all upstream processes are shown. If various upstream processes are not included, this is apparent by examining the bottom of the box. Small lines (tick marks) indicate that the full analysis consists of upstream processes feeding in to that box.

The computer software produces output in colour. On the right of each box there is a green line, with a red lower portion. The red lower proportion represents the proportion of the total value (0.926) accumulated up to that point. This can be seen by carefully examining the fuel box. The bottom 20% of the bar on the right of the box is darker than the remainder. The two top boxes have bars that are completely red.

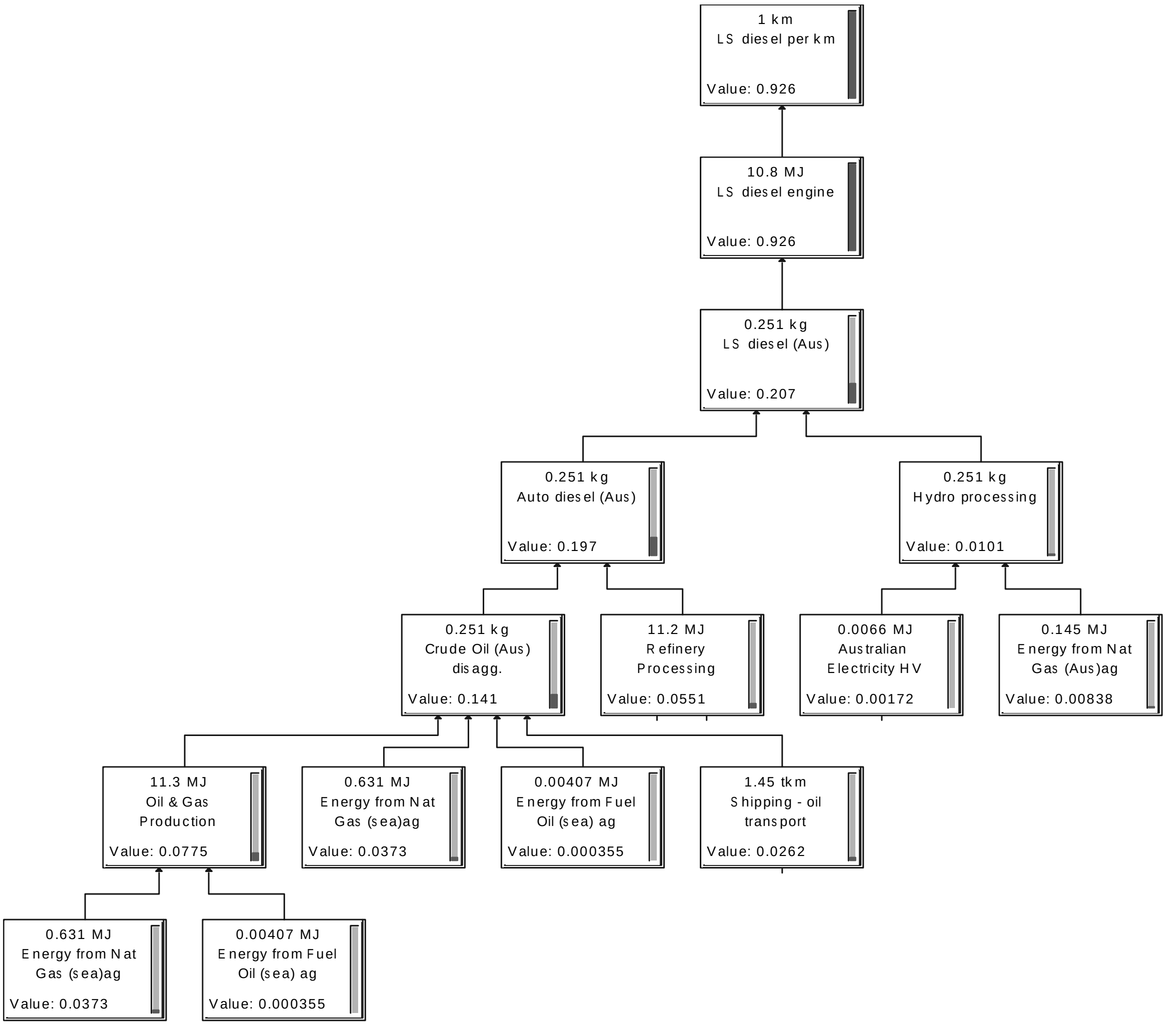

Figure A2.1
Exbodied greenhouse gases emissions (kg CO_2-eq) from LSD production, processing and use in vehicle. The value is given in the bottom of each box.

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Appendix 3 Uncertainty Analysis

An important consideration in the examination of alternative fuels is that most emissions data is highly variable. Thus it is difficult to know, when comparing different fuels, whether observed variations reflect a genuine difference between the two fuels or merely reflect the statistical variability. Beer et al. (2000) stress that this indicates that, wherever possible, comparison between alternative fuels needs to be done on a statistical basis.

Comparing fuels on a statistical basis means that one needs an estimate of both the mean value and the standard deviation of the variable that is being studied. Beer et al. (2000) characterised the uncertainty as the standard deviation divided by the mean value (expressed as a percent). Both these quantities were evaluated on the basis of the measured tailpipe emissions from trucks and buses that Beer et al. (2000) obtained from the US Department of Energy web site.

Tables A3.1 and A3.2 give the percentage uncertainties from Beer et al. (2000). These uncertainties have been reproduced in each chapter of this report, and the uncertainty for the emissions in g/MJ has also been estimated as the average of the two values.

The numerical values of the uncertainties given in Part 2 of the report have been used to determine the uncertainty limits displayed on the bar charts of Part 1 of the report. They also form the basis for the determination of whether fuels are significantly better or worse than the reference fuel, as given in Table 1 of the executive summary.

A3.1 Buses

The uncertainties are tabulated for buses in Table A3.1.

Table A3.1
Uncertainties (in percent) of tailpipe emissions for buses

Fuel	*N*	*f*	CO	THC	NOx	PM	CO_2
BD	11	2.7	37	15	38	61	7
BD20	8	2.3	55		36	50	6
CNG	90	4.6	22	136	72	108	12
Diesel	73	4.4	78	17	27	50	11
E93	6	1.9	66		26	45	7
E95	47	4.0	46	73	35	46	13
LNG	22	3.4	106	11	28	46	8

The smallest uncertainties are associated with CO_2 emissions. This is to be expected because CO_2 can be estimated from fuel usage, which is determined by the engine technology and the mechanical energy required to accomplish the test cycle. The other emissions are trace, unwanted side products. In general, the lowest uncertainties are associated with THC and NOx emissions, and the highest with CO and particulate emissions. The large uncertainties associated with air pollutant emissions from CNG are particularly noticeable. As this fuel is in widespread use in Australian bus fleets, it appears that further analysis is required to reduce the uncertainties associated with CNG emissions and hence enable a more accurate assessment of their air pollution potential.

A3.2 Heavy vehicles other than buses

The uncertainties are tabulated for heavy vehicles other than buses in Table A3.2.

Table A3.2
Uncertainties (in percent) of tailpipe emissions for heavy vehicles other than buses

Fuel	*N*	*f*	CO	THC	NOx	PM	CO_2
BD	8	2.3	106	71	23	81	15
BD35	12	2.8	49		35	54	39
CNG	7	2.2	11		29	17	2
Diesel	33	3.8	144	50	30	39	9
E95	6	1.9	36	17	8	45	15
LNG	18	3.2	18		47	48	6
LSD	8	2.3	80		9	84	11

Appendix 4 Stakeholder Consultation

Stakeholder consultation was an essential part of the process of undertaking this comparison of transport fuels. In addition to the consultation with the AGO and EA, this took the following forms:

Presentations given by members of the project team on the methodology to be adopted. This meeting took place at the National Gallery of Australia on 7 March 2001, and was organised by the AGO.

Discussions or meetings with individual stakeholders. These included:

Attendance by Dr Tom Beer at the Australian Trucking Association meeting on the Diesel NEPM on 8 March 2001

Telephone conversation with Mr Thomas Carroll of Lubrizol on 14 March 2001 and subsequent receipt of information concerning PuriNOx.

Telephone conversation between Jack Lapszewicz and Bob Gordon of the Australian Biofuels Association on 21 March 2001.

Telephone conversation between Mr John Eisner on 21 March 2001 that was followed up with a face-to-face meeting (in Camberwell) on 4 April 2001 between Tom Beer, Tim Grant, John Eisner (Biofuel manufacturer) and Bob Coutts.

Face-to-face meeting (in Aspendale) on 29 March 2001 between Tom Beer, Lou Daniel (Biofuel manufacturer) and Geoff Peel (Croydon bus lines).

Extensive telephone conversation between Tom Beer and Dr Russell Reeves (APACE, Diesohol manufacturer) on 3 April 2001 and subsequent receipt of information on diesohol emissions. This was followed by a face-to-face meeting at the Tullamarine Qantas Club on 16 April 2001 between Tom Beer, Tim Grant, Russell Reeves and Ernie Lom.

Extensive telephone conversation between Tom Beer and Phillip Calais (Murdoch University, biodiesel researcher) on 5 April 2001 and subsequent receipt of information on biodiesel.

Visit by Tim Grant to Libby Anthony (General Manager of the Alternative Technology Association) on 6 April 2001.

Extensive telephone conversation between Tom Beer and Adrian Lake (Australian Biodiesel Association) on 9 April 2001 and subsequent receipt of e-mails containing information on biodiesel emissions.

Face-to-face meeting (at RMIT) on 11 April 2001 between Tom Beer, Tim Grant and Mark Sanders (BP) concerning low sulfur diesel.

On 7 June 2001 a stakeholders forum was held at CSIRO Atmospheric Research at Aspendale, Vic. The presentations at the forum, along with a list of attendees (reproduced below) are posted on the web at:

http://www.dar.csiro.au/res/ggss/Life%20Cycle%20Analysis%20for%20Alternative%20Fuels.htm

As a result of the forum it was decided to have further consultation in the form of focussed roundtable meetings that were held at RMIT in Melbourne. On 25 June meetings were held with the biofuels stakeholders in the morning, and with the gaseous fuels stakeholders in the afternoon. On the morning of 26 June a meeting was held with the remaining stakeholders.

The forum and roundtables generated considerable further information that was incorporated into the study.

Attendees at
Comparison of Transport Fuel Stakeholders Forum
7 June 2001,
CSIRO Atmospheric Research

Tom Beer CSIRO Atmospheric Research	Ian Galbally CSIRO Atmospheric Research
Roger Coogan Australian Greenhouse Office	Jane Sellenger CSIRO Atmospheric Research
Peter Anyon PARSONS	Harry Watson University of Melbourne
Peter Nelson CSIRO Energy Technology	Jim Edwards CSIRO Energy Technology
Tim Grant R.M.I.T.	Chris Mitchell CSIRO Atmospheric Research
Janine Cullen Australian Greenhouse Office	Darren Sanford Biodiesel Power
Vicki Ratliffe Environment Australia	Kate Gainer Environment Australia
Paul Martin Biodiesel Association	Darryl Butcher Amadeus Petroleum NL
Rod Jones Wesfarmers Kleenheat	Horst Koerner Scania Australia Pty Ltd
Mark Morarty Toyota Motor Corp. Australia (TMCA)	Geoff Peel Croydon Bus Service Pty Ltd
Phil Stirling FCAI (Holden)	Tracey Winters Sasol Chevron
Robin Davies Origin Energy	Rod James Wesfarmers Kleenheat
Stewart McDonald Ford Motor Company of Australia	Tony Moleta Dept of Transport and Regional Services
Sanjay Chatterjee	Jim Le Cornu Shell Australia
Ian Bridgland Shell Australia	
Michael Apps Australian Trucking Association	Warring Neilsen Elgas
Sheryll Fisher Urban Energy Pty Ltd	Ewan MacPherson Australian Institute of Petroleum
Henry O’Clery Greenfleet	Brett Jarman ANGVC
Sean Blythe ANGVC	Phillip Westlake Australian LP Gas Association Ltd
Kerrie Hepworth Australian Taxation Office (ATO)	Yuanfang Shen Australian Taxation Office (ATO)
John Eisner Equinox Management Pty Ltd	Max Blamey Australian Taxation Office (ATO)
Peter Nimmo Queensland EPA	Kerry Lack NSW EPA
Stuart Ballingal RACV	Kevin Black NGV Solutions Pty Ltd

David Graham Daimler Chrysler	John Bortolussi Cummins
Terry Green Cummins	Paul Harrison Advanced Fuels Technology Pty Ltd
Damien Tangey Dipetane Australia	Kym Godson Clean Fuels Technology Inc.
Hien Ly Agility Management	Elliott Curley Agriculture, Fisheries and Forestry - Australia
Adrian Lake Biodiesel Association of Australia Inc	Steve Isles RTA
David Kernich Transport SA	Glenn Cooper IMPCO Technologies
Peter Wrigley Vicol Petroleum Pty Ltd	Terry Shulze Biodiesel
Kathryn Hannan RACV	Mark Dess Dept Natural Resources & Environment
Rowena Main Department of Infracture, ODPT	Deb Wilkinson Senator Allisons Office
Guy Macklan Detroit Diesel	Ros Pyett Department of Transport and Regional Services
Mark Sanders BP Australia	Frank Russell BP Australia
Chris Russell Elgas	Fred Goede Sasol Chevron
David Liversidge Australian Greenhouse Office	Ernie Lom Apace Research Ltd
Scott McDowall Queensland EPA	Matthew Minchin EPA Victoria
Luke Hardy State Transit Authority	Tony Sharp State Transit Authority

In addition, input was also sought from the following organizations that were unable to attend the stakeholder forum:

National Environment Consultative Forum
Australian Trucking Association
Bus Industry Confederation
Federal Chamber Automotive Industries
Australian Institute of Petroleum
Australian Automobile Association

The following Government departments were consulted:

- Agriculture Fisheries and Forestries Australia
- Australian Bureau of Agricultural Research Economics
- Australian Taxation Office
- Environment Australia
- Department of Health and Aged Care
- Department of Industry Science and Resources
- Department of Transport and Regional Services
- Department of Treasury

Motor Vehicle Environment Committee members

National Environment Protection Committee
National Road Transport Commission

Appendix 5 Emissions of pollutants per tonne-kilometre and per passenger-kilometre

Emissions per tonne-kilometre

Table A5.1

Urban and rural life cycle emissions

Full Lifecycle	**Units**	**LS diesel (Aus)**	**ULS diesel (Aus)**	**ULS diesel (100% hydroprocessing)**	**Fischer-Tropsch diesel**
Greenhouse	kg CO2	0.1030	0.1055	0.1032	0.1105
NMHC total	g HC	0.168	0.152	0.150	0.105
NMHC urban	g HC	0.133	0.115	0.114	0.058
NOx total	g NOx	1.253	1.102	1.086	1.147
NOx urban	g NOx	1.185	1.033	1.017	0.991
CO total	g CO	0.303	0.379	0.376	0.260
CO urban	g CO	0.291	0.367	0.363	0.224
PM10 total	mg PM10	48.8	38.3	38.2	29.6
PM10 urban	mg PM10	47.1	36.6	36.5	27.5
Energy Embodied	MJ LHV	1.41	1.46	1.44	1.90

Full Lifecycle	**Units**	**LS diesel (Aus)**	**Biodiesel (canola)**	**Biodiesel (soybean)**	**Biodiesel (rape)**	**Biodiesel (tallow-expanded sys. boundary)**	**Biodiesel (tallow-eco.allocat.)**	**Biodiesel (waste oil)**	**Biodiesel (waste oil 10% original oil value)**
Greenhouse	kg CO2	0.1030	0.0480	0.0362	0.0491	0.0465	0.0552	0.0079	0.0082
NMHC total	g HC	0.168	0.160	0.190	0.161	0.157	0.067	0.066	0.068
NMHC urban	g HC	0.133	0.148	0.180	0.148	0.145	0.065	0.065	0.066
NOx total	g NOx	1.253	1.436	1.423	1.456	1.431	1.312	1.310	1.316
NOx urban	g NOx	1.185	1.350	1.369	1.352	1.349	1.311	1.309	1.315
CO total	g CO	0.303	0.189	0.243	0.190	0.188	0.157	0.156	0.161
CO urban	g CO	0.291	0.172	0.232	0.172	0.171	0.156	0.156	0.161
PM10 total	mg PM10	48.8	33.1	32.6	33.8	33.0	30.6	30.5	30.5
PM10 urban	mg PM10	47.1	31.5	31.5	31.5	31.4	30.6	30.5	30.5
Energy Embodied	MJ LHV	1.41	0.46	0.50	0.47	0.45	0.19	0.18	0.18

Full Lifecycle	**Units**	**LS diesel (Aus)**	**CNG (Electric compression)**	**CNG (NG compression)**	**LNG (from existing transmission line)**	**LNG (Shipped from north west shelf)**	**LNG (perth)**	**LPG (Autogas)**	**LPG (HD5)**
Greenhouse	kg CO2	0.1030	0.0852	0.0874	0.0833	0.0841	0.0873	0.0930	0.0998
NMHC total	g HC	0.168	0.034	0.037	0.035	0.035	0.038	0.123	0.126
NMHC urban	g HC	0.133	0.003	0.004	0.003	0.002	0.004	0.091	0.092
NOx total	g NOx	1.253	0.179	0.195	0.258	0.260	0.305	0.170	0.503
NOx urban	g NOx	1.185	0.162	0.176	0.240	0.221	0.225	0.108	0.439
CO total	g CO	0.303	0.014	0.018	0.015	0.016	0.017	0.046	0.043
CO urban	g CO	0.291	0.006	0.010	0.007	0.004	0.005	0.035	0.032
PM10 total	mg PM10	48.8	8.4	8.5	8.2	8.3	10.4	10.8	7.9
PM10 urban	mg PM10	47.1	8.2	8.3	8.0	7.8	8.0	9.2	6.3
Energy Embodied	MJ LHV	1.41	1.39	1.46	1.39	1.40	1.44	1.29	1.33

Table A5.1 (cont).

Urban and rural life cycle emissions

Full Lifecycle	Units	LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	kg CO2	0.1030	0.0960	0.0483	0.0838	0.0425	0.0769	0.0383	0.0092	0.1636	0.1852
NMHC total	g HC	0.168	0.159	0.096	0.095	0.086	0.162	1.116	0.720	0.743	0.179
NMHC urban	g HC	0.133	0.127	0.092	0.093	0.084	0.092	1.046	0.719	0.656	0.140
NOx total	g NOx	1.253	1.158	1.116	1.115	1.083	1.311	1.249	1.032	1.351	0.172
NOx urban	g NOx	1.185	1.094	1.080	1.109	1.080	1.118	1.057	1.030	1.302	0.151
CO total	g CO	0.303	0.402	1.010	1.194	0.363	1.258	4.303	2.543	0.427	1.105
CO urban	g CO	0.291	0.390	1.003	1.192	0.362	0.366	3.412	2.543	0.407	1.096
PM10 total	mg PM10	48.8	38.1	32.8	32.1	56.1	60.1	83.0	62.2	37.7	40.5
PM10 urban	mg PM10	47.1	36.5	32.1	31.9	56.0	56.9	79.7	62.1	37.0	40.2
Energy Embodied	MJ LHV	1.41	1.33	0.49	0.56	0.50	0.79	0.92	3.14	4.03	1.69

Table A5.2

Urban and rural upstream emissions

Precombustion	Units	LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	kg CO2	0.0229	0.026	0.023	0.036
NMHC total	g HC	0.068	0.070	0.069	0.047
NMHC urban	g HC	0.033	0.034	0.033	0.001
NOx total	g NOx	0.120	0.138	0.121	0.163
NOx urban	g NOx	0.052	0.068	0.053	0.006
CO total	g CO	0.027	0.031	0.027	0.037
CO urban	g CO	0.015	0.018	0.015	0.001
PM10 total	mg PM10	6.503	6.704	6.581	2.260
PM10 urban	mg PM10	4.799	4.966	4.855	0.082
Energy Embodied	MJ LHV	1.414	1.459	1.436	1.904

Precombustion	Units	LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	kg CO2	0.0229	0.048	0.036	0.049	0.047	0.055	0.008	0.008
NMHC total	g HC	0.068	0.156	0.186	0.157	0.153	0.062	0.062	0.063
NMHC urban	g HC	0.033	0.144	0.176	0.144	0.140	0.061	0.061	0.062
NOx total	g NOx	0.120	0.155	0.141	0.175	0.150	0.031	0.029	0.034
NOx urban	g NOx	0.052	0.069	0.088	0.071	0.068	0.030	0.028	0.034
CO total	g CO	0.027	0.038	0.092	0.039	0.037	0.006	0.005	0.010
CO urban	g CO	0.015	0.021	0.082	0.021	0.020	0.005	0.005	0.010
PM10 total	mg PM10	6.503	2.784	2.216	3.463	2.695	0.242	0.208	0.208
PM10 urban	mg PM10	4.799	1.125	1.180	1.158	1.088	0.228	0.196	0.196
Energy Embodied	MJ LHV	1.414	0.461	0.501	0.473	0.451	0.188	0.179	0.184

Table A5.2 (cont).
Urban and rural upstream emissions

Precombustion	Units	LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	kg CO2	0.0229	0.015	0.017	0.014	0.015	0.018	0.021	0.021
NMHC total	g HC	0.068	0.032	0.035	0.033	0.033	0.036	0.122	0.124
NMHC urban	g HC	0.033	0.001	0.001	0.001	0.000	0.002	0.090	0.090
NOx total	g NOx	0.120	0.034	0.049	0.037	0.039	0.084	0.111	0.110
NOx urban	g NOx	0.052	0.016	0.030	0.019	0.000	0.004	0.049	0.046
CO total	g CO	0.027	0.009	0.014	0.011	0.012	0.013	0.025	0.025
CO urban	g CO	0.015	0.002	0.006	0.004	0.000	0.001	0.014	0.013
PM10 total	mg PM10	6.503	0.562	0.673	0.506	0.534	2.706	6.459	6.136
PM10 urban	mg PM10	4.799	0.329	0.420	0.263	0.008	0.263	4.888	4.532
Energy Embodied	MJ LHV	1.414	1.391	1.462	1.392	1.403	1.436	1.292	1.325

Precombustion	Units	LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	kg CO2	0.0229	0.026	0.048	0.084	0.043	0.077	0.038	0.009	0.115	0.100
NMHC total	g HC	0.068	0.064	0.015	0.013	0.004	0.080	1.034	0.638	0.661	0.040
NMHC urban	g HC	0.033	0.032	0.010	0.011	0.003	0.011	0.964	0.637	0.575	0.001
NOx total	g NOx	0.120	0.124	0.148	0.147	0.116	0.343	0.282	0.065	0.383	0.063
NOx urban	g NOx	0.052	0.059	0.112	0.141	0.112	0.150	0.090	0.062	0.334	0.041
CO total	g CO	0.027	0.090	0.660	0.844	0.013	0.909	3.953	2.194	0.077	0.015
CO urban	g CO	0.015	0.078	0.654	0.842	0.012	0.016	3.062	2.194	0.057	0.005
PM10 total	mg PM10	6.503	5.957	1.058	0.340	24.387	28.395	51.223	30.511	5.924	0.811
PM10 urban	mg PM10	4.799	4.354	0.357	0.214	24.275	25.166	47.994	30.400	5.267	0.521
Energy Embodied	MJ LHV	1.414	1.325	0.491	0.561	0.504	0.790	0.920	3.140	4.031	1.693

Table A5.3
Urban and rural tailpipe emissions

Combustion	Units	LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	kg CO2	0.080	0.080	0.080	0.075
NMHC total	g HC	0.100	0.081	0.081	0.057
NMHC urban	g HC	0.100	0.081	0.081	0.057
NOx total	g NOx	1.132	0.964	0.964	0.985
NOx urban	g NOx	1.132	0.964	0.964	0.985
CO total	g CO	0.276	0.349	0.349	0.223
CO urban	g CO	0.276	0.349	0.349	0.223
PM10 total	mg PM10	42.31	31.62	31.62	27.38
PM10 urban	mg PM10	42.31	31.62	31.62	27.38
Energy Embodied	MJ LHV	0	0	0	0

Table A5.3 (cont.)

Urban and rural tailpipe emissions

Combustion	Units	LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	kg CO2	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NMHC total	g HC	0.100	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NMHC urban	g HC	0.100	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NOx total	g NOx	1.132	1.281	1.281	1.281	1.281	1.281	1.281	1.281
NOx urban	g NOx	1.132	1.281	1.281	1.281	1.281	1.281	1.281	1.281
CO total	g CO	0.276	0.151	0.151	0.151	0.151	0.151	0.151	0.151
CO urban	g CO	0.276	0.151	0.151	0.151	0.151	0.151	0.151	0.151
PM10 total	mg PM10	42.31	30.34	30.34	30.34	30.34	30.34	30.34	30.34
PM10 urban	mg PM10	42.31	30.34	30.34	30.34	30.34	30.34	30.34	30.34
Energy Embodied	MJ LHV	0	0	0	0	0	0	0	0

Combustion	Units	LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	kg CO2	0.080	0.070	0.070	0.069	0.069	0.069	0.072	0.079
NMHC total	g HC	0.100	0.002	0.002	0.002	0.002	0.002	0.001	0.003
NMHC urban	g HC	0.100	0.002	0.002	0.002	0.002	0.002	0.001	0.003
NOx total	g NOx	1.132	0.146	0.146	0.221	0.221	0.221	0.059	0.393
NOx urban	g NOx	1.132	0.146	0.146	0.221	0.221	0.221	0.059	0.393
CO total	g CO	0.276	0.004	0.004	0.004	0.004	0.004	0.021	0.018
CO urban	g CO	0.276	0.004	0.004	0.004	0.004	0.004	0.021	0.018
PM10 total	mg PM10	42.31	7.85	7.85	7.74	7.74	7.74	4.31	1.74
PM10 urban	mg PM10	42.31	7.85	7.85	7.74	7.74	7.74	4.31	1.74
Energy Embodied	MJ LHV	0	0	0	0	0	0	0	0

Combustion	Units	LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	kg CO2	0.080	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.085
NMHC total	g HC	0.100	0.095	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.139
NMHC urban	g HC	0.100	0.095	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.139
NOx total	g NOx	1.132	1.035	0.968	0.968	0.968	0.968	0.968	0.968	0.968	0.109
NOx urban	g NOx	1.132	1.035	0.968	0.968	0.968	0.968	0.968	0.968	0.968	0.109
CO total	g CO	0.276	0.312	0.350	0.350	0.350	0.350	0.350	0.350	0.350	1.091
CO urban	g CO	0.276	0.312	0.350	0.350	0.350	0.350	0.350	0.350	0.350	1.091
PM10 total	mg PM10	42.31	32.16	31.73	31.73	31.73	31.73	31.73	31.73	31.73	39.67
PM10 urban	mg PM10	42.31	32.16	31.73	31.73	31.73	31.73	31.73	31.73	31.73	39.67
Energy Embodied	MJ LHV	0	0	0	0	0	0	0	0	0	0

Table 2.4

Summary of life cycle emissions from alternative fuels

		LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	Precombustion	0.0229	0.0255	0.0233	0.0359
Greenhouse	Combustion	0.0801	0.0800	0.0800	0.0747
NMHC total	Precombustion	0.0678	0.0705	0.0686	0.0473
NMHC total	Combustion	0.1002	0.0813	0.0813	0.0574
NMHC urban	Precombustion	0.0325	0.0341	0.0330	0.0010
NMHC urban	Combustion	0.1002	0.0813	0.0813	0.0574
NOx total	Precombustion	0.1203	0.1381	0.1214	0.1626
NOx total	Combustion	1.132	0.964	0.964	0.985
NOx urban	Precombustion	0.052	0.068	0.053	0.006
NOx urban	Combustion	1.132	0.964	0.964	0.985
CO total	Precombustion	0.0271	0.0310	0.0274	0.0370
CO total	Combustion	0.2761	0.3485	0.3485	0.2228
CO urban	Precombustion	0.0147	0.0183	0.0149	0.0010
CO urban	Combustion	0.2761	0.3485	0.3485	0.2228
PM10 total	Precombustion	6.50	6.70	6.58	2.26
PM10 total	Combustion	42.31	31.62	31.62	27.38
PM10 urban	Precombustion	4.80	4.97	4.86	0.08
PM10 urban	Combustion	42.31	31.62	31.62	27.38
Energy Embodied	Precombustion	1.41	1.46	1.44	1.90

		LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	Precombustion	0.0229	0.048	0.036	0.049	0.047	0.055	0.008	0.008
Greenhouse	Combustion	0.0801	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NMHC total	Precombustion	0.0678	0.156	0.186	0.157	0.153	0.062	0.062	0.063
NMHC total	Combustion	0.1002	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NMHC urban	Precombustion	0.0325	0.144	0.176	0.144	0.140	0.061	0.061	0.062
NMHC urban	Combustion	0.1002	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NOx total	Precombustion	0.1203	0.155	0.141	0.175	0.150	0.031	0.029	0.034
NOx total	Combustion	1.132	1.281	1.281	1.281	1.281	1.281	1.281	1.281
NOx urban	Precombustion	0.052	0.069	0.088	0.071	0.068	0.030	0.028	0.034
NOx urban	Combustion	1.132	1.281	1.281	1.281	1.281	1.281	1.281	1.281
CO total	Precombustion	0.0271	0.038	0.092	0.039	0.037	0.006	0.005	0.010
CO total	Combustion	0.2761	0.151	0.151	0.151	0.151	0.151	0.151	0.151
CO urban	Precombustion	0.0147	0.021	0.082	0.021	0.020	0.005	0.005	0.010
CO urban	Combustion	0.2761	0.151	0.151	0.151	0.151	0.151	0.151	0.151
PM10 total	Precombustion	6.50	2.784	2.216	3.463	2.695	0.242	0.208	0.208
PM10 total	Combustion	42.31	30.339	30.339	30.339	30.339	30.339	30.339	30.339
PM10 urban	Precombustion	4.80	1.125	1.180	1.158	1.088	0.228	0.196	0.196
PM10 urban	Combustion	42.31	30.339	30.339	30.339	30.339	30.339	30.339	30.339
Energy Embodied	Precombustion	1.41	0.461	0.501	0.473	0.451	0.188	0.179	0.184

Table A5.4 (cont.)

Summary of life cycle emissions from alternative fuels

		LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	Precombustion	0.0229	0.0151	0.0173	0.0143	0.0150	0.0183	0.0207	0.0207
Greenhouse	Combustion	0.0801	0.0701	0.0701	0.0690	0.0690	0.0690	0.0723	0.0791
NMHC total	Precombustion	0.0678	0.0318	0.0350	0.0332	0.0332	0.0359	0.1225	0.1236
NMHC total	Combustion	0.1002	0.0025	0.0025	0.0020	0.0020	0.0020	0.0009	0.0026
NMHC urban	Precombustion	0.0325	0.0008	0.0013	0.0010	0.0001	0.0015	0.0903	0.0899
NMHC urban	Combustion	0.1002	0.0025	0.0025	0.0020	0.0020	0.0020	0.0009	0.0026
NOx total	Precombustion	0.1203	0.0336	0.0492	0.0371	0.0391	0.0843	0.1114	0.1100
NOx total	Combustion	1.132	0.146	0.146	0.221	0.221	0.221	0.059	0.393
NOx urban	Precombustion	0.052	0.016	0.030	0.019	0.000	0.004	0.049	0.046
NOx urban	Combustion	1.132	0.146	0.146	0.221	0.221	0.221	0.059	0.393
CO total	Precombustion	0.0271	0.0092	0.0138	0.0112	0.0117	0.0135	0.0254	0.0249
CO total	Combustion	0.2761	0.0043	0.0043	0.0039	0.0039	0.0039	0.0208	0.0185
CO urban	Precombustion	0.0147	0.0018	0.0057	0.0036	0.0001	0.0011	0.0140	0.0134
CO urban	Combustion	0.2761	0.0043	0.0043	0.0039	0.0039	0.0039	0.0208	0.0185
PM10 total	Precombustion	6.50	0.56	0.67	0.51	0.53	2.71	6.46	6.14
PM10 total	Combustion	42.31	7.85	7.85	7.74	7.74	7.74	4.31	1.74
PM10 urban	Precombustion	4.80	0.33	0.42	0.26	0.01	0.26	4.89	4.53
PM10 urban	Combustion	42.31	7.85	7.85	7.74	7.74	7.74	4.31	1.74
Energy Embodied	Precombustion	1.41	1.39	1.46	1.39	1.40	1.44	1.29	1.33

		LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	Precombustion	0.0229	0.0257	0.0483	0.0838	0.0425	0.0769	0.0383	0.0092	0.1147	0.0999
Greenhouse	Combustion	0.0801	0.0703	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0489	0.0853
NMHC total	Precombustion	0.0678	0.0638	0.0148	0.0131	0.0044	0.0802	1.0345	0.6381	0.6614	0.0399
NMHC total	Combustion	0.1002	0.0954	0.0816	0.0816	0.0816	0.0816	0.0816	0.0816	0.0816	0.1388
NMHC urban	Precombustion	0.0325	0.0316	0.0105	0.0114	0.0027	0.0109	0.9643	0.6369	0.5746	0.0013
NMHC urban	Combustion	0.1002	0.0954	0.0816	0.0816	0.0816	0.0816	0.0816	0.0816	0.0816	0.1388
NOx total	Precombustion	0.1203	0.1236	0.1481	0.1470	0.1158	0.3430	0.2817	0.0646	0.3831	0.0632
NOx total	Combustion	1.132	1.035	0.968	0.968	0.968	0.968	0.968	0.968	0.968	0.109
NOx urban	Precombustion	0.052	0.059	0.112	0.141	0.112	0.150	0.090	0.062	0.334	0.041
NOx urban	Combustion	1.132	1.035	0.968	0.968	0.968	0.968	0.968	0.968	0.968	0.109
CO total	Precombustion	0.0271	0.0896	0.6603	0.8441	0.0128	0.9086	3.9531	2.1937	0.0773	0.0146
CO total	Combustion	0.2761	0.3119	0.3498	0.3498	0.3498	0.3498	0.3498	0.3498	0.3498	1.0909
CO urban	Precombustion	0.0147	0.0779	0.6536	0.8418	0.0121	0.0165	3.0622	2.1937	0.0568	0.0055
CO urban	Combustion	0.2761	0.3119	0.3498	0.3498	0.3498	0.3498	0.3498	0.3498	0.3498	1.0909
PM10 total	Precombustion	6.50	5.96	1.06	0.34	24.39	28.40	51.22	30.51	5.92	0.81
PM10 total	Combustion	42.31	32.16	31.73	31.73	31.73	31.73	31.73	31.73	31.73	39.67
PM10 urban	Precombustion	4.80	4.35	0.36	0.21	24.28	25.17	47.99	30.40	5.27	0.52
PM10 urban	Combustion	42.31	32.16	31.73	31.73	31.73	31.73	31.73	31.73	31.73	39.67
Energy Embodied	Precombustion	1.41	1.33	0.49	0.56	0.50	0.79	0.92	3.14	4.03	1.69

Emissions per passenger kilometre

Table A5.5

Urban and rural exbodied emissions

Precombustion	Units	LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	kg CO2	0.0910	0.0931	0.0912	0.0976
NMHC total	g HC	0.148	0.134	0.132	0.092
NMHC urban	g HC	0.117	0.102	0.101	0.052
NOx total	g NOx	1.107	0.974	0.959	1.014
NOx urban	g NOx	1.046	0.912	0.898	0.875
CO total	g CO	0.268	0.335	0.332	0.229
CO urban	g CO	0.257	0.324	0.321	0.198
PM10 total	mg PM10	43.1	33.9	33.7	26.2
PM10 urban	mg PM10	41.6	32.3	32.2	24.3
Energy Embodied	MJ LHV	1.249	1.289	1.269	1.682

Precombustion	Units	LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	kg CO2	0.0910	0.0424	0.0320	0.0434	0.0411	0.0488	0.0069	0.0072
NMHC total	g HC	0.148	0.142	0.168	0.143	0.139	0.059	0.059	0.060
NMHC urban	g HC	0.117	0.131	0.159	0.131	0.128	0.058	0.058	0.059
NOx total	g NOx	1.107	1.268	1.257	1.286	1.264	1.159	1.157	1.162
NOx urban	g NOx	1.046	1.193	1.209	1.195	1.191	1.158	1.156	1.161
CO total	g CO	0.268	0.167	0.215	0.168	0.166	0.138	0.138	0.143
CO urban	g CO	0.257	0.152	0.205	0.152	0.151	0.138	0.138	0.142
PM10 total	mg PM10	43.1	29.3	28.8	29.9	29.2	27.0	27.0	27.0
PM10 urban	mg PM10	41.6	27.8	27.8	27.8	27.8	27.0	27.0	27.0
Energy Embodied	MJ LHV	1.249	0.407	0.443	0.418	0.398	0.166	0.158	0.162

Precombustion	Units	LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	kg CO2	0.0910	0.0752	0.0772	0.0736	0.0743	0.0771	0.0822	0.0882
NMHC total	g HC	0.148	0.030	0.033	0.031	0.031	0.033	0.109	0.111
NMHC urban	g HC	0.117	0.003	0.003	0.003	0.002	0.003	0.081	0.082
NOx total	g NOx	1.107	0.158	0.172	0.228	0.230	0.270	0.150	0.444
NOx urban	g NOx	1.046	0.143	0.155	0.212	0.196	0.198	0.095	0.387
CO total	g CO	0.268	0.012	0.016	0.013	0.014	0.015	0.041	0.038
CO urban	g CO	0.257	0.005	0.009	0.007	0.003	0.004	0.031	0.028
PM10 total	mg PM10	43.1	7.4	7.5	7.3	7.3	9.2	9.5	7.0
PM10 urban	mg PM10	41.6	7.2	7.3	7.1	6.8	7.1	8.1	5.5
Energy Embodied	MJ LHV	1.249	1.229	1.291	1.230	1.239	1.269	1.141	1.171

Table A5.5 (cont.)

Urban and rural exbodied emissions

Precombustion	Units	LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	kg CO2	0.0910	0.0848	0.0427	0.0741	0.0376	0.0680	0.0338	0.0081	0.1445	0.1636
NMHC total	g HC	0.148	0.141	0.085	0.084	0.076	0.143	0.986	0.636	0.656	0.158
NMHC urban	g HC	0.117	0.112	0.081	0.082	0.074	0.082	0.924	0.635	0.580	0.124
NOx total	g NOx	1.107	1.023	0.986	0.985	0.957	1.158	1.104	0.912	1.193	0.152
NOx urban	g NOx	1.046	0.966	0.954	0.980	0.954	0.988	0.934	0.909	1.150	0.133
CO total	g CO	0.268	0.355	0.892	1.055	0.320	1.112	3.801	2.247	0.377	0.976
CO urban	g CO	0.257	0.344	0.886	1.053	0.320	0.324	3.014	2.247	0.359	0.968
PM10 total	mg PM10	43.1	33.7	29.0	28.3	49.6	53.1	73.3	55.0	33.3	35.8
PM10 urban	mg PM10	41.6	32.3	28.3	28.2	49.5	50.3	70.4	54.9	32.7	35.5
Energy Embodied	MJ LHV	1.249	1.171	0.434	0.496	0.446	0.697	0.812	2.774	3.561	1.495

Table A5.6

Urban and rural upstream emissions

Precombustion	Units	LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	kg CO2	0.020	0.023	0.021	0.032
NMHC total	g HC	0.060	0.062	0.061	0.042
NMHC urban	g HC	0.029	0.030	0.029	0.001
NOx total	g NOx	0.106	0.122	0.107	0.144
NOx urban	g NOx	0.046	0.060	0.047	0.005
CO total	g CO	0.024	0.027	0.024	0.033
CO urban	g CO	0.013	0.016	0.013	0.001
PM10 total	mg PM10	5.744	5.921	5.813	1.997
PM10 urban	mg PM10	4.239	4.387	4.289	0.072
Energy Embodied	MJ LHV	1.249	1.289	1.269	1.682

Precombustion	Units	LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	kg CO2	0.020	0.042	0.032	0.043	0.041	0.049	0.007	0.007
NMHC total	g HC	0.060	0.138	0.164	0.139	0.135	0.055	0.055	0.056
NMHC urban	g HC	0.029	0.127	0.155	0.127	0.124	0.054	0.054	0.055
NOx total	g NOx	0.106	0.137	0.125	0.154	0.133	0.027	0.025	0.030
NOx urban	g NOx	0.046	0.061	0.077	0.063	0.060	0.027	0.025	0.030
CO total	g CO	0.024	0.034	0.081	0.035	0.033	0.005	0.005	0.009
CO urban	g CO	0.013	0.019	0.072	0.019	0.018	0.005	0.004	0.009
PM10 total	mg PM10	5.744	2.459	1.957	3.059	2.380	0.213	0.184	0.184
PM10 urban	mg PM10	4.239	0.993	1.043	1.023	0.961	0.202	0.173	0.173
Energy Embodied	MJ LHV	1.249	0.407	0.443	0.418	0.398	0.166	0.158	0.162

Table A5.6 (cont.)

Urban and rural upstream emissions

Precombustion	Units	LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	kg CO2	0.020	0.013	0.015	0.013	0.013	0.016	0.018	0.018
NMHC total	g HC	0.060	0.028	0.031	0.029	0.029	0.032	0.108	0.109
NMHC urban	g HC	0.029	0.001	0.001	0.001	0.000	0.001	0.080	0.079
NOx total	g NOx	0.106	0.030	0.043	0.033	0.035	0.074	0.098	0.097
NOx urban	g NOx	0.046	0.014	0.027	0.017	0.000	0.003	0.043	0.040
CO total	g CO	0.024	0.008	0.012	0.010	0.010	0.012	0.022	0.022
CO urban	g CO	0.013	0.002	0.005	0.003	0.000	0.001	0.012	0.012
PM10 total	mg PM10	5.744	0.497	0.595	0.447	0.472	2.390	5.705	5.420
PM10 urban	mg PM10	4.239	0.290	0.371	0.232	0.007	0.232	4.318	4.003
Energy Embodied	MJ LHV	1.249	1.229	1.291	1.230	1.239	1.269	1.141	1.171

Precombustion	Units	LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	kg CO2	0.020	0.023	0.043	0.074	0.038	0.068	0.034	0.008	0.101	0.088
NMHC total	g HC	0.060	0.056	0.013	0.012	0.004	0.071	0.914	0.564	0.584	0.035
NMHC urban	g HC	0.029	0.028	0.009	0.010	0.002	0.010	0.852	0.563	0.508	0.001
NOx total	g NOx	0.106	0.109	0.131	0.130	0.102	0.303	0.249	0.057	0.338	0.056
NOx urban	g NOx	0.046	0.052	0.099	0.125	0.099	0.133	0.079	0.055	0.295	0.037
CO total	g CO	0.024	0.079	0.583	0.746	0.011	0.803	3.492	1.938	0.068	0.013
CO urban	g CO	0.013	0.069	0.577	0.744	0.011	0.015	2.705	1.938	0.050	0.005
PM10 total	mg PM10	5.744	5.262	0.934	0.300	21.541	25.083	45.247	26.951	5.233	0.716
PM10 urban	mg PM10	4.239	3.846	0.316	0.189	21.443	22.230	42.394	26.853	4.653	0.460
Energy Embodied	MJ LHV	1.249	1.171	0.434	0.496	0.446	0.697	0.812	2.774	3.561	1.495

Table A5.7

Urban and rural tailpipe emissions

Combustion	Units	LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	kg CO2	0.071	0.071	0.071	0.066
NMHC total	g HC	0.089	0.072	0.072	0.051
NMHC urban	g HC	0.089	0.072	0.072	0.051
NOx total	g NOx	1.000	0.852	0.852	0.870
NOx urban	g NOx	1.000	0.852	0.852	0.870
CO total	g CO	0.244	0.308	0.308	0.197
CO urban	g CO	0.244	0.308	0.308	0.197
PM10 total	mg PM10	37.38	27.94	27.94	24.18
PM10 urban	mg PM10	37.38	27.94	27.94	24.18
Energy Embodied	MJ LHV	0	0	0	0

Table A5.7 (cont.)

Urban and rural tailpipe emissions

Combustion	Units	LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	kg CO2	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NMHC total	g HC	0.089	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NMHC urban	g HC	0.089	0.004	0.004	0.004	0.004	0.004	0.004	0.004
NOx total	g NOx	1.000	1.132	1.132	1.132	1.132	1.132	1.132	1.132
NOx urban	g NOx	1.000	1.132	1.132	1.132	1.132	1.132	1.132	1.132
CO total	g CO	0.244	0.133	0.133	0.133	0.133	0.133	0.133	0.133
CO urban	g CO	0.244	0.133	0.133	0.133	0.133	0.133	0.133	0.133
PM10 total	mg PM10	37.38	26.80	26.80	26.80	26.80	26.80	26.80	26.80
PM10 urban	mg PM10	37.38	26.80	26.80	26.80	26.80	26.80	26.80	26.80
Energy Embodied	MJ LHV	0	0	0	0	0	0	0	0

Combustion	Units	LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	kg CO2	0.071	0.062	0.062	0.061	0.061	0.061	0.064	0.070
NMHC total	g HC	0.089	0.002	0.002	0.002	0.002	0.002	0.001	0.002
NMHC urban	g HC	0.089	0.002	0.002	0.002	0.002	0.002	0.001	0.002
NOx total	g NOx	1.000	0.129	0.129	0.195	0.195	0.195	0.052	0.347
NOx urban	g NOx	1.000	0.129	0.129	0.195	0.195	0.195	0.052	0.347
CO total	g CO	0.244	0.004	0.004	0.003	0.003	0.003	0.018	0.016
CO urban	g CO	0.244	0.004	0.004	0.003	0.003	0.003	0.018	0.016
PM10 total	mg PM10	37.38	6.93	6.93	6.84	6.84	6.84	3.81	1.54
PM10 urban	mg PM10	37.38	6.93	6.93	6.84	6.84	6.84	3.81	1.54
Energy Embodied	MJ LHV	0	0	0	0	0	0	0	0

Combustion	Units	LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	kg CO2	0.071	0.062	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.075
NMHC total	g HC	0.089	0.084	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.123
NMHC urban	g HC	0.089	0.084	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.123
NOx total	g NOx	1.000	0.914	0.855	0.855	0.855	0.855	0.855	0.855	0.855	0.096
NOx urban	g NOx	1.000	0.914	0.855	0.855	0.855	0.855	0.855	0.855	0.855	0.096
CO total	g CO	0.244	0.276	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.964
CO urban	g CO	0.244	0.276	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.964
PM10 total	mg PM10	37.38	28.41	28.03	28.03	28.03	28.03	28.03	28.03	28.03	35.04
PM10 urban	mg PM10	37.38	28.41	28.03	28.03	28.03	28.03	28.03	28.03	28.03	35.04
Energy Embodied	MJ LHV	0	0	0	0	0	0	0	0	0	0

Table A5.8

Summary of life cycle emissions from alternative fuels

		LS diesel (Aus)	ULS diesel (Aus)	ULS diesel (100% hydroprocessing)	Fischer-Tropsch diesel
Greenhouse	Precombustion	0.0203	0.0225	0.0206	0.0317
Greenhouse	Combustion	0.0707	0.0706	0.0706	0.0660
NMHC total	Precombustion	0.0599	0.0623	0.0606	0.0418
NMHC total	Combustion	0.0885	0.0718	0.0718	0.0507
NMHC urban	Precombustion	0.0287	0.0301	0.0291	0.0009
NMHC urban	Combustion	0.0885	0.0718	0.0718	0.0507
NOx total	Precombustion	0.1062	0.1220	0.1072	0.1436
NOx total	Combustion	1.000	0.852	0.852	0.870
NOx urban	Precombustion	0.046	0.060	0.047	0.005
NOx urban	Combustion	1.000	0.852	0.852	0.870
CO total	Precombustion	0.0239	0.0273	0.0242	0.0327
CO total	Combustion	0.2439	0.3079	0.3079	0.1968
CO urban	Precombustion	0.0130	0.0161	0.0132	0.0009
CO urban	Combustion	0.2439	0.3079	0.3079	0.1968
PM10 total	Precombustion	5.74	5.92	5.81	2.00
PM10 total	Combustion	37.38	27.94	27.94	24.18
PM10 urban	Precombustion	4.24	4.39	4.29	0.07
PM10 urban	Combustion	37.38	27.94	27.94	24.18
Energy Embodied	Precombustion	1.25	1.29	1.27	1.68

		LS diesel (Aus)	Biodiesel (canola)	Biodiesel (soybean)	Biodiesel (rape)	Biodiesel (tallow-expanded sys. boundary)	Biodiesel (tallow-eco.allocat.)	Biodiesel (waste oil)	Biodiesel (waste oil 10% original oil value)
Greenhouse	Precombustion	0.0203	0.0424	0.0320	0.0434	0.0411	0.0488	0.0069	0.0072
Greenhouse	Combustion	0.0707	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NMHC total	Precombustion	0.0599	0.1377	0.1643	0.1387	0.1348	0.0552	0.0549	0.0559
NMHC total	Combustion	0.0885	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
NMHC urban	Precombustion	0.0287	0.1269	0.1554	0.1269	0.1239	0.0540	0.0539	0.0549
NMHC urban	Combustion	0.0885	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
NOx total	Precombustion	0.1062	0.1367	0.1249	0.1544	0.1328	0.0274	0.0255	0.0304
NOx total	Combustion	1.000	1.132	1.132	1.132	1.132	1.132	1.132	1.132
NOx urban	Precombustion	0.046	0.061	0.077	0.063	0.060	0.027	0.025	0.030
NOx urban	Combustion	1.000	1.132	1.132	1.132	1.132	1.132	1.132	1.132
CO total	Precombustion	0.0239	0.0337	0.0814	0.0345	0.0328	0.0050	0.0046	0.0093
CO total	Combustion	0.2439	0.1334	0.1334	0.1334	0.1334	0.1334	0.1334	0.1334
CO urban	Precombustion	0.0130	0.0186	0.0720	0.0189	0.0181	0.0047	0.0044	0.0090
CO urban	Combustion	0.2439	0.1334	0.1334	0.1334	0.1334	0.1334	0.1334	0.1334
PM10 total	Precombustion	5.74	2.46	1.96	3.06	2.38	0.21	0.18	0.18
PM10 total	Combustion	37.38	26.80	26.80	26.80	26.80	26.80	26.80	26.80
PM10 urban	Precombustion	4.24	0.99	1.04	1.02	0.96	0.20	0.17	0.17
PM10 urban	Combustion	37.38	26.80	26.80	26.80	26.80	26.80	26.80	26.80
Energy Embodied	Precombustion	1.25	0.41	0.44	0.42	0.40	0.17	0.16	0.16

Table A5.8 (cont.)

Summary of life cycle emissions from alternative fuels

		LS diesel (Aus)	CNG (Electric compression)	CNG (NG compression)	LNG (from existing transmission line)	LNG (Shipped from north west shelf)	LNG (perth)	LPG (Autogas)	LPG (HD5)
Greenhouse	Precombustion	0.0203	0.0133	0.0153	0.0126	0.0133	0.0161	0.0183	0.0183
Greenhouse	Combustion	0.0707	0.0619	0.0619	0.0610	0.0610	0.0610	0.0639	0.0699
NMHC total	Precombustion	0.0599	0.0281	0.0309	0.0293	0.0293	0.0317	0.1082	0.1092
NMHC total	Combustion	0.0885	0.0022	0.0022	0.0018	0.0018	0.0018	0.0008	0.0023
NMHC urban	Precombustion	0.0287	0.0007	0.0011	0.0009	0.0001	0.0013	0.0798	0.0794
NMHC urban	Combustion	0.0885	0.0022	0.0022	0.0018	0.0018	0.0018	0.0008	0.0023
NOx total	Precombustion	0.1062	0.0296	0.0435	0.0328	0.0345	0.0745	0.0984	0.0972
NOx total	Combustion	1.000	0.129	0.129	0.195	0.195	0.195	0.052	0.347
NOx urban	Precombustion	0.046	0.014	0.027	0.017	0.000	0.003	0.043	0.040
NOx urban	Combustion	1.000	0.129	0.129	0.195	0.195	0.195	0.052	0.347
CO total	Precombustion	0.0239	0.0081	0.0122	0.0099	0.0103	0.0119	0.0224	0.0220
CO total	Combustion	0.2439	0.0038	0.0038	0.0034	0.0034	0.0034	0.0184	0.0163
CO urban	Precombustion	0.0130	0.0016	0.0051	0.0031	0.0001	0.0009	0.0124	0.0118
CO urban	Combustion	0.2439	0.0038	0.0038	0.0034	0.0034	0.0034	0.0184	0.0163
PM10 total	Precombustion	5.74	0.50	0.59	0.45	0.47	2.39	5.71	5.42
PM10 total	Combustion	37.38	6.93	6.93	6.84	6.84	6.84	3.81	1.54
PM10 urban	Precombustion	4.24	0.29	0.37	0.23	0.01	0.23	4.32	4.00
PM10 urban	Combustion	37.38	6.93	6.93	6.84	6.84	6.84	3.81	1.54
Energy Embodied	Precombustion	1.25	1.23	1.29	1.23	1.24	1.27	1.14	1.17

		LS diesel (Aus)	LSdiesohol	Ethanol azeotropic (molasses-expanded sys.bound.)	Ethanol azeotropic (molasses-economic allocation)	Ethanol azeotropic (wheat starch waste)	Ethanol azeotropic (wheat)	Ethanol azeotropic (wheat) fired with wheat straw	Ethanol azeotropic (woodwaste)	Ethanol azeotropic (ethylene)	Hydrogen (from natural gas)
Greenhouse	Precombustion	0.0203	0.0227	0.0427	0.0741	0.0376	0.0680	0.0338	0.0081	0.1013	0.0882
Greenhouse	Combustion	0.0707	0.0621	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0432	0.0753
NMHC total	Precombustion	0.0599	0.0564	0.0131	0.0116	0.0039	0.0708	0.9138	0.5636	0.5843	0.0352
NMHC total	Combustion	0.0885	0.0843	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.1226
NMHC urban	Precombustion	0.0287	0.0279	0.0093	0.0100	0.0024	0.0096	0.8518	0.5626	0.5076	0.0012
NMHC urban	Combustion	0.0885	0.0843	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.1226
NOx total	Precombustion	0.1062	0.1092	0.1308	0.1298	0.1023	0.3030	0.2489	0.0571	0.3384	0.0559
NOx total	Combustion	1.000	0.914	0.855	0.855	0.855	0.855	0.855	0.855	0.855	0.096
NOx urban	Precombustion	0.046	0.052	0.099	0.125	0.099	0.133	0.079	0.055	0.295	0.037
NOx urban	Combustion	1.000	0.914	0.855	0.855	0.855	0.855	0.855	0.855	0.855	0.096
CO total	Precombustion	0.0239	0.0792	0.5833	0.7456	0.0113	0.8026	3.4919	1.9377	0.0683	0.0129
CO total	Combustion	0.2439	0.2755	0.3089	0.3089	0.3089	0.3089	0.3089	0.3089	0.3089	0.9636
CO urban	Precombustion	0.0130	0.0689	0.5774	0.7436	0.0107	0.0146	2.7050	1.9377	0.0502	0.0048
CO urban	Combustion	0.2439	0.2755	0.3089	0.3089	0.3089	0.3089	0.3089	0.3089	0.3089	0.9636
PM10 total	Precombustion	5.74	5.26	0.93	0.30	21.54	25.08	45.25	26.95	5.23	0.72
PM10 total	Combustion	37.38	28.41	28.03	28.03	28.03	28.03	28.03	28.03	28.03	35.04
PM10 urban	Precombustion	4.24	3.85	0.32	0.19	21.44	22.23	42.39	26.85	4.65	0.46
PM10 urban	Combustion	37.38	28.41	28.03	28.03	28.03	28.03	28.03	28.03	28.03	35.04
Energy Embodied	Precombustion	1.25	1.17	0.43	0.50	0.45	0.70	0.81	2.77	3.56	1.50
Energy Embodied	Combustion	0	18	19	20	21	22	23	24	25	26

Appendix 6. Diesohol Information

Attn: Tom Beer
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ATTACHMENT PAGE 1 OF 8

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ENERGY BALANCES AND CARBON DIOXIDE EMISSION REDUCTIONS FOR VARIOUS SCENARIOS OF PRODUCTION AND USE OF ETHANOL AS TRANSPORT FUEL

A. ENERGY BALANCES

A1. Future Proposed Major Scenario - Ethanol from DEDICATED Lignocellulosic Crops

As stated by Lynd et al. (1), the ratio of energy output to energy input, R, for an ethanol-from-lignocellulosics process may be defined as follows :

$$R = \frac{1 + (3*E)}{A + T + C + D + P} \qquad ......(1)$$

where : E = cogenerated electrical power;
A = agricultural inputs;
T = raw material transport;
C = chemical inputs in cellulosics to ethanol processing;
D = distribution of ethanol fuel;
P = plant amortisation;

where all energy flows are expressed as fractions of the lower calorific value of ethanol; and,

where the multiplier of E reflects the displacement of thermal energy for conventional coal-fired electrical power generation.

It should be recognised that Equation (1) requires that all processing energy inputs, including ethanol recovery and residues processing, are supplied from combustion of solid residues, principally the mixed cellulose/lignin solid residue. The factor "E" represents surplus cogenerated electrical power from combustion of this solid residue.

Based on the results of work by the United States National Renewable Energy Laboratories (NREL, formerly known as the Solar Energy Research Institute (SERI)), Lynd et al. arrive at a value of 5 for R.

Lynd et al. are silent on the matter of treatment of the liquid process effluents. NREL usually propose anaerobic digestion of the liquid effluent streams and combustion of the methane produced to provide additional electrical power cogeneration. This has the effect of increasing the value of R.

Lynd et al. and NREL are unaware of the Apace technology for the production of ethanol from lignocellulosics.

If the Apace technology, in particular the Apace simultaneous ethanol recovery/waste treatment process, proves successful the effect will be a significant increase in the value of R from the current value of 5 to a value of at least 7.

The above mentioned increase is achieved because the Apace technology significantly reduces the processing energy input. This in turn leaves an increased amount of cellulose/lignin solid residue available for electrical power cogeneration.

Immediate Future-Proposed Major Scenario - Ethanol from Lignocellulosic RESIDUE Materials

In this scenario the agricultural energy input (A) in Equation 1 can be considered as zero. Using the remaining energy input values ascribed by Lynd et al., R then has a value in excess of 12.

With use of the Apace technology R would have a value in excess of 17

Present Situation - Production of Ethanol by the Manildra Group from WASTE Starch Associated with Production of Wheat Products

In the Manildra case the processing energy input, principally that of distillation for ethanol recovery, is currently being switched from combustion of black coal to combustion of natural gas.

Unlike the case with the ethanol-from-lignocellulosics process, there are no solid residues available for combustion from Manildra's ethanol-from-starch plant.

All liquid effluent streams, principally the underflow from the "stripping" distillation column, are currently irrigated onto surrounding land used for intensive pasture production.

The liquid effluent has displaced use of conventional fertilisers and significantly increased the soil carbon content.

the present Manildra operation Equation (1 then becomes

$$R = \frac{1}{A + T + S + C + D + P} \qquad \ldots\ldots(1b)$$

where : S = processing energy input; and,

where all other factors are as defined in Equation 1).

The Manildra plant is a modern, integrated ethanol-from-starch plant based on well-proven conventional technology. Such plants have a processing energy input of approximately 4.5 MJ/litre of azeotropic ethanol and 5.9 MJ/litre of anhydrous ethanol (ref.2). Based on a lower calorific value of 19.43 MJ/litre for azeotropic ethanol and 21.15 MJ/litre for anhydrous ethanol, and assuming natural gas to steam conversion efficiency of 70%, this converts to a value of 0.33 for factor "S" in Equation (1b) for azeotropic ethanol, and 0.40 for anhydrous ethanol. Manildra have an on-going research and development programme on all stages of the starch-to-ethanol conversion process, and will be supporting work by Apace Research on a low energy requirement simultaneous ethanol recovery/liquid effluent treatment process. Improvements in any stage of the overall starch-to-ethanol conversion process, most particularly in the ethanol recovery and effluent treatment stages, serve to increase the energy balance and reduce greenhouse gas emissions.

A significant proportion of the starch feedstock used by Manildra for ethanol production is waste starch from Manildra's gluten production, or is derived from reject grain. For these starch feedstocks the agricultural energy input, factor "A" in Equation (1b), is zero. Factor "A" will need to be calculated for that proportion of the starch feedstock which is derived from prime wheat. Based on detailed analyses by the United States Department of Agriculture and Department of Energy on the energy input for corn production in the United States (ref. 3), factor "A" for wheat production in Australia is likely to be approximately 0.22. Manildra have a policy of applying best farming practice to wheat production. This will serve to steadily increase the energy balance and reduce greenhouse gas emissions.

If 50% of the starch feedstock used for ethanol production was derived from prime wheat, factor "A" in Equation (1b) would thus have a value of approximately 0.11.

Because the ethanol distillery is annexed to the existing starch/gluten plant the raw material transport input, factor "T", for the waste starch stream is zero. Factor "T" will need to be calculated for that proportion of the starch feedstock which is derived from prime and reject wheat. Transport of Manildra's wheat and starch is predominantly by rail, resulting in a higher energy balance and lower greenhouse emissions compared with road transport. If 55% of the starch feedstock used for ethanol production was from prime and reject wheat, factor "T" in Equation (1b) would have a value of approximately 0.02.

Chemical inputs and ethanol fuel distribution, factors "C" and "D" respectively, in ethanol-from-starch production are approximately the same as for ethanol-from-lignocellulosics production and can be taken as 0.01 (ref.1).

Due to the ethanol distillery being annexed to the existing starch/gluten plant and utilising already existing pretreatment and steam generation plant, the plant amortisation factor "P" for the Manildra distillery is considerably less than that of a new, stand-alone plant. In addition, because there is no solid residue with the Manildra ethanol-from-starch plant there is no solids handling or electrical power cogeneration equipment typical of an ethanol-from-lignocellulosics plant. Accordingly, a value of 0.01 is assumed for factor "P" (ref.1).

Thus from Equation (1b), R will initially have a value of approximately 2.0 for azeotropic ethanol and approximately 1.8 for anhydrous ethanol.

This compares favourably with existing best practice ethanol-from-corn plants in the United States which have a value for R of 1.87 for anhydrous ethanol. New, leading-edge United States ethanol-from-corn plants have a value for R of 2.21 for anhydrous ethanol (ref.3).

It is interesting to compare the value of R for Manildra's ethanol with that of CSR's azeotropic ethanol produced from molasses at Sarina in Queensland.

Molasses is the <u>residue</u> from the production of crystal sugar for food.

However, in the case of CSR's azeotropic ethanol-from-molasses plant, the processing energy input is supplied from combustion of the sugar cane bagasse.

Surplus bagasse is also used by CSR for electrical power cogeneration.

Equation (1) is thus relevant to this case

Agricultural input (A) can be considered as zero and raw material transport (T) is insignificant.

Chemical inputs into the ethanol-from-molasses process are likewise insignificant, being considerably less than for the ethanol-from-lignocellulosics and ethanol-from-starch processes.

Thus, even if no electrical power cogeneration is assumed (i.e., E = 0), and using the values for factors "D" and "P" ascribed by Lynd et al., R has a value of approximately 20 for CSR's azeotropic ethanol.

B. CARBON DIOXIDE BALANCES

As stated by Lynd et al., an indication of the contribution of the various ethanol fuel production scenarios to carbon dioxide accumulation in the atmosphere is the net carbon dioxide produced per unit energy N. This parameter may be estimated from :

$$N = \frac{f}{R} * C \qquad ...(2)$$

where f = the fraction of energy inputs met by fossil fuels;
C = carbon dioxide produced per unit energy for fossil energy inputs; and,
R is as defined in Equation (1).

All the energy inputs identified in Equation (1) and (1b) can be satisfied either by fossil fuels (corresponding to f = 1) or by fuels that do not contribute to carbon dioxide accumulation in the atmosphere, such as wood, bagasse or lignin in stationary applications such as boilers and neat ethanol produced efficiently from lignocellulosics for mobile applications (corresponding to f = 0).

The best case scenario is when f = 0, which results in 100% reduction in carbon dioxide emission.

B1. Ethanol from DEDICATED Lignocellulosic Crops

Reference to section A1 and Equation (2) above shows that R = 5 and f = 1 corresponds to a worst case scenario of approximately an 80% reduction in carbon dioxide emission associated with the use of neat ethanol as fuel compared to the use of fossil fuels, assuming equivalent thermal efficiency of use.

With use of the Apace technology and R = 7, the worst case scenario results in approximately an 85% reduction in carbon dioxide emission

The best case scenario is when f = 0, which results in a 100% reduction in carbon dioxide emission.

B2. Ethanol from Lignocellulosic RESIDUE Materials

Reference to section A2 and Equation (2) above shows that R = 12 and f = 1 corresponds to a worst case scenario of approximately a 92% reduction in carbon dioxide emission associated with the use of neat ethanol as fuel compared to the use of fossil fuels.

With use of the Apace technology and R = 17, the worst case scenario results in approximately a 94% reduction in carbon dioxide emission.

Again the best case scenario is when f = 0 which results in a 100% reduction in carbon dioxide emission.

B3. Production of Ethanol by the Manildra Group from WASTE Starch Derived from Gluten/Starch Plant

In the Manildra ethanol-from-starch plant natural gas is currently replacing black coal for the processing energy input. Chemical input is produced using fossil fuels. Diesohol E15 is replacing diesel as the transport fuel used for ethanol distribution. However, because the energy inputs are dominated by the processing energy input, a value of 1 is assigned to the factor "f" as a worst case scenario. Factor "C " for natural gas is approximately 56mg/KJ (ref.4).

Thus, for Manildra anhydrous ethanol N = 31 mgCO2/KJ, and for Manildra azeotropic ethanol N = 28 mgCO2/KJ. This compares to approximately 80 mgCO2/KJ for petrol and diesel (refs.1,4,5).

This corresponds to a 61% reduction in net carbon dioxide emission associated with the use of neat Manildra anhydrous ethanol and a 65% reduction with use of neat Manildra azeotropic ethanol compared to the use of petrol or diesel, assuming equivalent thermal efficiency of use. However the thermal efficiency of internal combustion engines increases when operating on neat ethanol and on ethanol blends compared to both neat petrol and diesel fuel, resulting in slightly greater reductions in net carbon dioxide emission.

It is noted that Manildra will be introducing improved ethanol production methods and replacing fossil fuel inputs with renewable fuel inputs as these become available. The latter measure in particular will dramatically increase the effectiveness of Manildra ethanol in reducing net carbon dioxide emission compared with use of diesel fuel and petrol.

Use of neat CSR azeotropic ethanol for which R = 20 would, under a worst case scenario of f = 1, result in an approximately 95% reduction in carbon dioxide emission compared to the use of petrol or diesel.

Ethanol Blend Fuel Example: DIESOHOL E15

One litre of Diesohol E 15 is comprised of:

0.845 litres of diesel fuel
0.150 litres of azeotropic ethanol
0.005 litres of chemical emulsifier

The emulsifier is a petrochemical comprised of only the elements carbon, hydrogen and oxygen. Due to its chemical nature and low concentration in Diesohol the emulsifier is assumed to be diesel fuel

Typical lower calorific values for the relevant fuels are:

36.0 MJ/litre for diesel fuel
19.4 MJ/litre for azeotropic ethanol

From Section B above, typical values for net carbon dioxide emission, N, are as set out below. The values for azeotropic ethanol are worst case scenarios based on factor f = 1 and no use of the Apace technology.

80 mgCO2/KJ for diesel fuel
28 mgCO2/KJ for Manildra azeotropic ethanol
16 mgCO2/KJ for ethanol from dedicated lignocellulosic crops
6 mgCO2/KJ for ethanol from lignocellulosic residue materials
4 mgCO2/KJ for CSR azeotropic ethanol from molasses

Thus the net carbon dioxide emission from one litre of neat diesel fuel is approximately 2.88 Kg, compared to 2.53 Kg from one litre of Diesohol E15 made with Manildra azeotropic ethanol. As noted in Section A3 above however, the liquid effluent from Manildra's ethanol production is used to displace conventional fertilisers and to increase soil carbon content. The reduction in carbon dioxide emission per litre of ethanol production associated with these aspects has been estimated by NSW Department Of Agriculture to be approximately 0.18 Kg thus reducing the net carbon dioxide emission from one litre of Diesohol E15 to 2.50 Kg. This corresponds to a 13.2% reduction in net carbon dioxide emission compared to the use of neat diesel fuel.

The reduction in net carbon dioxide emission is 13.2%, 14.2% and 14.6% for Diesohol E15 made with ethanol from dedicated lignocellulosic crops, lignocellulosic residue materials and CSR molasses, respectively

"Real world" field trials of Diesohol E15 in various countries have shown no significant increase in volumetric fuel consumption of vehicles using Diesohol E15 compared to neat diesel fuel. This is due to the increased thermal efficiency of diesel engines when operating on emulsion fuels containing alcohols and/or water. However, if a 5% increase in volumetric fuel consumption is assumed as a worst case scenario then the use of Diesohol E15 produced from Manildra azeotropic ethanol will result in an approximately 9% reduction in net carbon dioxide emission compared to the use of neat diesel fuel. In the case of CSR azeotropic ethanol the reduction is approximately 10.4%

It should be recognised that Diesohol E15 represents a conservative level of ethanol substitution and that higher levels of ethanol substitution are possible. Up to 30% of ethanol by volume (Diesohol E30) can be used in existing diesel engines with minor adaptation.

References

1. Lynd, L.R., et al., SCIENCE, 15 March 1991, Volume 251 pp. 1318-1323
2. RAPAD "Fuel Alcohol Production from Biomass - Ethanol Recovery" Research and Development on Synfuels - Annual Technical Report
3. Fuel Ethanol Update, U.S. Renewable Fuels Association, January
4. Milton, B.E., Proceedings NGV-88 Conference, Sydney, October 1988 Volume 2, Paper 22, p. 4
5. NRMA - Rules for "1993 Energy Challenge" Event

Appendix 7 Euro Standards

The terms of reference, given in Appendix 1, requested a determination of:

> an average "grams of emission per megajoule" for both greenhouse emissions and air quality emissions for both light and heavy vehicle Euro Standards I to IV. (The light vehicle Euro Standards are measured in grams per kilometer and each of the light vehicle Euro standards has three vehicle categories.)

We have obtained the Euro standards from Greening (2000, 2001) and from Arcoumanis (2000). Each section of the appendix provides the relevant Euro standard, as promulgated, and then converts the standard to a representative emission per megajoule of fuel consumed.

A7.1 Heavy duty vehicles

The EU standards for heavy duty vehicles (both gas and diesel) are given in Table A7.1.

Table A7.1
EU standards for heavy duty vehicles (g/kWh)

	CO	NOx	PM	THC	NMVOC	CH_4 NGV only	Test cycle
Euro1	4.5	8*	0.36*	1.1			ECE R-49
Euro2	4	7	0.15*	1.1			ECE R-49
Euro3	2.1	5	0.1	0.66			ESC/ELR
Euro3	5.45	5	0.16		0.78	1.6	ETC
Euro4-Level1	1.5	3.5	0.02	0.46			ESC/ELR
Euro4-Level1	4	3.5	0.03		0.55	1.1	ETC
Euro4-Level2	1.5	2	0.02	0.25			ESC/ELR
Euro4-Level2	3	2	0.02		0.4	0.65	ETC

* lowest value is given.

The heavy-duty vehicle standards are converted to g/MJ fuel consumed in Table A7.2 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 33%. This value may be compared to the truck and bus data found in Chapter 2 of Part 3 where the fuel to wheel efficiency of the bus ranged from 24 to 35% and for the truck ranged from 32 to 38% over the extreme range of driving conditions, congested-urban to highway cycles respectively, as identified (by means of the average speed) in the base of the CO_2 and NOx graphs.

Table A7.2
EU standards for heavy duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC	NMVOC	CH_4 NGV only	Test cycle
Euro1	3.75	6.67	0.30	0.92			ECE R-49
Euro2	3.33	5.83	0.13	0.92			ECE R-49
Euro3	1.75	4.17	0.08	0.55			ESC/ELR
Euro3	4.54	4.17	0.13		0.65	1.33	ETC
Euro4-Level1	1.25	2.92	0.02	0.38			ESC/ELR
Euro4-Level1	3.33	2.92	0.03		0.46	0.92	ETC
Euro4-Level2	1.25	1.67	0.02	0.21			ESC/ELR
Euro4-Level2	2.50	1.67	0.02		0.33	0.54	ETC

A7.2 Diesel light commercial vehicles with weight below 1305 kg

The EU standards for diesel passenger cars and diesel light commercial vehicles below 1305 kg mass are given in Table A7.3

Table A7.3
EU standards for light duty vehicles (g/km)

	CO	NOx	PM	THC+NOx
Euro1				
Euro2	1		0.08	0.7
Euro3	0.64	0.5	0.05	0.56
Euro4	0.5	0.25	0.025	0.3

The light duty vehicle standards are converted to g/MJ fuel consumed in Table A7.4 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 10.5 MJ/km.

Table A7.4
EU standards for light duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC+NOx
Euro1				
Euro2	0.10		0.01	0.07
Euro3	0.061	0.048	0.005	0.053
Euro4	0.048	0.024	0.002	0.029

A7.3 Diesel light commercial vehicles with weight between 1305 kg and 1760 kg

The EU standards for diesel passenger cars and diesel light commercial vehicles between 1305 kg and 1760 kg mass are given in Table A7.5

Table A7.5
EU standards for light duty vehicles (g/km)

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	0.8	0.65	0.07	0.72
Euro4	0.63	0.33	0.04	0.39

The light duty vehicle standards are converted to g/MJ fuel consumed in Table A7.6 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 10.5 MJ/km.

Table A7.6
EU standards for light duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	0.076	0.062	0.007	0.069
Euro4	0.060	0.031	0.004	0.037

A7.4 Diesel light commercial vehicles with weight greater than 1760 kg

The EU standards for diesel passenger cars and diesel light commercial vehicles above 1760 kg kg mass are given in Table A7.7

Table A7.7
EU standards for light duty vehicles (g/km)

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	0.95	0.78	0.1	0.86
Euro4	0.74	0.39	0.06	0.46

The light duty vehicle standards are converted to g/MJ fuel consumed in Table A7.8 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 10.5 MJ/km.

Table A7.8
EU standards for light duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	0.090	0.074	0.010	0.082
Euro4	0.070	0.037	0.006	0.044

A7.5 Petrol light commercial vehicles with weight below 1305 kg

The EU standards for petrol passenger cars and petrol light commercial vehicles below 1305 kg mass are given in Table A7.9.

Table A7.9
EU standards for light duty vehicles (g/km)

	CO	NOx	PM	THC+NOx
Euro1				
Euro2	2.2	0.252		0.341
Euro3	2.3	0.15		0.2
Euro4	1	0.08		0.1

The light duty vehicle standards are converted to g/MJ fuel consumed in Table A7.10 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 2.4 MJ/km.

Table A7.10
EU standards for light duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC+NOx
Euro1				
Euro2	0.92			0.14
Euro3	0.96	0.06		0.08
Euro4	0.42	0.03		0.04

A7.6 Petrol light commercial vehicles with weight between 1305 kg and 1760 kg

The EU standards for petrol passenger cars and petrol light commercial vehicles between 1305 kg and 1760 kg mass are given in Table A7.11

Table A7.11
EU standards for light duty vehicles (g/km)

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	4.17	0.18		0.25
Euro4	1.81	0.1		0.13

The light duty vehicle standards are converted to g/MJ fuel consumed in Table A7.12 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 2.4 MJ/km.

Table A7.12
EU standards for light duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	1.74	0.08		0.10
Euro4	0.75	0.04		0.05

A7.7 Petrol light commercial vehicles with weight greater than 1760 kg

The EU standards for petrol passenger cars and petrol light commercial vehicles above 1760 kg kg mass are given in Table A7.13

Table A7.13
EU standards for light duty vehicles (g/km)

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	5.22	0.21		0.29
Euro4	2.27	0.11		0.16

The light duty vehicle standards are converted to g/MJ fuel consumed in Table A7.14 for a vehicle in which the efficiency of conversion of fuel energy to wheel energy is 2.4 MJ/km.

Table A7.14
EU standards for light duty vehicles converted to g/MJ fuel

	CO	NOx	PM	THC+NOx
Euro1				
Euro2				
Euro3	2.18	0.09		0.12
Euro4	0.95	0.05		0.07

Appendix 8 Carbon Dioxide Emissions Factors

A8.1 Introduction

Table A.2 of Workbook 3.1 of the Australian National Greenhouse Gas Inventory (1996) specifies emission factors for carbon dioxide emissions in g/MJ. This appendix provides the emission factors for all the fuels used in this study.

Fuel	Carbon dioxide emission factor (g/MJ)	Notes
Low Sulfur Diesel	69.7	Workbook 3.1 – NGGIC (1996)
Ultra-low Sulfur Diesel	69.7	All diesel fuel taken to have the same emission factor
Fischer-Tropsch Diesel	69.7	All diesel fuel taken to have the same emission factor
Biodiesel	89	Beer et al. (2000) - Appendix 4
Canola	89	Assumed to be the same as biodiesel
Hydrated Ethanol	62.5	Stoichiometry (see note 1, 2)
Diesohol	69.7	Table 7.4 and Table 7.5 of Part 2 indicate that diesel and diesohol emissions of CO_2 do not differ.
CNG	54.4	Workbook 3.1 – NGGIC (1996) for natural gas
LNG	54.4	Workbook 3.1 – NGGIC (1996) for natural gas
LPG-HD5 (Propane)	59.8	Stoichiometry (see note 3)
Butane	61.3	Stoichiometry (see note 4)
LPG (Autogas)	59.4	Workbook 3.1 – NGGIC (1996) for liquefied petroleum gas
PULP	66	Workbook 3.1 – NGGIC (1996) for automotive gasoline
Anhydrous ethanol	62.5	Stoichiometry (see note 1, 2)
Petrohol	67.8	Based on reformulated gasoline results in MacLean (1998)
Hydrogen	0	No tailpipe emissions of CO_2

1. The calculations in the Workbook of the National Greenhouse Gas Inventory Committee (1996) are based on the gross calorific value (higher heating value). We have thus used the gross calorific value for the stoichiometric calculations. However, the note accompanying the table of fuel properties found on the alternative fuels data center web site (www.afdc.doe.gov) states: "since no vehicles in use, or currently being developed for future use, have powerplants capable of condensing the moisture of combustion, the lower heating value should be used for practical comparisons between fuels."
2. Based on the stoichiometry of ethyl alcohol with a gross calorific value of 30.6 MJ/kg.
3. Based on the stoichiometry of propane with a gross calorific value of 50.2 MJ/kg.
4. Based on the stoichiometry of butane with a gross calorific value of 49.5 MJ/kg.

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Appendix 9 Nitrogen Emissions from Vehicles

The aim of this appendix is to review the mechanisms that are believed to be responsible for the emissions of oxides of nitrogen (NOx) and nitrous oxide (N_2O) from motor vehicles so as to demonstrate that they are independent. One depends primarily on the air/fuel mixture, the other depends on the nature of the catalyst (if any) on the vehicle. It is not possible to estimate N_2O emissions on the basis of known NOx emissions.

A9.1 NOx Emissions

The presence of CO, NO and SO are evidence of incomplete combustion. The carbon, nitrogen and sulfur (if any) in the fuel combine with atmospheric oxygen. Complete combustion produces CO_2, NO_2, and SO_2. Automobile exhaust consists of a mixture of all these six gases. In particular, the amount of NO emitted from the exhaust depends on the peak temperature reached within the combustion system, and on the air/fuel ratio, as depicted in Figure 10.1 of Part 2. Once NO has been released into the atmosphere, it reacts with oxygen and ultraviolet light, and is slowly converted to NO_2 and ozone.

A9.2 N_2O Emissions

Workbook 3.1 of the Australian National Greenhouse Gas Inventory (1996: p.32) notes that there is considerable evidence to suggest that the use of catalysts to control pollutants actually increases the amount of N_2O emitted. There is also evidence that the amount of N_2O that is emitted increases as the catalyst ages.

A9.3 Conclusion

One may expect a vehicle without a catalyst to emit *higher* values of NOx than a vehicle equipped with a catalyst. However, one expects a vehicle without a catalyst to emit *lower* values of N_2O than a vehicle that is equipped with a catalyst. Thus, although there is probably an inverse relationship between NOx emissions and N_2O emissions, the complexity of the interaction between combustion temperature, air/fuel ratio, and the properties of the catalyst are such that it is not possible, at this stage, reasonably to approximate N_2O emissions from NOx levels.