LECG

ECONOMICS OF A QUEENSLAND ETHANOL INDUSTRY

Prepared for the

Queensland Department of State Development and Innovation

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OJECTIVE

This objective of this study is to provide an independent assessment of the economic potential of producing ethanol in Queensland. The analysis focuses on the economics of manufacturing ethanol from sugar, molasses and grain (notably sorghum) produced in Queensland, and assesses the benefits to the Queensland economy. Specific areas of concentration include an analysis of the market potential for ethanol in Queensland; distribution issues; and the impact of ethanol use on retail fuel prices.

BACKGROUND

1) Characteristics of ethanol

Ethanol is a renewable alcohol produced primarily by fermentation of sugars found in raw and processed sugar, grains and other biomass. Ethanol is a clear, colourless, flammable oxygenated hydrocarbon, with the chemical formula C_2H_5OH. Ethanol can be produced via fermentation from a diversity of feedstocks, including grains such as corn, wheat, barley, and sorghum or other biomass such as sugar cane and molasses, and vegetable waste. Converting cellulose into its constituent sugars, which then are fermented and distilled into alcohol, also can produce ethanol.

Synthetic ethanol, which is derived from crude oil or gas and coal, and fermentation ethanol are chemically identical. Less than 5 percent of total global ethanol production is accounted for by synthetic feedstocks.[1]

[1] According to F.O. Licht, synthetic alcohol production is concentrated in the hands of a relative few multi-national companies such as Sasol with operations in South Africa and Germany, SADAF of Saudi Arabia (a joint venture between Shell of the UK and Netherlands and the Saudi Arabian Basic Industries Corporation, and BP of the UK as well as Equistar in the US).

- Changes to the world price of oil (and/or exchange rate);
- Adverse consumer sentiment towards ethanol-based fuel;
- Increase in prices for alternative use of raw materials, both sugar and grain; and
- Changes to fuel excise arrangements that reduce the relative advantage of ethanol.

Economic Benefits of Ethanol Development

The economic benefits that Queensland will realize as a result of ethanol development will depend on the amount of new capacity added and the annual amount of ethanol produced. Ethanol will provide important rural economic benefits. Since ethanol plants and ethanol production are likely to be located near the sources of raw material supply, rural economies in Queensland would benefit significantly from development of an ethanol industry. This includes the primary impact resulting from capital spending for construction, direct new jobs and income, and a large share of the indirect spending effects.

In either of the two scenarios discussed above, the development of ethanol is expected to provide positive economic benefits for Queensland.

- The combination of spending for annual operations and capital spending for new plants is expected to add between A$441 million (130.6 megalitre industy) and A$1,490 million (435 megalitre industry) to the Queensland economy by 2010.

- New jobs would also be created as a consequence of increased economic activity caused by ethanol production. The increase in gross output (final demand) resulting from ongoing production and construction of new capacity is expected to support the creation of as many as 2,038 to 6,886 new jobs in all sectors of the Queensland economy by 2010.

Table E3
Potential supply for fuel grade ethanol

.	2004 Production (Thou mt)	2004 Exports (Thou mt)	Used for Ethanol (Thou mt)	Ethanol Yield (Litres/mt)	Potential Production (Mil litres)
Molasses	1,200	400	400	270	108.0
Sorghum	1,400	364	364	450	163.8
Sugar	5,500	4,019	201	600	120.6
Total	8,100	4,783	965	407	392.4

Assumptions:
Sorghum exports estimated at 26% of production (average of last 20 years)
All exportable supplies of molasses and sorghum used for ethanol
5% of sugar exports diverted to ethanol production

Ethanol profitability

The profitability of ethanol production is primarily dependent on the world oil price, the exchange rate, and ethanol prices. At current world oil prices ethanol production in Queensland is profitable. The net cost of producing ethanol from molasses at current commodity prices (including by-product credit for dunder) is estimated at A$0.295 per litre, while the net cost of producing ethanol from sorghum is A$0.337 per litre. This compares to an "ex-terminal" petrol price of A$0.871 per litre (including the .A$ 0.381 per litre excise tax on petrol). Using molasses as a basis for comparison, adding transportation and storage costs of 8 cents per litre to the plant-gate price of A$0.295 per litre provides a terminal price of A$0.375 per litre. When ethanol is blended with petrol the weighted average price of E10 is 5.9 percent below the price of unblended petrol. This does not take into consideration any credit for octane improvement or the price effect of increasing petrol supplies by 10 percent.

The economic viability of the ethanol product is largely sensitive to the world oil price (in $A). It is estimated the world oil price would have to fall below A$20 per barrel for ethanol-based fuel not to have a cost advantage. It is expected that only a slight retail price differential for ethanol would be sufficient for demand of ethanol-based fuel to rise significantly.

Impediments to Ethanol Development

The main potential impediments to ethanol industry growth include:

Table E2
Proposed Ethanol Projects in Queensland

Project Name	Location	Capacity (Mil litres/yr)	Feedstock(s)
QUEENSLAND			
Austcane	Burdekin, Qld	60-100	Cane juice
Australian Ethanol Ltd	Mossman, Qld	25	"C" molasses
Bundaberg Sugar	Mareeba, Qld	6-15	"C" molasses
CSR Ethanol	Burdekin, Qld	60-100	"C" molasses (on hold)
Subtotal Sugar		151-240	
Dalby Bio-Refinery Ltd	Dalby, Qld	82	Sorghum and feed wheat
Lemon Tree Ethanol Pty Ltd	Millmerran, Qld	76	Sorghum
Rocky Point Distillery	Brisbane, Qld	15	Hard grain / sugar
Subtotal Grain		173	
Total Queensland		**324-413**	

It should be noted that this list indicates ethanol projects that are under consideration or have been proposed. It is difficult to accurately assess at what stage any of these projects is, how likely they are to be completed, and on what timeline. It is likely that several of these projects may be only at the initial feasibility study phase.

Feedstock Supply

In order to expand production to meet potential demand, there not only need to be plants capable of producing ethanol, there also needs to be feedstock available at reasonable prices for the plants to draw on. Table E3 below presents data on the potential supply of feedstocks and the amount of ethanol that could be produced.

By diverting all of the molasses and sorghum currently being exported, and only 5 percent of sugar exports to ethanol production, Queensland could produce nearly 400 million litres of ethanol.

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ERDC Project No. 2511

Intensive Field Trial of Ethanol/Petrol Blend in Vehicles

Executive Summary

Prepared by
Apace Research Ltd
December 1998

Phone: 02-9639 0588
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- Materials compatibility

  Materials compatibility evaluation consisted of inspection of the fuel system components fitted to all the vehicles tested for emissions. The parts most likely to be affected i.e. elastomer hoses, fuel filters and strainers, plastic components, fuel tanks etc. were inspected by NRMA Service and Apace personnel. Fuel return hoses were replaced on all vehicles and the removed hoses were subsequently inspected by independent inspectors drawn from IAME, SAE and NRMA.

  A catalytic converter removed from a vehicle known to have operated exclusively on 10% v/v ethanol/petrol blend for 150,000 km was inspected by Prof. N.W. Cant of Macquarie University.

  GUD Pty. Ltd (manufacturers of after market fuel filters) have advised that their fuel filters are ethanol/petrol blend compatible.

  All of the test vehicles were of domestic build however confirmation was received from FCAI that all imported vehicles are compatible with 10% v/v ethanol/petrol blend.

- Engine wear

  A total of four engines were stripped by NRMA at their Villawood workshop and inspected by independent inspectors drawn from IAME, SAE and NRMA.

  Engine oil analysis was carried out by Oilcheck Pty. Ltd and included:

~ Wear metals	~ Fuel dilution
~ Water content	~ Oxidation
~ Viscosity	~ Nitration
~ Pentane insolubles	~ Dispersancy
~ Acid index	~ Total Base Number

- Water tolerance

  Blending, storage, transport and distribution systems were evaluated in conjunction with ethanol/petrol blend marketers.

2.2 Technical Results

The project confirmed the technical and commercial viability of using a 10% v/v ethanol/petrol blend in the existing vehicle fleet.

2. RECORD OF THE PROJECT

2.1 Work Program

The work program was in several parts, reflecting the project objectives, as follows.

- Emissions - measurement of exhaust and evaporative emissions formed the major part of the project. The parties involved included:
  - NRMA - contracted to prepare vehicles for testing;
  - NSW EPA - contracted to test vehicles in accordance with ADR37 protocols using both neat petrol and 10% v/v ethanol/petrol blend; and
  - CSIRO - contracted by NSW EPA to carry out exhaust gas speciation from selected vehicles and evaluate ozone formation potential.

- Power - evaluated by NSW EPA using an engine dynamometer.

- Fuel consumption - measured as follows:
  - NSW EPA carried out the City and Highway fuel consumption measurements to AS2877-1986 as part of the emissions test protocol;
  - selected vehicle owners were requested to keep fuel consumption records; and,
  - BOGAS customers were requested to complete a fuel consumption survey form.

- Drivability - Hot and Cold Drivability were evaluated according to test protocols supplied by FCAI.
  - Hot Drivability was evaluated in two parts:

    Part 1 - Four almost new vehicles were tested at Bourke, NSW, by NRMA representatives, however the results were not acceptable to the Steering Committee due to low test fuel Reid vapour pressure (RVP).

    Part 2 - Three post 1986 vehicles (two EFI, one carburetted) and one pre 1986 vehicle (LP, carburetted) were tested at Broken Hill, NSW, by a representative of FCAI.

  - Cold drivability was evaluated by NRMA representatives at Londonderry, NSW. Three 1986-on vehicles (two EFI, one carburetted) and one pre 1986 vehicle (LP, carburetted) were tested.

1.6 Benefits

There are a wide and diverse range of benefits to be obtained by industry, the economy, the community and Australia as a whole from an ethanol fuel industry.

These benefits include:

- increased fuel self-sufficiency;
- improved balance of trade/saved foreign exchange; and,
- reduction in vehicle regulated exhaust emissions.

In addition to the above mentioned benefits there are the following important benefits that are uniquely obtained from the use of ethanol fuel produced from biomass:

- Reduced emission of carbon dioxide.
- Expansion of the agricultural economy, value enhancement of existing biomass resources, treatment of land degradation and re-afforestation.
- Nationwide decentralisation and regional industry development.

An ethanol fuel industry is unique insofar as there is no other industry which offers the prospect of achieving a substantial reduction in the emission of carbon dioxide from the transport and industrial sectors whilst simultaneously addressing persistent lack of employment opportunities in rural areas and also providing solutions to land degradation which is arguably the biggest of Australia's environmental problems.

1.7 Recommendations

Ethanol/petroleum fuel blends directly address vehicle exhaust emissions and transport fuel security of supply issues. In addition to reducing currently regulated vehicle emissions, the renewable ethanol content of these fuels can result in a net reduction in the emission of carbon dioxide.

It is recommended that both Federal and State Governments encourage the use of ethanol in blends with hydrocarbon fuels by:

- supporting research and development into new low cost methods of fuel ethanol production; and,
- offering investment incentives to manufacturers and distributors of fuel ethanol.

It is also recommended that further research be conducted to:

- determine the level of evaporative emissions from 10% v/v ethanol/petrol blend under "real world" conditions such as by using the Multiday Diurnal SHED test method in force in the United States since January 1996; and,
- to improve the measurement methods for the determination of the "toxics" and aldehydes in exhaust and evaporative emissions.

Several alternatives exist to modify the characteristics and ethanol content of the blend. These include:

- Hydrated ethanol/petrol emulsions researched under ERDC Project No: 2512, "Emulsions of Hydrated Ethanol in Hydrocarbon Fuels" directly address issues relating to the use of ethanol/petrol blend in unmodified vehicles. Such an emulsion has a lower vapour pressure, greater water tolerance and, potentially, reduced NOx emission on combustion compared to the 10% v/v anhydrous ethanol/petrol solution currently used.
- Increase the ethanol content to 22-25% v/v (E22) as used in Brazil. This reduces evaporative emissions but requires dedicated engine tune and material compatibility issues need to be addressed.
- Increase the ethanol content to 85% v/v (E85). A dedicated engine/vehicle combination is required. Both Ford and General Motors in the United States produce significant numbers of such vehicles for the US market.

1.5 Commercialisation

Widespread commercial use of ethanol as a petrol supplement dependent upon ethanol availability. Fuel ethanol availability is to a large extent dependent on Federal and State energy, environment and industry policies. To increase investment in fuel ethanol production, governments must encourage fuel ethanol production and use by incentives and/or legislation.

- Fuel consumption:
  - increases by 2.6% for the City cycle; and
  - increases by 2.6% for the Highway cycle.

- Hot and Cold drivability:
  - reduced tendency for "knock" under both hot and cold conditions; and,
  - no other significant differences are observed.

- Materials compatibility:
  - there is no discernible effect on any plastic or elastomer materials; and,
  - there is no discernible corrosion in fuel wetted metal parts such as fuel tanks, lines, pressure regulators, etc.

- Engine wear:
  - there is no additional or unusual wear to that normally expected; and
  - there is no additional increase in wear metals or decrease in total base number (TBN) of the lubricating oil.

- Water tolerance:
  - the quality of ethanol produced and stored in its neat form must be of a high standard and the water content maintained below 1.25% w/w;
  - an ethanol compatible water detecting paste must be used to establish the water content of underground storage tanks (standard paste is not suitable) and the water content must be kept to a minimum; and,
  - older vehicles are more prone to suffer from phase separation when first fuelled with ethanol/petrol blend, however subsequent continuous use of ethanol/petrol blend prevents water accumulation within the fuel tank.

1.4 Applications

The use of biomass ethanol in petroleum fuels directly address vehicle exhaust emissions and transport fuel security of supply issues of national and international concern. Most importantly, the renewable ethanol content of these fuels can result in a net reduction in the emission of carbon dioxide.

The 10% v/v anhydrous ethanol/petrol blend as used in NSW, Australia, and internationally requires no modifications to vehicles in service now and in the foreseeable future and requires minimal changes to the fuel distribution infrastructure.

Aldehydes

- formaldehyde increases by approximately 25%;
- acetaldehyde increases by approximately 180%; and,
- acrolein increases by about 5%.

Note:

1. The value for acrolein is indicative only and must be treated with extreme caution.
2. The large increase in acetaldehyde emission is from a low base level and does not result in an overall increase in ozone formation potential or health risk assessments.

Carbon Dioxide

- exhaust CO_2 increases by 1%; however,
- net CO_2 emission decreases by up to 7% on full carbon cycle basis.

- Evaporative emissions (SHED test method - ADR37 protocol):
  - "diurnal" increases by approximately 10% ;
  - "hot soak" increases by approximately 40%;

  Note: It is reported that there is little or no increase in evaporative emissions with the Multiday Diurnal SHED test method in force in the United States since January 1996.

- Ozone formation potential:
  - of exhaust emissions decreases by approximately 22%
  - of the evaporative emissions (ADR37 SHED test method) increases by approximately 29%
  - little or no change in total ozone formation potential after weighting exhaust and evaporative emissions (+0.24%)

  Note: If evaporative emissions are lower than obtained with ADR37 SHED test method then ozone formation potential is decreased.

- Health risk assessment of "toxics" and aldehyde emissions:
  - carcinogenic risk decreased by approximately 24% (Environment Defence Fund risk factors); and,
  - acute and chronic (respiratory, reproductive and neurological) health risks increase by 3% (Environment Defence Fund risk factors).

  Note:

  1. The increase in acute and chronic health risk is almost entirely due to the estimated increase in acrolein and must therefore be treated with caution.
  2. Any increased acute or chronic health risk due to increased acrolein emission is negligible compared to the decreased health risk resulting from decreased CO emission.

1.3 Findings and Conclusions

10% v/v ethanol/petrol blend offers significant benefits in terms of reductions in exhaust and greenhouse gas emissions with no apparent detrimental effect on other aspects of engine or vehicle performance.

When measured according to ADR37 protocol (SHED test) there is a significant increase in evaporative emissions with 10% v/v ethanol/petrol blend compared to neat petrol. However, there is no increase in ozone formation potential with 10% v/v ethanol/petrol blend due to the lower ozone formation potential of the exhaust emissions from 10%v/v ethanol/petrol blend. In the United States the ADR37 SHED test method has been replaced by the "Multiday Diurnal" SHED test method which is considered by U.S. EPA to more accurately model "real world" conditions. United States reports suggest that, when tested using the Multiday Diurnal SHED test method, the mass of evaporative emissions from 10% v/v ethanol/petrol blend is not significantly different to that from neat petrol.

Further work needs to be undertaken to determine the "real world" evaporative emission from 10% v/v ethanol/petrol blend.

It is estimated that the 1999 passenger vehicle fleet comprises approximately 25% pre-1986 vehicles using leaded petrol (LP) and 75% 1986-on vehicles using unleaded petrol (ULP). The results of this project for the 1999 fleet composition show that, when compared to use of neat petrol, use of 10% v/v ethanol/petrol blend has the following effects:

- Regulated exhaust emissions:
  - CO decreases by approximately 32%;
  - THC decreases by approximately 12%; and
  - NOx increases by approximately 1%.

  Note: The large decrease in CO emission and the resultant decrease in health risk is the main reason for the mandating of use of oxygenates in CO non-attainment areas in the United States.

- Non-regulated exhaust emissions:

  "Toxics"
  - 1-3 butadiene decreases by approximately 19%;
  - benzene decreases by approximately 27%;
  - toluene decreases by approximately 30%;
  - xylenes decrease by approximately 27%;

1. ACCOUNTABILITY

1.1 Project Need

Ethanol/petroleum fuel blends directly address vehicle exhaust emissions and transport fuel security of supply issues. The renewable ethanol content of these fuels can result in a net reduction in the emission of carbon dioxide ("greenhouse gas") as well as reduce currently regulated vehicle exhaust emissions of carbon monoxide (CO) and hydrocarbons (HC). Use of ethanol/petroleum fuel blends initially in the existing vehicle fleet is essential to develop the technology and infrastructure necessary to support widescale production and use of ethanol fuel.

In the United States, Brazil and Sweden there is already widespread use of ethanol fuel and/or ethanol/petroleum fuel blends, while in many other countries such blends are being introduced. In Australia, Bowen Petroleum Services, Burmah Fuels and Marina Petroleum have been marketing 10% v/v ethanol/petrol blends (ULP and Super) within their respective market areas since 1992. Currently, approximately 16 million litres of fuel ethanol is sold in Australia each year.

This project addresses the need to:

- identify the effects resulting from introduction of ethanol fuel into the transport sector; and,
- provide Federal and State Governments with reliable information to assist in the development of effective strategies for achieving reductions in greenhouse gas and noxious emissions from the transport sector.

1.2 Project Objectives

The project objectives were to:

- establish the contribution of 10% v/v ethanol/petrol blend to reducing greenhouse gas and noxious emissions;
- compare fuel consumption of 10% v/v ethanol/petrol blend with that of neat petrol;
- compare vehicle drivability on 10% v/v ethanol/petrol blend with that on neat petrol under various climatic conditions;
- examine fuel system component materials for compatibility with 10% v/v ethanol/petrol blend;
- compare engine wear on 10% v/v ethanol/petrol blend with that on neat petrol;
- examine water tolerance issues arising from storage, distribution and use of 10% v/v ethanol/petrol blend.

1. Weighting Methodologies for Emissions from Transport Fuels

1.1 Introduction

1.1.1 Scope of Work

This chapter responds to a request from the Australian Greenhouse Office (AGO) to develop a weighting scheme for air quality that enables all emissions affecting air quality to be weighted and combined into a single measure of air quality. The international agreement on the use of the GWP as a weighting factor for different greenhouse gases means that it is straightforward to calculate the greenhouse gas emissions in CO_2-equivalents, and this measure can be used to compare the greenhouse gas emissions performance of different alternative fuels. There is no similar agreement in relation to other gases that fall under the general category of air pollutants.

The chapter explores alternative approaches to address the question of how to weight emissions that affect air quality. A range of models are presented that should only be considered as being illustrative of possible approaches and how they would be implemented. In section 1.4 and 1.5, the purpose of examining these models is to promote discussion about possible models and methodologies for weighting fuels, rather than a debate about the merits of each fuel.

No conclusions are meant to be drawn from the analysis of the fuels themselves in sections 1.4 and 1.5. Another approach might have been to refer to fuels “A”, “B” and “C” rather than specific fuels. However, this approach might have been considered to be too abstract. In summary, each example should be examined in terms of the merits of the model and the methodology by which it weights emissions rather than the outcome for each fuel.

Section 1.6 applies a weighting methodology as specified by Environment Australia.

1.2 Background

The air that we breathe is a mixture of many different gases. It is a mixture of 78% nitrogen, 21% oxygen, slightly under 1% argon, and about 0.037% carbon dioxide. These percentages are based on units for the gases that comprise volume mixing ratios.

We can represent such a mixture mathematically. In this case:

$$A = \Sigma w_i E_i \qquad (1)$$

where A represents air, w represents the proportions of each gas (0.78, 0.21, 0.00963, 0.00037), and E is the volume mixing ratio of each of the gases. The symbol Σ represents summation, in this case over four gases.

This simple example illustrates the difficulties that are involved in any weighting scheme. Firstly, there needs to be a decision on the choice of weights (w in this case). Secondly, there needs to be a decision as to the appropriate units for the gases (percentages by volume, in this case). Thirdly, there needs to be a decision on the number of entities to be summed.

The example given above, for air, is straightforward because its composition can be determined by direct experiment. There is another straightforward example, namely that of greenhouse gases. International agreement has been reached on how to combine greenhouse gases. Before proceeding to the more difficult case of air quality weighting schemes, the weightings used for greenhouse gases will be reviewed.

1.3 Greenhouse Gases

The Australian National Greenhouse Gas Inventory (NGGIC, 2000) follows the international agreement that Greenhouse gas emissions will be weighted using IPCC 100 year global warming potentials as given in Table 1.1.

Table 1.1
100 years global warming potentials

Gas	GWP
Carbon dioxide	1
Methane	21
Nitrous Oxide	310
Sulfur Hexafluoride	23900
CFC-11	3800*
CF_4	6500
C_2F_6	9200

*Direct only. Other estimates include indirect effects

This means that a measure of greenhouse gases, called the carbon dioxide equivalent (CO_2-e), is computed as:

$$CO_2\text{-e} = CO_2 + 21\ CH_4 + 310\ N_2O + 23900\ SF_6 + \ldots \qquad (2)$$

where the weights are as given in Table 1.1, and the gases are measured in units of mass per unit time, tonnes per year being a representative example.

1.4 Air Quality

There is no agreement on how to combine air pollutants. This section reviews existing available weighting methodologies.

1.4.1 Air quality indexes

Air pollution control authorities have found it useful, when presenting air quality information to the public, to use an Air Quality Index — or an Air Pollution Index — as a means of combining information on all of the pollutants.

Table 1.2
Victorian air pollution index categories

Air quality category	Associated colour	Index range
Very Good	Blue	0-33
Good	Green	34-66
Fair	Yellow	67-99
Poor	Red	100-149
Very Poor	Black	150 or higher

(Source: http://www.epa.vic.gov.au/aq/abindex.htm)

Australian authorities typically use the ratio of pollutant concentration to pollutant standard level as the basis from which to construct an air quality index. Victoria, for example, expresses the index value as a percentage that is calculated for ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, fine particles (PM10) and visibility. The maximum of these figures is taken as the index value for the relevant monitoring station, and one of five colour-coded air quality categories (from blue to black) is chosen on the basis of the index, as shown in Table 1.2.

In this case the weights, w, are given by

$$w = 100/(\text{value of the NEPM standard}) \qquad (3)$$

so that the measure of the pollutant, E, need to be expressed in the same units as the NEPM standard. Air pollution indexes in Australia are not based on a sum of weighted pollutants, unlike Equation (1), but are set equal to the maximum value of the weighted pollutants.

1.4.2 Stage 1 Alternative Fuels Study Method

The Stage 1 alternative fuels study (Beer et al., 2000) developed a weighting scheme to rank various alternative fuels. The scheme was based on two major criteria:

1. Health effects guided the choice of the weights, w.
2. The quantities being evaluated (E) were the **ranked score** for the pollutant.

Emissions of carbon monoxide do not cause problems in Australia, so that the study believed that it did not need to be considered in evaluating alternative fuels. NOx and NMHC (i.e. THC less methane) together are important because they are the precursors of smog. . NOx (in the form of NO_2) is linked to respiratory illness. Particulate matter is of concern because of the epidemiological evidence that particulate matter has short-term and long-term health effects, including mortality, such that a 10 $\mu g/m^3$ increase in PM10 is associated with a 1% increase in mortality.

These air pollution and health considerations indicated that fuel emissions should be considered in two classes – those used primarily in urban areas (e.g. buses), and those used primarily in rural areas (e.g. trucks). Urban vehicles need to have low emissions of NOx, THC and particulate matter. However, as smog is not a problem in rural areas, the THC and NOx levels of emission are not as important as the particulate emissions. This is especially the case as the NEPM for Ambient Air Quality seeks equal protection for all Australians. Though it may be argued that rural particulate emissions are not important because of the occurrence of natural dust, there are theories that health effects arising from inhalation of particulate matter arise only when carbonaceous particles, such as those from combustion, are inhaled. Accordingly it was recommend in Beer et al. (2000) that rural and highway air quality evaluation include particles, particularly as many small country towns sit alongside major transport routes.

Ranking (including uncertainty)

The Stage 1 study ranked the emissions according to their average characteristics in terms of global warming and pollution impact, and assigned its rank value to each gas as a score.. To allow for variation in the emission results, the gases were ranked for one standard deviation above and below their average emissions and again scored. The three scores were summed, and the final ranking based on this sum.

This method is straightforward when calculating the rankings on the basis of greenhouse gases (expressed in CO_2-equivalents). In relation to air quality, the ranking was less straightforward. Because of the concern for human health and well-being, particulate matter is believed to pose the greatest health risk. Hydrocarbons pose a health risk in the long term, as a number of compounds are carcinogenic. In addition hydrocarbons are considered to be one of the precursors for the formation of ozone, and reductions in hydrocarbon are the most effective way of reducing ozone. Oxides of nitrogen are also ozone precursors, and NO_2 poses a health risk at high concentrations (which are rarely found in Australian cities). Finally, carbon monoxide poses a health risk at concentrations that do not occur in Australia.

It was thus decided to weight the air pollutants on the basis of their health risk.

Air pollution health risk

The NEPM for Ambient Air Quality (National Environment Protection Council, 1998) provides estimates of the short-term health effects of the criteria pollutants.

CO – Loss of 1 day's earning for 50,000 people at a cost of $6 million. (National Environment Protection Council, 1998: p.52)

NO_2 – 10 to 15% of the population display respiratory symptoms at a cost of $5 million. (National Environment Protection Council, 1998: p. 61)

O_3 – Up to 10 deaths per year in Australia, with total costs up to $810 million. (National Environment Protection Council, 1998: p.75-76)

PM - Up to 2,400 deaths per year in Australia, with an associated health cost of $17.2 billion. (National Environment Protection Council, 1998: pp.122 & 127)

In the absence of more detailed information, the health effects related to ozone (O_3) are ascribed equally to NOx and hydrocarbons. (National Environment Protection Council, 1998: p. 78)

In addition, hydrocarbons have long-term health effects that were examined by Hearn (1998) for Melbourne. If we extrapolate his figures to all of Australia then there are approximately 1250 to 1785 deaths per annum as a result of hydrocarbons (excluding deaths ascribed to the particulate matter in the hydrocarbons).

Insufficient is known about the source of the particulate matter to determine how much of it is attributable to traffic, and how much of the health effects are attributable to traffic. Industry emits particles, but these are generally in the larger size ranges. Present evidence indicates that most health effects result from the smaller sizes below PM10. Traffic emits most particles in the PM2.5 size range. Information on emissions alone does not provide insights into the contribution of traffic to airborne concentration of particles other pollutants will form secondary particulate matter. This report has examined particulate matter emissions as PM10.

The main health risk for Australians arises from particulate matter and from hydrocarbons. Given the considerable uncertainties associated with these estimates of mortality, and the costs of morbidity, the health risk weighted air quality rankings were as follows:

The summed score for particulate matter was multiplied by 2, the summed score for hydrocarbons was multiplied by 1, the summed score for NOx was multiplied by 0 (i.e it was ignored because less than 0.2% of health effects are related to NOx),, and the summed score for carbon monoxide was multiplied by 0 (i.e it was also ignored because less than 0.2% of health effects are related to CO),, and the totals added together to produce a final air quality score, as shown in Table 1.3.

Table 1.3
Fuel scores and final ranking in relation to air quality; the lowest value denotes the lowest emissions

Fuel	CityPM	CityHC	City NOx	CityAQ	CityAQ	Hwy PM	HwyHC	Hwy NOx	HwyAQ	HwyAQ
				Score	Rank				Score	Rank
Weight	2	1	0			2	1	0		
Diesel	28	25	24	81	**10**	14	17	17	45	**5**
LSD	15	15	20	45	**4**	16	10	15	42	**4**
LSD+W5	21	10	19	52	**5**	20	11	24	51	**7**
ULS	18	19	14	55	**7**					
ULS+W5	21	14	13	56	**8**					
LPG	9	4	4	22	**1**					
CNG	3	18	7	24	**2**	7	3	7	17	**1**
LNG	6	32	33	44	**3**	3	18	3	24	**2**
E95	15	24	7	54	**6**	8	24	8	40	**3**
BD20/35	29	17	30	75	**9**	16	14	20	46	**6**
BD100	33	20	27	86	**11**	24	11	14	59	**8**

1.4.3 *Load-based licensing valuation methods*

As a result of the NSW load-based licensing legislation, there has been substantial activity devoted to assigning the load valuation to be placed on airborne pollutants. The Environment Protection Authority (1997) produced a table of results, based on cost-benefit analyses of health effects, which are reproduced in Table 1.4. The pollutants are intended to deal with motor vehicle emissions. The dollar values are determined on the basis of the mean of valuations for US and European conditions.

Table 1.4
Valuation of airborne pollutants from motor vehicles (Environment Protection Authority, 1997)

Pollutant	Valuation ($/kg)
Particles	1.81
CO	0.025
NO_X	1.49
Total hydrocarbons (THC)	0.96

Thus, in some respects the valuation weighting method – being based on health risk weightings, agrees with the philosophy of the Stage 1 weighting method. It may be noted that when expressed in dollars per tonne, the numerical value for particles is approximately equal to the annual number of deaths in Australia attributed to particulate matter. With this in mind, some of the actual values appear curious. NOx, for example, appears to have a much higher value than one would expect on the basis of expected Australian health effects. However, applying the weights directly to mass emissions (rather than ranked scores) leads to a far more significant difference. To appreciate this difference, Table 1.5 has used the results of Beer et al. (2000: Table 3.1) to determine load valuations for tailpipe emissions of urban buses. Because of the combination of high NOx emissions (on a g/km basis) and a high NOx valuation, the resulting load valuation rankings are dominated by NOx.

Table 1.5
Load valuation (c/km) for tailpipe emissions from urban buses

Fuel	CO (g/km)	THC (g/km)	NOx (g/km)	PM (g/km)	c/km
Biodiesel	7.68	0.84	17.2	0.6	2.77
CNG	0.66	2.75	9.87	0.05	1.75
Diesel	1.88	1.1	15	0.47	2.43
E95	14.6	4.85	7.83	0.21	1.71
LNG	9.05	2.45	32.5	0.01	5.10

1.4.4 Index-based weighting (hazard-quotient method)

By analogy with the construction of an air pollution index, it is possible to construct a fuels emission index based on the emission standards specified under either the Australian Design Rules or the European emission standards. This task will now be undertaken on the basis of the Euro4 ETC standards for heavy vehicles.

The Euro4 standards are based on vehicle emissions in units of g/kWh, which have been converted to g/MJ. The standards are given in Table 1.6.

Table 1.6
Euro4 emissions standards (g/MJ) for heavy vehicles

Pollutant	CO	NMHC	NOx	PM	CH_4
g/MJ	1.11	0.015	0.97	0.0083	0.31

Beer et al. (2000), in Table A4.1 of their Appendix 4, provide a table of emissions for buses expressed in g/MJ. The diesel fuel in this study was regular diesel used in US buses with engines that corresponded to Euro2 standards. These are reproduced in Table 1.7. These values enable one to construct a fuels emission index based on the sum of the ratios. The ratios are determined by the ratio of the emission to the Euro4 standard. These are given in Table 1.8. The introduction of advanced technologies will lead to improvements in all of the fuels.

Table 1.7
Tailpipe emissions from urban buses (g/MJ)

Fuel	CO (g/MJ)	THC (g/MJ)	NOx (g/MJ)	PM (g/MJ)	c/km
Biodiesel	0.521	0.054	1.176	0.041	0.001
CNG	0.027	0.111	0.398	0.002	0.101
Diesel	0.092	0.055	0.736	0.023	0.001
E95	0.641	0.213	0.345	0.009	0.004
LNG	0.382	0.113	1.332	0.001	0.102

Table 1.8
Fuels emission index for each pollutant, and the summed index

Fuel	CO (g/km)	THC (g/km)	NOx (g/km)	PM (g/km)	CH_4	Sum
Biodiesel	0.5	3.6	1.2	4.9	0.0	10.2
CNG	0.0	7.4	0.4	0.2	0.3	8.4
Diesel	0.1	3.7	0.8	2.8	0.0	7.3
E95	0.6	14.2	0.4	1.1	0.0	16.2
LNG	0.3	7.5	1.4	0.1	0.3	9.7

1.5 Air Toxics

Nolan-ITU (2001) reviewed and extended the valuation of airborne pollutants based on the NSW 1998 proposed pollution controls. They recommend a value of $0.96/kg for methane (apparently equating methane with total hydrocarbons). They obtained substantially different valuations for a number of the pollutants. Particulate matter increased to a value of $9.40/kg and oxides of nitrogen increased to $3.82/kg. The most dramatic change was in the valuation for hydrocarbons. The valuation for total hydrocarbons according to the 1998 proposed pollution controls was set at $3.52/kg, but the value for chlorinated and aromatic hydrocarbons was set at $5,873/kg.

The reason for this is that the term chlorinated and aromatic hydrocarbons is being used to encompass those chemicals that cause cancer. The US EPA designated toxics emitted from conventional automobile exhaust and evaporative emissions are benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and polycyclic aromatic hydrocarbons. The US EPA also designated diesel particulate matter to be an air toxic. The Environment Australia list of priority air pollutants under the air toxics program does not include diesel exhaust, but consists of 32 pollutants, including the other ones in the US EPA list.

MacLean (1998) and MacLean & Lave (2000) calculate weighted emissions of toxics from conventional and alternative fuels. Their weighting scheme is based on the occupational health and safety based threshold limit value (in mg/m^3) for 1,3-butadiene as 4.4 mg/m^3 , a value for benzene as 1.6 mg/m^3, formaldehyde as 0.9 mg/m^3, acetaldehyde as 360 mg/m^3, and diesel particulate matter as 0.15 mg/m^3. They did not examine polycyclic aromatic hydrocarbons as such. Thus, according to these values, the diesel particulate matter is the most toxic and acetaldehyde is the least. Their results for the total emissions (in grams) over the life of a vehicle are shown in Tables 1.9 and 1.10, where Table 1.9 shows the unweighted emissions (ie the weights are unity), and Table 1.10 shows the weighted emissions.

Table 1.9
Vehicle exhaust toxic emissions (grams per lifetime) from conventional and alternative fuels (Maclean, 1998)

Fuel	Benzene	1,3-butadiene	Formaldehyde	Acetaldehyde	Diesel PM	Aggregate toxics
Petrol	1540	112	252	168	-	2072
E85	161	18	672	3010	-	3861
CNG	4	0	175	20	-	199
Diesel					12,000	12,000

Table 1.10
Weighted vehicle exhaust toxic emissions (grams sulfuric acid equivalent per lifetime) from conventional and alternative fuels (Maclean, 1998)

Fuel	Benzene	1,3-butadiene	Formaldehyde	Acetaldehyde	Diesel PM	Aggregate toxics
Petrol	963	25	280	0.5	-	1268
E85	101	42	747	8.4	-	860
CNG	3	0	194	0.1	-	197
Diesel					80000	80000

The calculation of toxic risk from vehicle emissions has received considerable attention in California. The procedure adopted by the Office of Environmental Health Hazard Assessment (OEHHA) is to derive the toxic risk by using unit risk factors as the weighting coefficients (Marty, 2000). Table 1.11 gives values of these toxic risk factors for emissions that are liable to occur from alternative transport fuels as reported by OEHHA (1999).

Table 1.11
Unit risk factors for carcinogenic air toxics

	Benzene	1,3-butadiene	Formaldehyde	Acetaldehyde	Diesel PM	Polyclic Aromatic Compounds
$(\mu g/m^3)^{-1}$ (Swedish study)	8×10^{-6}	300×10^{-6}	100×10^{-6}	2×10^{-6}	70×10^{-6}	2.8×10^{-2}
$(\mu g/m^3)^{-1}$ (OEHHA, 1999)	2.9×10^{-5}	$1.7 \times 10^{4-}$	6.0×10^{-6}	2.7×10^{-6}	-	-
ppm (OEHHA, 1999)	9.3×10^{-5}	3.7×10^{-4}	7.0×10^{-6}	4.8×10^{-6}	-	-

An analysis from Sweden that is reported by Ospital (2000) followed a similar procedure but used substantially different unit risk factors, as also shown in Table 1.11. These values were then applied to the emissions from various alternative fuelled buses. Table 1.12 gives the comparison between the results using the Californian risk factors and the Swedish risk factors when the risk weighted emissions are normalised to that of uncontrolled ultra-low sulfur diesel, as used in Sweden.

Table 1.12
Relative Potency Weighted Emissions (Ospital, 2000)

Fuel/Treatment	Relative emissions using OEHHA risk factors	Relative emissions using risk factors from the Swedish study
Diesel	100	100
Diesel with catalyst	85	31
Diesel with particulate filter	10	37
Diesel, DPF+EGR	7.5	38
Ethanol with catalyst	4.9	88
CNG "Average"	6.1	110
CNG "BAT"	3.1	55

1.6 ADR and Fuel Quality Review Method

According to information received from Environment Australia, the Regulatory Impact Statements accompanying the 1999 Australian Design Rules for Vehicle Emissions and the Fuel Quality Standard Bill (2000) used economic weightings for the criteria pollutants determined by the NSW Environment Protection Authority. Environment Australia requested that we examine the results using these weightings as given in Table 1.13 (where it has been assumed that all NOx transforms to NO_2).

Table 1.13
ADR/FQR weights ($/tonne)

Pollutant	PM	HC	NOx	CO
$/tonne	$17,600	$1,440	$1,385	$12

These weights were examined with the results from the life-cycle analysis. The results of their application to low sulfur diesel in trucks are given in Table 1.14, and are shown for all of the fuels examined in this study in Table 1.15.

Table 1.14
ADR/FQR weights applied to exbodied emissions from low sulfur diesel

Pollutant	PM	HC	NOx	CO	
Weights	$17,600	$1,440	$1,385	$12	$/tonne
Emissions	0.428	2.62	11.0	2.71	g/km
Weighted emissions	7533	3773	15235	32.5	µ$/km

The results of Table 1.13 and Table 1.14 occasioned considerable comment when discussed with stakeholders during a forum held in June 2001. Some stakeholders (primarily representing biodiesel producers) felt that the weight assigned to PM was too high. Others (ANGVC, EPA Victoria) felt that the weighting assigned to PM was too low. We agree with the latter group. On the basis of the weightings that we were asked to use, fuels that decrease their NOx emissions are favoured over fuels that decrease particulate matter emissions. This weighting assigns greater value to the reduction of urban smog than to the preservation of human health. This is not in accord with current Australian air quality objectives as encapsulated in the desired environmental outcome of the Ambient Air Quality NEPM, namely the adequate protection of human health and well-being.

Environment Australia has requested that the following statement be included regarding the weightings:

> "Environment Australia recognises the lack of certainty in the results of the weighting exercise. These results have value in indicating the relative impact of various fuels on emissions of concern to the Commonwealth. Ultimately, however, future policy development will require the Commonwealth to determine the most cost-effective means of addressing priority pollutants/air toxics. For this reason, the Commonwealth would be concerned if stakeholders took the results of Part 3 as solely determinative of future policy directions."

Table 1.15
Weighted emissions obtained (in µ$/km) for trucks using alternative fuels on the basis of exbodied emissions

Fuel and processing method	HC	NOx	CO	PM10	Total
LS diesel (Aus)	2173	15581	33	7716	25502
ULS diesel (Aus)	1963	13712	41	6058	21773
ULS diesel (100% hydroprocessing)	1938	13504	41	6039	21521
Fischer-Tropsch diesel	1531	15117	30	4834	21512
Biodiesel (canola)	2072	17860	20	5235	25188
Biodiesel (soybean)	2461	17694	26	5145	25327
Biodiesel (rape)	2087	18109	20	5343	25559
Biodiesel (tallow-expanded sys. boundary)	2029	17805	20	5221	25075
Biodiesel (tallow-eco.allocat.)	864	16321	864	4833	22883
Biodiesel (waste oil)	860	16294	17	4828	21998
Biodiesel (waste oil 10% original oil value)	874	16363	17	4828	22083
CNG (Electric compression)	422	2123	1	211	2758
CNG (NG compression)	461	2308	2	228	2998
LNG (from existing transmission line)	454	3210	2	103	3768
LNG (Shipped from north west shelf)	455	3235	2	108	3799
LNG (perth)	490	3797	2	451	4739
LPG (Autogas)	1595	2114	5	1703	5417
LPG (HD5)	1632	6256	5	1245	9137
LSdiesohol	2046	14310	36	6010	22402
Ethanol azeotropic (molasses-expanded sys.bound.)	1160	14072	39	5510	20781
Ethanol azeotropic (molasses-economic allocation)	1200	12227	127	5059	18613
Ethanol azeotropic (wheat starch waste)	1121	12945	39	5062	19167
Ethanol azeotropic (wheat)	2102	15831	135	5716	23784
Ethanol azeotropic (wheat) fired with wheat straw	8255	15277	299	9416	33247
Ethanol azeotropic (woodwaste)	5317	12662	168	7445	25592
Ethanol azeotropic (ethylene)	9608	16800	46	5952	32407
PULP	593	619	27	1628	2867
E10PULP (molasses-exp.sys.bound.)	482	599	23	1626	2731
E10PULP (molasses-eco.allocat.)	482	573	24	1619	2699
E10PULP (wheat starch waste)	481	574	23	1624	2703
E10PULP (wheat)	495	614	24	1626	2760
E10PULP (wheat WS)	605	605	27	1691	2928
E10PULP (wood waste)	563	567	25	1663	2819
E10PULP (ethylene)	602	628	23	1630	2883
E85PULP (molasses-exp.sys.bound.)	457	810	29	1588	2884
E85PULP (molasses-eco.allocat.)	465	474	45	1505	2489
E85PULP (wheat starch waste)	449	477	29	1576	2531
E85PULP (wheat)	628	1002	47	1588	3264
E85PULP (wheat WS)	2019	876	84	2427	5405
E85PULP (wood waste)	1489	400	60	2068	4018
E85PULP (ethylene)	2005	1176	30	1637	4848
Hydrogen (from natural gas)	516	787	2	128	1432

1.7 Discussion

The choice of any weighting scheme for road transport emissions must meet two criteria of acceptability. The scientific aspects of the scheme must be acceptable, and the public policy aspects of the scheme must be acceptable.

The ambient air quality NEPM declared that "the desired environmental outcome of this Measure is ambient air quality that allows for the adequate protection of human health and well-being." Ever since then it has been accepted that health-risk weighting of pollutants is the most appropriate weighting scheme. However, the science in this area is changing rapidly (Beer, 2000) so that weightings that were deemed appropriate in 1997 or 1998 may no longer be deemed appropriate today. In particular, in Table 1.4, and even more so in Table 1.15 and 1.16, the relatively high weighting (as expressed by a high price) for NOx and the relatively low weighting for particulate matter do not agree with the present consensus of the Australian health effects of the criteria pollutants as summarised in section 1.4.2. This also reflects the current view in the US. In the appendix to Ospital (2000) the California EPA states that: "It is possible to use the total PM emissions on a mass basis as a rough surrogate for the non-cancer health effects related to particulate matter emissions from both conventionally and alternatively fuelled engines".

Australian public policy in this area is also in a state of rapid flux. Environment Australia released the final draft of its Air Toxics State of Knowledge report[1] in late 2000. Both the NEPC and the EnHealth Council continue to examine the way to use risk assessment within Australia. This means that there are no agreed Australian unit risk factors to use for cancer risk. In addition, it is uncertain whether there are sufficient data on emissions from Australian conventional and alternative fuelled vehicles to enable adequate speciation of air toxics to take place.

Given the present state of knowledge in this area, the weightings adopted in the Stage 1 report, as described in section 1.4.2 of this chapter, reflect the present understanding. Cancer risks are assigned to the total hydrocarbons. The practice of using total hydrocarbons emissions as an indication of air toxics and their impacts has severe limitations. The composition of the mixture of hydrocarbons in exhaust will vary with fuel. Where total hydrocarbons is used as an indicator for relative importance of air toxic emissions the results are indicative only. Particulate matter is weighted according to recent epidemiological results. The relative magnitude of the final weighted values should be in the same proportion to the mortality attributable to each pollutant. Given that the ratio of HC to PM is in the expected ratio of 1 to 2, we conclude that in the ADR/FQR weightings (given in Table 1.14) the NOx weighting appears to be far too high in comparison to the HC and PM weightings.

However, we suspect that all the air quality valuations are too low. Representative valuations for CO_2 range from \$5 per tonne to \$500 per tonne. If we use a value of \$50 per tonne (the geometric mean of the range of estimates)[2], and note that a typical bus emits 1,300 g/km of CO_2, then the valuation associated with exbodied greenhouse gases is µ\$65,000/km for greenhouse gases emitted using low sulfur diesel, compared to about µ\$25,000/km for criteria pollutants emitted from low sulfur diesel. Surveys of the Australian public regularly reveal that air quality is considered to be a much higher environmental priority than greenhouse gases. This seems to indicate that weightings that lead to a total valuation for air quality that is about one-third that of greenhouse gases are unlikely to be correct weightings.

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[1] http://www.environment.gov.au/epg/airtoxics/sok_final_draft.html

[2] This figure has been chosen by the consultants as being a representative one for calculations. It has not been endorsed by the Australian Greenhouse Office and should not be taken to indicate a policy position on the part of the AGO.