4. Biodiesel

4.1 Introduction

Biodiesel is a generic name for fuels obtained by esterification of a vegetable oil. The esterification can be done either by methanol or by ethanol. Biodiesel can be used in a diesel engine without modification. By the year 2002 it is expected that there will be a European wide standard for biodiesel.

Canola is a member of the *Brassica* Family, which includes broccoli, cabbage, cauliflower, mustard, radish, and turnip. It is a variant of the crop rapeseed, with less crucic acid and glucosinolates than rapeseed. Grown for its seed, the seed is crushed for the oil contained within. After the oil is extracted, the by-product is a protein rich meal used by the intensive livestock industry.

Soybeans are a bushy, leguminous plant, *Glycine max*, native of South-East Asia that is grown for the beans, which are used widely in the food industry, for protein in cattle feed and for oil production.

Soybeans are grown predominantly in the wheat belts of Queensland and NSW and to a lesser extent in Victoria.

Tallow comes from meat rendering. This evaporates the moisture and enables the fat, known as 'tallow', to be separated from the high-protein solids, known as 'greaves'. Pure tallow is a creamy-white substance. The greaves are pressed, centrifuged or subjected to a process of solvent extraction to remove more tallow, before being ground into meat and bone meal (MBM).

Current possibilities for the processing of waste cooking oils appear to be:

- Treatment and use in stockfeed in Australia
- Export to Asia for soap or stockfeed production
- Use for production of biodiesel

It is also clear that some waste cooking oil is not collected and is disposed of in landfill or other locations. Biodiesel made from waste cooking oil has come to be known as McDiesel, because the largest source of waste cooking oil is McDonald's restaurants.

4.2 Full Fuel-Cycle Analysis of Emissions

Results are given for biodiesel made from three types of seed crops (canola, soybean, and rape), for biodiesel made from tallow and for biodiesel from waste cooking oil. In the case of these last two feedstocks, it has been assumed that tallow is a commercial product, whereas the cooking oil is a waste product. In both cases an alternative allocation (alt. allocat.) has been made that allows for the opposite situation.

4.2.1 Greenhouse gas emissions

Figure 4.1 depicts the greenhouse gas emissions estimated for biodiesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses. We have used data from Apelbaum Consulting Group (1997) for the passenger task and the freight task in Australia and taken the mean energy intensity for the Australian freight task to be 1.2 MJ/tonne-km (Apelbaum Consulting Group, 1997: p.118), and the energy intensity of buses to be 1.06 MJ/passenger-km (Apelbaum Consulting Group, 1997: p.116).

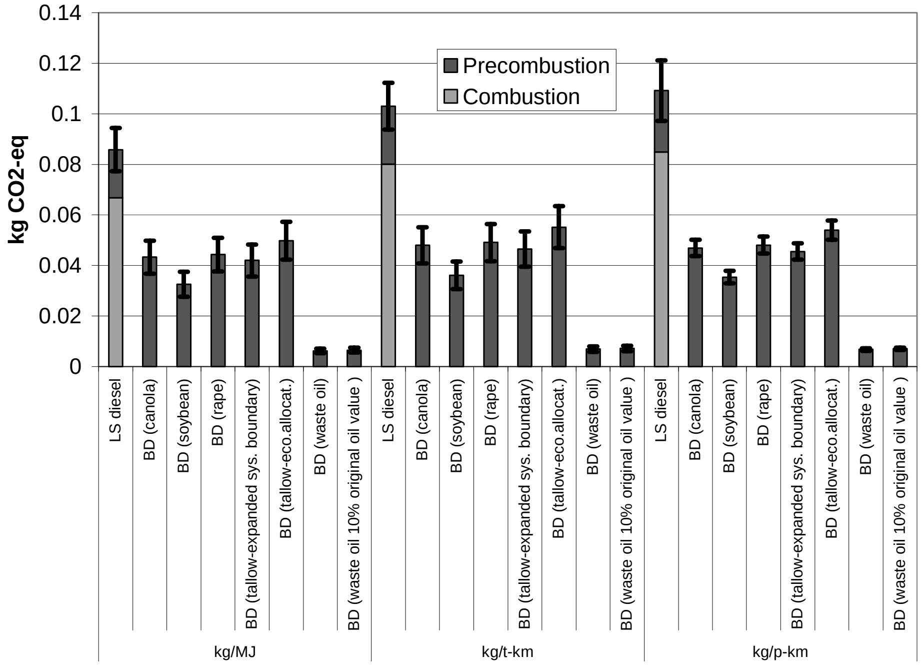

Figure 4.1
Exbodied emissions of greenhouse gases for biodiesel fuels and low sulfur diesel (LSD, the reference fuel). Tallow and cooking oil are treated both as waste and as physical inputs.

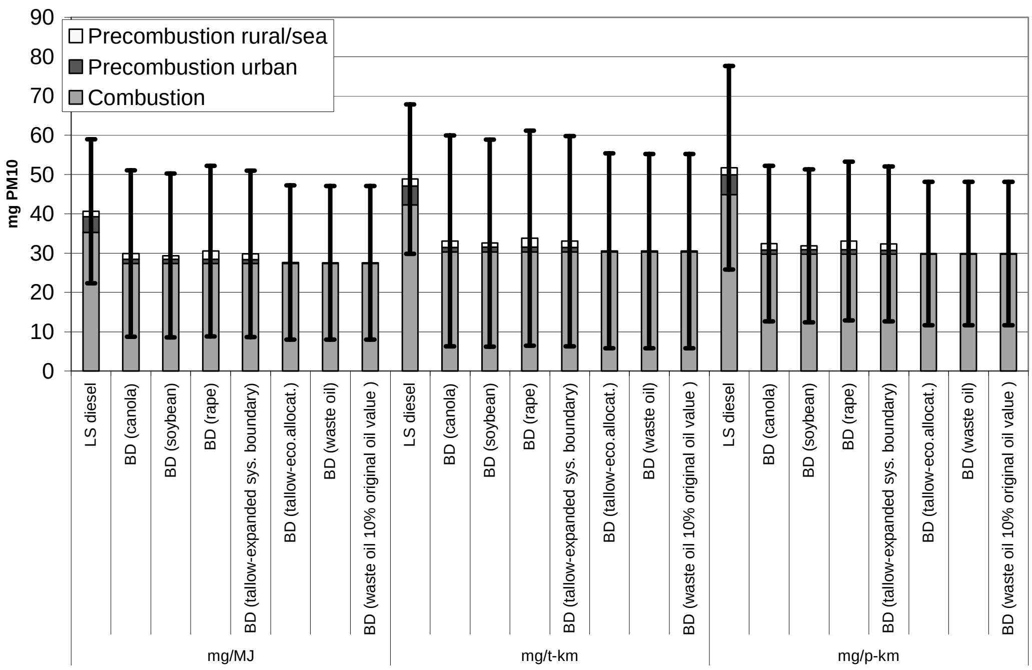

Figure 4.2
Exbodied emissions of particulate matter for biodiesel fuels and low sulfur diesel (LSD, the reference fuel). Tallow and cooking oil are treated both as waste and as physical inputs.

4.2.2 Particulate matter emissions

Figure 4.2 depicts the particulate matter (PM10) emissions estimated for diesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted.

4.2.3 Emissions of oxides of nitrogen

Figure 4.3 depicts the oxides of nitrogen (NOx) emissions estimated for diesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted.

4.2.4 Emissions of hydrocarbons

Figure 4.4 depicts the non-methanic hydrocarbon (HC) emissions estimated for diesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted.

The variability in the results is very evident. On the basis of the data that we used for the analysis, soy biodiesel emits more hydrocarbons than the reference fuel as a result of tailpipe emissions – the upstream hydrocarbon emissions are less. Canola and rape are comparable to LSD, being higher on a per energy basis but lower on a per distance basis. Tallow and waste oil have surprisingly small hydrocarbon emissions.

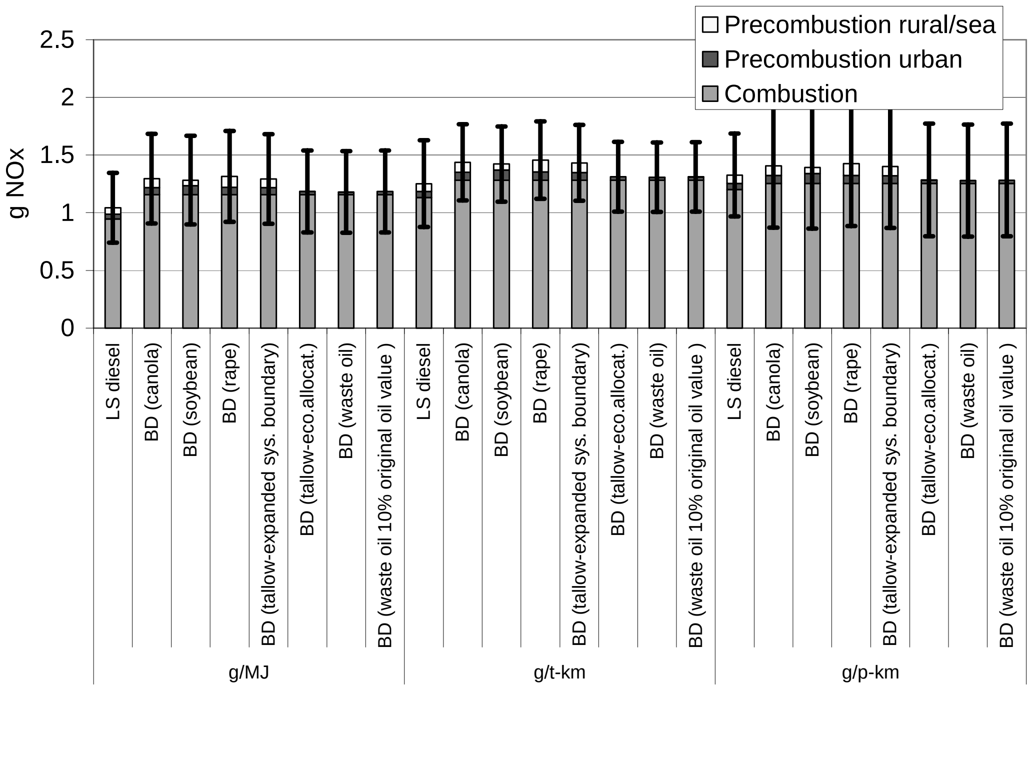

Figure 4.3
Exbodied emissions of oxides of nitrogen for biodiesel fuels and low sulfur diesel (LSD, the reference fuel). Tallow and cooking oil are treated both as waste and as physical inputs.

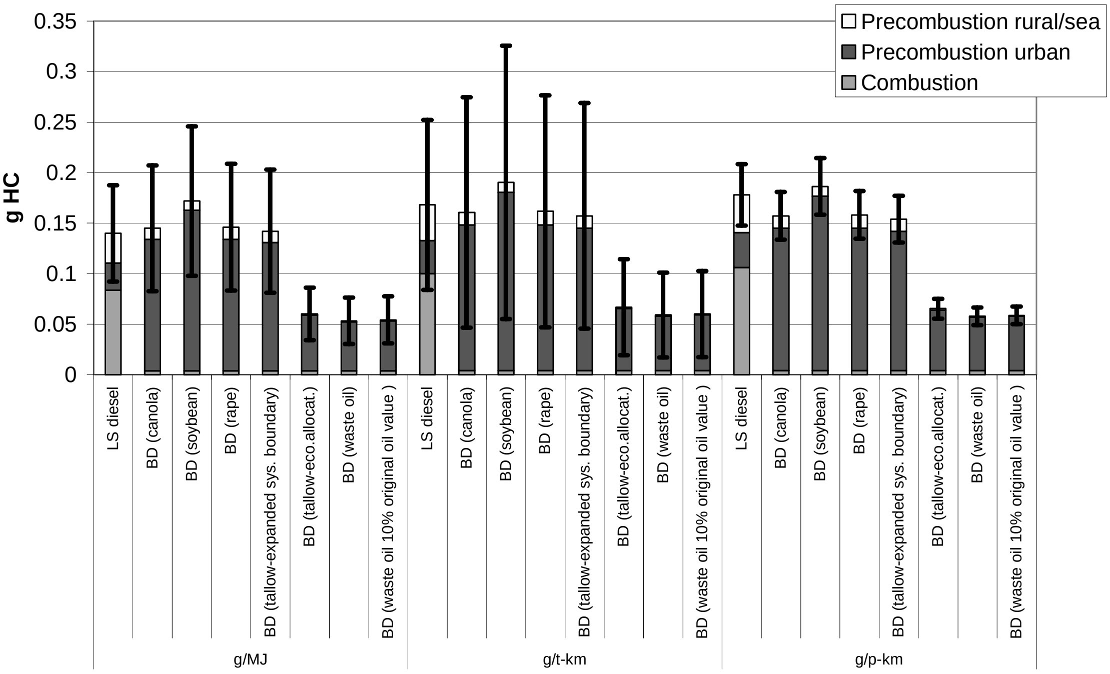

Figure 4.4
Exbodied emissions of hydrocarbons for biodiesel fuels and low sulfur diesel (LSD, the reference fuel). Tallow and cooking oil are treated both as waste and as physical inputs.

4.3 Viability, Functionality and Health Issues

There appear to be no health risks of air toxic emissions from biodiesel with respect to mortality, toxicity, fertility or teratology. All air toxic emissions from biodiesel are lower than equivalent diesel emissions except for acrolein. Though highly toxic, the slight increase in acrolein is offset by the decrease in the equally toxic aldehydes.

The National Biodiesel Board web site also points out that biodiesel over time will soften and degrade certain types of elastomers and natural rubber compounds. Precautions are needed when using high percent blends to ensure that the existing fueling system, primarily fuel hoses and fuel pump seals, do not contain elastomer compounds incompatible with biodiesel.

Cummins will warranty only biodiesel blends, though Caterpillar will warranty biodiesel in certain of their engines. In contrast to the cautious attitude of the manufacturers, the “truck in the park” project and other road-test projects found no difference in engine viability and functionality between diesel and biodiesel.

4.4 Environmental Issues

ESD issues

Biodiesel is made from agricultural crops and is thus more environmentally friendly and ecologically sustainable than fossil fuels. Our results confirm that, on a life-cycle basis, biodiesel is more climate-friendly than diesel. The carbon emissions caused by agricultural production and fertiliser production are less than the exbodied emissions from diesel made from fossil fuels.

Sustainability issues

Biodiesel is made from either crops or from animal product. Its feedstock is thus a renewable resource. Biodiesel will be a niche fuel, albeit a very useful one, because there is not sufficient area to grow the plants needed to convert all of Australia's diesel fuel usage to biodiesel.

Groundwater contamination

Not an issue with biodiesel, except for the possible use of i) pesticides or fertiliser during the growth of the crop from which the biodiesel is made, and ii) runoff from cattle feedlots (for biodiesel made from tallow).

4.5 ADR Compliance

100% biodiesel can be expected to meet all future Australian Design Rules for all pollutants except oxides of nitrogen which may be slightly above Euro3 and Euro4 standards, and possibly the particulate matter standard for Euro3. Arcoumanis notes that there is limited data for 100% biodiesel on which to make this judgement. He also indicates that a blend of 20% - 30% biodiesel with diesel in heavy vehicles is expected to meet all Euro 4 standards.

4.6 Summary

The advantages of biodiesel are:

- It is a renewable bio-based fuel and, as such, has lower life cycle CO_2 emissions than diesel derived from mineral oils.
- Neat biodiesel contains almost no sulfur and no aromatics. In a properly tuned engine this is expected to lead to lower particulate exhaust emissions.
- The material is bio-degradable and non-toxic.
- As an oxygenated compound, it reduces the non-soluble fraction of the particles.
- The PAH content of exhaust particles is reduced.
- In a mixture with low-sulfur diesel, biodiesel can act as a lubricity improver (Arcoumanis, 2000).
- The absence of sulfur allows more efficient use of oxidation catalysts.

The disadvantages of biodiesel are:

- Constraints on the availability of agricultural feedstock impose limits on the possible contribution of biodiesels to transport.
- The kinematic viscosity is higher than diesel fuel. This affects fuel atomisation during injection and requires modified fuel injection systems.
- Due to the high oxygen content, it produces relatively high NOx levels during combustion.
- Oxidation stability is lower than that of diesel so that under extended storage conditions it is possible to produce oxidation products that may be harmful to the vehicle components.
- Biodiesel is hygroscopic. Contact with humid air must be avoided.
- Production of biodiesel is not sufficiently standardised. Biodiesel that is outside European or US standards can cause corrosion, fuel system blockage, seal failures, filter clogging and deposits at injection pumps.
- The lower volumetric energy density of biodiesel means that more fuel needs to be transported for the same distance travelled.
- It can cause dilution of engine lubricant oil, requiring more frequent oil change than in standard diesel-fuelled engines.
- A modified refuelling infrastructure is needed to handle biodiesels, which adds to their total cost.

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5. Canola

5.1 Background

Canola is a member of the *Brassica* Family, which includes broccoli, cabbage, cauliflower, mustard, radish, and turnip. It is a variant of the crop rapeseed. Grown for its seed, the seed is crushed for the oil contained within. After the oil is extracted, the by-product is a protein-rich meal used by the intensive livestock industry.

5.2 Results

At present canola oil, per se, is not an automotive fuel, thus no results are presented because no results are available.

5.3 Viability and Functionality

The power output and tailpipe emissions using plant or animal oils are in most cases comparable with the power output and the emissions when running on petroleum diesel fuel, the main problem encountered has been the higher viscosity of the oils causing difficult starting in cold conditions, the gumming up of injectors, the coking-up of valves and exhaust, and the often high melting or solidification point of many vegetable and animal fats and oils. High melting points or solidification ranges can cause problems in fuel systems such as partial or complete blockage as the oil thickens and finally solidifies when the ambient temperature falls. The engine can quickly become gummed-up with the polymerised oil. With some oils, engine failure can occur in as little as 20 hours.

Only coconut oil has an iodine value low enough to be used without any special precautions in a unmodified diesel engine. However with a melting point of 25°C, the use of coconut oil in cooler areas would obviously lead to problems.

All of these problems can be at least partially alleviated by dissolving the oil or hydrogenated oil in petroleum diesel. Linseed oil for example, could be mixed with petroleum diesel at a ratio of up to 1:8. Likewise coconut oil can be thinned with diesel or kerosene to render it less viscous in cooler climates. Another method is to emulsify the oil or fat with ethanol.

5.4 Health Issues

The health issues associated with the use of canola oil in a diesel engine are not known.

5.5 Environmental Impact and Benefits

The environmental issues associated with the use of canola oil in a diesel engine are not known. If diesel vehicles were modified to run on straight vegetable oils then the following environmental considerations would apply.

ESD issues

Canola is made from agricultural crops and is thus widely perceived to be more environmentally friendly than fossil fuels.

Sustainability issues

Sustainability is not currently an issue for canola as a transport fuel because there is no demand for it.. Australia has a production land base able to increase canola, though low oilseed prices could restrict expansion.

Groundwater contamination

Not an issue with vegetable crops, except for the possible use of pesticides or fertiliser during their growth.

6. Hydrated Ethanol

6.1 Background

Ethanol (C_2H_5OH) is an alcohol, an oxygenated organic carbon compound. It is the intoxicating component of alcoholic beverages, and is also used as a solvent (methylated spirits). By contrast, diesel is a mixture of a range of hydrocarbon compounds, none of which contains oxygen. In blended fuels, the addition to diesel of the oxygen contained in the alcohol changes a number of important fuel characteristics. These include changes in combustion properties, energy content and vaporisation potential.

Ethanol will easily blend with gasoline but not with diesel. Alcohols can be used in diesel engines by either modifying the fuel or by extensive engine adaptations. This chapter will examine hydrated ethanol produced from wheat, sugar cane, molasses and wood, and will discuss one source of ethanol from a non-renewable resource. Hydrated ethanol production is a one-stage refining process, unlike the two-stage anhydrous ethanol. However, from the viewpoint of the LCA, the upstream emissions for ethanol production will be different for every process.

Ethanol can be manufactured from:

- biomass via the fermentation of sugar derived from grain starches or sugar crops;
- biomass via the utilisation of the non-sugar lignocellulosic fractions of crops;
- petroleum and natural gas via an ethylene (C_2H_4) intermediate step (reduction or steam cracking of ethane [C_2H_6] or propane [C_3H_8] fractions).

6.2 Results

We present results for seven different scenarios. These are ethanol made from wheat using natural gas as the energy source, ethanol made from wheat using wheat straw as the energy source (wheat WS), ethanol made from wheat starch, ethanol from molasses treated as a waste product, ethanol from molasses treated on the basis of physical inputs (alt. allocation), ethanol from lignocellulosic processes (woodwaste), and ethanol via ethylene.

6.2.1 Greenhouse gas emissions

Figure 6.1 depicts the greenhouse gas emissions estimated for ethanol and diesohol. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basisfor buses. We have used data from Apelbaum Consulting Group (1997) for the passenger task and the freight task in Australia and taken the mean energy intensity for the Australian freight task to be 1.2 MJ/tonne-km (Apelbaum Consulting Group, 1997: p.118), and the energy intensity of buses to be 1.06 MJ/passenger-km (Apelbaum Consulting Group, 1997: p.116).

As may be expected, the use of a renewable fuel, such as ethanol considerably reduces greenhouse gas emissions because the greenhouse gas accounting rules mean that there are no tailpipe emissions from the combustion of ethanol. If ethanol is made from a fossil fuel (as in the case of ethanol via ethylene) then there are more greenhouse gas emissions involved than if diesel was used.

6.2.2 Particulate matter emissions

Figure 6.2 depicts the particulate matter (PM10) emissions estimated for ethanol. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basisfor buses using the same energy intensities previously noted. In all cases but one the emissions of PM10 are less from ethanol than from the reference fuel (LSD). The exception is the case where the energy to manufacture the ethanol comes from the use of wheat straw (rather than from natural gas). Combustion of the wheat straw generates higher levels of PM10 than use of natural gas or bagasse.

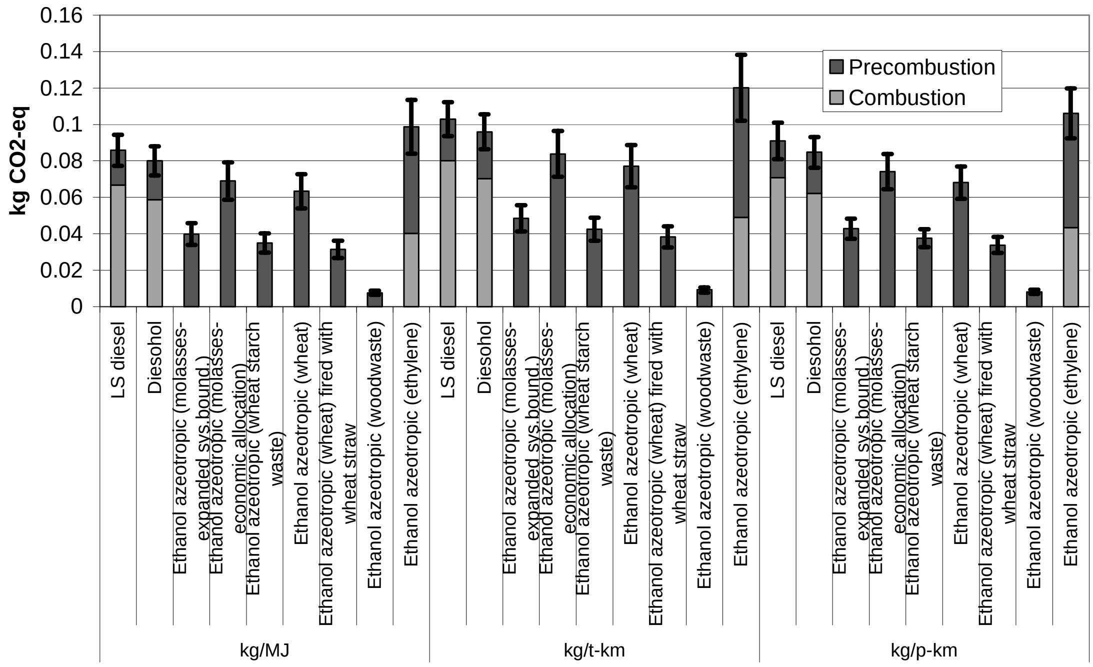

Figure 6.1
Exbodied emissions of greenhouse gases for diesohol and ethanol made from various sources.

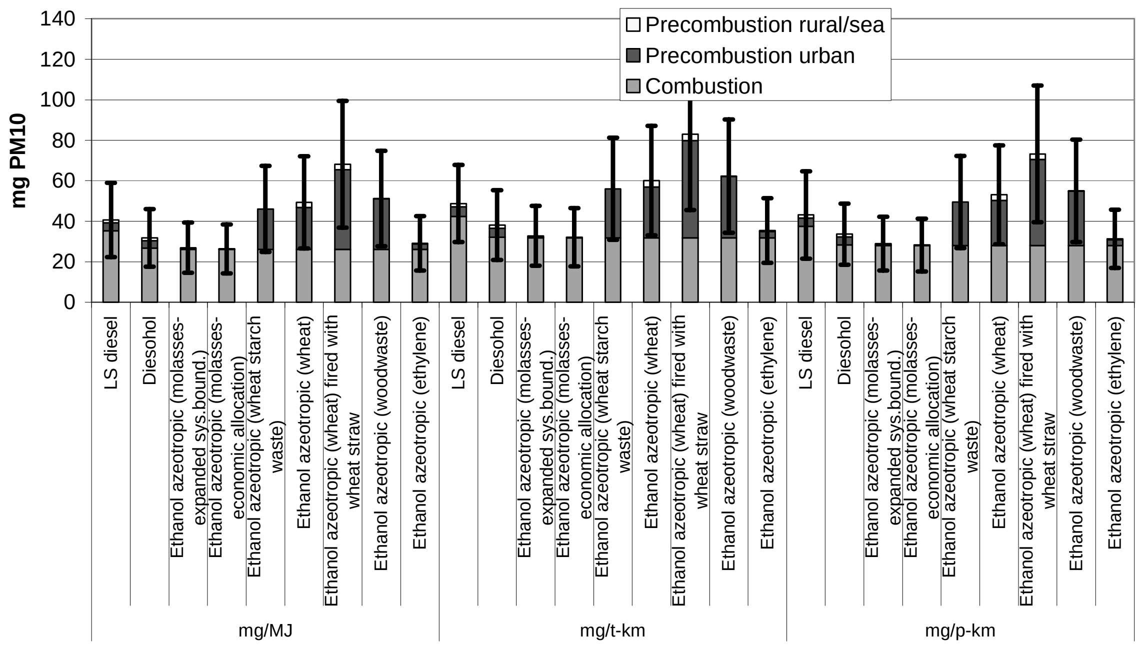

Figure 6.2
Exbodied emissions of particulate matter for diesohol and ethanol made from various sources.

6.2.3 Emissions of oxides of nitrogen

Figure 6.3 depicts the oxides of nitrogen (NOx) emissions estimated for alcohol fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basisfor buses using the same energy intensities previously noted. As a general rule the NOx emissions from ethanol, on a full fuel cycle basis, are comparable to those of the reference fuel.

6.2.4 Emissions of hydrocarbons

Figure 6.4 depicts the non-methanic hydrocarbon (HC) emissions estimated for alcohol fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basisfor buses using the same energy intensities previously noted.

Wheat straw and ethylene have very high precombustion emissions of hydrocarbons. Ethanol made from other sources has emissions comparable to those of the reference fuel.

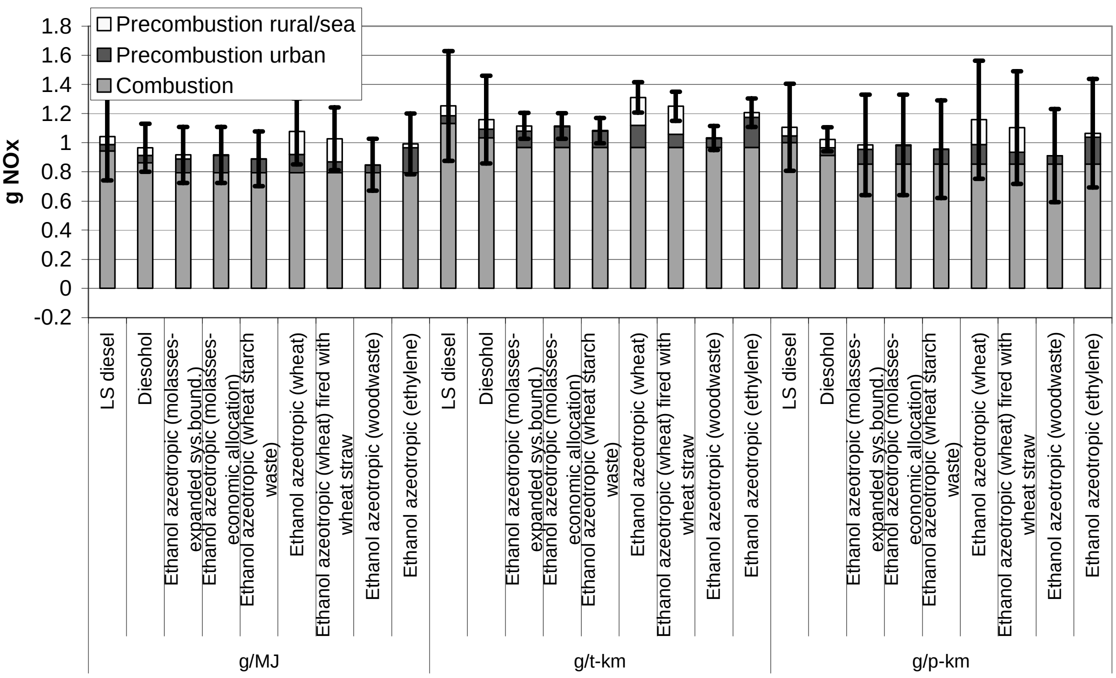

Figure 6.3
Exbodied emissions of oxides of nitrogen for diesohol and ethanol made from various sources.

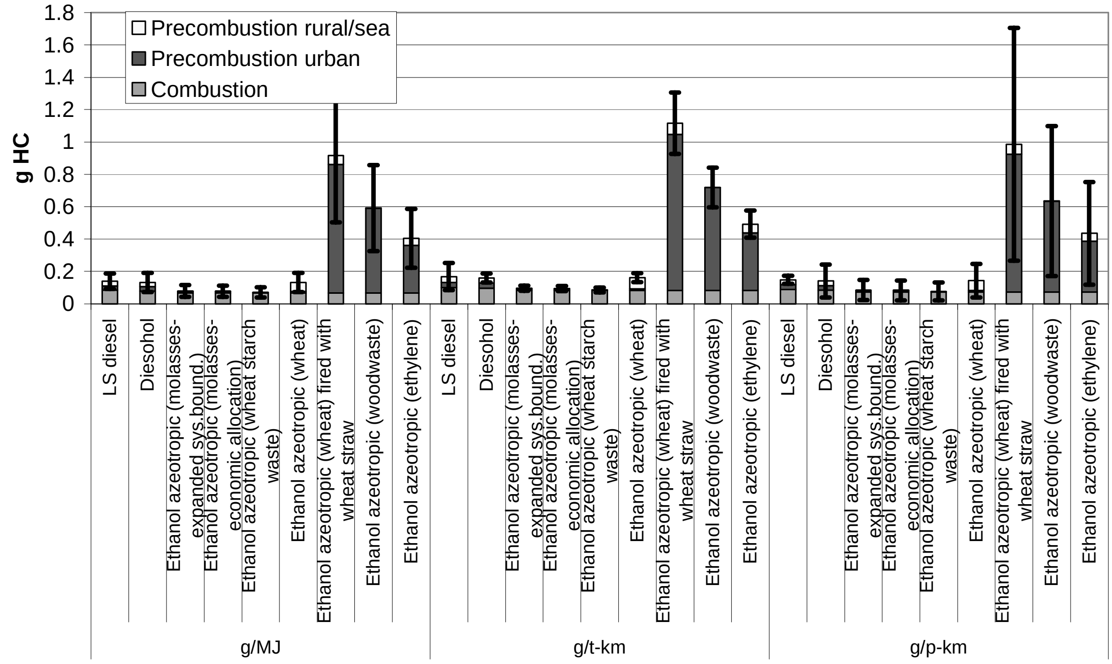

Figure 6.4
Exbodied emissions of hydrocarbons for diesohol and ethanol made from various sources.

6.3 Viability and Functionality

The third generation fleet of ethanol buses runs with oxidation catalysts. In general, ethanol buses have enlarged holes for the fuel injector, modified injection timing, and increased fuel pump capacity. Gaskets and filters need to be alcohol-resistant. In addition, because ethanol has a tendency to dissolve the oil film on greased metal surfaces, castor oil needs to be used for fuel pump lubrication. US transit authorities experienced high rates of engine failure and poor engine reliability with the earlier generation of ethanol buses.

6.4 Health and OH&S

Ethanol upstream emissions of particulate matter and HC range from lower to higher than LSD emissions depending on the feedstock. Ethanol tailpipe emissions of particulate matter and HC for all feedstocks are marginally less than LSD. Limited tailpipe emissions data indicate that ethanol is likely to reduce benzene and 1,3 butadiene emissions compared with LSD, formaldehyde emissions would be similar, while acetaldehyde emissions would increase substantially.

Ethanol in solution is hazardous according to Worksafe Australia, with high flammability, moderate toxicity, and a moderate irritant.

The OHS issues in the lifecycle of ethanol are covered by a range of State and Commonwealth occupational health and safety provisions. While there will be different OHS issues involved in the production process associated with ethanol compared with LSD, no OHS issues unique to the production and distribution of ethanol have been identified.

Diesel fuel has very low vapour pressure, but the addition of alcohol to diesel (for example diesohol) creates a fuel with a vapour pressure similar to that of ethanol. While modern gasoline vehicles have some evaporative emission control measures, diesel vehicles do not. Evaporative emissions may be a significant problem from unmodified vehicles using ethanol based fuels, but this needs to be tested.

To contain evaporative emissions from vehicles using alcohol fuel, measures may need to be implemented to control fuel vapour pressure.

6.5 Environmental Issues

ESD issues

Ethanol is not persistent in the environment. Virtually any environment supporting bacterial populations is believed to be capable of biodegrading ethanol. Atmospheric degradation is also expected to be rapid. Provided that the source of ethanol is not fossil fuels then it satisfies ESD principles.

In particular, we draw attention to the fact that appropriate disposal of the refinery waste-products is crucial to environmental impacts or benefits. Dunder application is often criticised as being the cause of poor waste quality in Queensland, though there is little evidence of this (www.sunfish.org.au/fishkills/fishkills.htm). Conversely, appropriate and careful disposal of dunder means that many farmers in the district near Sarina now use it as a fertiliser and soil condition - even though it was once considered a poison.

Sustainability

Ethanol from sugar or wheat is liable to be a niche fuel and thus there are no sustainability issues associated with it. Large-scale usage of ethanol will require ligno-cellulosic production to be economical.

Foran and Mardon (1999) contains details of ethanol and methanol production technology and supply constraints, and of the environmental consequences of both crop and fuel production processes. They claim that if ligno-cellulosic ethanol production is used then it would be possible to establish biomass plantations over the next 50 years that meet 90% of Australia's oil requirements, and specifically to supply all transportation fuels. To do this using ethanol requires biomass production to cover up to 19 million hectares of Australia's croplands and high rainfall pasture zones. Their modelling approach envisages substantial environmental benefit. In addition to the reduction in greenhouse gas emissions (up to 300 million tonnes by the year 2050), the large-scale planting of tree and shrub crops as ethanol feedstock would help to control dryland salinity and associated problems.

Groundwater

We are not aware of any issues related to groundwater contamination except to note that in the US the replacement of methyl tertiary butyl ether (MTBE) by ethanol in oxygenated fuels was specifically done to reduce groundwater contamination.

We also note ethanol when used as a heavy vehicle fuel may contain 2.3% MTBE. This additive was extensively examined in the US where 15% MTBE (or 7.5% ethanol) was added to petrol to achieve the 2.7% oxygen content required under the Clean Air Act. The use of MTBE is no longer permitted because of concerns in relation to health as a result of groundwater, and hence drinking water, contamination by MTBE.

6.6 Expected Future Emissions

Ethanol can be expected to meet all future Australian Design Rules for all pollutants except hydrocarbon which may be slightly above Euro3 and Euro4 standards.

6.7 Summary

6.7.1 Advantages

- As a renewable fuel, ethanol produces less fossil CO_2 than conventional fuels.
- Particulate emissions are lower with ethanol than with conventional fuels.
- 1,3 butadiene and benzene levels decrease as the ethanol concentration increases.
- Ethanol contains less sulfur than conventional fuels.

6.7.2 Disadvantages

- The chemical emulsifiers and ignition improvers used to blend ethanol may contain harmful chemicals.
- There are higher emissions of formaldehyde and acetaldehyde from ethanol vehicles than from diesel vehicles.
- There may be an odour problem.

7. Diesohol

7.1 Background

Diesohol is a fuel containing alcohol that comprises a blend of diesel fuel (84.5%), hydrated ethanol (15%) and an Australian developed emulsifier (0.5%). Hydrated ethanol is ethyl alcohol that contains approximately 5% water. The emulsifier is an important component in the preparation of the fuel. It has been developed in Australia by APACE Research.

In this chapter we examine ethanol (and hence diesohol) from wheat starch waste, as the buses that were tested in the diesohol tests whose results were used for the tailpipe emissions used diesohol with the ethanol made from wheat starch. However, we also present results that compare diesohol emissions with ethanol made from a range of different feedstocks.

7.2 Full Fuel-Cycle Analysis of Emissions

7.2.1 Greenhouse gas emissions

Figure 7.1 depicts the greenhouse gas emissions estimated for ethanol and diesohol. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses. We have used data from Apelbaum Consulting Group (1997) for the passenger task and the freight task in Australia and taken the mean energy intensity for the Australian freight task to be 1.2 MJ/tonne-km (Apelbaum Consulting Group, 1997: p.118), and the energy intensity of buses to be 1.06 MJ/passenger-km (Apelbaum Consulting Group, 1997: p.116).

As may be expected, the addition of 15% of a renewable fuel, such as ethanol, to diesel reduces greenhouse gas emissions.

7.2.2 Particulate matter emissions

Figure 7.2 depicts the particulate matter (PM10) emissions estimated for diesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted. Particulate matter emissions using diesohol are lower than those using LSD.

7.2.3 Emissions of oxides of nitrogen

Figure 7.3 depicts the oxides of nitrogen (NOx) emissions estimated for diesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted.

NOx emissions of diesohol are lower than NOx emissions of LSD.

7.2.4 Emissions of hydrocarbons

Figure 7.3 depicts the non-methanic hydrocarbon (HC) emissions estimated for diesel fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted.

HC emissions of diesohol are comparable with those of LSD.

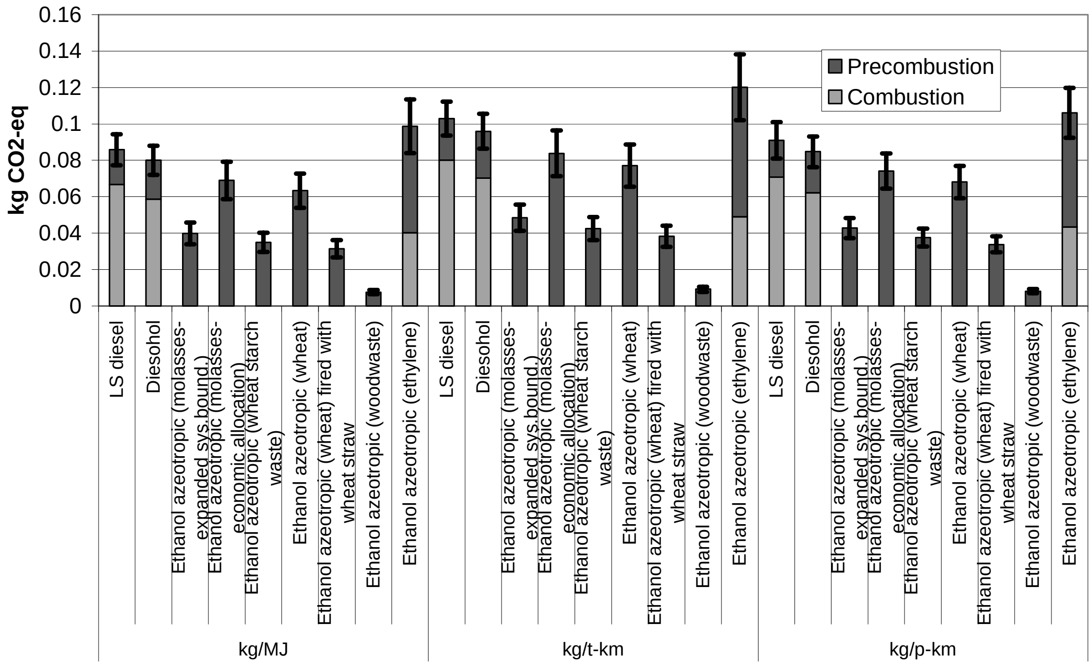

Figure 7.1
Exbodied emissions of greenhouse gases for diesohol and ethanol made from various sources.

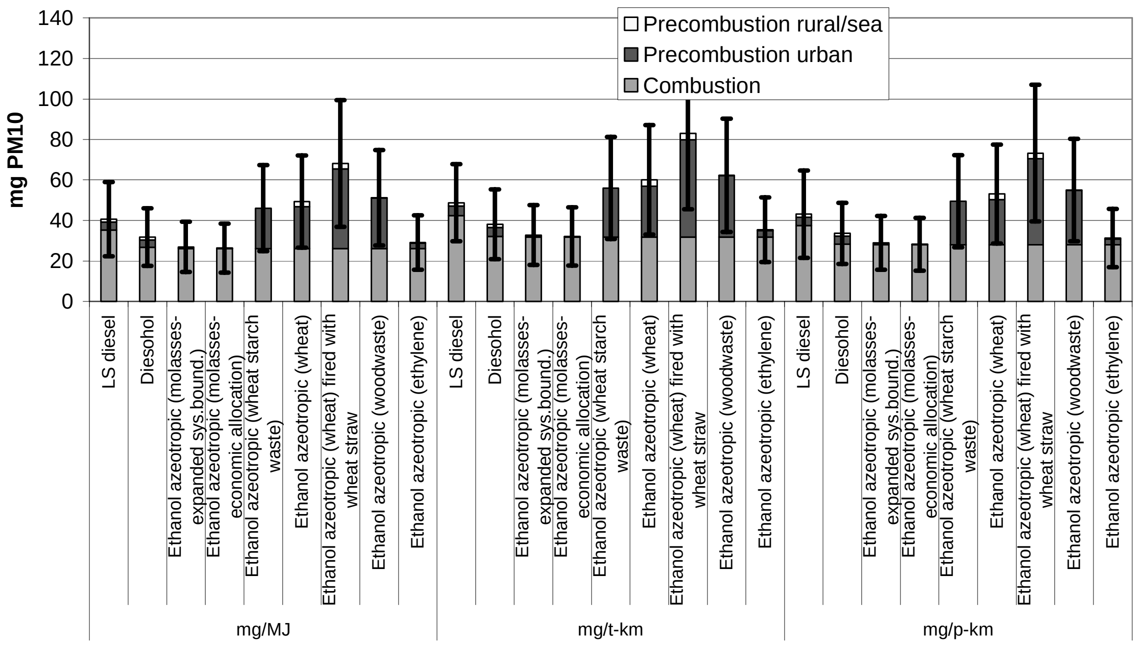

Figure 7.2
Exbodied emissions of particulate matter for diesohol and ethanol made from various sources.

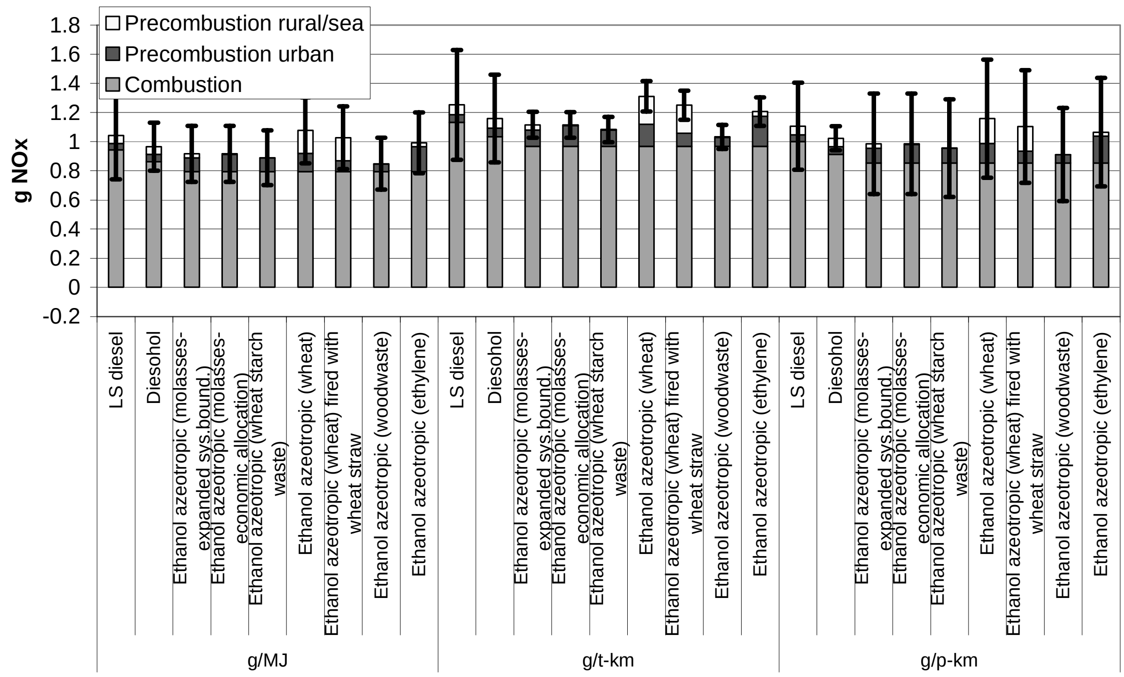

Figure 7.3
Exbodied emissions of oxides of nitrogen for diesohol and ethanol made from various sources.

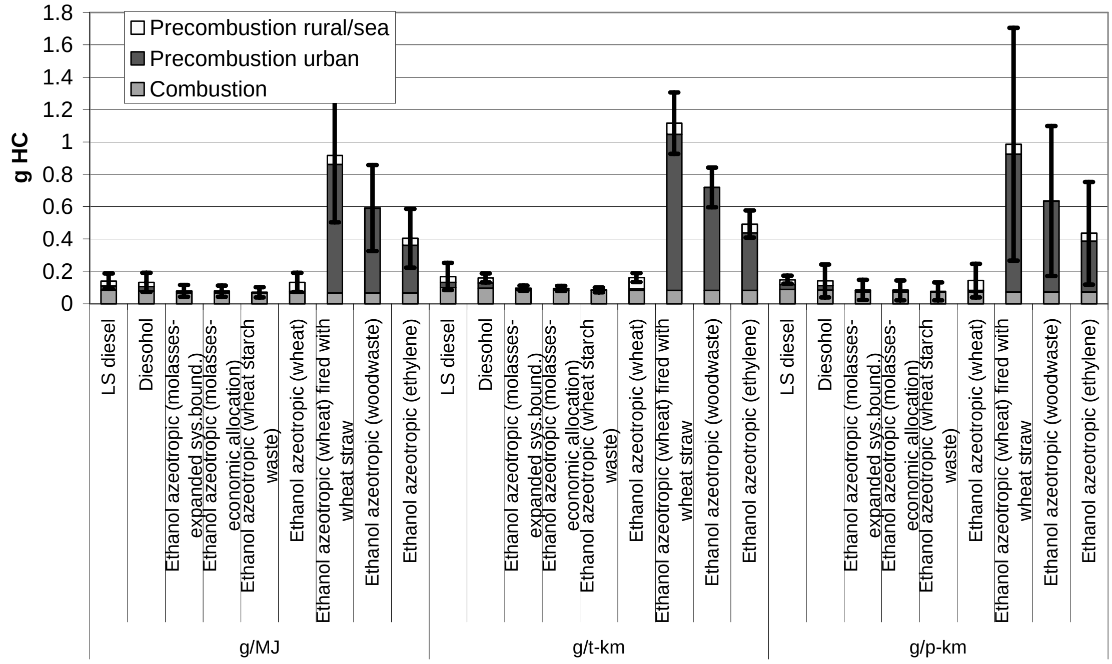

Figure 7.4
Exbodied emissions of hydrocarbons for diesohol and ethanol made from various sources.

7.3 Viability and Functionality

Problems may occur with the fuel injection equipment, and with the formation of vapour locks. Both can be easily remedied. Diesohol has passed stability test conducted by Shell. To date diesohol has been a niche fuel and thus the situation with respect to availability and warranty has not been clarified. During testing of buses using diesohol, the fuel was blended by delivering diesel to Manildra, near Nowra, and blending the diesel with ethanol and emulsifier.

7.4 Health and OH&S

As the composition of diesohol is 85% diesel the production and transport emissions associated with diesohol production are assumed to be similar to LSD. The LCA indicates that urban precombustion PM10 emissions of diesohol (39 mg/km or 3.63 mg/MJ) are marginally lower than LSD (43 mg/km or 4.0 mg/MJ), though the urban precombustion HC emissions are similar at 0.29 g/km or 0.026 g/MJ.

The LCA indicates that combustion PM emissions from diesohol (289 mg/km or 26.8 mg/MJ) are lower than LSD (380 mg/km or 35.3 g/MJ).

There is limited information available on air toxic emissions for diesohol. The high proportion of diesel in diesohol suggests that the air toxic emissions are unlikely to be substantially different to LSD, though tailpipe emissions of acrolein from diesohol appear to be lower than from diesel. The LCA indicates that HC combustion emissions of diesohol are similar to LSD.

The flash point and flammability characteristics of diesohol are those of alcohol. This requires that diesohol be considered and handled as gasoline (petrol) rather than as diesel fuel, even though the flash point of petrol is considerably lower than that of ethanol (13^{o}C). In practical terms, APACE Research handles the fuel as it would ethanol to ensure safety.

7.5 Environmental issues

ESD issues

The environmental impact from the production of diesohol are the same as those from the production of the diesohol feedstocks; namely diesel and ethanol.

In particular, we draw attention to the fact that appropriate disposal of the refinery waste-products is crucial to environmental impacts or benefits. Dunder application is often criticised as being the cause of poor waste quality in Queensland, though there is little evidence of this (www.sunfish.org.au/fishkills/fishkills.htm). Conversely, appropriate and careful disposal of dunder means that many farmers in the district near Sarina now use it as a fertiliser and soil conditioner - even though it was once considered a poison.

Sustainability

Ethanol from sugar or wheat is liable to be a niche fuel and thus there are no sustainability issues associated with it. Large-scale usage of ethanol will require ligno-cellulosic production to be economical.

Foran and Mardon (1999) contains details of ethanol and methanol production technology and supply constraints, and of the environmental consequences of both crop and fuel production processes. They claim that if ligno-cellulosic ethanol production is used then it would be possible to establish biomass plantations over the next 50 years that meet 90% of Australia's oil requirements, and specifically to supply all transportation fuels. To do this using ethanol requires biomass production to cover up to 19 million hectares of Australia's croplands and high rainfall pasture zones. Their modelling approach envisages substantial environmental benefit. In addition to the reduction in greenhouse gas emissions (up to 300 million tonnes by the year 2050), the large-scale planting of tree and shrub crops as ethanol feedstock would help to control dryland salinity and associated problems.

Groundwater
We are not aware of any issues related to groundwater contamination.

7.6 ADR Compliance

Diesohol can be expected to meet all future Australian Design Rules for all pollutants except total hydrocarbon which may be slightly above Euro3 and Euro4 standards. APACE Research advises that vapour lock problems led to higher HC and CO emissions as reflected in Arcoumanis (2000). APACE has indicated that the addition of a booster pump now overcomes vapour lock and the resulting HC and CO problem which means that low sulfur diesohol should be able to meet all future ADRs.

7.7 Summary

7.7.1 Advantages

- Since it contains a renewable fuel component it produces less fossil CO_2 than conventional fuels.
- Particulate emissions are lowered.
- 1,3 butadiene and benzene levels decrease as the ethanol concentration increases.
- Less sulfur.

7.7.2 Disadvantages

- Overseas, the chemical emulsifiers used to blend ethanol and diesel contain harmful chemicals. According to APACE the chemical emulsifier that they use is composed only of hydrocarbons and oxygen and is thus no more harmful than diesel fuel.

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8. Compressed Natural Gas (CNG)

8.1 Background

Natural gas (NG) is a mixture of hydrocarbons, mainly methane (CH_4). It is stored onboard a vehicle in a compressed gaseous state (CNG). Natural gas is distributed throughout Australia in extensive pipeline systems. A national fuel standard for CNG is to be developed in 2001-2002 under the *Fuel Quality Standards Act 2000.*

Most gas losses from the distribution systems are by way of leakage from the low pressure network (7 kPa). This includes both the reticulation network and appliances operated by end users. Losses from the distribution network are difficult to estimate as they may occur both upstream and downstream from the meters.

8.2 Results

Two modes of compression were examined: compression using natural gas and compression using electricity. The assumptions that are made in terms of methane losses, both upstream and during vehicle operation, determine whether one concludes that CNG (or LNG) emits more, or less, greenhouse gases. We assumed for Australia, on the basis of the advice received from stakeholders, that fugitive emissions are 0.1% of supply. This leads to the results, depicted below, that exbodied emissions of greenhouse gases are less than that of diesel. Earlier studies and overseas studies, based on assumptions of higher fugitive emissions, produce opposite results in relation to greenhouse gases. We undertook a sensitivity study, as depicted in Figure 8.3 of Part 2, that indicates that if fugitive emissions exceed approximately 4 % of supply then exbodied emissions of greenhouse gases exceed those of low sulfur diesel.

8.2.1 Greenhouse gas emissions

Figure 8.1 depicts the greenhouse gas emissions estimated for gaseous fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses. We have used data from Apelbaum Consulting Group (1997) for the passenger task and the freight task in Australia and taken the mean energy intensity for the Australian freight task to be 1.2 MJ/tonne-km (Apelbaum Consulting Group, 1997: p.118), and the energy intensity of buses to be 1.06 MJ/passenger-km (Apelbaum Consulting Group, 1997: p.116). An extra allowance of 400 kg for the weight of CNG tanks over diesel fuel tanks has been built into these figures.

Exbodied emissions of greenhouse gases are lower from CNG than from LSD under both scenarios.

8.2.2 Particulate matter emissions

Figure 8.2 depicts the particulate matter (PM10) emissions estimated for gaseous fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted. Particulate emissions of CNG are markedly lower than those of LSD.

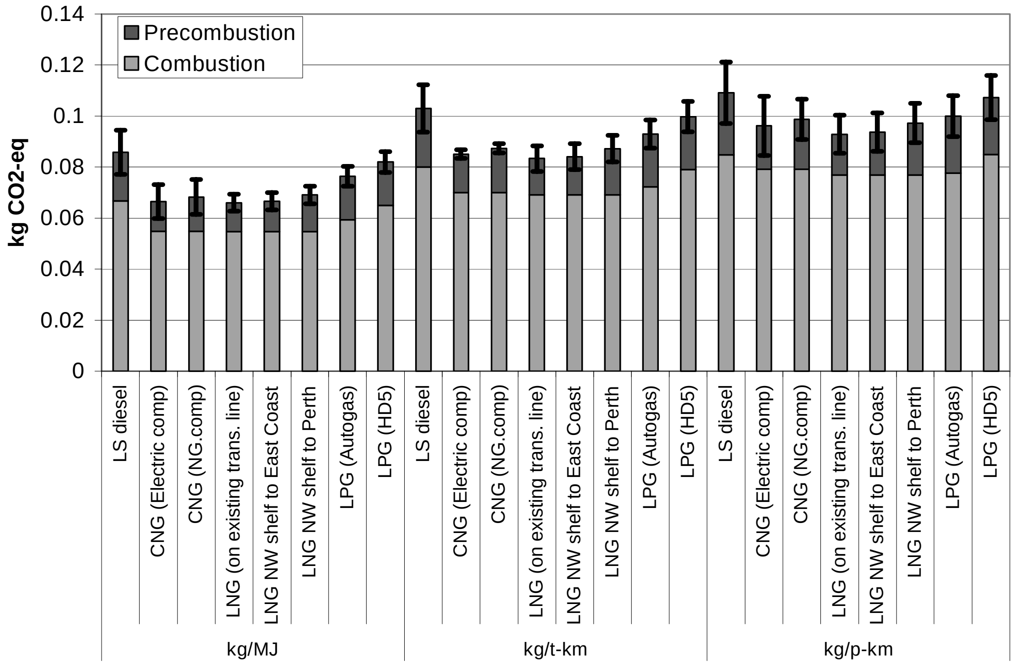

Figure 8.1
Exbodied emissions of greenhouse gases for gaseous fuels. The two CNG scenarios consist of gas compression and electric compression of the gas

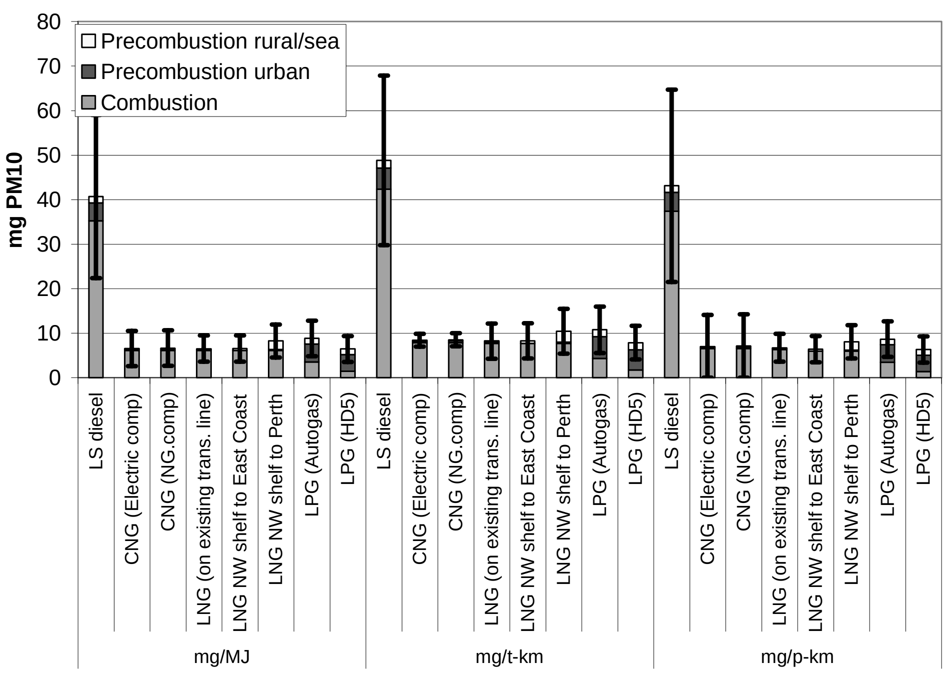

Figure 8.2
Exbodied emissions of particulate matter for gaseous fuels. The two CNG scenarios consist of gas compression and electric compression of the gas

8.2.3 Emissions of oxides of nitrogen

Figure 8.3 depicts the oxides of nitrogen (NOx) emissions estimated for gaseous fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted. NOx emissions from CNG are lower than those of LSD.

8.2.4 Emissions of hydrocarbons

Emissions of hydrocarbons for the gaseous fuels are shown in Figure 8.4. In every case, the gaseous fuels have lower hydrocarbon emissions than low sulfur diesel, both on an upstream and tailpipe basis.

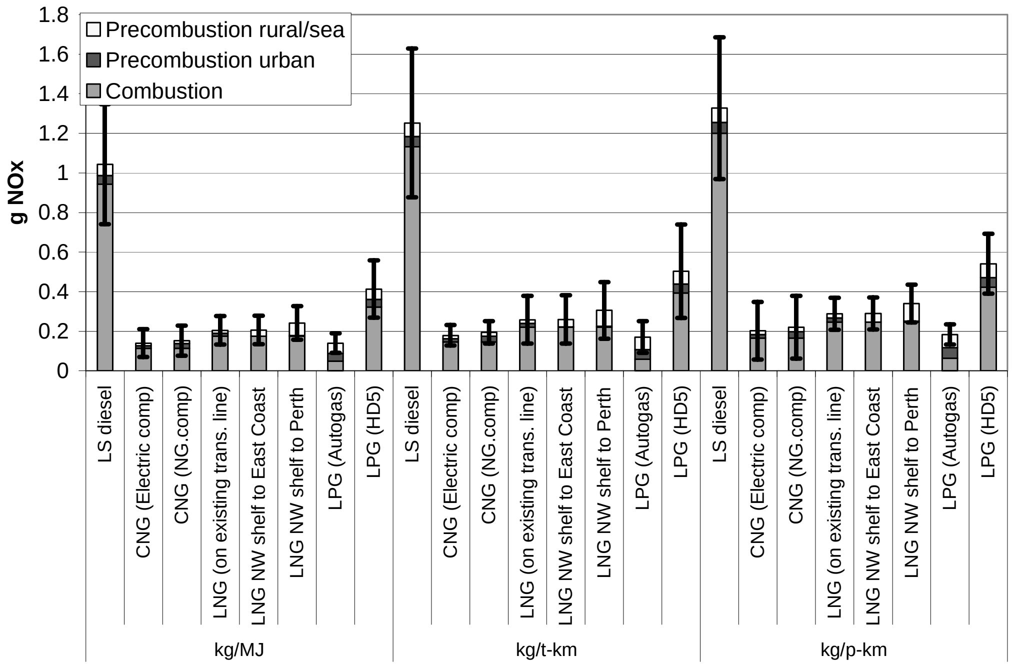

Figure 8.3
Exbodied emissions of oxides of nitrogen for gaseous fuels. The two CNG scenarios consist of gas compression and electric compression of the gas

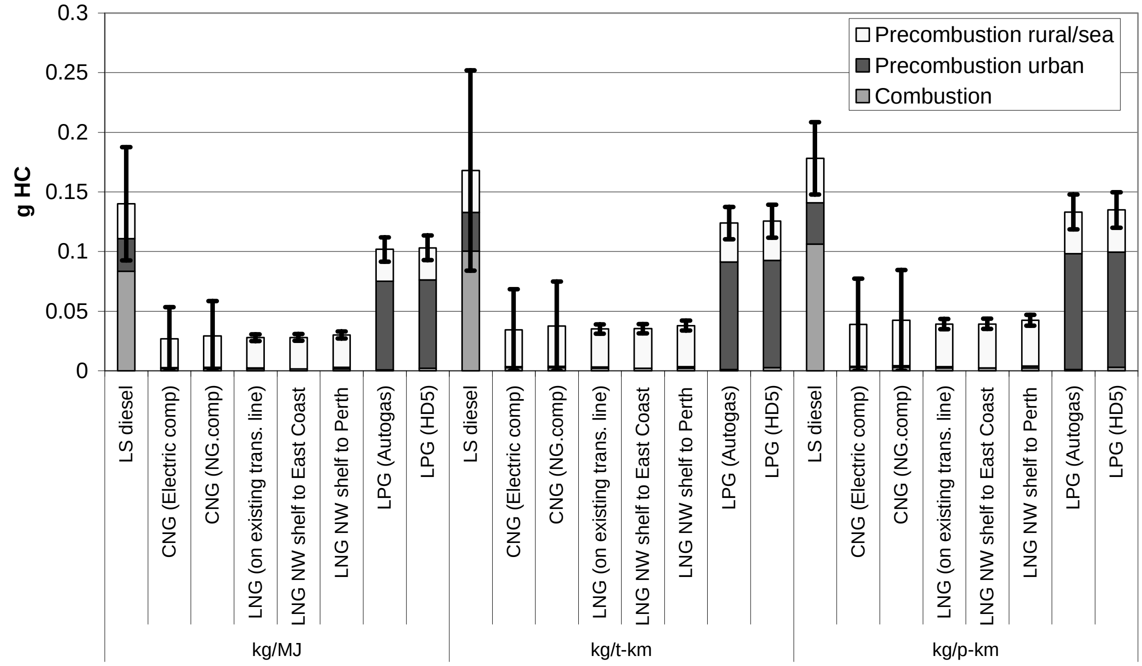

Figure 8.4
Exbodied emissions of hydrocarbons for gaseous fuels. The two CNG scenarios consist of gas compression and electric compression of the gas.

8.3 Viability and Functionality

Due to chronic problems with the engine and fuel system components (of the earlier generation of CNG engines) CNG buses in operation have had a significantly greater defect rate than diesel buses. The industry is confident that these problems have been overcome. Currently there are limited public CNG refuelling facilities, but the industry expects the number of facilities to more than double by the end of 2002.

Australian natural gas is vulnerable to disruption in the gas supply. This was most evident with the Longford incident in 1998 when gas supplies to Melbourne, and much of the rest of Victoria, were halted following the disaster at the Longford plant.

The majority of CNG vehicles in Australia were sourced as new vehicles. However, there has been growing interest in the conversion of conventionally fuelled vehicles to CNG through after-market conversions.

The emissions performance of converted Australian CNG vehicles is unclear due to a lack of comprehensive industry-wide data. The only results available were from one system that was used in a small number of vehicles. That system is currently being upgraded and is no longer sold in the previous configuration. Some tailpipe emissions from the previous configuration were much higher than those for OEM vehicles. It is possible that the difference in emission levels between converted vehicles and OEMs may decrease as the heavy duty vehicles conversion industry becomes more firmly established.

8.4 Health Issues

CNG upstream emissions of both particulate matter and air toxics are substantially less than LSD. CNG tailpipe emissions of particulate matter are substantially less than LSD. CNG tailpipe emission of benzene, 1,3 butadiene, formaldehyde and acetaldehyde are less than LSD.

On release to the atmosphere CNG is much lighter than air and thus it is safer than spilled diesel. In the case of a CNG leak, because of the gaseous nature of the fuel, the gas will issue as a very high velocity jet into the surroundings, aiding greatly in the rapid dispersion of the fuel.

8.5 Environmental Impact and Benefit

ESD *principles*

Noise levels from natural gas buses are less than those of diesel buses. CNG buses produce less air pollutants and greenhouse gases than diesel buses. The potential for water and soil pollution is effectively eliminated by the use of natural gas.

Sustainability

Natural gas is an indigenous fuel that could replace imported, expensive crude oil.

CNG can also be a renewable fuel for vehicles because it can be purified from the biogas extracted from waste treatment facilities.

Groundwater

Being a gaseous fuel, CNG does not impact groundwater.

8.6 ADR Compliance

CNG can be expected to meet all future Australian design rules for all pollutants.

8.7 Summary

8.7.1 Advantages

- CNG has very low particulate emissions because of its low carbon to hydrogen ratio.
- There are negligible evaporative emissions, requiring no relevant control.
- Due to its low carbon-to-hydrogen ratio, it produces less carbon dioxide per GJ of fuel than diesel.
- It has low cold-start emissions due to its gaseous state.
- It has extended flammability limits, allowing stable combustion at leaner mixtures.
- It has a lower adiabatic flame temperature than diesel, leading to lower NOx emissions.
- It has a much higher ignition temperature than diesel, making it more difficult to auto-ignite, thus safer.

- It contains non-toxic components.
- It is much lighter than air and thus it is safer than spilled diesel.
- Methane is not a volatile organic compound (VOC).
- Engines fuelled with natural gas in heavy-duty vehicles offer more quiet operation than equivalent diesel engines, making them more attractive for use in urban areas.
- It has nearly zero sulfur levels and, thus, negligible sulfate emissions.

8.7.2 Disadvantages

- CNG on board a vehicle takes 3 to 4.5 times more volume for storage than diesel.
- It requires dedicated catalysts with high loading of active catalytic components to maximise methane oxidation.
- The composition can vary widely depending on the CNG source, which affects stoichiometric air/fuel ratios.
- Its driving range is limited because its energy content per volume is relatively low as a result of its gaseous state.
- It requires special refuelling stations.
- The extra weight of the fuel tank leads to higher fuel consumption or loss of payload.
- Exhaust emissions of methane, which is a greenhouse gas, are relatively high compared with low sulfur diesel.
- It can give rise to backfire in the inlet manifold if the ignition system is faulty or fails in use.
- Relatively small fugitive emissions of methane can have a significant effect on the exbodied greenhouse gas emissions.

9. Liquefied Natural Gas (LNG)

9.1 Background

Natural gas (NG) is a mixture of hydrocarbons, mainly methane (CH_4). LNG is generally refrigerated to –180^{o}C for liquefaction, and requires vacuum-insulated cryogenic tanks to maintain it in liquid form for storage. Natural gas consumed in Australia is domestically produced from Australian oil and gas fields.

9.2 Results

Three LNG scenarios are examined. The base scenario (marked LNG) is that of piped movement of natural gas that is liquefied at central liquefaction plants. A shipping scenario (LNG to E. Coast) assumes that LNG from the Northwest Shelf is shipped to the East Coast of Australia. The road scenario (LNG to Perth) assumes that LNG is trucked (in LNG road trucks) to Perth from the Northwest Shelf.

9.2.1 Greenhouse gas emissions

Figure 9.1 depicts the greenhouse gas emissions estimated for gaseous fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses. We have used data from Apelbaum Consulting Group (1997) for the passenger task and the freight task in Australia and taken the mean energy intensity for the Australian freight task to be 1.2 MJ/tonne-km (Apelbaum Consulting Group, 1997: p.118), and the energy intensity of buses to be 1.06 MJ/passenger-km (Apelbaum Consulting Group, 1997: p.116). An extra allowance of 400 kg for the weight of LNG tanks over diesel fuel tanks has been built into these figures.

Exbodied emissions of greenhouse gases are lower from LNG than from LSD under all three scenarios.

9.2.2 Particulate matter emissions

Figure 9.2 depicts the particulate matter (PM10) emissions estimated for gaseous fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted. Particulate emissions of LNG are markedly lower than those of LSD.

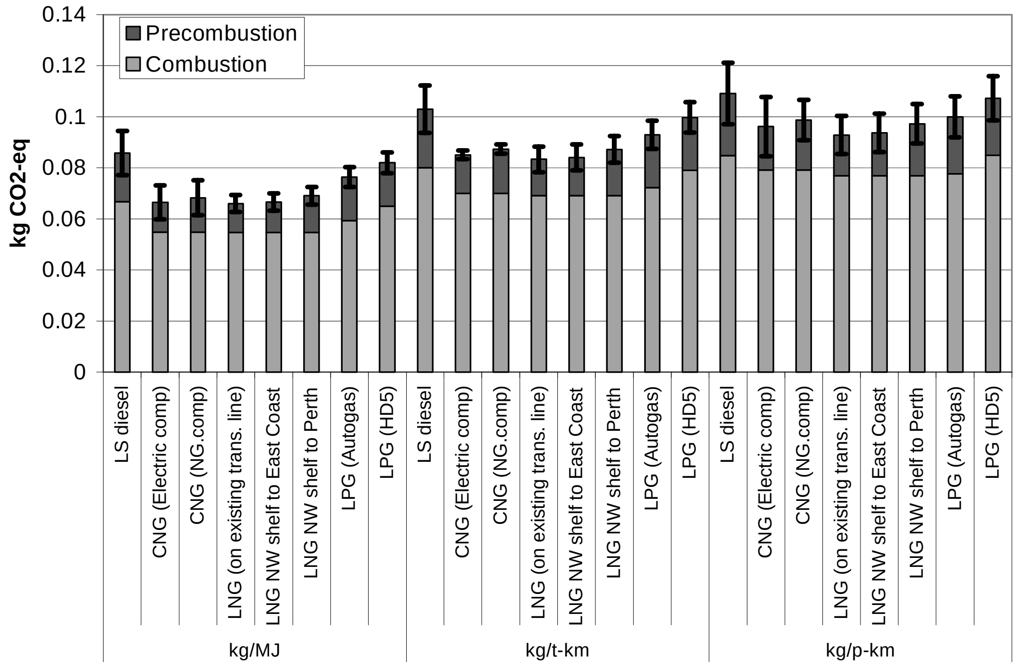

Figure 9.1
Exbodied emissions of greenhouse gases for gaseous fuels

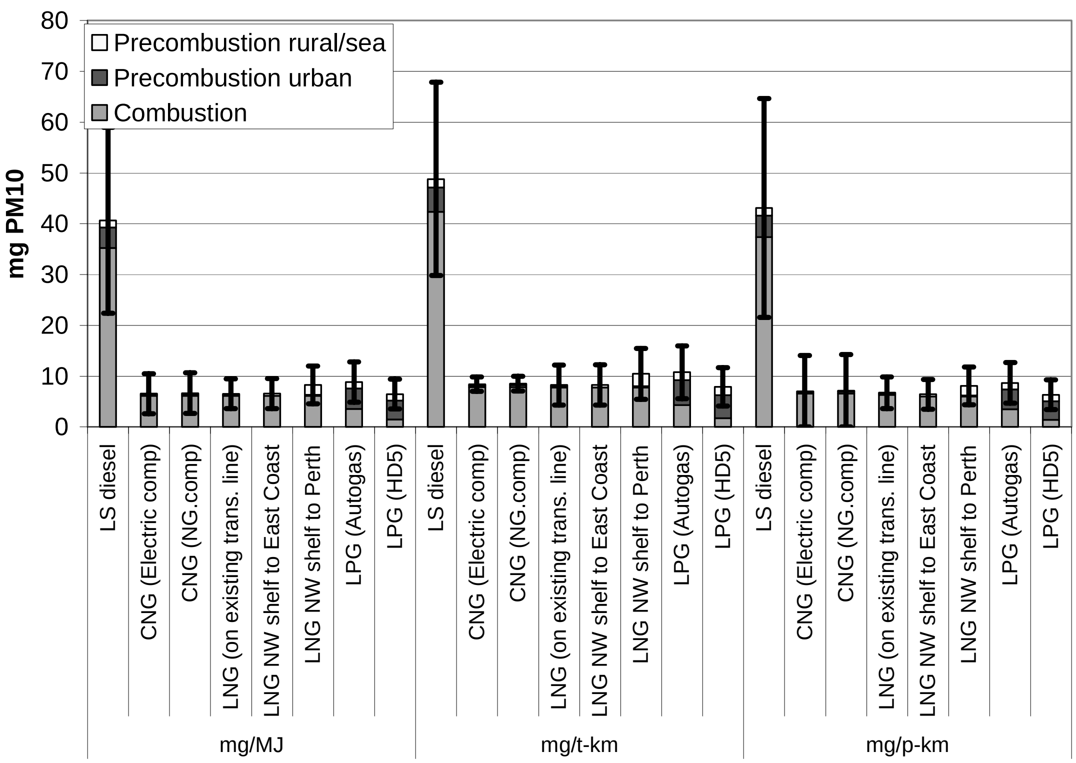

Figure 9.2
Exbodied emissions of particulate matter for gaseous fuels.

9.2.3 Emissions of oxides of nitrogen

Figure 9.3 depicts the oxides of nitrogen (NOx) emissions estimated for gaseous fuels. These are shown as emissions on an energy basis, as emissions on a per tonne-km basis for trucks, and on a per passenger-km basis for buses using the same energy intensities previously noted.

LNG emissions of NOx are lower than those from LSD.

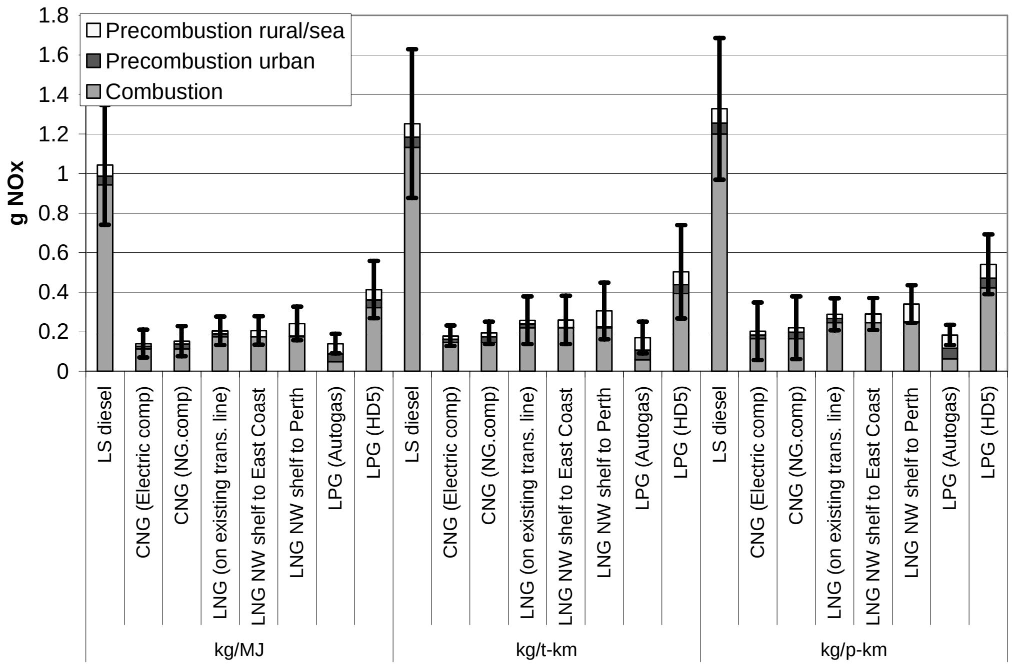

Figure 9.3
Exbodied emissions of oxides of nitrogen for gaseous fuels.

9.2.4 Emissions of hydrocarbons

Emissions of hydrocarbons for the gaseous fuels are shown in Figure 9.4. In every case, the gaseous fuels have lower hydrocarbon emissions than low sulfur diesel, both on an upstream and tailpipe basis.

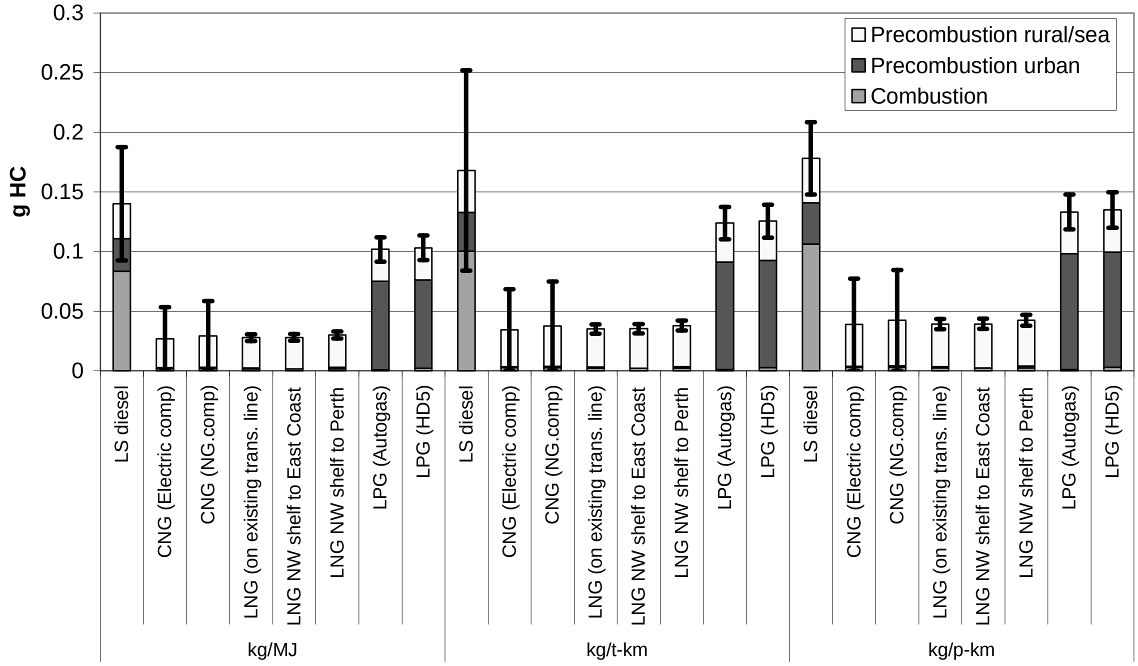

Figure 9.4
Exbodied emissions of hydrocarbons for gaseous fuels.

9.3 Viability and Functionality

LNG buses have the same reliability and operating cost issues as CNG buses. There were problems with earlier generations of heavy vehicle gas engines that appear to have been overcome. LNG vehicles have the advantage of less bulky fuel storage and longer vehicle operating range than CNG vehicles.

9.4 Health Issues

Emissions of particulate matter, some of which is carcinogenic, are almost eliminated with natural gas use. Lubricating oil appears to be the source of remaining particulate emissions. LNG upstream emissions of both particulates and air toxics are substantially less than LSD. LNG tailpipe emissions of particulates are substantially less than LSD. LNG tailpipe emission of THC as well as benzene, 1,3 butadiene, formaldehyde and acetaldehyde are less than LSD.

When released to the atmosphere and evaporated LNG is much lighter than air and thus it is safer than spilled diesel.

9.5 Environmental Impact and Benefit

ESD principles

Noise levels from natural gas buses are less than those of diesel buses. LNG buses produce less air pollutants and greenhouse gases than diesel buses. The potential for water and soil pollution is effectively eliminated by the use of natural gas.

Sustainability

Natural gas is an indigenous fuel that could replace imported, expensive crude oil.

Groundwater

LNG is a gaseous fuel at normal temperature and pressure. Being a gaseous fuel, it does not impact groundwater.

9.6 ADR Compliance

LNG can be expected to meet all future Australian design rules for all pollutants.

9.7 Summary

9.7.1 Advantages

- LNG has very low particulate emissions because of its low carbon to hydrogen ratio.
- There are negligible evaporative emissions, requiring no relevant control.
- Due to its low carbon-to-hydrogen ratio, it produces less carbon dioxide per GJ of fuel than diesel.
- It has low cold-start emissions due to its gaseous state.
- It has extended flammability limits, allowing stable combustion at leaner mixtures.
- It has a lower adiabatic flame temperature than diesel, leading to lower NOx emissions.
- It has a much higher ignition temperature than diesel, making it more difficult to auto-ignite, thus safer.
- It contains non-toxic components.
- When released to the atmosphere and evaporated it is much lighter than air and thus it is safer than spilled diesel.
- Methane is not a volatile organic compound (VOC).
- Engines fuelled with natural gas in heavy-duty vehicles offer more quiet operation than equivalent diesel engines, making them more attractive for use in urban areas.
- It has nearly zero sulfur levels and, thus, negligible sulfate emissions.

9.7.2 Disadvantages

- There is considerable extra infrastructure involved with gas liquefaction.
- It requires dedicated catalysts with high loading of active catalytic components to maximise methane oxidation.
- Its driving range is limited because its energy content per volume is relatively low as a result of its gaseous state.
- It requires special refuelling stations and handling of a cryogenic liquid making it suitable only for fleet operations.
- The energy required to liquefy natural gas leads to increased greenhouse gas emissions in comparison to CNG.
- Exhaust emissions of methane, which is a greenhouse gas, are relatively high compared with low sulfur diesel.
- Refuelling time typically is longer than that of diesel.
- It can give rise to backfire in the inlet manifold if the ignition system is faulty or fails in use.

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