10. Liquefied Petroleum Gas (LPG) - Autogas

10.1 Background

Liquefied petroleum gas (LPG) a petroleum industry by-product, consists mainly of propane, propylene, butane, and butylene in various proportions according to its State of origin. Autogas grade LPG is a mixture of propane and butane in approximately equal ratios. The Australian industry has prepared a set of performance-based specifications that are widely seen as a de facto standard. LPG has particularly low particulate levels, which make it an attractive fuel for urban buses and delivery vehicles. However, as diesel particulate emissions reduce to Euro4 levels this advantage may be lost. A national standard for LPG is being developed under the *Fuel Quality Standards Act 2000*.

10.2 Full Fuel Cycle Results

Because it is relatively rare for LPG to be used in heavy vehicles, there is a lack of published data on its emissions characteristics though there is considerable data in relation to LPG used in cars. The AGO also has some data on dual fuel vehicles as a result of the Alternative Fuels Conversion Program.

10.2.1 Greenhouse gas emissions

Figure 10.1 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).

Exbodied emissions of greenhouse gases are lower from Autogas than from LSD.

10.2.2 Particulate matter emissions

Figure 10.2 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 Autogas are markedly lower than those of LSD.

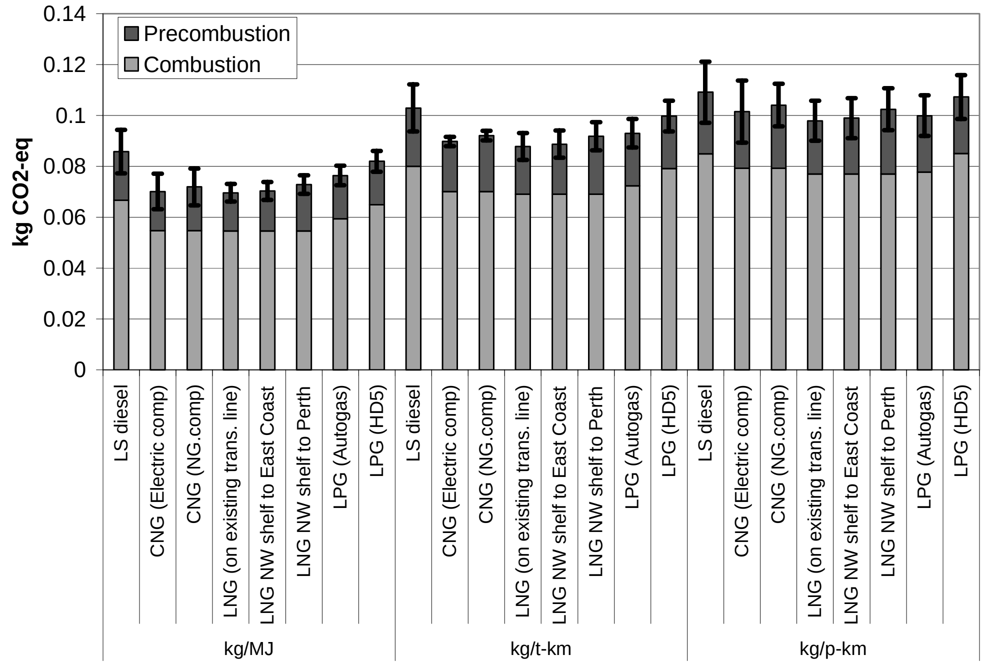

Figure 10.1
Exbodied emissions of greenhouse gases for gaseous fuels.

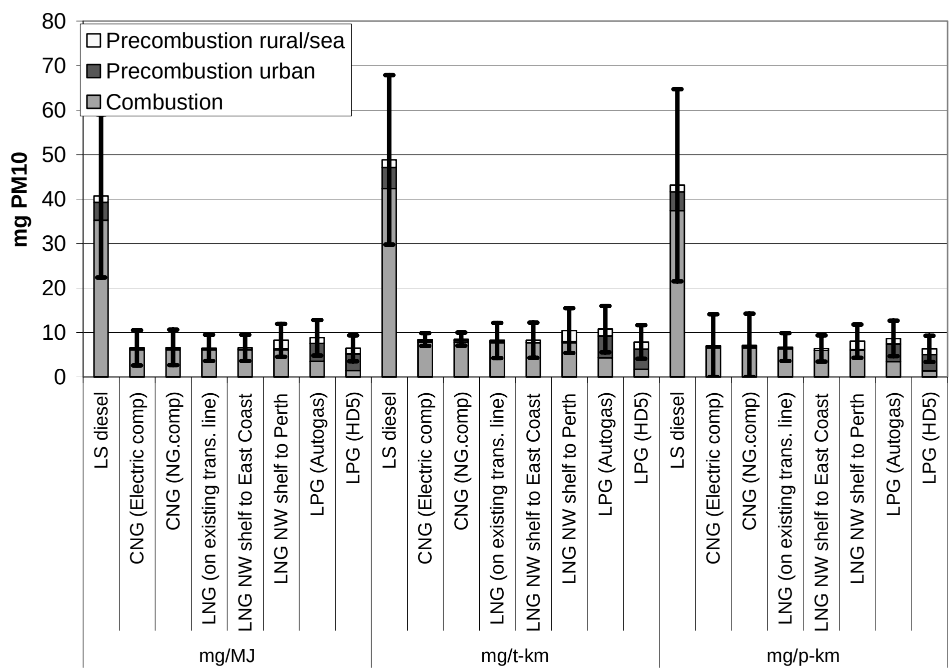

Figure 10.2
Exbodied emissions of particulate matter for gaseous fuels.

10.2.3 Emissions of oxides of nitrogen

Figure 10.3 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. Emissions of NOx from Autogas are lower than those of LSD.

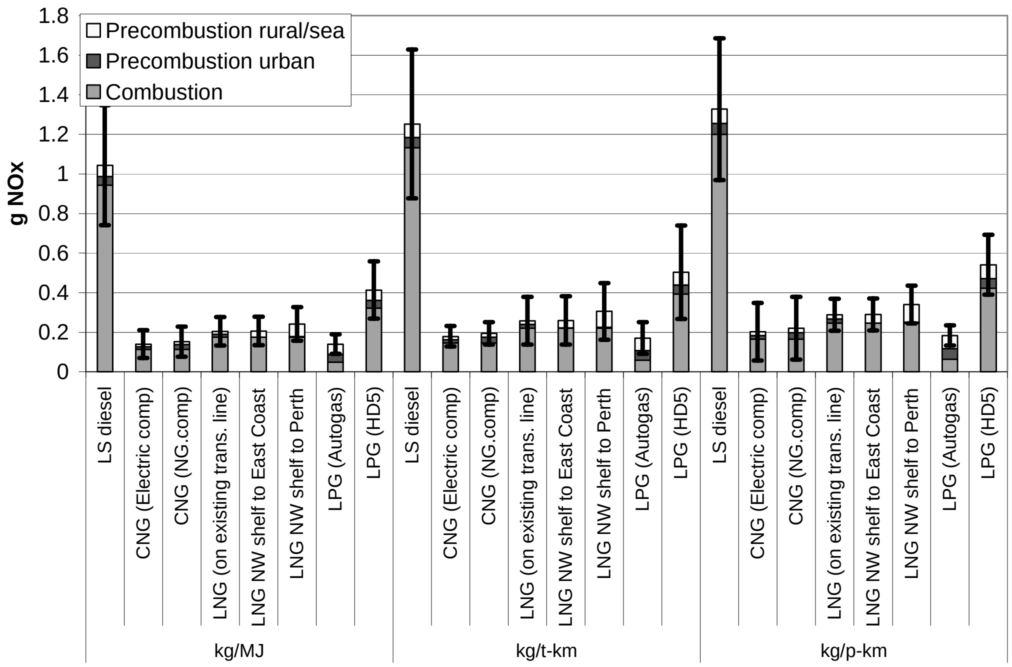

Figure 10.3
Exbodied emissions of oxides of nitrogen for gaseous fuels.

10.2.4 Emissions of hydrocarbons

Emissions of hydrocarbons for the gaseous fuels are shown in Figure 10.4. In every case, the gaseous fuels have lower exbodied hydrocarbon emissions than LSD, though we estimate larger pre-combustion emissions of hydrocarbons from autogas than from LSD, primarily as a result of leakage.

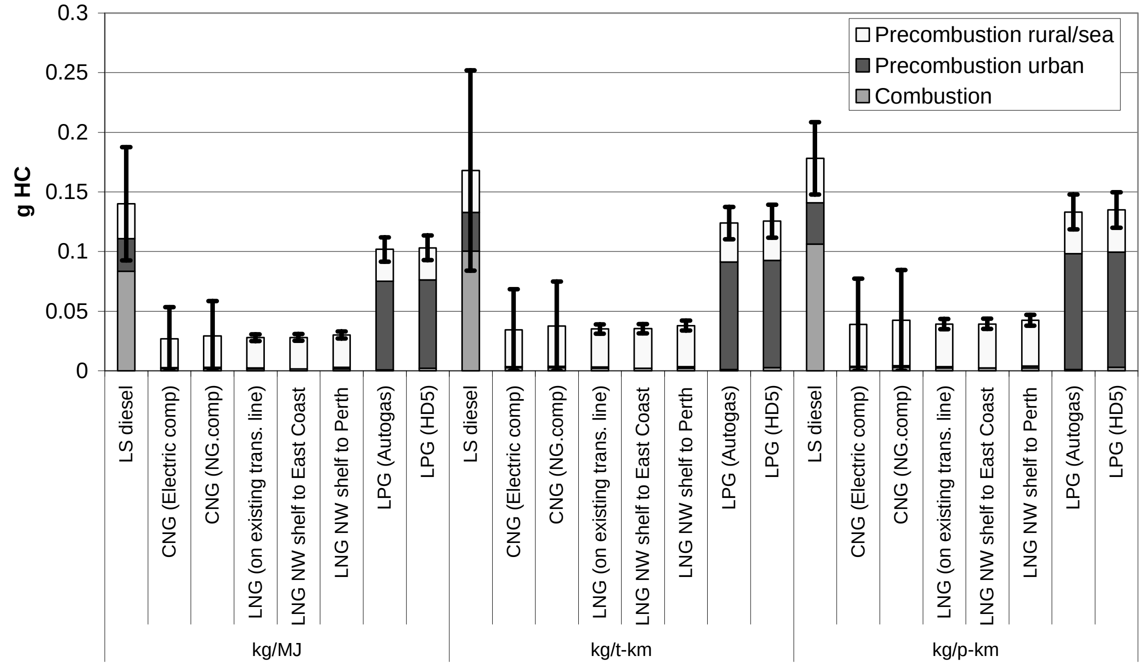

Figure 10.4
Exbodied emissions of hydrocarbons for gaseous fuels

10.3 Viability and Functionality

DAF, the Dutch vehicle maker, developed a dedicated LPG fuelled bus using the stoichiometric process rather than lean burn. This process reduces the emission rate of particulate matter to one twentieth of Euro2, whereas lean burn only comes to half of Euro2.

Some ullage space must be left in an LPG tank because the liquid volume expands significantly if the tank encounters increasing ambient temperatures. Gaseous fuelled engines are generally considered easier to start than petrol or diesel engines in cold weather, because the fuel is vaporized before injection into the engine. Hot starting may, however, produce difficulties.

Australian LPG, being primarily sourced from natural gas, is vulnerable to disruption in the gas supply. This was most evident with the Longford incident in 1998 when gas supplied to Melbourne, and much of the rest of Victoria were halted following the disaster at the Longford plant. During the period of gas shortage, LPG was sourced from interstate and there was, in fact, no disruption to supply. The NSW cavern storage of LPG at Port Botany provides added security.

Presently there are no data on emissions from diesel vehicles converted to use autogas. It is expected that the performance of such converted vehicles will be similar to vehicles that have been converted to use propane (LPG-HD5). These are dealt with in the next chapter.

10.4 Health Issues

LPG's low emissions have low greenhouse gas effects and low NOx precursors. LPG upstream emissions of particulate matter are similar to LSD. LPG upstream emissions of air toxics are greater than LSD. LPG tailpipe emissions of particulate matter are substantially less than LSD. LPG tailpipe emission of benzene, 1,3 butadiene, formaldehyde and acetaldehyde are less than LSD.

LPG vapor is heavier than air, disperses slowly, and can accumulate in local valleys. LPG, when involved in a leak will discharge in a liquid form requiring a period of time to vaporize and disperse. LPG fires tend to persist within the leakage area due to its liquid and heavier than air state. For fuel line ruptures, pressurized gaseous fuels represent higher hazard levels than petrol.

10.5 Environmental Issues

The environmental issues surrounding LPG are the same as those for CNG and LNG, in that they are gaseous fuels that do not cause land or water pollution. Air pollutants are reduced when compared to LSD. Dedicated LPG vehicles have lower emissions than dual-fuelled vehicles.

ESD principles

Noise levels from dedicated LPG buses are less than those of diesel buses. LPG 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 LPG.

Sustainability

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

Groundwater

Being a gaseous fuel, LPG does not impact groundwater.

10.6 ADR Compliance

LPG can be expected to meet all future Australian Design Rules for all pollutants.

10.7 Summary

10.7.1 Advantages

- It has low cold-start emissions due to its gaseous state.
- It has lower peak pressure during combustion, which generally reduces noise and improves durability; noise levels can be less than 50% of equivalent diesel engines.
- LPG fuel systems are sealed and evaporative losses are negligible.
- It is easily transportable and offers 'stand-alone' storage capability with simple and self-contained LPG dispensing facilities, with minimum support infrastructure.
- LPG vehicles do not require special catalysts.
- It contains negligible toxic components.

- LPG has lower particulate emissions and lower noise levels relative to diesel, making it more attractive for urban areas.
- Its low emissions have low greenhouse gas effects and low NOx precursors.
- Relative to other fuels, any increases in future demand for LPG can be easily satisfied from both natural gas fields and oil refinery sources.
- Emissions of PAH and aldehydes are much lower than those of diesel-fuelled vehicles.

10.7.2 Disadvantages

- Although LPG has a relatively high energy content per unit mass, its energy content per unit volume is low which explains why LPG tanks take more space than diesel fuel tanks.
- The LPG tanks are pressure vessels and therefore weigh more than diesel tanks.
- It is heavier than air, which requires appropriate handling.
- Its vapour flammability limits in air are wider than those of petrol, which makes LPG ignite more easily.
- It has a high expansion coefficient so that tanks can only be filled to 80% of capacity.
- LPG in liquid form can cause cold burns to the skin in case of inappropriate use.

11. Liquefied Petroleum Gas (LPG) – HD5

11.1 Background

LPG HD-5 is essentially liquefied propane gas. Most LPG used on the East Coast of Australia is Autogas. Propane as a vehicle fuel is limited to Western Australia. There is very little usage of LPG in Australian heavy vehicles. LPG has particularly low particulate levels, which make it an attractive fuel for urban buses and delivery vehicles. However, as diesel particulate emissions reduce to Euro4 levels this advantage may be lost.

11.2 Results

Because it is relatively rare for LPG to be used in heavy vehicles, there is a lack of published data on its emissions characteristics though there is considerable data in relation to LPG used in cars.

11.2.1 Greenhouse gas emissions

Figure 11.1 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). Exbodied emissions of greenhouse gases are lower from HD5 than from LSD.

11.2.2 Particulate matter emissions

Figure 11.2 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 HD5 are markedly lower than those of LSD.

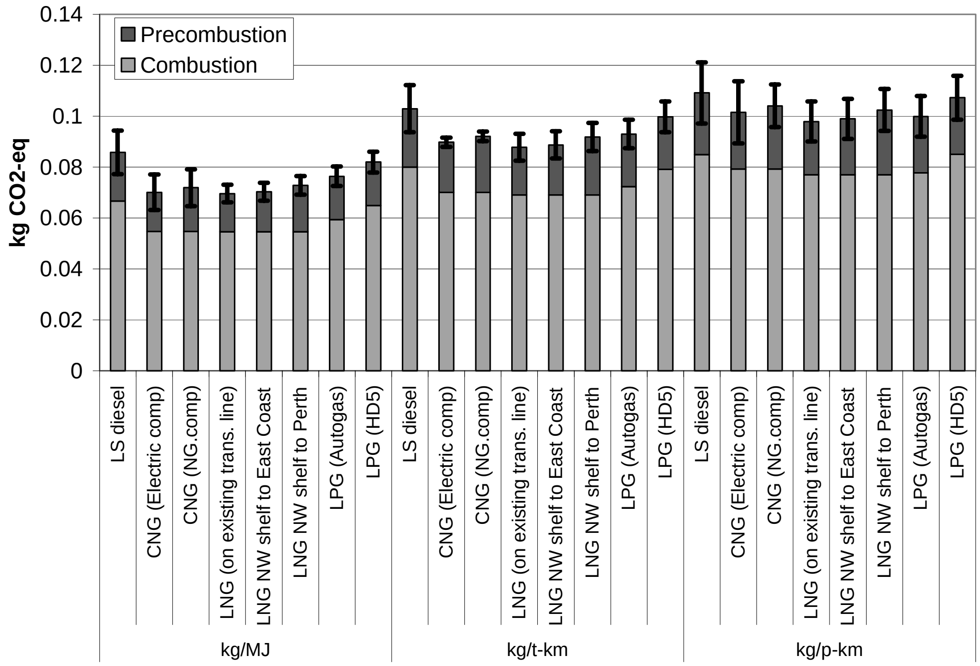

Figure 11.1
Exbodied emissions of greenhouse gases for gaseous fuels.

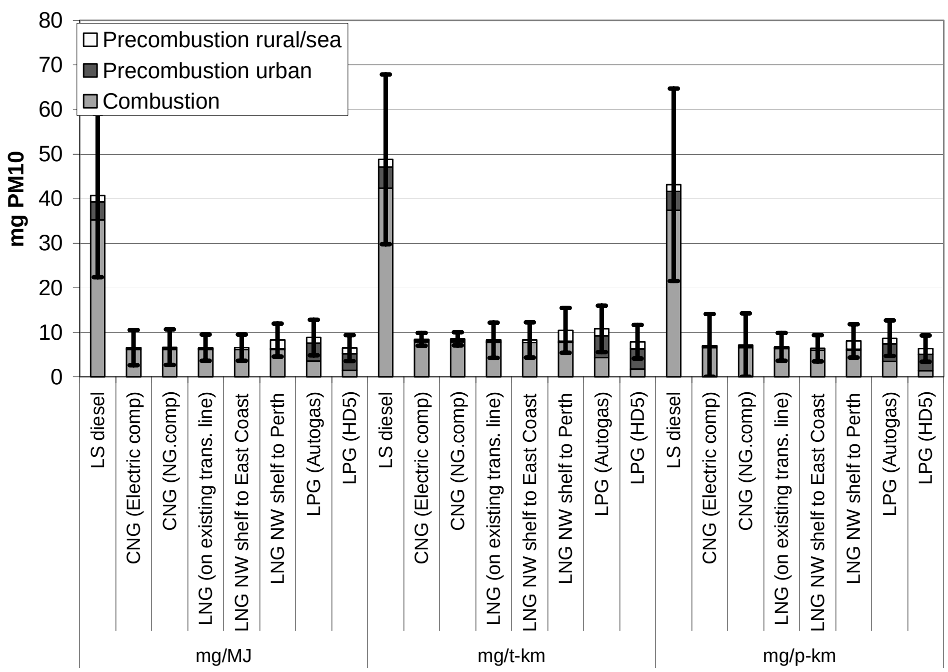

Figure 11.2
Exbodied emissions of particulate matter for gaseous fuels.

11.2.3 Emissions of oxides of nitrogen

Figure 11.3 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. Emissions of NOx from HD5 are lower than those of LSD.

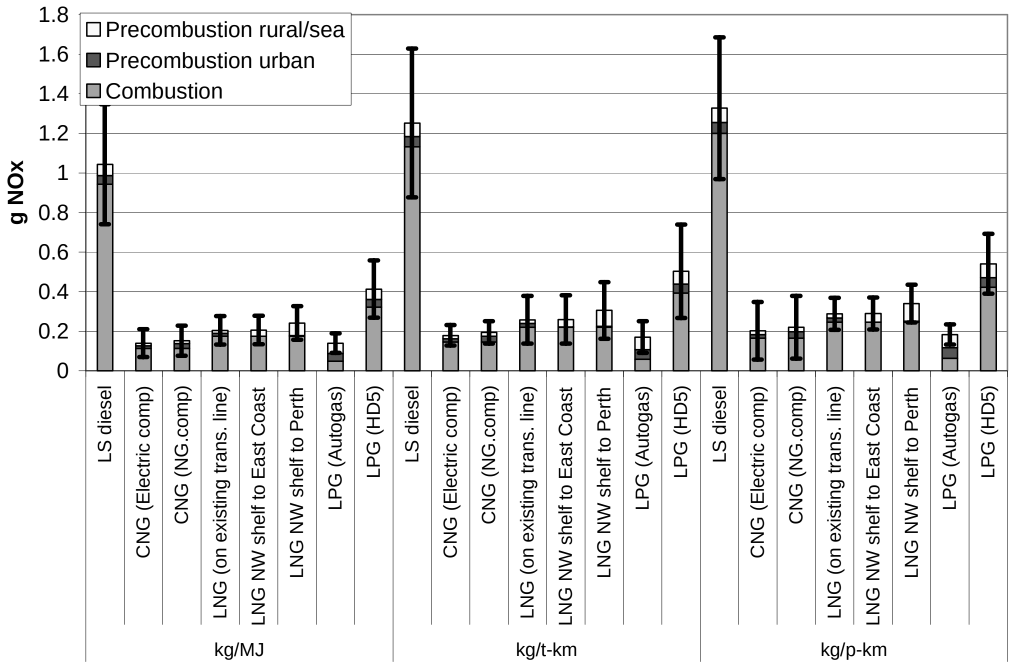

Figure 11.3
Exbodied emissions of oxides of nitrogen for gaseous fuels.

11.2.4 Emissions of hydrocarbons

Emissions of hydrocarbons for the gaseous fuels are shown in Figure 11.4. In every case, the gaseous fuels have lower exbodied hydrocarbon emissions than LSD, though we estimate large pre-combustion emissions of hydrocarbons from propane primarily from leakage.

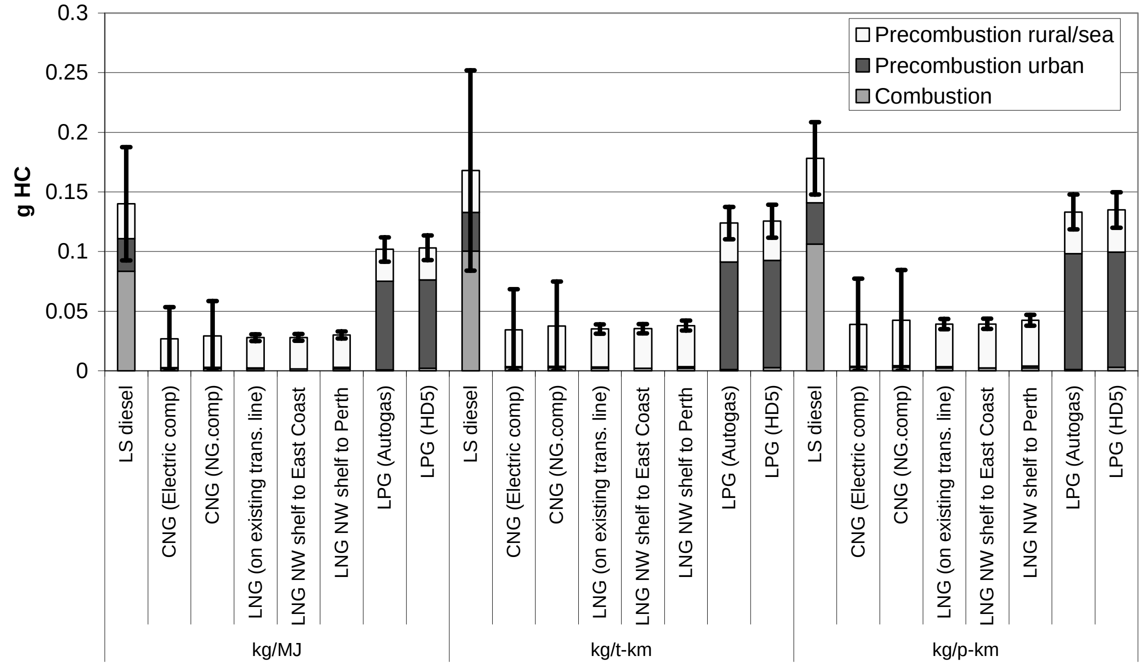

Figure 11.4
Exbodied emissions of hydrocarbons for gaseous fuels

11.3 Viability and Functionality

Propane (HD5) viability and functionality issues are identical to those of Autogas. The main benefit of propane is that the vehicle compression ratio can be adjusted to make use of the higher octane fuel and thus improve fuel economy.

Stakeholder input from Cummins noted that when comparing diesel, propane and natural gas in the same engine then the engine performance ratings are highest for diesel, then CNG, then propane.

Kleenheat Gas recently developed a diesel/LPG fuel substitution conversion kit that was used in a trial of an articulated Volvo B10M MkIII LPG bus in Darwin. Was Diesel Now Gas offers conversion to a dedicated HD-5 vehicle. From the very limited data available, vehicles converted to LPG appear to be less successful at reducing emissions than newly purchased LPG vehicles. Converted vehicles appear to have higher tailpipe emission of hydrocarbons than diesel vehicles, though particulate matter emissions are lower. Other emissions affecting air quality appear to be similar to those of diesel while emissions of carbon dioxide are similar to, or slightly less than, those of similar diesel vehicles. However, it should be reiterated that these conclusions are based on the testing of one converted dual fuel vehicle and one vehicle converted from diesel to dedicated LPG-HD5. The Australian LPG conversion industry for heavy vehicles is at an early stage in its development and the data from such test may not reflect the emissions performance of converted vehicles in the longer term.

DAF, the Dutch vehicle maker, has developed a dedicated LPG fuelled bus using the stoichiometric process rather than lean burn. This process reduces the emission rate of particulate matter to one twentieth of Euro2, whereas lean burn only comes to half of Euro2.

Some ullage space must be left in an LPG tank because the liquid volume expands significantly if the tank encounters increasing ambient temperatures. Gaseous fuelled engines are generally considered easier to start than petrol or diesel engines in cold weather, because the fuel is vaporized before injection into the engine. Hot starting may, however, produce difficulties.

Australian LPG, being primarily sourced from natural gas, is vulnerable to disruption in the gas supply. This was most evident with the Longford incident in 1998 when gas supplied to Melbourne, and much of the rest of Victoria were halted following the disaster at the Longford plant. During the period of gas shortage, LPG was sourced from interstate and there was no disruption to the LPG supply. The NSW cavern LPG storage facility at Port Botany provides added security.

11.4 Health Effects

Emissions of PAH and aldehydes are much lower than those of diesel-fuelled vehicles. LPG in liquid form can cause cold-burns to the skin in case of inappropriate use. In general, the health effects of Autogas and HD5 are the same.

LPGHD5 upstream emissions of particles are similar to LSD. LPGHD5 upstream emissions of air toxics are greater than LSD. LPGHD5 tailpipe emissions of particles are substantially less than LSD. LPGHD5 tailpipe emission of benzene, 1,3 butadiene, formaldehyde and acetaldehyde are less than LSD.

11.5 Environmental Issues

Air pollutants are reduced when compared to LSD. Dedicated LPG vehicles have lower emissions than dual-fuelled vehicles. When compared to Autogas, HD5 produces more NOx but less particulate matter.

ESD principles

Noise levels from dedicated LPG buses are less than those of diesel buses. LPG 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 LPG.

Sustainability

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

Groundwater

Being a gaseous fuel, LPG does not impact groundwater.

11.6 ADR Compliance

LPG can be expected to meet all future Australian Design Rules for all pollutants.

11.7 Summary

11.7.1 Advantages

- Propane has low cold-start emissions due to its gaseous state.
- Propane has lower peak pressure during combustion than conventional fuels, which generally reduces noise and improves durability.
- LPG fuel systems are sealed and evaporative losses are negligible.
- Propane is easily transportable and offers ‘stand-alone’ storage capability with simple and self-contained LPG dispensing facilities, with minimum support infrastructure.
- LPG vehicles do not require special catalysts.
- Propane contains negligible toxic components.
- LPG has lower particulate emissions and lower noise levels relative to diesel, making propane attractive for urban areas. Noise levels can be less than 50% of equivalent engines using diesel.
- Propane’s emissions are low in greenhouse gases and low in NOx, thus they are low in ozone precursors.
- Increases in future demand for LPG can be easily satisfied from both natural gas fields and oil refinery sources.
- Emissions of PAH and aldehydes are much lower than those of diesel-fuelled vehicles.

11.7.2 Disadvantages

- Although LPG has a relatively high energy content per unit mass, its energy content per unit volume is low which explains why LPG tanks take more space than diesel fuel tanks of the same energy storage capacity.
- Propane tanks are pressure vessels and thus weigh more than the equivalent diesel tank.
- Propane is heavier than air, which requires appropriate handling.
- Propane vapour flammability limits in air are wider than those of petrol, which makes LPG ignite more easily.
- Propane has a high expansion coefficient so that tanks can only be filled to 80% of capacity.
- Propane in liquid form can cause cold burns to the skin in case of inappropriate use.

12. Premium Unleaded Petrol Summary

12.1 Introduction

The study brief requires an examination of Premium Unleaded petrol (PULP), which is a 95 RON fuel meeting either the Euro II specification for unleaded petrol or the fuel specifications for PULP proposed by the Commonwealth for implementation in 2002. It is assumed that this fuel does not contain ethanol and that it is used in light vehicles as defined in ADR 79/00 and 79/01. Our analysis treats PULP as a reference fuel against which to compare ethanol blends. Our analysis is thus based on a hypothetical vehicle that satisfies Euro 2 tailpipe emissions.

The difference between ULP and PULP is determined by differences in octane rating. PULP blend typically contains larger proportion of high octane streams, i.e those containing aromatics, isoparaffins and naphthenes.

Upstream emissions in petrol production arise from oil recovery, transportation and processing. Further emissions derive from the distribution through the retail network.

12.2 Results

Because PULP is treated as a reference fuel, its results are used as a basis of comparison for petrohol and for anhydrous ethanol in the following chapters.

12.3 Viability and Functionality

Petrol is the most common automotive fuel, and unleaded petrol has been in use in Australia since 1986. Manufacturers produce premium unleaded petrol and its use does not cause warranty problems. Vehicle operational range depends on the size of the fuel tank, but typical values for a four or six cylinder car range from 400 to 600 km.

All forms of petrol are considered hazardous according to Worksafe Australia criteria, more so than diesel fuel. Petrol has an extreme flammability rating and extreme chronic effect rating. It has moderate toxicity and body contact ratings.

12.4 Health Issues

A typical material data safety sheet will note that unleaded petrol is highly flammable; harmful by inhalation, in contact with skin and if swallowed; possibly carcinogenic; and may cause damage to health from prolonged exposure.

12.5 Environmental Impact and Benefits

ESD

Ecologically sustainable development (ESD) is based on the principles of equity, efficiency and ecological integrity. The modern western economy is based on petroleum products, of which petrol, unleaded petrol, and premium unleaded petrol are examples. Though substantial arguments can be advanced that such an economy is not sustainable, in the sense that fossil fuels constitute a non-renewable resource, over the past three decades exploration activity has continually discovered new hydrocarbon reserves. In addition, the current concern over climate change has highlighted the burning of fossil fuels as one of the main causes. Thus even if one argues that the fossil fuel economy is economically efficient, it is more difficult to argue that it encourages equity or ecological integrity.

Sustainability

The sustainability of petrol depends on the sustainability of the crude oil from which it is refined. Australian oil reserves are, or soon will be in decline. There will either be increased reliance on imports or there will need to be fuel substitution. This means that sustainability of petrol is dependent on global oil supplies.

Groundwater contamination

Petrol is refined from crude oil. Spills of crude oil, especially during transport in oil tankers at sea, pose an environmental hazard that contaminates marine life and bird life. Environmental damage from petrol itself can also occur, especially from leaks, at service stations and refuelling depots, which have been known to contaminate groundwater supplies.

13. Anhydrous Ethanol

13.1 Background

Anhydrous ethanol can be used as an additive in petrol, or as a fuel in its own right. Despite this, as an automotive fuel it is usually composed of 85% ethanol with 15% petrol (E85P) and this is the fuel that will be examined in this chapter. The reason for this is that the addition of 15% petrol improves the ignitability of alcohol, especially at low temperature. Other additives have also been trialled as ignition improvers. Ethanol is probably the most widely used alternative automotive fuel in the world, mainly due to Brazil's decision to produce fuel alcohol from sugar cane.

13.2 Results

The upstream emissions associated with anhydrous ethanol are essentially the same as those associated with hydrated ethanol, with a requirement for extra energy input arising from the extra process step to transform the hydrated ethanol to anhydrous ethanol. According to Table 10 of the chapter on hydrated ethanol, 30% more energy is needed to convert hydrated ethanol to anhydrous ethanol. Our calculations also include the emissions associated with the production of the 15% of petrol added to the anhydrous ethanol. We have taken tailpipe emissions as being those from a representative car, and compare E85P against PULP.

13.2.1 Greenhouse gas emissions

Figure 13.1 depicts the greenhouse gas emissions estimated for the reference fuel (PULP) for light vehicles, and for anhydrous ethanol (E85P). These are shown as emissions on an energy basis, and as emissions per kilometre for a car.

Exbodied greenhouse gas emissions of E85P are approximately half those of PULP, or less, depending on the fuel source provided it is sourced from renewable material. Ethanol manufactured from fossil fuels emits more greenhouse gases than petrol.

13.2.2 Particulate matter emissions

Figure 13.2 depicts the particulate matter (PM10) emissions estimated for PULP and E85P. These are shown as emissions on an energy basis, as emissions on a per km basis for cars. Emissions from PULP are generally comparable to those from E85D, though if waste (wheat waste or wood waste) is used as a combustion source (instead of natural gas) then the particles emitted during the upstream phases mean that the exbodied particulate matter emissions are greater than those from PULP.

13.2.3 Emissions of oxides of nitrogen

Figure 13.3 depicts the oxides of nitrogen (NOx) emissions estimated for E85P and PULP. These are shown as emissions on an energy basis, and as emissions on a per km basis for cars. NOx emissions from E85P, in comparison with those of PULP, are very variable. The exact nature of the process and the assumptions made in terms of life-cycle allocations are crucial in determining whether the E85P emissions of NOx are less than those of PULP (which occurs when waste material is used), or greater than those of PULP (which occurs when fossil fuels or non-waste material are used).

13.2.4 Emissions of hydrocarbons

Figure 13.3 depicts the non-methanic hydrocarbon (HC) emissions estimated for PULP and E85P. These are shown as emissions on an energy basis, and as emissions on a per km basis for cars. PULP. If natural gas is used to fire the plant then exbodied HC emissions of E85P are comparable to, or possibly slightly below, those of PULP. If wheat or wood is used as an energy source, or if fossil fuels are used to make the ethanol, then HC emissions are greater than those from PULP.

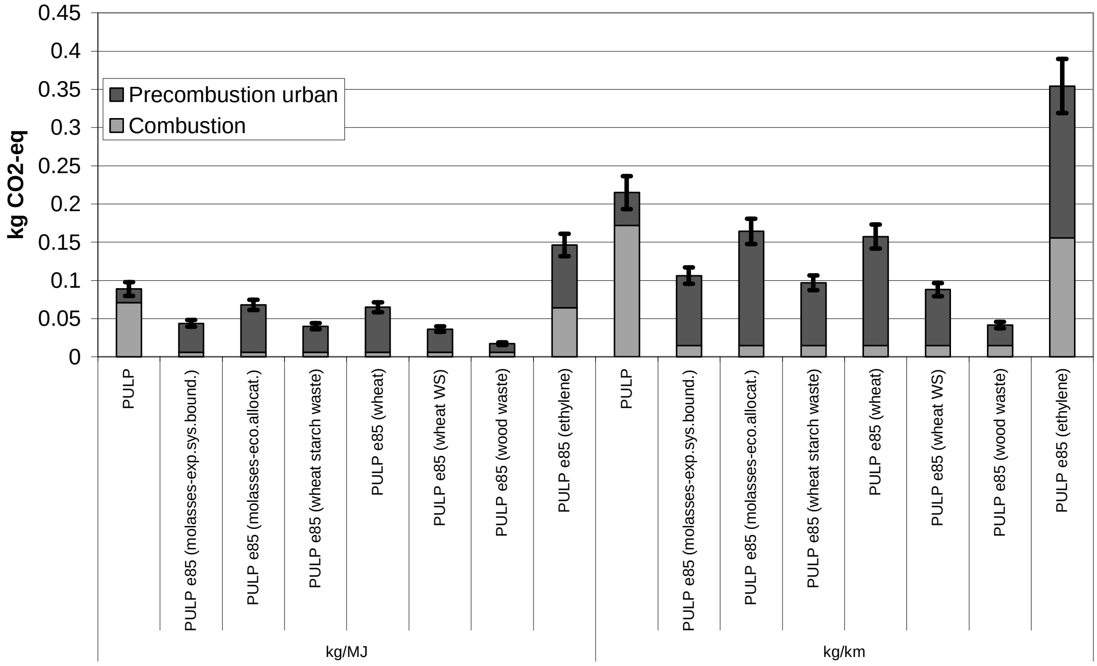

Figure 13.1
Exbodied emissions of greenhouse gases for premium unleaded petrol and anhydrous ethanol (E85P).

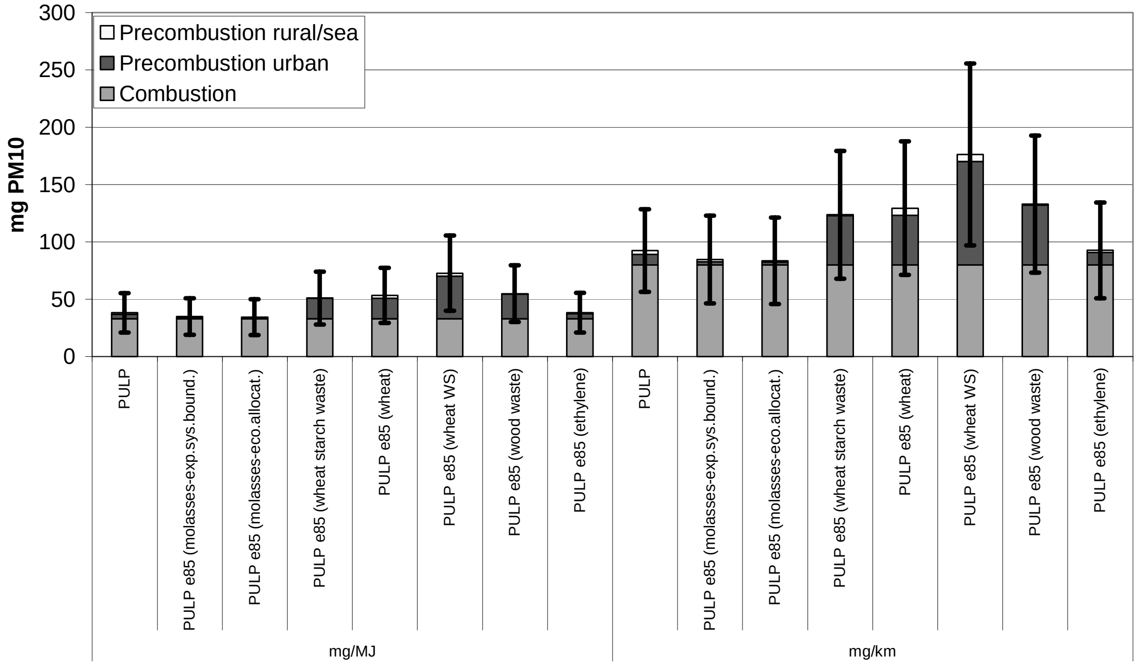

Figure 13.2
Exbodied emissions of particulate matter for premium unleaded petrol and anhydrous ethanol (E85P).

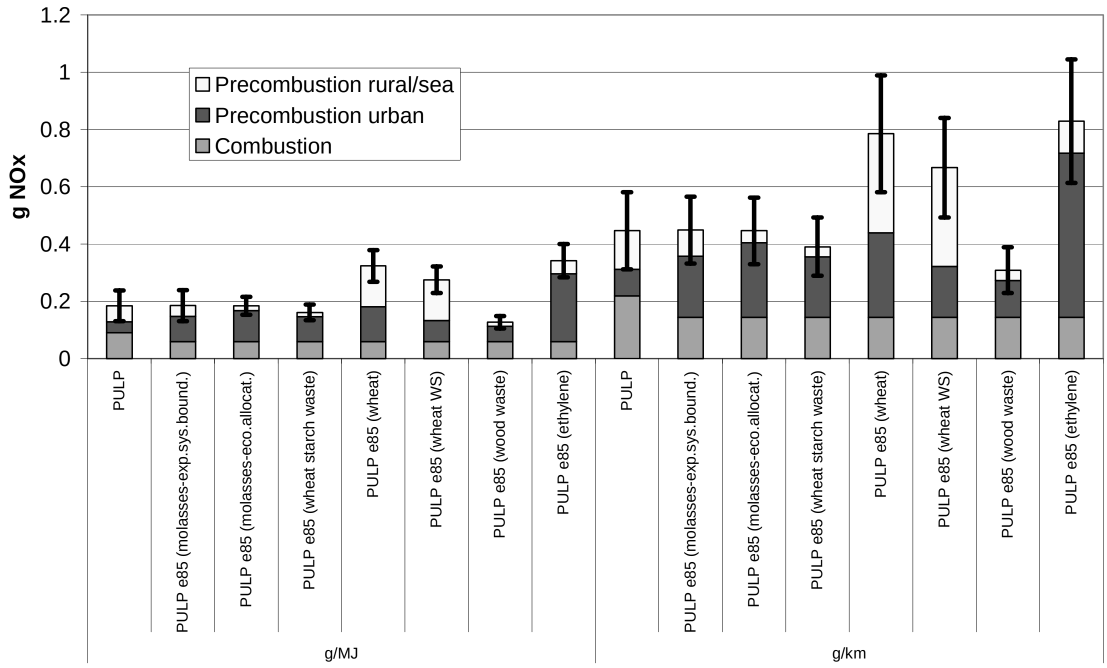

Figure 13.3
Exbodied emissions of oxides of nitrogen for premium unleaded petrol and anhydrous ethanol (E85P).

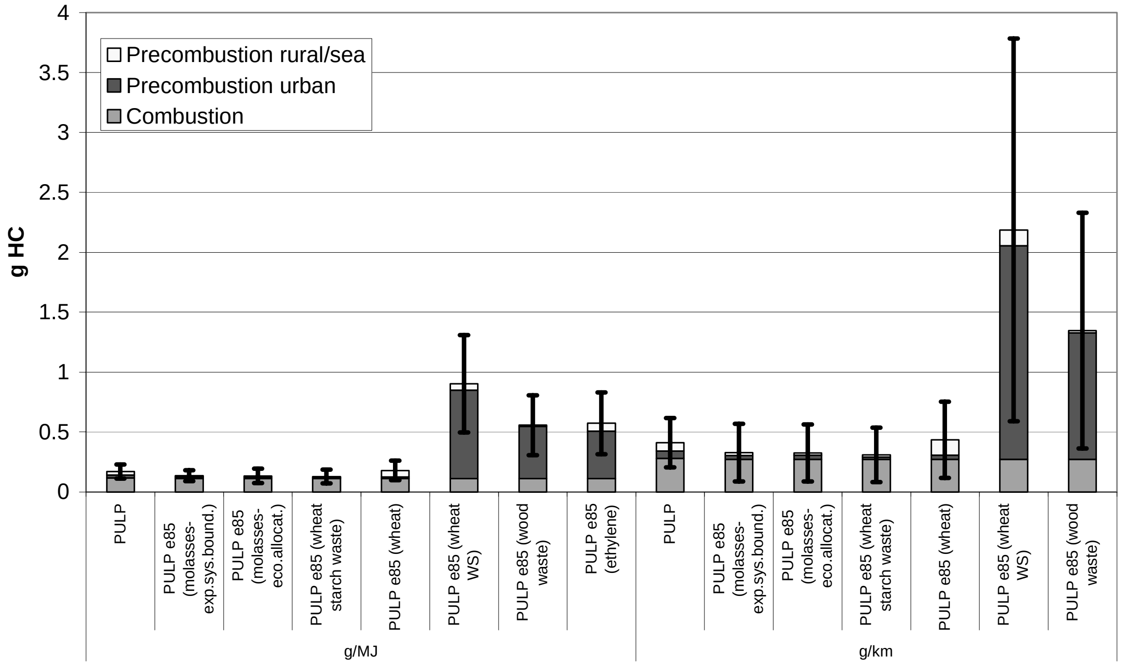

Figure 13.4
Exbodied emissions of hydrocarbons for premium unleaded petrol and anhydrous ethanol (E85P).

13.3 Viability and Functionality

There is considerable international experience on the use of ethanol in Brazil where sugar-derived ethanol is used as an automotive fuel. The ethanol used in Brazil is called Alcool and consists of 93% ethanol by volume. IEA Alternative Fuels Information Service (1996) note that "the techniques for the production and use of methanol and ethanol as a vehicle fuel are known. Obstacles that hinder the use of alcohols as a vehicular fuel are the relatively high costs of alcohol and the investments necessary to introduce an extra fuel."

The viability and functionality issues related to ethanol and its use in heavy vehicles (as diesohol) or in light vehicles (as petrohol) have been examined in other chapters, and the same considerations will apply for E85P.

13.4 Health and OH&S

Ethanol produces a marked decline in the emissions of air toxics, except for the aldehydes. When weighting factors are applied, the weighted air toxics emissions from ethanol are below those of petrol.

13.5 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. The particulate emissions are lowered as are the emissions of ozone pre-cursors. The concentrations of emitted air toxics are lower from ethanol than from petrol.

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 except to note that in the US the replacement of MTBE by ethanol in oxygenated fuels was specifically done to reduce groundwater contamination.

13.6 Expected Future Emissions

Ethanol can be expected to meet all future Australian Design Rules for all pollutants, except for hydrocarbon emissions.

13.7 Summary

13.7.1 Advantages

- As a renewable fuel it produces less fossil CO_2 than conventional fuels
- Tailpipe emissions of NOx and PM appear to be lower on average.
- Air toxic levels (except for aldehydes) are lower than those of conventional fuels.

13.7.2 Disadvantages

- Cold starting in cool climates is difficult unless ethanol is blended with petrol as a starting aid, or unless some other starting aid is used.

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14. Petrohol

14.1 Background

Anhydrous ethanol can be used as an additive in petrol. We use the term petrohol for a blend of 10% anhydrous ethanol in premium unleaded petrol. The symbols E10P or E10PULP are also used for this fuel, depending on whether it is necessary to specify the type of petrol (P) with which the ethanol is blended.

There has been substantial US interest in the use of ethanol in cars. The reason for this is that the Californian Government, through their Air Resources Board, requires vehicles to use "reformulated gasoline". Originally such reformulated gasoline could be made by blending MTBE (methyl tertiary-butyl ether) into petrol. Because of the contamination of Californian groundwater with MTBE the Californian Governor ordered the removal of MTBE from petrol and studies on the environmental and health effects of ethanol in petrol. The use of ethanol produces an oxygenated fuel that satisfies the requirements of Californian reformulated gasoline.

Oygenates are added to petrol to improve the anti-knock performance and to reduce emissions. Reuter et al (1992) studied European petrol oxygenated with MTBE, ETBE and ethanol and found that the tailpipe emissions of oxygenated petrol are independent of the oxygenate that is used.

On 8 May 2001 the Minister for Environment and Heritage, Senator Hill, announced the first national fuel quality standard for petrol and diesel under the *Fuel Quality Standards Act 2000*. Senator Hill said in that context, that further assessments were necessary before setting an ethanol limit for petrol. Studies are currently being undertaken by independent experts and a decision is expected within 12 months.

14.2 Results

14.2.1 Greenhouse gas emissions

Figure 14.1 depicts the greenhouse gas emissions estimated for PULP, which we take as the reference fuel for light vehicles, as well as for petrohol. These are shown as emissions on an energy basis, and as emissions per kilometre for a car. The differences between exbodied greenhouse gas emissions of PULP and E10P are slight.

14.2.2 Particulate matter emissions

Figure 14.2 depicts the particulate matter (PM10) emissions estimated for PULP and E10P. These are shown as emissions on an energy basis, and as emissions on a per km basis for cars. Emissions of PULP and E10P are similar.

14.2.3 Emissions of oxides of nitrogen

Figure 14.3 depicts the oxides of nitrogen (NOx) emissions estimated for PULP and E10P. These are shown as emissions on an energy basis, and as emissions on a per km basis for cars. Emissions of PULP and E10P are similar.

14.2.4 Emissions of hydrocarbons

Figure 14.3 depicts the non-methanic hydrocarbon (HC) emissions estimated for PULP and E10P. These are shown as emissions on an energy basis, and as emissions on a per km basis for cars. Hydrocarbon emissions from E10P are generally similar to those from PULP.

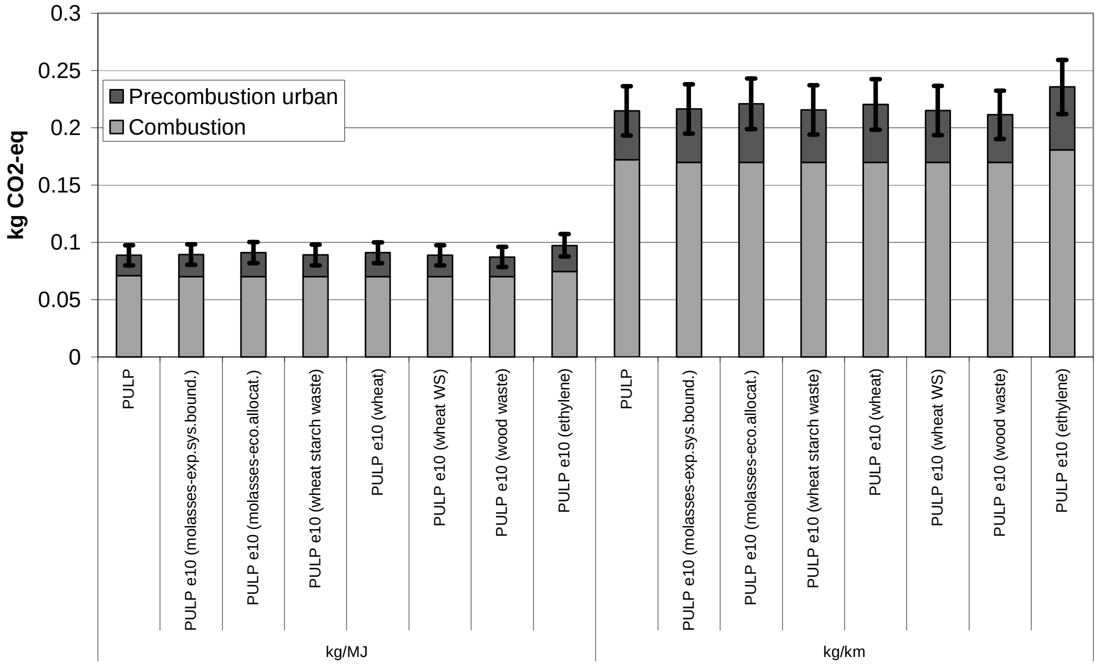

Figure 14.1
Exbodied emissions of greenhouse gases for premium unleaded petrol and petrohol.

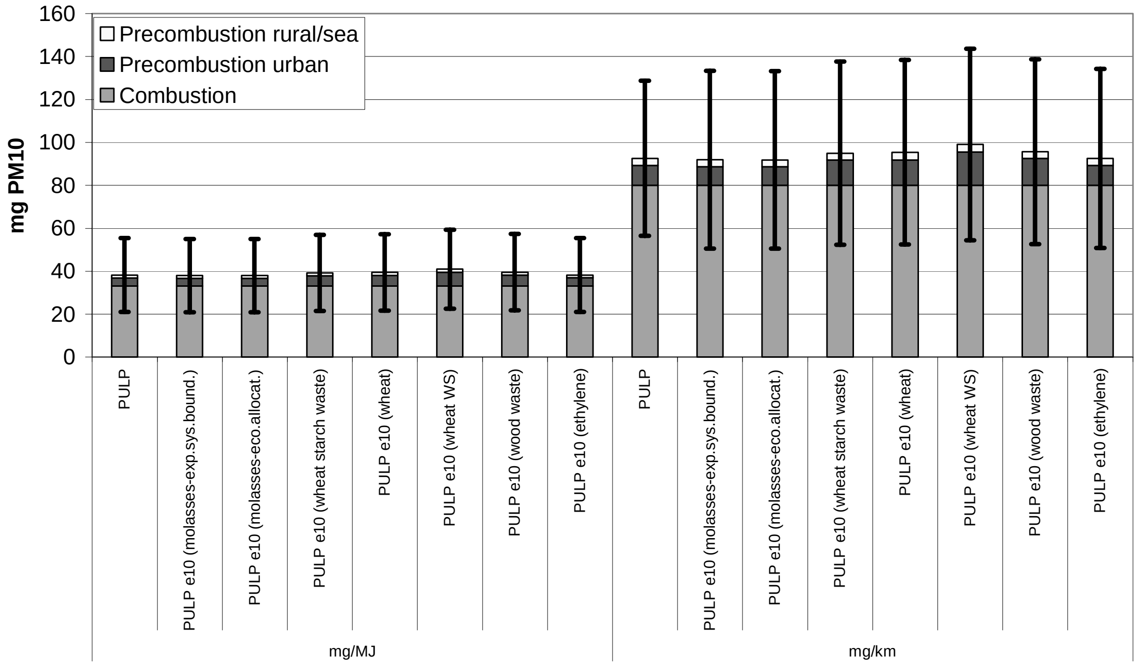

Figure 14.2
Exbodied emissions of particulate matter for premium unleaded petrol and petrohol.

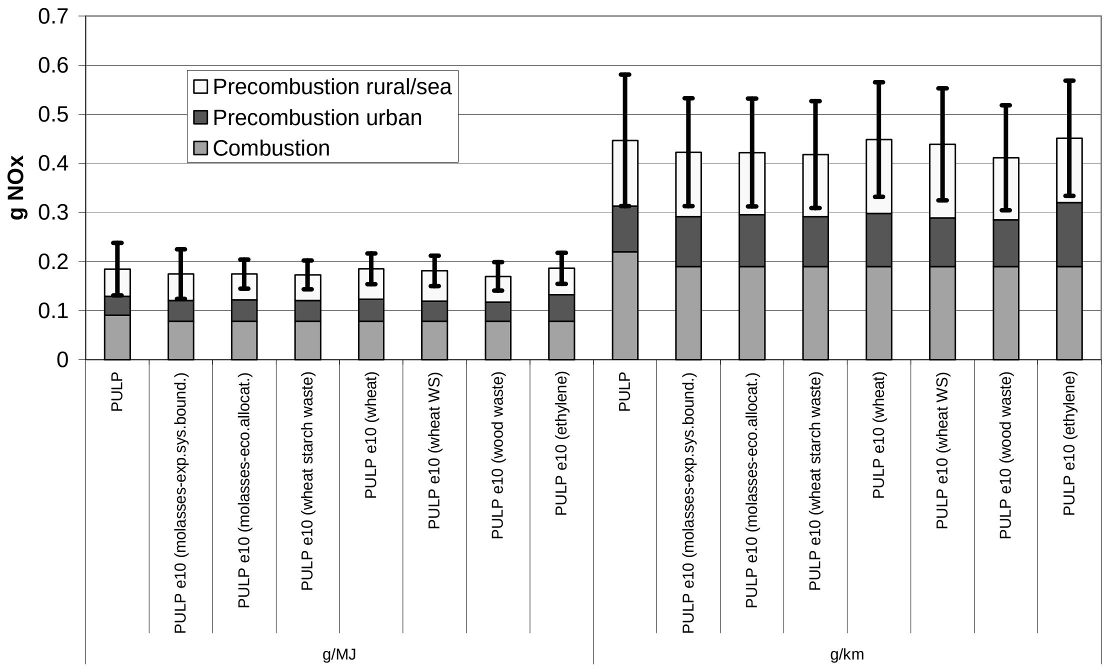

Figure 14.3
Exbodied emissions of oxides of nitrogen for premium unleaded petrol and petrohol.

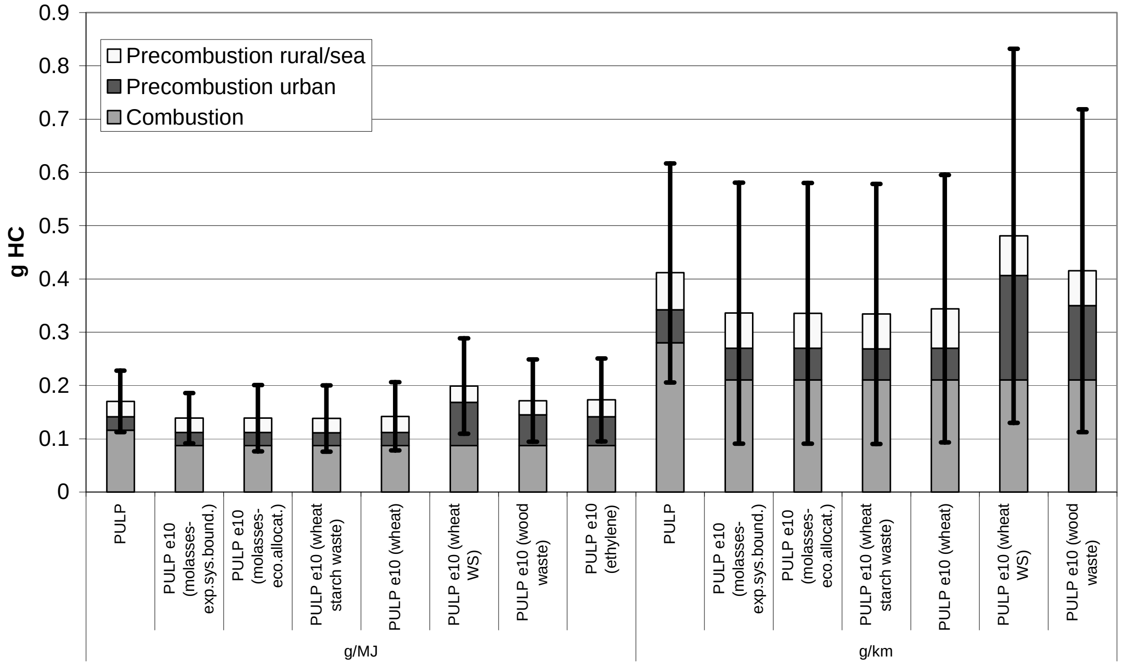

Figure 14.4
Exbodied emissions of hydrocarbons for premium unleaded petrol and petrohol.

14.3 Viability and Functionality

There is considerable international experience on the use of ethanol as a blend in petrol in the United States, where it is needed under the legislation requiring the use of reformulated gasoline, and in Brazil where sugar-derived ethanol is used as an automotive fuel and also as a blend (gasohol). No special engine modification or handling precautions are needed when using a 10% ethanol blend. Such widespread international experience indicates that the viability and functionality of petrohol will be much the same as of the corresponding petrol with which the ethanol is blended. Ethanol can loosen contaminants and residues that have been deposited by previous gasoline fills. These can collect in the fuel filter. This problem has happened occasionally in older cars, and can easily be corrected by changing fuel filters. Symptoms of a plugged fuel filter will be hesitation, missing, and a loss of power.

14.4 Health and OH&S

Motor vehicle emissions data indicates that the use of ethanol results in substantial reductions in air toxics emissions.

E10PULP tailpipe emissions of benzene, 1,3 butadiene, are substantially less than petrol vehicles, while formaldehyde emissions are similar. There is contradictory information about the emissions of acetaldehyde tailpipe emissions with some studies showing an increase while other show a decrease compared with petrol. More research is required to clarify this issue.

Ethanol in solution is hazardous according to Worksafe Australia, with high flammability, moderate toxicity, and a moderate irritant. The flash point of the fuel emulsion becomes that of alcohol when the alcohol content exceeds 5% of the volume.

Ethanol fuels increase permeation on elastomers that have been used in automotive applications (eg: rubber hoses, plastic fuels tanks). Research is required to quantify the permeation impacts of ethanol. (Harold Haskew & Associates, 2001)

14.5 Environmental Issues

ESD principles

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. A blend of 10% ethanol with petrol will be more in accord with ESD principles than petrol on its own.

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, and the sustainability issues associated with such production have been discussed in the chapters on ethanol.

Ethanol is a renewable fuel. Petrol is a non-renewable fuel. A blend of 10% ethanol will be more sustainable than petrol on its own.

Groundwater contamination

There is no evidence of widespread groundwater contamination from petrohol, unlike fuels oxygenated with MTBE. It may be expected that petrohol has a similar impact on local groundwater supplies as petrol.

14.6 ADR Compliance

Petrohol can be expected to meet all future Australian Design Rules for all pollutants.

14.7 Summary

14.7.1 Advantages

- Tailpipe emissions of CO and HC appear to be lower on average.
- Air toxic levels decrease as the ethanol concentration increases.

14.7.2 Disadvantages

- There are high hydrocarbon evaporative emissions that require adjustment of the vapour pressure of the base petrol to which ethanol is added.
- There are problems of phase stability in the petrol mixture if water is present.

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15. Hydrogen

15.1 Introduction

The hydrogen energy content per unit mass is high. Compared to petrol for example, it is three times as high. On a volume basis, the energy content of hydrogen is relatively small. All mixtures of hydrogen and air with a volumetric hydrogen content between 4% and 75% are inflammable. Compared to mixtures of petrol and air, this is a wide range. Hydrogen can burn in mixtures with air from very lean (excessive air) to rich (excessive fuel).

15.2 Full Fuel Cycle Analysis Results

We consider only fuel-cell powered vehicles with the hydrogen derived from steam reforming of natural gas. Such hydrogen vehicles have virtually no emissions, even of NOx, because fuel cells operate at temperatures that are so much lower than internal combustion engines that NOx is not formed from the nitrogen and oxygen in the air. Theoretically, a hydrogen-fuelled fuel cell vehicle emits only water vapour.

15.2.1 Greenhouse gas emissions

Figure 15.1 depicts the greenhouse gas emissions estimated for the reference fuel (LSD) and hydrogen. 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).

The upstream emissions of greenhouse gases from hydrogen manufacture equates closely to the total exbodied emissions of greenhouse gases from low sulfur diesel.

15.2.2 Particulate matter emissions

Figure 15.2 depicts the particulate matter (PM10) emissions estimated for hydrogen. 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. In all cases but one the emissions of PM10 are less from hydrogen than from the reference fuel (LSD).

15.2.3 Emissions of oxides of nitrogen

Figure 15.3 depicts the oxides of nitrogen (NOx) emissions estimated for hydrogen. 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. As a general rule the upstream NOx emissions from hydrogen processing are less than those of the reference fuel.

15.2.4 Emissions of hydrocarbons

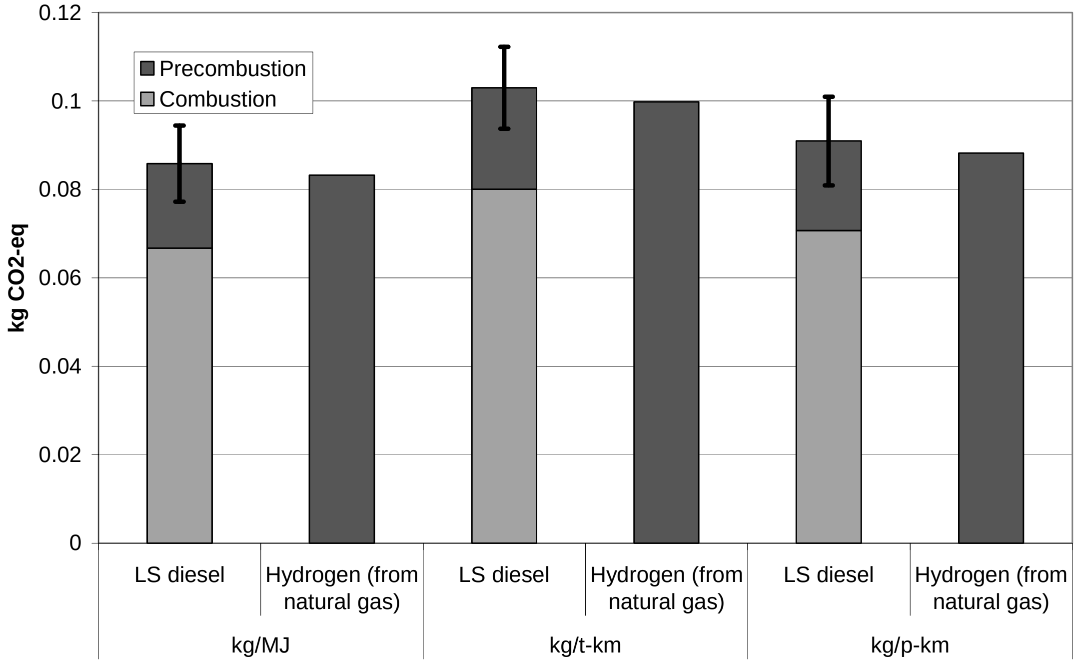

Figure 15.1
Exbodied emissions of greenhouse gases for low sulfur diesel and hydrogen

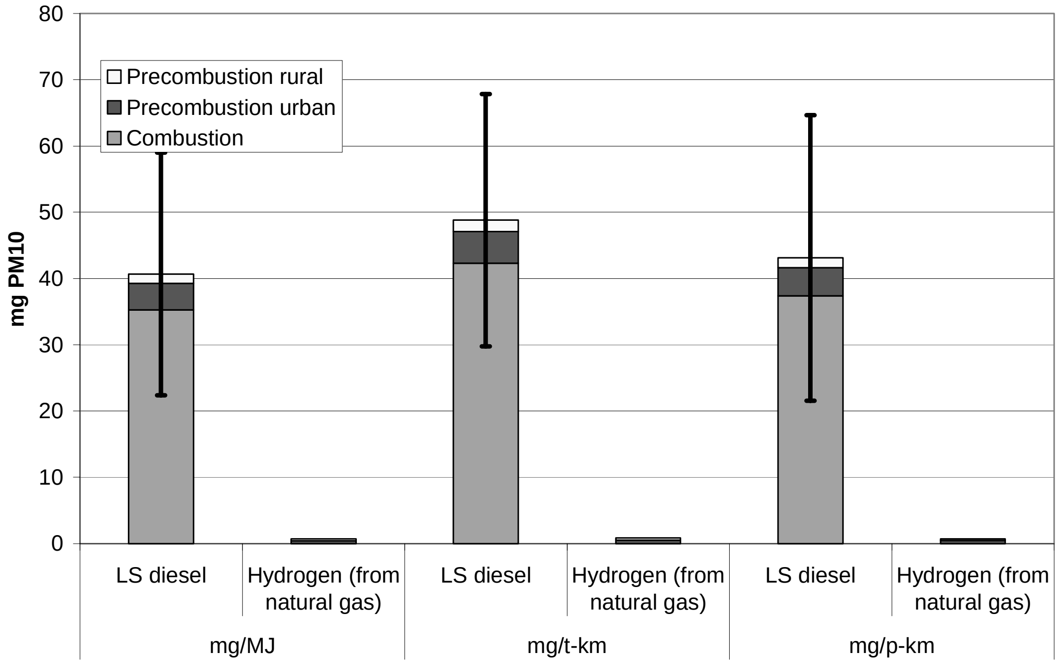

Figure 15.2
Exbodied emissions of particulate matter for low sulfur diesel and hydrogen

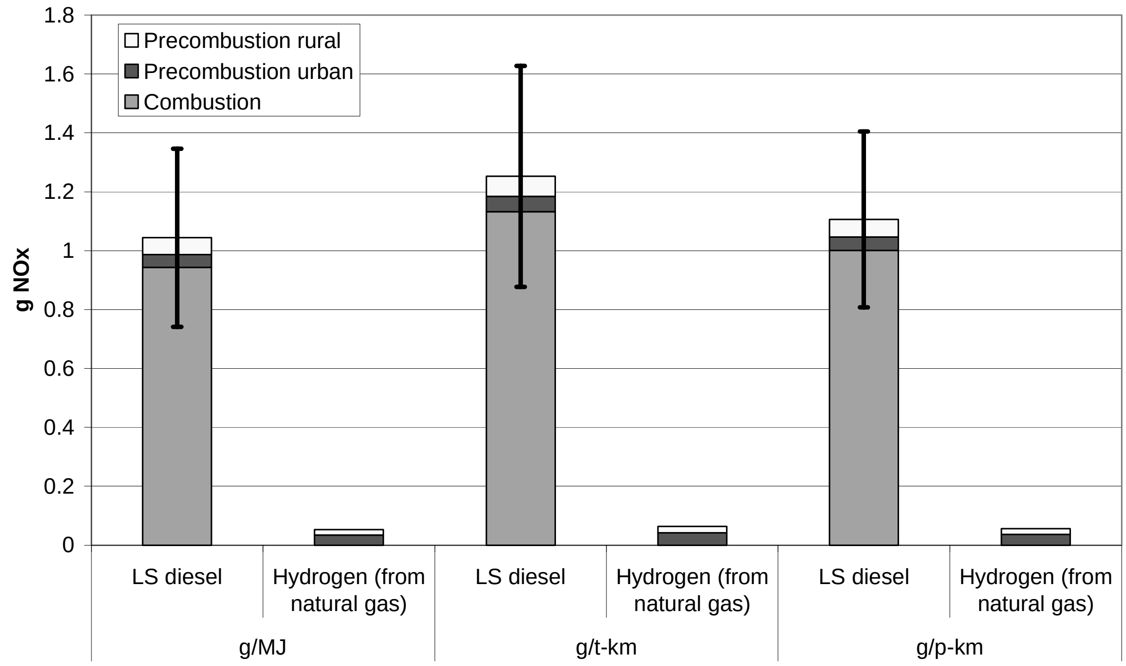

Figure 15.3
Exbodied emissions of oxides of nitrogen for low sulfur diesel and hydrogen

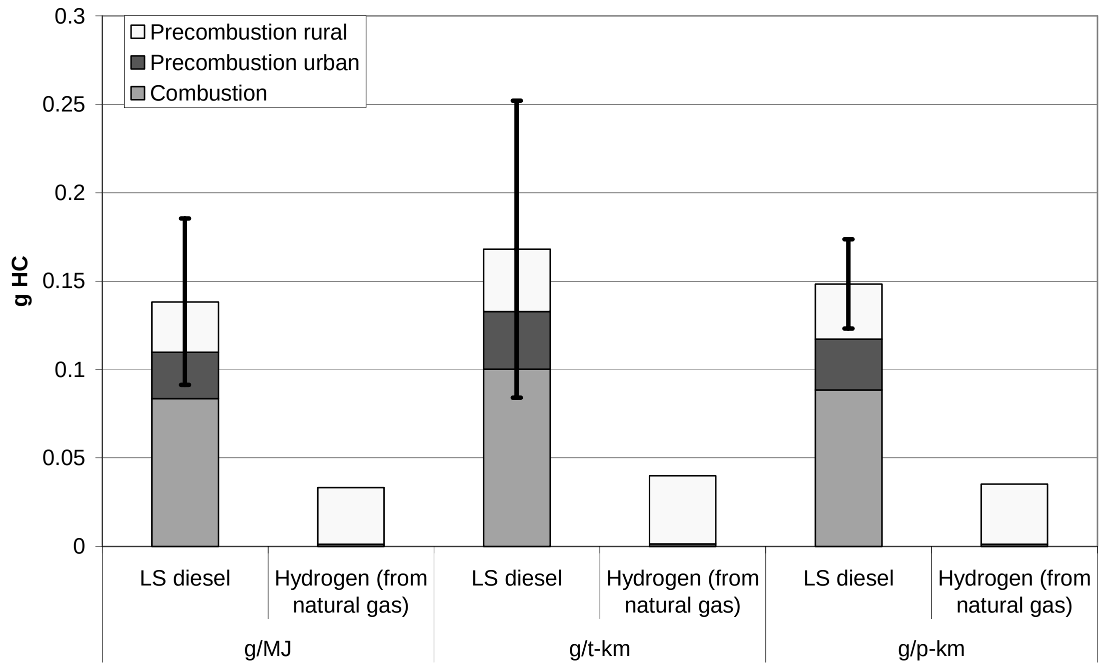

Figure 15.4
Exbodied emissions of hydrocarbons for low sulfur diesel and hydrogen

Figure 15.4 depicts the hydrocarbon (HC) emissions estimated for hydrogens. 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. Hydrogen has very low emissions of hydrocarbons compared to diesel.

15.3 Viability and Functionality

Important advantages of fuel cells are: high energy efficiency, because the efficiency is not limited to the maximum efficiency of thermal energy processes; low emissions during operation, though manufacturing of fuel cells may cause emissions as shown in Figures 15.1 to 15.4; and low noise production. However, fuel cells have some disadvantages as well. Compared to internal combustion engines, the disadvantages are: fuel cells are very expensive; and fuel cells are large and heavy per kW output.

Hydrogen rises when it is released into the open air. Its safety is then similar to that of conventional fuels. To avoid explosions, evaporating hydrogen is extracted during the refuelling process. The safety of hydrogen fuel systems is important during vehicle collisions. There is substantial testing designed to ensure leakproof hydride tanks, and to place the vehicle tank inside the safety cage of vehicles so as to reduce the risk of damage to the tank during a collision. No results from collision tests with hydrogen vehicles could be found in the literature.

The refuelling time of a hydrogen vehicle can be up to ten times the refuelling time of a petrol vehicle.

15.4 Health Issues

There are no air pollutant or greenhouse gas emissions during operation. The only emissions that may be of concern arise during precombustion.

Hydrogen upstream emissions of both particulate matter and HC are substantially less than LSD. Hydrogen has no tailpipe emissions of particulate matter or air toxics.

15.5 Environmental Impact and Benefits

ESD issues

It is difficult to see how natural gas reforming to produce hydrogen could be seen as ecologically sustainable development. It uses a fossil fuel, and considerable energy (and thus exbodied greenhouse gases), to manufacture the fuel. Production of hydrogen by low pressure water electrolysis would be an ecologically sustainable method of production, provided the electricity to undertake the electrolysis is based on renewable energy.

Sustainability

Present plans are for hydrogen to be generated from steam reforming of natural gas in the Northwest Shelf. Though there are large amounts of natural gas available, this uses a fossil fuel to produce hydrogen. An innovative, sustainable scheme has been proposed based on using tidal power to dissociate hydrogen and thus run a hydrogen economy. The theoretical potential is there for great environmental benefits provided the technology can be implemented.

Groundwater contamination

Hydrogen is a gaseous fuel with no air pollutant or greenhouse gas emissions. It thus cannot contaminate soil or water.