11. Liquefied Petroleum Gas — HD5

11.1 Background

HD5 requires a minimum propane (C_3H_8) content of 90% and a propylene content of less than 5% on a volume basis. The remainder is normally n-butane (C_4H_{10}), with isobutane and butanes also present. LPG HD-5 is essentially propane. Table 11.1 gives properties of liquefied petroleum gas (LPG) HD5 based on its main component, propane.

Table 11.1
Properties of LPG HD5 (Propane)

Property	**Value**
Liquid density	499 kg/m^3
Energy density (LHV)	23.1 MJ/L
CO_2 emission factor	65 g/MJ

The components of LPG are gases at normal temperatures and pressures, but can easily be liquefied for storage by an increase in pressure to about 8 atmospheres or by a reduction in temperature. In Australia, LPG used in motor cars is stored on board the vehicle in a steel cylinder in liquid form, but is converted to gaseous form via a regulator before supply to a gas-air mixer (the equivalent of a carburettor) for intake to the engine. There is very little usage of LPG in Australian heavy vehicles, though the company Was Diesel Now Gas undertakes conversions of vehicles to run on HD-5. The few dedicated LPG engine options in Australia are designed to operate on LPG-HD5.

LPG is a by-product from two sources: natural gas processing and crude oil refining. Most of the LPG used in Australia is produced domestically, though a small quantity is imported. Natural gas, as extracted at the well-head, contains methane and other light hydrocarbons. The light hydrocarbons are separated in a gas processing plant using high pressures and low temperatures.

The natural gas liquid components recovered during processing include ethane, propane, and butane, as well as heavier hydrocarbons.

Propane and butane, along with other gases, are also produced during crude oil refining as a by-product of the processes that rearrange and/or break down molecular structures to obtain more desirable petroleum compounds.

The utilisation of LPG as an automotive fuel varies very widely within a country and from one country to another, depending on the cost and availability of the fuel in relation to alternative fuels, notably gasoline and diesel. Table 11.2 shows the variation in LPG fuel composition in Europe in 1982. The performance of passenger vehicles using different LPG grades has been documented by Watson and Gowdie (2000).

Table 11.2
LPG Composition (% by volume) as automotive fuel in Europe in 1982

Country	Propane	Butane
Austria	50	50
Belgium	50	50
Denmark	50	50
France	35	65
Greece	20	80
Ireland	100	-
Italy	25	75
Netherlands	50	50
Spain	30	70
Sweden	95	5
United Kingdom	100	-
Germany	90	10

Source: www.vps.com/LPG/WVU-review.html

Table 11.2 indicates that there are two different classes of LPG. LPG HD5 is used in the United States. Its specifications have been regulated by the California Air Resources Board (http://www.arb.ca.gov/regact/lpgspecs/lpgspecs.htm) under Amendment of Title 13, California Code of Regulations, section 2292.6.

In 1992, the Board adopted section 2292.6, which took effect on January 1, 1993. The Board included a maximum limit of 10% by volume on the propylene content of vehicular LPG. That propylene limit was to have declined to 5% on January 1, 1995. However, in 1994, the Board delayed the effective date of the 5% propylene limit to January 1, 1997, and then in 1997, the Board again delayed the effective date of the propylene limit until January 1, 1999. In the interim, the propylene limit remained at 10% by volume. The Board delayed the effective date of the propylene limit out of concerns raised by the vendors of commercial propane (who supply the motor vehicle LPG used in California) that too little of the commercial propane available to them meets the original specifications set by the Board.

The LPG specifications also include a maximum limit on butanes and heavier species, of 2.5% by volume. This limit is also contained in the specifications for industrial and commercial grade propane.

When the Board adopted the specifications for vehicular LPG, and other alternative fuels, it set essentially identical standards for the motor vehicle fuel sold commercially in California and the fuel used for emission standard certification testing of new motor vehicles. The purpose for the commercial fuel specifications is to ensure that motor vehicles certified on LPG will receive in-use fuel having a quality similar to that of the certification fuel, so that the vehicles will achieve their emission standards in use.

On 8 December 1999 the following amendments came into force:

(1) Retain the current interim propylene limit of 10% by volume as a permanent limit.

(2) Establish a new 2.0% by volume maximum limit for butenes.

(3) Establish a new 0.5% by volume maximum limit for pentenes and heavier.

(4) Amend the optional 2.5% by volume maximum limit for butanes and heavier to a 5.0% by volume limit for butanes.

(5) Reduce the maximum sulfur content limit from 120 to 80 parts per million by weight.

Finally, the Board approved an amendment, which requires the staff to review the LPG regulation in five years to determine whether it should be retained, revised, or repealed.

11.1.1 LPG in heavy vehicles

As a result of the recent environmental concern in relation to the health effects of particulate matter (Beer, 2000), especially particulate matter of diameter less than 10 μm known as PM10, LPG is being reconsidered as a heavy vehicle fuel. Particulate matter emitted by diesel is all PM10. Anyon (1998) points out that LPG, like CNG, has much lower emissions than diesel, and 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, though the LPG industry believes that a fully optimised LPG engine may be capable of producing lower particulate emissions than an equivalent Euro4 diesel engine.

DAF, the Dutch vehicle maker, has developed a dedicated LPG fuelled bus. DAF prefers the stoichiometric process over lean burn. The advantage of the stoichiometric combustion principle is that it allows the use of a three-way catalyst, which is impossible in lean burn. With a three-way catalyst the emission of all polluting compounds can be reduced, resulting in extremely low emission rates. If a two-way catalyst is used, the NO_x is not removed. The stoichiometric process reduces the emission rate of particulate matter to one twentieth of Euro2, whereas lean burn only comes to half of Euro2. The drawback of the stoichiometric process is that it loses the efficiency advantage of lean burn and correspondingly increases CO_2 emissions. Figure 1.1 shows the influence of air-fuel ratio on emissions.

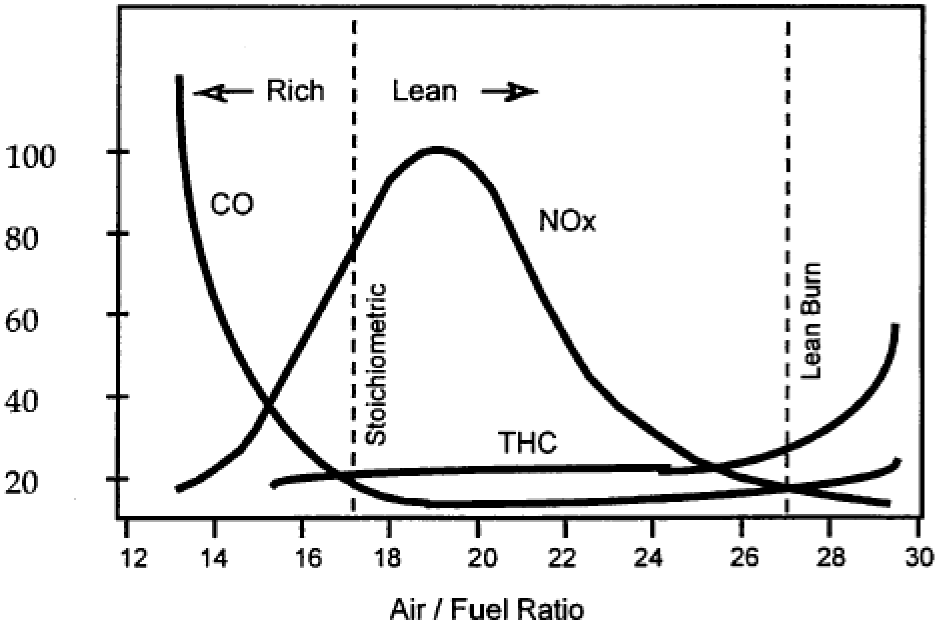

Figure 11.1
Influence of air-fuel ratio on emissions and fuel consumption of a spark-ignition engine. The ordinate is in ppm, and the abscissa is a volumetric ratio (Nylund and Lawson, 2000).

11.2 Exbodied Emissions

11.2.1 Emissions tests

Because it is relatively rare for LPG to be used in heavy vehicles, there is a lack of published data on its emissions characteristics. There is considerable data in relation to LPG used in cars. (NSWEPA, 1997).

Beer et al. (2000) quote values provided by Anyon (1998) reproduced in Table 11.3. As a result of stakeholder input, and a further literature search we found further information as given in Table 11.4. The Cummins B5.9LPG data from ADEPT (1998) was used in our analysis.

The LPG sold in the United Kingdom, Ireland, Sweden, Germany and in the United States (when sold as HD5) is propane. As noted by ANGVC (2000) this means that the widely quoted Millbrook trials data, Table 11.3, for the LPG bus in the London Transport Study (Anyon, 1998; Expert Reference Group, 1998; Beer et al., 2000) refers to propane rather than the LPG sold in eastern Australia.

Table 11.3
LPG (Propane) emissions (g/km)

	CO	THC	NOx	PM	CO_2
London LPG Bus with 3 way catalyst	0.13	0.03	5.4	0.02	1309

Table 11.4
LPG (Propane) emissions (g/kWh)

	CO	THC	NMHC	NOx	PM	CO_2	FC
Ford 6.8L V10 engine (Nylund & Lawson, 2000:p105)	3.8		0.15	0.7			
Cummins B5.9LPG with catalyst (ANGVC submission)	1.34		1.09*	3.06*	0.01		
Cummins B5.9LPG (ADEPT, 1998)	0.56	1.185	1.138	3.724	0.008	897.8	315

*These values were from T. Green of Cummins Inc.

Anyon (1998) also points out that US tests on medium-large engines confirm that LPG has lower emissions of air toxics than CNG and diesel. The toxics examined were 1,3-butadiene (LPG emissions of 0.1 mg/kWh), acetaldehyde (3.8 mg/kWh), formaldehyde (16.5 mg/kWh) and benzene (0.2 mg/kWh). Nylund and Lawson (2000: Figure 11.4) provide graphs with values for unregulated emissions at low temperature (-7°C) for 1,3 butadiene of 0.2 mg/km, formaldehyde of 1 mg/km, and benzene of 1 mg/km.

The default emission factors in the methodology for the US Greenhouse Gas Inventory are given in Table 11.5 in terms of pounds per million BTU (the original units), and their conversion into g/MJ, for both controlled (i.e. equipped with catalytic converters) and uncontrolled vehicles.

Table 11.5
Default Emission Factors for LPG (USEPA 1995)

	Controlled HDV (lb/million BTU)	Uncontrolled HDV (lb/million BTU)	Controlled HDV (g/MJ)	Uncontrolled HDV (g/MJ)
CH_4	0.022	0.066	0.0095	0.0284
N_2O				
CO	0.199	3.359	0.0855	1.4438
NMVOC	0.155	1.127	0.0666	0.4844
NOx	0.53	0.796	0.2278	0.3421
CO_2 as C	37.8	37.8	16.2476	16.2476

11.2.2 Upstream

Upstream processing has been dealt with in the description of autogas. The processing of HD5 is identical, except for the rejection of the butane and the subsequent provision of propane gas.

11.3 Results

11.3.1 Emissions per unit energy

Table 11.6
Urban and total life cycle emissions calculated for diesel and propane

Full Lifecycle	Units (per MJ)	LS diesel	LPG (HD5)
Greenhouse	kg CO_2	0.0858	0.0820
HC total	g HC	0.140	0.103
HC urban	g HC	0.111	0.076
NOx total	g Nox	1.044	0.413
NOx urban	g Nox	0.987	0.361
CO total	g CO	0.253	0.036
CO urban	g CO	0.242	0.026
PM10 total	mg PM10	40.7	6.5
PM10 urban	mg PM10	39.3	5.2
Energy embodied	MJ LHV	1.18	1.09

Table 11.7
Precombustion emissions per MJ for diesel and propane

Precombustion	Units (per MJ)	LS diesel	LPG (HD5)
Greenhouse	kg CO_2	0.0191	0.0170
HC total	g HC	0.0565	0.101
HC urban	g HC	0.027	0.074
NOx total	g Nox	0.100	0.090
NOx urban	g Nox	0.043	0.038
CO total	g CO	0.023	0.021
CO urban	g CO	0.012	0.011
PM10 total	mg PM10	5.42	5.05
PM10 urban	mg PM10	4	3.72
Energy embodied	MJ LHV	1.18	1.09

Table 11.8
Combustion emissions per MJ for diesel and propane

Combustion	Units (per MJ)	LS diesel	LPG (HD5)
Greenhouse	kg CO_2	0.067	0.065
HC total	g HC	0.084	0.002
HC urban	g HC	0.084	0.002
NOx total	g NOx	0.944	0.323
NOx urban	g NOx	0.944	0.323
CO total	g CO	0.230	0.015
CO urban	g CO	0.230	0.015
PM10 total	mg PM10	35.26	1.43
PM10 urban	mg PM10	35.26	1.43
Energy embodied	MJ LHV	0	0

Table 11.9
Summary of life cycle emissions per MJ from diesel and propane

		LS diesel	LPG (HD5)
Greenhouse	Precombustion	0.0191	0.0170
Greenhouse	Combustion	0.0667	0.0650
HC total	Precombustion	0.0565	0.1010
HC total	Combustion	0.0835	0.0021
HC urban	Precombustion	0.0271	0.0739
HC urban	Combustion	0.0835	0.0021
NOx total	Precombustion	0.1000	0.0904
NOx total	Combustion	0.944	0.323
NOx urban	Precombustion	0.043	0.038
NOx urban	Combustion	0.944	0.323
CO total	Precombustion	0.0225	0.0205
CO total	Combustion	0.2301	0.0152
CO urban	Precombustion	0.0123	0.0110
CO urban	Combustion	0.2301	0.0152
PM10 total	Precombustion	5.42	5.05
PM10 total	Combustion	35.26	1.43
PM10 urban	Precombustion	4.00	3.72
PM10 urban	Combustion	35.26	1.43
Energy embodied	Precombustion	1.18	1.09

11.3.2 Emissions per unit distance

Table 11.10
Exbodied emissions per km for diesel and propane

Full Lifecycle	Units (per km)	LS diesel	LPG (HD5)
Greenhouse	kg CO_2	0.9250	0.8963
HC total	g HC	1.509	1.133
HC urban	g HC	1.192	0.830
NOx total	g NOx	11.250	4.517
NOx urban	g NOx	10.638	3.939
CO total	g CO	2.723	0.390
CO urban	g CO	2.612	0.286
PM10 total	mg PM10	438.4	70.7
PM10 urban	mg PM10	423.1	56.3
Energy Eembodied	MJ LHV	12.7	11.9

Table 11.11
Precombustion emissions per km for diesel and propane

Precombustion	Units (per km)	LS diesel	LPG (HD5)
Greenhouse	kg CO_2	0.2060	0.1860
HC total	g HC	0.609	1.11
HC urban	g HC	0.292	0.807
NOx total	g NOx	1.080	0.988
NOx urban	g NOx	0.468	0.410
CO total	g CO	0.243	0.224
CO urban	g CO	0.132	0.120
PM10 total	mg PM10	58.4	55.1
PM10 urban	mg PM10	43.1	40.7
Energy embodied	MJ LHV	12.7	11.9

Table 11.12
Emissions from combustion per km for diesel and propane

Combustion	Units	LS diesel	LPG (HD5)
Greenhouse	kg CO_2	0.719	0.710
HC total	g HC	0.900	0.023
HC urban	g HC	0.900	0.023
NOx total	g NOx	10.177	3.529
NOx urban	g NOx	10.177	3.529
CO total	g CO	2.480	0.166
CO urban	g CO	2.480	0.166
PM10 total	mg PM10	380.00	15.63
PM10 urban	mg PM10	380.00	15.63
Energy embodied	MJ LHV	0	0

Table 11.13
Summary of life cycle emissions per km from diesel and propane

		LS diesel	LPG (HD5)
Greenhouse	Precombustion	0.2060	0.1860
Greenhouse	Combustion	0.7190	0.7103
HC total	Precombustion	0.6090	1.1100
HC total	Combustion	0.9000	0.0231
HC urban	Precombustion	0.2920	0.8070
HC urban	Combustion	0.9000	0.0231
NOx total	Precombustion	1.0800	0.9880
NOx total	Combustion	10.170	3.529
NOx urban	Precombustion	0.468	0.410
NOx urban	Combustion	10.170	3.529
CO total	Precombustion	0.2430	0.2240
CO total	Combustion	2.4800	0.1657
CO urban	Precombustion	0.1320	0.1200
CO urban	Combustion	2.4800	0.1657
PM10 total	Precombustion	58.40	55.10
PM10 total	Combustion	380.00	15.63
PM10 urban	Precombustion	43.10	40.70
PM10 urban	Combustion	380.00	15.63
Energy embodied	Precombustion	12.70	11.90

11.3.3 Uncertainties

In the absence of information on the variability and uncertainties associated with LPG emissions, we assume that the uncertainties are the same as those associated with LNG.

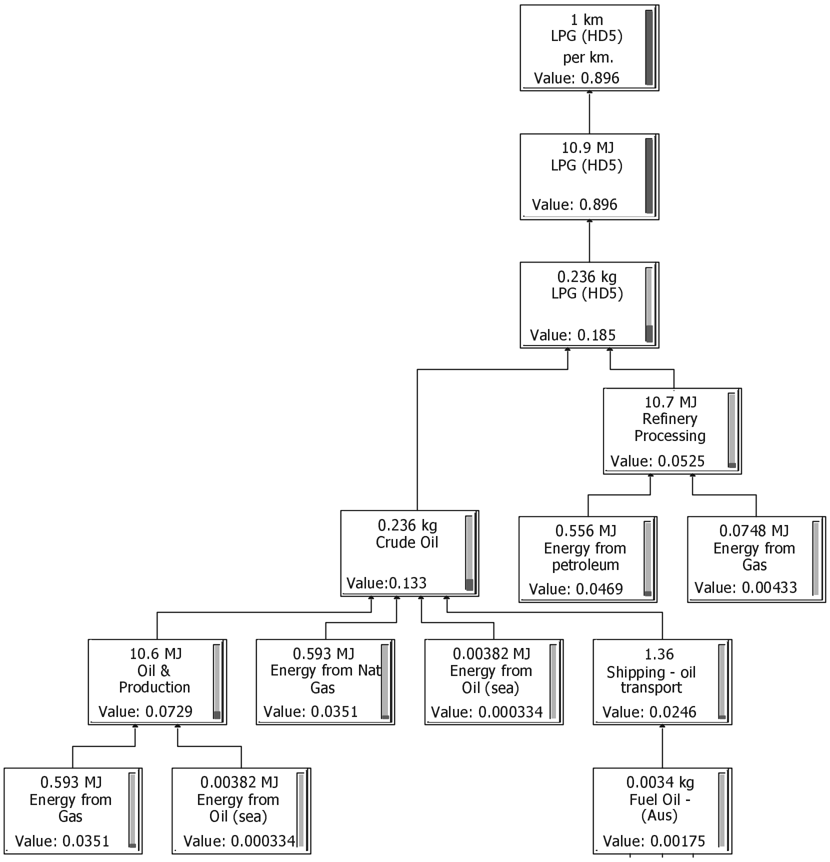

Figure 11.2
Exbodied greenhouse gases emissions (kg CO_2eq) from LPG (HD5) production and processing and use in vehicle

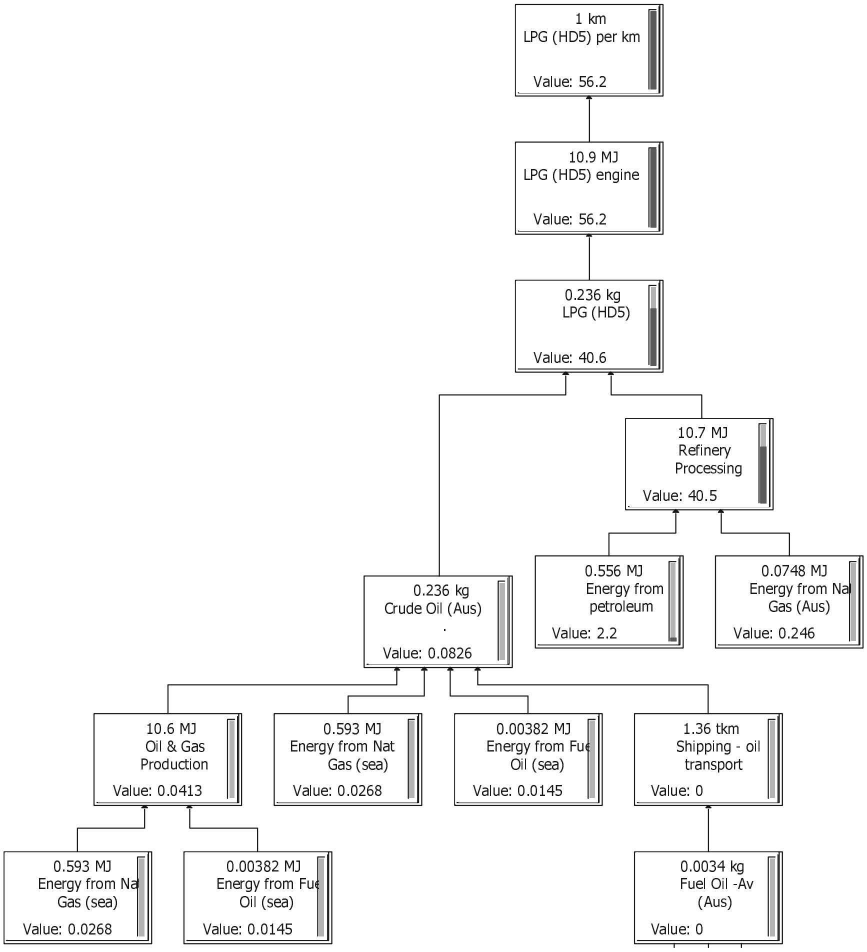

Figure 11.3
Exbodied particulate matter (mg - urban) from LPG (HD5) production and processing and use in vehicle

11.4 Dual fuel and converted vehicles

One relevant issue is a comparison of dual-fuelled vehicles' emissions with those of dedicated LPG only vehicles.

Table 11.14, in the first two columns, gives results reported to the AGO for a 42,000kg GVM 6 cylinder dual fuel (converted) prime mover (when compared to diesel) undergoing tests on the CUEDC drive cycle. Table 11.14 also reproduces the tailpipe results in Table 11.12, in the last two columns. In addition to these results, both maximum power and maximum tractive effort were higher for the dual fuel vehicle.

Table 11.14
Comparative emission (gram per km) for dual fuel and LPG only vehicles

	Dual Fuel		LPG-HD5 only	
	Diesel	**Diesel/LPG**	**Diesel**	**Propane only**
NO_x	18.18	17.67	10.18	3.53
HC	0.69	3.53	0.90	0.023
CO	3.35	8.54	2.48	0.166
CO_2	1296	1359	719	710
PM	0.234	0.227	0.38	0.016

The AGO also provided results (Table 11.15) of tests a Rigid Tray Truck of 13,900 kg GVM that was converted from diesel to a dedicated LPG (HD5) vehicle. The LPG conversion included: modified combustion chambers; reduced compression ratio; sequential port LPG injection; electronic closed loop engine management; and very slight 'lean of stoichiometric' combustion.

The converted vehicle was first tested on the CUEDC cycle. A 3-way catalyst and a turbo boost control valve were then fitted and the vehicle retested in a DT80 test. No testing was done on this vehicle prior to conversion.

Table 11.15
Comparative emission for converted LPG-HD5 only vehicles

	Converted vehicle		Diesel comparison	
	CUEDC (no emission control)	**DT80 (3C+turbo boost)**	**Diesel similar to tested vehicle**	**Generic diesel (Table 11.12)**
NO_x (g/km)	17.1	6.3	4.33	10.18
HC (g/km)	10.6	1.73	0.5	0.90
CO (g/km)	7.16	0.1	2.29	2.48
CO_2 (g/km)	701		763	719
PM (mg/km)	14.1	2.2	453	380
Fuel L/100km	48.3		33.5	
Average opacity (%)	0.1		4.6	

Technical advice communicated by the AGO indicates that the DT80 procedure produces higher emissions than the CUEDC, though the DT80 results correlate well with CUEDC (National Environment Protection Council, 2001). The results for diesel vehicles tested under the CUEDC and DT80 cycles show higher NOx and HC emissions in the DT80 cycle, but substantially lower CO and PM emissions.

Summary

A dedicated LPG vehicle emits lower quantities of all criteria pollutants and greenhouse gases from its tailpipe than an equivalent diesel vehicle. This advantage is lost with dual fuel vehicles and with converted vehicles. On the basis of the two test for which data was available, total hydrocarbon emissions from both types of vehicles are higher than those of the equivalent diesel vehicles. The dual fuel vehicle emitted higher quantities of CO and CO_2 (as well as HC) than the equivalent diesel vehicle.

The three way catalyst and turbo boost reduced NOx, HC, CO and PM emissions. However, the converted propane vehicle emitted higher quantities of NOx, as well as HC, (when compared to an equivalent diesel vehicle) even when fitted with a three way catalyst, though the three way catalyst and turbo boost was very successful in reducing CO emissions. Neverthless, in all cases the change from diesel to LPG – whether from dedicated, converted or dual fuel vehicles - results in lower particulate matter (PM) emissions.

The Australian LPG conversion industry for heavy vehicles is at an early stage in its development. The data from these two tests may not reflect the emissions performance of converted vehicles in the longer term.

11.5 Viability and Functionality

Propane (HD5) viability and functionality issues are identical to those of autogas. The main benefit of propane is that the compression ratio can be altered to suit the higher octane fuel.

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. The use of an exhaust brake (guillotine style) is not permitted with the propane or CNG engine, due to the high exhaust temperature. The results, as provided, are reproduced in Table 11.14.

Table 11.16
Relative performance of a Cummins 5.9 L engine

	Maximum bhp rating	Maximum torque
Diesel	260	660
Propane	195	420
CNG/LNG	230	500

Source: J. Bortolussi (pers. comm.)

11.6 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.

11.6.1 Production and transport

LPG’s low emissions have low greenhouse gas effects and low NOx precursors.

Particulate Matter

The LCA estimate for LPGHD5 urban precombustion (truck) PM10 emissions of 41 mg/km is similar to the LSD estimate of 43 mg/km.

Air Toxics

The LCA estimate for LPGHD5 urban precombustion (truck) HC emissions of 0.807 g/km is greater than the LSD estimate of 0.292 g/km.

The public health effects of air toxics will be mainly associated with combustion emissions in large urban centres. An accompanying disk to this report provides details of air toxic emissions from upstream activities.

11.6.2 Use

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

LPG, like CNG, has much lower emissions than diesel, and LPG has 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. (Anyon 1998).

Anyon (1998) also points out that US tests on medium-large engines also confirm that LPG has lower emissions of air toxics than CNG and diesel. The toxics examined were 1,3-butadiene (LPG emissions of 0.1 mg/kWh), acetaldehyde (3.8 mg/kWh), formaldehyde (16.5 mg/kWh) and benzene (0.2 mg/kWh). Nylund and Lawson (2000: Figure 11.4) provide graphs with values for unregulated emissions at low temperature (-7^{o}C) for 1,3 butadiene of 0.2 mg/km, formaldehyde of 1 mg/km, and benzene of 1 mg/km.

Particulate matter

Research consistently shows that LPG (and gaseous fuels in general) with its simple chemistry and very low sulphur content, emit extremely low levels of particulates. (Anyon, 1998).

The LCA estimate for LPGHD5 combustion (truck) PM10 emissions of 16 mg/km is substantially less than the LSD estimate of 380 mg/km.

Air Toxics

LPG produces much lower emissions of the main air toxics such as benzene, 1,3 butadiene, formaldehyde and acetaldehyde, compared with diesel (Anyon, 1998).

The LCA estimate for LPGHD5 combustion (truck) HC emissions of 0.023 g/km is substantially less than the LSD estimate of 0.900 g/km.

11.6.3 Summary

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

No comparative emissions data for LPGHD5 and LSD has been identified for:

- polycyclic aromatic hydrocarbons (PAH)
- toluene
- xylene.

11.7 Environmental Issues

The environmental issues related to propane will be identical to those related to autogas.

Propane may be thought of as a natural gas by-product, or as a petroleum refinery by-product. In the former case the upstream environmental issues are those of CNG; whereas in the latter case the environmental issues are those of diesel.

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.

11.8 Expected Future Emissions

Arcoumanis (2000) developed a model that examines a given alternative fuel relative to the reference diesel engine (Euro2) in terms of a specific regulated pollutant. A value of 1 implies identical performance to the low sulfur diesel/Euro2 combination. A value greater than 1 implies inferior performance, whereas a value less than 1 indicates superior performance.

Table 11.1 lists the estimated emissions factors for LPG. The columns in bold represent the standards relative to the Euro2 standard. The adjacent column gives the expected performance of LPG. The estimates of Arcoumanis (2000) indicate that LPG can be expected to meet all future Australian Design Rules for all pollutants.

Table 11.17

Estimated emission factors for LPG under future technologies

Technology	CO	CO	HC	HC	NO_x	NO_x	PM	PM	CO_2	LCA CO_2
Euro2	**1.0**	0.4	**1.0**	0.5	**1.0**	0.3	**1.0**	0.3	1.1	1.2
Euro3	**0.53**	0.2	**0.6**	0.3	**0.71**	0.2	**0.67**	0.2	1.0	1.2
Euro4	**0.38**	0.1	**0.42**	0.1	**0.5**	0.2	**0.2**	0.05	1.0	1.1

11.9 Summary

11.9.1 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.

11.9.2 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 and weigh more than diesel fuel tanks of the same energy storage capacity.
- Propane is heavier than air, which requires appropriate handling.
- Though the lower flammability limit for propane is actually higher than the lower flammability limit for petrol, the vapour flammability limits in air are wider than those of petrol, which makes propane ignite more easily.
- Propane has a high expansion coefficient so that tanks can be filled to only 80% of capacity.
- LPG in liquid form can cause cold burns to the skin in case of inappropriate use.