

10. Liquefied Petroleum Gas — Autogas

10.1 Background

Liquefied petroleum gas (LPG) consists mainly of propane, propylene, butane, and butylene in various proportions according to its state or origin. 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. Kleenheat Gas recently developed a diesel/LPG fuel substitution conversion kit that was used in a three month trial of an articulated Volvo B10M MkIII LPG bus in Darwin in late 2000 (see www.nt.gov.au/ministers/palmer/media00/1213lpgdiesel_darwinbus.shtml). Other manufacturers (Ecotrans, Was Diesel Now Gas) offer a similar capability. The few dedicated LPG engine options in Australia are designed to operate on the LPG-HD5 specification.

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. In 1997, Australia produced 4.1 GL of LPG, of which 1.6 GL was from refineries.

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.

More than 550,000 Australian vehicles use LPG. LPG powers all taxis in Victoria, and many other taxi fleets around the country. It is a familiar and widely available light vehicle fuel.

The utilisation of LPG as an automotive fuel varies very widely from one country to another, depending on the cost and availability of the fuel in relation to alternative fuels, notably petrol and diesel, Table 10.1 shows the variation in LPG fuel composition in Europe in 1982.

Table 10.1
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

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Table 1 indicates that there are two different classes of LPG. Autogas grade LPG is a mixture of propane and butane. A European specification (EN589) is presently being prepared to standardise the composition. In eastern Australia Anyon (1998) notes that the LPG mixture supplied is typically around 60-70% propane and 40-30% butane. The addition of butane slows down combustion speed in an engine, so that it reduces NO_x emission, while it increases emissions of THC and CO.

In January 2000 the ALPGA published performance-based specifications for LPG. These are widely perceived to be more stringent than the European standards and have become a de-facto standard within Australia. The performance of passenger vehicles using different LPG grades has been documented by Watson and Gowdie (2000).

10.1.1 LPG in heavy vehicles

As a result of the recent environmental concern in relation to the health effects of particulate matter (Beer, 2000) and 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 particle levels, which make it an attractive fuel for urban buses and delivery vehicles. However, as diesel particle 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 particle emissions than an equivalent Euro4 diesel engine.

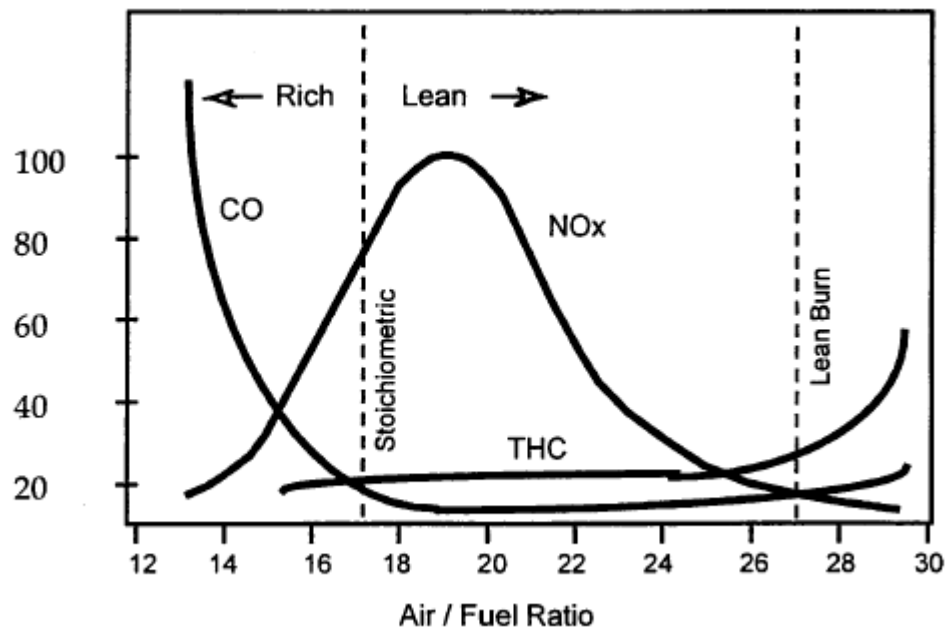


Figure 10.1
Influence of air-fuel ratio on emissions and fuel consumption of a spark-ignition engine.
The abscissa is a volume ratio, whereas the ordinate is in ppm (Nylund and Lawson, 2000).

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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 10.1 shows the influence of air-fuel ratios on emissions.

10.2 Embodied Emissions

10.2.1 Emission 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). In addition, most of the data that we were able to find relates to propane, rather than autogas. Beer et al. (2000) quote values provided by Anyon (1998), and the default values in the Australian NGGI. Nylund and Lawson (2000: Table 10.2) provide emission data for autogas for the DAF LPG 8.65 litre bus operating on a stoichiometric mixture and equipped with a three way catalyst. These are shown in Table 10.2., and were used in the subsequent full-fuel cycle analysis. According to publicity material about these buses the fuel consumption of these LPG buses varies between 0.5 and 0.9 L/km. (CADDET, 1997).

Table 10.2
Autograde LPG emissions

	CO (g/kWh)	THC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	FC (L/km)
DAF GG170LPG	0.25	0.01	0.4	0.015	0.5-0.9
Diesel comparison	4	1.1	7	0.15	0.3-0.5

The properties of LPG, as given by NGGIC are given in Table 10.3.

Table 10.3
Properties of LPG (NGGIC, 1996, 1998)

Property	Value
Energy Density (HHV)	25.7 MJ/L
CO_2 Emission Factor	59.4 g/MJ
SO_2 Emission Factor	0.008 g/MJ

This chapter deals with dedicated LPG vehicles. Dual fuel LPG vehicles operating on LPG (autogas) are expected to have higher emissions than dedicated vehicles, given the results of dual fuel vehicles operating on LPG-HD5 referred to in the chapter on that fuel.

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Table 10.4
Default Emission Factors (g/km) for LPG (NGGIC, 1996)

	Buses	Light Trucks	Medium Trucks	Heavy Trucks
CH ₄	0.12	0.089	0.13	0.22
N ₂ O	0.011	0.008	0.011	0.02
CO	24.00	21.99	24.00	24.00
NM VOC	2.41	1.72	2.46	4.21
NO _x	2.76	1.98	2.82	4.83

The default emission factors in the methodology for the Australian National Greenhouse Gas Inventory are given in Table 10.4.

10.2.2 Upstream

Raw natural gas from gas fields must be processed before being fed into pipelines or liquefied. Raw gas contains vapours and liquids, both hydrocarbons and water, which need to be separated.

In natural gas processing plants, non-hydrocarbon gases such as water, hydrogen sulfide (H₂S), and CO₂ are removed from the gas stream during a gas conditioning stage. Water is removed in a dehydrator through a chemical reaction with solvent or through physical adsorption.

The gas then passes through a processing stage where higher hydrocarbons are stripped from the gas. Stripping may be done by refrigeration (condensation, absorption in hydrocarbon solvent, adsorption on sorbents, compression, or any combination of the above methods). The particular configuration will depend on the composition of natural gas to be processed. Finally, stripped hydrocarbons are separated into ethane, LPG and pentanes plus.

Another source of LPG is crude oil processing at the refinery. LPG fraction is recovered from the top of the atmospheric pressure distillation unit and from various process units such as crackers and hydrotreaters.

Schematic diagram of LPG production and delivery is shown in Figure 10.2.

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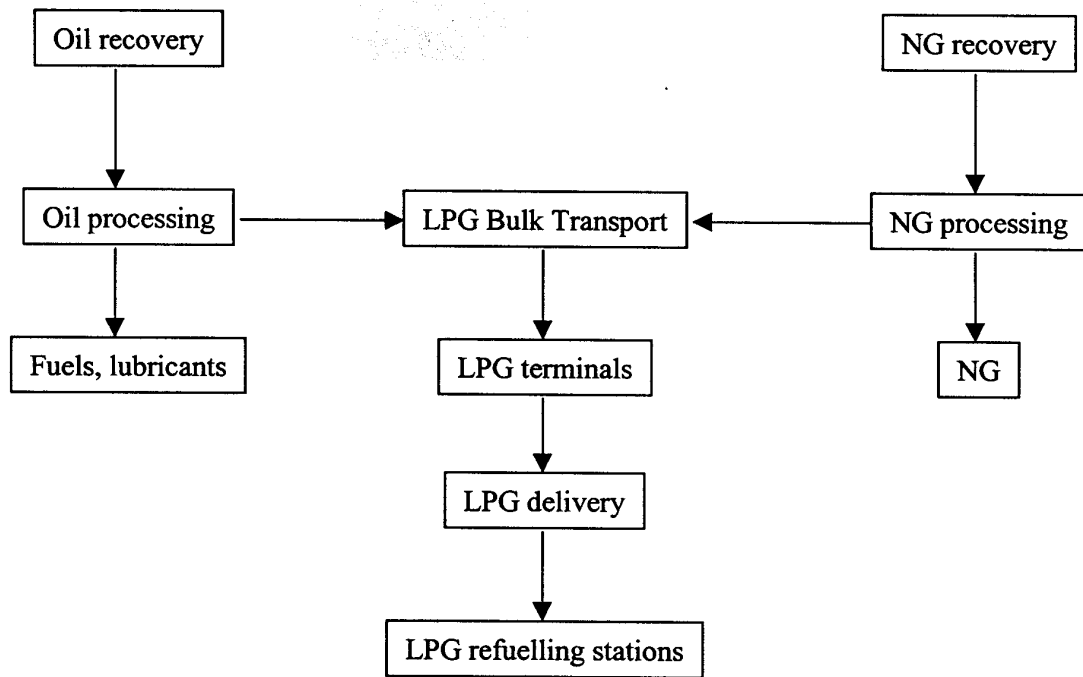


Figure. 10.2
LPG production and delivery flowchart.

Australian annual LPG production is about 6000 ML from combined natural sources and refinery production. Of this approximately 55% is used domestically and 45% exported. Bass Strait is the biggest source of LPG (over 40%), followed by Cooper Basin and the refineries.

Main Australian users are residential (cooking and heating), commercial/industrial (fuel), autogas (petrol/diesel replacement) and petrochemical (as feedstock).

While the term LPG means broadly a mixture of propane and butane, motor vehicles run on autogas which has to meet relevant specifications. Most important of those are the vapour pressure range required to be between 800 kPa and 1530 kPa at 40°C and minimum motor octane number of 92.

In some overseas countries automotive LPG (HD-5 specification) must contain a minimum of 95% propane, the balance being butane and propylene.

Upstream emissions associated with LPG use arise from energy used in gas and oil recovery and processing. Further emissions result from the delivery to retail outlets.

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10.3 Results

Table 10.5
Urban and total life cycle emissions per MJ calculated for diesel and autogas

Full lifecycle	Units (per MJ)	LS diesel	LPG (Autogas)
Greenhouse	kg CO ₂	0.0858	0.0764
HC total	g HC	0.140	0.102
HC urban	g HC	0.111	0.075
NOx total	g NOx	1.044	0.140
NOx urban	g NOx	0.987	0.089
CO total	g CO	0.253	0.038
CO urban	g CO	0.242	0.029
PM10 total	mg PM10	40.7	8.9
PM10 urban	mg PM10	39.3	7.6
Energy embodied	MJ LHV	1.18	1.06

Table 10.6
Urban and total precombustion emissions per MJ for diesel and autogas

Precombustion	Units	LS diesel	LPG (Autogas)
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	0.092
NOx urban	g NOx	0.043	0.040
CO total	g CO	0.023	0.021
CO urban	g CO	0.012	0.012
PM10 total	mg PM10	5.42	5.31
PM10 urban	mg PM10	4	4.02
Energy embodied	MJ LHV	1.18	1.06

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Table 10.7
Urban and total combustion emissions per MJ for diesel and autogas

Combustion	Units	LS diesel	LPG (Autogas)
Greenhouse	kg CO ₂	0.067	0.059
HC total	g HC	0.084	0.001
HC urban	g HC	0.084	0.001
NOx total	g NOx	0.944	0.048
NOx urban	g NOx	0.944	0.048
CO total	g CO	0.230	0.017
CO urban	g CO	0.230	0.017
PM10 total	mg PM10	35.26	3.55
PM10 urban	mg PM10	35.26	3.55
Energy embodied	MJ LHV	0	0

Table 10.8
Summary of life cycle emissions per MJ from diesel and autogas

		LS diesel	LPG (Autogas)
Greenhouse	Precombustion	0.0191	0.0170
Greenhouse	Combustion	0.0667	0.0594
HC total	Precombustion	0.0565	0.1010
HC total	Combustion	0.0835	0.0007
HC urban	Precombustion	0.0271	0.0742
HC urban	Combustion	0.0835	0.0007
NOx total	Precombustion	0.1000	0.0919
NOx total	Combustion	0.944	0.048
NOx urban	Precombustion	0.043	0.040
NOx urban	Combustion	0.944	0.048
CO total	Precombustion	0.0225	0.0208
CO total	Combustion	0.2301	0.0171
CO urban	Precombustion	0.0123	0.0116
CO urban	Combustion	0.2301	0.0171
PM10 total	Precombustion	5.42	5.31
PM10 total	Combustion	35.26	3.55
PM10 urban	Precombustion	4.00	4.02
PM10 urban	Combustion	35.26	3.55
Energy embodied	Precombustion	1.18	1.06

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10.3.1 Emissions per unit distance

Table 10.9
Embodied emissions per km for diesel and autogas

Full lifecycle	Units (per km)	LS diesel	LPG (Autogas)
Greenhouse	kg CO ₂	0.9250	0.8352
HC total	g HC	1.509	1.108
HC urban	g HC	1.192	0.819
NOx total	g NOx	11.250	1.527
NOx urban	g NOx	10.638	0.969
CO total	g CO	2.723	0.415
CO urban	g CO	2.612	0.313
PM10 total	mg PM10	438.4	96.7
PM10 urban	mg PM10	423.1	82.6
Energy embodied	MJ LHV	12.7	11.6

Table 10.10
Precombustion emissions per km for diesel and autogas

Precombustion	Units (per km)	LS diesel	LPG (Autogas)
Greenhouse	kg CO ₂	0.2060	0.1860
HC total	g HC	0.609	1.1
HC urban	g HC	0.292	0.811
NOx total	g NOx	1.080	1.000
NOx urban	g NOx	0.468	0.442
CO total	g CO	0.243	0.228
CO urban	g CO	0.132	0.126
PM10 total	mg PM10	58.4	58
PM10 urban	mg PM10	43.1	43.9
Energy embodied	MJ LHV	12.7	11.6

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Table 10.11
Combustion emissions per km for diesel and autogas

Combustion	Units	LS diesel	LPG (Autogas)
Greenhouse	kg CO ₂	0.719	0.649
HC total	g HC	0.900	0.008
HC urban	g HC	0.900	0.008
NOx total	g NOx	10.177	0.527
NOx urban	g NOx	10.177	0.527
CO total	g CO	2.480	0.187
CO urban	g CO	2.480	0.187
PM10 total	mg PM10	380.00	38.75
PM10 urban	mg PM10	380.00	38.75
Energy embodied	MJ LHV	0	0

Table 10.12
Summary of life cycle emissions per km from diesel and autogas

		LS diesel	LPG (Autogas)
Greenhouse	Precombustion	0.2060	0.1860
Greenhouse	Combustion	0.7190	0.6492
HC total	Precombustion	0.6090	1.1000
HC total	Combustion	0.9000	0.0080
HC urban	Precombustion	0.2920	0.8110
HC urban	Combustion	0.9000	0.0080
NOx total	Precombustion	1.0800	1.0000
NOx total	Combustion	10.170	0.527
NOx urban	Precombustion	0.468	0.442
NOx urban	Combustion	10.170	0.527
CO total	Precombustion	0.2430	0.2280
CO total	Combustion	2.4800	0.1869
CO urban	Precombustion	0.1320	0.1260
CO urban	Combustion	2.4800	0.1869
PM10 total	Precombustion	58.40	58.00
PM10 total	Combustion	380.00	38.75
PM10 urban	Precombustion	43.10	43.90
PM10 urban	Combustion	380.00	38.75
Energy embodied	Precombustion	12.70	11.60

10.3.2 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.

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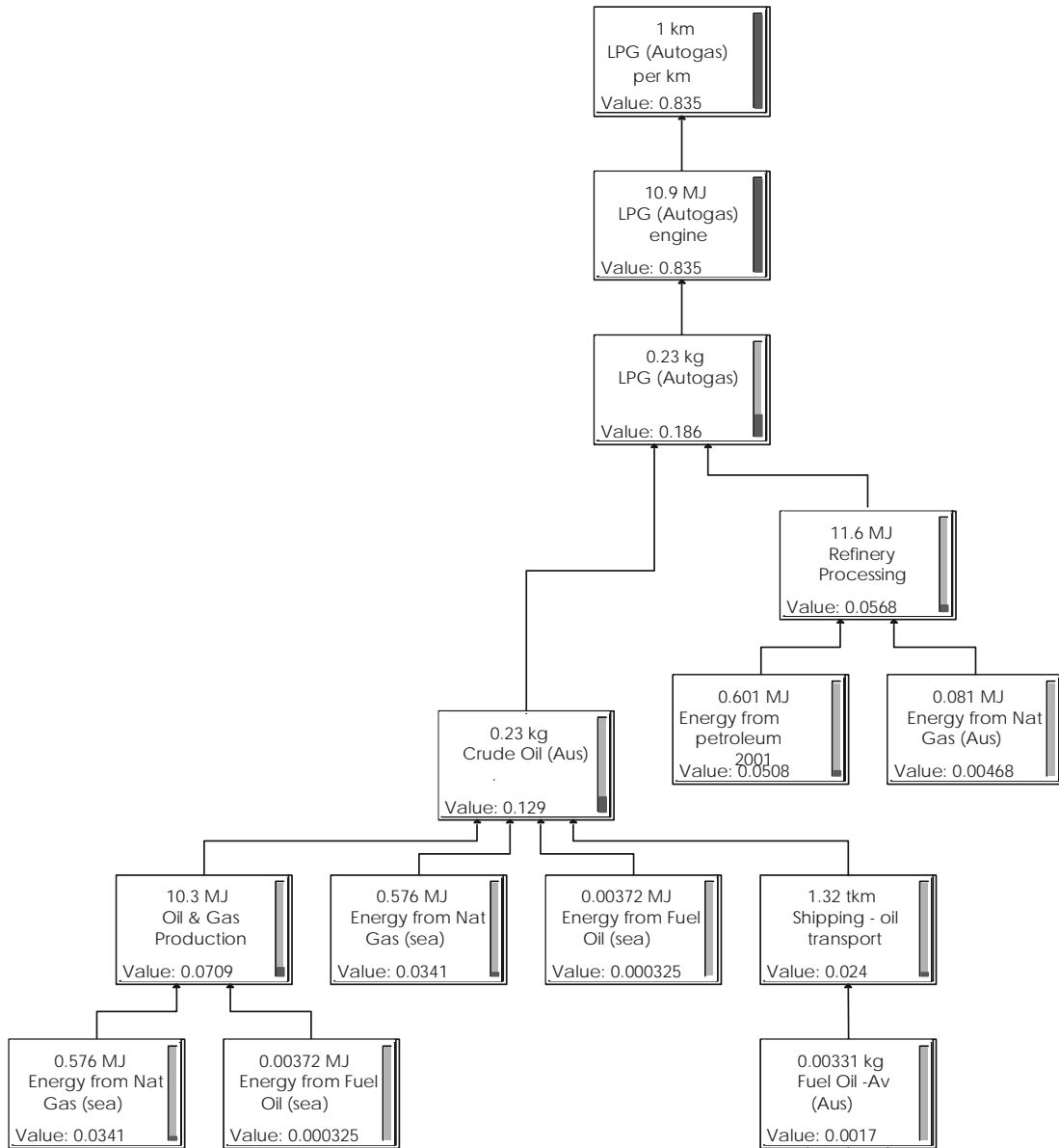


Figure 10.3
Embodied greenhouse gases emissions (kg CO₂eq) from LPG (Autogas) production and processing and use in vehicle

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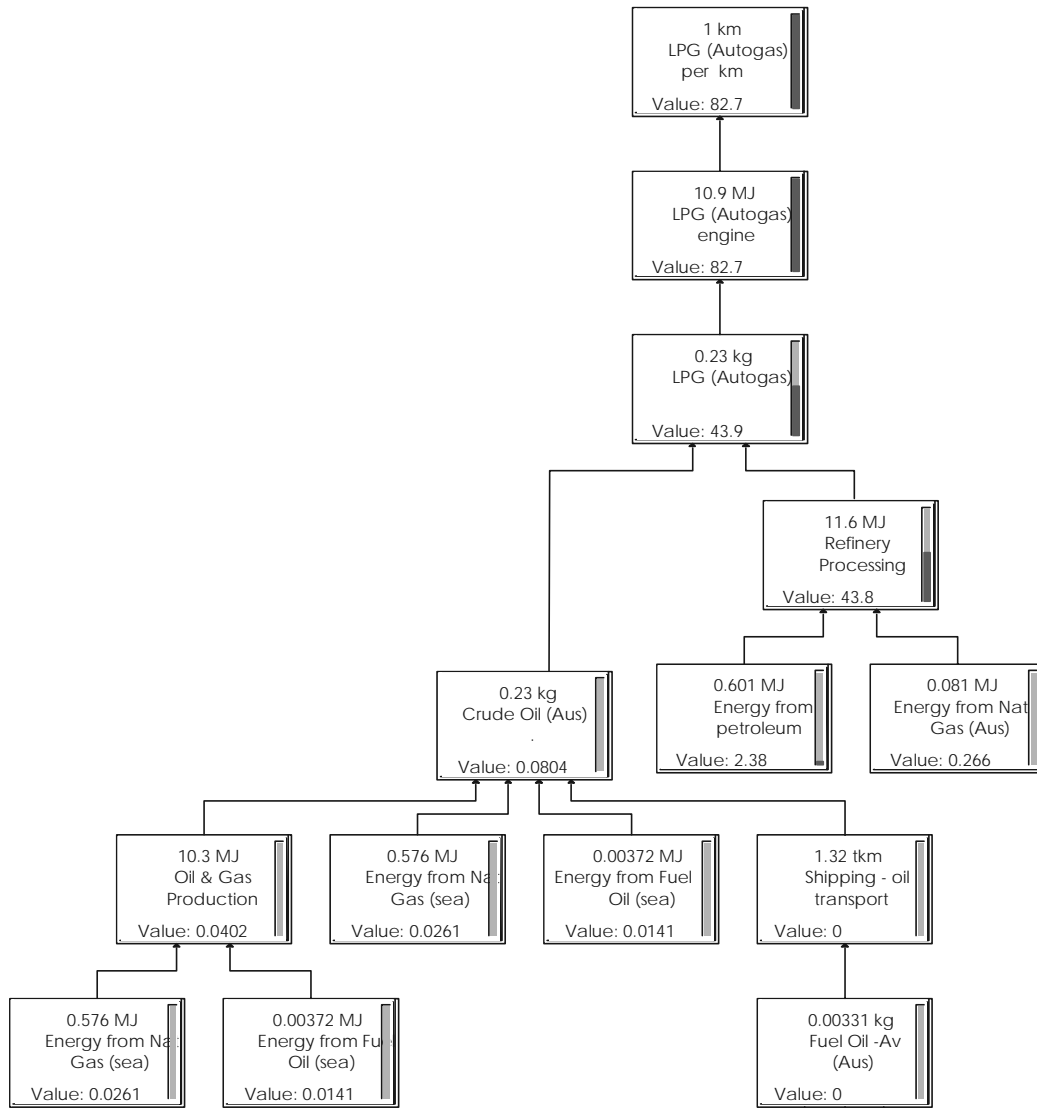


Figure 10.4
Embodied particulate matter (mg - urban) from LPG (Autogas) production and processing and use in vehicle

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10.4 Viability and Functionality

10.4.1 Handling, transport, storage and safety issues

LPG is gas at normal temperatures and pressures. Its physical properties depend strongly on the temperature and pressure at which it is being stored. As the temperature rises, the vapour pressure of LPG increases exponentially. Some ullage space must be left in an LPG tank because the liquid volume expands significantly if the tank encounters increasing ambient temperatures. Between -3°C and 37°C , for example, the liquid volume expands by 13 %. Due to this, and its lower density, LPG requires a 35 % greater storage volume than petrol. LPG systems have a safety device known as an automatic fill limiter (AFL) to ensure no more than 80 % of tank volume fills. This allows room for liquid expansion if the temperature rises after the tank is filled. Due to the low viscosity of LPG and its storage under pressure, it may leak through small cracks, pumps, seals and gaskets. LPG refuelling systems, being totally enclosed and pressure tight, have no refuelling, evaporative, running losses and emissions from the fuel storage system. LPG fuel tank is installed, along with a refuelling port, fuel lines, and pressure safety valves. LPG tanks are constructed of heavy gauge steel, to withstand a pressure of 1000 psi. Common operating pressures are in the range of 130-170 psi. Tanks are equipped with pressure relief valves that will release LPG vapours to the atmosphere to prevent tank explosion under abnormally high pressure conditions.

10.4.2 Engine manufacturers' acceptance of the fuel for warranty purposes;

Australian cars that are converted to LPG are warrantied by the converter. For example, Sprint Gas provides a 3 year, 100,000 km warranty on new cars (that have travelled less than 2,000km at the time of conversion) and a 2 year, 50,000 km warranty on used cars. (<http://www.sprintgas.com.au/pgfive.html>). Dedicated LPG cars typically have a 3 year, 100,000 km warranty provided by the manufacturer. Dedicated LPG heavy vehicles will come with similar warranties.

LPG engines are commercially available in the US from two major North American engine manufacturers for buses up to 30 feet in length. The Caterpillar G3306 and the Cummins B5.9-195 LPG engines were developed for mid-sized, heavy-duty vehicles. The Cummins B5.9-195 LPG engine is certified to the EPA 1999 Clean Fuel Fleet Vehicle Low Emission Vehicle (LEV) standard and the California Air Resources Board low NO_x standard of 2.5 g/bhp-hr for heavy duty engines. Detroit Diesel discontinued development of an LPG version of the Series 50G and 60G for larger heavy duty vehicles.

In Europe, according to the web page of the Vienna bus fleet, the European manufacturer MAN will provide Vienna with extra LPG buses (http://www.klip.wien.at/english/verkehr/ve_bus.htm). Renault has developed an LPG bus, whereas DAF introduced the stoichiometric process for their LPG buses.

10.4.3 Functionality

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. After an engine is shut down, the engine coolant continues to absorb heat from the engine, raising its temperature. If the vehicle is re-started within a critical period after shutdown (when both the coolant and the engine are at high temperature) then the coolant will heat the gas more than normal, lowering its volumetric heating value and density.

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10.4.4 Fuel energy density and vehicle operational range;

Although LPG has a relatively high energy content per unit mass, its energy content per unit volume is low. Thus LPG tanks take more space and weigh more than petrol or diesel fuel tanks. The range of LPG vehicles is equivalent to that of petrol or diesel vehicles.

10.4.5 Refuelling requirements;

The time to refuel LPG tanks is similar to that of refuelling times for petrol and diesel. The filling system of LPG tanks is not uniform across Europe, though new CEN standards are being designed to standardise this. In this respect, as with electricity plugs, Australia is ahead of Europe having standardised LPG refill nozzles across the country.

There are small losses of LPG during refuelling.

10.4.6 Issues affecting the availability of fuel

The 60% of Australian LPG that is sourced from 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. During the period of gas shortage, LPG was sourced from interstate and there were no disruptions to LPG supply. The NSW cavern storage provides added security.

10.4.7 Other issues

It is nowadays standard to use a multi-point fuel injection system. If this is not used then there can be back-firing to the inlet manifold. Some manufacturers discontinue fuel supply during deceleration to achieve the same result.

10.5 Health Issues

LPG's low emissions have low greenhouse gas effects and low NO_x precursors.

10.5.1 Production and transport

Upstream emissions associated with LPG use arise from energy used in gas and oil recovery and processing. Further emissions result from the delivery to retail outlets.

Particulate matter

The LCA estimate for LPG(Autogas) urban precombustion (truck) PM₁₀ emissions of 44 mg/km is similar to the LSD estimate of 43 mg/km.

Air toxics

The LCA estimate for LPG(Autogas) urban precombustion (truck) HC emissions of 0.811 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.

10.5.2 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.

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LPG, like CNG, has much lower emissions than diesel, and LPG has particularly low particle levels, which make it an attractive fuel for urban buses and delivery vehicles. However, as diesel particle 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 2.4) 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. Though these results may well refer to HD-5, it is likely that autogas would have similarly low emissions of air toxics.

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 particulate matter. (Anyon, 1998)

The LCA estimate for LPG(Autogas) combustion (truck) PM10 emissions of 39 mg/km is substantially less than the LSD estimate of 380 mg/km.

Air toxics

LPG has very low 1,3 butadiene and benzene emissions, but aldehyde emissions increase substantially, as with alcohol fuels (compared to gasoline vehicles). However, these higher aldehyde emissions would likely be reduced with a catalyst specifically designed for an LPG vehicle. (USEPA, 1993). Compared to diesel vehicles LPG produces much lower emissions of the main air toxics such as benzene, 1,3 butadiene, formaldehyde and acetaldehyde. (Anyon, 1998)

The LCA estimate for LPG(Autogas) combustion (truck) HC emissions of 0.008 g/km is substantially less than the LSD estimate of 0.900 g/km.

10.5.3 Summary

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 expected to be less than LSD.

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

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

10.5.4 OHS

The release of one unit volume of LPG in air generates a mixture that is around 2.5 times more than the volume of the mixture formed following the release of a similar amount of diesel.

The extent of hazards associated with such a leakage will depend largely on the relative tendency of the fuel to form a combustible mixture and the length of time for this mixture to persist in the vicinity of discharge and away from it either to be ignited from numerous potential ignition sources or feed a fire that may be engulfing the tank.

The tendency for the fuel to disperse in the surroundings from a leak is governed by the role of buoyancy and diffusional effects.

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LPG vapour 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 vaporise and disperse. In the case of CNG leak, because of the gaseous nature of the fuel, the gas will issue as a very high velocity jet into surroundings aiding greatly in the rapid dispersion of the fuel.

It takes a minimum of from over 2 % by volume of LPG in air at ambient conditions to just support a continuous flame propagation, as compared to around 5 % for methane and 1 % for petrol. The ignition energy for LPG, as well as methane and petrol, are sufficiently low that ignition is usually assured in the presence of thermal ignition sources such as sparks, lighted matches, hot surfaces and open flames. The quenching of methane-air flames by cold surfaces, as indicated by quenching distance, is easier than in the case of flames involving LPG-air mixtures. Due to this, flame traps are more successful in suppressing methane fires than those involving LPG.

LPG fires tend to persist within the leakage area due to its liquid and heavier than air state. For fuel line ruptures, pressurised gaseous fuels represent higher hazard levels than petrol.

10.6 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.

LPG 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.

10.7 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 10.13 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 10.13
Estimated emission factors for LPG under future technologies

Technology	CO	CO	HC	HC	NOx	NOx	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

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10.8 Summary

10.8.1 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 particle 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 NO_x 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.

10.8.2 Disadvantages

- Although LPG has a relatively high energy content per unit mass, its energy content per unit volume is lower than diesel, which explains why LPG tanks take more space than diesel fuel tanks. They are pressure vessels so that they also weigh more than diesel tanks.
- It is heavier than air, which requires appropriate handling.
- Though the lower flammability limit for LPG is actually higher than the lower flammability limit for petrol, the 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.