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LPG - The Clean Transport Alternative

Presenting the Environmental Case

Peter Anyon
(BSc Mech Eng)

September 2003

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LPG - The Clean Transport Alternative:
Presenting the Environmental Case

Report commissioned by the
Australian Liquefied Petroleum Gas Association Limited
and prepared by

Peter Anyon
(BSc Mech Eng)

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Foreword from the ALPGA

The Report, LPG – *The Clean Transport Alternative: Presenting the Environmental Case*, is the third in an ongoing series of Information Papers being published by the Australian Liquefied Petroleum Gas Association Limited (ALPGA). The planned series of research reports and information papers relate to important policy and industry issues affecting the position of LPG in the Australian energy market.

This Report also forms part of the ongoing policy, research and analysis program announced as part of the ALPGA's Autogas Industry Development Strategy released in April 2003 and was commissioned by the ALPGA's Autogas Task Force to demonstrate the comparative environmental performance of LPG as a transport fuel.

Peter Anyon prepared the Report (his biography is on page 25). It is an overview of LPG's environmental credentials and based upon the most recently available international data. The Report, therefore, provides an update to Peter Anyon's previous publication, *Liquefied Petroleum Gas as an Automotive Fuel: An Environmental and Technical Perspective*, which was released by ALPGA in late 2002.

LPG as an automotive fuel (Autogas) is the leading alternative transport fuel used in Australia. The ALPGA argues that Autogas makes a significant and ongoing contribution to improved environmental outcomes in road transport – in greenhouse abatement and reduced pollution levels. These benefits arise with the current policy of exempting LPG from transport fuel excise as an appropriate, effective and efficient policy to encourage LPG use in transport. The industry argues that the excise exemption is justified on environmental and economic grounds and should be continued.

The Report highlights a number of important conclusions relevant to policy makers and the LPG industry:

- LPG is a clean alternative fuel. It is the lowest polluting transport fuel in Australia.

- Current moves towards enhanced emission standards for vehicles (including Euro 3 and Euro 4 standards) still maintain LPG's position as a cleaner fuel than petrol and diesel (even where ultra low sulphur diesel is available).

- New engine technologies are in continuous development for LPG vehicles to optimise the inherent environmental qualities of the fuel.

- LPG environmental emissions are demonstrably superior to petrol and diesel in greenhouse gas emissions (including carbon dioxide) and in air quality emissions of photochemical producing compounds (such as oxides of nitrogen and hydrocarbons) as well as air toxics (such as benzene, formaldehyde, acetaldehyde and 1,3-butadiene) and particulate emissions.

- Health costs from LPG are substantially lower for LPG than petrol or diesel (even at fuel quality and technology levels which will be effective in 2006 and beyond when new emission standards are adopted).
- Even where older technologies (such as retrofit engines) are being used in Australian vehicles the greenhouse performance of Autogas is better than equivalent petrol cars.

In summary, the Report concludes:

Viewed objectively, the national and community benefits flowing from long-term local supply, widespread retail availability, lower community health costs, lower greenhouse emissions and quieter commercial vehicles, makes LPG the logical fuel of choice for vehicles operating in Australia.

The ALPGA believes that Autogas is a low carbon, high hydrogen fuel delivering immediate environmental and economic benefits to Australian businesses and consumers. As an abundant domestically available fuel and by providing greater energy choice, it increases the likelihood of Australia moving towards cleaner future transport fuels and supports energy security.

The Association appreciates the work undertaken by Peter Anyon in preparing this Report as well as the co-ordination of this research project by Taskforce member, Warring Neilsen.

Alan Beale
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Alan Beale, Taskforce Chairman (Elgas); Gary Ireson (Wesfarmers Kleenheat Gas); Ian Kennedy (ExxonMobil); Don Sargeant (BHPBilliton Petroleum); Ian Maloney (Elgas); Warring Neilsen (Elgas); Ian Woodward (Maestro Communication – Policy Strategy); Ray North (ALPGA); Bill Hazell (Wesfarmers Kleenheat Gas); Peter Israel (Origin Energy); Phil Westlake (ALPGA)

Contents

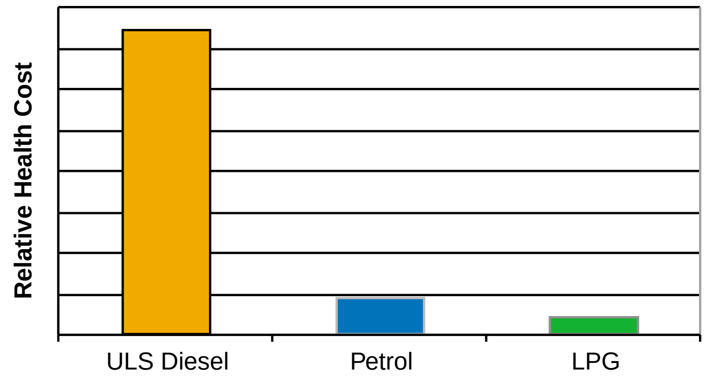
LPG – The Clean Transport Alternative: Presenting the Environmental Case

1. Why LPG?

Looking forward to 2006 and beyond, Liquefied Petroleum Gas (LPG) stands out as Australia's lowest polluting transport fuel, as well as being among the most greenhouse-friendly. Objective comparisons with petrol, diesel and "natural" gas indicate that LPG produces fewer harmful emissions than any competing fuel.

Using official European certification data[1] for a typical Euro 3 passenger car[2] and other independent test results, Figure A below (based on Australian health-cost values) shows that, even using the latest fuels and engine technologies, the adverse health impact of ultra-low sulphur (ULS) diesel is many times higher than LPG. Petrol is much less damaging than diesel, but health costs attributable to this fuel are still around twice that of LPG.

A. **Relative Health Cost (per litre) for a Typical Euro 3 Car Operating on Ultra Low Sulphur Diesel, Petrol and LPG**



These relativities are also maintained for buses and medium-duty trucks, which not only produce much lower toxic emissions than comparable diesel vehicles, but also have engine noise levels typically less than half those of their diesel counterparts.

The introduction of particle traps on diesel cars after 2006 cars may significantly narrow this margin, but many questions remain about the cost and durability of these devices[3]. The inherently "dirty" combustion of diesel will still result in much higher emissions of the two most damaging pollutants (oxides of nitrogen [NOx] and fine particulate matter [PM]) than LPG or petrol, even after Euro 4 comes into force and particle traps are widely fitted to diesel fuelled vehicles.

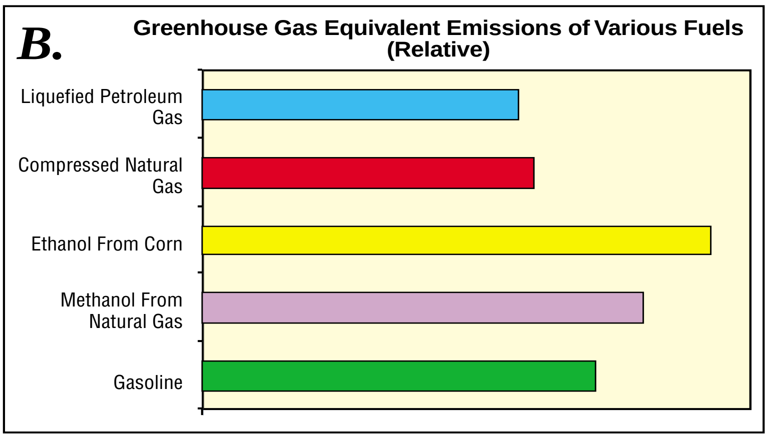
1. LPG Compared to:	
Ultra-Low Sulphur Petrol	**Ultra-Low Sulphur Diesel**
15% to 80% less oxides of nitrogen	90% to 99% less oxides of nitrogen
20% to 40% less hydrocarbons	80% to 95% less particles
30% to 35% less carbon monoxide	99% to 99.8% less ultra-fine particles

Table 1 above, published by Shell[4] and based on recent independent testing of Euro 3 cars in Europe, summarises LPG emissions compared with both ultra-low sulphur petrol and ultra-low sulphur diesel. Of particular note is the huge gap between diesel and LPG emissions of oxides of nitrogen (NOx) and fine particulate matter (PM). NOx impairs the lung function in humans and is strongly linked to increases in asthma attacks. PM is a known carcinogen and intense efforts are underway to limit human exposure to this pollutant. Further detail on the health impacts of air pollution is provided in Annex A.

From a true greenhouse emissions perspective, where account is taken of the energy expended in producing the fuel as well as the greenhouse gases emitted from vehicle tailpipes, LPG again has very low net emission levels.

For example, the US Department of Energy[5] has reported the relative climate change impacts of a range of conventional and alternative fuels. This work concluded that LPG not only has lower net greenhouse gas equivalent emissions than petrol and Compressed Natural Gas (CNG), but also surpasses a number of highly promoted bio-fuels, once the energy expended in growing, harvesting, transporting and processing these fuels is accounted for (see Figure B below). Only diesel, through the high efficiency of diesel engines' combustion process, can challenge LPG's full life-cycle greenhouse performance.

Hence, until the decade arrives when hydrogen is commercialised as a mainstream fuel, and the car manufacturers produce hydrogen powered vehicles, LPG will remain the most people-friendly and environmentally responsible fuel available to the Australian community.



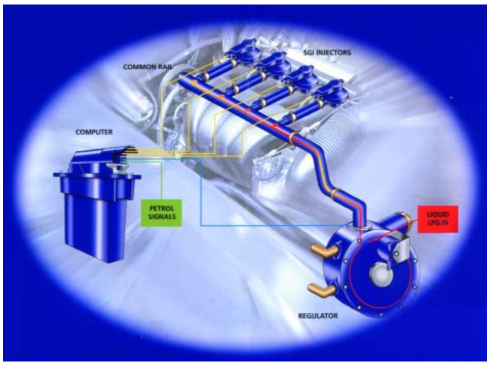
Australia is completely self-sufficient in meeting its LPG requirements, and could accommodate a further 50% growth in demand from existing, known resources. Long-term availability is assured, with naturally occurring reserves that are capable of satisfying the domestic market for well over 20 years.

Most importantly, the distribution and delivery infrastructure for LPG is already in place. Australia has the world's most extensive network of LPG refuelling stations, with over 3,500 retail outlets across the nation. It is therefore possible to drive virtually anywhere on Australia's road system using existing LPG refuelling stations. This is in stark contrast to other alternative fuels, such as "natural" gas (CNG and LNG), and bio-fuels, for which the public refuelling sites and/or production facilities have, in most cases, yet to be established. There is presently no indication as to who might provide the massive investment capital required for a viable infrastructure network to support these fuels.

2. LPG Comes of Age

LPG's inherently clean burning characteristics make it an ideal automotive fuel, but its full potential has not always been delivered. For three decades, governments in Australia chose not to set any performance standards for alternative fuel vehicles, despite the introduction of increasingly stringent regulations for their diesel and petrol counterparts.

This situation promoted the growth of a highly fragmented industry, based almost solely on small businesses that provided after-market petrol-to-LPG conversions for in-use cars. With no environmental standards to meet, price competition became the market driver, with low grade and mostly outdated technology components being fitted. Emissions performance and fuel efficiency became the prime casualties.



However, the situation is now radically changing. Recent government decisions to regulate emissions from alternative fuelled vehicles are transforming the marketplace.

With a stable, performance-based business climate that demands rigorous engineering and quality management, the car manufacturers are now able to enter the market and are ramping up to produce fully developed, factory assembled LPG cars and light commercials that embody the latest fuel management and emission reduction technologies.

Moving from the 1980's vintage carburettor fuel mixer, to the latest computer-controlled, sequential multi-point injection systems (see illustration above), the new generation of LPG cars embody a degree of sophistication that is the equal of any comparable petrol vehicle. Precise control over the timing and amount of fuel injected provides a quantum improvement in emissions and a significant fuel consumption benefit. Many of the new LPG fuel systems are already certified to Euro 4.

In the heavy-duty vehicle sector, LPG bus engines that already comply with Australia's 2006 standards are now becoming commercially available, opening the way for quiet, low-polluting urban buses that release fleet operators from the fuel supply, payload reduction and capital investment issues associated with CNG. Urban delivery trucks fuelled by LPG are already operating in Sydney, Melbourne and Perth.

From a regional standpoint, diesel particles are by far the most pressing air quality issue in Asia. The Australian vehicle and component industries, by forging ahead with LPG technologies, could find their products in strong demand throughout the Asian region and other export markets, if the industry is encouraged to be a leader and not a follower in adopting clean fuel technology.

It is ironic that European authorities, having recognised the value of LPG as an automotive fuel, and having moved rapidly to establish a policy environment that encouraged its uptake, were held back by the limited availability of refuelling facilities.

On the other hand Australia, with the best retail availability in the world, has until recently viewed LPG with a somewhat jaundiced eye and, through a lack of appropriate policies, effectively suppressed its development as a mainstream fuel of choice.

With an appropriate regulatory framework now in place, industry is responding to the challenge, and Australia will see a new generation of factory-produced LPG vehicles that deliver the true potential of this fuel, provided the right pricing signals are maintained.

3. The European Test Programme 2003

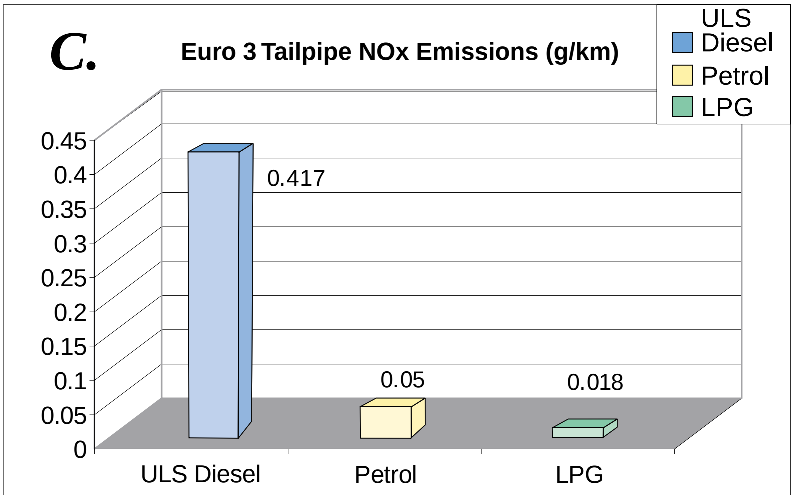
In August of this year, an exhaustive collaborative test program[6], commissioned by several major oil companies, was completed. The project compared emissions from current-model vehicles, using Europe's leading independent emission testing laboratories.

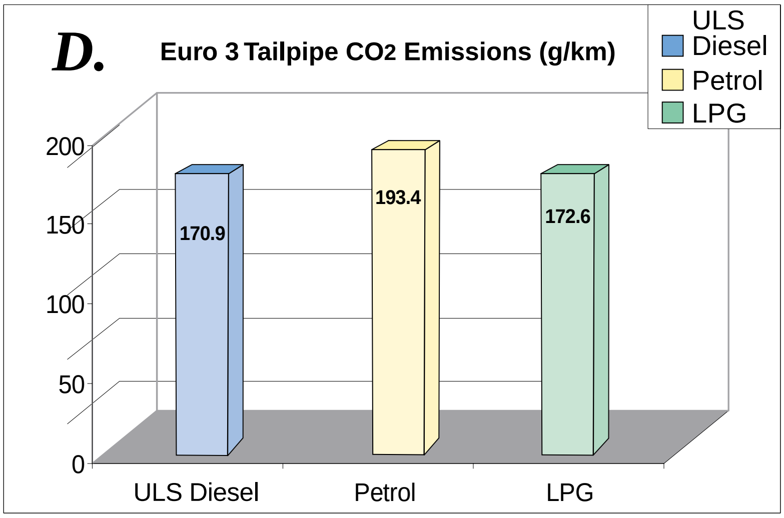
The core of this project was a group of 26 vehicles, comprising the diesel, petrol and LPG variants of seven current, Euro 3 certified cars and light commercial vehicle models. All vehicles were tested on the Euro 3 certification test cycle and the new "Artemis" cycle, which is much more aggressive and includes speeds up to 130 km/h. Results from driving each cycle with both a "cold" and a "warm" start were recorded.

By selecting models with factory-produced variants covering all three commercially available fuels, and subjecting them to identical test procedures in independent test facilities, this project delivers a robust and reliable "apples with apples" comparison of emissions from vehicles typical of those available in European showrooms.

As well as measuring the pollutants regulated under Euro 3 (PM, NO_x, HC and CO), the project also measured carbon dioxide (CO_2) and a number of "air toxic" pollutants not presently covered under any regulation, but nevertheless of growing concern to health authorities.

The regulated pollutant and CO_2 test results have been released ahead of the final report (together with some preliminary results on fine particle number counts), in response to the intense interest generated by the project. Air toxic and other non-regulated results are still being processed and will be released later.





Figures C and D above summarise key findings of the project, in relation to NOx and CO_2 emissions.

It can be seen that, even in the latest vehicles, NOx levels from diesels were found on average to be around 20 times higher that petrol, and 40 times higher than their LPG counterparts.

Moreover, the extremely "lean" combustion characteristics of diesel engines make significant NOx reductions very difficult and expensive to achieve, and the few diesel-powered models already designed to meet the 2005 Euro 4 standards, do so by only a very narrow margin.

As discussed in a later section of this document PM emissions, the number of fine particles from the diesel variants (per km of travel) was found to exceed LPG levels by a factor of 120.

The project also confirmed that tailpipe hydrocarbon (HC) and carbon monoxide (CO) emissions from all fuels are now extremely low, due to a combination of inherent fuel characteristics and the high effectiveness of modern pollution control systems in respect of these pollutants.

It was found, however, that the volume of HC vapours displaced from the tanks of petrol vehicles during refuelling represents a much higher pollution source than the products of combustion. Measuring the mass of vapours displaced, and dividing that figure by the vehicle range (in kilometres) on one tank of fuel, results in a fugitive HC emissions figure (in grams/km) ten times that of the tailpipe HC emissions.

This high figure undermines the intent of the ADRs, but is unavoidable unless effective vapour recovery systems are fitted to all petrol refuelling bowsers. Diesel, because of its low volatility and LPG, because of the sealed refuelling systems used, have negligible fugitive emissions, relative to those of petrol.

4. A Closer Look at Some Key Issues

Over the coming decade and beyond, petrol, diesel, CNG and LPG will continue to be the most viable fuel types available to the motoring public and transport fleets.

Production of bio-fuels such as ethanol and a range of bio-diesel variants will increase, but they will be used predominantly for blending with traditional fuels to improve their air quality and/or greenhouse performance, rather than as fuels in their own right. Vehicles manufactured for petrol or diesel operation will generally run satisfactorily on these blended fuels with little or no adjustment to the engine.

More advanced propulsion technologies, such as fuel cells, are still some way from high-volume commercialisation. In addition to any cost and market acceptance issues, some standardisation of fuels for these technologies may also be required. If hydrogen, methanol or CNG are selected, a new fuel distribution system will need to be developed. If the fuel cells are designed for LPG operation, the existing LPG refuelling infrastructure can be utilised.

Rational decisions on fuel selection are strongly influenced by availability, cost (operating and capital) and suitability for any particular application. Using these criteria, it is highly unlikely that any single fuel will be the optimal choice for all transport needs, at least in the foreseeable future.

The practical, operational and environmental characteristics of all four commercially available fuels are summarised in the following Table 2.

2.	FUEL CHARACTERISTICS			
Fuel Characteristic	**Petrol**	**Diesel**	**CNG/LNG**	**LPG**
Urban Air Pollution	Moderate to low emissions of hydrocarbons (HC) and Oxides of Nitrogen (NOx). Low particle (PM) emissions.	High NOx, low HC emissions. High PM emissions relative to other fuels even with reduced sulphur levels. By far the highest adverse impact on public health.	HC (methane) emissions can be high but do not contribute to smog formation. Moderate to low NOx. Very low PM.	Low NOx and moderate to low HC emissions. Very low PM.
Global Warming (Greenhouse)	Moderate CO_2, low methane (CH_4) emissions. Some questions re nitrous oxide (N_2O) formation in the catalyst.	Lower CO_2, low CH_4 and HC. Airborne PM may increase global warming. High NOx levels may result in elevated N_2O emissions.	Potentially lowest CO_2 of all fuels, but this can be offset by the very high green-house impact of methane (CH_4) emissions from these engines.	Tailpipe CO_2 levels lie between petrol and diesel. Life-cycle CO_2 com-parable to diesel, lower than petrol and CNG. Negligible CH_4 emissions.
Engine Noise	Low	High	Low	Low
Application	Lowest cost fuel system, so attractive for cars and light commercials.	Complex high-pressure fuel system increases cost, but most fuel-efficient. Very durable and reliable in heavy duty applications.	High cost and limited range preclude use in light duty vehicles. Use effectively limited to depot-based trucks and buses with their own refuelling facilities.	Cost, range and on-road performance equivalent to petrol in light duty vehicles. Euro 3/4 engines now available for buses and medium trucks. Not constrained to depot-based operations.
Retail Availability	Nationally Available	Nationally Available	Virtually zero. Depot-based refuelling only.	Nationally Available

The characteristics summarised above tend to naturally identify the optimum applications for each fuel.

For **passenger cars and derivatives**, the low initial purchase price of petrol and LPG vehicles, together with their relatively low pollutant emissions, make these fuels well suited to mainstream private and business use. Significantly lower greenhouse emissions and generally lower pollution levels from current-technology LPG cars tip the balance in favour of this fuel.

Diesel cars are very popular in Europe, primarily because of aggressive taxation policies that have driven vehicle owners to seek out the most fuel-efficient vehicles, regardless of their impact on air pollution. The high particulate problems in many European cities reflect the downside of fuel excise policies that encourage the use of diesel vehicles in urban areas.

CNG is not a consideration for this sector, due to the very high on-vehicle cost, limited range and the almost total absence of public-access refuelling facilities.

Light Commercial Vehicles (LCVs) are used very intensively in urban areas. Hence, although they can operate satisfactorily on any of the commercially available fuels, use of the cleanest possible fuel should be encouraged.

Australian availability of diesel LCVs is increasing, but their use in urban areas can create major pollution and public health problems, as evidenced in cities such as Bangkok and Manila, where light-duty diesel vans and pickups represent a significant proportion of the vehicle population.

Research recently undertaken by the National Environment Protection Council (NEPC) found that diesel light commercials on Australian roads tend to emit high levels of pollution, often exacerbated by poor maintenance. PM emissions from vehicles in this group often exceed those of the largest trucks and buses.

Hence the use of diesel in light commercial vehicles (even those certified to the current and upcoming standards) should be discouraged, as their PM levels are likely to remain considerably higher than their petrol or LPG counterparts.

Medium Trucks, such as those widely used for urban delivery and freight carriage, currently operate almost exclusively on diesel. Again, the NEPC emissions research has shown that PM emissions from these vehicles can be very high, and rigid trucks have been identified as a vehicle group of particular concern from a public health standpoint.

Some larger depot-based fleets with regular driving patterns, such as daily delivery rounds, are finding that CNG vehicles are not only a low-noise, low-polluting alternative, but also have a beneficial impact on the bottom line.

However, as many vehicles in this category are operated either by very small fleets or by owner-drivers working on contract, the lack of general-access CNG refuelling facilities precludes the use of this fuel as an alternative to diesel for these operators.

Factory-produced LPG engines, with similar environmental credentials to those of CNG, are now commercially available for medium duty trucks. They deliver measurable economic benefits, both in direct fuel costs and through extended access hours due to their lower noise levels. Of specific importance to the small operator, refuelling facilities are both accessible and widely distributed.

Heavy-Duty Trucks, particularly those on long-haul operations, are effectively restricted to diesel operation, due to fuel availability considerations coupled with the ruggedness and fuel efficiency of heavy-duty diesel engines. Theoretically, LNG has potential for this application, but no refuelling facilities exist in Australia.

Dual fuel diesel/LPG or diesel/CNG trucks, in which a virtually standard diesel engine burns both fuels together, have demonstrated their ability to reduce PM and greenhouse emissions but to date have achieved only very minor penetration into the trucking market. Further work is needed to achieve satisfactory levels of reliability and consistency from these conversions, and to gain the confidence of the trucking industry.

Some diesel-to-CNG and diesel-to-LPG conversions show considerable promise, with lower greenhouse and air pollutant emissions than their diesel counterparts, but again, they have yet to gain strong commercial acceptance.

Buses have traditionally used diesel, but the low cost of CNG, coupled with its reduced noise levels and "clean" image, has led to some major fleets adopting CNG for new vehicle purchases. Adoption of CNG involves significant investment in a fuel compression, storage and dispensing facility, as well as a large premium on the vehicle purchase price to cover the cost of installing and structurally supporting multiple high-pressure on-board fuel cylinders.

Several Euro 4 LPG bus engines have now become available in Europe. These engines share with CNG the same low noise and emission levels, but do not require high-cost fuelling facilities, nor extensive vehicle modifications to accommodate the fuel tanks.

In summary, it can be seen that there is a continuing role for all the currently available fuels, over the foreseeable future. There is, however, considerable scope to improve air quality, reduce community health problems and lower greenhouse emissions through the increased uptake of:

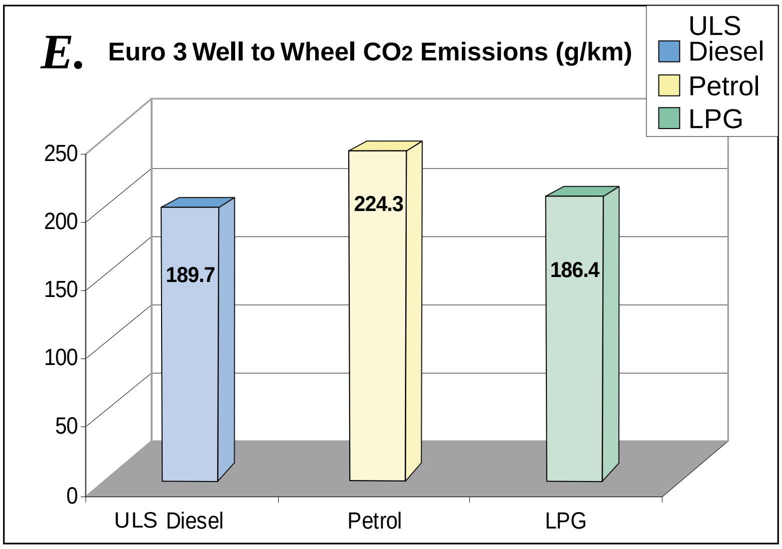
- CNG as an alternative to diesel for depot-based trucks and buses; and
- LPG as an alternative to both petrol and diesel in cars, light commercials, buses and medium trucks.

5. Comparative Greenhouse Gas Performance of Transport Fuels

Very high direct and indirect costs are attached to climate change impacts associated with increased levels of greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC) places values ranging up to US$70 per tonne of CO_2 avoided, while Denmark, through its Carbon Tax, estimates the value to be US$25 (A$38.50) per tonne. Australian Government estimates tend to be lower.

Fuel composition and inherent engine characteristics have a direct influence on greenhouse gas emissions For instance, the very high compression ratios used in diesel engines deliver relatively high thermal efficiency (ie, more effective conversion of fuel energy content into useful work). This generally results in better fuel economy, so that diesel vehicles have tended to emit less carbon dioxide (CO_2) per kilometer travelled than equivalent petrol or LPG vehicles, although this CO_2 advantage tends to be at least partially offset diesel’s higher upstream (pre-combustion) energy demands.

However, the greenhouse balance is now changing, with the most fuel-efficient LPG engines now having CO_2 tailpipe emission levels almost equal to their diesel counterparts, and even lower when considered on a "well-to wheel" basis (see Figure E following based on the European Test Programme 2003).



LPG and petrol engines have generally very similar characteristics and thus have comparable thermal efficiencies. The lower carbon content in LPG therefore results in lower CO_2 emissions than from the equivalent petrol engine, for a given amount of work.

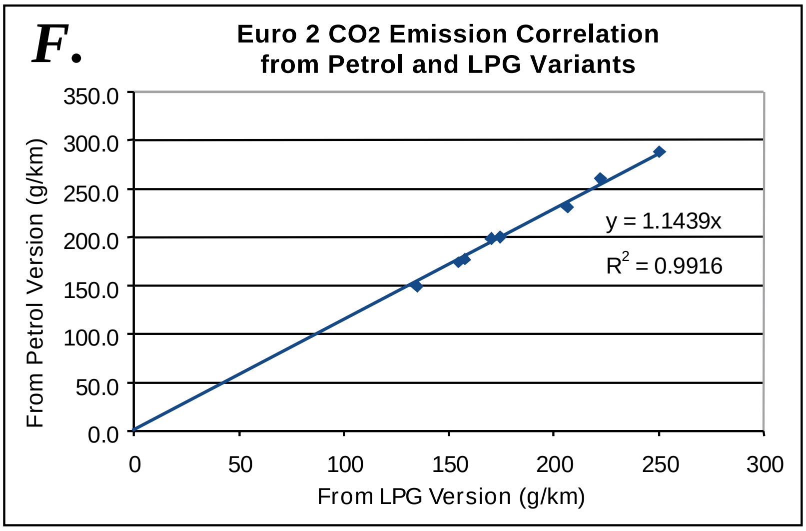
In practical terms, these technical issues and differences in chemical composition generally result in diesel fuelled vehicles producing less CO_2 per km than their LPG counterparts, which in turn produce lower CO_2 tailpipe emissions than petrol vehicles.

Test data for the petrol and LPG variants of some Euro 2 cars[7] illustrates a high degree of consistency in the relationship between CO_2 emissions from petrol and LPG versions of a given model.

The vehicle models tested (and their engine sizes in litres) were:

Renault Twingo	1.2
Vauxhall Omega	2.0
Vauxhall Combo	1.6
Ford Scorpio	2.3
Renault Mégane	1.6
Opel Vectra	1.8
Chrysler Voyager	2.5
Renault Laguna	1.8

Figure F opposite shows that, for each model tested, the petrol version consistently produced around 14% more CO_2 than the LPG variant, on the same test cycle. Similar correlation exercises for newer and older vehicle groups also deliver a similar



relationship between petrol and LPG greenhouse emissions. A similar relationship exists for Euro 3 cars and, interestingly, even the older 1980's vehicles delivered a CO_2 improvement of 12% or more, even though their regulated pollutant emissions were, at that time, no better than their petrol counterparts (see next Section).

In 1994 the US Department of Energy (DoE)[5] analysed total life cycle, or "Well-to-Wheel" greenhouse gas emissions from a number of alternative fuels, relative to petrol.

After compiling upstream (production) and downstream (use) emissions, and applying the appropriate weightings to each greenhouse gas, the relative greenhouse impacts of each fuel under consideration are summarised in Table 3 (lower = better).

3.	Fuel	Relative Net GHG Emissions
	Gasoline (Petrol)	10.71
	Methanol From Natural Gas	12.02
	Ethanol From Corn	13.88
	Compressed Natural Gas	9.03
	Liquefied Petroleum Gas	8.61

Both of the gaseous fuels demonstrate clear advantages over the liquid fuels, with LPG recording the best overall GHG performance. CNG had the lowest CO_2 emissions, but was relegated to second place because of the high greenhouse impact of methane (CH_4) emissions from this fuel.

A recently completed collaborative study[8] by CSIRO, Melbourne University and the RMIT University has explored the upstream (well-to-tank) greenhouse emissions from LPG, using the latest available data. Combining their analysis with the known greenhouse gas equivalent (CO_2-e) emission rates from combustion of petrol and LPG in an engine, the team concluded that the total "well-to wheel" CO_2-e emissions from petrol and LPG are 2.9 and 1.8 kg per litre, respectively.

Correcting for the differences in fuel consumption between petrol and LPG (1.0 : 1.3 on a g/km basis), the net difference in "well-to wheel" emissions per kilometre of travel is: (2.9/(1.8x1.3)) = 1.24

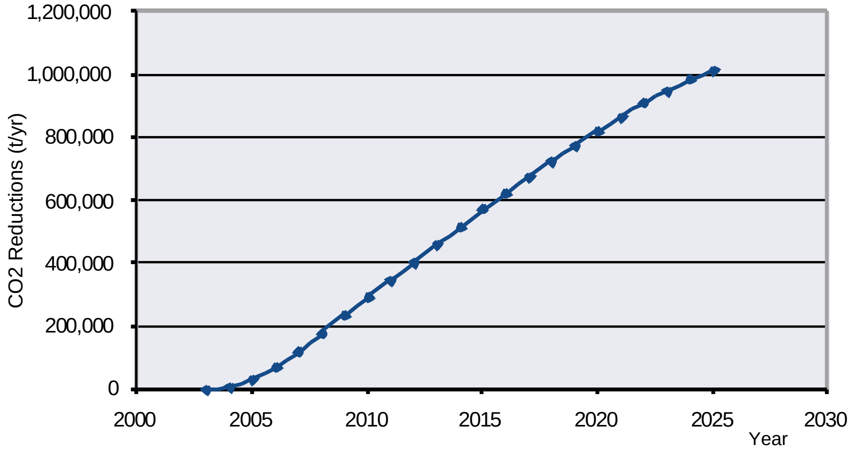
ie: On a "well to wheel" basis, using Australian upstream production data, petrol generates 24% higher greenhouse gas emissions than LPG.

However, in its published greenhouse emission factors table for transport fuels (http://www.greenhouse.gov.au/challenge/tools/workbook/factorsmethod_section2.html) the Australian Greenhouse Office allocates a higher greenhouse gas equivalent (CO_2-e) figure for LPG than for petrol. It is therefore assumed that the AGO's figure relates only to the 30% of LPG that is refinery-produced, and does not take account of the lower upstream energy levels associated with the 70% of LPG that comes from naturally occurring sources.

Moreover, there is a strong argument that the upstream energy allocation for refinery-produced LPG should be very much lower than for petrol or diesel, as refinery LPG is an unavoidable and incidental by-product of diesel and petrol fuel refining, with no additional energy consumption attached to its production. In reality, only the relatively small amount of energy required to compress (or refrigerate) and distribute the LPG should be allocated to upstream greenhouse emissions.

To estimate the overall impact of market-based policies that continue to support the uptake of LPG vehicles, a computer model has been developed to quantify the greenhouse benefits flowing from increased use of LPG cars (see Figure G).

G. **Projected CO_2 Reductions from LPG New Car Sales Accounting for 10% by 2008 (tonnes/yr)**



Assuming a gradual increase in LPG vehicle sales to 10% of new car purchases by 2008, together with a 1% per annum growth in overall fleet VKT, offset by a 0.5% per annum improvement in fuel consumption, the estimated annual reduction in greenhouse emissions by 2025 (from a 2003 base) is estimated to be slightly over 1 million tonnes of CO_2 per annum.

6. Greenhouse Emissions from Existing LPG Conversions

Some questions have been raised as to whether older vehicles, which were converted to LPG operation by retrofit LPG installation businesses, deliver any greenhouse benefits.

Using Australian Government reports and data sources, it is apparent that even pre-ADR 37 vehicles (ie those manufactured prior to 1986) delivered significantly lower CO2 emissions than their petrol-fuelled counterparts, even though their emissions of ADR-regulated pollutants were generally little different to those of the petrol vehicles.

To calculate the relative CO_2 emissions, we need to know two things for each fuel:

(a) the mass of CO_2 produced by burning one litre of each fuel (kg of CO_2 per litre); and

(b) the number of litres of each fuel consumed per 100km of travel, under identical operating conditions.

Multiplying (a) by (b) and dividing the answer by 100 gives us the mass of CO_2 produced per kilometre of travel, for each fuel.

The Australian Greenhouse Office website[9] , states that……"For every litre of petrol used 2.3 kilograms of carbon dioxide is released from the exhaust and, for every litre of LPG used, 1.5 kilograms of carbon dioxide is released from the exhaust".

A Federal Office of Road Safety report of Motor Vehicle Pollution in Australia looking at In-Service Vehicle Emissions from LPG vehicles, which was based on testing performed in 1996 by the NSW Environment Protection Authority's vehicle emissions laboratory, compared LPG and petrol vehicle fuel consumption rates, for the same base vehicle models.

LPG fuelled Ford Falcon and Holden Commodore vehicles (the cars most commonly used as taxis) consumed 17.8 litres/100km, while the petrol variants consumed 13.5 litres/100km, using the Australian Design Rule (ADR 27 and ADR 37) certification test cycles.

Hence the CO_2 emissions per kilometre for LPG cars was:

$$(1.5 \times 17.8) / 100 = 0.267 \text{ kg/km},$$

and for petrol fuelled vehicles was:

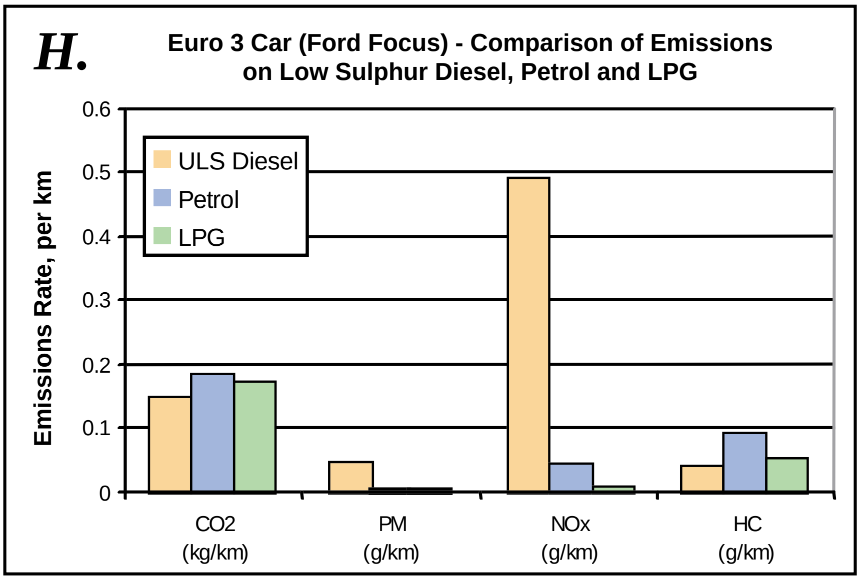
$$(2.3 \times 13.5) / 100 = 0.3105 \text{ kg/km}$$

These test results indicate that tailpipe CO_2 emissions from older LPG vehicle conversions are ((0.3105 - 0.267) / 0.3105) x 100 = **14% lower** than their petrol fuelled counterparts, based on the results of the Federal Government's own test programs.

This outcome is corroborated by many reports that have, through similar testing, found that LPG fuel consumption (in litres/100km) is typically between 28% and 36% higher than an equivalent petrol car. Using the same calculation methods as above, LPG has therefore repeatedly been found to deliver between 11.3% and 16.5% lower CO_2 emissions than petrol.

7. Light-Duty Vehicle Emissions – Regulated Pollutants

Taking as an example a typical European small/medium car (Ford Focus) which is also sold (in petrol form only) on the Australian market, it can be seen that LPG variant delivers a significantly better emissions performance than the petrol version, for all pollutants and greenhouse gases.



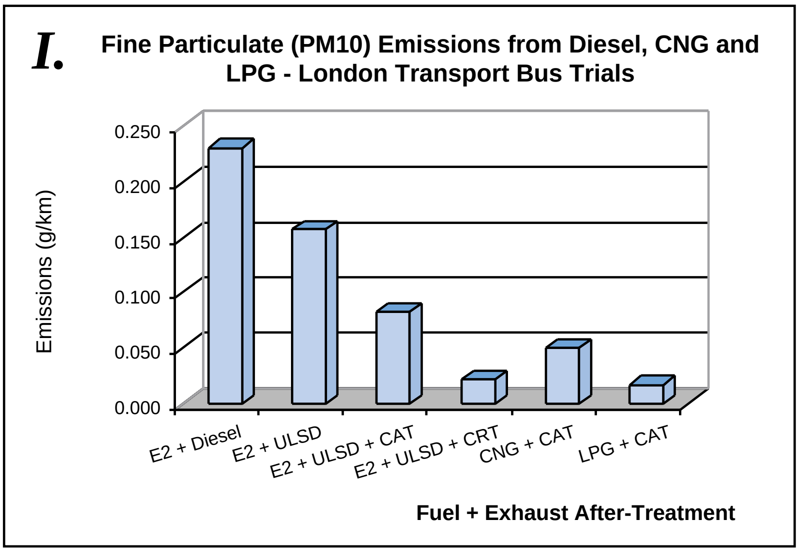
The diesel variant has high levels of oxides of nitrogen (NOx) and fine particles, which have the highest impact of the regulated pollutants. NOx is a fairly intractable pollutant, especially in an air-rich (lean) combustion situation, such as that found in diesel engines. Measures to reduce NOx in diesel engines can entail fuel consumption penalties.

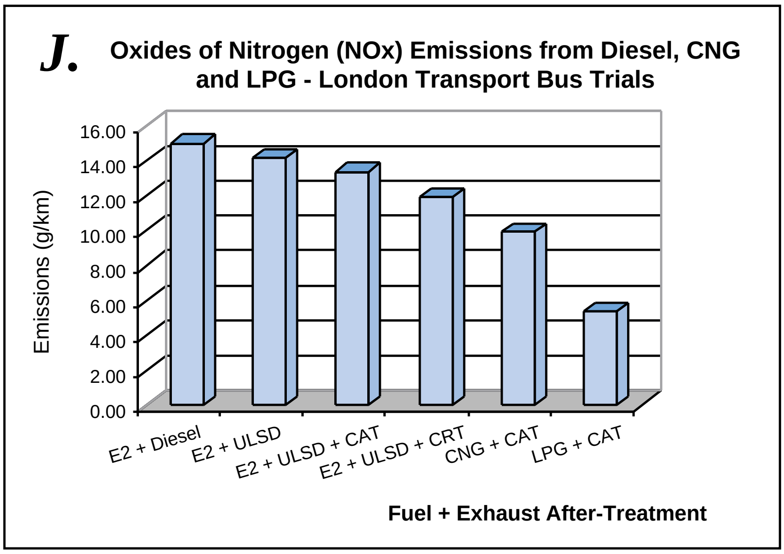
These data, taken from UK Government certification records[11], are typical for the current generation of Euro 3 vehicles, and emphasise the low emissions levels that are now being achieved by factory-produced vehicles developed using the resources and development capabilities of a large manufacturer. The final report of the European Test Programme 2003 will, when released, provide a more comprehensive review of these comparative emissions.

8. Heavy-Duty Vehicle Emissions – Regulated Pollutants

LPG and CNG are now being used in an increasing number of heavy-duty vehicles.

Through the Alternative Fuels Conversion Program (AFCP), the Government is encouraging the use of vehicles operating on LPG and CNG, which can deliver better greenhouse gas performance and significantly lower particle and NOx emissions. These vehicles also tend to have much lower emissions of "air toxic" substances, which are discussed in section 10 of this document.





KEY TO ABBREVIATIONS

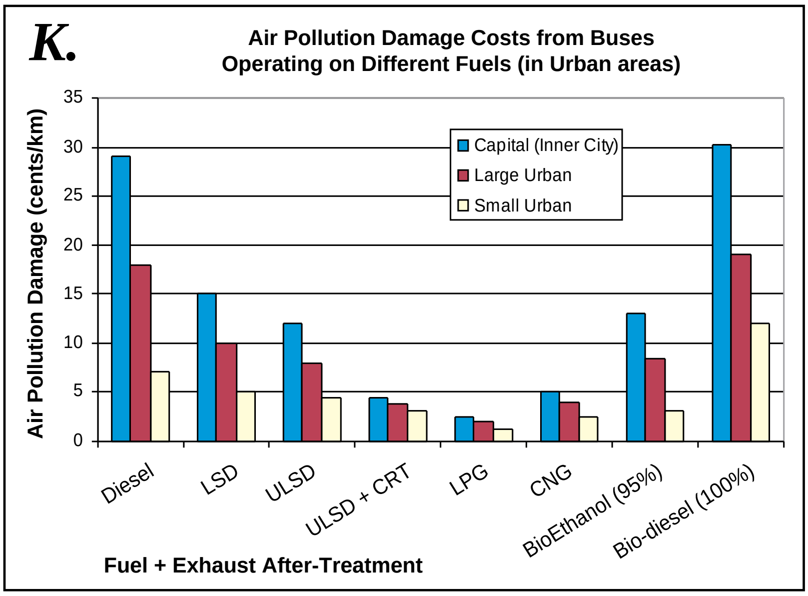
E2 + Diesel:	Euro2 spec engine with standard UK diesel (.05per cent sulphur).
E2 + ULSD:	Euro2 spec engine with Ultra-Low Sulphur diesel (.001per cent sulphur).
E2 + ULSD + CAT:	Euro2 spec engine with Ultra-Low Sulphur diesel (.001per cent sulphur) and oxidation catalyst.
E2 + ULSD + CRT:	Euro2 spec engine with Ultra-Low Sulphur diesel (.001per cent sulphur) and continuously regenerating particulate trap.
CNG + CAT:	Compressed Natural Gas with oxidising catalyst
LPG + CAT:	Liquefied Petroleum Gas with 3-way catalyst

HC and CO levels can be significantly higher than from diesel engines, but a simple oxidation catalyst in the exhaust system can generally reduce these emissions by up to an order of magnitude.

The above Figures I and J very clearly summarise relative emissions levels of heavy vehicle emissions of particulate matter (PM) and oxides of nitrogen (NOx) – the two pollutants from buses and trucks of greatest concern.

Data in the charts was drawn from a comparative emissions study of buses performed by London Transport[12] to measure emissions from a range of fuels, and the effect of a number of exhaust after-treatments, under identical test conditions. The two gaseous fuels, CNG and LPG again demonstrate their low-emitting characteristics.

One of Europe's foremost experts in transport economics, Mr Paul Watkiss, translated the outcomes of a European externality study, into an Australian context, in a report completed for the Bus Industry Council[13]. His work takes account of Australia's human and vehicle population densities, and city size, as well as local vehicle emissions performance.



KEY TO ABBREVIATIONS	
LSD:	Low Sulphur diesel (.05per cent sulphur).
ULSD:	Ultra-Low Sulphur diesel (.001per cent sulphur).
ULSD + CRT:	Ultra-Low Sulphur diesel (.001per cent sulphur) and continuously regenerating particulate trap.
LPG:	Liquefied Petroleum Gas
CNG:	Compressed Natural Gas

Figure K above summarises his estimates of air pollution damage for buses running on a range of conventional and alternative fuels. LPG is estimated to have the lowest adverse impacts of all available fuels.

Several major bus fleets have now made a strong commitment to CNG – some to the extent that they have a policy of not purchasing any diesel buses at all. However, bus operators using LPG are still very few in number, primarily due to the poor availability in Australia of factory-produced buses with LPG engines. This situation is now likely to improve, with at least one major European manufacturer planning to introduce their heavy-duty LPG engines on to the Australian market.

A number of urban trucks are also now using both LPG and CNG, as engines start to become available from several major manufacturers.

Conversion kits that allow the engine to run on a continuous mixture of diesel and gas (either LPG or CNG) are also slowly gaining a foothold, due primarily to the low cost of the conversions, reductions in overall fuel costs, and the avoidance of any modifications to the engine itself. These conversions reduce PM emissions significantly and can also have a beneficial impact on NOx and (if installed correctly) on carbon dioxide (CO_2).

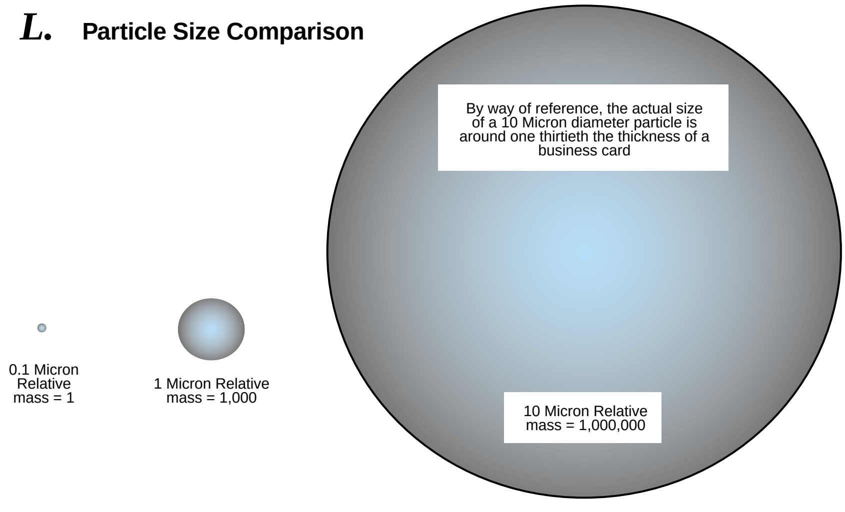
9. A Closer Look at Particles

As emission standards move to Euro 4 and beyond, the traditional method of measuring PM emissions (by weighing the mass of particulate matter deposited on a filter by a known volume of exhaust sample) becomes less relevant.

Particles with a nominal diameter of ten microns (one hundredth of a millimetre) and smaller are considered to be the size range that can bypass the body's defence mechanisms and lodge in the lungs. As a consequence interest has focused, in the past, on controlling the mass emissions (g/km or g/kWh) of particles up to 10 microns diameter (PM10).

However, as most particles emitted from modern diesel engines are generally much smaller than 10 microns (typically in the range 0.05 to 0.15 microns), there is a body of scientific opinion that considers the number of particles emitted to be more important than their mass. Indeed, the negligible mass of very small particles allows them to be carried into the deepest and most sensitive lung tissue, where they can do most harm.

L. **Particle Size Comparison**



When one considers that the deposition of just one stray 10-micron particle adds the equivalent mass of between 100,000 and one million typical ultra-fine exhaust particles, it is easy to understand why mass measurements become less meaningful.

The European Test Programme 2003 brought together Europe's foremost independent emission testing laboratories (Millbrook UK, TNO Netherlands, TuV Germany and IFP France). One important element of this project was to measure the number (as opposed to the mass) of fine and ultra-fine particles emitted from current technology cars and light commercials running on diesel, petrol and LPG.

Although the final report has not yet been released, some preliminary results have been outlined in presentations made to European authorities. One the key findings was that Euro 3 diesel cars operating on ultra-low sulphur fuel produced, on average, over **120 times** more ultra-fine particles than equivalent LPG cars.

Direct-injection engines, where the fuel is sprayed directly into the combustion chamber rather than being entrained into the engine's inlet air, have been the mainstay of diesel fuel systems for a number of years. This technology is now starting to be adopted in petrol-fuelled vehicles, where they can help to deliver better fuel economy. However, a downside to their use appears to be a very significant increase in particle emissions, at least with examples produced to date.

If gasoline direct injection (GDI) was to be widely adopted, and they retain this characteristic, the gap between LPG and other fuels would widen even further than the present.

While the fitment of particle traps is often cited as a measure that will bring diesel particle emissions down to levels similar to those of other fuels, an increasing body of research questions the long-term value of these devices.

Particle traps have demonstrated they can remove up to 95% of particle mass in diesel exhaust by trapping the relatively larger particles, but as yet their durability and resistance to contamination in routine service is largely unknown. It is also suggested that many of the ultra-fine particles, which potentially do the most harm, are not captured by the trap and are still emitted to atmosphere. Only two or three currently available model variants incorporate these devices, so it is unlikely that a great deal of in-use experience will be accumulated before Euro 4 requires their widespread installation.

An independent report[14] completed in December 2002 evaluated ULS diesel / particle trap combinations against LPG. Some of the issues raised in the report include:

- the high cost of particle traps (A$900 to A$2,000 for an average car);
- the need for regular removal and servicing;
- propensity to block up and/or degrade in service; and
- fuel consumption penalty of up to 6% from the use of particle traps.

The overriding conclusion was that LPG, as an inherently clean-burning fuel, is environmentally and economically preferable to a ULS diesel / particle trap combination.

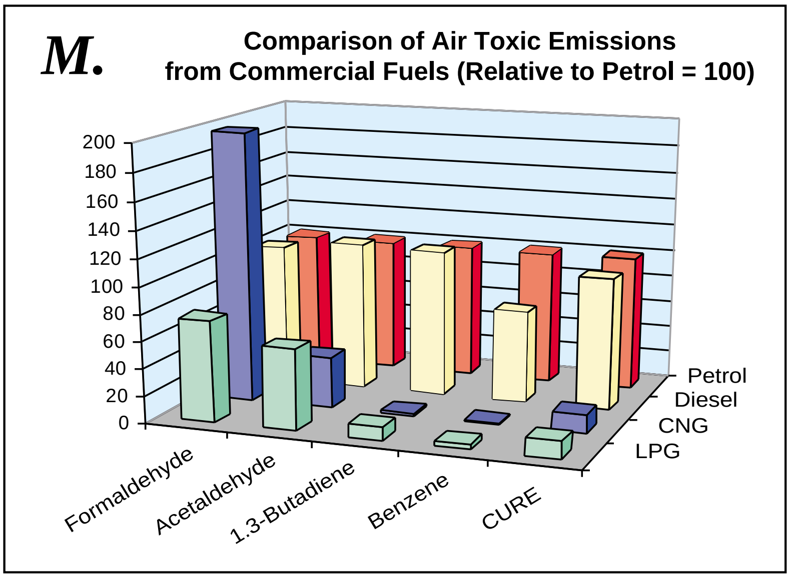
10. Air Toxic (Unregulated) Pollutants

Diesel and petrol vehicles also tend to have significantly higher emissions of a large group of hazardous chemicals, generically termed "air toxics", of which the most significant are considered to be benzene, formaldehyde, acetaldehyde and 1,3-butadiene. As their hazardous concentration thresholds are not yet fully understood, they are not yet regulated.

Pollutants in this category are emitted in only very small quantities, but their high toxicity is a concern to health authorities. Extensive research is being undertaken to explore potential linkages with a number of "20th century diseases", including a very significant increase in asthma cases and other allergy-related illnesses.

Relative levels of air toxics emissions for different fuels are shown on Figure M below based on testing conducted in the USA[15]. Once again, the gaseous fuels emit much lower levels of these substances (with the exception of CNG's formaldehyde emissions, which tend to be higher than for some other fuels).

Of particular concern is the tendency for these substances to attach themselves to fine particles in vehicle exhaust streams, where they can be inhaled into the most sensitive deep-lung tissue. The much higher particle emissions from diesel engines are suspected to represent a proportionally higher risk level.



Note: CURE = Cancer Unit Risk Estimate, defined as "the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent (eg. chemical) at a concentration of 1 microgram per cubic metre in air or 1 microgram per litre in water". Hence the higher the CURE number, the higher the human cancer risk.

11. What About CNG?

CNG shares many of the positive environmental advantages of LPG, such as lower NOx than petrol or diesel, and much lower particle emissions than diesel. As such, there is little to differentiate between LPG and CNG in respect of noxious emissions affecting local or regional pollution levels.

CNG is also often heralded as a very greenhouse "friendly" fuel because of its low carbon content, and hence low CO_2 emission levels. Although CO_2 is certainly the dominant greenhouse influence, it is often overlooked that natural gas (CNG and LNG) is composed almost entirely of methane, which has a greenhouse effect 21 times greater than that of CO_2.

Extensive testing has shown that residual unburnt methane in the exhaust of some natural gas vehicles can completely outweigh any greenhouse benefits that LNG and CNG engines theoretically offer through reduced CO_2 levels. LPG contains only negligible amounts of methane, so there is no potential for this gas to compromise LPG's inherently low CO_2 emissions.

Despite its relatively good greenhouse and noxious emissions credentials, CNG has failed to penetrate the Australian automotive fuels market, except for some large bus fleet orders. The principal reason for this is the almost total lack of publicly accessible refuelling infrastructure. Only large depot-based fleets, such as the major bus operations, can justify the cost of a dedicated refuelling facility to support their own vehicles, which travel predictable distances and usually return to the depot at least once per day.

Private cars and commercial vehicles that do not operate on regular routes must have access to a wide network of refuelling facilities in order to reliably complete their journeys. As there seems little likelihood that the massive investment required to establish such a network will be forthcoming, there is little chance of a significant CNG vehicle population being established in Australia in the foreseeable future.

SUMMARY

Transport fuel choice has a major impact on the health and wellbeing of people living in Australian towns and cities. LPG is a naturally occurring and inherently low-polluting automotive fuel that offers a number of social and economic benefits when compared with other commercially available fuels, including:

- Greatly reduced emissions of the two most harmful vehicle pollutants (PM and NOx), compared with emissions of these pollutants from Euro 3 diesel vehicles;
- Net hydrocarbon emissions (fugitive plus tailpipe) ten times lower than comparable petrol vehicles;
- much lower health cost impacts than diesel and petrol (even at fuel quality and technology levels effective from 2006 and beyond);
- 12% to 14% lower greenhouse gas emissions than petrol cars, and arguably lower life-cycle greenhouse emissions than diesel, particularly using the latest LPG fuel management systems;
- abundant long-term supply from naturally-occurring Australian sources;
- extensive availability through a national network of 3,500+ retail service stations, compared with just a handful of CNG outlets, and no LNG infrastructure at all.

Table 4 below summarises some of the key characteristics of fuels that are either available now, or are likely to be commercially available over the next decade or so. Note that the chart uses petrol as a baseline for comparison.

4.	Petrol	LS Diesel	ULS Diesel	CNG	LNG	LPG	Ethanol (corn)	Bio Diesel	Hydro gen
Gaseous Pollutants	O	X	X	√	√	√	√	?	√√
Particulates	O	X	X	√	√	√	O	?	√√
Tailpipe GHG Emissions	O	√	√	√	√	√	√	√	√√
Life-Cycle GHG Emissions	O	√	√	√	√	√	X	?	?
Air Toxics	O	X	X	√	√	√	O	?	√√
Retail Availability	O	O	O	XX	XX	√	X	X	X
On-Vehicle Storage	O	O	O	XX	X	O	O	O	X
Australian Reserves	O	O	O	√	√	√	√√	√√	√√

(Legend: √√=significantly better, √=better, O=neutral, X=worse, XX=significantly worse, ?=Uncertain)

Only LPG consistently rates better than petrol and gives little or no ground to any other fuel across all of the features considered to be of greatest importance in a transport fuel.

Now that Australia's vehicle emission policies and regulations create a positive business climate for the large-scale production of alternative fuelled vehicles, the Australian car industry is gearing up to take LPG fuelled cars from their low-tech, retrofit installation roots into fully developed, factory-produced mainstream vehicles. These vehicles will, for the first time in Australia, deliver the full environmental and economic potential of LPG as an automotive fuel.

Fuel excise policies that lead to an increased uptake of diesel vehicles in urban areas may result in highly adverse outcomes. It is widely acknowledged that current technology diesel vehicles are highly undesirable from a health and environmental perspective. Cities with a high proportion of diesel vehicles tend to have serious and intractable particulate pollution problems, coupled with inordinately high incidence of respiratory diseases and cancer among the population.

There is, however, a widely held view that the technologies enabled by ultra-low sulphur diesel will overcome these problems. These views may be misguided, as the new technologies have largely unproven durability in "real-world" use, are expensive and will require active periodic maintenance. Evidence suggests they are also likely to increase fuel consumption.

Moreover, there is a body of scientific opinion (and emerging evidence) that they may not even trap large numbers of the most health damaging ultra-fine particles emitted from diesel engines. Recent independent test programs indicate that the number of ultra-fine particles emitted from the latest model European diesel cars is typically over 500 times higher than from their LPG fuelled counterparts.

Viewed objectively, the national and community benefits flowing from long-term local supply, widespread retail availability, lower community health costs, lower greenhouse emissions and quieter commercial vehicles, makes LPG the logical fuel of choice for vehicles operating in Australia.

Annexe A

Air Pollution and Health

Each fuel has different emission characteristics, with consequently different impacts on public health. The key regulated pollutants, and their impacts on human health, are summarised below:

Oxides of Nitrogen (NOx) include several gaseous compounds made of nitrogen and oxygen emitted by both spark-ignition and diesel vehicles. Oxides of Nitrogen are lung irritants and can increase susceptibility to respiratory illness (especially asthma) and pulmonary infection.

In addition, NOx contributes to the formation of ground level ozone, which is a major constituent of photochemical smog. Smog severely irritates the mucous membranes of the nose and throat, which can lead to coughing and even choking. It also impairs normal functioning of the lungs and long-term exposure may cause permanent damage.

Volatile Organic Compounds (VOCs) or Hydrocarbons (HC) are gaseous organic chemical compounds derived from diesel, gasoline and most alternative fuels which also contribute to the formation of ground level ozone.

As well as being emitted from the tailpipe of motor vehicles, these compounds are also released to the atmosphere in vehicles during refuelling, through evaporation via leaks in fuel filler caps, hot engine parts or failures in a vehicle's on-board vapour recovery systems. LPG and CNG systems, because they are pressure sealed, do not displace any vapours during normal operation and only release very small quantities during refuelling.

Fine Particulate Matter (PM) is emitted by both diesel and spark ignition engines, though diesel sources tend to dominate. In 1998 the California Air Resources Board (CARB) determined diesel particulates to be a Toxic Air Contaminent. In 2002, after much research, the US EPA concluded that PM in diesel exhaust causes acute throat and bronchial irritation, poses a chronic respiratory hazard to humans, and is a likely carcinogen. Particles may also adsorb potentially health-threatening organic "air toxics" found in engine exhaust.

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15 Argonne National Laboratory USA

BIOGRAPHY – PETER ANYON

Graduating from the University of Salford, UK in 1969 with a Science Degree in Mechanical Engineering, Peter has held a number of senior engineering and policy positions in both the private and public sectors.

Over the past decade, his close involvement with national and international vehicle emissions issues has included:

- Director of Regulation Policy, Department of Transport and Regional Services, Canberra (coordination of national vehicle emissions regulation and standards development from a transport agency perspective);
- Two terms as Chair of the National Advisory Committee on Vehicle Emissions and Noise;
- Chair of the Transport Panel of the National Inquiry Into Urban Air Pollution;
- Administrator of the Motor Vehicle Standards Act (under which the Australian Design Rules are promulgated);
- Project Director, National In-Service Emissions Project (NISE 1);
- As Managing Director of Parsons Australia, oversight of emissions research and testing projects for Australia's Diesel National Environment Protection Measure (Diesel NEPM);
- Development of vehicle emission factor, fleet emission and impact analysis computer models for Federal and State government agencies; and
- Author of numerous papers, publications and comparative studies on vehicle emissions and emission testing technologies.

In 2002 Peter joined Air Quality Technologies Pty Ltd as Technical Director, providing advice and technical services to governments, industry and international agencies on vehicle emission and greenhouse issues.

This new role will see Peter involved in managing the design and development of novel, low-cost technologies for measuring vehicle emissions.

Notes

ALPGA