

SETTING NATIONAL FUEL QUALITY STANDARDS

Paper 5

Proposed Standards for Liquefied Petroleum Gas (Autogas)

Prepared by

Environment Australia

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FOREWORD

As part of the Government's commitment to improve air quality, the development of fuel quality standards for alternative fuels, such as Liquefied Petroleum Gas (LPG), is an important part of our continuing work to deliver cleaner fuels. This paper represents the Commonwealth's proposed LPG standards - and we welcome your feedback.

LPG is a significant transport fuel in light duty vehicles and beyond petrol and diesel, LPG has the third largest market share in Australia. Interestingly, Australia is also one of the most intensive users of LPG on a per capita basis.

Transport is the most significant contributor to ambient air pollution in urban Australia, with cars and light commercial vehicles being the dominant source of transport pollutants.

Commonwealth environment, greenhouse, transport and industry agencies have been working together on direct action to improve the emissions performance of the transport fleet. The Commonwealth recently announced the new fuel quality standard for petrol and diesel under the national *Fuel Quality Standards Act 2000*. The Act provides the framework for the implementation of improved fuel quality; outlining the way it is specified and managed. These standards are a major achievement and contribute significantly to reduction of greenhouse gas emissions and air pollutants from Australian road transport.

The 1997 Australian Academy of Technological Sciences and Engineering report *Urban Air Pollution In Australia*, commissioned by Environment Australia, found that new, tighter vehicle emission standards were 'the long-term foundation for maintaining and improving air quality'. The Prime Minister, in his 1997 statement, *Safeguarding the Future: Australia's response to Climate Change* identified harmonisation with international vehicle emission standards as a goal of the Government - with a target date of 2006. The timetable for vehicle standards harmonisation was set, in May 1999, as part of the *Measures for a Better Environment* initiative under the New Tax System for Australia. The emission standards included those for LPG and CNG vehicles.

Any proposal to improve, and mandate, the quality of alternative fuels used in Australia, has the potential to impact on a wide range of stakeholders. I look forward to considering your views on the matter and urge you to make a submission.

A handwritten signature in cursive script, appearing to read 'Robert Hill'.

Robert Hill
Minister for the Environment and Heritage

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1 INTRODUCTION

Many of the issues raised in this paper have been identified by the Liquefied Petroleum Gas (LPG) Working Group, which is made up of Commonwealth officers and key industry representatives. This Group was established by Environment Australia in October 2000, and met on 3 occasions (December 2000, January 2001 and March 2001) to assist in the development of this discussion paper. The recommendations presented in this paper are the Commonwealth's *preferred preliminary position* and are not necessarily those of the LPG Working Group.

1.1 Objective of this paper

The Liquefied Petroleum Gas (LPG) industry acknowledges that the full realisation of the environmental potential of LPG in the future may require improved vehicle technology and/or tighter fuel composition constraints than those that currently apply¹.

There are a variety of fuel properties that can be more tightly managed (and/or mandated nationally) to bring about improvements in the environmental and vehicle performance of LPG. Informed public debate is necessary to ascertain how these parameters are best managed. This involves decisions relating to both the level at which they are managed (nationally or at the State/Territory level); and the specifications that are set for each parameter.

In evaluating outcomes, consideration needs to be given to a diverse range of policy considerations, as in many instances compromises and trade-offs may be necessary between differing requirements. This is as likely between common interests (such as reducing both noxious and greenhouse emissions), as between competing interests (such as environmental protection and product competition requirements).

It also needs to be recognised that the debate is taking place within pre-determined boundaries. A number of existing policy decisions, particularly the Government's commitment to align with European vehicle emission standards, effectively determine the direction and timing of certain decisions.

This paper presents an assessment of, and recommended content limits for, those LPG fuel parameters identified as significant in managing transport-sourced air pollutants and greenhouse gases, and vehicle operability/performance. The paper also canvasses outstanding issues and identifies any further information needs.

1.2 Fuel Quality Standards (FQS) Act

The National *Fuel Quality Standards Act* was passed on 21 December 2000 and provides a legislative framework for setting national fuel quality standards. It is the first step in providing a nationally consistent approach to improving the quality of fuel in Australia.

¹ 2000, ALPGA, Wide Range Fuel Trial, p. 2

The main object of the Act is to regulate the quality of fuel supplied in Australia in order to:

- (a) reduce the level of pollutants and emissions arising from the use of fuel that may cause environmental and health problems;
- (b) facilitate the adoption of better engine technology and emission control technology; and
- (c) allow the more effective operation of engines.

The first standards, addressing petrol and automotive diesel, were tabled on 22 August 2001.

The next set of standards to be developed will be for LPG.

1.3 Structure of Paper

The information in this paper is arranged as follows: Chapter 2 provides the Background (policy direction and the case for developing national standards); Chapter 3 presents the starting premise for developing standards, describes and compares existing (European and Australian) standards; Chapter 4 discusses setting national standard and related key issues, and; Chapter 5 details the recommendations and conclusions.

1.4 Call for public submissions

In order to ensure that the most appropriate fuel quality standards are adopted in Australia, comment on the proposals put forward in this discussion paper is sought from all interested stakeholders and members of the public.

While comments are welcomed on any matter discussed in this paper, attention should also be directed to the specific questions raised throughout the text (in italics). All submissions will be treated as public documents and will be provided to the Fuel Standards Consultative Committee.

Written comments are requested by **14 December 2001**.

And should be sent to:

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Or submitted electronically to: fiona.beynon@ea.gov.au

2 BACKGROUND

There are a number of pressures to mandate the fuel characteristics of LPG. The principal reason for ensuring consistency in LPG fuel quality is an environmental one – the need to ensure that the emission performance of LPG vehicles is not compromised by the quality of the fuel. The development of LPG fuel standards is also timely given the range of Government policies which promote alternative fuels.

2.1 Environmental policy

The Prime Minister announced the establishment of the Australian Greenhouse Office in his statement *Safeguarding the Future: Australia's Response to Climate Change*, published just prior to the landmark Kyoto Conference on climate change in late 1997. The statement outlined actions designed to reduce air pollution and greenhouse gases, and improve the health of Australian cities.

Under the *Kyoto Protocol* to the *United Nations Framework Convention on Climate Change* (agreed in December 1997 and signed by Australia on 29 April 1998), Australia is committed to a target for national greenhouse gas emissions of 8% above 1990 levels by 2008-12. This represents about a 30% reduction against current business-as-usual projections of greenhouse gas emissions for 2008-12.

National Greenhouse Gas Inventory² data indicate that from 1990 to 1999 national transport emissions grew by 20.3% - the fastest growth of any sector. In 1999 the transport sector was responsible for 16.1% of Australia's net greenhouse gas emissions. Road transport accounted for 90.2% of total transport greenhouse gas emissions in 1999, or approximately 14.5% of total national emissions. Emissions from passenger vehicles predominate, but light commercial vehicles are a fast growing area. The outlook for the transport sector continues to be of serious concern. Without reduction measures, emissions from the transport sector are predicted to increase by 38% above 1990 levels by the year 2010. The reduction of emissions from this sector is therefore a key focus of the Government.

The reduction of emissions from road transport is a key element of air quality management strategies established by Commonwealth, State and Territory governments to meet the National Environment Protection Measure (NEPM) ambient air quality standards agreed by the National Environment Protection Council in 1998.

In 1999 the Commonwealth launched a new initiative, the Living Cities – Air Toxics Program. The overall objective of this program is the development of a national strategy to “monitor, establish the levels of community exposure to, and manage emissions of selected air toxics”. It is envisaged that this strategy will ultimately lead to the development and implementation of a NEPM for air toxics.

2.1.1 Measures for a Better Environment

A number of initiatives with respect to the improved management of transport emissions were announced by the Commonwealth Government in May 1999 as part of A New Tax System (ANTS) for Australia.

² The 1999 National Greenhouse Gas Inventory provides the latest report on Australia's greenhouse gas emissions. It can be accessed at <http://greenhouse.gov.au/inventory/>

These initiatives known collectively as the “Measures for a Better Environment” (MBE), include timetables for Australian harmonisation with international vehicle emission standards (for both petrol and diesel engines [LPG and CNG are included in the gazetted Euro vehicle emission standards]) and the reduction of sulfur levels in diesel fuel, as well as foreshadowing the need for changes to petrol specifications.

The Measures for a Better Environment initiatives also include renewable energy generation, alternative fuel programs and a major Greenhouse Gas Abatement Program.

2.1.2 Promoting Alternative Fuels

Under the *Measures for a Better Environment* and *Safeguarding the Future: Australia’s Response to Climate Change* there are a suite of programs which promote the use of alternative fuels.

The Government recognises some of the environmental and economic benefits of LPG as a transport fuel and has identified LPG (and Compressed Natural Gas [CNG]) as the key alternative fuels in its package of alternative fuels programs.

Alternative fuels programs are designed to reduce greenhouse gases and other vehicular emissions from Australia’s road transport sector. The aim of the programs is to increase the use of alternative fuels, especially LPG and CNG in medium to heavy road vehicles. The alternative fuels programs are:

- Compressed Natural Gas Infrastructure Program (CNGIP) which provides funding towards the establishment of public refuelling stations facilities for CNG;
- Alternative Fuels Conversion Program (AFCP) which provides assistance for vehicle purchases, conversions or upgrades of vehicles to operate on CNG or LPG; and
- Diesel and Alternative Fuels Grants Scheme (DAFGS) which provides grants to maintain the fuel price relativity between alternative fuels and diesel. The Scheme aims to maintain the percentage price relativities that existed between diesel and a range of alternative fuels, before the introduction of the grant for diesel under the Scheme and prior to reduction in the diesel excise on 1 July 2000.

As part of the 1997 Safeguarding the Future package of greenhouse measures, the Prime Minister also announced that the Government is seeking a commitment from the automotive industry to a National Average Fuel Consumption (NAFC) target for passenger cars which is 15% below business as usual NAFC by 2010. Reducing the fuel consumption of the Australian car fleet is aimed primarily at reducing its greenhouse emissions. Moving to LPG will improve the greenhouse efficiency of the motor vehicle fleet but it will not improve the fuel efficiency of new motor engines per se³. Currently NAFC does not account for improved greenhouse outcomes that would flow from a switch to LPG-fuelled vehicles, but it is recognised that as the market share of dedicated LPG passenger cars increases, the associated greenhouse benefits should be considered in the NAFC context⁴.

³ AGO pers. comm.

⁴ AGO pers. comm.

There is also some evidence, that suggests (in comparison to petrol) exhaust emissions of gases such as carbon dioxide, carbon monoxide, nitrous oxide, hydrocarbons and particulates may be reduced through the use of LPG.

2.2 Transport policy

The Commonwealth Government has an ongoing program of introducing new vehicle emission standards to ensure that the environmental benefits of evolving emission control and fuel efficiency technologies are realised in Australia. New vehicle emission standards are established as Australian Design Rules (ADRs) under the *Motor Vehicles Standards Act 1989*. In the past, these standards (at least for light vehicles) have been largely based on US vehicle emission standards.

The 1997 Australian Academy of Technological Sciences and Engineering report "Urban Air Pollution in Australia" found that new vehicle emission standards were "the long term foundation for maintaining and improving air quality". The Report recommended that Australia should, "without delay, move to adopt the current United Nations Economic Commission for Europe (UN ECE) vehicle emission regulations for spark ignition (petrol) and diesel engines, as the basis for certifying all new vehicles sold in Australia".

The Prime Minister, in his 1997 statement *Safeguarding the Future - Australia's Response to Climate Change*, identified harmonisation with international vehicle emission standards (including those fuelled by LPG and CNG) as a goal of the Commonwealth Government. A target date of 2006 was identified. The statement also specified that the fuel efficiency of vehicles would be improved.

In response to the Prime Minister's statement, the Government established new vehicle emission standards for petrol and diesel vehicles in December 1999, to help achieve reductions in emissions of significant pollutants. LPG and CNG vehicles are included in the new emission standards.

The emission standards for LPG fuelled light duty vehicles (<3.5 tonnes GVM) will take effect from 1 January 2003 and will involve progressive tightening of the standards with a view to greater harmonisation with international standards (taken to be those set by the UN ECE - or equivalent EC Directive). LPG vehicles will be required to meet the following standards - Euro 2 in 2003 and Euro 3 in 2005. It is likely that adoption of Euro 4 standards will occur in the 2008-2010 period

Euro 2 (ECE Reg 83.04 - ADR 79/00) emission standards for new LPG vehicles will be introduced from 2003 (for new models) and from 2004 for continuing models. The introduction dates have been determined to allow domestic vehicle manufacturers sufficient lead time to source new engine technology, thus minimising disruption to the industry.

Euro 3 (EC Directive 98/69/EC - ADR 79/01) emission standards for new LPG vehicles will be introduced from 2005 and from 2006 for continuing models. The adoption of Euro 3 emissions standards will offer further emission gains.

LPG fuel and technology issues

To ensure the emission benefits from the new LPG vehicle standards are delivered in practice, sulfur, MON (including olefins) and vapour pressure are considered some of the most critical parameters⁵.

LPG single or multi-port fuel injection⁶ using dry gas or liquid fuel (known as 3rd generation) technologies are utilised in Europe,⁷ but are currently emerging⁸ in other regions. In Australia, LPG vehicle technology still relies on 2nd generation technology comprising a carburettor or venturi mixer for vaporised gas and closed loop air-fuel ratio control. This technology regulates the control of fuel from closed looped oxygen sensor readings, and is not as sophisticated as the 3rd generation single or multi-port fuel injection technology.

Technology requiring liquid injection (Generation 4 and Generation 3 [which rely on direct liquid injection]) may require a move to lower vapour pressures, whereas present technology (Generation 2 and some Generation 3) performs better with higher vapour pressure fuels. Appendix A highlights the differences between various technologies and provides comment on possible, potential, fuel requirements.

While the use of generation 3 technology in Europe can assist in compliance with Euro 2 and 3 emission standards, it is not clear that these technologies are essential. Further investigation is required to determine the capability of generation 2 LPG systems, as OEMs (Original Engine Manufacturers) using generation 2 vehicles can already meet Euro 2 emission standards.

Comment: Could OEMs and equipment suppliers comment on the ability of current technology to meet Euro 2 and Euro 3 emission requirements? Do you think that it may be necessary to review the LPG fuel standard if emerging fuel technologies and market experience warrant such a review? - what do you believe would be an appropriate timeframe for such a review?

Nevertheless, it is important to consider future markets in the standards setting process, and thus it is necessary to also consider the fuel requirements for generation 3 vehicles (particularly if generation 2 vehicles cannot meet Euro 3 emission requirements) and generation 4 vehicles. Further work may be required to determine the fuel parameters suitable for generation 3 and 4 LPG systems, as it has been suggested that additives may be required to prevent injector "clogging".⁹ There have been proposals in Europe to lower the level of olefins to prevent such clogging¹⁰.

Discussions to date have not revealed the need to tighten the existing Australian industry standards to meet Euro2 (or Euro 3) emission requirements or to enable the uptake of generation 3 vehicles. It is acknowledged, however, that any technology

⁵ ALPGA Per. Comm.

⁶ Includes computerised fuel management system and closed loop feedback.

⁷ ALPGA, 1998, LPG as an Automotive Fuel, p.1

⁸ Erwin Van den Berkmortel, Current Situation in Europe of LPG Gas Systems and Emissions, ALPGA Conference, February 2001.

⁹ Bruce Priddle, Pers. Comm.

¹⁰ Erwin van den Berkmortel, pers. comm.

that relies on liquid fuel (ie those Generation 3 and 4 vehicles which rely on liquid injection etc) may require a lower vapour pressure (see Appendix A).

Comment: Could stakeholders clarify if particular fuel standards are required for the up-take of particular generation technology vehicles? Could stakeholders clarify the vapour pressure requirements for technology that requires liquid injection? Are there particular fuel requirements for Euro 3 (see also section 3.3.2 'Specification for Euro Reference Fuels)?

Even if tighter standards are not required to meet Euro 2 and 3, there are other benefits associated with tightening some specifications. For example, if an LPG engine is optimised to a higher octane range, higher engine compression and therefore, better fuel efficiency and performance can be achieved.

2.3 The case for LPG national standards

During consultation on the national fuel quality standards for petrol and diesel, several key stakeholders (Motor Vehicle Environment Committee (MVEC), Federal Chamber of Automotive Industries (FCAI), Automobile Association of Australia (AAA) and Shell raised the need to develop complementary LPG standards.

There are a range of reasons which support the need for mandatory and enforceable national standards for LPG.

- LPG is a significant transport fuel in light duty vehicles. Beyond petrol and diesel, LPG has the third largest market share. It is estimated to account for at least 8% of all road transport fuel usage by 2010¹¹. Furthermore, Australia is one of the most intensive users of LPG on a per capita basis.
- As a key strategy in managing air pollution and greenhouse gas emissions, there is a need to ensure the provision of fuels that facilitate the adoption of future vehicle engine and emission control technologies, as well as fuel technology.
 - the LPG industry agrees that the full realisation of the potential of LPG in the future may require improved technology and/or tighter fuel composition constraints than currently apply¹².
 - To achieve the anticipated emissions benefits the Government has established new emission standards for LPG vehicles, which involves harmonisation with the UN ECE regulations (or the EC Directives).
- The latest available Australian data indicate that in-service emissions performance of dual-fuelled LPG vehicles is comparable to petrol fuelled cars (see *FORS LPG In-Service Vehicle Emission Study [1997]*). However, vehicles in this study pre-date the current emission standard for petrol cars (ADR 37/01). There is a need to examine fuel parameters that could be more tightly managed to bring about improvements in environmental performance.
- Examining the LPG properties that improve environmental performance is especially important, as with the phasing in of Euro emissions controls, it is

¹¹ ALPGA – LPG as an Automotive Fuel.

¹² 2000, ALPGA, Wide Range Fuel Trial, pg. 2

possible that the advantages of LPG and CNG relative to diesel may reduce over time¹³.

- The development of standards will ensure quality of LPG in the market place, and possibly assist in the control of residues and other contaminants. National implementation of standards (with fuel meeting specs at the dispenser) will further help to ensure consistent quality and promote the fuel and ensure good vehicle operation.
- The national *Fuel Quality Standards Act (2000)* sets the necessary framework for development of standards for all fuels. The setting of petrol standards is expected to result in a 300,000 tpa excess of butane, which the Fuel Quality Review recommends should be absorbed by the LPG market.
 - Stakeholders suggest that the development of LPG standards will provide the certainty for future market decisions and investment.
- Responding to the challenge of air quality and climate change requires involvement by all sectors of the economy and the community. A number of key Government programs and policies promote broad involvement in the air quality and greenhouse response.
 - The development and implementation of standards will benefit the variety of key government initiatives which promote the uptake of LPG. The development of LPG standards will support beneficial emission outcomes and facilitate the development of an adequate rebate scheme under the diesel and alternative fuels grants scheme.

Comment: What is your view on the need to develop mandated national fuel quality standards for LPG?

¹³ Vic EPA, Draft Air Quality Improvement Plan, p.36

3 DEVELOPING LPG STANDARDS

Most commonly, “naturally occurring LPG ” is extracted directly from ‘wet’ natural gas¹⁴ at a gas well-head, and like natural gas it can have a variety of compositions related to its source of supply. LPG from natural gas condensate consists entirely of paraffins (alkanes) – mainly propane and butane. These are usually separated and sold as distinct products so that the propane will typically contain less than 2% butane.

LPG can also be derived from the oil refinery as a by-product of gasoline production, in which olefins (alkenes such as propylenes and butylenes) may also be present¹⁵. It is worth noting that propylene and butylene are sometimes referred to as propene and butene, respectively. This paper will, wherever possible, utilise the terms propylene and butylene.

LPG can also be described as 'C3' and 'C4' components. For example, propane and propylene are known as C3s - with the chemical equation of propane being C_3H_8 and propylene being C_3H_6 . Butane and butylene are known as C4s - with the chemical equation of butane being C_4H_{10} and butylene being C_4H_8 .

For more information on LPG and LPG supply issues, refer to Appendix B.

3.1 Harmonisation with the EU Fuel Standards

The decision to harmonise Australian vehicle emission standards with UN ECE emission standards effectively gives rise to a starting premise that Australian fuel specifications should be harmonised with EU fuel specifications¹⁶.

As just described, LPG typically can have a range of C3, C4 ratios. This is because LPG is derived from a number of sources. In Europe as in Australia, LPG is derived from natural gas sources and refinery by-product. Given the compositional variation in LPG in Europe, the European standard appears the most applicable to the Australian context - particularly in light of Australia's adoption of 'Euro' vehicle emission standards.

Further details on the fluctuation of C3, C4 ratios in the European market are contained in section 4.3.1 "Hydrocarbon Ratios".

Recent changes to EU fuel specifications have been driven by vehicle emission requirements and by engine emission control technologies, with new emission control standards coupled with mandated quality and compositional requirements for petrol, diesel and LPG fuel.

¹⁴ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, p.1

¹⁵ Watson and Gowdie, pg 1

¹⁶ While the UN ECE regulations and the European Commission Directives both set technically equivalent vehicle emission standards and these standards include test (reference) fuel specifications, the supporting fuel standards for commercial diesel, petrol and LPG are set via European Directives (for petrol and diesel) or industry standards (LPG).

It is recognised, however, that recent changes to the EU fuel specifications have also been designed to address a number of other issues, some of which are specific to European Union member countries. While the standards include technology-enabling fuel specifications they are also designed to contribute directly to the management of air pollutants identified as posing significant health or environmental problems within the European Union.

While there are similarities between Europe and Australia in terms of public exposure to air pollutants of concern, there are also some significant differences. The most recent Australian State of the Environment Report found that in general, annual mean concentrations of common pollutants within major Australian airsheds were low by world standards.¹⁷ Furthermore, it is also acknowledged that the current Australian industry standard for LPG (ALPGA Specification 2000) is more stringent than the most recent EN 589 European Standard¹⁸ 2000 for commercial automotive LPG and the Euro vehicle emissions standards reference fuel.

3.2 Guiding Principles

The starting premise for the development of LPG fuel quality standards - harmonisation with European fuel specifications - is therefore subject to a number of qualifications. The first of these are the environmental and industry policy decisions previously announced by the Government. These establish a number of criteria, and pre-determine a number of issues, in relation to the development of national fuel quality standards. These are then further qualified by the need to take into account a number of more general, but equally important Commonwealth Government principles, such as those addressing legislative / regulatory approaches and competition policy.

The guiding principles for the development of national LPG standards are:

Fuel standards are intended to manage those fuel qualities/parameters that are known to have the potential to impact adversely on the environment.

Fuel standards should be compatible with relevant international or internationally accepted standards in order not to impede competition and trade.

Fuel standards are intended to be mandated and implemented on a national basis. In particular, fuel standards that are technology enabling must apply nationally. Local environmental circumstances may, however, dictate variation within the national standard to achieve environmental outcomes.¹⁹

- Consideration will be given to State by State establishment of fuel standards that address airshed specific environmental conditions, however, in such cases a national standard may be determined as a default.

Fuel standards will apply to, and be enforced equally in respect of, imports as well as domestically produced fuels.²⁰

¹⁷ SOE Advisory Committee, 1996, Australia State of the Environment, p. 5-28.

¹⁸ ALPGA Pers. Comm.

¹⁹ DISR, 1999, Downstream Petroleum Products Action Agenda.

²⁰ DISR, 1999, Downstream Petroleum Products Action Agenda.

- Fuel standards must not impede competition, either between Australian refiners, or with imported refined product.

Fuel standards that directly address environmental or health issues will be determined on the basis of Australian-specific requirements. In such instances, harmonisation with European specifications may be neither necessary nor desirable.

The timetable for the introduction of new fuel standards will be based on Australian requirements. Harmonisation, in terms of timing, will not be based on European or any other regional timetable, except where there is a previous policy decision to this effect or the standard is technology enabling and the need for such harmonisation is clearly demonstrated.

Consideration will be given to setting standards that provide, as far as possible, flexibility in terms of compliance, providing

- flexibility provisions must not impede competition or trade; and
- flexibility provisions must not add significantly to legislative/regulatory complexity or implementation/enforcement costs to Government.

3.3 Existing standards

There is no European Union market directive for LPG fuels. In the absence of a directive, European member countries have adopted the industry standard (CEN EN 589) into national law. The countries that have adopted the standards are: Italy, France, Germany, The Netherlands and the United Kingdom. However, according to the CEN Internal Regulations, the national standards organisations of remaining member countries are bound by law to implement EN 589.

The European standard was established in 1993 (CEN EN 589) and has been reviewed twice (1998 and 2000). The EN 598 (2000) standard took effect from November 2000.

The reference fuels for LPG in the Euro 2 and 3 vehicle emissions standard are the same (ie same as each other) and were developed as part of the European Emissions Directive. These emission standards have been adopted into the Australian Design Rules (ADRs) and will be progressively phased in over the next few years.

The ALPGA has recently reviewed the industry standard for Australia (LPG for Automotive Use - Specification 2000).

3.3.1 EN 589

The EN 589 standard was last reviewed in 2000. All relevant characteristics, requirements and test methods are now specified (see Table 3.3.1.1).

Table 3.3.1.1. - EN 589 Standard 2000

Property	Limits	Test Method
Motor octane number	89.0 MIN	Annex B* ²¹
Total dienes content (mole %)	0,5	EN 27941
Hydrogen sulfide	Pass	EN ISO 8819
Total sulfur content (after stenching) mg/kg	100	EN ISO 24260 ASTM D 3246-96
Copper strip corrosion (1h at 40°C) (rating)	Class 1	EN ISO 6251
Evaporative residue mg/kg	100	EN ISO 13757
Vapour Pressure, (absolute at 40°C) kPa	1550	EN ISO 4256 EN ISO 8973 and Annex C
Vapour pressure, absolute min. 150 kPa for various winter grades (A-D) (°C)	-10 to +10 (A-D)	ISO 4256 and Annex C
Water content	No free water at 0°C	Propane rich=EN ISO 13758, EN ISO 3993
Methanol content (mg/kg)	2000	ISO 8174
Odour	Unpleasant and distinctive at 20% LEL	Annex A

Annex A describes the test method for odour of LPG (not described in this paper).

Annex B describes method of calculation of MON (described below in footnote)

Annex C describes factors for the calculation of the vapour (absolute) of LPG (not described in this paper). For quality control purposes the values as given in the informative Annex D may also be used.

Annex D describes the seasonal vapour pressure (gauge) limits at 40°C and is described in the section on Vapour Pressure (see Section 4.1.2).

3.3.2 Specification of Gaseous Reference Fuel for ADR 79/00 and 79/01

As there is a large market variation in LPG fuel composition in Europe, the reference fuel used for vehicle certification under the Euro emissions standards contains two extreme fuels (these are described as fuel types A and B listed in Table 3.3.2.1). This approach is unique to LPG and CNG, and results in the gaseous reference fuel representing more closely what is commercially available in the European market.

These fuels described below at Table 3.3.2.1 (Euro 2 - ADR 79/00 and Euro 3- ADR 79/01) are used to demonstrate the self-adaptability of the fuelling system. Self-adaptability of the fuelling system is a measure of the fuel management system's ability to adjust to the necessary fuel flow requirements (using a closed loop system) to achieve correct emission levels. Closed loop is a function of the electronic control system, which monitors the exhaust oxygen concentration and automatically varies the fuel supply to provide the best conversion of HC, CO and NOx in the exhaust

²¹ *The partial MON for each component in the mixture as follow – partial MON = $M \times C$ where: M is the motor octane factor of a specific component as below and C is the mole fraction in the mixture. The partial octane numbers for all of the components are determined and the sum rounded down to the nearest 0,1. Specific Components and their MON factors [] are as follows - Propane (+ C2) [95,4]; Propene [83,9]; Butane (+ C5) [89,0]; 2-Methylpropane (isobutane) [97,2]; Butenes [75,8].

catalyst. This is achieved by reading a signal from a sensing device fitted to the exhaust system (an Oxygen sensor, sometimes called a Lambda Sensor)²².

Under the vehicle Emissions Directive, a vehicle has to be tested on two extreme reference fuels (Fuel A and Fuel B - see the reference fuel in Table 3.3.2.1) to demonstrate the self-adaptability of the fuelling system²³. These reference fuels vary markedly in their propane ratios. Whenever the self-adaptability of a fuelling system has been demonstrated on a vehicle, such a vehicle is considered as a parent vehicle of a family. Vehicles that comply with the requirements to be members of that family, if fitted with the same fuelling system, need to be tested on only one fuel.

As stated previously, the LPG reference fuel (comprising of Fuel A and Fuel B as described in Table 3.3.2.1) for Euro 2 and Euro 3 emissions tests is the same. The Euro 2 and Euro 3 emission tests differ only in their drive cycle, with the Euro 3 emissions test setting lower emission limits and requiring sampling from the start of engine cranking (ie. it includes cold start emissions). Euro 2 allows for a period of engine starting and idle stabilisation.

Overall, the small difference between Euro 2 and Euro 3 emission requirements suggests that no reference (or market) fuel variation is required to complement the change from Euro 2 to Euro 3 emissions requirement. Furthermore, the European market fuel standard does not specify a different fuel for Euro 2 and Euro 3, and as a result, this paper will only recommend one market fuel type (ie. one fuel standard) for Euro 2 and 3.

Table 3.3.2.1. - Reference Fuel for Euro 2 and 3 emissions standards

		Limits		Test Method
		Fuel A	Fuel B	
Composition	% vol			ISO 7941
C3	% vol	30+2	85+2	
C4	% vol	Balance	Balance	
<C3, >C4	% vol	Max. 2%	Max. 2%	
Olefins	% vol	9+3	12+3	
Evaporative Residue	mg/kg	Max.50	Max.50	NFM 41-015
Water content		None	None	
Sulfur content	ppm weight*	Max. 50	Max. 50	EN 24260
Hydrogen sulfide	None	None		
Copper corrosion	Rating	Class 1	Class 1	ISO 625
Odour		Characteristic	Characteristic	
MON		Min. 89	Min. 89	EN 589 Annex B

*Value to be determined at standard conditions (293.2 K (20°C) and 101.3 kPa)

²² LPG as an Automotive Fuel, p. 73.

²³ Annex 12 – Granting of an ECE type approval for a vehicle fuelled by LPG or Natural Gas – ADR 79/00 – page 193.

After compilation of further research and information to fully demonstrate the adaptability of LPG systems to all the range of LPG fuel composition allowed in the EN 589 specification, the European Union has indicated that it may decide to use one reference fuel to perform the emission limits tests²⁴. This would be in line with the approach for other conventional fuels. The potential adoption of the reference fuel by some countries also warrants the consideration of the reference fuel specification in the standards setting process.

Although there are also Euro emission standards and Euro reference fuels specified for the Heavy Duty Vehicle (HDV) ADRs (which have also been adopted in Australia), a different market fuel for HDVs is not available in the European Union. The European LPG industry is not in favour of two different products (one for the light vehicles applications and the other for heavy duty vehicles).

Currently, in Europe the LPG HDV consumers run their vehicles on the same LPG product as that sold for light duty vehicles (LDV). A minimum of 50% propane is required for HDV²⁵ and most European countries deliver automotive LPG with a propane content of more than 50%. The European LPG industry is prepared to adapt its product (so that it is at least 50% propane) where needed, bearing in mind that the fuel price may vary accordingly as it is directly related to the dimension of the distribution network²⁶.

The ALPGA also does not support a different LPG specification for HDV, as the OEM HDV engine manufacturers are not offering LPG engine options and the separate distribution fuelling infrastructure costs could not be justified. Some HDV that are currently being imported into Australia require specific blends (ie. Cummins vehicles require HD-5 blends - see Appendix C - US fuel specification) for warranty reasons, these fuel blends are already available in Australian LPG market fuel range as high propane blends.

The LPG working group considers that Australia should not develop two different market fuel products, and separate HDV market fuel requirements are not discussed further in this paper.

3.3.3 The ALPGA's Product Specification (2000)

In January 2000 the ALPGA published “Liquefied Petroleum Gas for Automotive Use Specification 2000” and “Liquefied Petroleum Gas for Heating Use Specification 2000”. The two new documents represented the results of intensive efforts over the previous four years by the Australian Liquefied Petroleum Gas Association's (ALPGA) Product Specification Committee, which in turn built upon decades of specification work.

As is the nature of the standards development process, outcomes evident in the standards have tended to reflect a compromise between what would be ideal and what could be economically achievable. Where the specifications could be sensibly tightened to ensure better performance, they have been. Examples included the introduction (for heating) and reduction (for automotive) of the diene limit; and also

²⁴ AEGPL Strategy Paper

²⁵ International Fuel Quality Centre, Pers. Comm.

²⁶ International Fuel Quality Centre, Pers. Comm.

the reduction in permitted sulphur levels (for both). Further, the residue on evaporation limit was approximately halved but was set specifically at the point of odourisation.

Overall both Specifications 2000 are “tighter” than previous versions and “tighter” in many respects than most comparable overseas specifications.

The *Australian Liquefied Petroleum Gas for Automotive Use - Specification 2000* (referred to as ALPGA standard for the purposes of this discussion paper) applies to LPG intended to fuel general-purpose spark ignition engines (commonly in automotive vehicles), and applies specifically at the loading point in a production, distribution or other major terminal²⁷. The industry standard is not mandated under any Commonwealth or State/Territory legislation.

Table 3.3.3.1 - ALPGA - Specification 2000

Property	Unit	Limits	Test Method
Vapour pressure (gauge) at 40°C	kPa	800 min - 1530 max	ISO 4256:1996 ISO 8973:1997
Volatile Residue C5 and higher hydrocarbons	mole %	2.0 max	ISO 741:1988
Residue on Evaporation	mg/kg	20max	JLPGA-S-05T/86 (105°C)
Corrosion, copper strip		Class 1	ISO 6251:1996
Sulfur	mg/kg	100 max	ASTM D 2784-98
Dienes	mole%	0.3 max	ISO 7941:1998
Moisture content (dryness)		Pass	ISO 13758:1996
Free Water		Pass	Visual inspection
Fluorine	mg/kg	10 max	(j)
Odour		20% LFL	(j)
Motor Octane		92.0min	ASTM D 2598-96
Hydrocarbon composition	-	Report ²⁸	-

3.4 Comparison of existing standards

There are some slight differences in the parameters for each standard - including the test methodology and the calculation of factors, but overall the ALPGA standard is more stringent (tighter) than the European Standards.

There are also some parameters which are unique to each standard. Some European parameters are not relevant to Australian conditions, and therefore will be omitted from any further discussion in this paper. Conversely, under Australian conditions,

²⁷ ALPGA – LP Gas Australia – specification, 2000.

²⁸ The ALPGA standard also requires a report on hydrocarbon composition to be provided in conjunction with the result of testing to demonstrate compliance with the standard.

there are specific parameters not addressed in the CEN which may warrant continued inclusion in a national standard.

The differences between the standards are described more fully in the next section - "Setting Fuel Quality Standards".

4 SETTING FUEL QUALITY STANDARDS

4.1 Critical parameters

MON, vapour pressure, and hydrocarbon composition are used to define the vaporisation and combustion characteristics of LPG. These characteristics are responsible for the overall environmental and operability performance of LPG, and therefore warrant further consideration in the process of developing future standards.

There are, however, several product characteristics which either affect or may affect the vaporisation and combustion of LPG. Therefore, in an attempt to provide assurance of product, several other parameters also need to also be controlled, and as such, may warrant further consideration in the standard setting process. These parameters are - residue content, copper corrosion, sulfur content, moisture content and free water content²⁹. Some of these parameters are not considered contentious, and are already aligned with (or are even more stringent than) the EN standards. Therefore, discussion of following parameters will be detailed in the next section 'non-critical parameters': copper corrosion; moisture content / free water; odour, and fluorine.

In terms of compliance with future ADRs, it is important to focus on parameters which may contribute to vehicle emissions of hydrocarbons, carbon monoxide, nitrogen oxides and particulates.

The ALPGA's Product Specification Committee has identified tailpipe emission (hydrocarbons, carbon monoxide, and nitrogen oxides) performance of LPG vehicles as a key factor in the future growth of the autogas market, and as a primary constraint under its 'fitness for purpose' philosophy in setting product specifications³⁰.

The majority of emission data examine the effects of differing hydrocarbon ratios (paraffins and olefins) on tailpipe emissions, as hydrocarbons are known to alter the hydrocarbon (HC), carbon monoxide (CO) and oxides of nitrogen (NOx) emission outcomes. A summary of studies which have examined emissions outcome is at Appendix D.

The most recent systematic evaluation of Australian LPG fuels (Wide Range Fuel Trial - published in 2000) observed that total hydrocarbons are known to increase with C4s. Carbon monoxide is significantly correlated with C4 content, and both C4 and olefin content have a strong correlation with NOx emissions³¹. The Wide Fuel Range Trial concluded that -

- if non-methane hydrocarbons and nitrogen oxides are taken as indicators of photochemical smog precursors, then only fuels with high olefins content perform worse than petrol
- fuels in the mid range of the C4 and olefin content provide similar to or better than petrol results for CO, HC and NOx.

²⁹ ASTM US LPG Standard

³⁰ Wide Range Fuel Trial, pg 2

³¹ Wide Range Fuel Trial

Furthermore, the earlier FORS study³² observed that the in-service emissions of NOx are generally higher for LPG vehicles than for equivalent petrol models.

It is therefore important to initially highlight those parameters (directly and indirectly) which control hydrocarbons composition of the fuel and/or affect noxious tailpipe emissions, these being:

- MON (and its indirect control on olefins, and to some extent, C4)
- vapour pressure (and its indirect control on C4, and to some extent, olefins)
- volatile residue
- dienes
- residue on evaporation
- sulfur

Key parameters for vehicle manufacturers are MON (including olefins); vapour pressure and sulfur.

4.1.1 Motor Octane Number (MON)

MON is designated to ensure adequate anti-knock characteristics of the fuel and constrains the composition (to some extent) since olefins and some C4s³³ have relatively low octane.

Impact on Engine Performance

The Motor Octane Number (MON) can have a major impact on engine performance and durability. A higher MON value allows engine design for a higher compression ratio which in turn allows greater power generation and better efficiency. If the MON value is insufficient for a particular engine, knocking or ‘pinging’ can occur, especially when the engine is heavily loaded. This in turn can cause serious damage to the engine.

A minimum MON is designated to ensure adequate anti-knock characteristics of the fuel. For LPG, MON is more critical than the Research Octane Number (RON) because of the higher combustion temperatures which occur with LPG in comparison with petrol. Engine performance under these conditions correlates better with MON. Also, because of the high sensitivity (difference between RON and MON) of LPG components, if MON is adequately defined, then RON also will be adequate. The use of MON rather than RON is consistent with international practice.

It should be noted that for generation 2 fuel systems, when autogas and air are mixed there is no drop in temperature such as occurs when petrol is injected and evaporates. These higher mixture temperatures promote knocking. This effect may be less significant in regions of Australia which do not experience high ambient temperatures during summer months, and allow somewhat lower MON requirements, as in Europe. The effect, however, is more significant in regions in Australia which experience high ambient temperatures.

³² FORS, Motor Vehicle Pollution in Australia, Supplementary Report No.1 LPG In-Service Vehicle Emissions Study, May 1997

³³ Noting that iso-butane has a higher MON value than propane

The current ALPGA specification (using ALPGA MON calculations) sets a minimum MON of 92.0. This value can be raised to 92.8 if more than 25% propylene and more than 10% butylene is present. This range was considered necessary, as some members of the ALPGA Product Specification Committee were concerned about the validity of the MON factors for olefins at high concentrations. These concerns could, however, be addressed by adopting the European MON calculation and MON factors (described below). Adopting the European approach results in a more streamlined approach for the calculation of MON.

Emission Effects

MON can impact indirectly on both urban and greenhouse emissions and directly on the latter. The MON values of some LPG components are higher than other components. The MON value of paraffins (alkanes) such as propane and butane are higher than for olefins (alkenes) such as propylene and butylene. Thus setting a minimum MON indirectly limits the olefin content of autogas.

In relation to urban emissions there are two factors which impact on smog formation. The first is that the olefins typically produce more nitrogen oxides (NO_x) on combustion than do paraffins, and an increased proportion of olefin content in a blend is generally associated with higher NO_x production, as demonstrated in the ALPGA's "Wide Range Fuel Trial". The second is that unburnt olefins emitted from the tailpipe are more reactive with NO_x to form smog than are unburnt paraffins. So limiting olefin content by setting a minimum MON directly impacts on urban emissions.

In relation to greenhouse emissions there are two factors, one directly related to MON, and the other indirect which must also be considered. Engines designed to take advantage of higher MON fuel can be more efficient and produce the same power for lower fuel consumption and carbon dioxide production. This benefit is not realised if a high MON fuel is used in an engine designed for low MON fuel.

There is, however, a clear but indirect impact on greenhouse emissions from setting a minimum MON. This occurs because paraffins have higher hydrogen:carbon ratios than olefins and when burnt, produce relatively less carbon dioxide and more water for the same energy output. This benefit is realised irrespective of whether the engine is or is not designed with a high compression ratio to take advantage of high MON fuel. However, these benefits can be increased for engines designed to capitalise on the higher MON³⁴.

In order to understand the meaning of setting a minimum MON level it is necessary to appreciate the differences in the calculation methods between the ALPGA and EN standards. It is also important to understand the ability of MON to constrain composition (particularly olefins).

Calculation of MON

The MON of an autogas blend is calculated using MON factors for each component of the blend. The MON factors used in the ALPGA Specification 2000 are based on North American practice, while European factors are generally somewhat less than the North American factors.

³⁴ FCAI, Pers. Comm.

Hydrocarbon Component	Australian MON Factor	European MON Factor
Propane	97.1	95.4
Propylene	84.9	83.9
n-butane	89.6	89.0
Iso-butane	97.6	97.2
Butylenes	82.0	75.8

These factors are multiplied by their molar proportion in the autogas blend. The average difference between MONs calculated using the differing MON factors for Europe and Australia approximates 1.5 for MON levels approaching the specification limit of 90.5 as measured by European factors. The difference is demonstrated in Appendix E which provides MON calculations for a range of LPG composition examples, including the European reference fuels and the ALPGA/NSW EPA standard (Blend A2). It is also worth noting that in Appendix E, 90.5 represents the minimum MON value for the range of Australian LPG composition examples.

The minimum MON used in Europe is 89.0. If a decision were made to use European MON factors in Australia but retain very similar octane performance as currently required, it could be appropriate to specify a minimum MON of 90.5. This would correspond to a maximum of 40% propylene in a propylene/propane mix. Setting the MON at 90.5 min would 'lock-in' gains (both environmental and operability) and would be more stringent (provides for a higher and narrower range) than the European standard.

MON Constraint on Composition (Olefins)

An olefin is a family of chemicals containing carbon-to-carbon double bonds. Olefins are unsaturated hydrocarbons (such as propylene (propene) and butylene (butene)) and can lead to engine deposit formations and increased emissions of ozone-forming hydrocarbon and toxic compounds. Olefins are oxidatively and thermally unstable and may lead to gum formation and deposits in an engine's intake system³⁵. It is known that combustion chamber deposits in petrol spark-ignition engines increase tailpipe emissions of CO, HC and NOx.

It has been observed, that by decreasing olefins, the octane (MON) reading of the LPG fuel will be increased. Generally, US studies have revealed that a 5 vol.% decrease of propylene results in a one octane number increase³⁶.

A comparison of the Australian and European C3:C4 ratios indicates that autogas composition is much more constrained by MON in Australia than in Europe. Typically the olefin content of Australian LPG is about 15% lower. For example the maximum propylene in a propylene/propane mix is currently about 55% in Europe and 40% in Australia. It should be noted that in both Europe and Australia the levels of olefins in autogas are generally considerably lower than the maximum allowed due to their diversion for use as chemical feedstocks.

In California, a limiting butylene specification for LPG was considered necessary, due to the contribution of olefins to the ozone forming potential (OFP) of vehicle exhaust

³⁵ Coffey Geosciences Pty Ltd, 2000, Fuel Quality Review p. 3 - 3

³⁶ CARB, Public Hearing to consider LPG amendments, p.5

emissions. These considerations led to limiting the maximum butylene content to 2.0%³⁷. Consideration of limiting olefin content was considered important, as higher volatile organic compounds occur with higher olefin content³⁸. It is, however, worth noting that the 2% level is extremely stringent and was specifically set to manage a significant air pollution problem (ie. OFP) in a specific location (ie. California). The US standards, do however, set maximum content limits on olefins, HD-10 specifies a 10% v/v limit for butylene (see Appendix C for further details).

As stated previously, a recent study has revealed that only those fuels with high olefins content perform worse than petrol, with propane fuels high in olefins (30%) performing about the same or slightly worse than petrol. Although olefin content of LPG market fuel varies (between 0-30%³⁹) in the Australian LPG market, the LPG working group has acknowledged that there may be merit in setting an olefin limit in addition to a MON specification. However, as several international studies, particularly in the US, are underway, the decision to set a separate olefin limit will not be considered until these studies are concluded. It is also important to consider the impact or contribution of an olefin limit on excess butane levels (see Section 4.3.1 on Hydrocarbon Ratios).

Furthermore, although it has been proven on gasoline vehicles that NO_x emissions increase with the increase of olefins content, the European LPG Association (AEGPL) claims this effect does not significantly affect LPG vehicles. This comment is in direct contrast to the findings of the LPG working group. The AEGPL claim that olefin molecules involved in the combustion process are not of the same types as for the gasoline combustion⁴⁰. However, the influence of olefins in LPG are still being considered by the European LPG industry. The AEGPL also state that recent IFP tests have shown no significant effect of the variation of the olefin content (0-30%) for regulated components of the vehicle test cycles.⁴¹ Consideration of setting an olefin limit would need to be viewed in light of such claims and findings of current international studies.

It is also worth noting, that the lighter fractions of olefins can also be controlled by setting appropriate vapour pressure limit/s. This is similar to petrol, where lighter volatile olefin fractions are typically removed where reduction in Reid Vapour Pressure limit are required.⁴²

Conclusion: If the lower MON value used in Europe was adopted in Australia, there could be adverse consequences both for individual motorists (engine performance and durability) and the environment (urban and greenhouse emissions).

The present Australian minimum MON (together with other requirements) have assured “fitness for purpose” under local conditions, and provides for a better environmental and operability outcome. Overall, when compared to the EN MON, the Australian MON constraint is tighter, eg. autogas blends containing only

³⁷ CARB, Public Hearing to consider LPG amendments, p.3

³⁸ Oct/Nov 1999, Propane Vehicle Magazine.

³⁹ Can also be up to 40% based on current industry spec - but normally it is much less.

⁴⁰ AEGPL Strategy Paper, p.18

⁴¹ NEN, March 2001.

⁴² Setting National Fuel Quality Standards - Petrol and Diesel, p. 72

propylene and propane would be limited to 55% propylene in Europe, but to 40% in Australia.

While there is a case for the use of EN589 MON factors in Australia, the difference in ambient temperatures in Australia (in comparison to Europe), warrant setting a minimum MON of 90.5 (as opposed to the European level of 89.0). Furthermore, this limit is more stringent (provides for a higher and narrower range) than the European standard and 'locks-in' current gains (vehicle performance and environmental).

Adopting the European MON calculation method (and MON factors) would streamline the current ALPGA calculation for MON. The current ALPGA calculation requires the incorporation of a 'range' of MON values associated with various butylene content. Adopting the EN approach addresses MON factors for olefins at various concentrations and therefore does not require the incorporation of a range of MON values.

Adopting the EN methodology and MON factors will facilitate alignment with international standards. Although the proposed MON limit is more stringent relative to the EN 589 standard, any greater stringency in Australian requirements relative to the European standard is not likely to significantly impact on international trade. This is because world trade in LPG is generally by ship as unodorised propane and butane from 'natural' sources⁴³.

In terms of olefins and their potential impact, consideration of the need to set a separate limit for olefins will be deferred until further international information becomes available.

Comment: What are the impacts of setting a 'more stringent' parameter limit (ie. more stringent than the EN MON limit) on industry and other stakeholders, particularly importers/exporters⁴⁴? What are the associated costs and benefits? Do vehicle manufacturers employ technology that would easily allow their product to adapt or be adapted to a 1.5 lower MON fuel ie. will manufacturers be able to easily export their product to other markets?

Recommendation:

It is proposed that -

- (a) MON be set at 90.5 min [EN589:2000 Annex B]⁴⁵ and;
- (b) the consideration of setting a separate level for olefins be deferred.

⁴³ Such product is usually low in sulfur and water and includes no unsaturated hydrocarbons such as olefins and dienes - ALPGA pers. comm.

⁴⁴ Although, it is the usual scenario for imports/exports to be 'natural products' there are exceptions and as result this discussion paper highlights the need for comment on potential impacts of the proposed standards on trade.

⁴⁵ that is, utilising the EN calculation methodology

4.1.2 Vapour Pressure

Vapour pressure is an indirect measure of the most extreme low-temperature conditions under which initial vaporisations can be expected to take place. It is a semi-quantitative measure of the amount of the most volatile material present in a product (ie. it indirectly controls paraffin ratios and to some extent the olefin content) and can be used as a means for predicting the maximum pressure which may be experienced at fuel tank temperatures.

Vapour pressure limits are related to climatic conditions, and therefore there are different vapour pressure requirements for Australia in comparison to the European Union. Appendix F illustrates the vapour pressure of the Wide Range Fuel Trial fuels calculated for 40 and 5°C and includes the European and ALPGA standard fuels.

The ALPGA standard sets a minimum of 800 kPa and a maximum of 1530 kPa for vapour pressure at 40°C, whereas the EN standard sets a maximum of 1550 kPa at 40°C. The EN standard also specifies the minimum gauge vapour pressure at 150 kPa at various temperatures for a range of hydrocarbons. The EN seasonal vapour pressure (gauge) limits at 40°C are as follows:

Table 4.1.2.1 - EN 589 - Seasonal Vapour Pressure (gauge) Limits⁴⁶

Grade	Minimum (kPa)	Equivalent to 150 kPa at (°C)
A	1050	-10
B	900	-5
C	800	0
D	600	+10

Although there are small differences in the vapour pressure limits set in the EN and ALPGA standards (due to differences in climatic conditions experienced between Australia and Europe), the approach adopted by both standards, ie. to control the C4 content, is similar. The approach of limiting C4 by vapour pressure allows for the standards to represent what is commercially available in the market.

Under the ALPGA standard, the minimum vapour pressure requirement corresponds to approximately (up to) 60% C4 content. However the EN standard allows for a much wider fluctuation in the C4 range - varying between 20% and 100%. Therefore, the ALPGA standard's constraint on C4 is somewhat tighter than the EN standard.

Comment: If the EN standard was to be adopted, what would be the most relevant grades for Australian climatic conditions?

Stakeholders should also comment on the feasibility/applicability of adopting the EN standard vapour pressure with relevant grades.

It is difficult to discuss the vapour pressure parameters in the absence of hydrocarbon ratios (ie. C3/C4 ratios), particularly as vapour pressure indirectly controls C3/C4 ratios. Discussion on hydrocarbon ratios has raised a number of complex associated issues, such as: fluctuation in butane/propane ratios; international variation in

⁴⁶ Note: no minimum vapour pressure applies in summer

butane/propane ratios; adoption of the Euro emission standards; excess butane and the effects of limiting ratios on LPG market fuel supply.

These issues are complex and therefore have been detailed under the separate section 4.3 titled "Other Issues of Concern" and should be referred to before providing any comment on vapour pressure limits.

Discussion on vapour pressure is also hindered by the limited information on the current vapour pressure limits experienced in the LPG autogas market - there are currently no industry statistics available on the range of butane and propane ratios in the marketplace.

Environment Australia has sought expert technical advice to assist in the development of an appropriate vapour pressure limit range. However, no definitive opinion on the appropriate range limit and implementation approach is available. This is partly due to the lack of existing information (and data) on vapour pressure limits.

Vapour pressure affects vehicle operability (it impacts on fuel dispensing and cold startability), and these issues, along with emission outcome, are discussed below. Vapour pressure requirements for Generation 3 and Generation 4 vehicle technology (ie. those that rely on liquid injection) require particular attention.

Previous research suggests that, in terms of overall environmental (emission) performance, the optimal propane to butane ratio is 50:50. It is, however, acknowledged that restricting supply to such blends would significantly impact on the widespread availability of LPG.

Given the lack of available data it is not possible to provide a meaningful recommendation for vapour pressure limits at this time. In response to the lack of a recommended limit, several options for vapour pressure limits have been presented below and detailed stakeholder comments are requested.

The LPG working group considered the following three options for consideration when setting vapour pressure limits:

- 1) lower the current industry standard minimum vapour pressure limit
- 2) increase the current industry standard minimum vapour pressure limit
- 3) adopt the current industry standard (business as usual)

These options are considered below.

Impact on Engine Performance

In terms of vehicle operability, the vapour pressure limit is specified to control both engine startability and variation in pressure which could lead to dispensing problems when switching from a fuel with high to one with low vapour pressure.

Lower the current industry standard minimum vapour pressure limit (by increasing the butane content)

Although it can be argued that increasing the butane content of Australian LPG market fuel would absorb excess butane (see Section on Hydrocarbon Ratios - Excess Butane), provide for better fuel consumption and (by lowering vapour pressure)

perhaps ensure proper functioning of liquid fuel injection technologies; the increase in butane content would result in a wider variation in vapour pressure and a wider fluctuation of propane:butane (C3:C4) ratios than those provided by the current industry standard.

Aligning the Australian standard with European market fuel range (C4 European blends) would provide inadequate vapour pressure and therefore, contribute further to hot weather dispensing problems experienced in Australia. Hot weather dispensing problems occur when a vehicle's fuel tank cannot be filled due to extreme pressure differences between the vehicle fuel tank and the dispenser tank. This problem is exacerbated during the warmer months experienced in Australia and particularly when a consumer is trying to refuel their fuel tank with a blended product when the previous fill was with a propane product. As an example, a vehicle's fuel tank containing 100% propane at 50°C requires a transfer pump to develop pressure in excess of 1300kPa in order to be filled from a dispenser containing 70% butane at 30°C. This level of pressure is not achievable at most LPG dispensers in Australia.

Furthermore, the performance of LPG engines is optimised against the current LPG fuel blends (ie. up to 60% C4). Altering current blends, by increasing the butane content, will result in wider fluctuations in butane:propane ratios, which vehicles are not optimised/calibrated against. Appendix G illustrates the chemically correct, air-fuel ratios (by volume and mass) for the Wide Range Fuel Trial fuels and the European and ALPGA standard fuels.

Comment: Can stakeholders comment on available transfer pump technology (or other relevant technology) which would provide the adequate pressure necessary to transfer low pressure fuels?

What would be the costs to industry to employ such technology?

Please comment on these costs in comparison to any known savings to industry (ie. utilisation of excess butane) and the environment (ie. better fuel consumption).

Would lowering the current vapour pressure limit facilitate (or ensure) the effective operation of generation 3 and 4 technologies (some of which rely on liquid injection)? (See appendix A for more information) Or does the current (industry) vapour pressure range accommodate the potential future (low vapour pressure) requirements?

Noting that the hot weather dispensing problem occurs by travelling between regions (and refuelling in those regions), is there any benefit in setting an approach similar to regional vapour pressure limits (ie. similar to process for setting Reid Vapour Pressure for petrol)? Should states and territories be responsible for setting such limits? Is such an implementation approach feasible?

Increase the current industry standard minimum vapour pressure limit (by decreasing the butane content).

Lowering the C4 content in LPG market fuel would assist in reducing hot weather dispensing problems (but would not solve the problem). However, reducing C4 levels in LPG may be undesirable if the petrochemical markets (or other markets) cannot utilise the excess butane. If excess butane levels are not utilised in the LPG market

or petro-chemical markets, then refineries may be left with no option but to flare the excess product. This action is considered unacceptable by most stakeholders.

Comment: What markets are available for excess butane? (Please consider future/potential markets).

Will the combination of lowering the C4 content and setting vapour pressure at a regional level significantly assist in the management of dispensing problems? What are the associated costs?

If the excess butane can be absorbed in other markets (ie. other than the LPG market) - is this option preferable?

Some stakeholders have taken this option further, by stating that there is a need to examine C3:C4 ratios with a view to limiting particular hydrocarbons. Although some studies conclude that a 50:50 C3:C4 blend (by weight) provides for better emission outcomes when compared to petrol, restricting the total market to such a fuel blend would result in a potential loss of supply to regional areas (see Section on Hydrocarbon Ratios - Section 4.3.1 - Effect on Supply). Furthermore, it is worth noting that 50:50 blends are already typically supplied in the largest metropolitan markets and are readily obtained without special blending.

Consideration of future liquid injection technologies also requires further consideration (see Appendix A for more information).

Adopt the current industry standard (business as usual).

In comparison to the EN standard, the current industry vapour pressure limit provides for less fluctuation in C3:C4 ratios.

In terms of engine startability, the current industry vapour pressure allows for startability down to about -2°C. This limit also avoids the need for retuning for driveability if ever a switch has to be made between blends at the two extremes of the designated vapour pressure range⁴⁷. Although this is considered satisfactory, if the current industry vapour pressure limit is adopted there would be no scope to adjust vapour pressure limits to better reflect climatic conditions.

In addition, adopting the current limit would not allow further consideration of altering the limit to minimise hot weather fuel dispensing problems.

Comment: To more adequately address startability, is it more appropriate to set vapour pressure limits at a regional level based on climatic conditions? What are the advantages / disadvantages of such an approach? What would be the impact of this approach on other parameters and on hot weather refuelling? Who would be responsible for enforcing these limits (ie States/Territories)?

What limit would be necessary to provide for protection against the presence of volatile residues - ie. what level is necessary to ensure there will be no cold startability problems?

⁴⁷ ALPGA. Technical Data Sheet, 1986

Effects on Emissions

Hydrocarbons are known to alter tail-pipe emissions of total hydrocarbons, carbon monoxide and oxides of nitrogen. Australian studies have observed that carbon monoxide is significantly correlated with C4 content, and both C4 and olefin content have a strong (negative) correlation with NOx emissions⁴⁸. Tail-pipe emissions of total hydrocarbons, carbon monoxide and oxides of nitrogen from fuel with around 15% olefins and 50:50 C4:C3 (blend by weight) performed similar to or better than petrol.

While there is a plethora of international information⁴⁹ on the impact of hydrocarbons on LPG emissions, some of this information is contradictory. Three Californian Air Resources Board (CARB) LPG technical working group studies on the effects of LPG butane contents, indicated that for some LPG vehicles, emissions of hydrocarbons, CO and the overall Ozone-Forming Potential (OFP) may increase slightly, and NOx may decrease slightly, if the butane content is high⁵⁰. Other CARB studies on heavy duty vehicles (Cummins LPG engine - emission results from CARB Test Program) showed that propylene and butane contents of the LPG blends appeared to decrease HC emissions but increase NOx and CO emission and the OFP of emissions⁵¹.

A more recent US study⁵² which examined tail-pipe emissions from a range of butane:propane blends (HD5 (95% propane in this study); 20:80; 30:70; 50:50) contradicts previous studies by concluding that for emission results for total hydrocarbons, non-methane HCs, CO and NOx failed to indicate a significant difference between the fuels. Differences of ozone-forming potential among fuels were not statistically significant. However, butadiene emissions had a noticeable increase with increasing butane content, while emission of the other toxic compounds had a noticeable decrease.

Conclusion: Although it is acknowledged that increasing levels of C4 increase emissions of CO, and (when with olefins) decrease NOx emissions, it is difficult to reconcile limiting the C4 content of LPG market fuel based on total emissions outcome alone. Capping the blends at C4 50% (ie 0 - 50%) will significantly limit the capacity of the LPG market to absorb excess butane expected from changes to petrol specifications, perhaps resulting in the need for refineries to flare butane, which is an undesirable environmental outcome. If other markets can absorb the excess butane then this approach, given the potential emission outcome benefits, may be the preferred option.

Increasing C4 content will exacerbate the dispensing problem, unless other measures, such as a regional implementation of vapour pressure and the employment of appropriate technology (which is yet to be defined) are adopted. If the dispensing

⁴⁸ Wide Range Fuels Trial

⁴⁹ It should, however be noted that international studies utilise different vehicle technology and different fuel types (see Appendix A and C for further explanation), making the result rather difficult to reconcile with the Australian scenario. Furthermore, the range of studies reveal somewhat contradictory results.

⁵⁰ CARB, 1998, Initial Statement of Reasons for Proposed Rulemaking – Proposed amendments to the Specification for Liquefied Petroleum Gas Used in Motor Vehicles, p.3

⁵¹ Cummins test referred to in CARB, 1998, Initial Statement of Reasons for Proposed Rulemaking – Proposed amendments to the Specification for Liquefied Petroleum Gas Used in Motor Vehicles, p.3

⁵² Automotive Engineering International/December 1999

problem can be overcome, and does not represent a significant cost to industry, this option could be explored further. It is also important to consider future vehicle technologies, such as liquid injection (3rd and 4th Generation) and their requirement for low vapour pressure or a reduced vapour pressure range (particularly if such a requirement requires a large deviation from the current C3:C4 range).

However, given the uncertainty of future vapour pressure requirements and the inability to adequately address the dispensing problem, this option is considered unworkable (at least in the near term).

The current industry standard, if adopted, may not adequately address the dispensing problems experienced by Australian consumers, and may not adequately address future fuel technology requirements.

Comment: Can stakeholders comment on the frequency of cold startability and dispensing problems experienced by consumers? Does the frequency justify altering the current vapour pressure limit?

The ALPGA has recently suggested that a vapour pressure limit of 700-1400 kPa at 40°C during summer should be investigated. Currently the ALPGA limit of 800 kPa to 1530 kPa at 40°C, corresponds to approximately 50% butane (providing no ethane present) at the low end and 6.5% ethane (providing no butane present) at the high end. The suggested vapour pressure range of 700 kPa to 1400 kPa, corresponds to approx 60% butane at the low end and 3.5% ethane at the high end.⁵³ The suggestion of increasing the lower end of vapour pressure limit will involve some potential reduction in the maximum butane content, but the expected benefits would reduce starting problems in dedicated engines.

Comment: Stakeholders should also comment on the appropriateness of the ALPGA's suggested vapour pressure limit.

Overall, the vapour pressure limits of LPG requires further consideration. As a starting point, the three options (and the ALPGA's suggestion - outlined above) should be considered by addressing their impact on industry, other parameters and emission outcome. Comment should also be provided on the appropriateness of utilising vapour pressure to control the lighter fractions of olefins.

Each option presented has obvious pros and cons, and in the absence of further information it is difficult to determine the best option. Not only is there absence of

⁵³ The Vapour Pressure in an underground tank at about 25°C (if no ethane were present) would be approximately 550 kPa (current) or 480 kPa (suggested summer). The Vapour Pressure in a vehicle tank at 50° C (if no butane were present) would be approximately 1870 kPa (current) at 50° C or 1730 kPa (suggested summer). So the pressure differential between vehicle and underground tanks would be 1320 kPa (current) or 1250 kPa (suggested summer). A reduction in the spread between maximum and minimum Vapour Pressures at 40°C of 30 kPa would lead to a reduction in practice of about 70 kPa. In fact there could be expected a bigger improvement than this at the high end, particularly if the vehicle tank was almost empty. The proportion of ethane in the vapour space will tend to be higher than in the LPG liquid due to the much higher VP of ethane than propane. At high temperatures the ethane will tend to come out of solution more readily than it will be reabsorbed. If the suggested summer Vapour Pressure limits were adopted, the "hot-filling" problems should be reduced. At the same time, at least some of the butane excluded from petrol due to RVP could be incorporated in autogas. Consideration could be given to aligning summer RVP (for petrol) and summer Vapour Pressure (for autogas) calendar periods. It should be noted that the compositions corresponding to the maximum and minimum VP's are very sensitive to both ethane and butane content. Each 1% ethane allows over 4.6% additional butane at the low end, and each 1% butane allows over .21% ethane at the high end of the VP range.

data on the current blends within the market; there is also no documentation on the occurrence of dispensing problems. Until further information becomes available (eg. the extent and occurrence of dispensing problems etc.) a change to the current industry limit is not considered warranted.⁵⁴ Therefore, as an interim measure, the current industry limit will be proposed.

Before any change to the current industry standard can be undertaken it will be necessary to obtain information of the current blends of LPG in the market place, as it is critical in determining the costs/impacts associated with limiting blends. Such information is not currently available. Stakeholders should also comment on the occurrence of dispensing problems and provide comment/suggestion on how to obtain/establish an information base.

Comment: Can stakeholders comment on applicability of vapour pressure options outlined above, and if possible, propose a limit - outlining the associated costs (for industry and other stakeholders) and overall benefits?

What test methodology should be utilised?

Recommendation:

It is proposed that -

Vapour Pressure (gauge) at 40°C kPa be set at - 800 min to 1530 max [ISO 4256:1996; ISO 8973:1997⁵⁵]

4.1.3 Residue limits

The ALPGA standard states that control over residue content is of considerable importance as residue materials can cause troublesome deposits in regulators and vaporisers. Excessive clogging of residues in regulators and vaporiser can cause an engine to stop, and in extreme cases, to catch on fire. The impact of residues is, therefore, considered an operability issue, rather than an environmental issue. European IFP test programmes indicate that (at least) evaporation residue does not influence the pollutant emissions (regulated and non-regulated)⁵⁶. European studies on the quantity and quality of evaporative residues that may affect the performance of LPG vehicles are currently underway⁵⁷.

It is, however, acknowledged that as residues affect operability, they are likely to impact on emission performance (either directly or indirectly). However, as no studies have specifically examined the emission outcome of 'residue affected' engines, this section does not cover the effect of residues on tailpipe emissions.

⁵⁴ The ALPGA has recently agreed to work more closely with the OEMs in an effort to identify the refuelling/startability problems and make appropriate equipment or fuel specifications changes.

⁵⁵ ISO 4256 provides for direct measurement of vapour pressure, whereas ISO 8973 yields a calculated value obtained from applying standard values to molar fractions for each of the hydrocarbon species (ie. the ALPGA specification provides for values taken from ISO 8973 with the subtraction of 101kPa to convert from absolute to gauge pressure - and the gauge vapour pressures is usually calculated by molar proportion). The ALPGA's position has been to apply direct measurement by ISO 4256 in the case of dispute.

⁵⁶ NEN, Conference, The Netherlands, March 2001.

⁵⁷ NEN, Conference, The Netherlands, March 2001

The ALPGA standard limits residues by using three parameters: 'volatile residue', 'residue on evaporation', and 'dienes'. It should be noted that 'volatile residue' is an important cold startability performance parameter as it limits the presence of lighter hydrocarbons. These hydrocarbons have sufficient volatility such that they are unlikely to contribute to clogging of vaporisers and regulators.

The EN standard limits residues by using two parameters: total dienes and evaporation residue. These two parameters are similar to the ALPGA standard - ie. for 'dienes' and 'residue on evaporation'. The EN standard sets no limit for 'volatile residue'.

The recommendations for volatile residue, dienes and residue on evaporation are summarised at the end of this section.

Volatile Residue

Volatile residue limits the C5s (pentanes) and above which would generally be vaporised along with the predominant C4s and below. The ALPGA standard sets a limit of 2.0 max (mole %). Although there is no equivalent property in the EN or reference fuel standard, it is important to control residues as the level of C5s may lead to cold starting problems.

The Californian Air Resources Board recently (1998) regulated standards for “volatility residue” by a standard for evaporated temperature or a percentage volume (max) for butane.

It is therefore, proposed that the ALPGA limit for 'Volatile Residue' be adopted as a national standard, provided that stakeholders agree its continued use is important/necessary for engine operability.

Comment: If 'volatile residue' is important for cold startability, why is there no equivalent parameter in the EN standard?

Although the limit is important for cold startability, does it only provide extra insurance against startability problems? That is, do you consider that this extra insurance is necessary - or do you believe cold startability could be adequately managed via minimum vapour pressure?

Dienes

The ALPGA standard sets a diene limit of 0.3 max (mole%) - to reduce the likelihood of residue problems in regulators and vaporisers. The EN standard sets a limit for total dienes at 0.5 max (mole%).

The adoption of a stringent diene limit is important as a number of countries report that minute concentrations of butadienes in LPG can cause severe fouling and plugging of vaporiser equipment in automotive fuel applications⁵⁸.

The ALPGA established a task force to investigate the cause of residues. The results of the investigation are at Appendix H 'Residues'.

⁵⁸ Technical Data Sheet TDS 16-1992 - Guideline for Automotive LPG.

Residues are considered a key performance issue, and as such, adoption of a more stringent diene limit may be necessary/desirable. However, the adoption of a more stringent limit must demonstrate performance benefits and not impact on trade (disadvantage importers/exporters). Furthermore, as the current ALPGA standard of 0.3 max (mole %) is below the level of detection for the prescribed test method (ISO 7941:1998), and in order to facilitate alignment with the international standard, adoption of the EN standard should be considered.

Comment: Is it necessary to go beyond the EN 0.5 mole % limit? Would a diene limit more stringent than the EN standard (such as the ALPGA diene limit) impact on the capacity for (future) importers to supply the Australian market?

Can stakeholders provide comment on the availability, or appropriateness of another test method for 0.3 max (mole %)? If a test method is available is it internationally accepted?

Residue on Evaporation

The EN standard sets the evaporation residue at 100 mg/kg (at the dispenser), whereas the ALPGA standard is set at 20mg/kg max (at the terminal gate). The reference fuel sets a limit of 50 mg/kg⁵⁹.

The ALPGA recently embarked on a study to identify typical changes of residues levels as product moves from the terminal gate to the retail dispenser. This study will provide some data to inform the setting of a realistic residue limit at the end of the supply chain. This study will be independently technically reviewed to determine the applicability of its findings to inform the setting of a standard for 'residue on evaporation'. European studies are also underway.

In the absence of the study's findings, it is proposed that as the limit must be enforced throughout the whole supply chain (to satisfy the requirements of the *Fuel Quality Standards Act* and to facilitate harmonisation with international standards), a limit similar to the EN standard would be applicable. The CEN has proposed a target of 50 (mg/kg) maximum for 2003, in an attempt to improve the durability of automotive LPG equipment. This target is dependent on an appropriate measurement method being defined⁶⁰.

The fact that the national standards will apply to the whole supply chain may represent a challenge to the industry, particularly as to date the 'residue on evaporation' parameter has only been applied at the terminal gate.

The ALPGA's test methodology utilises a Japanese method (JLPGA-S-05T). This test methodology is aligned with the most widely utilised method in the Asia-Pacific region. However, to facilitate international harmonisation, consideration should be given to allowing the EN test methodology (ISO 13757).

⁵⁹ mg/kg is equivalent to ppm by mass

⁶⁰ NEN, Conference, The Netherlands, March 2001

Comment: Should the Japanese test methodology remain - is it necessary to set a limit at the dispenser utilising the EN test methodology? In terms of test methodology, what are the key issues for importers and local supplies of LPG?

Conclusion: The LPG working group considers that residues are one of the most important parameters to control in LPG. The utilisation of the volatile residue limit should continue to apply as it is considered important to control the level of C5s to maintain cold startability performance.

Applying the residue limits throughout the supply chain will represent a significant challenge to industry.

The outcome of the ALPGA's supply chain study may provide important information toward the setting of the standard. The ALPGA's residue study (protocol and results) will be independently technically reviewed before the findings are used to inform the process for setting a national standard for 'residues on evaporation'. The 'residue on evaporation' limit may need to be revised downwards after further European studies are complete. Once these levels are known, Australia could then consider its capacity to harmonise with world best practice.

Comment: Will the utilisation of 'unique'(ie. when compared to the EN standard) parameters, such as volatile residue, limit the capacity for (future) importers to supply the Australian market? What would be the costs/benefits of such an approach?

Do stakeholders believe that there are other parameters which need to be utilised to control residues? Is further control on pentanes required (or feasible) under the national standards? (See Appendix H).

Recommendation:

It is proposed that -

- volatile residue be set at 2.0 max (mole %) [ISO 7941:1988]
- residue on evaporation be set at 100 mg/kg [ISO 13757 or JLPGA-S-05T/86(105°C)] (with a view to adjust limit downwards in the future)
- dienes be set at 0.5 max (mole %) [ISO 7941:1998 or EN 27941]

4.1.4 Sulfur Content limits

Although sulfur limit is also an important parameter for the efficient function of key vehicle technologies necessary for compliance with the proposed emission standards (particularly hydrocarbon emissions), it is acknowledged that LPG has one of the lowest sulfur contents of any petroleum derived fuel.

The sulfur limit minimises sulfur oxide emissions and limits potential corrosion by exhaust gases from combustion of LPG⁶¹. In Australia and Europe the limit is set after odorant is added. In Australia the odorant (ethyl mercaptan) is a sulfur compound and as such contributes to the sulfur content of LPG. Both standards set

⁶¹ ATSM 1835 - 97, Standard Specification for Liquefied Petroleum Gases, p.3

the sulfur limit at 100 mg/kg, whereas the sulfur limit for the Euro reference fuel is set at 50 ppm weight (equivalent to 50 mg/kg).

In Europe there has been a recent move to decrease the sulfur content of conventional fuels for the years 2000 - 2005 to enable the adoption of advanced catalyst technologies and on-board diagnostic systems. In this context, a further reduction of sulfur content of automotive LPG is being considered by the European Standards (CEN), but the European LPG industry argues that no study has confirmed yet the influence of LPG sulfur molecules on the efficiency and durability of conventional catalysts⁶².

The CEN is considering revising the EN 589 in 2003, to set a sulfur limit of 50 mg/kg. The reduction is only a target as it is dependent on appropriate measurement and odorisation methods being defined⁶³. This is in response to European policy to move to sulfur free automotive fuels. The European LPG industry objective is 'no sulfur' in automotive LPG by 2005⁶⁴.

Conclusion: The current EN standard specifies a limit for sulfur of 100 mg/kg, equivalent to current ALPGA standard. Although the CEN is proposing to set a 50mg/kg limit in 2003, it is likely, given the current debate in the European Union, that this will be revised downwards for all conventional fuels, as well as LPG. Once these levels are known, Australia could then consider its capacity to harmonise with world best practice for sulfur limit levels.

Recommendation:

It is proposed that -

- (a) sulfur limit be set at 100 mg/kg [ASTM D 2784-98],
- (b) with a view to revising the limit downwards, in the near future (ie. for Euro 4).

4.2 Non-critical parameters

There are several parameters which are considered non-critical in terms of their emission outcome (non-contentious), but are important for vehicle operability.

These parameters include:

- Copper corrosion
- Water Content
- Odour
- Hydrogen Sulfide
- Fluorine
- Methanol

These parameters are detailed below, and compared across the existing standards (ALPGA standard, EN standard and the Reference fuel standard).

⁶² AEGPL Strategy Paper p.18

⁶³ NEN, Conference, The Netherlands, March 2001.

⁶⁴ NEN, Conference, The Netherlands, March 2001.

Comment: What do you think the parameters (environmental and operability) for a mandated Australian standard should be?

4.2.1 Copper Corrosion

This measure provides assurance that difficulties will not be experienced in the deterioration of the copper and copper-alloy fittings and connections which are commonly used in many types of utilisation, storage and transportation equipment. This limit also provides assurance that the LPG does not contain H₂S (hydrogen sulfide) in such quantities as to present a health and safety hazard.

Conclusion: All three standards include this property, with a 'Class 1' limit, but the EN and reference fuel standards also include a separate property for hydrogen sulfide (which is set as 'negative').

Recommendation:

Is it proposed that -
Copper Corrosion be set at Class 1 (ISO 6251:1996).

4.2.2 Water Content

The ALPGA standard specifies Free Water and Moisture Content (Dryness). Moisture content is specific for propane types of LPG, and Free Water is specific for C3:C4 mixes of LPG⁶⁵.

The EN standard specifies Water Content as 'no free water at 0°C' at the saturated vapour pressure on visual inspection⁶⁶. The reference fuel sets water content as 'none on visual inspection'.

The purpose of water content control is to provide assurance that pressure reducing regulators and similar equipment will operate consistently without troublesome freeze-ups caused by the separation of dissolved water from the product.

Conclusion: There is little difference in the parameters which limit water content. However, to facilitate alignment with the EN standard, adoption of the EN 'water content' limit should be considered.

Comment: Are there any problems with adopting the EN 'water content' parameter and limit?

What would be the advantages/disadvantages of adopting the EN parameter- would it impact on other parameters (ie. would a methanol limit also be required)? What would be the costs/benefits to industry and other stakeholders?

⁶⁵ ASTM D 1835 - 97.

⁶⁶ Noting that for propane rich mixes compliance with EN ISO 13758 equally satisfies this requirement, and that the equipment for this purpose is described in EN ISO 3993 may be used.

Would the adoption of the ALPGA's existing parameters impact on (future) importers/exporters? Would there be any significant impacts on trade/competition etc.?

Although the preferred option is to ensure alignment with the EN standard (and therefore adopt the EN parameter) stakeholders should consider the appropriateness of ALPGA parameters as an alternative option.

Recommendation:

It is proposed to that -
Water content be set at no free water at 0°C⁶⁷

4.2.3 Odour

The ALPGA and EN standards set the same limit for odour - the odour of the gas shall be characteristic, (distinctive and unpleasant), detectable at a concentration in air at 20% of the lower flammability limit.

This is a necessary safety measure which ensures that the LPG is odorised to a sufficient level so that leaks can be detected.

The similar process is adopted for the reference fuel.

Conclusion: There is no difference in the parameter (or test methodology) which sets a limit for odour.

Recommendation:

It is proposed that -
the odour limit be set at 20 % LFL (lower flammability limit).

There are also some parameters which are unique to each standard. Some European parameters are not relevant to Australian conditions (and vice versa). Therefore the following parameters are omitted from any further discussion in this paper.

4.2.4 Hydrogen Sulfide

The EN589 standard set a hydrogen sulfide limit and a copper corrosion limit, whereas the ALPGA standard only sets a copper corrosion limit. The EN reference fuel sets a limit for both parameters.

Hydrogen sulfide may be a naturally occurring contaminant of natural gas from which LPG may be derived⁶⁸.

As both parameters provide assurance that the LPG does not contain hydrogen sulfide, the ALPGA suggests that only one parameter limit (ie. the copper corrosion limit) is necessary.

⁶⁷ Noting that for propane rich mixes compliance with EN ISO 13758 equally satisfies this requirement, and that the equipment for this purpose is described in EN ISO 3993 may be used.

⁶⁸ LPG Specifications and Test Methods, Gas Processor Association.

However, the additional separate hydrogen sulfide limit is a field test and added safeguard to ensure that LPG does not contain detectable amounts of hydrogen sulfide. This limit is important for health and safety as hydrogen sulfide is highly toxic⁶⁹.

Conclusion: Although the working group considers that adoption of the hydrogen sulfide parameter (and limit) would not be problematic, as long as there are no significant costs associated with the test methodology, the group claims that its adoption is unnecessary as the hydrogen sulfide and copper corrosion limits measure the same thing.

However, a separate hydrogen sulfide limit ensures against the presence of hydrogen sulfide (a highly toxic substance) in the field. To allow for this added safeguard and to facilitate alignment with the international standard, adoption of the EN hydrogen sulfide limit should be considered.

Comment: Why do some suppliers test for both hydrogen sulfide and copper corrosion? Do suppliers agree that only the copper corrosion test is necessary? What would be the advantages/disadvantages of setting/not setting a hydrogen sulfide limit? What would be the costs/benefits?

Recommendation:

It is also proposed that -
Hydrogen sulfide be set at negative (EN ISO 8819)

4.2.5 Fluorine

The ALPGA standard sets a limit to control the amount of fluorine in LPG. This is an issue if any blend component of the LPG has been sourced from a HF Alkylation Unit within a refinery. This is unique to the Australian standard, and the current industry limit is considered adequate.

Although the standard is unique to Australia, other standards provide notes on fluorides for 'additional consideration'⁷⁰. The US standard states that certain refining processes, during process upset or malfunction, can also result in contamination of LPG by fluoride compounds. Such contamination can be extremely destructive in the distribution and end-user system. The US standard also notes that fluorocarbons, such as certain refrigerants, can contaminate gas through dual use of storage or tankage facilities. Such contamination is rare but, if the possibility exists, users of LPG should take extreme precautions to ensure the absence of fluorides⁷¹.

The combustion of products of fluorides can cause physical damage to property and health. High levels of fluorine or hydrogen fluoride gas are toxic and corrosive and can cause death, as can concentrated hydrofluoric acid. At low levels these substances can irritate the eyes, skin and lungs. Contact with hydrofluoric acid (even diluted) can burn the eyes (causing blindness) and skin, causing severe burns deep beneath the skin and damaging internal tissues⁷².

⁶⁹ ASTM D 1835 - 97

⁷⁰ Fluoride compounds contain one or more of the element fluorine.

⁷¹ LPG Specifications and Test Methods, Gas Processors Association

⁷² State of Knowledge Report - Air Toxics, Environment Australia, 2001.

Conclusion: In the absence of an internationally recognised non-proprietary test method, the ALPGA has not specified a test method for a fluorine limit. However, given the extremely destructive combustion products of fluorine (particularly hydrofluoric acid), the limit control for fluorine should continue.

Comment: Do stakeholders have any comments related to an appropriate method which could be adopted as a test method for fluorine? Would setting a limit impact on importers/exporters? What are the costs/benefits?

Recommendation:

It is proposed that -
Fluorine be set at 10 ppm (mg/kg) max

4.2.6 Methanol

Under cold conditions hydrocarbons can associate with water and ice (under freezing conditions), and result in clogging the regulator. In Europe, improvements of refinery technologies require methanol limits to be introduced to improve the environmental characteristics of the automotive characteristics of LPG⁷³ - the methanol limit has been introduced to prevent freezing problems.

Methanol is used to lower the dew point of the dissolved water within LPG. This is to avoid volatile water forming at low temperatures⁷⁴ and to prevent freezing problems⁷⁵.

The current EN methanol limit is 2000 mg/kg.

Conclusion: Australian temperatures are considered (on the whole) to be higher than European temperatures and therefore a methanol limit is not considered necessary. There is, however, a cautionary note in the ALPGA specification for when assessing water/moisture content - ie. the presence of methanol can give a false reading.

Comment: Can stakeholder comment on the need for a future methanol limit? (ie. will refinery improvements require a methanol limit to be set for LPG?). Would not setting a limit have any ramifications for (future) importers/exporters? What would be the costs/benefits of setting a methanol limit?

If the EN water content limit is adopted, will a methanol limit be necessary?

Recommendation:

It is proposed that -
a methanol limit not be set, but the cautionary note regarding assessing water content should remain.

⁷³ AEGPL Strategy Paper p.18

⁷⁴ Ortwin Constenoble, NEN, pers. comm.

⁷⁵ NEN, Conference, The Netherlands, March, 2001.

4.3 Other Issues of Concern

There are several other key issues which need to be considered when setting the LPG standard. The issues may indirectly/directly impact on the prescribed limits for particular parameters, or may even necessitate the listing of additional parameters.

The issues are as follows:

- Hydrocarbon Ratios
- Fuel consumption and carbon dioxide production

4.3.1 Hydrocarbon Ratios

This section outlines the key issues relevant to the ratio of paraffins (butane/propane) which are indirectly controlled by MON and Vapour Pressure.

Butane/Propane (Paraffins)

Under the current ALPGA standards, the level of butane is indirectly set at a level of 60% mole, and is controlled by vapour pressure and to some extent the MON⁷⁶ performance indicator. This approach is similar to the European approach and allows for the current fluctuation in butane and propane ratios to continue in the commercial LPG fuel market.

As previously stated, several stakeholders have commented on the need to examine butane/propane ratios with a view to limiting particular hydrocarbons (ie. 50:50 mix) or allowing for a two-tiered approach - ie.50:50 mix and pure propane products.

Stakeholders claim that this approach would guarantee a consistent supply (ie. one that does not fluctuate in C4:C3) and would also assist in optimising the calibration of LPG vehicles. It should, however, also be noted that as engine compression ratio is set to accommodate the lowest octane fuel, the potential benefits offered by higher octane LPG will not be realised in practice.

In addition, in terms of propane/butane ratios, the working group considers that the following issues require examination:

- national and international variation in the ratios – as determined by LPG composition;
- Euro fuel and emission standards;
- absorption of excess butane (as recommended by the Fuel Quality Review), and;
- the current supply and distribution chain of the LPG market.

International variation in ratios

The ‘types’ of LPG used internationally (and nationally) vary in composition. US auto-LPG is mainly propane, whereas the composition of Australian, European and Japanese autogas is highly variable in their propane:butane ratios. In comparison with European standards, the current ALPGA standards for MON provides for a narrower octane band than that found in Europe⁷⁷.

In Australia the oil majors produce about 25%⁷⁸ of current supply, with the remainder sourced from natural gas fields. As stated previously, this fuel is higher in olefins (–

⁷⁶ LPG working group, pers. comm.

⁷⁷ LPG WG – minutes 16 Oct.

⁷⁸ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, an environmental and technical assessment

ie. propylene and butylene) than LPG sourced from natural gas fields. The composition of Australian LPG can range from virtually 100% propane to 60% butane. On the east coast of Australia the mixture supplied for automotive use is typically around 60-70% propane and 30-40% butane⁷⁹. (See Appendix B for more information).

Comment: The current ALPGA standard has a requirement for the reporting of hydrocarbon composition. Such a requirement is not evident in the EN 589 standard. Do you believe it is/is not necessary for this requirement to be adopted by a national LPG standard?

In Europe about 55% of LPG is extracted from natural gas fields versus 45% from oil refining. The CEN standards EN589 defines the commercial automotive LPG specification. The European standard does not address precisely the hydrocarbon composition of the mixture but shows four grades based on the vapour pressure of the mixture⁸⁰. These fuels grades have been introduced in the standard to cope with the different climatic conditions within Europe.

According to the physical properties of the mixtures, for example, grade A will allow for mixtures having a propane content varying between almost 50% to 100%. Overall, the European marketed fuels are generally within the range 30 to 95% propane content⁸¹. No minimum vapour pressure limits are set in summer, but each member country can set a summer limit if desired.

The table below (4.3.1.1) presents an overview of the commercial automotive LPG specifications available in the different European Countries⁸² (Source: AEGPL-2000).

Table 4.3.1.1. - Overview of Commercially available Autogas LPG in Europe

Country	Grade as per EN589 selected in national standard / regulation (dates in brackets)	% propane in commercial automotive LPG market.
Belgium	Grade A	60%
Germany	Grade A	Min 95%
Denmark	Grade A (from 1/9 – 31/3)	70%
Spain	Grade B in winter (from 1/11 – 31/3)	30% to 40% for LDV 60% to 70% for HDV
Finland	Grade A in winter (from 1/9 – 31/05)	Min 95%
France	Grade A in winter (from 1/11 – 15/3)	45% propane \pm 5% all the year
UK	Grade A (from 1/9 – 15/3)	50% to 100%
Greece	Grade D	20%
Hungary		40%
Ireland		Min 90%
Italy		20 – 90%

⁷⁹ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, an environmental and technical assessment

⁸⁰ EN Automotive LPG fuel quality – Appendix 2.

⁸¹ EN Automotive LPG fuel quality – Appendix 2.

⁸² EN Automotive LPG fuel quality – Appendix 2.

Netherlands		40 – 70%
Poland	Grade B	18% - 55%
Portugal		Min 92%

The table below presents the variation in range of European commercial automotive LPG composition compared to the EN 589 (2000) specification⁸³.

Table 4.3.1.2 - Comparison of commercial automotive fuel and the EN 589 2000 specification.

	EN 589	Commercial automotive LPG composition variations currently observed on the European market
Hydrocarbons in C1 (%mol)	A mixture able to achieve a minimum of MON 89	0% to 30% (mainly below 5%) ⁸⁴
Hydrocarbons in C2 (%mol)		
Hydrocarbons in C3 (%mol)		-
Hydrocarbons in C4 (%mol)		-
Hydrocarbons in C5 and heavier (% mol)		0% to 2% (mainly below 1%)
Unsaturated hydrocarbons (%mol)	-	0% – 30%
Evaporative residues (mg/kg)	Max 100	0 to 100
Sulfur (mg/kg)	Max 100	0 to 100 (mainly below 50)

Euro fuel and emission standards

As discussed above, in response to the variation in composition, the granting of the ECE type approval for LPG vehicles (ADR 79/00 Euro 2, ADR 79/01 Euro 3) includes the demonstration of a vehicle's capability to adapt its fuelling rates. The vehicle has to be tested on two extreme reference fuels and demonstrate the self-adaptability of the fuelling system⁸⁵. These reference fuels vary markedly in their propane ratios (30% - 85%) see Table 4.3.1.3 below. The reference fuels are deliberately variable in the C3/C4 so that they represent what is commercially available. Fluctuating C3/C4 market fuels complement the emission standards reference fuel.

⁸³ EN Automotive LPG fuel quality – Appendix 2.

⁸⁴ These figure were taken as a direct quote from published AEGPL literature and by AEGPL pers comm.

⁸⁵ Annex 12 – Granting of an ECE type approval for a vehicle fuelled by LPG or Natural Gas – ADR 79/00 – page 193.

Table 4.3.1.3 - Extract for the Reference Fuel for ECE type approval.

Composition	Fuel A	Fuel B
C3	30+2	85+2
C4	Balance	Balance
<C3,>C4	Max. 2%	Max. 2%

Excess butane

The consultants undertaking the Fuel Quality Review concluded that the auto-LPG market is the most appropriate means to dispose of excess butane produced from petrol RVP reduction. The disposal of excess butane (around 300,000 tpa) would require substantial infrastructure investment for distribution, and stakeholders suggest that LPG standards would provide the necessary certainty for infrastructure investment. If the excess butane was simply added to the automotive market, it is estimated that the current typical supply scenario (60:40 ratio) would change to a 50:50 mix⁸⁶.

Constituents of LPG can vary from refinery to refinery and from season to season. Butane composition in LPG reduces from summer to winter due to its greater use in petrol to increase vapour pressure in winter⁸⁷.

To deal with excess refinery butane, refiners have presented several options (which may require the need for additional infrastructure).

- export surplus (dependent on availability of storage facilities)
- import propane to maintain current blend profile (dependent on available tankage)
- absorb the excess butane (mixed with propane) into the autogas market

Butane is not usually as sought after by petrochemical producers as propane, since it produces less ethylene. Therefore, other uses for the excess butane are limited - the industrial market would only account for about 10,000 - 20,000tpa. Other options, such as flaring, are less than desirable for several reasons:

- butane has a high energy content and should, where possible, be utilised in other refinery processes (such as alklyation units).
- flaring will contribute to refinery emissions.

With tighter petrol specifications under the European Union's Euro 3 limits, European traders are predicting longer seasons for butane as a petrochemical feedstock as petrol blending demand for butane falls. In Europe, the spot market represents only a tiny fraction of the petrochemical consumption of butane in Europe. For petrochemical producers it is viewed that the economies of scale support regular butane throughputs⁸⁸.

Comment: Is the absorption of excess butane more of an issue for those Australian refineries that do not have access to markets (plastics and petrochemical) that can absorb the excess olefins associated with the butane? Some refineries have a ready avenue for sale of olefins to the petrochemical industry as a feedstock.⁸⁹

⁸⁶ ALPGA pers. comm.

⁸⁷ Delivering LPG Fuel Quality - Don Sargeant.

⁸⁸ LPG World, Argus Volume VII, 3, 8 Feb. 2001.

⁸⁹ Delivering LPG Fuel Quality - Don Sargeant

What are the associated costs for each refinery (infrastructure cost) for the storage and absorption of excess butane? (See Appendix B - Storage and Infrastructure).

Effects on supply

The LPG industry has stated that setting limits on butane:propane will restrict supply in particular regions. The majority of regional networks are designed for propane, so strict limits on ratios will impact significantly on infrastructure.

There is currently no industry information on the distribution of various C3:C4 mixes of autogas - except to state that regional areas receive 'pure' propane LPG for domestic and automotive use. It is important to understand the current supply scenario (ie. range of C3:C4 in autogas) to fully examine/understand the impacts of setting standards which limit butane and/or propane. This issue will need to be addressed when setting a vapour pressure limit.

The impact of standards on supply has been well documented overseas. In California, the concerns of vendors of commercial propane led to the permanent deferment of the HD-5 standard (5% limit on propylene). Although there was sufficient statewide production of auto LPG in California, vendors argued that there would be inadequate supplies of the HD-5 on a regional basis to meet the demand given the current delivery and storage infrastructure.

The original CARB LPG specification in 1992, included a maximum limit on propylene content of 5.0% by volume (known as HD-5). CARB established an interim propylene content limit of 10% vol, with the vol% propylene limit becoming applicable 1 January 1995. In 1994 and again in 1997, the CARB delayed the 5% propylene limit because of continuing supply concerns; the second delay ran until 1 January, 1999⁹⁰. Following the 1998 hearing and the continued concerns of vendors, the Board adopted the interim propylene limit of 10% by vol as a permanent limit (known as HD-10). Although this example relates to olefin content (rather than paraffins), it details the importance of supply issues.

Furthermore, as stated above, the European ECE type approvals and EN 589 were designed to accommodate the large variation in the C3:C4 composition in the market. This approach is especially important, as Australia is committed to aligning with the ECE standards under ADR 79 (light duty) and ADR 80 (heavy duty).

4.3.2 Fuel Consumption and carbon dioxide production

The ALPGA Products Specification Committee has recognised the importance of examining various other aspects of vehicle performance, particular acceleration characteristics, fuel consumption and carbon dioxide production.

Fuel consumption and carbon dioxide production impact on greenhouse gas emissions. These issues have been examined in part by the Wide Range Fuel Trial which found:

⁹⁰ CARB, Public Hearing to consider LPG amendments, p.1

- Fuel consumption (measured volumetrically) changes significantly with increased C4 content relative to the gasoline reference. This is to be expected because of the increased energy content of C4 over C3 components on a volumetric basis
- For CO₂ emissions, emissions levels are generally 10 to 12% less than those for gasoline, as a consequence of the hydrocarbon ratio (H/C) of the gaseous fuels being in the region of 2.5 compared with 1.85 for gasoline. The energy content per unit of fuel tends to partly offset the change in H/C. There also appears to be a reasonably strong correlation with olefins content. The main reason for this is the reducing H/C ratio with increasing olefins content and a small influence from the reducing HC and CO with larger olefins content.

The expected trend of increasing fuel economy with increasing butane content has been observed in other studies⁹¹. However, while the fuel economy differences between the 50:50 blends and other C3:C4 blends (20:80 C3:C4; 30:70 C3,C4) were statistically significant, the difference between HD5 and 20/80 fuels was not. Refer to Appendix D for further information.

These issues are somewhat related to discussion of hydrocarbon ratios and MON.

The Australian Greenhouse Office is awaiting the outcome of a life-cycle analysis on various fuel types (which includes LPG), known as "*Comparison of Transport Fuels*" to determine if the proposed standard will have up-stream implications for greenhouse gas emissions. It is anticipated that the study will be completed in October 2001.

Conclusion: Fuel consumption and CO₂ production are important environmental issues which will be considered in the development of the LPG standard. In an attempt to optimise the overall environmental performance of LPG, these issues will be addressed/considered (in light of other associated issues and environmental outcomes) within the current suite of LPG parameters.

Recommendation:

Wherever possible, an applicable standard will address fuel consumption and carbon dioxide within the current range of parameters.

⁹¹ Automotive Engineering International/December 1999

5 SUMMARY OF RECOMMENDED ACTIONS

Preliminary Position

This section lists proposed parameters and limits.

Parameter	Limit	Test Method
Motor Octane Number (min)	90.5	Calculations as in EN589:2000 Annex B. Determination - EN 27941
Vapour Pressure (gauge) at 40°C	800 min 1530 max	ISO 4256:1996 ISO 8973:1997
Volatile Residue (C5s and higher)	2.0 max mole %	ISO 7941
Residue on Evaporation	100mg/kg**	EN ISO 13757 or JLPGA-S-05T
Corrosion, Copper Strip	Class 1	EN ISO 6251
Hydrogen Sulfide	Negative	EN ISO 8819
Sulfur	100 mg/kg**	ASTM D 2784
Dienes	0.5 mole % max	EN 27941 or ISO 7941:1998
Moisture Content	No free water at 0°C	Pass on visual inspection (as in EN 589:2000)
Fluorine	10 ppm max	Not specified (TBA) *
Odour	20%LFL	Annex A:EN589:2000 or Note (J):ALPGA:2000

* dependent on determining an appropriate test methodology.

** with a view to revising the limit downwards

Comment: Is it important to ensure that the standards do not impact on the ability of (future) importers to supply the Australian market, and that they do not disadvantage (future) exporters. Would the adoption of limits more stringent than the EN standard create such impacts? Would the adoption of 'unique' parameters also create impacts?

What parameters should be included in the standard and what do you think is the appropriate limit for each parameter?

What are the costs (to industry) and benefits (operability/environmental) of setting the above parameter limits as mandatory national standards? How would these impacts compare to the impacts of adopting the current EN or ALPGA standard?

What would be the impacts on other stakeholders?

Additional Issues

This section lists the parameters which require further consideration. The options or proposals presented are for further discussion.

The most critical outstanding decision relates to Vapour Pressure.

For Vapour Pressure the following options require further consideration.

- decrease vapour pressure
- increase vapour pressure
- adopt current ALPGA standard

These options should also be considered with regional/climatic implementation.

To align with the EN standard, consideration should also be given to adopting the EN 589 standard for vapour pressure (at 40°C), with the view to limiting the parameter to particular grades.

The ALPGA's suggested vapour pressure limit proposal (700-1400 kPa at 40°C during summer) should also be considered.

Comment: What are the impacts (costs/benefits - advantages/disadvantages) of such limits?

Further Information / Research

This section highlights parameters and issues which require further information or research.

The ALPGA's residue supply chain will provide initial details to inform the development of an appropriate 'evaporation on residue' limit.

The setting of an appropriate vapour pressure limit will require detailed consideration of several options, and an assessment of the impact of those options on industry and environment. In the absence of such information, business as usual will be adopted.

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7 APPENDICES

7.1 APPENDIX A - Generation of Engine Technology.

For the purposes of this standard it is useful to define the types of LPG fuel supply systems since the fuel composition and the supply systems are not necessarily independent. It is probable that the LPG technology market may in the next decade undergo a similar change to that which has occurred in the delivery of petrol to engines. In petrol engined vehicles there was an increase in complexity level and cost: carburettors were replaced by throttle body injectors (TBI) for electronic fuel management. In some car models this step was omitted and they went to the next level of complexity with port injection for each cylinder (MPI). Not all of these systems injected the fuel at the same time in the engine cycle, but today almost all engines have sequential fuel injection (SFI) which achieves this. Direct cylinder injection engined (known as 'GDI') cars have yet to reach the Australian market.

It is expected that LPG systems may follow a similar path in fuel supply complexity with the additional option of the supply as gas or liquid. One of the reasons that LPG has been a 'clean' fuel is that it can be provided to the engine inlet manifold as a gas when passed through a pressure regulator and vaporiser. This avoids the substantial problem of 'liquid fuel handling' which occurs with petrol engines. This problem occurs to a lesser extent with the increased level of petrol engine technology, but is only avoided with GDI. During transient driving manoeuvres (accelerating or decelerating) the existence of uncontrolled quantities of liquid fuel in the manifold prevents the accurate control of the fuel-air mixture close to stoichiometric, needed to maximise the conversion of HC, CO and NO_x to CO₂ and water in the 'three-way' exhaust catalyst. Emerging in the market at this time are LPG systems which inject liquid LPG in a similar way to petrol, whilst others exist which inject vaporised LPG in a similar way to CNG (compressed natural gas) systems.

For the present purposes:

- Generation 1 LPG systems are those with no exhaust oxygen feed back control.
- Generation 2 systems are those which, through a converter, supply vaporised LPG and have electronic feedback control to the converter (usually controlling the supply pressure). The supply of fuel to the engine can be by a venturi mixer or a gas carburettor.
- Generation 3 systems in overseas market engines have distribution systems to individual intake ports with valves or injectors. These systems utilise single or multi-port fuel injection of either dry gas or liquefied fuel and have a faster closed loop response time and more precise delivery of the LPG to the engine⁹².
- Generation 4 systems are systems which inject LPG in either liquid or gaseous form directly into the combustion chamber after the valves have closed. The system provides full timed sequential injection. These will be compatible only with the new wave of direct injection spark ignition engines (comparable to MPFi petrol systems)⁹³.

⁹² ALPGA – LPG as an Automotive Fuel.

⁹³ Erwin van den Berkmortel, pers. comm

A significant difference may exist on desirable fuel properties between generation 2 (which do not rely on liquid injection) and 3/4 systems (which may rely on liquid injection).

For some generation 3 and 4 systems it is desirable to keep the fuel liquid at all times, which may be particularly difficult in high fuel temperatures experienced in Australian outback conditions (hot fuel handling). Especially as a result of flow system pressure drops, the fuel must not boil in the injectors (before injection into the manifold air) or afterwards in the fuel return line as re-liquefying the fuel may be problematic in the fuel tank, by raising the fuel tank temperature. Hot fuel handling is known to be one of their implementation issues. Another is presence of transient (petrol like) fuel pools in the manifold.

In generation 2 and 3 systems (which do not rely on liquid injection) the reverse is true. Within fuel tank temperature and pressure storage limitations, it is desirable to have a fuel that vaporises readily to ensure that there is no liquid fuel carry over.

Relationship between Generation of Technology and European Emission Standard Stages.

Although publications from LPG system supply companies claim that specific technologies are needed for different stages of emission control this cannot be generalised. However some general comments can be made. As with current technology that voluntarily meets the ADR37/01 standards, Generation 2 technology will be needed to meet Euro 2 standards. Generation 2 and 3 technology may also meet Euro 3 standards although some manufacturers meeting Euro3 standards in Europe have opted for Generation 3 and 4 technology although this may call for the more advanced technology to control mixture at engine cranking. In principle the OBD requirements of Euro 3 may be met with Generation 2 and 3 technologies.

Euro 4 implementation is still at the concept stage in Europe. Australian emission control technologies for petrol engines have always been more mature and durable in implementation than their US counterparts and is possible that the same outcome could be achieved for LPG.

7.2 APPENDIX B - What is LPG?

This section outlines how LPG is derived, where it sourced and supplied.

7.2.1 What is LPG?

LPG is a generic name for the mixtures of hydrocarbons (mainly propane and butane, but may also contain propylenes (also known as 'propenes') C_3H_6 and butylenes (also known as 'butenes') C_4H_8) which, when lightly compressed (to approx.800 kPa or 120psi) change from a gaseous state to a liquid⁹⁴.

Natural gas on the other hand is comprised of a mixture of gases, almost exclusively hydrocarbons, found in petroliferous geological formation. Methane (CH_4) is the principal component, generally comprising from 87 per cent to 97 per cent by volume depending on the source of gas. Natural gas also contains small percentages of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), nitrogen, oxygen and naturally occurring carbon dioxide⁹⁵. Natural gas may be used as a transport fuel in either compressed (CNG) or liquefied form (LNG)

Where does LPG come from?

Most commonly, “naturally occurring LPG ” is extracted directly from ‘wet’ natural gas⁹⁶ at a gas well-head, and like natural gas it can have a variety of compositions related to its source of supply. LPG from natural gas condensate consists entirely of paraffins – mainly propane and a small amount of butane (less than 2%)

LPG can also be derived from the oil refinery as a by-product of gasoline production, in which olefins (propylenes and butylenes) may also be present⁹⁷.

There are also different LPG blends and products which are market specific and they are not interchangeable.

Autogas

One blend of LPG is specifically for automotive use only and will be a mixture of mainly propane and butane, and may have compounds such as propylene and butylene present (referred to as 'Autogas')⁹⁸. The other is predominantly pure C3 which is also used for domestic, industrial, commercial and recreational use.

General

The two products in common use for heating purposes in Australia consist predominantly of C_3 hydrocarbons (propane C_3H_8 or blends of propane and propylene C_3H_6), or predominantly of C_4 hydrocarbons (butanes C_4H_{10} or blends of butylenes C_4H_8). The latter product is normally used only as a commercial or industrial fuel in this country.

⁹⁴ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel,p.1

⁹⁵ BTCE, 1994, Alternative Fuels in Australian Transport

⁹⁶ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, p.1

⁹⁷ Watson and Gowdie, pg 1

⁹⁸ ALPGA – LP Gas Australia – Frequently Asked Questions

7.2.2 Supply

Australia produces over 2.4 million tonnes of LPG from major oil and gas fields located around the continent. The largest producer of LPG is the Bass Strait oil and gas production system off Victoria. Other major producers are the North West Shelf Project in Western Australia and the Cooper Basin in South Australia. In addition, around 250,000 tonnes of North West Shelf LPG is extracted at Kwinana, Western Australia, from gas in the Dampier to Bunbury pipeline.

In addition to production from naturally occurring sources, Australia's eight major refineries produce around 700,000 tonnes of LPG.

In 1999, Australia could be characterised as a producer of about 3 million tonnes, a consumer of 2 million tonnes with net exports of around 1 million tonnes.

Supply has expanded in WA which has the potential to expand production even further. With Eastern State (including SA in this case) production at mature levels and imports growing to satisfy demand, it is stated that Australia will be in surplus LPG in the West and in deficit on the Eastern States⁹⁹.

Exports from Australia were around 1.4 million tonnes in 1997 and 1998 against imports of around 400,000 tonnes.

At present, the bulk of the WA surplus is exported due to the need of the exporters from WA to simultaneously ship both propane and butane whilst Eastern States markets desire mainly propane. Favourable shipping economies are hindered by this fundamental logistical issue. This issue is likely to remain even though the cavern at Port Botany has been designed for propane only (65,000 tonnes capacity). Nevertheless because the balance of trade in LPG is forecast surplus, Australia should be able to earn more in exports in LPG than it would need to pay for its imports.

Imports into the Eastern States are expected to grow as NSW and Qld markets are forecast to expand above slightly declining local availability such that a deficit in the Eastern States supply is forecast to occur by 2002.

Australia is, and is likely to remain a significant LPG producer. A surplus of production over supply will remain well into the next century despite the regional supply logistics.

7.2.3 Storage Infrastructure

LPG storage terminals located around the coast of Australia provide for export or imports or in some cases both for LPG. The major export facilities are located at Westernport, Victoria (Esso), Port Bonython, South Australia (Santos), Kwinana, Western Australia (Wesfarmers), and Dampier, Western Australia (Woodside). These terminals include large refrigerated storage tanks and most are capable of handling very large gas carriers (VLGC) with capacities of up to 77,000m³.

⁹⁹ Supply and Demand Study - 1999

The Elgas 65,000 tonne capacity storage cavern for propane at Port Botany provides both import and export facilities and permits VLGCs to discharge full cargoes in Sydney.

A number of smaller pressure storage terminals are located around the coast at major demand centres. Coastal shipping remains the major means of supply of LPG into these centres.

Major propylene, ethylene and ammonia storage facilities are located at Port Botany, Newcastle and Brisbane. These are similar to LPG facilities (and could be converted to LPG if required).

In addition to these major storage facilities, Elgas operates a major inland storage at Dandenong, near Melbourne. This is supplied by pipeline from the ExxonMobil BHP plant at Long Island Point, near Hastings.

7.3 Appendix C - International Standards

7.3.1 European Standards:

According to the CEN/CENLEC Internal Regulations - the national standards organisations of member countries are bound to implement the EN 589 Standards.

The history of EN 589 is presented below.

EN 589 (1993) - Automotive fuels - LPG - Requirements and test methods are equivalent to Euro 2 LPG fuel specs. This standard has been modified from the 1987 standards (BS 4250) as follows:

- Requirements for composition are no longer included
- Requirements for pump marking have been introduced
- The minimum octane number requirement has been reduced from 90 to 89
- No requirements are now included for levels of mercaptan sulfur, ethylene and C₅ and higher hydrocarbons
- Requirements for gauge vapour pressure are no longer included but vapour pressure is now specified for winter grade fuels
- Comprehensive cautionary statements on health and safety considerations when undertaking odour testing are now included

Property	Limits	Test Method
Motor octane number	89,0 MIN	See below*
Dienes content (as 1,3 butadiene mole %)	0,5	ISO 7941
Hydrogen sulfide	Pass	ISO 8819
Total sulfur content (after stenching) mg/kg	200	EN 24260
Copper strip corrosion (1h at 40°C) (rating)	Class 1	ISO 6251
Evaporative residue mg/kg	100	NF M 41-015
Vapour Pressure, (absolute at 40°C) kPa	1550	ISO 4256
Vapour pressure, absolute min. 250 kPa for various grades (°C)	-10 - +10	ISO 4256

*The partial MON for each component in the mixture as follow –
partial MON = $M \times C$ where

M is the motor octane factor of a specific component as below.

C is the mole fraction in the mixture.

The partial octane numbers for all of the components are determined and the sum rounded down to the nearest 0,1

Component	MON factor
Propane (+ C2)	95,4
Propene	83,9
Butane (+ C5)	89,0
2-Methylpropane (isobutane)	97,2
Butenes	75,8

In 1998, EN589:1998 replaced EN589:1993 in whole. Significant technical changes between this European Standard and the previous standard were:

- Normative references were updated;
- The year of publication of normative references were deleted, with some exception.

The EN589:2000 standard was developed in 2000 and replaced EN589:1998 in November 2000. All relevant characteristics, requirements and test methods are now specified in the EN

standard. Significant technical changes between this Standard and the previous (EN589:1998) standard are on:

- Determination of water (no free water at 0°C)
- Requirement of sulfur content (100mg/kg)
- Test method for sulfur
- Testing method for vapour pressure, including Annex C
- Requirement for methanol (2000mg/kg)
- Requirement for vapour pressure.

UN Regulation 67 relates to the adoption of uniform conditions for LPG motor vehicle equipment and parts (Directive 97/23/EC). The Directive 99/96/EC also includes a specification for LPG reference fuel.

7.3.2 USA Standards:

There are no federal requirements for LPG standards in USA.

The US 1994 regulation states the US EPA's position on LPG fuel standards –
 “.....there is little information available about in-use LPG composition upon which such a fuel specification could be based. Thus, EPA believes it prudent to adopt commercial LPG as the certification fuel at this time. Should adequate information on in-use LPG composition become available at some point in the future, EPA may elect to define a certification fuel specification for LPG at that time. Today's rule contains no controls on in-use fuel composition for either natural gas or LPG. EPA does not believe that the need for such in-use controls has been adequately demonstrated. Further, the cost-effectiveness of such controls is not likely to justify such action. The Agency is concerned, however, about the possibility of in-use fuel composition changes over time, and urges the natural gas and LPG industries to take steps to minimise such variations. Should the in-use compositions of these fuels change in such a way as to adversely impact the emissions performance of gaseous-fuelled vehicles the Agency would likely take steps to address the issue at that time, either through corresponding changes in certification fuel specifications, or possibly through in-use fuel composition specifications.”

The US industry requirements for auto-LPG (Special-Duty Propane – which is mostly propane) are as follows -

<i>Specification</i>	<i>Value</i>	<i>Test Method</i>
Vapour pressure at 100°F	208 psig (max.)	ASTM D 1267-89
Volatility residue: Evaporated temp., 95%	-37°F (max.)	ASTM D 1837-86
Propene content	5.0 vol. % (max.)	ASTM D 2163-87
Residual matter: residue on evap. Of 100 ml oil stain observ.	0.05 ml (max.) pass ^b	ASTM D 2158-89 ASTM D 2158-89
Corrosion, copper strip	No. 1 (max.)	ASTM D 1838-89
Sulfur	123 ppmw (max.)	ASTM D 2784-89
Hydrogen Sulfide	pass	ASTM D 2420-89
Moisture content	Pass	ASTM D 2713-86

Commercial PB (propane/butane) mix is only used where intermediate volatility is required. This mixture is usually only used for industrial or domestic purposes, and the specifications are included below for your information.

<i>Specification</i>	<i>Value</i>	<i>Test Method</i>
Vapour pressure at 100°F	208 psig (max.)*	ASTM D 1267-89
Volatility residue: Evaporated temp., 95% Or	-37°F (max.)	ASTM D 1837-86
Butane and heavier	2.5 vol. % (max.)	ASTM D 2163-87
Pentane and heavier	2.0 vol. % (max.)	ASTM D 2163-87
Residual matter: residue on evap. Of 100 ml oil stain observ.	0.05 ml (max.) pass ^b	ASTM D 2158-89 ASTM D 2158-89
Relative density	Not a specific requirement, but must be reported for other purposes (see*)	
Corrosion, copper strip	No. 1 (max.)	ASTM D 1838-89
Sulfur	140 ppmw (max.)	ASTM D 2784-89
Hydrogen Sulfide	pass	ASTM D 2420-89
Moisture content	Pass	ASTM D 2713-86
Free Water	none	

* additionally must not exceed that calculated from the following relationship between the observed and vapour pressure and the observed relative density.

Specifications for other commercial LPGs are also available – these include Commercial Propane and Commercial Butane¹⁰⁰.

7.3.3 Californian Standards

Currently in the USA, only CARB (the Californian Air Resource Board) has set specifications for LPG as an automotive fuel.

In 1992, the California Air Resources Board (CARB) established motor vehicle fuel specs for liquefied petroleum gas under Title 13, CCR, section 2292.6 (see Table attached). This regulation provides engine manufacturers with a known fuel quality for designing engines, to prevent performance problems and excess emissions.

The regulation took effect on January 1, 1993. The Board included a maximum limit of ten percent by volume on the content of vehicular LPG. That propene limit was to decline to five percent on January 1, 1995 (the HD-5 standard). However, in 1994, the Board delayed the effective date of the five-percent propene limit to January 1, 1997, and then in 1997, the Board again delayed the effective date until January 1, 1999. In the interim, the propene limit remained at ten volume percent. The Board delayed the effective date of the propene 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. This limit is also contained in the specifications for industrial and commercial grade propane.

When the Board adopted the specifications for motor vehicle 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 was to ensure that motor vehicles certified on

¹⁰⁰ Note: There is very little mixed product used in the US but it could be used industrially.

LPG would 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.

Following a December 1998 hearing, the Board adopted the following amendments to the specifications for LPG intended for use in motor vehicles:

- (1) Retain the current interim propene limit of 10 percent by volume as a permanent limit.
- (2) Establish a new 2.0 percent by volume maximum limit for butenes.
- (3) Establish a new 0.5 percent by volume maximum limit for pentenes and heavier.
- (4) Amend the optional 2.5 percent by volume maximum limit for butanes and heavier to a 5.0 percent 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 LPG regulation to be reviewed in five years (2003) to determine whether it should be retained, revised, or repealed.

The HD-5 standard is not mandated and is a more stringent industry voluntary specification for producers and suppliers.

Specifications for Liquefied Petroleum Gas (as amended)

The following standards apply to liquefied petroleum gas (The identified test methods are incorporated herein by reference.):

<i>Specification</i>	<i>Value</i>	<i>Test Method</i>
Propane	85.0 vol. % (min.)	ASTM D 2163-87
Vapour pressure at 100°F	208 psig (max.)	ASTM D 1267-89 ASTM D 2598-88 ^a
Volatility residue: Evaporated temp., 95% Or	-37°F (max.)	ASTM D 1837-86
Butanes	5.0 vol. % (max.)	ASTM D 2163-87
Butene	2.0 vol. % (max)	ASTM D 2163-87
Pentenes and heavier	0.5 vol % (max)	ASTM D 2133-87
Propene	10.0 vol. % (max.)	ASTM D 2163-87
Residual matter: residue on evap. Of 100 ml oil stain observ.	0.05 ml (max.) pass ^b	ASTM D 2158-89 ASTM D 2158-89
Corrosion, copper strip	No. 1 (max.)	ASTM D 1838-89
Sulfur	80 ppmw (max.)	ASTM D 2784-89
Moisture content	Pass	ASTM D 2713-86
Odorant	^c	

^a In case of dispute about the vapour pressure of a product, the value actually determined by Test Method ASTM D 1267-89 shall prevail over the value calculated by Practice ASTM D 2598-88.

^b An acceptable product shall not yield a persistent oil ring when 0.3 ml of solvent residue mixture is added to a filter paper, in 0.1 increments and examined in daylight after 2 min. as described in Test Method ASTM 2158-89.

^c The liquefied petroleum gas upon vaporisation at ambient conditions must have a distinctive odour potent enough for its presence to be detected down to a concentration in air of not over 1/5 (one-fifth) of the lower limit of flammability.

According to the Propane Gas Association of Canada, the CAN/CGSB-3.14-M95 Standard states that Grade 1 LPG (“a special fuel intended for use in internal combustion engines operating under moderate to high engine severity”) specifications (as compared to the CARB Standard) are:

7.3.4 Canadian Standards:

Canada has no federally mandated standards. In 1998, the Canadian General Standards Board implemented an industry standard for LPG quality. A comparison of the CARB mandated standards and the Canadian industry standards are considered in the table below–

Comparison of CARB and Canadian Specifications

<i>Specification</i>	<i>CARB</i>	<i>Canada</i>
Propane	85.0 vol. % (min.)	90 vol. % (min.)
Vapour pressure at 100°F	208 psig (max.)	208 psig (max.)
Butanes	5.0 vol. % (max.)	2.5 vol. % (max.)
Propene	10.0 vol. % (max.)	5 vol. % (max.)
Sulfur	80 ppmw (max.)	123 ppmw (max.)

7.3.5 Japanese Standards

LPG Quality Standards in Japan applies to both residential and autogas use. The standards are set by the Japan LPG Association are set as follows:

	Commercial Propane	Commercial Butane	Test Method
Density (15oC, g/cm3)	0.500 - 0.620	0.500 - 0.620	JIS K 2240
Vapour pressure (40oC, Kgf/cm2)	Less 15.5	Less 5.3	"
Composition (mol%)			"
Ethane+Ethylene	Less 5.0	Report	"
Propane + Propylene	Over 92.0	Report	"
Butane	Report	Pver 95.0	"
Butylene	Report	Less 2,0	"
Butadiene	Less 0.5	Less 0.5	"
Pentane	Report	Less 2.0	"
Copper corrosion (40oC, 1h)	Less 1	Less 1	"
Residues			
(40oC, Wt ppm)	Less 60	Less 60	JLPGA 5-05T
(105oc, Wt ppm)	Less 10	Less 10	"
Sulfur	Less 50	Less 50	JLPGA 2240
Moisture	-	-	JLPGA S-03
Free Water	Nil	Nil	ISO DIS

For autogas, propane is mixed with butane according to temperature of the areas in Japan as examples shown below:

	January	June	October
At the northern areas (eg. Hokkaido)	70%	20%	30%
At the main lands (eg. Tokyo)	20%	10%	10%
At the southern areas (eg. Kyushuu)	20%	10%	10%
At Okinawa islands (south end of Japan)	0%	0%	0%

7.4 Appendix D - Greenhouse gas /emissions from LPG vehicles

As the primary driver for the development of standards is environmental, it is important to examine the existing Australian information set on emissions from LPG vehicles.

This information set summarises the key finding from relevant Australian studies.

7.4.1 Emission Studies

In-Service Emissions

Studies such as the *FORS LPG In-Service Vehicle Emission Study (1997)* emphasise the need to examine a variety of LPG properties which could be more tightly managed to bring about improvements in environmental in -service emissions performance.

The study highlighted that there are deficiencies in the data available on the make up and operation of the LPG fleet¹⁰¹, but summarised the emission picture for dual fuelled (petrol/LPG vehicles) when operated on LPG as¹⁰²:

- There are relatively small differences in exhaust emissions performance between the vehicles tested and comparable vehicles operating on petrol
- Most of the vehicles complied with the exhaust emission standards applicable to comparable petrol engined vehicles. Unlike hydrocarbons, NOx emission levels are generally widely scattered, even for vehicles of the same model and similar ages.

The FORS study also raised a number of serious concerns about ‘real world’ levels of evaporative emissions¹⁰³. As the vehicles have completely sealed fuel systems, LPG vehicles should have effectively zero evaporative emissions, and fugitive emissions should be limited to the small release of gas when the fuelling coupling is attached and removed. In practice, however, most gaseous-fuelled light vehicles have dual fuel capability, so they still are prone to losses through the gasoline side of the fuel system¹⁰⁴.

In consultation with industry and Commonwealth/State agencies, the Department of Transport and Regional Services on behalf of MVEC is developing LPG/CNG in-service standards. This is in response to the lack of measures in place to demonstrate that vehicles which are certified to the emission Australian Design Rules (ADRs) as petrol or diesel engined vehicles, and are subsequently converted to run on LPG or CNG, are still in compliance with the emission standard.

¹⁰¹ Fleet consisted of 1st and 2nd generation technology

¹⁰² FORS LPG In-Service Vehicle Emission Study 1997, Exec Summary

¹⁰³ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, an environmental and technical assessment. p. 45

¹⁰⁴ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, an environmental and technical assessment, p. 45

LPG as an automotive fuel - Peter Anyon, 1998

Commissioned by ALPGA

Although previous studies have observed that Australian LPG fuelled vehicles overall have emissions comparable to those of their contemporary gasoline powered cars, this does not reflect the situation in Europe, where it has been repeatedly shown that LPG vehicles perform substantially better than their gasoline equivalents¹⁰⁵. Although there has been little or no uptake of the latest (more expensive) Generation 3 LPG systems now widely used internationally, the situation may change when Euro emissions come into effect. However, the LPG working group has noted that while LPG fuel injection technologies (generation 3) can assist compliance with Euro 2 & 3 emissions standards, it is not a given that these are essential. Further investigation is required to determine the capability of generation 2 systems.

The development of fuel quality standards for LPG must be viewed in light of vehicle technology issues. There are also a series of other issues that relate to the broader use of LPG in the market place. In an attempt to facilitate the development of standards, it is proposed that those issues be discussed when/where relevant, but not be included in the scope of future work. Some of these issues include-

- LPG conversion issues - ADRs and LPG aftermarket conversions (DoTRS lead on this issue)
- Review of in-service emissions
- Inspection and maintenance issues for private and fleet vehicles.

Life-Cycle Emissions

A review of the environmental examination of LPG as an automotive fuel¹⁰⁶ observed that running a light duty vehicle on automotive LPG, instead of petrol or diesel, significantly reduced tailpipe emissions of greenhouse gas. However, for heavy duty applications, the superior efficiency of diesel engines erodes any environmental advantage of LPG, so there is little difference between the two fuels in these applications.¹⁰⁷

In terms of life-cycle analysis, the *Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles (CSIRO, March 2000)* commissioned by the Australian Greenhouse Office observed that biodiesel has the lowest greenhouse gas emission on a life-cycle basis, followed by ethanol derived from lignocellulose feedstocks and then the gaseous fuels (LPG, CNG and LNG). In terms of air pollution on a life-cycle basis the gaseous fuels (LPG, CNG) provided the lowest contribution to air pollution¹⁰⁸.

The CSIRO study was designed as a brief overview of existing literature and is being followed up with a more comprehensive analysis of transport fuels including LPG in a consultancy titled *Comparison of Transport Fuels* which will be completed in October 2001. Further details of the study can be found at <http://www.greenhouse.gov.au/ec/fuels.html>

¹⁰⁵ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, p.58

¹⁰⁶ adapted from ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, an environmental and technical assessment.

¹⁰⁷ ALPGA, 1998, Liquefied Petroleum Gas as an Automotive Fuel, an environmental and technical assessment, p. 53

¹⁰⁸ 2000, Life-cycle Emission Analysis of Alternative Fuels for Heavy Vehicles, Exec Summary.

7.4.2 LPG Blend Studies

Determination of an LPG Certification Test Fuel - NSW EPA, 1996.

Studies have been performed in Australia on emissions from vehicles using different blends of autogas. The NSW EPA (as part of a study commissioned by the then Commonwealth Environment Protection Authority) measured performance on four blends ranging from pure propane to 60% butane by mass:

- 100% propane
- 70% propane and 30% butane
- 50% propane and 50% butane
- 40% propane and 60% butane

The study was conducted on two vehicles, a V6 Holden Commodore and a V8 Ford Fairlane each with a different LPG conversion kit. The study found that the LPG blend test confirms the improvements able to be realised in CO₂ emission (10% to 16%), even though fuel consumption increased when compared to unleaded petrol. Also, it indicated the general trends in criteria emission by the conversion to LPG, namely¹⁰⁹:

- slightly decreasing HC Emissions (variable)
- significantly increasing NO_x emissions
- significantly decreasing CO emissions.

As the butane content of the LPG blend increases, the following trends were found:

- slight increase in HC emissions
- decrease in NO_x emissions
- significant increase in CO emissions.

However these trends in blend emissions are probably due to the richening of the fuel/air mixture as the heavier butane component is increased and metered into the engine.

The study recommended that a 50% propane:50% butane by mass blend be used as the autogas emissions certification fuel¹¹⁰. This blend is also specified as the test fuel for determining autogas consumption under AS 2877:1989 by the carbon balance method.

Wide Range Fuel Trial - Professor Harry Watson and Dr David Gowdie.

Published by the ALPGA - 2000In response to the need to examine the emissions outcome of LPG derived from refineries (which contains olefins) a recent study was completed (commissioned by the ALPGA) to examine the effect of olefins (propylene and butylene – 0-30%) as well as C₄ content (ie. both butane and butylene – 0-60% molar) on emissions. This work was performed on the new generation of vehicles (two six-cylinder sedan vehicles fitted by their Australian manufacturers with OEM LPG fuel systems) designed to conform to the current emissions standards, ADR37/01.

Emissions were determined for total hydrocarbons (THC), methane (CH₄), non-methane hydrocarbons (NMHC), carbon monoxide (CO), nitrogen oxides (NO_x) and carbon dioxide (CO₂). The results for the two vehicles were generally consistent and

¹⁰⁹ NSW EPA, Determination of an LPG Certification Test Fuel, p 83

¹¹⁰ Wide Fuel Range Trial, p.3

combined into composite values for comparison between the LPG Gas blends and the petrol reference fuel¹¹¹. Specific conclusions included¹¹²:

- THC, CO and NO_x for fuels in the mid range of olefins and C4 content were similar to or better than petrol.
- If the NMHC+NO_x is taken as an indicator of photochemical smog precursors, then only those fuels with high olefins content perform worse than gasoline.
- For all gaseous fuels, CO₂ equivalent emissions are reduced by 7% to 10% or more compared with gasoline.
- If NMHC + NO_x and CO₂ equivalent are combined as an urban + global index, LPG was better in performance than gasoline by 4 to 15%, with fuels (30,0; olefins,C4) and (20,0:olefins,C4) being about the same or slightly worse than gasoline.
- The choice of a 50:50 (by mass) propane:butane reference fuel gives mid range performance and should be continued as the reference fuel.
- Overall, exhaust emissions from the gaseous fuels for the ADR37/01 cars tested were lower than the gasoline. However, the level of benefit was probably not as significant in comparison with the earlier leaded fuel, non-catalyst technology, to which LPG was first applied.
- The results, of the test of the bi-fuel cars' acceleration performance, indicate that there was no performance sacrifice through the use of gaseous fuel in these OEM developed cars, although there may be some related to the increased vehicle mass of the dual fuel tanks etc. of these cars when compared to a single fuel car.

¹¹¹ Wide Fuel Range Trial, p.1

¹¹² Watson and Gowdie, p. 8

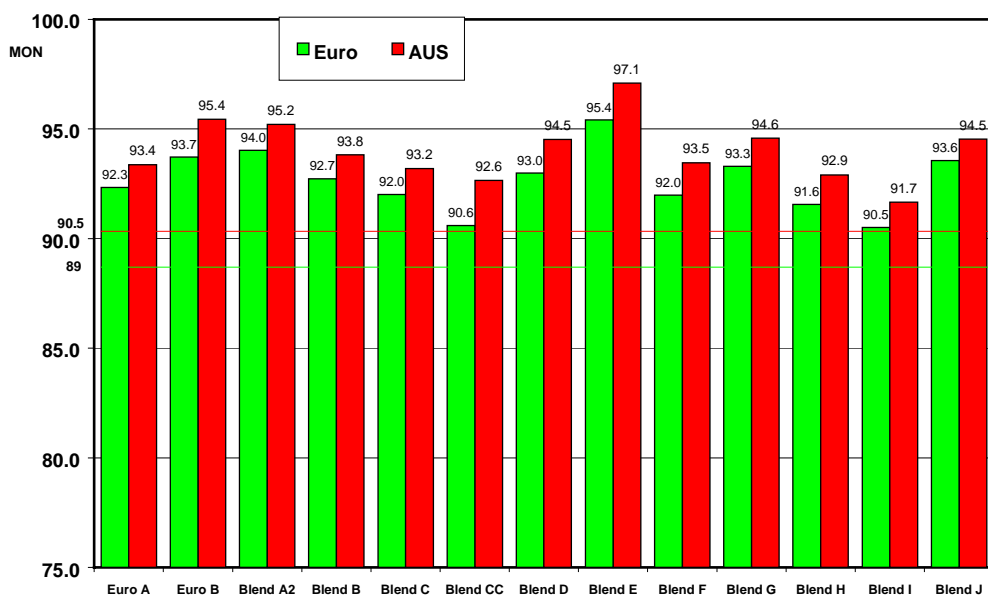
7.5 Appendix E

Examples of the Effect of Fuel Composition on Motor Octane

The figure below shows the MON for the European Reference Fuels A and B, a blend A2 representative of an Australian (50:50) reference fuel and the fuels used in ALPGA's Wide Range Fuels Trial. Extra grid lines are drawn for the 89 and 90.5 MON values representing the EN and Proposed Standards. The bars show the difference in the calculation procedure (blending MON) between the ALPGA's method and the European EN method. It is proposed that the EN method would be adopted.

Calculated Motor Octane Number for Various Blends of LPG

Compound	COMPOSITION (mol fraction)												
	Euro A	Euro B	Blend A2	Blend B	Blend C	Blend CC	Blend D	Blend E	Blend F	Blend G	Blend H	Blend I	Blend J
ETHENE	0	0	0	0.0006	0.0017	0.001	0.0018	0	0.0004	0.0008	0.0009	0.003	0
ETHANE	0	0	0.0056	0.0063	0.0114	0.0096	0.0147	0.0112	0.0072	0.0086	0.0077	0.1133	0.0045
PROPYLENE	0.0675	0.09	0	0.1086	0.2122	0.1535	0.206	0	0.2955	0.1078	0.1466	0.1422	0
PROPANE	0.3	0.85	0.5571	0.4312	0.4753	0.5357	0.7679	0.9794	0.6891	0.6035	0.3928	0.1393	0.3876
BUTYLENES	0.0225	0.03	0	0	0	0.1433	0	0	0	0	0.0512	0.058	0
N-BUTANE	0.36	0.015	0.2634	0.2702	0.176	0.0547	0.0029	0.0014	0.0011	0.1644	0.2243	0.3089	0.3574
ISO-BUTANE	0.25	0.015	0.1732	0.1824	0.1229	0.1006	0.0066	0.008	0.0066	0.1145	0.1758	0.2348	0.2492
N-PENTANE		0	0.0007	0.0007	0.0005	0.0016	0.0001	0	0.0001	0.0004	0.0007	0.0005	0.0013



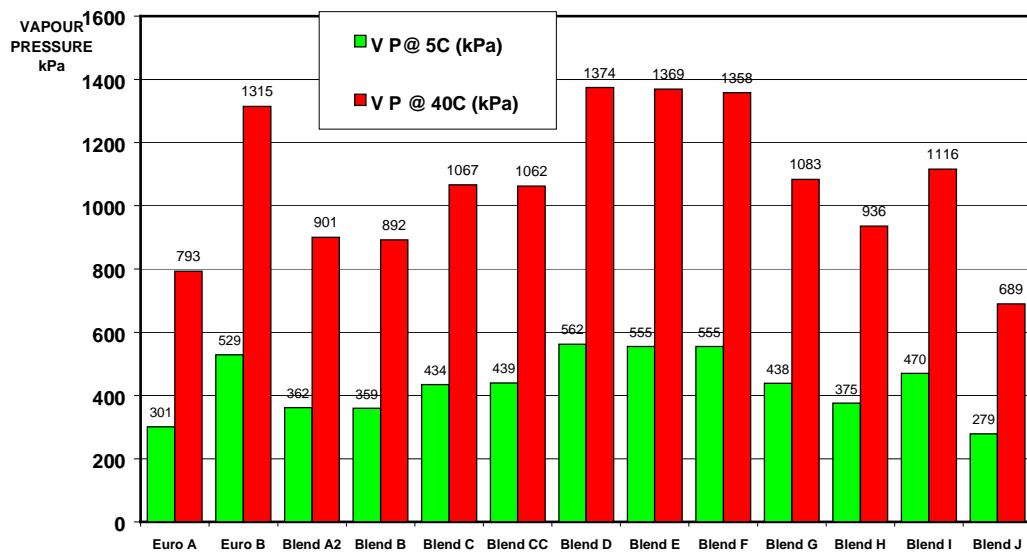
7.6 Appendix F

Examples of the Effect of Normal Temperature Range on Vapour Pressure

The figure below shows the vapour pressure for the fuels used in the ALPGA's wide range fuels trial (Watson and Gowdie, 2000). Where comparisons are possible, the calculations in this table agree with the wide range fuel trial data to within 2%.

Calculated Vapour Pressure for Various Blends of LPG

Compound	COMPOSITION (mol fraction)													
	Euro A	Euro B	Blend A2	Blend B	Blend C	Blend CC	Blend D	Blend E	Blend F	Blend G	Blend H	Blend I	Blend J	
ETHENE	0	0	0	0.0006	0.0017	0.001	0.0018	0	0.0004	0.0008	0.0009	0.003	0	
ETHANE	0	0	0.0056	0.0063	0.0114	0.0096	0.0147	0.0112	0.0072	0.0086	0.0077	0.1133	0.0045	
PROPENE	0.0675	0.09	0	0.1086	0.2122	0.1535	0.206	0	0.2955	0.1078	0.1466	0.1422	0	
PROPANE	0.3	0.85	0.5571	0.4312	0.4753	0.5357	0.7679	0.9794	0.6891	0.6035	0.3928	0.1393	0.3876	
BUTENES	0.0225	0.03	0	0	0	0.1433	0	0	0	0	0.0512	0.058	0	
N-BUTANE	0.36	0.015	0.2634	0.2702	0.176	0.0547	0.0029	0.0014	0.0011	0.1644	0.2243	0.3089	0.3574	
ISO-BUTANE	0.25	0.015	0.1732	0.1824	0.1229	0.1006	0.0066	0.008	0.0066	0.1145	0.1758	0.2348	0.2492	
N-PENTANE		0	0.0007	0.0007	0.0005	0.0016	0.0001	0	0.0001	0.0004	0.0007	0.0005	0.0013	



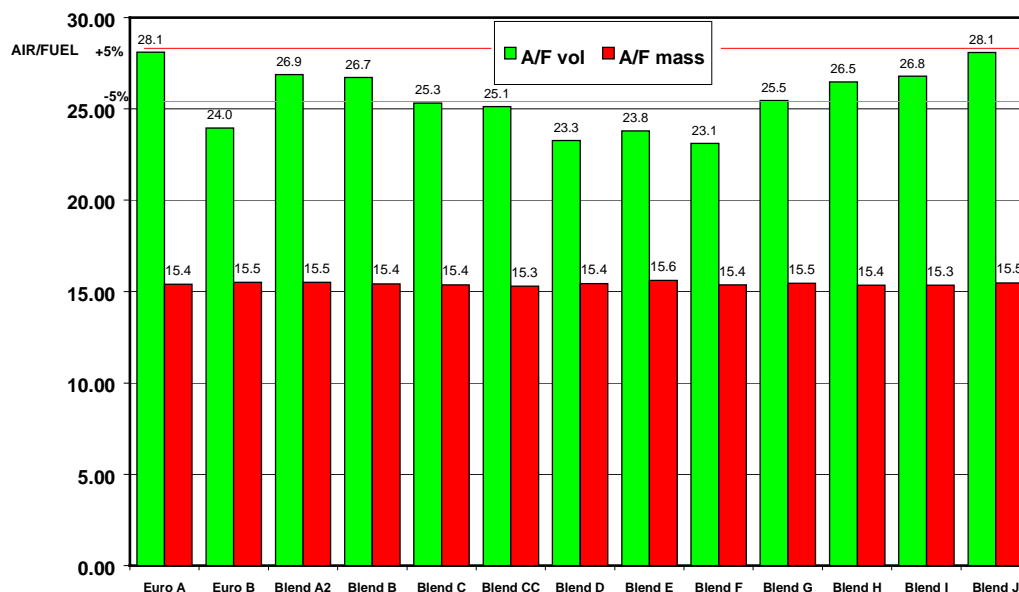
7.7 Appendix G

Examples of the Stoichiometric Air-Fuel Ratio for a Range of Fuels.

The figure below shows the air-fuel ratio by volume as a vapour and by mass for the European Reference Fuels, a fuel representative of an Australian (50:50) reference fuel and the fuels used in ALPGA's Wide Range Fuels Trial. With later European emission legislation (Euro 4) there is a requirement for on-board diagnostic (OBD) systems which identify failure of the emission control system. With gaseous supplied LPG either by carburettor or port injection it will be necessary to have a failure mode identifier on air-fuel ratio in the event that the closed loop control system components such as oxygen sensors become defective. To illustrate typical limit detection, extra grid lines are drawn for the +/- 5% variation in air fuel ratio from the Australian reference fuel. It is plain that some fuels fall outside this limit range suggesting the need for fuel type recognition for the continuance of a wide range of gaseous fuel in the market.

Calculated Stoichiometric Air/Fuel for Various Blends of LPG

Compound	COMPOSITION (mol fraction)												
	Euro A	Euro B	Blend A2	Blend B	Blend C	Blend CC	Blend D	Blend E	Blend F	Blend G	Blend H	Blend I	Blend J
ETHYLENE	0	0	0	0.0006	0.0017	0.001	0.0018	0	0.0004	0.0008	0.0009	0.003	0
ETHANE	0	0	0.0056	0.0063	0.0114	0.0096	0.0147	0.0112	0.0072	0.0086	0.0077	0.1133	0.0045
PROPYLENE	0.0675	0.09	0	0.1086	0.2122	0.1535	0.206	0	0.2955	0.1078	0.1466	0.1422	0
PROPANE	0.3	0.85	0.5571	0.4312	0.4753	0.5357	0.7679	0.9794	0.6891	0.6035	0.3928	0.1393	0.3876
BUTYLENES	0.0225	0.03	0	0	0	0.1433	0	0	0	0	0.0512	0.058	0
N-BUTANE	0.36	0.015	0.2634	0.2702	0.176	0.0547	0.0029	0.0014	0.0011	0.1644	0.2243	0.3089	0.3574
ISO-BUTANE	0.25	0.015	0.1732	0.1824	0.1229	0.1006	0.0066	0.008	0.0066	0.1145	0.1758	0.2348	0.2492
N-PENTANE	0	0	0.0007	0.0007	0.0005	0.0016	0.0001	0	0.0001	0.0004	0.0007	0.0005	0.0013



7.8 Appendix H - Residues

The ALPGA's previous investigation of residues has shown that a wide range of contaminants and other factors that lead to the formation of residues. The investigation concluded that it is "exceedingly clear that a wide range of entry points and agents may be ultimately responsible for residues and therefore any solution is likely to require tackling the problem on several fronts"¹¹³.

In terms of fuel parameters, the investigation recommended that the LPG industry review the specification for LPG production, with particular emphasis on polyaromatic hydrocarbons, olefins, pentanes+, amines and total abrasives/residuals.

The ALPGA has long recognised the serious problem posed by residues in automotive convertors. The current industry standard states that control over residue content is of considerable importance, and sets three parameters to control residue levels.¹¹⁴

Overseas investigations by the ALPGA have also revealed that residues are not a problem confined to Australia, nor to autogas blends including C₄ hydrocarbons and olefins. Japan, Europe and the USA have also yielded a mass of information on residues¹¹⁵. In California, a task force was established in 1997 to examine residues. The work has been somewhat inconclusive, with the task force stating that "the nature of deposits in LPG engines is not well understood and could also be caused by other contaminants not yet identified".¹¹⁶

The Japanese industry has addressed its residue problem by limiting contact between product and rubber hoses, introducing the drainage of convertors as routine maintenance, and by ensuring low residue on evaporation of product entering the supply chain. This example was followed in Australia by the tightening of the ALPGA residue on evaporation limit, and the development (not quite complete at this time) of two industry codes of practice. The first is for the supply chain and outlines "best practice", including limiting the extractable content in rubber hoses. The second is for installers, and advises on good installation and maintenance practice.

As stated earlier the ALPGA has recently embarked on a supply chain study to examine residue levels. Other initiatives taken by the ALPGA in attempts to identify and remedy causes of the problem include:

- The "Review of Auto LP Gas Residue Reference Material" report which covered a wide range of published and unpublished material. It also included some commercial material relating to additives which were claimed to have various benefits in addition to reducing residue problems. Such additives, however, do not appear to have found favour with LP Gas producers or distributors abroad.

¹¹³ Investigation of Residues found in LPG systems - Recommendations

¹¹⁴ ALPGA Specification 2000

¹¹⁵ Delivering LPG Fuel Quality - Don Sargeant

¹¹⁶ Oct/Nov 1999 Propane Vehicle Magazine

- Some small-scale experimental work has been undertaken locally on extraction of plasticisers from hoses and on the possible coating of the interior of hoses with a polymer impervious to LPG. In a more rigorous experimental exercise the diaphragms from a number of convertors in common use were tested in a range of autogas blends typical of the Australian market. No adverse interactions were observed.
- Within the LPG industry numerous attempts have been made to collect information on the occurrence of residue problems, particularly in Victoria. However, the epidemiology of residue outbreaks remains unstudied. Fortunately from anecdotal sources it would appear that there were fewer problems in 2000 than in recent years.

Although it is important to consider limiting residues when developing standards, (particularly 'residue on evaporation') an examination of the casual factors relating to residues is considered outside the scope of the proposal for developing national standards. There have been numerous international and national studies which have failed to conclusively detail the cause of residue formation.