MOTOR VEHICLE POLLUTION IN AUSTRALIA

Supplementary Report No. 1
LPG In-Service Vehicle Emissions Study

prepared by the

NSW Environment Protection Authority

for

Environment Australia

&

Federal Office of Road Safety

May 1997

GPO Box 594
Canberra ACT 2601
Australia

Tel: +61 6 274 7111
Fax: +61 6 274 7714

ACKNOWLEDGMENTS

Environment Australia commissioned the NSW EPA to undertake the LPG In-service Vehicle Emissions Study. The Federal Office of Road Safety was responsible for overall financial and project management of the Study.

The NSW EPA Project Team wishes to acknowledge the considerable support given by a number of organisations over the duration of the study. Particular thanks are extended to the following contributors:

- the thirteen householders who entrusted their private vehicles to the emissions laboratories for testing;
- ALPGA, for providing advice on technical matters, supplying information on the LPG vehicle fleet characteristics and arranging industry support through the coordination of its members;
- DASFleet, for providing new-model ‘replacement’ vehicles at nominal rates for use by the private vehicle owners who agreed to let us test their cars;
- ELGAS Ltd., for supplying and delivering the test fuel (free of charge) to both laboratories;
- NSW Taxi Council and the Victorian Taxi Council for assisting with arrangements to test a variety of taxis from a number of the members;
- NRMA Limited, for providing comprehensive insurance coverage for all ‘replacement’ vehicles and for the provision of roadside service coverage for ‘replacement’ vehicles in NSW;
- RACV Ltd, for the provision of roadside service coverage for all ‘replacement’ vehicles being driven in Victoria;

Other organisations who contributed to the project include:

- AGB McNair
- Boral Transport Maintenance Services (NSW)
- Gameco (NSW) Pty Ltd
- Parnell LPGas Systems Pty Ltd (Victoria)
- Environment Protection Authority (Victoria)

As well as the aforementioned contributions, everyone who became involved in the project - laboratory staff, mechanics, industry bodies, contractors and the people from other State and Federal government bodies - all worked long and hard, often behind the scenes, to make this project a success.

To all of you, our sincere thanks.

Stephen Brown - Project Manager

Mustafa Kadayifci - Project Officer

Michael Faber - Project Officer.

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GLOSSARY

ADR	Australian Design Rule
ADR27	Australian Design Rule on Emission Control for Light Vehicles. For this report, ADR27 incorporates 27A, 27B and 27C as well as the original ADR27.
ADR37	Australian Design Rule (ADR37/00) on Emission Control for Light Vehicles
ADR37/01	The modified ADR37, due to be phased in starting in 1997
ALPGA	Australian Liquefied Petroleum Gas Association
Blend Study	A study commissioned by the EPA to determination of an LPG Certification Test Fuel”
Closed Loop	An EMS that has the ability to analyse the exhaust gases from each piston stroke (through the Oxygen sensor), adjusting the amount of fuel delivered to the engine for optimum engine efficiency and stoichiometric level (see Attachment 5)
CO	Carbon monoxide - a criteria pollutant
DASFleet	Department of Administrative Services (Vehicle Fleet)
EA	Environment Australia (the Federal Government's Environment Department)
EMS	Engine Management System
EPA (Vic)	The Environment Protection Authority of Victoria
FORS	Federal Office of Road Safety
Gross Emitter	A vehicle whose exhaust and/or evaporative emissions are considerably higher than the relevant ADR limit
HC	Hydrocarbons - a criteria pollutant
In-Service	A motor vehicle other than new, that is currently registered
LPG	Liquefied Petroleum Gas
LPG Vehicle	For the purposes of this report, an LPG vehicle is one which is able to operate on either LPG or petrol (dual-fuelled vehicle).
NISE Study	the National In-Service Vehicle Emissions Study carried out by FORS (report titled “Motor Vehicle Pollution in Australia”)
NOx	Oxides of nitrogen - a criteria pollutant
NRMA	National Roads and Motorists Association
NSW EPA	New South Wales Environment Protection Authority
OEM	Original Equipment Manufacturer
Open Loop	the vehicle’s fuel system operation that delivers a “base” quantity of fuel which is determined by engine speed, load and various electronic sensors. Exhaust gases are not analysed (ie no Oxygen Sensor) and therefore, no adjustments are made to achieve stoichiometry (see Attachment 5).
SHED	Sealed Housing for Evaporative Determination.
Stoichiometric	Ideal air/fuel mixture ratio for optimum engine efficiency and exhaust emissions
US EPA	United States Environmental Protection Agency
Venturi	There are two main types of mixer design: Variable Venturi/Fixed Depression - This type of mixer uses an air valve design which responds to the pressure difference created by the engine’s air flow requirements which is controlled by the engine demand. This design utilises a relatively constant pressure drop to the converter diaphragm to draw LPG vapour from cranking to full load.

	Fixed Venturi/Variable Depression - This mixer function creates a depression signal which activates the converter diaphragm so as to deliver LPG vapour to the engine. The higher the engine speed, the greater the depression signal causing a greater gas flow to the engine.
VKT	Vehicle Kilometres Travelled. Usually expressed as the number of kilometres travelled per year for a given set of vehicles.

1. EXECUTIVE SUMMARY

INTRODUCTION

With the increasing interest in alternative fuels and the growth in the LPG dual fuel automotive market, the LPG In-service Vehicle Emissions Study (LPG Study) was undertaken to obtain emissions data from a sample of LPG vehicles, as an adjunct to the National In-service Vehicle Emission (NISE) study. For logistical reasons only petrol fuelled vehicles were tested under the NISE Study.

The NISE Study was completed by the Federal Office of Road Safety (FORS) in 1996. Its principal objectives were to evaluate the emission characteristics of Australia's passenger vehicle fleet and to investigate to what extent pollution control systems deteriorated over time. The results of the NISE Study were published in May 1996 as the *Motor Vehicle Pollution in Australia* Report, which is available from the Federal Office of Road Safety.

The information on the emissions performance of LPG fuelled vehicles provided by the LPG Study is timely, given the introduction from 1997 of tighter emission standards for petrol engined vehicles under Australian Design Rule 37/01. A review of ADR37/01 is also underway which, in part, aims to bring LPG fuelled vehicles supplied by original equipment manufacturers within its scope, thus applying the same emissions standards to both petrol and LPG fuelled cars.

Based on fuel usage figures supplied by the Australian Liquefied Petroleum Gas Association there are approximately 400,000 vehicles of all types operating on LPG fuel in Australia. The number of actual registered vehicles running on LPG is unclear, however it is estimated that approximately 3% of the total car fleet are dual-fuelled (petrol/LPG) vehicles. These vehicles mainly comprise taxis, company fleet vehicles and private vehicles.

Objectives of Study

The LPG Study was commissioned by Environment Australia to:

1. assess the magnitude and characteristics of emissions from the in-service LPG vehicle fleet;

2. assess the potential for reductions in emissions through tuning;

3. compare those emission levels with similar vehicles operating on petrol; and,

4. evaluate the same short emission tests as conducted in the NISE Study for possible inclusion in an inspection/maintenance program.

Method

The LPG study used the same test and vehicle processing protocols as the NISE Study.

Note: Cars tested in the LPG Study fall into two distinct groups that are generally treated separately when analysing test data:

(a) Vehicles manufactured after January 1986 were built to comply with Australian Design Rule ADR 37 and designed to run on unleaded petrol. They generally have computer-controlled engine management systems, fuel injection, and are fitted with catalytic converters.

(b) Cars made between 1974 and 1986 were designed to meet the less stringent ADR 27 and run on leaded petrol, do not have catalytic converters and generally have carburettors rather than fuel injection systems.

A sample of 36 vehicles representative of the in-service LPG fleet were selected comprising 13 taxis, 10 fleet vehicles and 13 private vehicles. The private vehicles were broken up into two subsets of seven vehicles manufactured before 1986 and six manufactured after 1986. A further subset of vehicles was also subjected to evaporative emission tests.

Most of the LPG vehicles tested used the more sophisticated "closed loop" technology, in which the fuel delivery is continuously adjusted via a electronic feedback mechanism from the exhaust system. Some vehicles, mostly from the private fleet, used the older "open loop" technology, where there is no feedback and the air/fuel ratio is manually set at a fixed value.

Tests ranged from the complex and time consuming ADR certification test protocol (to which vehicle manufacturers have to comply to supply vehicles to the Australian market), to the simplest checks which can be done with minimal equipment at a repair shop. Each vehicle was tested both in its "as received" condition and then again after tuning and minor repairs had been carried out. A 60/40 blend of propane/butane was used as the test fuel. This is representative of that available in the Sydney and Melbourne metropolitan areas.

The tuning of vehicles was carried out as would be performed in a typical LPG repairer workshop to optimise the vehicle for operation on LPG. The vehicle's air filter, spark plugs, points (if applicable) and oil were routinely replaced however the focus was on repairing faults rather than replacing components.

KEY FINDINGS

The key findings of the LPG Study are listed below.

Emissions from LPG Vehicles

The emissions measured in the LPG Study were the four emissions regulated by the ADRs for petrol engined vehicles. These are exhaust emissions of carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen (NOx), and evaporative hydrocarbon emissions.

1. The majority of the LPG vehicles tested were able to meet the relevant ADR exhaust emission limits for which the vehicles were designed.
2. Company fleet vehicles, on average, were the lowest emitters of CO and HC, whilst private vehicles were the highest emitters. Average NOx emissions were similar in all categories.
3. “Gross emitting” vehicles (those emitting many times above ADR limits) existed across all categories.
4. Of the seven vehicles which underwent evaporative emission tests, only one result was under the ADR limit. Those vehicles which failed the test emitted from three to more than thirty times the limit. Both the LPG and petrol fuel systems on a vehicle can contribute to evaporative emissions in a dual fuelled vehicle. A speciation test conducted on one vehicle with high evaporative HC emissions revealed that most of these emissions from this vehicle were derived from the petrol fuel system.
5. Taxis and company fleet vehicles had an LPG fuel consumption rate of approximately 18 L/100 km, whilst private vehicles operated at approximately 20 L/100 km.

Comparison with the Petrol Fleet (NISE Study results)

Similar make and model vehicles (Holden Commodores and Ford Falcons) from the NISE study have been used when comparing the two fuel types. The difference in sample size between the two fleets (36 LPG vehicles, 129 Petrol vehicles) should be considered when comparisons are made between the two fuel types. The key findings in this comparison were:

1. The average evaporative emissions from LPG vehicles were more than twice those of similar petrol vehicles from the NISE study.

2. The older (pre 1986) vehicles emitted slightly lower emissions of CO, HC and NOx than NISE study petrol vehicles of similar make and model.

3. Newer (post 1986) vehicles also emitted less HC emissions, but slightly higher CO and NOx, than NISE study petrol vehicles of similar make and model.

Effects of Tuning and Maintenance on Emission Levels

1. Tuning of both older (pre-1986) and newer (post-1986) vehicles with open loop systems had a significant effect on reducing CO and HC emissions, while NOx emissions increased (significantly for older and marginally for newer vehicles) after tuning.

2. Whilst vehicles with open loop systems benefited substantially from tuning, tuning had a minimal impact on CO, HC and NOx emissions from vehicles with closed loop systems.

3. The pre-tune HC and CO emission levels on vehicles with closed loop systems are significantly lower than vehicles with open loop systems.

4. Tuning did not have a significant effect on reducing evaporative emissions, which on occasion were slightly higher after tuning.

5. The average cost for tuning and minor maintenance regime undertaken in the Study was $260, compared to $220 for similar vehicles in the NISE Study.

6. The fuel consumption of these vehicles was reduced by an average of twelve percent after tuning.

Short Emission Test Performance

A long-standing goal for governments seeking to reduce vehicle pollution has been to develop a short test that reliably identifies high polluting vehicles. To address this all vehicles in the NISE study were tested using a number of short tests both prior to and after tuning.

The vehicles in the LPG Study were subjected to the same short tests. The tests were:

IM-240 - Modified IM240 (Inspection & Maintenance) Test Procedure

This test is based on the first four minutes of the ADR37/00 certification test cycle and covers about 2km total distance. Emission results are converted to grams per kilometre for HC, CO and NOx.

ASM - Acceleration Simulation Mode Test Procedure (ASM2525)

The vehicle is driven on a chassis dynamometer at a speed of 40km/h. Concentrations of raw exhaust emissions of HC, CO and NOx are measured.

SS60 - Steady State Loaded 60km/h

The vehicle is driven on a chassis dynamometer at a constant 60km/h. Emissions of HC, CO and NOx are measured.

HIGH IDLE - Steady State High Idle Test Procedure

With the engine running at a speed of 2500 rpm the concentrations of raw exhaust emissions are measured for HC and CO.

IDLE - Steady State Idle Test Procedure

With the engine running at idle speed (accelerator not depressed) the concentrations of raw exhaust emissions are measured for HC and CO.

For each vehicle tested, the results of the short tests have been compared with the ADR certification test results obtained from that vehicle. The results of these comparisons follow.

1. The IM-240 test was found to correlate best with the ADR certification test.

2. The loaded steady state SS60 and ASM25/25 tests show a better correlation with ADR certification test than the idle and high idle tests.

SUMMARY

The study produced diverse information regarding the emission characteristics and the deterioration of pollution control systems of the LPG in-service fleet. The study also highlighted deficiencies in the data available on the make up and operation of the LPG fleet. While these shortcomings did not affect this Study directly, they do limit the capacity to use the Study results to accurately estimate LPG vehicle impacts on urban air quality.
The following points summarise the emissions picture for dual fuelled (petrol/LPG) vehicles when operated on LPG:

- There were 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

- Most of the vehicles exceeded the evaporative emissions standards applicable to comparable petrol engined vehicles by a wide margin

- Tuning and minor maintenance improved HC and CO emissions and fuel consumption on most vehicles, but the benefits were not evenly distributed. Tuning did not improve NOx or evaporative emissions.

- The in-service tests based on the use of a dynamometer were the most effective.

MAIN REPORT

2. BACKGROUND

With the increasing need to find solutions for improved urban air quality, the potential emission reductions from the in-service motor vehicle fleet (LPG, petrol and diesel vehicles) has become a key element in environmental planners' vehicle emission control strategies.

The Federal *Motor Vehicle Standards Act 1989* gives legal effect to the Australian Design Rules (ADRs) as national standards for motor vehicles, covering vehicle safety and emissions. The current standard covering 'emission control for light vehicles', is ADR 37/00 which applies to the design and construction of all petrol fuelled passenger cars (and derivatives). ADR 37/00 does not apply to fuels other than petrol.

Australian Design Rules are frequently being reviewed. The review of ADR 37/00 has lead to modifications which have been incorporated in ADR 37/01 due to be implemented in 1997. The primary objective of ADR37/01 is to reduce the emission limits for new vehicles. One of the issues being considered for the next review of ADR37 (ie ADR 37/XX), is the inclusion of emissions limits for new vehicles manufactured to operate on alternative fuels such as LPG, as current in-service LPG vehicles are not required to conform to any emission standards. The inclusion of LPG emission limits is timely due to the increasing number of vehicles using LPG and the growth in annual VKT of these vehicles.

The proposed Inspection & Maintenance program for NSW is currently being designed to include emission testing of LPG vehicles as well as other alternative fuelled vehicles. This program will require in-service vehicles to be tested for emissions as part of a registration check and thus endeavouring to maintain emission levels to those the vehicles was designed to meet.

Accurate data on the number of LPG vehicles in Australia is currently unavailable. Estimates range between 135 000 (ABS data) to 400 000 (ALPGA estimate). This discrepancy is possibly due to the different methods used in calculating the number of vehicles operating on LPG.

The ABS' figures are derived from vehicle registrations from each state (Although NSW and the ACT are the only two states/territories that have accurate records on the number of LPG vehicles). This data indicates that over 76 percent of LPG vehicles are registered in NSW and Victoria.

The ALPGA's figure of 400 000 is derived through fuel sales to the automotive market. Due to many LPG vehicles (taxis, fleet vehicles etc.) travelling a high number of annual kilometres (referred to as Vehicle Kilometres Travelled - VKT), and the questions regarding the number of LPG vehicles outside NSW and the ACT, the actual number of LPG vehicles could be anywhere between these two estimates.

Table 1: Estimates of the number of LPG vehicles in Australia

Source	Year	Passenger Vehicles	Total Vehicles[1]
'LPG Motor Fuels' paper presented at SAE Conference *Motor Vehicles & the Environment*	1993	-	250 000
ABS[2] 'Motor Vehicle Census Australia'	1993	43 000	60 500
ABS 'Motor Vehicle Census Australia'	1995	98 500	136 500
ALPGA	1996	-	400 000

Whilst the potential emission advantages from using LPG have been well documented from studies overseas (US EPA, 1995; Hollemans *et al.*, 1995), after-market vehicle conversions to dual fuel operation do not fully utilise this potential. While some progress has been made with the introduction of closed loop fuel management systems for new vehicles, concerns still exist regarding the emission performance of the LPG in-service fleet.

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[1] LPG registered vehicles including trucks.

[2] NSW and the ACT are the only states/territories that keep accurate records on LPG conversions and dual fuelled vehicles.

3. INTRODUCTION

The NSW EPA was commissioned by EA in September 1995, to carry out a study into the LPG in-service fleet using test procedures similar to those used in the NISE Study.

EA utilised FORS' experience from managing the NISE Study to provide overall financial and project management for the study. EPA (Vic) was in turn contracted by NSW EPA to carry out a portion of the emission testing work.

A steering committee comprising EA, FORS, ALPGA, EPA (Vic) and NSW EPA was assembled to oversee the study and ensure that the objectives were met.

3.1 PRECEDING STUDIES TO THE LPG IN-SERVICE STUDY:

The LPG In-Service Emission study was designed to complement the NISE Study and utilise the information obtained from the LPG Blend Study.

LPG Blend Study:

In 1995, EA contracted the NSW EPA to evaluate the effect on vehicle exhaust emissions and engine performance of different propane/butane LPG mixes. From this information a standard LPG test fuel (consisting of a 50 percent propane and 50 percent butane mix) was recommended for use as a certification fuel for future ADR testing requirements. Commercially available LPG blends range from a 60/40 mix of propane/butane to 100 percent propane (refer 5.2 for the test fuel used in the Study).

NISE Study:

The NISE study conducted by FORS evaluated the emission characteristics of the petrol in-service passenger vehicle fleet, assessed the effects of maintenance, and determined the correlation between ADR Certification Tests and a number of short emission tests.

LPG vehicles were originally included in the NISE study, however were later excluded due to logistical difficulties in tuning to manufacturer's (ie petrol) specifications (a requirement of the study). The LPG Study required vehicles to be tuned by a licensed LPG mechanic for optimised operation using LPG rather than to the vehicle manufacturer's specifications.

3.2 LPG STUDY OBJECTIVES

The following objectives were identified and met:

i) To give an indication of the magnitude and characteristics of emissions produced from the LPG in-service fleet.

ii) To assess the potential for reductions in emissions from the LPG in-service fleet from regular maintenance; and

iii) To compare the emission levels from LPG vehicles to those operating on petrol only. Comparisons to be made with the vehicles tested in the NISE Study.

iv) To evaluate various short emission tests (compared to ADR Certification Tests) for possible inclusion in an Inspection/Maintenance Program. These tests were to be conducted using the same methodologies used in the NISE Study.

3.3 PARTIES INVOLVED

The roles of the organisations that participated in the study are listed below:

3.3.1 Management

Environment Australia (EA
)

Responsible for the commissioning and funding of the study, and providing input into the Steering Committee.

Federal Office of Road Safety (FORS)

Appointed by EA to provide financial management and to oversee the design and implementation of the study in accordance with the agreed management plan. FORS was also responsible for the publication of the final report. A member and contributor to the Steering Committee.

NSW Environment Protection Authority

The NSW EPA was responsible for initially proposing the Study for Federal funding consideration. As Project Managers the Motor Vehicle Testing Unit chaired the Steering Committee and coordinated all aspects of the Study including design, execution, data analysis and final reporting. The testing laboratory was responsible for developing the test procedures, sourcing, tuning and testing 14 of the 36 vehicles involved in the Study.

Environment Protection Authority (Victoria)

EPA (Vic) played a significant role in assisting the NSW EPA with the design, test procedure development and execution of the Study. EPA (Vic) were sub-contracted to the NSW EPA to carry out emission testing of 22 vehicles, including vehicle sourcing, tuning and data processing.

A member and contributor to the Steering Committee.

Australian Liquefied Petroleum Gas Association (ALPGA)

The ALPGA provided advice on technical matters, information on the LPG vehicle fleet characteristics and arranged industry support through the coordination of its members. The assistance and contribution in kind provided by the ALPGA was received by both NSW and Victorian testing laboratories. A member and contributor to the Steering Committee.

3.3.2 Contributors

Boral Transport Maintenance Services (NSW) and Parnell LPGas Systems Pty Ltd (Victoria)

Both companies provided licensed mechanics and replacement parts for tuning the test vehicles, connected flexible hosing for test fuel cylinders and provided technical advice to the testing laboratories.

ELGAS Ltd

Supplied and delivered all test fuel (free of charge) to each laboratory.

AGB McNair

As in the case of the NISE study, AGB McNair provided details on privately owned LPG fuelled vehicles who, following a telephone interview, agreed to have their vehicle participate in the study.

NSW Taxi Council & Victorian Taxi Council

Both Taxi Councils assisted in obtaining the much needed support from individual taxi company operators to participate in the study by providing vehicles for testing.

DASFleet

Provided vehicles to both the NSW and Victorian laboratories to use as replacement vehicles in exchange for LPG test vehicles.

Gameco (NSW) Pty Ltd

Provided LPG fittings to NSW EPA and technicians to connect and disconnect the test-fuel LPG cylinder prior to and after testing.

NRMA Limited

As in the NISE study, the NRMA provided insurance coverage for the replacement vehicles used by EPA (Vic) and NSW EPA.

4. STUDY OUTLINE

4.1 SCOPE

The study involved testing 36 vehicles ranging in make, model, age and usage that were considered to represent the current LPG vehicle fleet.

Each vehicle tested was subjected to the same protocols used in the NISE study to enable comparisons to be made with the petrol fleet. These protocols were:

- All vehicles underwent emission tests prior to, and following, a tune-up.
- The testing schedule included ADR37 (incorporating ADR27[3]), IM-240, SS60, ASM25/25, High Speed Idle and Low Speed Idle emission tests (these tests are described fully in Attachment 3).
- Seven of the vehicles were subjected to evaporative HC emission (SHED) tests.
- The tuning of vehicles was restricted to the level of work received from a typical commercial workshop within the LPG industry.
- Tests were conducted using commercially available fuel.

As previously stated, the NSW EPA was responsible for the design and management of the study; however, the execution of the study was carried out in partnership with EPA (Vic). Due to limited laboratory testing time available in NSW and because the majority of LPG vehicles operate in Victoria, the Vehicle Emissions Laboratory of EPA (Vic) was subcontracted to test 22 of the 36 vehicles.

Each laboratory (NSW and Victoria) was responsible for coordinating the collection and return of test vehicles, tuning, emission testing and data collection as detailed in the following section.

4.2 PHASES OF THE STUDY

The study was divided into the following phases:

i) Sample Design
ii) Vehicle Survey & Sourcing
iii) Vehicle Processing, Testing and Servicing
iv) Data Handling and Reporting

Throughout the study, the project team maintained, as practically as possible, the methodologies and test protocols used during the NISE Study, including testing, data handling and reporting.

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3 For the purposes of simplicity of presenting results, ADR27, A, B and C emission standards are referred to as ADR27.

4.2.1 Sample Design

The sample design phase ensured an appropriate representation (albeit limited in terms of sample size) of the LPG fleet was tested. Following extensive discussions with the ALPGA regarding the composition of the LPG fleet and review of fleet statistics, vehicles were categorised into three groups - Private, Fleet and Taxis. Table 2 lists which vehicles were tested at the NSW and Victorian laboratories.

Table 2: Type of Vehicles tested at specific laboratory

	Vehicle Category			
Laboratory	**Private**	**Fleet**	**Taxi**	**Total**
NSW	6	0	8	**14**
Victoria	7	10	5	**22**
Total	**13**	**10**	**13**	**36**

A search of LPG fleet statistics (vehicle age, make, model, kilometres travelled, conversion kit types and fuel usage patterns) was undertaken by both NSW and Victoria. Both States found that information regarding the composition of the LPG fleet and fuel usage was poor and inaccurate. Therefore the design of the sample was primarily carried out using fleet information (refer to page 8 for details) obtained through detailed discussions with State representatives of the ALPGA. Data from the Australian Bureau of Statistics and State transport agencies was used as background information only.

Note: The limited data on the LPG fleet held by government agencies is of concern and has been noted in the key findings.

From this information, a comprehensive matrix of the LPG fleet encompassing vehicle models and conversion kit types was developed and proportioned between the two testing laboratories. The vehicles selected in the matrix were manufactured by either Ford or Holden and having either six or eight cylinder engines. This type of vehicle is most suitable for LPG conversion (ie. a large vehicle with adequate space to install an LPG cylinder).

The following points were also considered in developing the test-vehicle matrix (refer to Table 3 and 4):

- ratios of different vehicle manufacturers and models
- conversion kit type - fixed or variable venturi
- range of vehicle ages and manufactured to meet the relevant emission standards of ADR27,A,B,C or ADR37
- odometer reading
- maintenance history

Table 3: EPA Victoria's test vehicle matrix.

Vehicle Source	**LPG Conversion Kit Type**	**Holden**	**Ford**
Private (7)	Random sample (7)	3 Pre-1986 & 4 Post-1986	
Fleet (10)	Fixed Venturi* (4)	1	3
	Variable Venturi* (6)	3	3
Taxi (5)	Fixed Venturi (3)	1	2
	Variable Venturi (2)	-	2

Table 4: NSW EPA's test vehicle matrix.

Vehicle Source	**LPG Conversion Kit Type**	**Holden**	**Ford**
Private (6)	Random Sample (6)	3 Pre-1986 & 3 Post-1986	
Taxi (8)	Fixed Venturi (1)	1	-
	Variable Venturi (7)	-	7

* Refer to the Glossary for definitions of terms.

There is an emphasis on Taxi and Fleet vehicles manufactured after 1986. This is because taxis and fleet vehicles both comprise a large portion of the fleet (refer to information from the ALPGA below), perform a large portion of the total kilometres travelled and are generally only a few years old. All taxi and fleet vehicles tested in this study were manufactured to meet the ADR37 emission standards.

Information on the current LPG vehicle fleet obtained from the ALPGA:

Taxis:

- 100 percent manufactured to ADR37 (post 1986)
- 85 percent manufactured by Ford
- 70 percent fixed venturi, 30 percent variable venturi conversion kit type

Fleet:

- 10 percent manufactured to ADR27 (pre 1986), 90 percent to ADR37 (post 1986)
- 60 percent Ford, 40 percent Holden
- Ford; 50 percent fitted with fixed venturi type conversion kits 50 percent variable.

- Holden; 40 percent fitted with fixed venturi type conversion kits; 60 percent variable.

Private:

- 50 percent manufactured to ADR27 (pre 1986); majority fitted with variable venturi type conversion kits.
- 50 percent manufactured to ADR37 (post 1986); majority fitted with fixed venturi type conversion kits.

4.2.2 Vehicle Survey & Sourcing

Vehicles were sourced from the Sydney and Melbourne metropolitan areas. The following methods were used to obtain vehicles.

Private Vehicles

The Private Vehicles were sourced through a random survey of householders in the Sydney and Melbourne metropolitan region (which included the Central Coast in NSW). A consultant, AGB McNair, gathered various data including the type of vehicle, the owner's name, address and a contact phone number via a random telephone survey. The owner was then contacted by way of an introductory letter from FORS explaining the purpose of the study (see Attachment 1). The letter was followed up with a telephone call from the respective laboratory, and arrangements made to test the vehicle. The owners were provided with a replacement vehicle whilst their vehicle was being tested which was generally for a period of three days.

Fleet Vehicles

Fleet vehicles were sourced through ALPGA members. A maximum of two vehicles were selected from each company nominated by the ALPGA, to obtain a wide cross section of the fleet. A mix of vehicle make, model, age and level of maintenance was obtained.

Taxis

Taxis were sourced with the assistance of state Taxi Councils. A representative from the Taxi Council explained the purpose of the testing to its respective members (taxi companies) before being contacted by the relevant testing laboratory. A maximum of three taxis were tested from each company in order to maximise the representation of the taxi fleet. Additionally, each taxi company was requested to supply taxis with odometer readings above 150,000 kilometres, which would be indicative of the fleet. A hire fee was paid to the taxi operators for the use of their vehicles.

4.2.3 Vehicle Processing, Testing and Servicing

Vehicle Processing

Prior to exchanging the owners vehicle with a replacement vehicle, an inspection checklist and a vehicle handover form was completed and signed by both the owner of the vehicle and a representative from the testing laboratory (see Attachment 4a and 4b). Replacement vehicles for the taxis were not supplied to Taxi companies as a hire fee was paid for the use of these vehicles.

Vehicles were returned to all owners with a full tank of LPG. The vehicle was cleaned (inside and out) and any parts replaced during servicing (eg. spark plugs, air filter, etc.) were returned to the owner with the vehicle.

The owners were also provided with a test sheet detailing:

- Any repairs/replacement/adjustments made as part of the tuning; and
- Results from the ADR 37/00 Exhaust Emission test, including fuel economy, with a comparison to ADR 27 or ADR 37/00 limits the vehicle was required to meet when new.

Vehicle Testing Procedure

Vehicles were tested both in the “as received” condition (Pre-Tune) and again after servicing/tuning (Post-Tune). Tuning was carried out to optimise the vehicle’s operation on LPG and not to vehicle manufacturers original specifications (as performed in the NISE study).

All tests were carried out in accordance with the NISE Study test procedures. However, to accommodate the specific differences of the LPG fuel system, minor changes to fuel and vehicle preparation were necessary. The two most significant changes are outlined below, (refer Attachments 2 and 3 for a full description of the test procedures).

- The vehicles petrol tank was filled to 40 percent capacity using the commercial grade fuel used during the NISE Study, in accordance with ADR regulations. The vehicle’s integral LPG fuel tank was bypassed by closing the outlet tap on the cylinder and connecting a flexible line from a point downstream of the tap to an external cylinder containing the LPG test fuel. The external test cylinder was secured in the boot of the vehicle behind the vehicle’s integral tank during all phases of testing, including evaporative emission tests.
- The LPG was not heated during the diurnal stage of the SHED test; however the petrol tank was heated in accordance with ADR specifications.

Each vehicle was subjected to the following tests and emissions recorded for both the Pre and Post-tune condition as listed in Table 5.

Table 5: Emission Tests Conducted in the Study

Name of Test	**Data Recorded**
ADR37 Exhaust Emissions (& includes the corresponding ADR27 test)	CO, HC, NOx, CO_2, Fuel Consumption
ADR37 Evaporative Emissions (& includes the corresponding ADR27 test)	Total HC (only 6 of the 36 vehicles were tested for evaporative emissions)
IM-240	CO, HC, NOx, CO_2
Steady State Loaded (SS60)	CO, HC, NOx, CO_2
Acceleration Simulation Mode (ASM-25/25)	CO, HC, NOx, CO_2
Steady State (Idle)	CO, HC, CO_2
Steady State (High Idle @ 2500 rpm)	CO, HC, CO_2

Vehicle Servicing

Prior to testing, vehicles were inspected by the participating licensed LPG servicing organisation to identify any problems and parts required for replacement. The vehicle was then driven to the testing laboratory. The external test fuel cylinder was installed and checked for leaks in readiness for the Pre-tune emission test.

Following Pre-tune emission testing, defective parts were replaced and the vehicle tuned for optimum operation on LPG by the LPG servicing organisation. Tuning of the vehicles was carried out using the LPG test fuel. The following parts were routinely replaced on all vehicles:

- oil (using SG20W-50 oil) and oil filter
- air filter
- spark plugs (including adjusting gap)
- points (where fitted)

A “replacement parts” budget of approximately $150 was set for each vehicle. Replacement of major components (eg catalytic converter) was carried out on an individual assessment basis and within the total study fund limitations. In order to reflect normal workshop practise, all major components were, where possible, repaired or adjusted rather than replaced.

If a vehicle was supplied without a catalyst or with one inoperative, it was tested as received. A new catalyst was then fitted (as part of the tune) and the vehicle retested.

The following items were inspected (and if necessary, replaced) during the pre-tune inspection:

- Distributor condition and operation
- LPG stepper motor operation
- Ignition timing where applicable
- Hoses and other items of the fuel, electrical and emission control systems as necessary.

The vehicle computer was also interrogated for faults. All work carried out by the licensed LPG servicing organisation was covered by the normal industry warranty conditions.

4.2.4 Data Handling and Reporting

Emissions and fuel consumption results were calculated by each laboratory using the appropriate hydrocarbon fuel fractions and fuel densities for the specified LPG blend.

Once the results were verified by the respective laboratories, the NSW EPA collated all results into one database for analysis.

Comparisons between the two fuel types (LPG and Petrol) was carried out using relevant test results specific to Ford Falcons and Holden Commodores extracted from the NISE data base. This sub set was further filtered so that only vehicles manufactured during the same years as the LPG vehicles were included. While this enabled comparisons to be made between the LPG Study results and the petrol NISE Study results, the sample size of LPG vehicles was several times smaller than the NISE petrol vehicles and should therefore be taken into account when viewing results.

5. TEST FUEL

5.1 LPG AS A FUEL

LPG has been used as a transport fuel in Australia since the 1970s, particularly in taxis and vehicles operating indoors (forklifts). It is sold commercially to the automotive market as a mixture of propane and butane (unregulated but is usually either 100 percent propane or a 60/40 blend). The domestic market is regulated and supplied with 100 percent propane. Small amounts of other gases (ethane, propylene and butylene) are also occasionally included in the mixture.

At ambient temperature and pressure, LPG is a gas. Automotive LPG is converted to liquid form by increasing the pressure inside the storage cylinders to approximately eight atmospheres. LPG can also be converted to a liquid form through cooling, although the high costs involved mean this method is rarely used.

LPG is stored in motor vehicles in its liquid form in a certified cylindrical pressure tank. It is converted to gaseous form via the vehicles regulator before being supplied to the gas-air mixer and directed into the combustion chamber of the engine.

Due to the supply and demand characteristics and the locations at which propane and butane occur naturally, different States are supplied with varying proportions of the gases within the automotive market. According to the ALPGA, the major metropolitan cities on the east and south-eastern coasts of Australia, are usually supplied with a 60/40 blend whilst rural areas in the east and most of the central and western regions of Australia are supplied with 100 percent propane. However, these blends vary according to current supply and demand.

5.2 TEST FUEL USED

The LPG Blend Study (referred to earlier in this report - see section 3.1) reported that different variations in fuel blends had a significant effect on CO emission levels. The report also recommended a mix of 50:50 be considered as a certification test fuel. However, An LPG blend of 60 percent propane and 40 percent butane (60/40 blend) was chosen as the test fuel as this is the blend that is commercially available in metropolitan NSW and Victoria.

All fuel used by both the NSW and Victorian Testing Facilities was supplied by ELGAS. The LPG blend was prepared in new cylinders with a Propane/Butane ratio tolerance of three percent (ie 60 to 63 percent by volume) propane to limit the variation in vehicle emissions due to fuel composition.

6. AUSTRALIAN DESIGN RULES

6.1 BASELINE TEST CYCLE - EXHAUST EMISSIONS

To demonstrate compliance with the relevant ADRs, exhaust emissions are measured using a rolling road (chassis) dynamometer capable of simulating engine load/speed conditions similar to those typically found in city driving conditions.

By "driving" the car on the dynamometer to a pre-determined and tightly controlled cycle of acceleration, cruise and braking, together with idle periods to simulate stationary traffic periods, an accurate and repeatable measurement of exhaust emissions is possible. Several such test cycles are used around the world.

The ADRs require that certification testing be done using a transient cycle, which simulates driving a distance of 12 km at speeds up to 94 km/h. It is described fully in Attachment 3. The current emission test procedure in use in Australia is the ADR37 drive cycle. This was the baseline test cycle used in both this study and NISE study (where it was referred to as the FTP) and is the test to which vehicles must comply when new.

6.2 EVAPORATIVE EMISSIONS MEASUREMENTS

In addition to tailpipe emissions, new vehicles are required to undergo a test to measure evaporative emissions of hydrocarbons. These emissions are measured by placing the vehicle in a sealed "room" and measuring the change in hydrocarbon levels in the room's atmosphere. The test is known as a "**SHED**" (**S**ealed **H**ousing for **E**vaporative **D**etermination) test and is conducted in three phases.

Stage one - Diurnal Soak: simulates the effect of a cold vehicle (engine is cold to touch) which is gradually heated as the temperature rises on a summer day. Since the entire LPG fuel system operates under pressure, evaporative emissions from this fuel system should be zero, regardless of the temperature of the fuel (the results indicate that this may not be the case). Therefore only the petrol fuel tank was heated (see Attachment 2 for details). After pre-conditioning by driving an ADR cycle, the vehicle is "soaked" for a minimum of twelve hours in controlled ambient conditions of $25 \pm 5^{o}C$. Without starting the engine, the vehicle, with the test-fuel cylinder connected and positioned in the boot, is moved into the SHED and the room sealed. Evaporative emissions are calculated by the change in hydrocarbon levels measured over a one hour period as the fuel in the petrol tank is heated from approximately $16^{O}C$ to $29^{O}C$.

Stage two - Drive Cycle: Following the diurnal soak, the vehicle is driven as per the ADR test cycle and exhaust emissions measured. Immediately after the drive cycle is completed, the vehicle is moved back into the SHED for the hot soak stage.

Stage three - Hot Soak: This stage simulates the effect of parking a hot vehicle at the end of a journey (from home to the shops, for example) or in case of the ADR at the end of the drive cycle. The engine and fuel is hot, rather than cold as the case in stage one. Evaporative emissions are calculated by the change in hydrocarbon levels over a one hour period. The fuel tank (LPG or petrol) is not heated in this stage.

The results for stage one and two are summed and recorded as the resulting grams of hydrocarbons emitted by the vehicle (in grams per test).

6.3 AUSTRALIAN DESIGN RULE (ADRS) LIMITS

Not all vehicles manufactured prior to July 1976 are required to comply with emission standards. However, from this date onwards, all petrol passenger vehicles (and derivatives) were required, when new, to comply with a performance standard (ADR) that set limits for exhaust emissions of:

- Hydrocarbons (HC)
- Oxides of Nitrogen (NOx)
- Carbon Monoxide (CO)

The Australian Design Rules also set maximum limits for evaporative emissions of total hydrocarbons, including emissions from the fuel system, engine, paintwork, and interior of the vehicle.

Cars tested in this study, were manufactured according to one of five Australian Design Rules introduced since 1976:

- ADR27, 27A, 27B and 27C applied to vehicles manufactured from July 1976 to January 1986.
- ADR37/00 covers the period from February 1986 to the present.

The emission limits set by these standards are shown in Table 6:

Table 6: Emission Limits for Passenger Vehicles

Standard	**HC (g/km)**	**CO (g/km)**	**NOx (g/km)**	**Evap (g/test)**
ADR27 A,B & C*	2.1	24.2	1.9	6.0**
ADR37	0.93	9.3	1.93	2.0
ADR37/01***	0.26	2.1	0.63	2.0

* From 1/7/76 only
** From 1/1/82 onwards
*** Phased in from 1/1/97

7. RESULTS

7.1 INTRODUCTION

Results, where practical, have been presented for each vehicle rather than as an average to avoid fleet generalisation and to highlight the degree of scatter between vehicles.

When viewing results, the following coding applies to identify individual vehicles, their fleet category and the laboratory at which they were tested:

- Fleet (F) vehicles tested at Victorian lab (V): FV01 to FV10
- Taxi (T) vehicles tested at Victorian (V) or NSW (N) lab: TV01 to TV05, TN06 to TN13
- Private (P) vehicles tested at : Victorian (V) or NSW (N) lab: PV01 to PV07, PN08 to PN13

For the purposes of simplicity of presenting results, ADR27/A/B/C emission standards are referred to as ADR27 in all illustrations.

7.2 FORMAT OF RESULTS

The results have been presented in such a way that initially show the emissions performance of the LPG sample fleet as a whole, including the magnitude and certain characteristics of exhaust emission levels, and to what extent did tuning reduce the vehicles' exhaust and evaporative emissions.

Following an overall picture, the data is then broken down into vehicle categories (private (ADR27 and ADR37 vehicles), fleet vehicles and taxis). This method identified any problems that may be isolated to certain sections of the LPG vehicle industry.

Comparisons were also made with the NISE Study petrol fleet. By doing this, questions regarding the LPG in-service vehicles' performed in relation to the petrol fleet could be investigated.

After tuning, several vehicles showed abnormal results. These results were used as case studies to highlight some of the potential problems that can affect emissions on LPG vehicles. These case studies investigated:

- Incorrect Tuning of Vehicle
- Faulty Engine Management System
- Disconnected Vacuum Hose
- High Evaporative Emissions

7.3 CHARACTERISATION OF EXHAUST EMISSIONS BY VEHICLE CATEGORY VS ADR LIMITS

Vehicle category results have been presented in Figure 7-1 to illustrate the characteristics of the LPG fleet while also showing the variation between vehicles and the comparison to the relevant ADR limits. The horizontal lines on the figures are the ADR limits applicable to the vehicle when new. The difference in the ADR limits reflect the change to unleaded fuel and the advancement in emission control technology.

Only the Private Vehicle category contained vehicles manufactured prior to and after 1986 and thus referred to both ADR27 and ADR37 limits. The Fleet vehicles and Taxis were all manufactured after 1986 reflecting the nature of the current in-service fleet and therefore only the ADR37 limits apply.

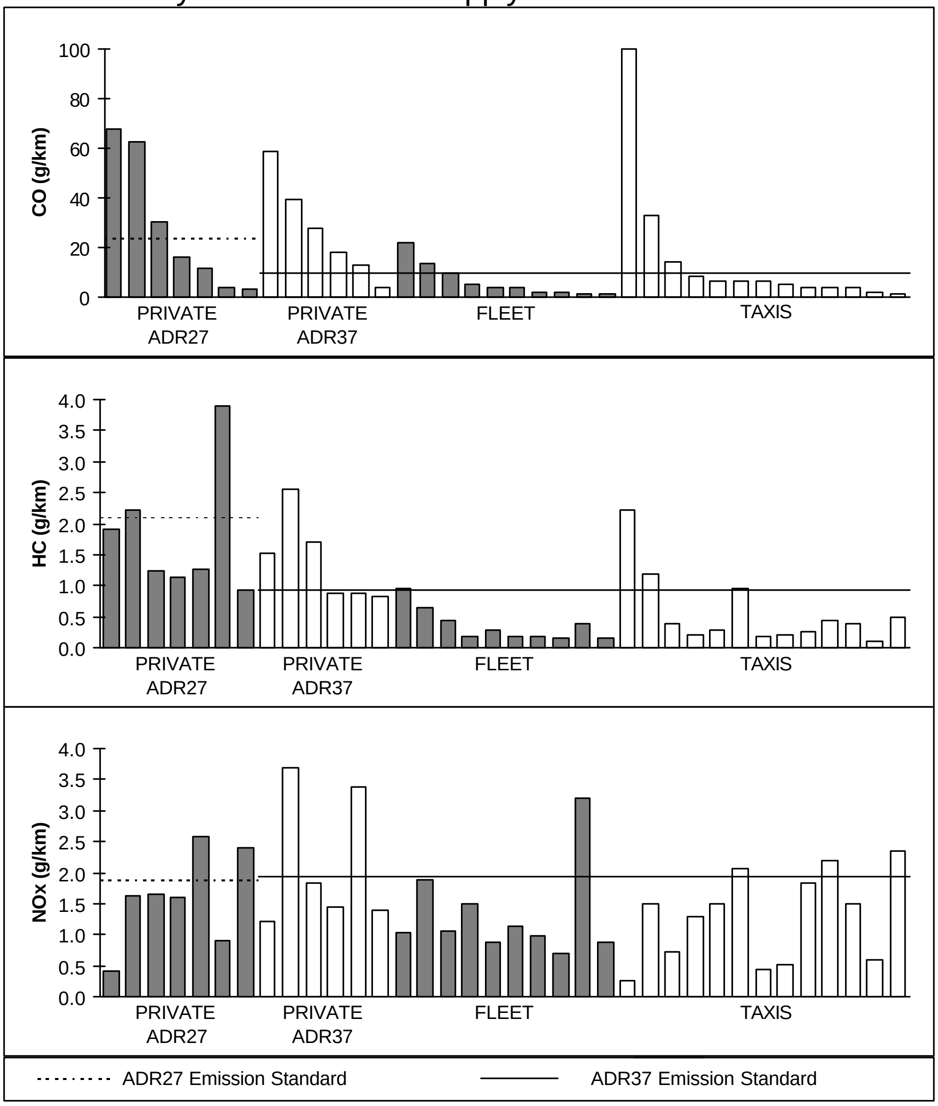


Figure 7-1: Vehicle Categories in “as received “condition vs ADR limits

All vehicles are shown in their "as received" or Pre-tune condition. Each bar represents results from a specific vehicle tested and arranged in each category by decreasing magnitude of CO emissions.

Key Findings

- Fleet vehicles are generally the lowest emitters of CO and HC while Private vehicles are generally the highest emitters.
- The majority of vehicles tested recorded emission levels that were below the ADR limits for which they were designed to comply.
- All categories had at least one "gross emitting" vehicle with at least one pollutant far above the ADR limit.

7.4 Maintenance of Vehicle Fleet

7.4.1 Effectiveness of tuning on tailpipe emission levels

The extent to which the vehicles were "tuned" varied slightly depending on the conversion kit type and vehicle age; however the work constituted optimising the engine for operation on LPG as would be performed in a commercial workshop situation.

The following section evaluates:

1. The effectiveness of tuning vehicles in each vehicle category;
2. The costs associated with tuning each category and compares these to the NISE study costs (ie similar make, model vehicles);
3. The effectiveness of tuning on an individual vehicle basis;
4. Specific vehicle faults by "Case Study" analysis to highlight the nature of some of the repairs carried out during the study.

Figure 7-2(a) & (b) present a comparison of the vehicles tested against each criteria pollutant. Separate figures are provided for ADR27 and ADR37 vehicles.

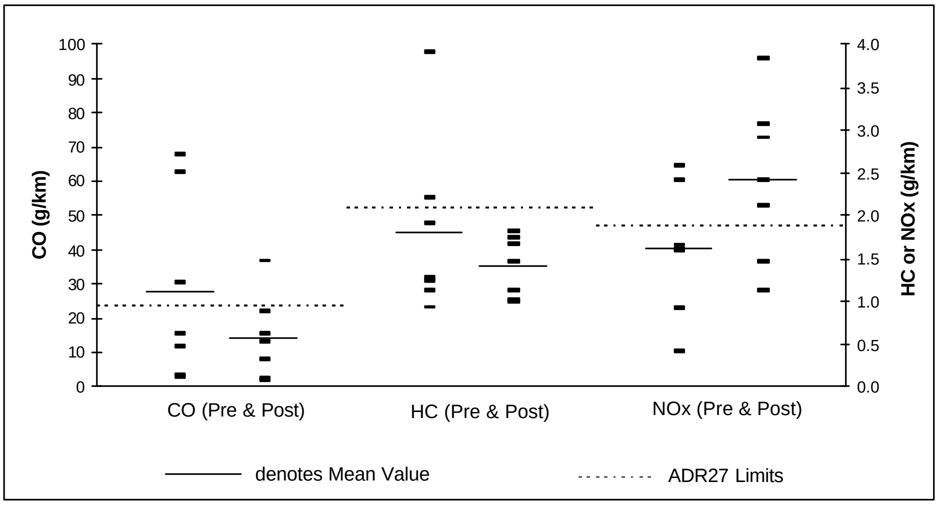


Figure 7-2(a): Effects of Tuning compared with ADR27

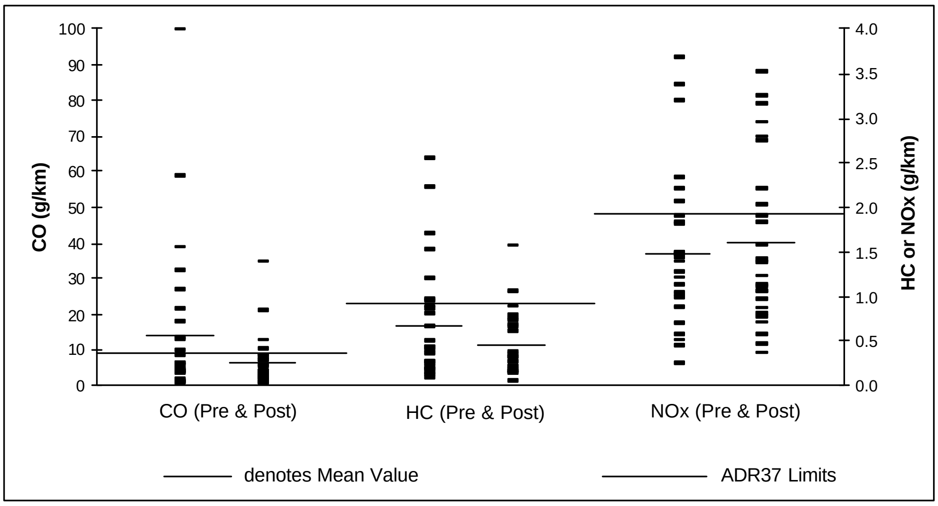


Figure 7-2(b): Effects of Tuning compared with ADR37

Key Findings:

- Tuning of vehicles in both ADR categories had a significant effect on reducing CO and HC emissions.
- ADR27 vehicles exhibited a significant increase in NOx emissions after tuning while ADR37 vehicles showed only a marginal increase.
- Tuning significantly reduced the number of “gross emitting” vehicles, and reduced the scatter in the emission results.

7.4.2 Effect of tuning of individual vehicle categories

The following figures provide a break down of results by vehicle category to show the degree of scatter and to highlight the variation in the effectiveness of tuning. For individual vehicle results, refer to sections 7.7.1 for Private vehicles, 7.7.2 for Fleet vehicles and 7.7.3 for Taxis.

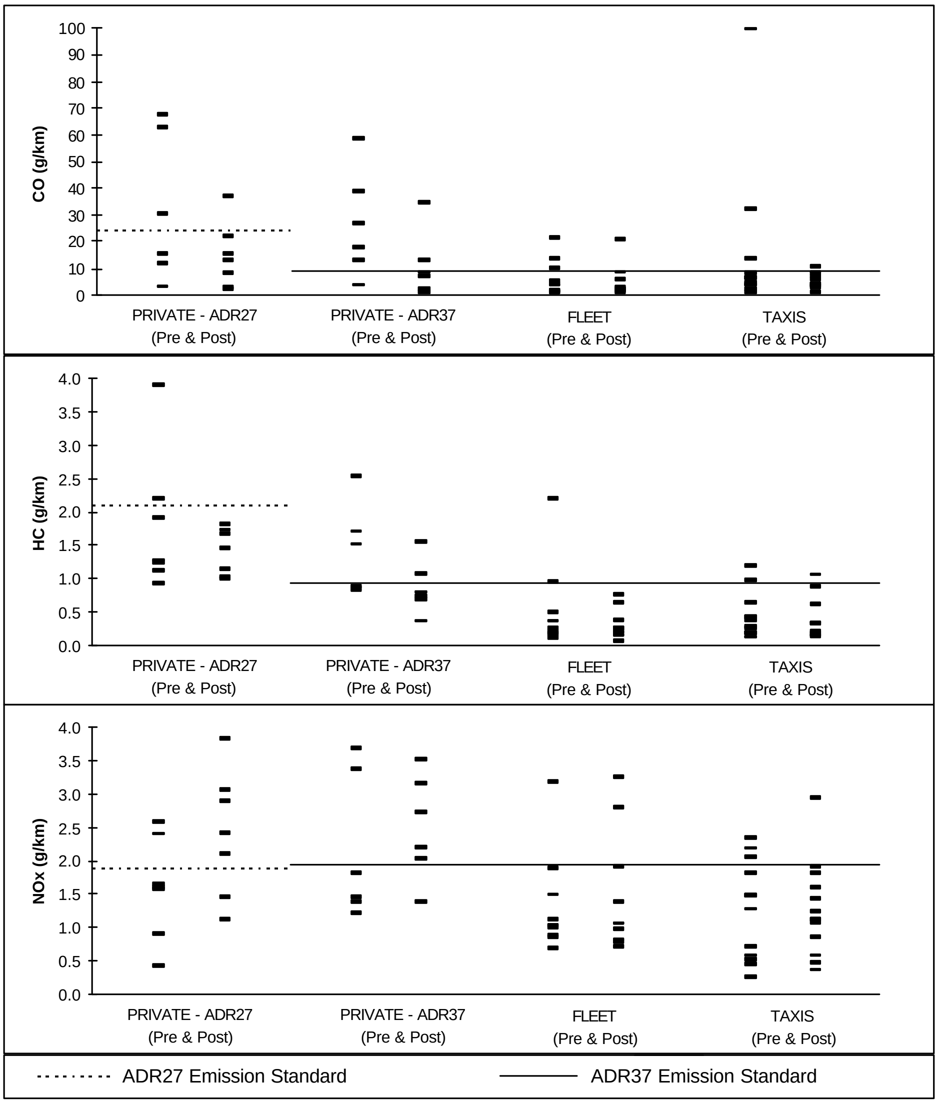


Figure 7-3: Emissions from Vehicle Type for each Pollutant (lines indicate ADR limit)

Key Findings:

- Results from the Taxi and Fleet categories were reasonably consistent, although some outliers were apparent. Emissions from the Private vehicle category were inconsistent.
- Private vehicles exhibited a significant improvement in CO and HC emissions after tuning and a slight worsening of NOx emissions. Apart from one or two taxis and fleet vehicles, there was little change in emission levels from tuning for these categories. This may be due to the dominance of closed-loop fuel management systems in these two categories.
- Overall, the effect of tuning was to reduce the “gross emitting” vehicles of each category. This trend did not hold true for NOx emissions from ADR27 vehicles.

7.4.3 Cost of tuning

A parts budget and a labour budget of $150 each was set for each vehicle. However, due to the poor condition of some of the vehicles and an initial underestimation of labour costs, the budget was not always adhered to. Ultimately the average cost of tuning, including parts and labour, was approximately $260. This consisted of:

- *Parts*:- $121 average for NSW EPA and $30 for EPA Victoria
- *Labour*:- $220 average for NSW EPA and $180 for EPA Victoria

The difference in the average cost of parts between testing facilities stemmed from several vehicles tested by the NSW EPA which required replacement of expensive parts (ie catalytic converters, EGR valves and Oxygen Sensors).

The labour charge included the mechanics travel time to the testing facility, thereby inflating the fee normally charged for a typical workshop tune.

Figure 7-4 shows the individual costs incurred by each vehicle, the average for each vehicle category and the comparison to the NISE Study.

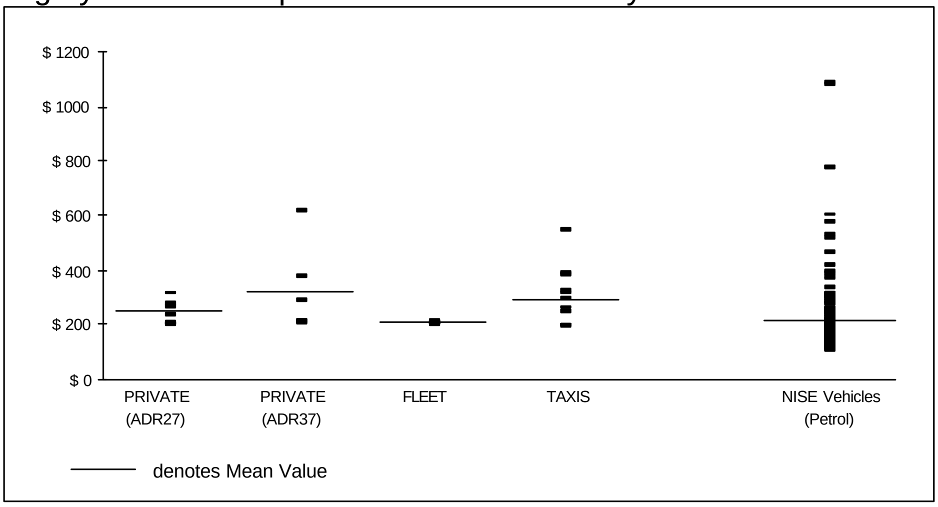


Figure 7-4: Tuning Costs of Vehicle Class

- Tuning of ADR27 Private vehicles and Fleet Vehicles averaged ~$240 per vehicle whilst ADR37 Private vehicles and Taxis averaged ~$300 per vehicle.
- The NISE Study average was ~$210

7.5 COMPARISON OF LPG VEHICLE EXHAUST EMISSIONS WITH SIMILAR MAKE AND MODEL PETROL FUELLED VEHICLES TESTED IN THE NISE STUDY

Qualification:

- As mentioned in section 4.2.4, only Ford Falcons and Holden Commodores were tested in this study. To provide a comparison between this study and the NISE Petrol Vehicle Study, Ford Falcons and Holden Commodores of the same make and model (1982-1993) have been extracted from the NISE database. Although the LPG sample size is small, the method used enables a simple and practical comparison between the two vehicle fleet types.

- Vehicles in the NISE study were all privately owned while the LPG study contained a high proportion of commercial (fleet/taxi) type vehicles. These vehicles would generally be regularly maintained.
- The average odometer reading for LPG vehicles was ~150 000 km but only ~130 000 km for the NISE vehicles. This is due to the large portion of taxis in the LPG sample.

The vehicles have been grouped according to the relevant design standard. Figure 7-5 shows the emissions (both pre-tune and post-tune) for LPG vehicles compared to petrol vehicles manufactured to the ADR27 standards. Figure 7-6 shows the same comparison but for ADR37 vehicles. All three criteria pollutants are shown for both ADR categories.

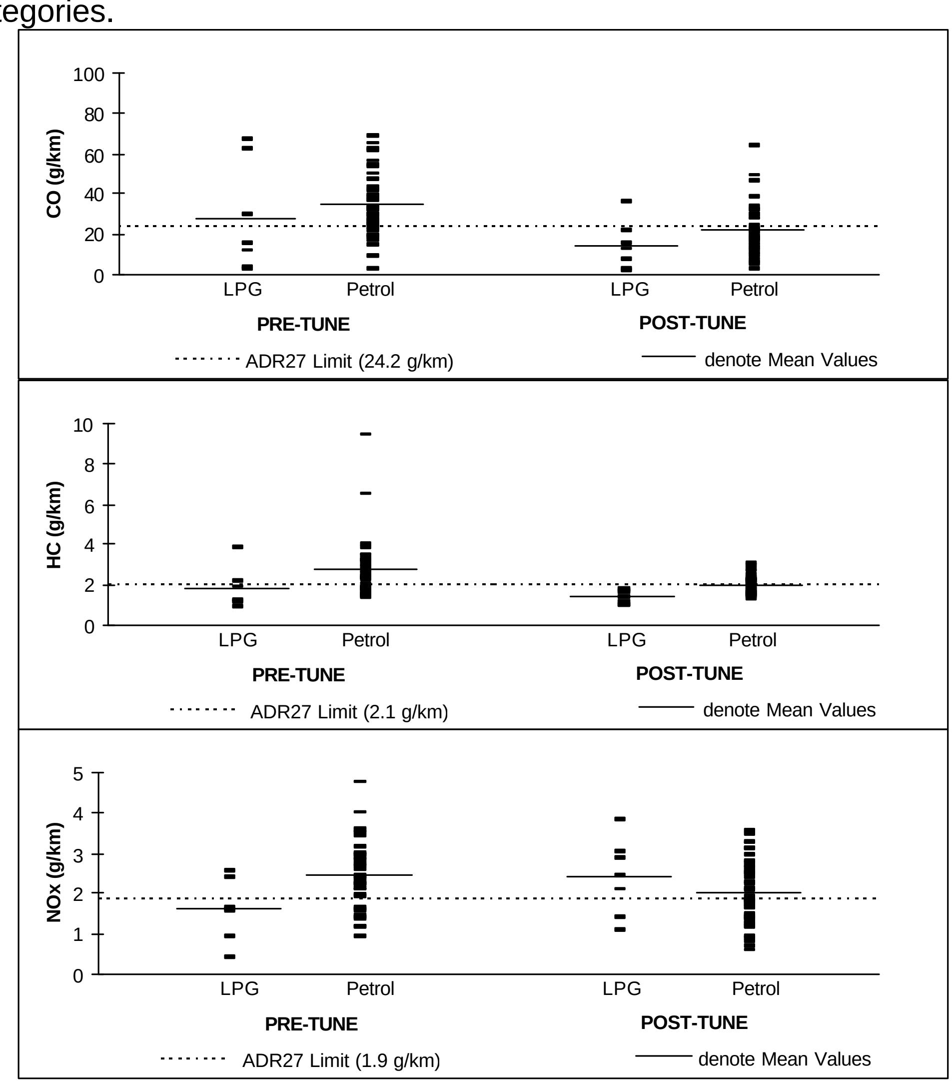


Figure 7-5: Comparison of ADR27 LPG and Petrol Fuelled Vehicles for both Pre-tune and Post-tune.

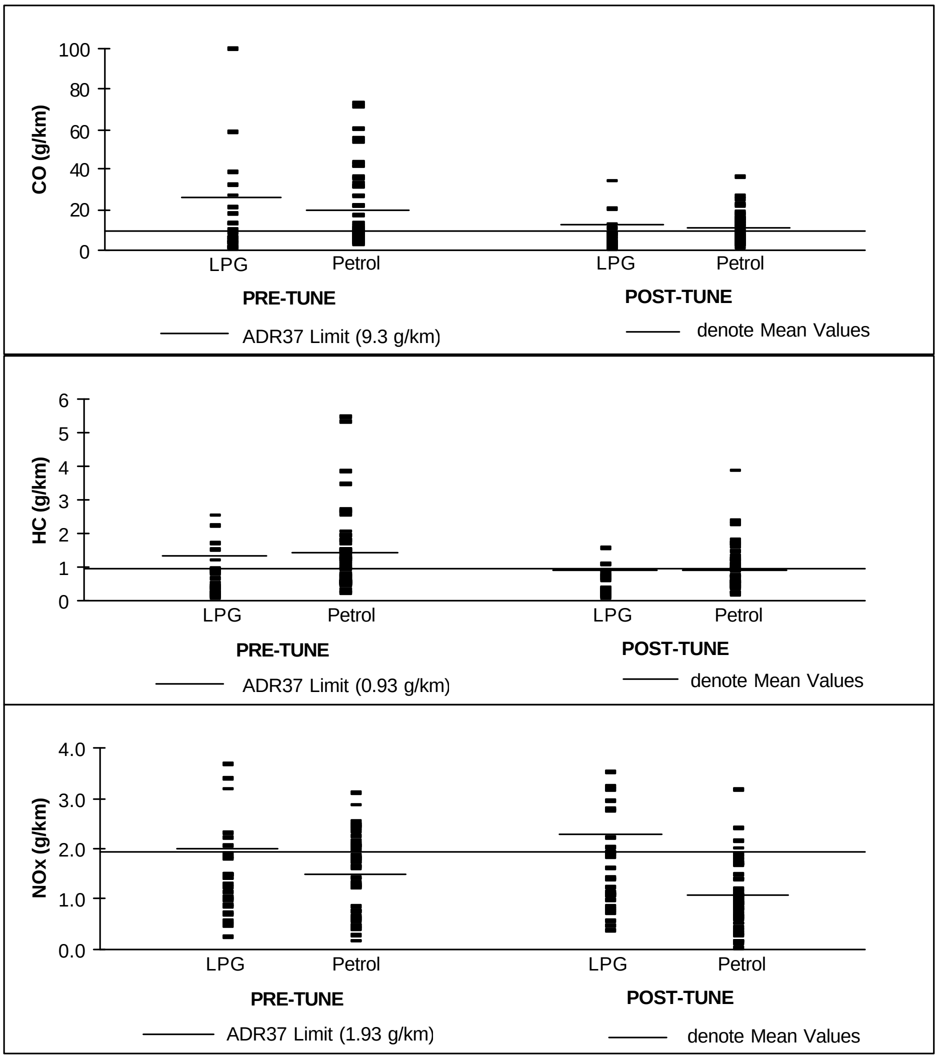


Figure 7-6: Comparison of ADR37 LPG and Petrol Fuelled Vehicles for both Pre-tune and Post-tune.

Key Findings:

- ADR27 LPG vehicles emit lower exhaust emissions than similar petrol vehicles for all three pollutants in a Pre-tune state.

  After tuning, NOx emissions from LPG vehicles are greater than petrol vehicles, whilst, for CO and HC, LPG vehicles have lower mean values.

- ADR37 LPG vehicles were marginally higher for CO and NOx emissions for the Pre-tune test, whilst there was little change in HC emissions.

  While a small decrease in NOx emissions was recorded following tuning of petrol vehicles, NOx emissions from LPG vehicles increased. CO and HC emissions were reduced for both LPG and petrol vehicles after tuning.

- Both the LPG and petrol vehicle sample contain “gross emitting” vehicles and generally a large spread in results.

- Tuning reduces the proportion of high emitting vehicles for both LPG and Petrol.

7.6 CHARACTERISATION OF EVAPORATIVE EMISSIONS (SHED)

A sub set of seven vehicles were subjected to the SHED test, comprising three private, two taxis and two fleet vehicles.

7.6.1 Comparison of LPG Evaporative Emissions to ADR Limits

The ADR37 limit for evaporative emissions is two grams per test and the ADR27 limit is six grams. Figure 7-7 illustrates the Pre and Post-tune SHED results.

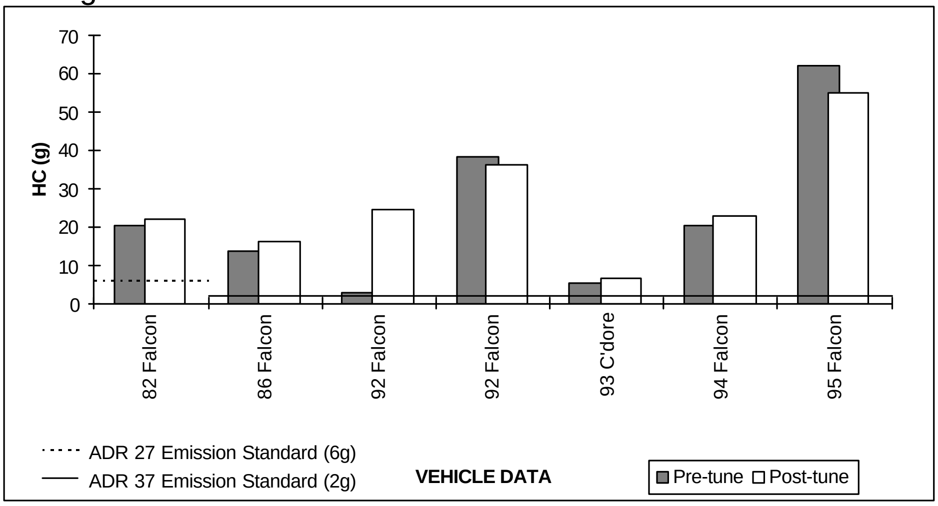


Figure 7-7: LPG Vehicle SHED Results

Qualification:

- The method used for determining evaporative emissions does not identify the origin of those emissions. On an LPG vehicle, the SHED result is derived from both fuels. A speciation test is required to determine the specific fuel origin of these emissions.
- Only one vehicle, a 1982 Ford Falcon, was manufactured prior to 1986 and required to meet the ADR27 limit. All the others were manufactured after 1986 and required to meet the lower ADR37 limit.
- Six of the seven vehicles tested were Ford Falcons which may bias the result. Further tests using a larger proportion of Holden Commodores is required before results can be compared between vehicle manufacturers.

Key Findings:

- Apart from the 1993 Commodore and a 1992 Falcon Pre-tune test, all results were well above the ADR limits. More importantly is the high degree of exceedence.

- The age of the vehicle does not influence the result. Rather the results are scattered, ranging from three, to an exceptionally high 62 grams across the various year models.
- Emissions were often higher after tuning. No explanation is given for this.

7.6.2 LPG vs Dedicated Petrol NISE Study SHED results

Ford Falcons and Holden Commodores of the same age bracket (1982-1993) were extracted from the NISE study for comparison. The results from both SHED test studies are illustrated in Figure 7-8.

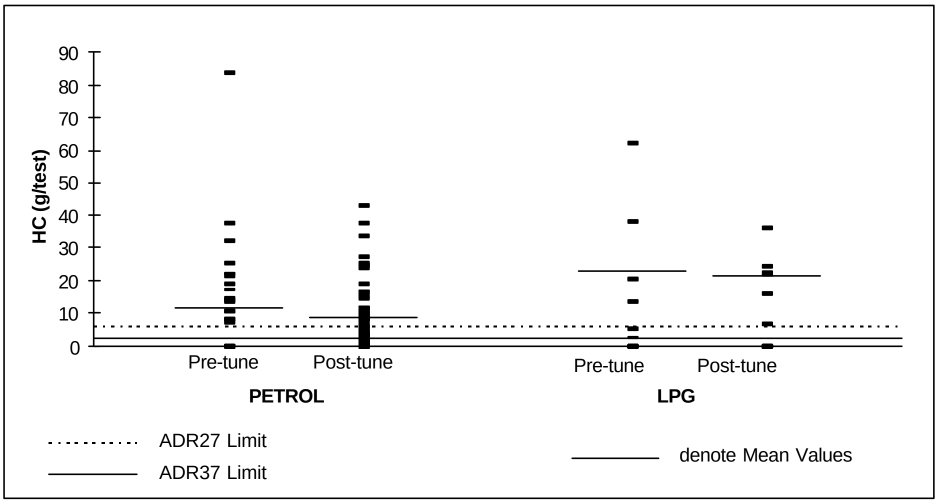


Figure 7-8: SHED results, LPG vs Petrol (Pre and Post tune)

Key Findings:

- Evaporative emission results from dedicated petrol vehicles, whilst exceeding the ADR limits, are generally lower than the LPG vehicles.
- Both petrol and LPG vehicle evaporative emissions are varied and range from below ADR limits to over 30 times the limit.
- The effect of tuning has a marginal benefit on lowering the emissions for LPG fuelled vehicles.
- The Post tune mean values obtained for the LPG vehicles were more than twice those of the petrol vehicles.

7.6.3 Observations regarding the high SHED results

If an LPG vehicle operates almost entirely on LPG, the vehicle's secondary fuel system (in this case, the petrol system) can deteriorate (hoses drying out, petrol going 'off' etc.) if the fuel is not 'flushed' through the system on a regular basis. The result can be excessive evaporative emissions from this system.

It is not clear why these evaporative emissions were so high or where they originate from. It is clear, however, that faults in either fuel system (LPG or Petrol) can have a large impact on the magnitude of evaporative emissions. Some possible LPG vehicle faults are outlined below. For more details about petrol evaporative emissions, refer to the NISE report.

Faulty Fuel Filler Cap:

The main cause for evaporative emissions noted in the NISE study was a faulty fuel filler cap. This could also be a major cause of LPG vehicle evaporative emissions.

Carbon Canister Damaged or Disconnected:

As carbon canisters are only used to collect petrol vapours from the fuel tank, they may not be included in regular servicing schedules (for both LPG and petrol fuelled vehicles) and therefore any damaged canisters would not be detected or repaired. Also, the canister may be mistakenly de-activated or disconnected when converting the vehicle to LPG operation. As a result, any residual fuel remaining in the petrol tank will be allowed to vent directly to atmosphere.

Leaking Gas Lines:

Several vehicles were found to have LPG fuel line leaks around the LPG cylinder connection. Whilst any detectable leaks were repaired before testing, there is a possibility that other leaks were undetected and not repaired. As the system is under pressure even a minor leak would produce a high SHED result.

7.7 COMPARISON OF INDIVIDUAL VEHICLES WITHIN EACH LPG VEHICLE CATEGORY

The following section provides details of individual vehicle results within each category and discusses the effectiveness of tuning on emission performance.

7.7.1 Private Vehicles

The Private vehicle sample consisted of both ADR27 and ADR37 vehicles. A total of thirteen private vehicles were tested of which seven were manufactured prior to 1986 (ADR27) and six after 1986 (ADR37). Table 7 provides a summary of the vehicles tested at each of the testing facilities.

Table 7: Summary of where Private Vehicles were tested

Private Vehicles		
Vehicle Standard:	ADR-27	ADR-37
NSW EPA	3	3
EPA Victoria	4	3

Vehicles having to comply with ADR27 and ADR37 have been graphed separately to enable comparisons with the respective limits. Figure 7-9 illustrates results from vehicles manufactured to the ADR27 limit and Figure 7-10 illustrates ADR37 vehicle results.

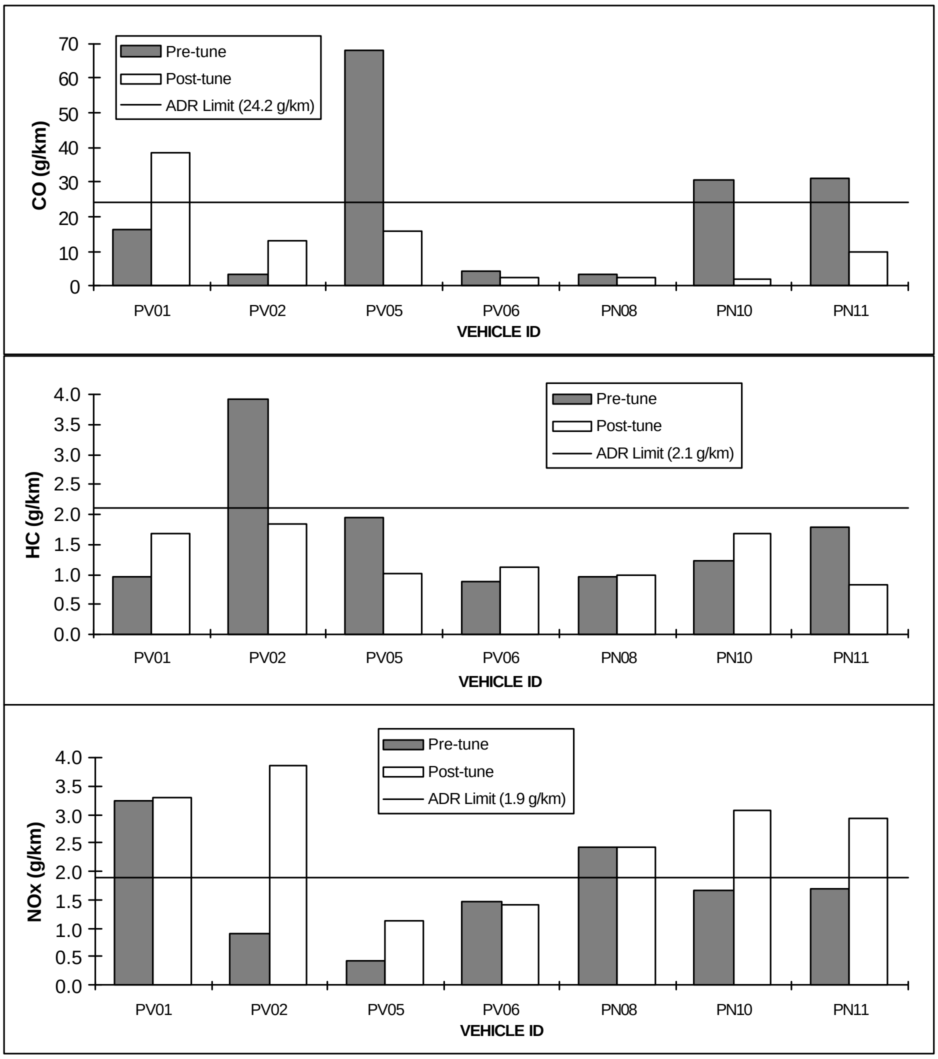


Figure 7-9: Pre and Post-tune Exhaust Emissions for ADR27 Private Vehicles

Key Findings:- ADR27 vehicles.

- Except for PV05 (CO), PV02 (HC) and PV01 (NOx), these vehicles were below or marginally above the ADR limit prior to tuning.
- Vehicles tuned to correct for the high Pre-tune CO results (PV05, PN10 & PN11) and high HC result (PV02) had an increase in NOx emissions that exceeded the limit (except PV05). This indicates that when tuning LPG vehicles, one needs to be aware of the relationship between CO, HC and NOx emissions and have the means to measure the effect of changing the vehicle's state of tune. The current focus of tuning would appear to be on lowering CO and HC without adequate concern for the effect on NOx.

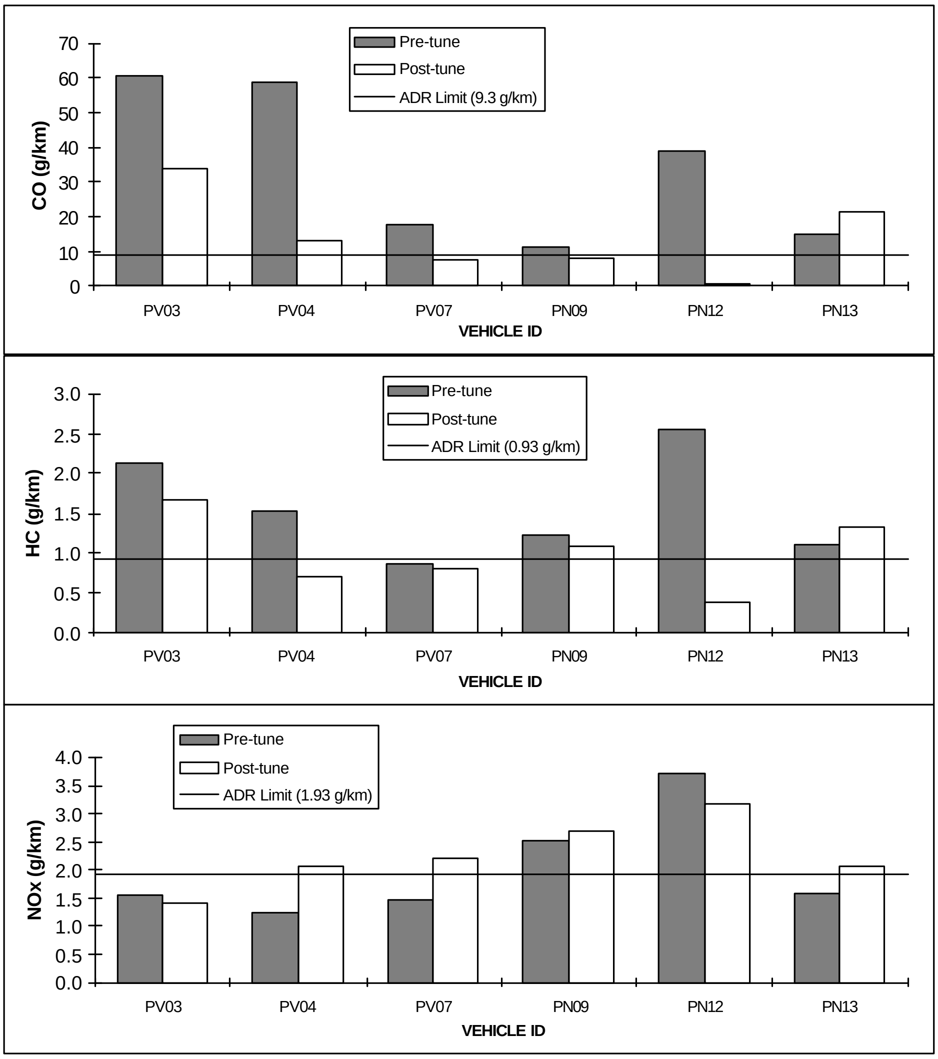


Figure 7-10: Pre and Post-tune Exhaust Emissions for ADR37 Private Vehicles

Key findings :- ADR37 vehicles.

- ADR37 vehicles exceeded their appropriate ADR limits more often than ADR27 vehicles. This is particularly evident when making a comparison of the CO and HC emissions. Rather than the odd one or two as with the ADR27 vehicles, all six vehicles failed to meet the CO limit and five of the six vehicles failed to meet the HC limit. The NOx exceedences are similar for both ADR categories.
- Tuning the vehicles significantly improved the emissions of CO and HC but NOx emissions were on occasion increased above the ADR limit.

7.7.2 Fleet Vehicles

EPA (Vic) tested all ten Fleet vehicles selected in the sample. Exhaust emission levels obtained from each of the vehicles are illustrated in Figure 7-11. Again both the Pre and Post tune results are shown as well as the ADR37 limit.

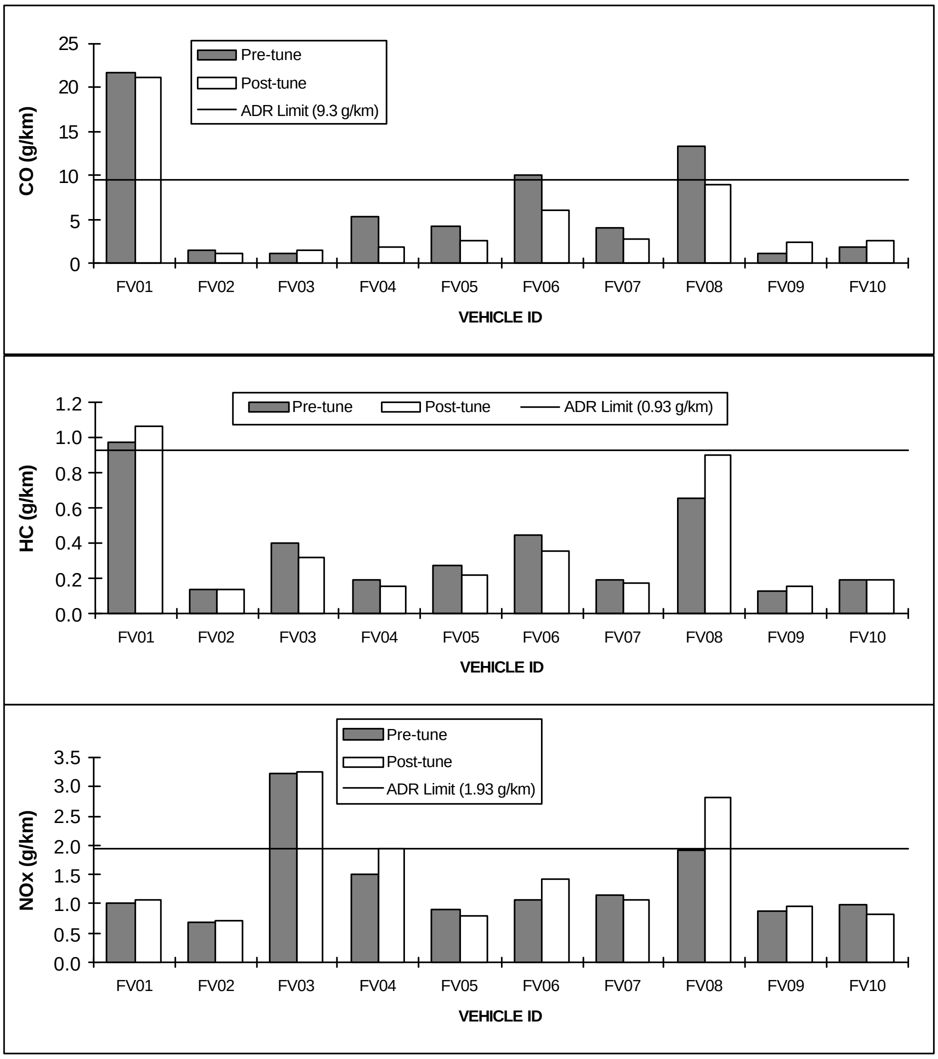


Figure 7-11: Pre and Post-tune Exhaust Emissions for Fleet Vehicles

Key Findings:

- Generally Fleet vehicle emissions could be classed as "low". Four vehicles exceeded ADR limits for any one pollutant prior to tuning.
- On average, tuning reduced both CO and HC emissions while increasing NOx emissions.
- Vehicle FV01, which emitted more than twice the level of CO specified in ADR37 did not respond significantly to tuning. A further test (results not illustrated) was then conducted following replacement of the catalytic converter. A significant reduction in emissions was recorded, confirming the catalytic converter had failed.

7.7.3 Taxis

The NSW EPA tested eight taxis, and EPA (Vic) tested five. All were manufactured to comply to ADR37 limits. Two of the Victorian taxis were also included in the subset of vehicles subjected to a SHED test. Figure 7-12 illustrates Pre and Post-tune exhaust emissions for each vehicle.

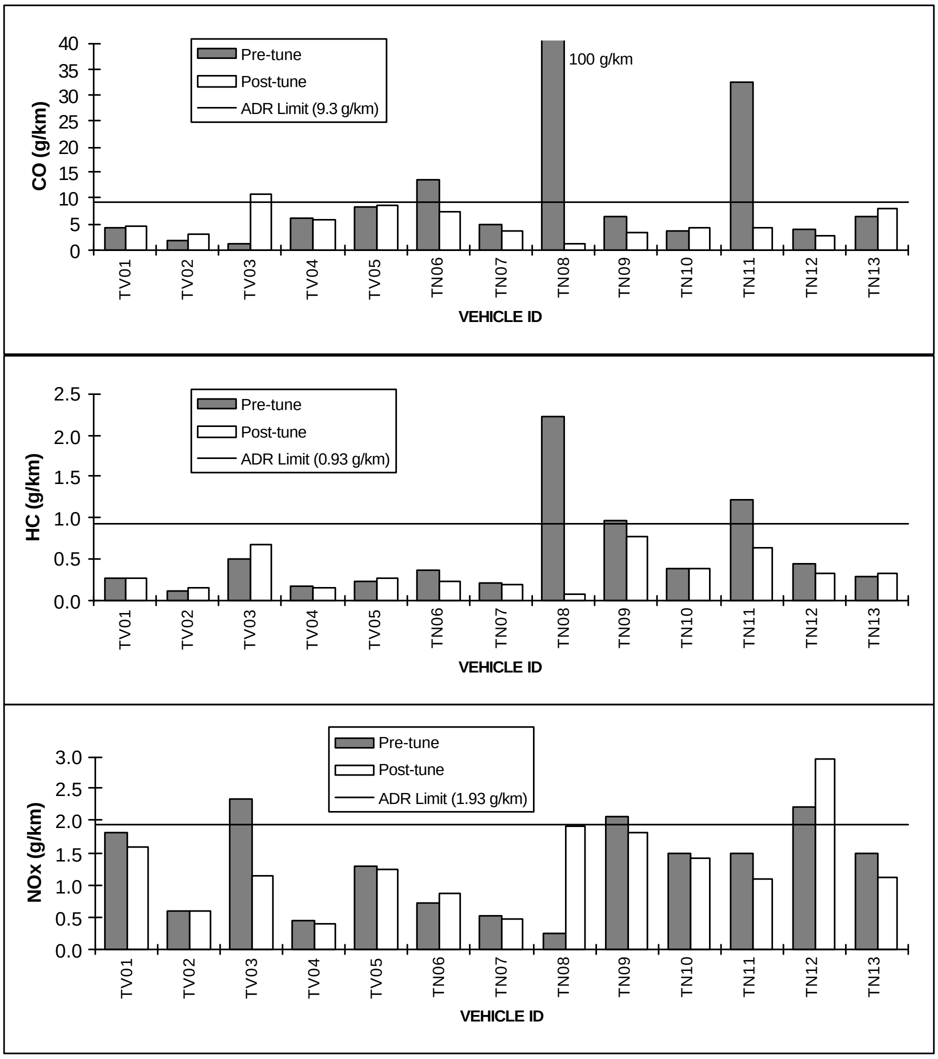


Figure 7-12: Pre and Post-tune Exhaust Emissions for Taxis

With the exception of vehicles TN08 and TN11, exhaust emissions of CO and HC are below or just above ADR limits. NOx emission generally were below the limit however the margin between the result and the limit was relatively small.

TN08 was found to have a defective catalytic converter, however the cause of the defect was most likely due to the engine operating in an extremely rich condition and the engine emission control equipment was disconnected. The Post-tune result shows a dramatic improvement in both CO and HC results due to the reconnection of the emission control equipment, engine tune and the installation of a new catalytic converter. The relative emission performance of each repair is discussed further as a case study in section 7.7.3.

7.8 COMPARISONS OF LPG FUEL SYSTEMS

To explore the possible reasons for the variations between vehicle categories and the large scatter of results, further analysis of the data was carried out. Specifically, the characteristics of the LPG fuel system were evaluated in terms of the LPG conversion kit type, the system of fuel management (Open or Closed loop) and the method (fixed or variable venturi) used to convert the LPG and meter the fuel/air mix prior to combustion.

7.8.1 Open vs Closed Loop Fuel Management Systems

In December 1993, the Australian Standard (AS1425-1989) was changed to require that all closed loop vehicles converted to LPG fuel operation must continue to operate with a closed loop management system. This requirement, combined with improvements in LPG conversion kit technology, has resulted in the almost universal introduction of closed loop fuel management systems. Figure 7-13 illustrates the difference in emission levels of the vehicles using the two fuel management systems. The effectiveness of tuning is also shown.

Table 8 lists the number of vehicles with open or closed loop systems in each category. See Attachment 5 for a diagram of the Open and Closed Loop Engine Management System.

Table 8: Summary of Engine Management Systems on Sample

Engine Managment System		
	Open loop	Closed Loop
Private (ADR27)	7	-
Private (ADR37)	3	3
Fleet	-	10
Taxi	1	12

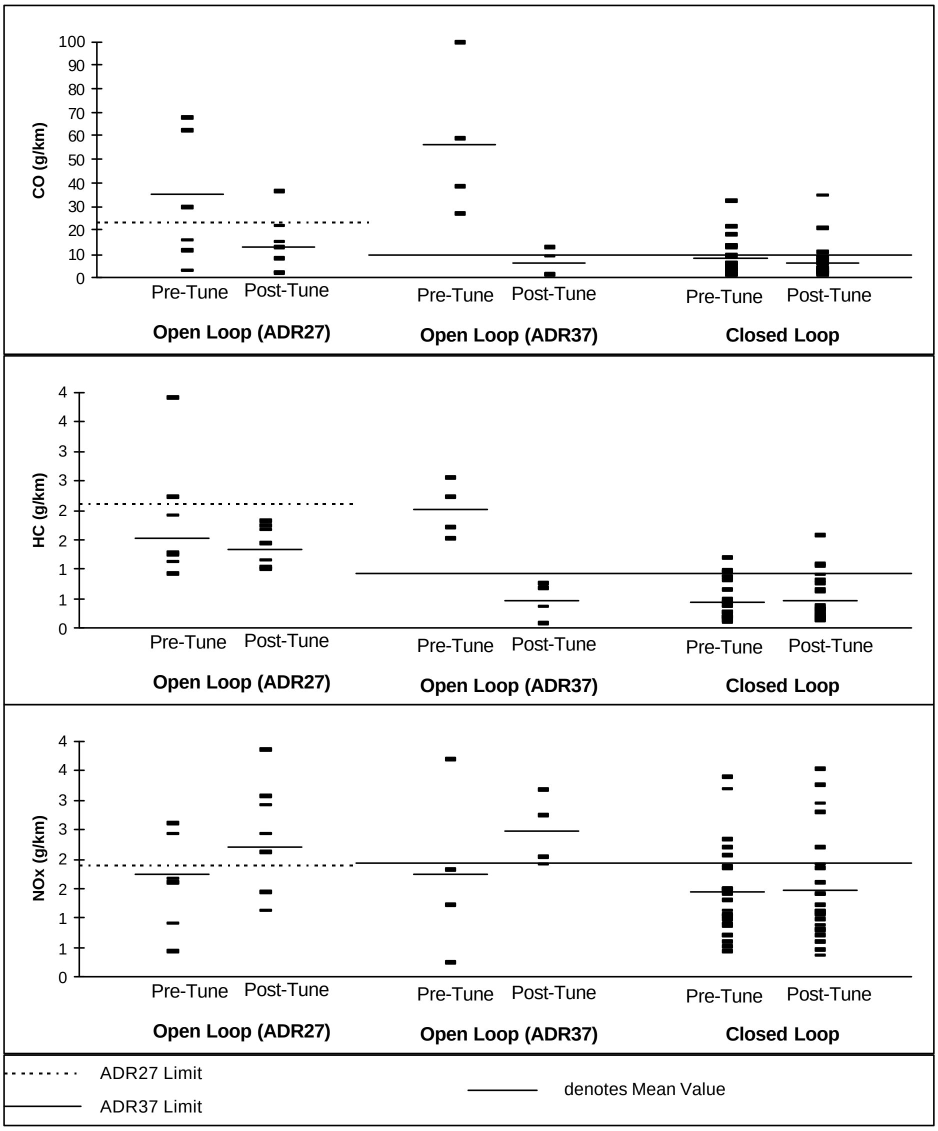


Figure 7-13: Emission Reduction from Different Systems

Key Findings:

- The Pre-tune HC and CO emission levels on vehicles with closed-loop systems are significantly lower than vehicles with open loop systems. However, both open and closed loop vehicles on occasion exceeded ADR limits.
- Vehicles with open loop systems benefit substantially from being tuned (refer to section 4.2.3 for scope of tuning) while little change is obtained from tuning vehicles with closed loop systems.
- CO and HC emissions from ADR37 vehicles with open loop engine management systems improved dramatically after tuning. Conversely, NOx emissions increased after tuning.

7.8.2 Fixed vs Variable Venturi Fuel/Air Mixing

The two main venturi types (fixed and variable) used in LPG vehicles to mix the LPG gas with intake air have been analysed separately to trends in vehicle emission performance. Each venturi type can be present on both open or closed loop systems. Table 9 lists the type of venturi used in the vehicles.

Figure 7-14 compares the venturi types with vehicle emissions and the effectiveness of tuning.

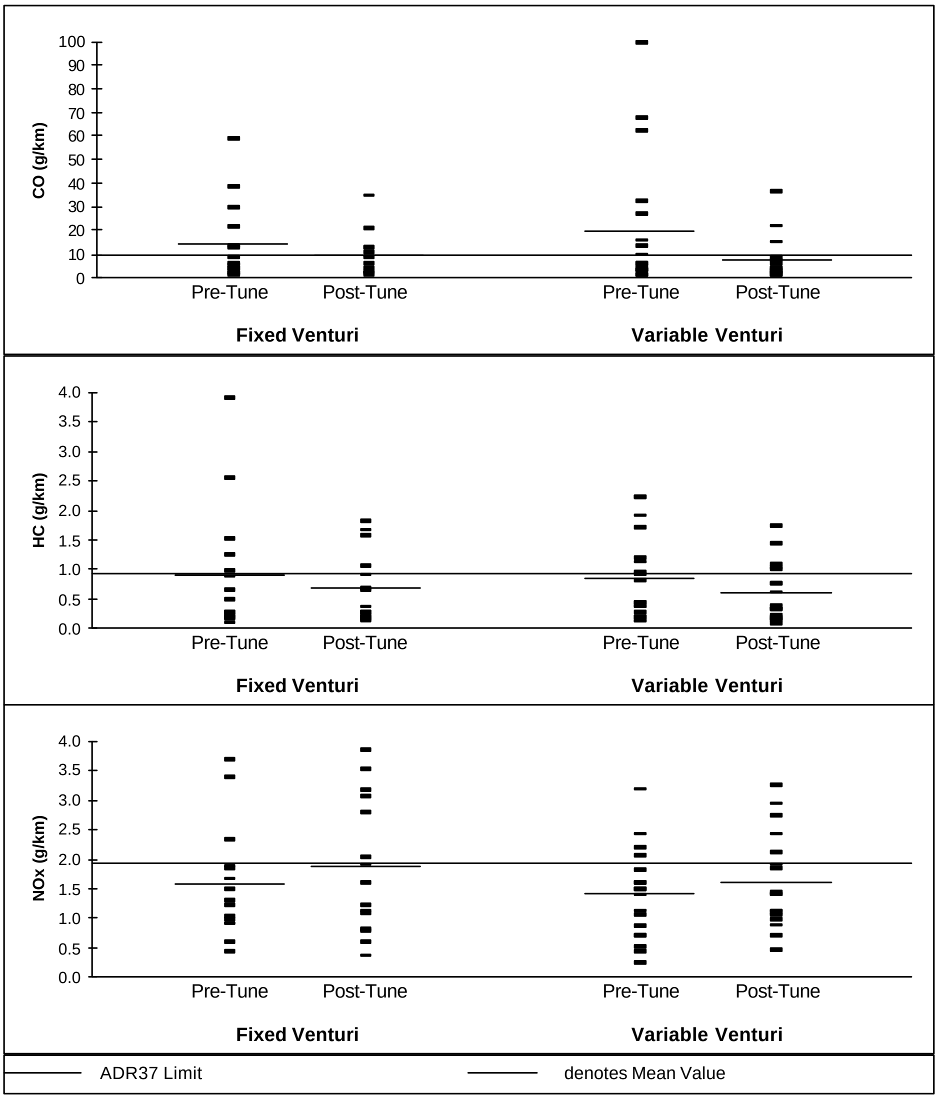


Figure 7-14: Emissions from different Venturi Types from all Vehicles

Table 9: Venturi type used in test vehicles

Venturi Type		
	Fixed	Variable
Private (ADR27)	2	4
Private (ADR37)	3	3
Fleet	5	5
Taxi	5	8

Key finding:

- Tuning can reduce emissions on vehicles fitted with either a fixed or variable venturi and the effectiveness of the tune is not related to the type of venturi used.

7.9 CASE STUDIES

This section discusses some of the problems encountered with specific test vehicles during the study. While the study aimed to test vehicles in the "as received" condition, a number were rejected due to their poor condition, whilst others were tested but tuning proved difficult. The following case studies highlights some of the problems that were encountered.

7.9.1 Incorrect Tuning of Vehicle

Pre-tune test results from an EF Falcon (TN06) indicated that the vehicle exceeded (by four times) the CO limit, but was under the NOx and HC limit. After tuning, the test results indicated the vehicle was emitting very high levels of CO and HC and low NOx emissions - indicating incorrect tuning. Further investigation into the fault identified a poor earth connection of the Engine Management System that resulted in the vehicle continuously operating in a rich condition. The LPG system feeds off the petrol system and as such any problem with either system can influence the emissions when the vehicle is operating on LPG. The problem was identified and rectified and the vehicle re-tested. Refer to Table 10 for summary of results.

The test results identified as "Post-tune with Earth Leakage" in Table 10 were classified as a development test and were not included in the results reported in other tables and figures in this report.

Table 10: Results from Earth-Leakage Post-tune test

	CO (g/km)	**HC** (g/km)	**NOx** (g/km)	**Fuel Con** (L/100km)
Pre-Tune	13.79	0.37	0.72	17.42
Post tune with Earth-Leakage	60.00	2.19	0.29	19.53
Post-Tune	7.24	0.22	0.88	16.87

This case study demonstrates how ineffective emission controls can be if incorrectly installed and maintained. The benefits that can be achieved by this are highlighted by the change in fuel consumption (in Table 10) after the fault had been repaired.

7.9.2 Faulty Engine Management System (EMS)

An EF Falcon (TN08) was received with the primary functions of the Engine Management System disconnected. This resulted in the vehicle operating without any form of fuel regulation, allowing excessive quantities of LPG to be delivered to the engine. Consequently, the mixture was rich resulting in the emissions shown on the first line of Table 11.

Table 11: Results of Vehicle with faulty EMS

	CO (g/km)	HC (g/km)	NOx (g/km)	Fuel Con (L/100km)
Pre-Tune without EMS connected	99.92	2.22	0.25	24.22
No EMS but Catalytic Converter replaced	1.02	0.07	1.91	19.53
Re-tuned privately & EMS reconnected	0.03	0.11	5.97	18.26

Inspection of the vehicle's catalyst showed that certain sections of the catalyst had been displaced, reducing exhaust flow and increasing back pressure on the engine. As a consequence, the engine was required to work harder and consume excess fuel. The vehicle was tuned and the catalytic converter replaced, however the EMS was not re-connected in order to evaluate the effect of a new catalyst.

The installation of the new catalyst dramatically improved the CO emissions from 99.9 g/km to 1.0 g/km. However, the catalyst would soon fail again if the vehicle was allowed to continue operating without the EMS connected.

The vehicle was returned to the owner for reconnection of the EMS and other emission control systems. The vehicle was tuned privately and returned to the laboratory for a second Post-tune test.

While CO and HC emissions were again reduced (CO from ~100 to 0.03 g/km and HC from 2.2 to 0.11 g/km), NOx emissions increased to nearly three times above the ADR limit. This result indicated that the vehicle was tuned to minimise CO emissions without due consideration for the effect on NOx emissions.

Note: The data from the second Post-tune test has not been included in the test averages reported elsewhere in this report.

7.9.3 High SHED results

Due to the nature of the LPG/Petrol dual fuel system, (ie a closed pressurised LPG system and an open petrol system that permits vapours to be vented to atmosphere through the carbon canister), any evaporative hydrocarbon emissions should originate from the petrol system. To verify this assumption, the CSIRO was requested to investigate the speciation of the hydrocarbon emissions to determine their origins (ie LPG or petrol). This test was conducted on a 1992 Falcon, vehicle PN06.

Analysis of the CSIRO results showed that evaporative emissions from both the Pre-tune and Post-tune SHED tests were derived predominantly from petrol. The

Pre-tune and Post-tune emissions from this vehicle were 38 and 36 grams respectively. Only one other vehicle recorded higher Pre-tune and Post-tune emissions.

The high evaporative emission result caused primarily by petrol vapours raises concerns regarding the use of dual fuel systems. Further testing is required to establish if this is a common occurrence.

7.9.4 Disconnected Vacuum Hose at LPG Fuel System Converter

An ED Falcon (TN13) was delivered with a disconnected vacuum hose. This vacuum hose connects the fuel control valve to the LPG fuel converter. Before the Pre-tune test was conducted, the hose was mistakenly reconnected to the converter. The Pre-tune test is designed to test the vehicle in its original condition and therefore the hose should have remained disconnected. This mistake remained undetected until the vehicle was being tuned. The project team decided to conduct the Post-tune test, and then carry out a repeat test with the vacuum hose disconnected; as should have been in the Pre-tune test. The results of the additional test illustrate the effect the vacuum hose has on the vehicle's emissions performance. Table 12 summarises the ADR37 results obtained for the vehicle.

Table 12: Effects of a disconnected vacuum hose

	CO (g/km)	**HC** (g/km)	**NOx** (g/km)	**Fuel Con** (L/100km)
Pre-Tune with Vacuum hose on	6.38	0.27	1.49	17.25
Post-tune with vacuum hose on	8.13	0.33	1.13	17.80
Post-tune - vacuum hose disconnected	83.59	1.80	0.16	22.70

Comparison of the two Post-tune results

With the hose disconnected, all emissions except NOx increased significantly. The results highlight the importance of regularly inspecting the vehicle and carrying out necessary maintenance to ensure the vehicle is in accordance with manufacturers specifications.

Note: The Post-tune result with the vacuum hose disconnected does not form part of the LPG results presented elsewhere in this report.

7.9.5 Incorrect parts

A '93 Falcon was found to be fitted with an incorrect diaphragm for the type of mixer that was installed on the vehicle. After the Post-tune test, the diaphragm was replaced with the correct type and the vehicle was tested a third time.

The Pre and Post-tune results that were conducted with the incorrect diaphragm fitted resulted in CO emissions of approximately 25 g/km for both tests. After installing the correct diaphragm, CO emissions dropped to 4.9 g/km.

Further investigation into why the wrong diaphragm had been installed on this vehicle revealed that, within the servicing industry, some issues that may be considered to be more important than emissions control were:

- minimise backfiring; and
- improving fuel economy

It was also revealed that by fitting an incorrect diaphragm onto a vehicle running in closed loop operation can cause the vehicle to run open loop and therefore become a ‘quick fix’ solution.

8. FUEL CONSUMPTION

The energy content of commercial petrol is 33 percent greater than that of commercially available LPG. This means an LPG fuelled vehicle uses a third more fuel to achieve the same power per kilometre than it would on petrol.

A 1974 estimate (BTCE, 1974) claimed that fuel consumption for an LPG vehicle was ten percent greater than for the same vehicle on petrol. The latest Fuel Consumption Guide (DPIE 1995/96) however, claims an EF Falcon operating on LPG consumes 28 percent more than it would operating on petrol. This difference is possibly due to the recent improvements in fuel efficiency for petrol engines (BTCE, 1994).

The fuel consumption values of vehicles in each category are illustrated in Figure 8-1. The effect of tuning is also shown by referencing the Pre and Post-tune mean values.

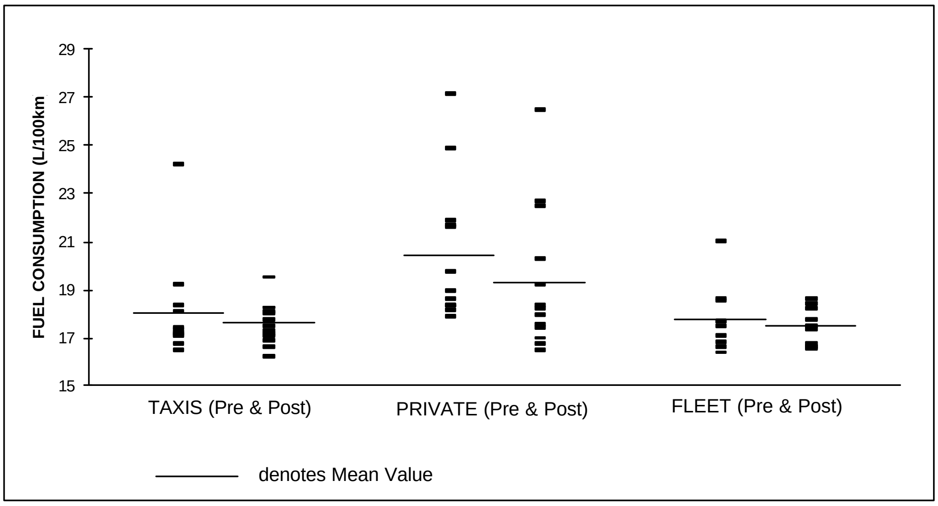


Figure 8-1: Fuel Consumption for Vehicle Categories
Pre-tune and Post-tune shown.

Key Findings:

- Fuel consumption levels are highly variable and vehicle specific.
- Private vehicles had the highest average (20.4 L/100km) then taxis (18.0 L/100km) and fleet vehicles (17.8 L/100km).
- Tuning improved fuel consumption across all categories by an average of twelve percent. This, with the acknowledgment that taxis and fleet vehicles may be better maintained than private vehicles, suggests that savings can be made by tuning your vehicle.

8.1 LPG FUEL CONSUMPTION COMPARED TO PETROL

In order to compare LPG results to the petrol results in the NISE Study, the energy contents of LPG and petrol were standardised by converting the LPG results into a petrol-equivalent. By dividing the fuel consumption values for LPG by the energy equivalent ratio of LPG to petrol, a petrol-equivalent value for LPG was calculated. This effectively eliminates the difference in energy content of the two fuels enabling a direct comparison to be made.

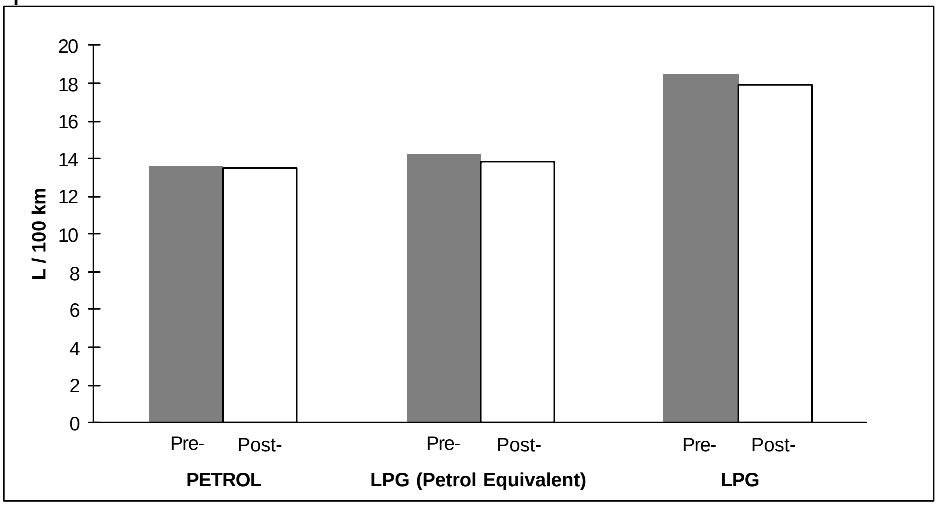


Figure 8-2: LPG Fuel Consumption compared to Petrol

Key Findings:

- Tuning has a greater effect on fuel consumption (twelve percent improvement) for LPG vehicles than for the same make and model petrol vehicles (two to three percent improvement).
- In volumetric terms, the LPG sample fleet used 36 percent more fuel (than the similar NISE fleet) for the pre-tune results and 33 percent for the post-tune.

9. EFFECTIVENESS OF INSPECTION/MAINTENANCE SHORT TESTS

There is currently a great deal of interest in the development of a short emission test for use in inspection and maintenance (I/M) programs. One of the objectives of the NISE study was to evaluate and correlate the emission results from ADR27 and ADR37 tests with emission results produced from a number of short emission tests. This correlation has also been performed for LPG vehicles in this study.

A short emissions test should have the following characteristics:

- good correlation with ADR test results
- ability to identify high emitting vehicles whose criteria emissions (CO, HC and NOx) may be reduced through tuning
- take only a few minutes to perform
- preferably be capable of being conducted at either a centralised, distributed or roadside locations.

Until recently, the only short tests commonly in use were the Idle or High Idle tests. The Idle test is performed without the engine loaded while CO and HC tailpipe emissions are measured. The High Idle test is carried out the same way, but at a more elevated engine speed (approximately 2500 rpm). However, there are a number of shortcomings of both these tests. Some modern vehicles are known to operate in an open loop mode whilst idling and switch to closed loop when the vehicle is driven under load. In these instances, the idle tests would give little indication of the vehicles' overall emissions performance.

Also, as NOx is primarily produced when the engine is under load, an idle test will not determine the emission level. Therefore, alternative measures such as a loaded mode test and/or a functional/visual inspection of emissions control equipment are required.

To address these issues, several short dynamometer (loaded) tests have been developed in recent years. All vehicles in the LPG study were tested using the same short tests (loaded and unloaded) used in the NISE study before and after tuning. The tests are listed below. For details of the specific conditions to which the vehicles were subject during testing, refer to Attachment 3.

Loaded Tests

- IM-240 (240 second transient cycle)
- SS-60 (Steady State)
- ASM-25/25 (Acceleration Simulation Mode)

Unloaded Tests

- Low Speed Idle (approximately 800 rpm)
- High Speed Idle (approximately 2500 rpm)

9.1 IM-240 TEST RESULTS

The IM-240 is the test prescribed by the US EPA for enhanced vehicle inspection and maintenance programs. The test involves a short (240 second) driving cycle which is the same as the start of the ADR37 drive cycle, covering the first two kilometres of the twelve kilometre test. Results are recorded in grams per kilometre for HC, CO and NOx.

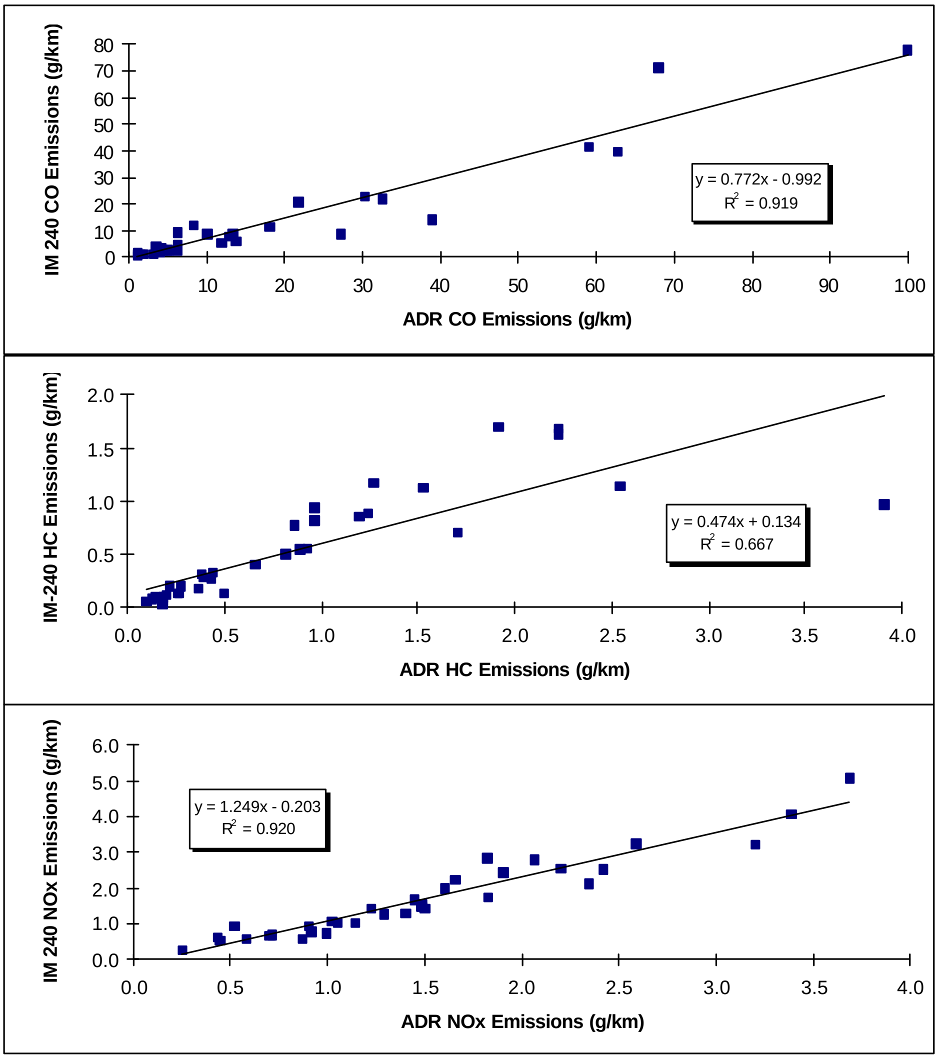


Figure 9-1: IM-240 vs ADR Test Results

Key Finding:

- As expected, the correlations for CO and NOx are very good, but surprisingly, it was relatively low for HC.

The NISE study found this test to correlate the best with ADR37 and therefore the most capable of identifying “gross emitters” in an inspection maintenance program.

9.2 SS-60 TEST RESULTS

During the SS60, vehicles are driven on a chassis dynamometer at a constant 60 km/h. Exhaust emissions of CO, HC and NOx are analysed over the measurement stage of the test and recorded in grams per minute.

Figure 9-2 illustrates the correlation of this test with the ADR37 emission test.

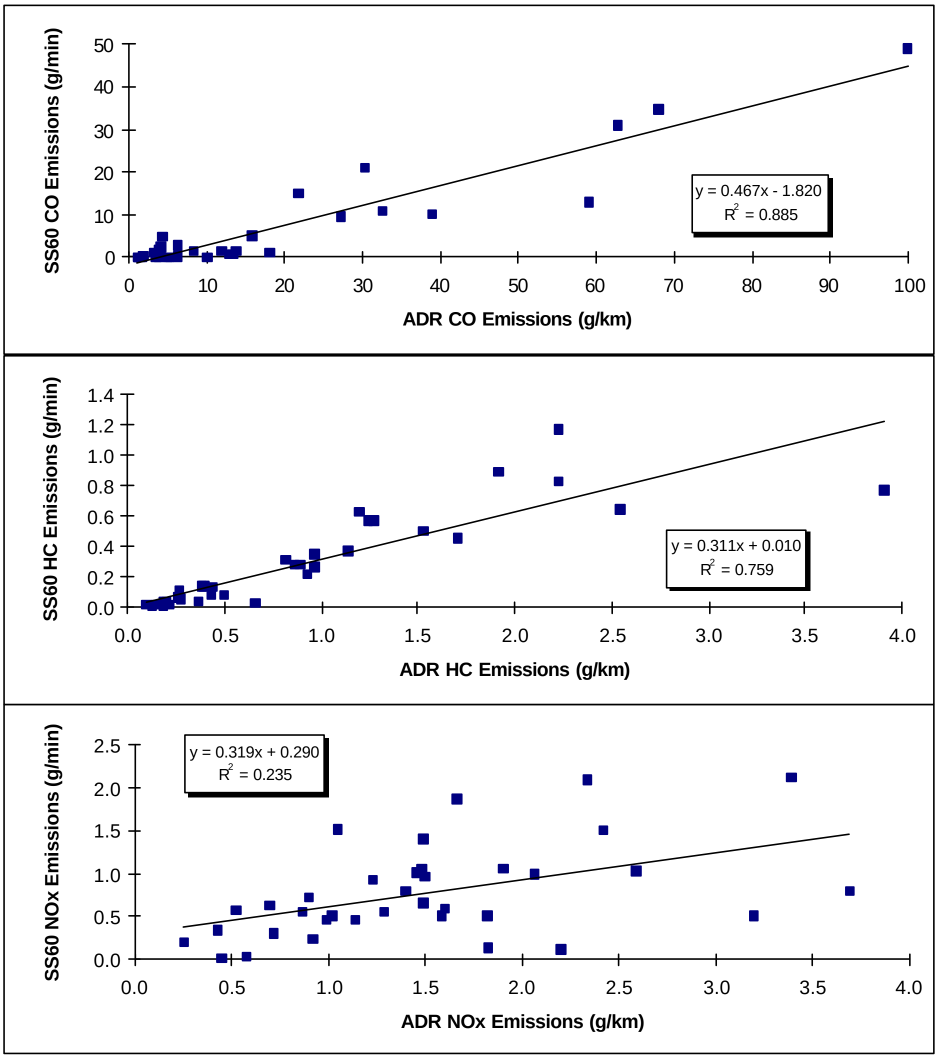


Figure 9-2: SS-60 vs ADR Test Results

Key Finding:

- There is a reasonable correlation for CO and HC but a poor correlation for NOx

9.3 ASM-25/25 TEST RESULTS

The ASM25/25 test requires vehicles to be driven on a chassis dynamometer at a speed of 40 km/h (or 25 mph as the name suggests) at 25 percent of the vehicle's maximum power. Manual vehicles are operated in second gear. Exhaust emissions are measured raw (not diluted with air) using infra-red analysers. The results are recorded in parts per million for HC and NOx and percent volume for CO.

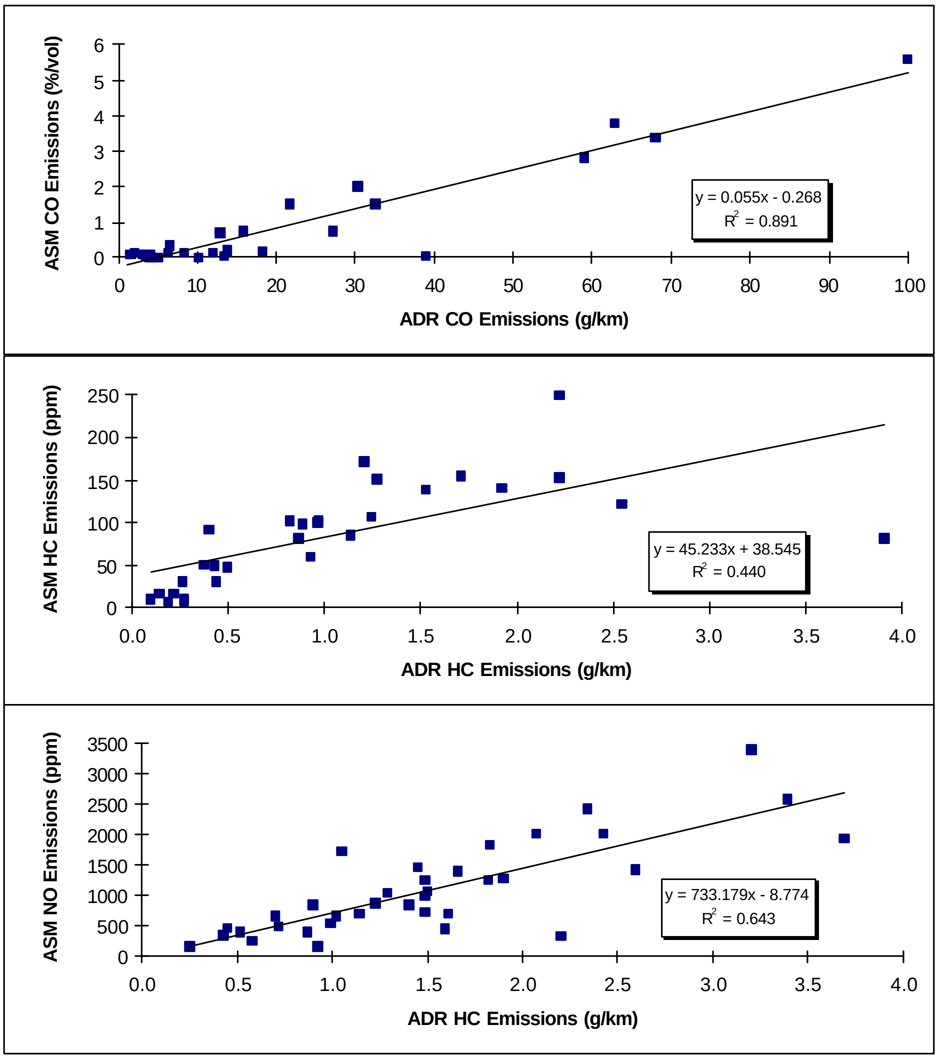


Figure 9-3: ASM-25/25 vs ADR Test Results

Key Finding

- There is a reasonable correlation for CO while HC and NOx correlate poorly.

9.4 IDLE TEST RESULTS

This is a static test whereby the vehicle remains stationary and the engine is operated at an idle speed of ~800 rpm. The concentrations of raw exhaust emissions are measured using infra-red analysers and results recorded in parts per million for HC and percent volume for CO. NOx is not measured as the engine is not placed under load.

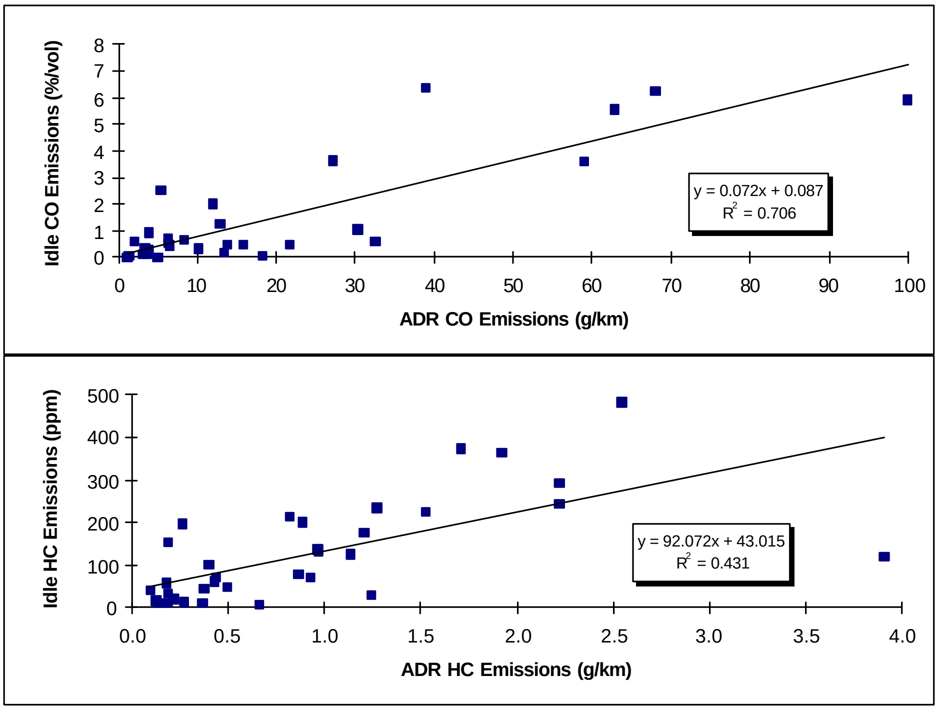


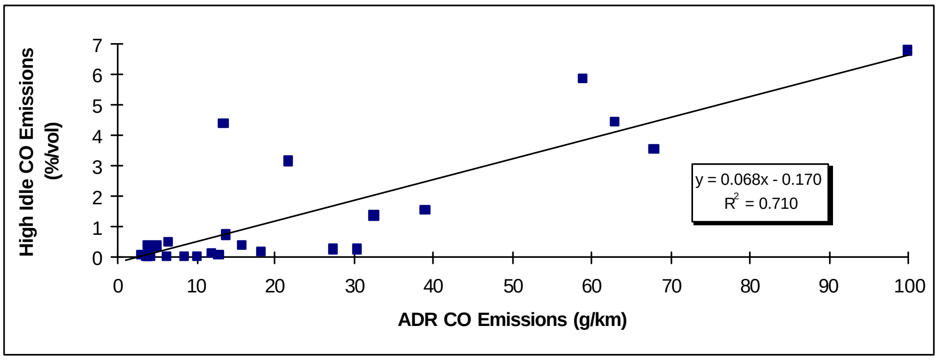
Figure 9-4: Idle vs ADR Test Results

Key Finding:

- There is a poor correlation of both pollutants.

9.5 HIGH IDLE TEST RESULTS

This is a static test whereby the vehicle remains stationary and the engine is operated at a speed of 2500 rpm. The concentrations of the raw exhaust emissions are measured using infra-red analysers and results recorded in parts per million for HC and percent volume for CO. NOx is not measured as the engine is not placed under load.



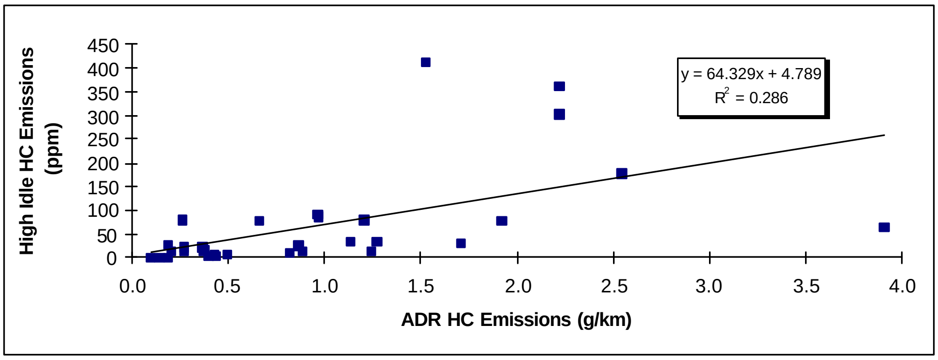


Figure 9-5: High Idle vs ADR Test Results

Key Finding:

- There is a poor correlation for both CO and HC.

9.6 SUMMARY OF SHORT EMISSION TEST CORRELATION RESULTS

Table 13 lists the "r" and "R^2" values calculated for the LPG vehicles and the "r" values reported by the NISE study.

The correlation values are deceptively high due to the fact that the low-emitting vehicles can be detected quite accurately. The difficulty arises when the emission levels are higher. As the emission levels increase, the ability of the short emission tests to predict the actual emission level become more evident.

Table 13: Relationship between ADR and Short Emission Tests

		NISE	LPG Study	
		r	r	R^2
SS 60	CO	0.84	0.94	0.89
	HC	0.80	0.87	0.76
	NOx	0.72	0.49	0.24
IM 240	CO	0.90	0.96	0.92
	HC	0.94	0.82	0.67
	NOx	0.90	0.96	0.92
ASM 25/25	CO	0.78	0.94	0.89
	HC	0.64	0.66	0.44
	NOx	0.68	0.80	0.64
High Idle	CO	0.62	0.84	0.71
	HC	0.70	0.54	0.29
	NOx	-	-	-
Idle	CO	0.67	0.84	0.71
	HC	0.72	0.66	0.43
	NOx	-	-	-

As was the case with petrol vehicles tested in the NISE Study, the IM-240 test correlates best with the ADR test and would be the most effective test for predicting vehicles with high emissions.

The SS60 and ASM loaded tests show better correlation for all three criteria pollutants than the Idle and High Idle tests.

10. SUMMARY OF RESULTS AND OBSERVATIONS

The results of the study have been presented primarily on a per vehicle basis due to the small sample tested and the variation in results from vehicle to vehicle. However, definite trends are evident from which the following observations have been made. They are not conclusive but provide an indication of the characteristics of the LPG in-service fleet.

1. In comparison to petrol vehicles of similar make and model tested in the NISE study, the exhaust emissions from the ADR27 LPG vehicles tested were slightly lower than comparable petrol vehicles. The ADR37/00 LPG vehicles also emitted less HC emissions, but their CO and NOx emissions were slightly higher.
2. Of the three categories, the private vehicles (ADR27 and ADR37/00) were the worst polluters. This may be due to the lower level of maintenance these vehicles receive in comparison to fleet and taxis.
3. In general, LPG vehicles produce exhaust emissions that satisfy the current ADR37 requirements.
4. As with the petrol fleet, the LPG fleet is tainted with "gross emitters" whose emission levels far exceed the ADR limits. These vehicles exist in all three categories.
5. Evaporative emissions from LPG vehicles far exceed the ADR limits. This was also found to be the case with the petrol engined vehicles tested in the NISE Study. The result is a significant concern for both the petrol and LPG vehicle fleets.
6. In general, emissions of CO and HC from the LPG in-service fleet were reduced after tuning. However, NOx emissions remained unchanged, or in some cases actually increased.
7. Tuning of open loop fuel management vehicles has a significant benefit on reducing CO and HC emissions while slightly increasing NOx emissions. However the effect of tuning on vehicles equipped with closed loop fuel management systems was minimal. Tuning LPG open loop vehicles is a sensitive operation that, if not performed with the correct and most advanced equipment and by experienced personnel, leads to large variations in emission levels. That is, introducing a small tuning change (ie a "tweak" of the system) can result in a large increase or decrease in emissions.
8. Some vehicles were found to have a mix of components from different kit manufacturers and in at least one case this had an adverse effect on emissions.
9. Fuel consumption can be improved by twelve percent (on average) by tuning.

10. Correlation of Inspection & Maintenance short tests with the ADR test for LPG vehicles is similar to that of the petrol vehicles. That is, the IM240 test has the best correlation followed by the other loaded tests, SS60 and ASM25/25 . The two idle tests had the lowest correlation.

The study also identified deficiencies in the data available on the make up and operation of the LPG fleet, which limit the capacity to use the results from this study to accurately estimate LPG vehicle impacts on urban air quality.

10. REFERENCES

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10.1 INFORMATION ON DEDICATED LPG FUELLED VEHICLES

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LPG In-Service

Vehicle Emissions Study

ATTACHMENTS

CONTENTS

ATTACHMENT

ATTACHMENT 1

• CONFIRMATION LETTER

DEAR CAR OWNER

As a follow-up to the recent telephone call from a representative of the Environment Protection Authority of ___, I am writing to confirm details about the testing program for LPG-fuelled vehicles.

The EPA representative will have explained that your household was identified as owning an LPG dual-fuelled motor vehicle when interviews were conducted for the national in-service vehicle study, which is being managed by the Federal Office of Road Safety.

You may recall that the Federal Office of Road Safety has responsibility for a number of environmental issues relating to motor vehicles and that the national in-service vehicle study is being conducted to gather information about the relationships between motor vehicles and the air quality of our cities.

The study, until recently, has focussed on the operation of petrol-engine passenger vehicles only. However, it has been decided that there would be benefit in testing a small number of LPG dual-fuelled vehicles because of the increased popularity as both private and commercial transport. Testing of the LPG vehicles will provide useful information on the quality of operation and general condition of these cars.

Should you agree to have your car tested, the following procedures will take place:

TESTING OF YOUR VEHICLE

Testing of your vehicles would be undertaken in a specially equipped laboratory under the supervision of highly qualified engineers. No actual road testing is involved.

Although your car would be needed for approximately 3 days, the actual testing is quite short, involving a pre-tune and then a post-tune test of some 2-3 hours. However, the preparation , conditioning, tuning and checking of the vehicle between the two tests is quite extensive and accounts for most of the time we would have your car.

INSURANCE

Arrangements have been made through the NRMA, as well as the Commonwealth and the Testing Station to have the insurance cover on all the vehicles involved in testing.

While a vehicle is with the laboratory, it is covered by that organisation’s insurance cover. This cover extends to the collection and delivery of each participating vehicle.

The replacement vehicle is provided to participating householders over the testing period is covered by a standard NRMA comprehensive insurance policy with the normal excess being covered by the Commonwealth Government.

REPLACEMENT VEHICLE

A replacement current-model vehicle will be provided to you, for use during the time your vehicle is being tested.

There are, of course, a few minor formalities to be dealt with at handover of vehicles. These are standard requirements and we ask that you read the conditions prior to handover of your vehicle and keep a signed copy for your own purposes.

It is essential that the driver of the replacement vehicle has a current driver's licence.

HANDOVER DOCUMENT

The handover document contains an outline of the obligations of the driver whilst the replacement vehicle is in his or her care. This includes such items as compliance with all road laws, not driving whilst under the influence of alcohol or drugs, and an expectation that you will look after the vehicle. Once again you should read this before signing.

CHECK LIST ON CONDITION OF YOUR VEHICLE

A check sheet on the condition of your vehicle is also to be filled out by the officer collecting your vehicle and signed by you or your authorised agent at the time of collection and return of your vehicle.

RETURN OF YOUR VEHICLE

Every effort is made to ensure that participating householders are not inconvenienced throughout the test period and to make their contribution to the study worthwhile.

The Federal Office of Road Safety does this by providing vehicle with a tune-up, and in addition the car will be cleaned and filled with LPG before it leaves the testing station. The tune-up will be done by a licensed LPG service agent who is a member of the Australian Liquefied Petroleum Gas Association.

On the return of your vehicle, you will be provided with a report summarising the test results.

If, for some reason, your vehicle does not fully meet normal roadworthy requirements, you will be notified of what needs to be rectified. This is purely advisory and no action will be taken against any owner.

I hope you find this extension to the national in-service vehicle study interesting and can contribute to its success. Thank you for taking the time to read this letter.

A representative of the EPA Motor Vehicle Testing Laboratory will contact you again shortly to talk about your participation in the testing program. In the meantime, if you have any questions at all about the testing, please contact _______ from the EPA.
Telephone: ________

Yours sincerely

Peter Anyon
Project Director

August 1995

ATTACHMENT 2

INSPECTION AND TEST SEQUENCE

Part 1 Pre-Test Inspection

The laboratory representative at the time of vehicle pick up shall be required to complete an inspection sheet prior to accepting a test vehicle. The inspection sheet is to be signed by the laboratory representative and the vehicle owner (or person handing over the test vehicle).

Once accepted, the owner will be given a replacement vehicle (except in the case of taxis where no replacement vehicle will be given) and the relevant paperwork for insurance purposes shall be completed.

The test vehicle will be driven to the predetermined licensed LPG service centre. The following activities will be performed by approved staff:

- Fill the vehicles integral LPG cylinder with commercial LPG.
- Inspect the general condition of the engine and identify any problems and parts that are required when tuning the vehicle; particular attention paid to the LPG system components.
- Record vehicle details as per the FORS pre inspection check sheet, noting additional features and component details specific to the LPG system. Such additional features should include the following:

  - LPG converter make:
  1. AIROD
  2. BRC
  3. CENTURY
  4. GRFT
  5. IMPCO
  6. LANDI
  7. LANDI HARTOG
  8. LANDI RENZO
  9. O.H.G.
  10. O.M.V.L.
  11. OMNIGAS
  12. POLIAUTO
  13. VIALLE

  - control system:
  1. CLOSED LOOP
  2. OPEN LOOP

  - conversion kit type:

1. FIXED VENTURI FLOW

2. VARIABLE VENTURI FLOW
3. IMPCO/O.H.G. CARBURETTOR

- LPG conversion kit compatibility:
  1. YES
  2. NO

- general condition of lines and other accessories.

These LPG conversion kit features shall be entered into their designated fields and if additional fields are required to enter any other features deemed necessary then the *Modifications* field in the FORS database shall be utilised.

- Make provision in the LPG supply line for a LPG compatible hose to be connected, for bypassing the vehicles integral LPG tank when undertaking emission testing in the testing laboratory. The line shall be connected to an LPG external test tank at the testing laboratory prior to testing the vehicle.

The pre-test checklist used for the test vehicles during the FORS Study shall be completed before testing is commenced. This checklist shall entail items (e.g., the features listed above) that are relevant to LPG systems.

Part 2 Preparing Vehicle for Testing

All vehicles shall be prepared in the following manner when undertaking exhaust emission tests:

- drain fuel in petrol tank,
- fill 40% of petrol tank capacity with FORS specification test fuel, and weigh the vehicle to determine its inertia category without the external LPG cylinder fitted,

NOTE: **If evaporative emission test (SHED) is to be carried out; replenish petrol tank with the FORS specified fuel and ensure that the LPG test blend cylinder is in the boot of the vehicle during the evaporative emission test.**

- connect LPG external cylinder containing the specified LPG test blend to flexible supply line, bypassing the vehicles' integral tank, and ensuring that the LPG external cylinder remains in the boot of the vehicle during the entire duration of preconditioning and testing,

- complete the normal ADR 37 preconditioning cycle, and

- allow a soaking period of at least 12 hours before commencement of testing.

Any work requiring the replacement of parts and tuning is to be completed by the tuning contractor after completion of the first [pre-tune] round of tests. Apart from any adjustments to enable safe operation of the vehicle during the test, the person undertaking the re-test inspection shall not undertake any work to alter the "as received" condition of the vehicle, as this would defeat the objective of the pre-tune test program.

PART 3 Testing Program

The sequence of the testing program is as follows.

1. Inspect vehicle and as received.

* **If suitable** for testing, go on to item 2 and provide report on pre-test inspection, including advice of parts required for tuning, and other matters requiring attention by the LPG servicing contractor.

* **If not suitable** for testing, vehicle should be tuned, cleaned [washed externally and vacuumed & wiped over inside], filled with LPG, and returned to vehicle owner with a copy of the completed checklist [including tuning information].

2. Prepare and precondition vehicle in accordance with ADR37/00 ensuring LPG external cylinder is in the boot of the vehicle, including requirements for evaporative emissions test, where applicable and the instructions specified in Attachment 3a.

3. Overnight temperature soak as specified in ADR37/00.

4. Commence ADR37/00 test sequence.

5. At completion of heat build [where required] conduct Fuel Filler Cap Sealing test and Canister sniff check.

6. Complete ADR37/00 drive cycle ADR37/00 ensuring LPG external cylinder is outside the vehicle.

7A. For vehicles undergoing ADR37/00 Evaporative Emissions test, complete test in accordance with ADR37/00 procedures and then return vehicle to dynamometer. Immediately prior to commencing the Acceleration Simulation Mode [ASM] Test at Step 8, bring vehicle to normal operating temperature by running vehicle at the ASM speed and load for 5 minutes.

7B. For vehicles not undergoing ADR37/00 Evaporative Emissions test, leave vehicle on the dynamometer. If the vehicle does not immediately proceed to the Acceleration Simulation Mode [ASM] Test at Step 8, bring vehicle to normal operating temperature by running vehicle at the ASM speed and load for 5 minutes immediately prior to commencing the ASM test.

8. Conduct Acceleration Simulation Mode test.

9. Conduct Steady State Loaded [60km/hr] test.

10. Conduct Steady State [High Idle] test and immediately the test is completed conduct the Catalyst Temperature test.

11. Conduct the Steady State [Idle] test.

12. Conduct the IM240 test.

13. Provide vehicle to licensed LPG servicing contractor for tune/repair to optimise operation on LPG and replacement of parts.

14. Repeat steps 2 to 12 of the above sequence.

15. Prepare summary sheet for vehicle owner.

16. Process test result data required for analysis and reporting.

17. Testing completed - vehicle cleaned inside and out.

18. Vehicle driven to LPG servicing contractor for removal of the bypass line and return of the vehicle to its standard condition.

19. Return vehicle to owner in accordance with contract requirements.

ATTACHMENT 3

TESTING SPECIFICATIONS

The LPG test fuel shall be contained within certified LPG cylinders. Utmost care should be taken to ensure safety whilst handling the LPG cylinders.

The following tests shall be undertaken in accordance with the specified procedures:

NAME OF TEST	*TEST PROCEDURE*
EMISSIONS TESTS	
ADR37/00 EXHAUST EMISSIONS	As set out in Clauses 37.6 to 37.8 of Australian Design Rule [ADR] 37/00 *Emission Control for Light Vehicles,* subject to the following conditions: [1] Where the vehicle is not going to be subject to the ADR37/00 evaporative emissions test, the heat build and associated drain and fill of the petrol tank shall not be conducted. [2] The vehicle shall be weighed in its "as delivered" condition, and the road power absorber setting shall be the appropriate value from Table 8.2 of ADR37/00. [3] If the vehicle is fitted with air conditioning, the road power absorber setting shall be increased by 10% and the air conditioning unit switched off. [4] The ADR37/00 default speeds shall be used to determine manual gear change points. [5] The actual distance recorded in the test shall be used to calculate emissions in g/km. [6] The HC and fuel consumption calculations will be different to those used for petrol. Therefore, the equations illustrated in section 1.7 of Appendix 5 [IM240] shall be used.
ADR37/00 EVAPORATIVE EMISSIONS	As set out in Clauses 37.6 to 37.7 of ADR37/00 *Emission Control for Light Vehicles*, subject to the following condition: [1] The attachment of a fuel temperature sensor to the outside surface of the fuel tank is an acceptable alternative method to that specified in ADR37/00, provided it can be established that this method provides equivalent results to the method specified in the ADR.
ACCELERATION SIMULATION MODE [ASM2525]	As set out in Appendix 1 to this attachment.
STEADY STATE LOADED [60km/hr]	As set out in Appendix 2 to this attachment.
STEADY STATE [IDLE]	As set out in Appendix 3 to this attachment.
STEADY STATE [HIGH IDLE]	As set out in Appendix 4 to this attachment.
IM240	As set out in Appendix 5 to this attachment.

ATTACHMENT 3

Appendix 1

Acceleration Simulation Mode Test Procedure [ASM2525]

The Acceleration Simulation Mode Test shall be conducted in accordance with the following procedures:

1. The vehicle is placed on the dynamometer and driven to the target speed of 40km/hr ± 1km/hr.

2. Vehicle load is determined by the formula

$$\frac{\underline{\textit{Equivalent Test Inertia Weight}}\ \text{[lbs]}}{300}$$

- where the horsepower is determined at 25mph [possible values range from 6-20hp at 25mph]. The load applied simulates 25% of the power required to accelerate the vehicle at 3.3mph/second at 25mph.

The load applied to the dynamometer at 40km/hr shall be determined from the "*Determination of Load*" table used in the FORS test procedure. Flywheels, electrical devices or other means of simulating *Equivalent Test Inertia Weight* [mass] shall be used.

3. Maintain test condition for 1 minute.

4. For vehicles with manual transmissions, the vehicle is tested in 2nd gear, for automatics in Drive.

5. The exhaust emissions are collected after a minimum of 10 seconds of operation in the speed window. If the emission readings are stable the test is completed and readings recorded. If the readings are unstable [±20ppm HC, ±0.20% CO, ±150ppm NOx] continue the test for 60 seconds and collect the sample within the last 10 seconds and record the result.

6. The raw exhaust measurements of HC [in ppm] and CO [in %vol] shall be recorded using a calibrated non-dispersive infrared analyser at least equivalent to a BAR90 3-gas smart bench. The raw exhaust measurements of NOx [recorded as NO in ppm] shall be recorded using a calibrated Horiba VIA 300 non-dispersive infra red analyser or equivalent.

ATTACHMENT 3

Appendix 2

Steady State Loaded [60km/Hr] Test Procedure

Method Of Measurement Of The Rates Of Emission Of Carbon Monoxide, Hydrocarbons And Oxides Of Nitrogen In The Exhaust Gases Of A Motor Vehicle Operating At A Steady Speed Of 60 Km/Hr By The Method Of Constant Volume Sampling

1. The Test

The test consists of driving the vehicle on a chassis dynamometer with the aid of a driving schedule indicator so that the vehicle speed, measured from the dynamometer rolls, is at a constant speed of 60 km/hr.

The test is to consist of 2 phases:
(a) a preconditioning phase of 5 minutes at 60 km/hr, and
(b) a measurement phase.

The exhaust emissions must be diluted with air to a constant volume. A portion of the diluted mixture must be sampled continuously during the measurement phase of the test and collected in a bag for analysis. A parallel sample of the dilution air must also be collected during this phase for analysis.

The concentrations of carbon dioxide, carbon monoxide, and oxides of nitrogen in the samples collected are determined as normal petrol. However, hydrocarbon emissions will be calculated by considering the ratio of propane to butane in the LPG blend and the respective HC fraction and HC density as illustrated in the following equation:

$$HC_{mix} = \frac{V_{mix} \times r_{HC} \times HC_{conc} \times 10^{-6}}{D}$$

where V_{mix} (L) = volume of the mixture, equation of which will remain the same for LPG.
HC_{conc} (mol p.p.m. carbon equivalent) = concentration of HC from emissions analysis.
D (km) = measured driven distance.

density of HC for propane = 0.6110 g/L and density of HC for butane = 0.6040 g/L
then density of HC for LPG test blend of 60/40, $\mathbf{r_{HC} = 0.6082}$ **g/L**.

Raw exhaust measurements shall also be recorded as per the latest testing schedule of the FORS Study that was agreed by the testing authorities and laboratories.

2. Test Conditions

The test must be carried out under the following conditions:

(a) The test vehicle must be preconditioned as described above.

(b) The vehicle must be tested at an ambient air temperature between 20°C and 30°C.

(c) The deviation in speed at any given time during the measurement phase must not exceed 1 km/hr.

(d) The road load power setting shall be determined by reference to the vehicle's engine capacity and dynamometer inertia setting as specified in the table below. If the vehicle is equipped with air conditioning, the air conditioner must be switched off during the test.

Table - Calculation of Dynamometer Road Load Setting

Engine Capacity of Test Vehicle [L]	Inertia Setting [kg]	Road Load Power [kW]
< 1.7	794	5.7
> 1.7 & < 2.9	1134	7.0
> 2.9	1474	8.0

(e) An auxiliary fan with a capacity of not more than 2.5 cubic metres per second must be used to cool the engine.

(f) Prior to the test the air pressure in the tyres on the drive wheels of the vehicle must be equal to or greater than the pressure recommended, if any, in the owner's manual and, in any case, must be less than 310 kilopascals.

(g) The constant volume sampling unit must be connected to the vehicle exhaust pipe or pipes and turned on, the cooling fan must be turned on and the engine compartment cover must be raised before the beginning of the test.

The measurement phase of the test and the collection of samples are to begin after the preconditioning phase has ended. The engine ignition must not be turned off at the end of the measurement phase.

(h) The engine must be started according to the procedures recommended, if any, in the owner's manual. *If* the engine fails to start, the starting procedure must be repeated. A vehicle equipped with an automatic choke must be operated according to the procedures recommended, if any, in the owner's manual. *If* no recommendation is made as to the time at which the accelerator pedal is to be depressed in order to return the engine to normal idle speed, that time must be 13 seconds after the engine starts. A vehicle equipped with a manual choke must be operated according to the procedures recommended, if any, in the owner's manual. If no recommendation is made as to manual choke operation, the choke must be operated to maintain engine idle speed between 1050 and 1150 rpm during the first 20 seconds of the preconditioning phase and used during the remainder of the phase if considered necessary by the person performing the test to keep the engine running.

(i) If the owner's manual does not recommend a procedure for starting a warm engine, the engine (whether equipped with automatic or manual choke) can be started by depressing the accelerator pedal through about half of the available distance and cranking the engine until it starts.

(j) The following driving requirements must be met during the test -

(i) The transmission must be placed in the gear recommended in the owners manual for the speed of 60 km/hr.

(ii) A vehicle equipped with a freewheeling or overdrive unit must be tested with the freewheeling or overdrive unit placed out of operation.

3. Exhaust Collection and Sampling

A connecting tube must be used to connect the vehicle exhaust pipe or pipes to a constant volume sampling unit, which must dilute the exhaust gases to a constant volume of diluted mixture with dilution air which has been drawn through a charcoal filter. The filter assembly must be sized and maintained so that the pressure in the area where the exhaust gases mix with dilution air is less than 0.25 kilopascals below ambient air pressure when the constant volume sampling unit is in operation.

If the sampling unit employs a positive displacement pump, the temperature of the diluted mixture immediately before it enters the pump must not vary by more than 12°C during the test.

The sampling unit must have a capacity of not less than 0.09 cubic metres per second. The total volume of diluted gases, corrected to 20°C and 101.325 kilopascals, passed through the sampling unit during each phase of the test must be measured.

A constant proportion of the flow of diluted exhaust gases must be sampled at a rate of not less than 0.08 litres per second and collected in a separate collection bag for the measurement phase of the test. Dilution air must be sampled at a constant flow rate and similarly collected during the test.

4. Analysis

Within 10 minutes of the conclusion of the measurement phase of the test, the concentration of hydrocarbons, expressed as propane, in the samples of diluted exhaust gases and dilution air collected during that phase must be determined using flame ionisation detector analysis, the concentrations of carbon monoxide and carbon dioxide in the samples must be determined using non-dispersive infrared analysis and the concentration of oxides of nitrogen in the samples must be determined using chemiluminescent analysis.

The hydrocarbon analyser must be fuelled with a mixture of between 38% and 42% by volume hydrogen, with the balance being helium. The hydrocarbon analyser must be zeroed with air and the carbon monoxide, carbon dioxide and oxides of nitrogen analysers must be zeroed with either air or nitrogen. The concentration of impurities in the zero gas or gases must not exceed 6 ppm. hydrocarbons (expressed as propane), 10 ppm. carbon monoxide and 1 ppm. nitric oxide. For the purposes of this analysis air includes a blend made of nitrogen and oxygen with the oxygen concentration between 18% and 21% by volume. The hydrocarbon analyser must be spanned with a propane and air mixture which will result in a response equivalent to not less than 70% of the full scale deflection. The carbon monoxide analyser must be spanned with a carbon monoxide and nitrogen mixture which will result in a response equivalent to not less than 70% of the full scale deflection. The carbon dioxide analyser must be spanned with a carbon dioxide and nitrogen mixture which will result in a response equivalent to not less than 70% of the full scale deflection. The oxides of nitrogen analyser must be spanned with a nitric oxide and nitrogen mixture which will result in a response equivalent to not less than 70% of the full scale deflection. At least 3 gas mixtures must be used to calibrate each of the analysers.

ATTACHMENT 3

Appendix 3

Steady State [Idle] Test Procedure

The Steady State [Idle] Test shall be conducted in accordance with the following procedures:

1. Immediately before the test, the engine must be brought to normal operating temperature.

2. The engine is started and kept running throughout the test, with the accelerator pedal not depressed.

3. For vehicles with manual transmissions, the vehicle shall be in neutral gear with the clutch engaged. For vehicles with automatic or semi-automatic transmissions, the gear selector shall be in the Drive position and the handbrake placed in the fully "on" position.

4. For vehicles equipped with a manual choke, the choke must be in the "off" position.

5. The inlet probe of the sampling probe of a calibrated[4] non-dispersive infrared analyser shall be positioned in the exhaust pipe at any point between 350 mm and 500 mm from the discharge end of the exhaust pipe. For the purposes of the test, the pipe may be extended by use of an extension piece connected to the vehicle's discharge outlet with a suitable connection which does not allow dilution of the exhaust gases by air. Where the vehicle is fitted with more than one exhaust pipe, the concentration shall be measured in each pipe.

6. The raw exhaust measurement shall be recorded as the maximum value of the concentration of CO [in %vol] and total HC [in ppm] as determined by the analyser over a period of between 30 and 60 seconds, beginning not earlier that 60 seconds after the probe has been inserted in the exhaust pipe. Where the vehicle is fitted with more than one exhaust pipe, the maximum value shall be the highest value from either pipe.

[4] The analyser shall be calibrated within the preceding 30 days by being zeroed with dry nitrogen which contains less than 10ppm CO, or 6ppm total HC [equivalent carbon response], as applicable, and spanned with a CO or total HC mixture, as applicable, which will result in a response equivalent to not less than 70% of the full scale deflection. The instrument must be zeroed and spanned using a secondary electronic of mechanical system prior to each measurement.

ATTACHMENT 3

Appendix 4

Steady State [High Idle] Test Procedure

The Steady State [High Idle] Test shall be conducted in accordance with the following procedures:

1. Immediately before the test, the engine must be brought to normal operating temperature.

2. The engine is started and kept running throughout the test, with the accelerator pedal depressed until the engine rotational speed has stabilised at 2500 rpm ±50rpm.

3. For vehicles with manual transmissions, the vehicle shall be in neutral gear with the clutch engaged. For vehicles with automatic or semi-automatic transmissions, the gear selector shall be in the neutral position and the handbrake placed in the fully "on" position.

4. For vehicles equipped with a manual choke, the choke must be in the "off" position.

5. The inlet probe of the sampling probe of a calibrated[5] non-dispersive infrared analyser shall be positioned in the exhaust pipe at any point between 350 mm and 500 mm from the discharge end of the exhaust pipe. For the purposes of the test, the pipe may be extended by use of an extension piece connected to the vehicle's discharge outlet with a suitable connection which does not allow dilution of the exhaust gases by air. Where the vehicle is fitted with more than one exhaust pipe, the concentration shall be measured in each pipe.

6. The raw exhaust measurement shall be recorded as the maximum value of the concentration of CO [in %vol] and total HC [in ppm] as determined by the analyser over a period of between 30 and 60 seconds, beginning not earlier that 60 seconds after the sampling has commenced and the engine speed has stabilised. Where the vehicle is fitted with more than one exhaust pipe, the maximum value shall be the highest value from either pipe.

[5] The analyser shall be calibrated within the preceding 30 days by being zeroed with dry nitrogen which contains less than 10ppm CO, or 6ppm total HC [equivalent carbon response], as applicable, and spanned with a CO or total HC mixture, as applicable, which will result in a response equivalent to not less than 70% of the full scale deflection. The instrument must be zeroed and spanned using a secondary electronic of mechanical system prior to each measurement.

ATTACHMENT 3

Appendix 5

Modified IM240 Test Procedure

1. IM240 TEST PROCEDURE

1.1 General Requirements

1.1.1 Ambient Conditions
The ambient temperature, absolute humidity, and barometric pressure shall be recorded continuously during the transient driving cycle or as a single set of readings up to 4 minutes before the start of the transient driving cycle.

1.1.2 Restart
If shut off, the vehicle shall be restarted as soon as possible before the test and shall be running at least 30 seconds prior to the transient driving cycle.

1.2 Pre-inspection and Preparation

1.2.1 Accessories
All accessories (air conditioning, heat, demisters, radio, automatic traction control if switchable, etc.) shall be turned off.

1.2.2 Leaks
The vehicle shall be inspected for exhaust leaks. Audio assessment while blocking exhaust flow or gas measurement of $C0_2$ or other gases shall be acceptable. Vehicles with leaking exhaust systems shall be rejected from testing.

1.2.3 Operating Temperature
The vehicle temperature gauge, if equipped and operating, shall be checked to assess temperature. Vehicles in overheated condition shall be rejected from testing.

1.2.4 Tyre Condition
Vehicles shall be rejected from testing if the tyre cords are visible. Vehicle tyres shall be visually checked for adequate pressure level. Drive wheel tyres that appear low shall be inflated to approximately 30 psi, or to tyre sidewall pressure, or the manufacturer's recommendation.

1.2.5 Ambient Background
Background concentrations of HC, CO, NOx, and $C0_2$ shall be sampled as specified in ADR37/00 to determine background concentration of CVS dilution air. The sample shall be taken for a minimum of 15 seconds within 120 seconds of the start of the transient driving cycle, using the same analysers used to measure tailpipe emissions. Average readings over the 15 seconds for each gas shall be recorded in the test record. Testing shall be prevented until the average ambient background levels are less than 20 ppm HC, 30 ppm CO, and 2 ppm NOx or outside ambient air levels, whichever are greater.

1.2.6 Sample System Purge
While a lane is in operation, the CVS shall continuously purge the CVS hose between tests, and the sample system shall be continuously purged when not taking measurements.

1.2.7 Negative Values

Negative gram per second readings shall be integrated as zero and recorded as such.

1.3 Equipment Positioning and Settings

1.3.1 Roll Rotation
The Vehicle shall be manoeuvred onto the dynamometer with the drive wheels positioned on the dynamometer rolls. Prior to test initiation, the rolls shall be rotated until the vehicle laterally stabilises on the dynamometer. Drive wheel tyres shall be dried if necessary to prevent slippage during the initial acceleration.

1.3.2 Cooling System
Testing shall not begin until the test cell cooling system is positioned and activated. The cooling system shall be positioned to direct air to the vehicle cooling system, but shall not be directed at the catalytic converter, where fitted.

1.3.3 Vehicle Restraint
Testing shall not begin until the vehicle is restrained. Any restraint system shall meet the requirements of ADR37/00.

1.3.4 Dynamometer Settings
Dynamometer power absorption and inertia weight settings shall be those appropriate to vehicle as specified in Table 1. If the vehicle is fitted with air conditioning, the road power absorber setting shall be increased by 10% and the air conditioning unit switched off.

Table 1 - Determination of Dynamometer Settings

No. Of Cylinders	Actual Road Load [hp]	Test Inertia Weight [lbs]
4	9.4	2500
5	10.3	3000
6	10.3	3000
8	11.2	3500

1.3.5 Exhaust Collection System
The exhaust collection system shall be positioned to ensure complete capture of the entire exhaust stream from the tailpipe during the transient driving cycle. The system shall meet the requirements of ADR37/00.

1.4 Vehicle Preconditioning

The vehicle shall be preconditioned by driving the vehicle on the dynamometer at 30 miles per hour for up 90 seconds at road load.

1.5 Vehicle Emission Test Sequence

1.5.1 Transient Driving Cycle
The vehicle shall be driven over the IM240 drive cycle

1.5.2 Driving Trace
The inspector shall follow an electronic, visual depiction of the time/speed relationship of the transient driving cycle (hereinafter, the trace). The visual depiction of the trace shall be of sufficient magnification and adequate detail to allow accurate tracking by the driver and shall permit the driver to anticipate upcoming speed changes. The trace shall also clearly indicate gear shifts as specified in

clause 2.5.3.

1.5.3 Shift Schedule

For vehicles with manual transmissions, the operator shall shift gears according to the shift schedule used in the IM240 Test Procedures from the FORS Study. Gear shifts shall occur at the points in the driving cycle where the specified speeds are obtained. For vehicles with fewer than six forward gears the same schedule shall be followed with shifts above the highest gear disregarded.

1.5.4 Speed Excursion Limits

Speed excursion limits shall apply as follows:

[a] The upper limit is 2 mph higher than the highest point on the trace within 1 second of the given time.

[b] The lower limit is 2 mph lower than the lowest point on the trace within 1 second of the given time.

[c] Speed variations greater than the tolerances are acceptable provided they occur for no more than 2 seconds on any occasion.

[d] Speeds lower than those prescribed during accelerations are acceptable provided the vehicle is operated at maximum available power during such accelerations until the vehicle speed is within the excursion limits.

[e] Exceedences of the limits in [a] through [c] of this paragraph shall automatically result in a void test. The test facility manager can override the automatic void of a test if the manager determines that the conditions specified in paragraph [d] occurred. Tests shall be aborted if the upper excursion limits are exceeded. Tests may be aborted if the lower limits arc exceeded.

1.5.5 Speed Variation Limits

A linear regression of feedback value on reference value shall be performed on each transient driving cycle for each speed using the method of least squares, with the best fit equation having the form:

$y = mx + b$,

where:

y = the feedback (actual) value of speed; m = the slope of the regression line; x = the reference value; and

b = the y-intercept of the regression line.

The standard error of estimate (SE) of y on x shall be calculated for each regression line. A transient driving cycle that exceeds the following criteria shall be void and the test shall be repeated:

SE = 2.0 mph maximum;

m = 0.96-1.01;

r^2 = 0.97 minimum; and

b = ± 2.0mph.

1.5.6 Distance Criteria

The actual distance travelled for the transient driving cycle and the equivalent vehicle speed (ie., roll speed) shall be measured If the absolute difference between the measured distance and the theoretical distance for the actual test exceeds 0.05 miles, the test shall be void.

1.5.7 Vehicle Stalls
Vehicle stalls during the test shall result in a void and a new test. More than 3 stalls shall result in test failure.

1.5.8 Dynamometer Controller Check
For each test, the measured horsepower, and inertia if electric simulation is used, shall be integrated from 55 seconds to 81 seconds (divided by 26 seconds), and compared with the theoretical road-load horsepower (for the vehicle selected) integrated over the same portion of the cycle. The same procedure shall be used to integrate the horsepower between l89 seconds to ~01 seconds (divided by 12 seconds). The theoretical horsepower shall be calculated based on the observed speed during the integration interval. If the absolute difference between the theoretical horsepower and the measured horsepower exceeds O.5 hp, the test shall be void. For vehicles over 8500 pounds GVWR, if the absolute difference between the theoretical horsepower and the measured horsepower exceeds 2 hp, the test shall be void.

The dynamometer controller check in this clause 1.5.8 is not required, provided the dynamometer is checked at least daily as part of the laboratory normal quality assurance program.

1.5.9 Inertia Weight Selection
Operation of the inertia weight selected for the vehicle shall be verified as specified in ADR37/00. For systems employing electrical inertia simulation, an algorithm identifying the actual inertia force applied during the transient driving cycle shall be used to determine proper inertia simulation. For all dynamometers, if the observed inertia is more than 1% different from the required inertia, the test shall be void.

1.5.10 CVS Operation
The CVS operation shall be verified throughout the test by monitoring the difference in pressure from atmosphere for a CFV-typeCVS or the difference in pressure between upstream and throat pressure on a SSV-type CVS. The minimum values shall be determined from system calibrations. Monitored pressure differences below the minimum values shall void the test.

1.6 Emission Measurements

1.6.1 Exhaust Measurement
The emission analysis system shall sample and record dilute exhaust HC, CO, $C0_2$, and NOx during the transient driving cycle as described in ADR37/00.

1.6.2 Purge Measurement
The analysis system shall record the total volume of flow in litres over the course of the actual driving cycle as described in part 3.

1.7 Emission Calculations

The emission calculations remain the same as those used in the FORS Study except for the calculation for HC emissions and fuel consumption. Hydrocarbon emissions and fuel consumption shall be calculated by considering the ratio of propane to butane in the LPG blend and the respective HC fraction and HC density as illustrated in the following equations:

$$HC_{mix} = \frac{V_{mix} \times \rho_{HC} \times HC_{conc} \times 10^{-6}}{D}$$

where V_{mix} (L) = volume of the mixture, equation of which will remain the same for LPG.
HC_{conc} (mol ppm. carbon equivalent) = concentration of HC from emissions analysis.
D (km) = measured driven distance.

density of HC for propane = 0.6110 g/L and density of HC for butane = 0.6040 g/L
then density of HC for LPG test blend of 60/40, **ρ_{HC} = 0.6082 g/L**,

$$Fuel\ Consumption\ (L/100km) = \frac{(HC_{mass} \times Fraction_{HC}) + (CO_{mass} \times Fraction_{CO}) + (CO_{2\,mass} \times Fraction_{CO_2})}{Fraction_{HC} \times \rho_f \times 10}$$

where Density of LPG blend of 60/40 **ρ_f = 0.5300 kg/L**

HC fraction for propane = 0.8170
HC fraction for butane = 0.8270
HC fraction for the LPG test blend (60/40)
$Fraction_{HC}$ = (0.8170 × 0.6) + (0.8270 × 0.4)
= 0.8210
$Fraction_{CO}$ = 0.42880
$Fraction_{CO2}$ = 0.27291

and HC_{mass} = mass HC emissions in grams per vehicle kilometre.
CO_{mass} = mass CO emissions in grams per vehicle kilometre.
$CO2_{mass}$ = mass CO_2 emissions in grams per vehicle kilometre.

ATTACHMENT 3

Appendix 6

TUNING SPECIFICATIONS

General Requirements & Costs

The tuning will be undertaken by a separate contractor but on premises of the laboratory [if possible], otherwise the vehicle will be taken to the contractor's premises for servicing. The tuning contractor shall be provided with the pre-test inspection checklist for that vehicle and any replacement parts specifically ordered for the vehicle as a result of the pre-test inspection.

The parts budget for the tuning is set at a maximum of $150 per vehicle. Where it may be considered necessary to replace expensive parts such as the oxygen sensor, and the total parts budget for the vehicle will, as a result, exceed $150, the tenderer is authorised to approve additional parts expenditure, subject to an absolute maximum of $200 [except where specifically approved by the Project Manager], and provided that such extra expenditure does not lead to total parts expenditure exceeding an average of $150 per vehicle.

Procedure

The vehicle shall be tuned to optimise operation on the LPG test blend of 60% propane and 40% butane.

The tuning shall be limited to the following items [where applicable]:

- Replace points and air filter
- Replace oil [using SG20W-50 oil] and oil filter
- Check spark plug condition and gap, and adjust or replace as necessary
- Check distributor condition and operation and adjust as necessary
- Check and adjust idle mixture and speed
- Check and replace spark plug and distributor leads as necessary
- Check and replace hoses and other minor items in LPG fuel / electrical / emission control systems as necessary, subject to budget
- Interrogate vehicle diagnostics and replace faulty components, subject to budget detailed above.

  Note Failed or malfunctioning catalytic converters shall be replaced, and faulty oxygen sensors should be replaced where possible, if within running budget.

The transmission, radiator and battery fluids should be topped up if necessary.

Details of all work undertaken shall be recorded on the shaded area of the pre-inspection check list.

Range of Vehicles to be Tuned

The vehicles which will be selected for testing / tuning shall be either Falcons or Commodores with various types of LPG conversion kits [with the date of manufacture ranging from 1980-1991].

ATTACHMENT 4a

LPG Project Hand-over Inspection Sheet 1

(FILLED OUT BY NSW EPA)

Date:........../........../..........   Time:......... : ....am/pm

Owner's Details:
Name:..
Address:..
....
....
Telephone:..

Reg. No.:		Make:		Model:		Year:	

ITEMS TO BE INSPECTED				
Rego Label:	....../...../......		Coolant/Radiator Check:	
Windscreen:			Fluid Levels:	
Mirrors (all):			Wipers/Washers:	
Tyres (all)/Hub Caps:			Lights/Indicators:	
Seat Belts:			Smoke:	
Interior Condition/HI-FI:			Fuel Leaks:	
Fuel Filler Cap:			Oil Leaks:	
Exhaust Check/Leaks:			Battery:	
Brakes:			Spare Wheel/Tools:	
Steering:			Service Valve Operation:	
Drive Line:			Cylinder Inspection Date:	

Vehicle OK for Testing: **YES / NO**

If NO, why?: ____
____

Fuel Type: **Dual Fuel / LPG Only**

Last Petrol Use: **........../........../..........**

Inspection by (NSW EPA): .... **........../........../..........**

Signature of Owner: **...............................** **........../........../..........**

ATTACHMENT 4b

LPG Project Hand-over Inspection Sheet 2

(FILLED OUT BY LICENSED LPG SERVICING ORGANISATION)

Date:........../........../..........   Time:......... : ....am/pm

Reg. No.:		Make:		Model:		Year:	

Please Tick:

LPG Converter Make:			**Control System:**	
AIROD			Closed Loop	
BRC			Open Loop	
CENTURY				
GRFT			**Conversion Kit Type:**	
IMPCO			Fixed Venturi Flow	
LANDI			Variable Venturi Flow	
LANDI HARTOG			IMPCO/O.H.G. Carburettor	
LANDI RENZO				
O.H.G.			**LPG Conversion Kit Compatibility:**	
O.M.V.L.			Components Compatible	
OMNIGAS			Components NOT Compatible	
POLIAUTO				
VIALLE			**LPG System:**	
			Factory Fitted (Tickford)	
			After-Market Fitted	
			Other	

Initial Modifications:

LEAK CHECK: ....

Fit fuel bypass line to test vehicle.

Inspection by (Prospect Motors): ....

LPG Licence No.: ....

Time: .... **Date:** ..../............/.............

Final Modifications:

This vehicle has been inspected by a Licensed LPG repairer and is hereby certified to be in a roadworthy condition for operation with LPG.

Inspection by (Prospect Motors): ....

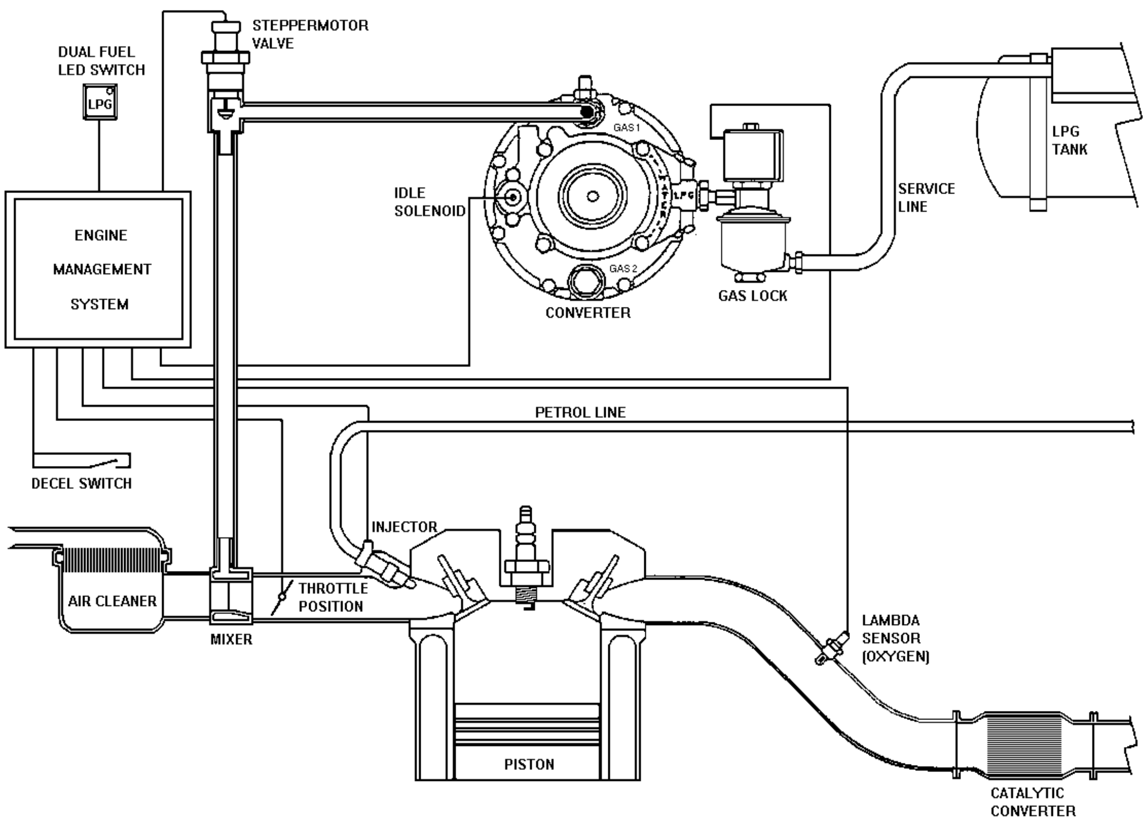
LPG Licence No.: ....

Time: .... **Date:** ..../............/.............

ATTACHMENT 5:

Closed Loop vs Open Loop Technology in Engine Management Systems

Closed Loop Systems are continuously receiving information regarding the oxygen content in the exhaust gases from the Lambda Sensor. This information feeds into the EMS which in turn adjusts the amount of fuel being fed to the engine via the Steppermotor Valve to maximise emission performance (stoichiometric air/furl ratio). If the air /fuel mixture is rich or lean, the EMS will adjust the air/fuel mixture to achieve stoichiometry.



Open Loop Systems do not have any feedback mechanism from the exhaust gases and therefore cannot adjust the air fuel mixture. A stoichiometric air/fuel mixture is established via the adjusting screw at the converter. This mixture remains constant whist the engine is running. The air/fuel mixture is not adjusted during normal operation.