ERDC Project No. 2511

Intensive Field Trial of Ethanol/Petrol Blend in Vehicles

Volume 1
Main Report

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Glossary

#	The difference (increase or decrease) is not statistically significant at the 95% confidence level
1986-on vehicle	Vehicle manufactured on or after 1 February 1986 that operates on unleaded petrol which in this report complies with ADR 37/00
ADR	Australian Design Rule
ADR 27A	Australian Design Rule 27A: Emission Control for Light Vehicles introduced in 1976. For this report ADR 27A denotes ADR 27 A, B (introduced 1978) and C (introduced 1981)
ADR 37/00	Australian Design Rule 37/00: Emission Control for Light Vehicles introduced from 1 February 1986 superseded by ADR 37/01 which is being phased in from 1 January 1997
AGL	AGL Gas Company NSW) Ltd. - also known as The Natural Gas Co.
Air Toxics	A large number of toxic air pollutants emitted by motor vehicles and other sources. In this report air toxics mean the toxic hydrocarbons 1,3-butadiene, benzene, toluene and xylene
Aldehydes	A range of organic species emitted by motor vehicles and other sources. In this report aldehydes means formaldehyde, acetaldehyde and acrolein
AlP	Australian Institute of Petroleum
Anhydrous	Without water
APACE	APACE Research Ltd.
Aromatics	Natural components of petrol, principally benzene and its derivatives
AS 2877	Australian Standard 2877-1986: Methods of Test for Fuel Consumption of Motor Vehicles Designed to Comply with Australian Design Rules 37 and 40
BF	Base Fleet vehicle
BF(s)	Base Fleet Sub-set vehicle
BMON	Blending Motor Octane Number
BOGAS	Bowen Petroleum Services Pty. Ltd. Distributor of 10% v/v ethanol/petrol blend
BRON	Blending Research Octane Number

CFR engine	Co-ordinating Fuel Research engine - an engine used for the determination of octane and cetane numbers
Closed loop	Engine air/fuel ratio control using exhaust composition feedback
CO	Carbon monoxide - a regulated motor vehicle pollutant emission
CO_2	Carbon dioxide - a greenhouse gas emitted by motor vehicles and other sources. Not a regulated pollutant but listed with the regulated pollutants in this report
CRC	Co-ordinating Research Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Division of Coal and Energy Technology
CT	The cold-start transient phase of the ADR 37/00 exhaust emissions test
CVS	Constant volume sampler used in exhaust emissions testing
DCI 11	Corrosion inhibitor marketed by Associated Octel
DEST	Department of Environment Sport and Territories
Distillation Curve	Plot of the fraction of fuel evaporated aginst temperature
DPIE	Department of Primary Industries and Energy
Drivability	Combination of factors which determine the smoothness and responsiveness affecting the ease and comfort of driving a vehicle
E10	10% v/v of ethanol in petrol blend
E70	Volume percentage of fuel evaporated at 70°C - a defining property of petrol
EMS	Engine management system
Enleanment	When there is more oxygen present than is required for stoichiometric combustion.
EPA	Environment Protection Authority
EPA (VIC)	Environment Protection Authority of Victoria
ERDC	Energy Research and Development Corporation
ETBE	Ethyl tertiary-butyl ether
Ethanol	Ethyl alcohol, an alcohol of formula C_2H_5OH
FBP	Final Boiling Point - a defining property of petroleum fuel

FCAI	Federal Chamber of Automotive Industries
FORS	Federal Office of Road Safety
FORS Study	National In-Service Vehicle Emissions Study carried out by FORS (Report titled "Motor Vehicle Pollution in Australia" 1996)
FVI	Flexible Volatility Index - a defining property of petrol
Gasohol	American term for E10
HC	Hydrocarbons - a range of emissions from motor vehicles regulated as total hydrocarbons
HD	Hot Drive – Part of drivability assessment
Hesitation	Temporary delay in response to the throttle being opened
HFH	Hot Fuel Handling
HT	The Hot-start Transient phase of the ADR 37/00 exhaust emissions test
HWY	Highway Fuel Consumption
IAME	Institute of Automotive Mechanical Engineers
IBP	Initial Boiling Point - a defining property of petroleum fuel
In-Service	A registered in-use motor vehicle
LHV	Lower Heating Value
LP	Leaded Petrol
LTIS	Long Term In-Service vehicle
MIR	Maximum Incremental Reactivity
MON	Motor Octane Number
MPI	Multi-point injection (fuel injection system)
MTBE	Methyl tertiary-butyl ether
NATA	National Association of Testing Authorities
NISE Study	National In-Service Vehicle Emissions Study carried out by FORS (Report titled "Motor Vehicle Pollution in Australia", 1996)
NOx	Oxides of nitrogen - a range of emissions from motor vehicles regulated as total oxides of nitrogen

NRMA	National Roads and Motorists Association
NSW EPA	New South Wales Environment Protection Authority
Octane	A "knock" defining property of petrol
Open loop	Engine air/fuel ratio control using fixed logic, without feedback correction
Ozone	A pollutant formed in the atmosphere by a series of complex reactions between NOx and reactive organic compounds under the influence of strong sunlight - a measure of photochemical smog
Ozone reactivity	Ozone formation potential of a reactive organic compound
Petrohol	Fuel which is a blend of ethanol and petrol, in this report 10% v/v ethanol/ petrol blend
Post-1986 model	Vehicle manufactured on or after 1 February 1986 that operates on unleaded petrol which in this report complies with ADR 37/00
Pre-1986 model	Vehicle manufactured prior to 1 February 1986 that operates on leaded petrol which in this report complies with ADR 27 A, B or C
Precursors	Primary emissions that later react to form ozone
RAF	Reactivity Adjustment Factor
ROC	Reactive Organic Compound
RON	Research Octane Number
RVP	Reid Vapour Pressure - a defining property of petroleum fuel
S	The Stabilised phase of the ADR 37/00 exhaust emissions test
SAE	Society of Automotive Engineers
SAEA	Society of Automotive Engineers Australasia
SHED	Sealed Housing for Evaporative Determination
Stoichiometric combustion	Complete combustion of fuel with no excess oxygen
TBI	Throttle Body Injection (fuel injection system)
THC	Total Hydrocarbons – Report description for HC
Transmission	Number of gears (3/4/5) manual or automatic (M/A) overdrive (0)
ULP	Unleaded Petrol
Vapour Lock	Vapour formation in fuel lines causing poor drivability

VOC	Volatile Organic Compound
Volatility	The tendency for a substance to evaporate at ordinary temperature and pressure
WOT	Wide Open Throttle

Abstract

The use of 10% v/v ethanol/petrol blend was evaluated under Australian conditions in order to establish the effects on:

- noxious and greenhouse gas emissions ;
- fuel consumption ;
- vehicle drivability under various climatic conditions;
- fuel system component materials compatibility;
- engine wear; and,
- water tolerance issues arising from blending, storage and distribution.

It was found that use of 10% v/v ethanol/petrol blend offers benefits in terms of reductions in exhaust and greenhouse gas emissions with no major detrimental effect on any of the other aspects of engine or vehicle performance.

It is recommended that both Federal and State Governments encourage the use of ethanol in blends with hydrocarbon fuels by:

- supporting research and development into new low cost ethanol production methods; and,
- offering investment incentives to manufacturers and distributors of fuel ethanol.

It is also recommended that further research be conducted to:

- determine the level of evaporative emissions from 10% v/v ethanol/petrol blend under "real world" conditions such as by using the multiday diurnal method in force in the United States since January 1996; and,
- improve the measurement methods for the determination of “toxics” and aldehydes in exhaust and evaporative emissions.

Main Report

1 PROJECT NEED

Ethanol/petroleum fuel blends directly address vehicle exhaust emissions and transport fuel security of supply issues. The renewable ethanol content of these fuels can result in a net reduction in the emission of carbon dioxide (“greenhouse gas”) as well as reduce currently regulated vehicle emissions of carbon monoxide (CO) and hydrocarbons (HC). Use of ethanol/petroleum fuel blends initially in the existing vehicle fleet is essential to develop the technology and infrastructure necessary to support widescale production and use of ethanol fuel.

In the United States, Brazil and Sweden there is already widespread use of ethanol fuel and/or ethanol/petroleum fuel blends, while in many other countries such blends are being introduced. In Australia, Bowen Petroleum Services, Burmah Fuels and Marina Petroleum have been marketing 10%v/v ethanol/petrol blends (ULP and Super) within their respective market areas since 1992. Currently, approximately 16 million litres of fuel ethanol is sold in Australia each year.

This project addresses the need to:

- identify the effects resulting from introduction of ethanol fuel into the transport sector; and,
- provide Federal and State Governments with reliable information to assist in the development of effective strategies for achieving reductions in greenhouse gas and noxious emissions from the transport sector.

2 BENEFITS

There are wide and diverse benefits to be obtained by industry, the economy, the community and Australia as a whole from a fuel ethanol industry.

In a direct sense, encouragement of the development of a fuel ethanol industry will facilitate and reduce the cost of production of ethanol by ethanol producers and fuel distributors.

In a broad sense, the benefits to be obtained from this project are the full range of national benefits to be obtained from a domestic ethanol fuel industry. These benefits include:

- Increased fuel self-sufficiency

  The Australian Bureau of Agricultural and Resource Economics (ABARE) estimates that net annual liquid petroleum imports (including crude oil, LPG, and refined petroleum products) will rise from 3061 ML in 1991-2 to 13,358 ML in 2004-5. In contrast, sufficient ethanol can potentially be produced domestically and renewably from lignocellulosic resources to meet all of Australia's liquid fuel demand.

- Improved balance of trade/saved foreign exchange

  ABARE estimates that, at projected oil prices, the cost of the abovementioned level of liquid petroleum imports would rise from $291 million to around $2.37 billion in real terms(1992-3 dollars) in 2004-5.

- Reduction in vehicle regulated exhaust emissions.

In addition to the above mentioned benefits there are the following important benefits that are obtained from the use of ethanol fuel produced from biomass.

- Reduced emission of carbon dioxide.

  Biomass is renewable and, using appropriate biomass production methods and new conversion technologies, can be converted to ethanol and lignin with no net release of carbon dioxide. Use of ethanol and lignin as fuels thus results in a net reduction in carbon dioxide emission of up to 100% by comparison with the use of petroleum fuels, natural gas, oil-shale, coal and other non-renewable fossil fuels.

- Expansion of the agricultural economy, value enhancement of existing biomass resources, treatment of land degradation and re-afforestation.

  The development of an ethanol fuel industry has important positive implications for the agricultural economy, for the treatment of land degradation and for re-afforestation programs.

- Nationwide decentralisation and regional industry development.

  Unlike fossil fuel resources lignocellulosic resources, whilst variable in nature, are very widely distributed geographically. Because it is inefficient and uneconomic to transport biomass long distances for conversion to fuel, the development of a biomass fuels industry necessitates local processing to fuel. Once converted to fuel the resultant energy is amenable to economic transportation to the sites of demand. The harvesting and conversion processing at sites close to the widely distributed biomass resource will result in widespread regional industrial development, so creating employment in rural areas.

An ethanol fuel industry is unique insofar as there is no other industry which offers the prospect of achieving a substantial reduction in the emission of carbon dioxide from the transport and industrial sectors whilst simultaneously addressing persistent lack of employment opportunities in rural areas and also providing solutions to land degradation which is arguably the biggest of Australia's environmental problems.

3 PROJECT OBJECTIVES

The project objectives were to:

- establish the contribution of 10% v/v ethanol/petrol blend to reducing greenhouse gas and noxious emissions;
- compare fuel consumption of 10% v/v ethanol/petrol blend with that of neat petrol;
- compare vehicle drivability on 10% v/v ethanol/petrol blend with that on neat petrol under various climatic conditions;
- examine fuel system component materials for compatibility with 10% v/v ethanol/petrol blend;
- compare engine wear on 10% v/v ethanol/petrol blend with that on neat petrol;
- examine water tolerance issues arising from storage, distribution and use of 10% v/v ethanol/petrol blend.

The methodologies used to achieve each of the objectives and the results obtained are presented in the following sections:

Section 4: Exhaust and Evaporative Emissions

Section 5: Fuel Consumption

Section 6: Vehicle Drivability

Section 7: Materials Compatibility

Section 8: Engine and Fuel System Wear

Section 9: Water Tolerance Issues

4 WORK PROGRAM

The overall project management was undertaken by Apace Research Ltd under the advisory supervision of the Project Steering Committee.

The Steering Committee members represented:

- Energy Research and Development Corporation (ERDC), Chair;
- Apace Research Ltd. (Apace), Project Manager;
- Australian Institute of Petroleum (AIP);
- Federal Chamber of Automotive Industries (FCAI);
- Federal Office of Road Safety (FORS);
- NSW Environment Protection Authority (NSW EPA);
- Environment Protection Authority, Victoria (EPA (Vic)); and
- Bowen Petroleum Services (BOGAS).

The work program was in several parts, reflecting the project objectives, as follows:

- Exhaust and evaporative emissions (Section 5) - the measurement of exhaust and evaporative emissions formed the major part of the project. The parties involved included:
  - NRMA - contracted to prepare vehicles for testing;
  - NSW EPA - contracted to test vehicles in accordance with ADR37 protocols using both neat petrol and 10%v/v ethanol/petrol blend; and
  - CSIRO - contracted by NSW EPA to carry out exhaust gas speciation from selected vehicles and evaluate ozone formation potential.
- Power (Appendix J)

  NSW EPA conducted power testing on a limited selection of vehicles using AGL's chassis dynamometer facility at Auburn.
- Fuel consumption (Section 6) - measured as follows:
  - NSW EPA carried out the City and Highway fuel consumption measurements to AS2877-1986 as part of the emissions test protocol;
  - selected vehicle owners were requested to keep fuel consumption records; and,
  - BOGAS customers were requested to complete a fuel consumption survey form.

- Drivability (Section 7) - Hot and Cold Drivability were evaluated according to test protocols supplied by FCAI.

  ~ Hot Drivability was evaluated in two parts:

  Part 1 - Four almost new vehicles (all EFI) were tested at Bourke, NSW, by NRMA representatives, however the results were not acceptable to the Steering Committee due to low test fuel Reid vapour pressure (RVP).

  Part 2 - Three 1986-on vehicles (two EFI, one carburetted) and one pre 1986 vehicle (LP, carburetted) were tested at Broken Hill, NSW, by a representative of FCAI.

  ~ Cold drivability was evaluated by NRMA representatives at Londonderry, NSW. Three 1986-on vehicles (two EFI, one carburetted) and one pre 1986 vehicle (LP, carburetted) were tested.

- Materials compatibility (Section 8)

  Materials compatibility evaluation consisted of inspection of the fuel system components fitted to all the vehicles tested for emissions. The parts most likely to be affected i.e. elastomer hoses, fuel filters and strainers, plastic components, fuel tanks etc. were inspected by NRMA Service and Apace personnel. Fuel return hoses were replaced on all vehicles and the removed hoses were subsequently inspected by independent inspectors drawn from IAME, SAEA and NRMA.

  A catalytic converter removed from a vehicle known to have operated exclusively on 10% v/v ethanol/petrol blend for 150,000 km was inspected by Prof. N.W. Cant of Macquarie University.

  Manufacturers of after market fuel filters were requested to advise whether their fuel filters are ethanol/petrol blend compatible.

  All of the test vehicles were of domestic build however confirmation was received from FCAI that all imported vehicles are compatible with 10%v/v ethanol/petrol blend.

- Engine and fuel system wear (Section 9)

  A total of four engines were stripped by NRMA at their Villawood workshop and inspected by independent inspectors drawn from IAME, SAE and NRMA.

- Engine oil analysis was carried out by Oilcheck Pty. Ltd and included:

~	Wear metals	~	Fuel dilution
~	Water content	~	Oxidation
~	Viscosity	~	Nitration
~	Pentane insolubles	~	Dispersancy
~	Acid index	~	Total Base Number

- Water tolerance issues (Section 10)

  Blending, storage, transport and distribution systems were evaluated in conjunction with ethanol/petrol blend marketers.

5 VEHICLE EXHAUST & EVAPORATIVE EMISSIONS

5.1 Introduction

The major objective of the project was to determine the effect on exhaust and evaporative emissions of use of a 10% v/v ethanol/petrol blend (E10) in the existing petrol engine vehicle fleet, with emphasis on:

- regulated emissions of carbon monoxide (CO), oxides of nitrogen (NOx) and total hydrocarbons (THC);
- "toxic" emissions of 1-3 butadiene, benzene, toluene and xylenes;
- emission of aldehydes (acetaldehyde, formaldehyde and acrolein);
- ozone forming potential; and,
- emission of carbon dioxide (CO_2).

A total of 60 motor vehicles were sourced from the public. Each vehicle was tested using a 10% v/v ethanol/petrol blend and neat petrol for reference and the exhaust and evaporative emissions measured.

The vehicles were divided into three categories, with each category being subjected to a different level of evaluation by NSW EPA at its Motor Vehicle Testing Unit at Lidcombe. The three categories were:

- Base Fleet (BF)
- Base Sub-Fleet (BF(s))
- Long Term In-Service Fleet (LTIS)

5.1.1 Base Fleet (BF)

The BF category comprised 35 vehicles. These were tested on one occasion only in a post-tune condition as follows:

- tuning of vehicles by NRMA to manufacturer's specification;
- SHED (Diurnal and Hot Soak evaporative emissions) test on 10% v/v ethanol/petrol blend and on reference neat petrol;
- exhaust emissions test on 10% v/v ethanol/petrol blend and on reference neat petrol;

5.1.2 Base Sub-Fleet (BF(s))

The BF(s) category comprised 12 vehicles. These vehicles were tested twice on the one occasion only, in a pre-tune and in a post-tune condition. The BF(s) vehicles were tested in the same manner as the BF vehicles, however, in addition of being tested in the "tuned" (post-tune) state they were also tested in an "as received" (pre-tune) state as follows:

- SHED (Diurnal and Hot Soak evaporative emissions) tests on 10% v/v ethanol/petrol blend and on reference neat petrol;
- exhaust emissions test on 10% v/v ethanol petrol/blend and on reference neat petrol;
- tuning of vehicles by NRMA;
- SHED (Diurnal and Hot Soak evaporative emissions) tests on 10% v/v ethanol/petrol blend and on reference neat petrol; and,
- exhaust emissions tests on 10% v/v ethanol petrol/blend and on reference neat petrol.

5.1.3 Long Term In-Service Fleet (LTIS)

The LTIS category comprised 11 vehicles. These vehicles were tested on two occasions, the second being approximately twelve months after the first occasion. The first series of tests were conducted in a post-tune condition only, while the second series were conducted in a pre-tune and in a post-tune condition using an extended test protocol. The tests consisted of:

- First occasion (LTIS 1)
  - ~ tuning of vehicle by NRMA;
  - ~ SHED (Diurnal and Hot Soak evaporative emissions) test on 10% v/v ethanol/petrol blend and on reference neat petrol; and,
  - ~ exhaust emissions test on 10% v/v ethanol/petrol blend and on neat reference petrol in "post-tune" condition.

  Note: The diurnal evaporative emissions test protocol was changed following the first series of tests, therefore no diurnal evaporative emissions results from this test series have been presented. The assessment of the protocol is presented in Appendix F.

- Second occasion, after approximately 12 months in-service use (LTIS 2)
  - ~ SHED (Diurnal and Hot Soak evaporative emissions) and exhaust emissions test on 10% v/v ethanol/petrol blend and on reference neat petrol in "pre-tune" condition;
  - ~ tuning of vehicles by NRMA; and,
  - ~ SHED (Diurnal and Hot Soak evaporative emissions) and exhaust emissions tests on 10% v/v ethanol/petrol blend and on reference neat petrol in "post-tune" condition.

All of the selected vehicles were tested by NSW EPA for the currently regulated emissions of CO, THC (both exhaust and evaporative) and NOx in accordance with ADR37/00: "Emission Control for Light Vehicles".

In addition, the following emissions were measured:

- CO_2;
- aldehydes (formaldehyde, acetaldehyde and acrolein); and,
- aromatics and alkenes (benzene, xylenes, toluene, 1-3 butadiene)

5.2 Vehicle Selection

The vehicle selection protocol was designed by Apace and the Project Steering Committee, and was based on the FORS "Motor Vehicle Pollution in Australia" project (FORS Study). The selection was narrowed down to the main makes and models within Australia, namely:

- Ford (Falcon and Laser)
- Holden (Commodore and Camira)
- Toyota (Camry, Corolla and Corona)
- Mitsubishi (Magna and Sigma)

Fig 1-1 shows the distribution of vehicles selected for this project against the same makes and models tested in the FORS Study.

A cross section of vehicle technology was selected covering:

- leaded and unleaded vehicles (18 LP, 40 ULP)
- carburetted and fuel injected vehicles (22 carb., 4 TBI, 32 MPI)

The majority of vehicles selected were regular users of E10 from the BOGAS customer fleet and were accessed by advertising at BOGAS service stations. The questionnaire used for identifying appropriate test vehicles is shown in Appendix G.

Included in the test fleet were three vehicles of make and model differing from but selected as complying with the project's selection criteria. These vehicles were:

1995 Holden Apollo (= Toyota Camry 1995);
1986 Nissan Skyline (= Holden Commodore 1986); and,
1995 Toyota Lexcen (= Holden Commodore 1995).

They are reflected in Figure 5-1 as the equivalents indicated.

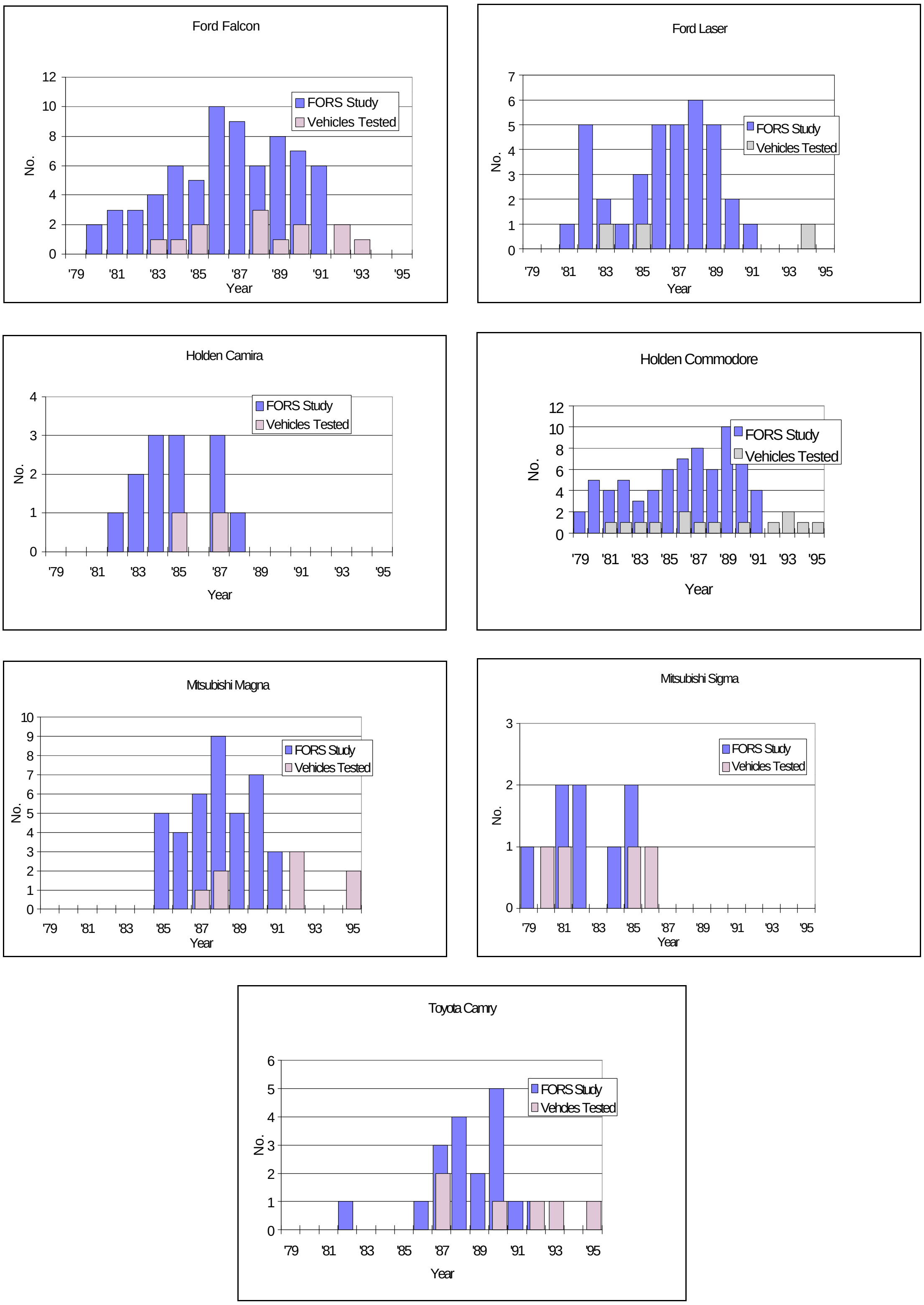

FIGURE 5-1: VEHICLES USED IN THIS PROJECT AGAINST FORS STUDY SELECTION

5.2.1 Current ULP & LP Market Share

In predicting the possible overall effect that use of E10 may have on emissions from the existing fleet, the weighting of LP and ULP in accordance with market share needs to be considered. Figure 5-2 shows actual petrol sales for 1995-97 and projected petrol sales for 1998 to 2007 based on AIP forecasts. The ratio of LP to ULP for 1999 is about 1:3 whereas the project fleet is 1:2.3. In the sales forecast, use of LP continues to decrease therefore analysis given in this report is based on a LP:ULP ratio of 1:3. The "All" category in NSW EPA's reported results reflects the 1:2.3 ratio of the project fleet.

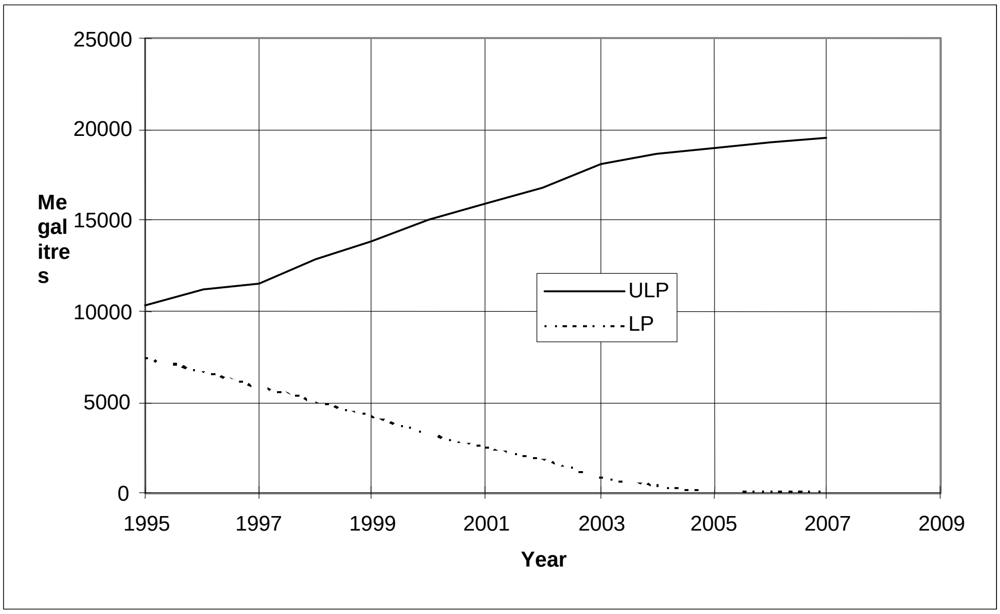

FIGURE 5-2: PETROL SALES: LEADED AND UNLEADED

5.3 Vehicle Collection

Having identified a prospective vehicle, the owner was fully briefed on the procedure then loaned a courtesy vehicle while the owner's vehicle was tested over approximately one week. The majority of vehicles were sourced from the Central Coast, namely Newcastle and Gosford, regions. Experienced drivers were used for the collection and delivery of the test vehicles so as to evaluate on-road vehicle condition and performance before and after tuning.

5.4 NRMA Servicing and Thermocouple Installation

5.4.1 Servicing and Parts

The servicing and preparation of the test vehicles was carried out at NRMA's Villawood workshop.

The servicing by NRMA involved checking the engine tune and its correction to manufacturer's specifications as necessary. Oil, air and fuel filters were replaced on all vehicles. High tension leads, points and spark plugs were checked and replaced if deemed necessary.

In many instances vehicles required additional work beyond a normal routine service to ensure they were in a safe and legal mechanical state. This additional work ranged from wheel alignment, radiator repairs and the replacement of brake cylinders, transmission seals, EGR valves, exhaust systems, rocker cover gaskets and, in one case, a cylinder head.

Blocked EGR systems were often found on the older vehicles and where possible, such blockages were cleared from the passages leading to the EGR valve. Repair of the EGR system in the community is not expected to be a high priority as its failure to operate does not adversely affect the drivability of the vehicle. However a correctly operating EGR valve significantly reduces NO_x emission.

So as not to influence evaporative emissions (diurnal and hot soak SHED) results, leaks emanating from fuel systems, engine and transmission seals or gaskets were repaired. The engine, engine bay and transmission were cleaned of accumulated oil with a hydrocarbon-free detergent prior to testing so as not to impact on the SHED test results.

The costs associated with vehicle preparation for this project were significantly higher than those estimated in the FORS study, as shown in Table 5-1. The differences in costs are mainly due to the FORS study assuming a fixed labour charge and rejecting some vehicles where the parts cost was likely to exceed $150. By contrast, the full costs associated with tuning the vehicle have been included in this project. The additional cost associated with thermocouple installation has not been included.

TABLE 5-1: AVERAGE SERVICE COSTS

	APACE	FORS
Average Cost of Parts (trade)	$161	$92
Average Cost of Labour	$162	$90
Total Average Cost	$323	$182

5.4.2 Thermocouple Installation

The first series of diurnal evaporative tests on LTIS vehicles was conducted using a Type J thermocouple bonded to the outside of the fuel tank at a level corresponding to 20% tank volume. This procedure was identical to that adopted for the FORS study, for ease of implementation. However, analysis of the initial set of results indicated that this method was not suitable when comparing fuels having differing physico-chemical characteristics, such as ethanol and petrol.

The procedure was therefore changed to comply with ADR37/00, which specifies the location of the thermocouple as being at the geometric centre of the 40% nominal volume of the fuel tank.

Accordingly, and at the direction of Apace engineers, NRMA subsequently installed a bonded tip thermocouple (Type J) in the fuel tank on receipt of the vehicle in their Villawood workshop. Typically the installation procedure consisted of:

- draining of the fuel tank;
- removal of the sender unit;
- modification of the sender unit mounting plate, to accept a bulkhead fitting;
- establishing the geometric centre of the 40% volume of the tank;
- installing the thermocouple, via the bulkhead fitting, with the thermocouple tip located at the geometric centre of the 40% tank volume (see Figure 5-3);
- checking for correct thermocouple installation by filling the tank with chilled fuel and observing the quantity of fuel required to record a rapid change in the thermocouple reading. The installation was considered satisfactory if this reading was within ±1 L of the nominal 20% tank volume; and,
- checking for vapour leakage.

Subsequent to vehicle ferrying from Villawood, similar checks for thermocouple position and vapour leakage were again carried out by NSW EPA prior to commencement of testing at Lidcombe.

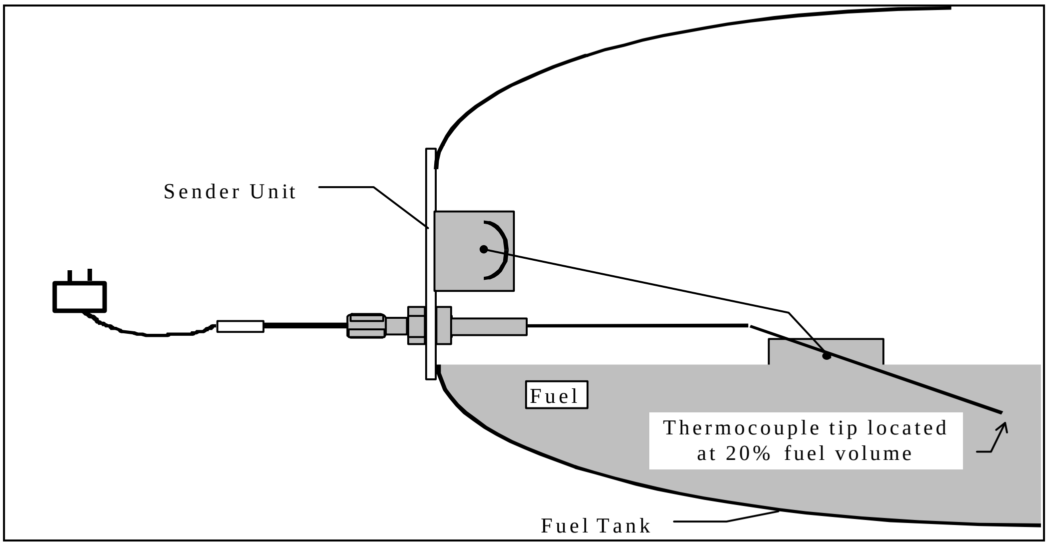

FIGURE 5-3: THERMOCOUPLE INSTALLATION VIA THE FUEL SENDER UNIT

5.5 Test Fuel

Test fuel preparation was carried out under supervision by representatives of AIP, NSW EPA and Apace at BP's Auburn storage depot.

The procedure adopted for fuel preparation was as follows:

- Anhydrous ethanol (99.6% v/v) denatured with 1% ULP was accurately decanted from 205L drums in 20.05 L lots into new 20L containers at Manildra Group premises Auburn. The 0.05L allowance was made for loss on subsequent drainage. Each container was numbered and 40 filled containers were transported to the BP depot at Auburn, for subsequent blending with neat petrol.

- At the BP depot the ethanol was transferred from each 20L container into 40 new 205L drums.

- Neat unleaded and leaded petrol having specifically formulated FVI (100-102), supplied by Ampol Ltd., was delivered to the BP depot by Metro Fuel Distributors (Glenorie) in a road tanker with an on-board metering dispenser.

- Eighty (80) new 205L drums, including the forty (40) already containing ethanol, were filled to the 200L level with neat petrol, either ULP or leaded. The drums were numbered consecutively as they were filled and labelled appropriately.

- Samples were taken and analysed by Ampol Pty Ltd. Laboratory and the results are shown in Table 5-2: Test Fuel Properties.

- All the fuel was stored at the BP depot in the 205L drums under open sided cover and delivered to NSW EPA's Lidcombe test facility as required.

During the test program, samples of the test fuel were taken from each drum as it came into use. Some difficulties were initially experienced with the sampling and storage procedures, leading to excessive vapour space within the sample bottles and hence invalid RVP determination. The sampling and storage practices for the samples were changed halfway through the project to reduce vapour space and eliminate vapour losses.

Later samples, which were filled to the appropriate level and showed no visible signs of leakage, were analysed for their RVP. The results are shown in Figure 5-4.

Each sample shown in Figure 5-4 is from a different drum and was taken when the drum was first opened at NSW EPA, Lidcombe, for project use. Although the variations in RVP from drum to drum on each fuel are small when compared with the differences between neat petrol and corresponding E10, it should be noted that a change of 6.8 kPa (1 psi) in RVP can result in a SHED diurnal evaporative emission change of around 40% {30}.

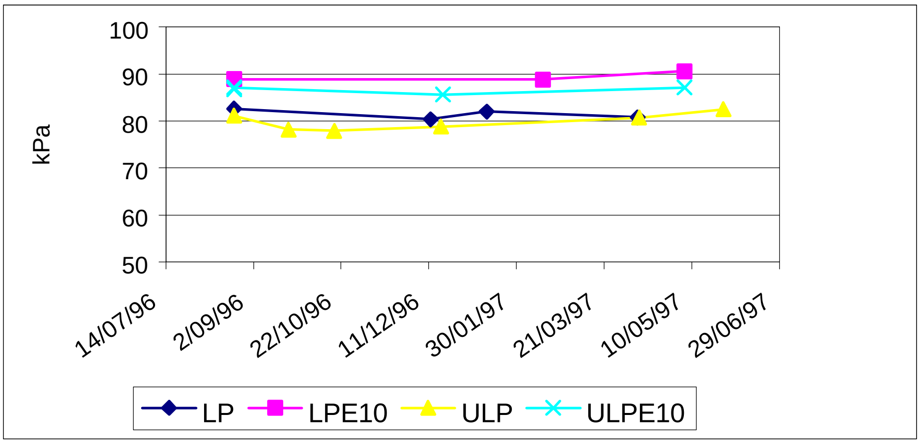

FIGURE 5-4: RVP OF TEST FUEL THROUGHOUT PROJECT

TABLE 5-2: TEST FUEL PROPERTIES

	ULP	ULP +10% Ethanol	LP	LP + 10% Ethanol
RON	91.9	95.5	96.0	98.7
MON	82.9	84.1	86.7	87.6
Density @ 15°C (kg/ℓ)	0.7329	0.7376	0.7369	0.7406
Density @ 20°C (kg/ℓ)	0.7284	0.7331	0.7324	0.7361
FVI	102	119	102	119
E70(%v)	30.0	48.6	28.2	45.8
RVP - Dry Vapour Pressure Equivalent (kPa)	80.6	85.4	82.3	87.4
Benzene (%v)	2.12		2.26	
Distillation (% Evaporated)				
IBP °C	30.7	32.3	30.7	33
5% °C	42.1	42.7	41.4	42.9
10% °C	48.7	47.2	48.7	48.0
20% °C	59.0	54.0	59.8	55.0
30% °C	70.0	60.2	72.3	61.5
40% °C	82.2	65.3	85.1	66.7
50% °C	95.2	72.5	98.1	79.7
60% °C	108.1	103.1	111.0	106.4
70% °C	121.8	116.9	124.0	119.7
80% °C	137.6	134.1	138.1	134.7
90% °C	161.9	159.5	157.1	156.4
95% °C	182.4	180.8	175.5	172.5
FBP °C	207.3	204.0	206.1	202.4

Note: RVP was determined using the mini vapour pressure technique (ASTM D5191)

5.6 Test protocol

The test protocol was originally based on the FORS "in-service" test program "Motor Vehicle Pollution in Australia" in order to utilise the much larger emissions data base for neat petrol vehicles.

However, following the initial testing of the LTIS vehicles and detailed analysis of the results, (see Appendix F, Impacts of Test Procedures), changes to the diurnal test procedure were made ensuring that the temperature of the fuel in the fuel tank and canister preconditioning were more closely controlled. Hot soak and exhaust emissions results remained comparable with the FORS data. The protocols used are shown in NSW EPA's report section 3.1, Appendix J, Volume III.

A summary of the testing regime is listed in Table 5-3.

TABLE 5-3: TESTS CONDUCTED

	BF	BF(s)		LTIS		
	Tune	Tune		Tune		
	Post	Pre	Post	Post	Pre	Post
Regulated Exhaust Emissions (ADR 37/00)	✓	✓	✓	✓	✓	✓
Regulated Evaporative Emissions (ADR 37/00)	✓	✓	✓	✓*	✓	✓
City and Highway Fuel Consumption (AS 2877)	✓	✓	✓	✓	✓	✓
Aldehyde Exhaust Emissions	✓	✓	✓	✓	✓	✓
Exhaust Toxic Emissions				✓	✓	✓
Evaporative Toxic Emissions				✓*	✓	
Ozone Formation Potential Exhaust				✓	✓	✓
Ozone Formation Potential Evaporative				✓*	✓	
Power Testing				✓		

* Diurnal evaporative emissions for the 1st LTIS "post-tune" were deemed invalid by Apace due to protocol change for subsequent SHED tests. NSW EPA invalidated both the Diurnal and Hot soak evaporative emission result for the 1st LTIS "post-tune" condition.

5.7 Discussion of Results

The final NSW EPA's final report No MV-A-35 titled "Petrohol In-Service Vehicle Emissions Study" is presented in Appendix J, Volume III. The report is comprehensive and deals with the following objectives of this project:

- establishment of the effect of 10% v/v ethanol/petrol blend on greenhouse gases and noxious emissions;
- comparison of in-service fuel consumption of 10% v/v ethanol/petrol blends with neat petrol; and,
- measurement of engine performance with 10% v/v ethanol/petrol blend.

NSW EPA's report contains, among other sections:

- Introduction
- Study outline
- Test program protocols, test methods and test calculations
- Results overview, summary and discussion (analysis)
- Summaries of emissions comparison, effect of maintenance and emissions deterioration over a 12 month period
- All relevant references, appendices, tables and figures.

Note: Many of the findings in NSW EPA's report are qualified by comment. Please refer to the full report in Appendix J, Volume III

The NSW EPA report also includes a separate report by CSIRO titled "Quantifying Ozone Impacts for the Petrohol Study".

In addition, NSW EPA provided Apace with the raw data in electronic form, for further analysis, as well as data not reported elsewhere in its report. The additional data consisted of:

- recorder charts showing the THC concentration in the test enclosure, and fuel temperature rise in the fuel tank, against time during the SHED evaporative emissions tests; and,
- the electric blanket energy consumption in raising the fuel temperature during the diurnal phase of the SHED test.

NSW EPA, Victorian EPA and Ford Motor Company of Australia also supplied the separate data for both the diurnal and hot soak phases of the SHED test obtained during the FORS 1996 "Motor Vehicle Pollution in Australia" study. The separate data was made available by kind permission from FORS.

5.7.1 Key to Tables and Graphs

Generally speaking an E10 result is compared to the corresponding neat petrol result on a percentage change basis. Hence a positive percentage means the E10 result is higher than the neat petrol result, and a negative percentage means that the E10 result is lower than the neat petrol result.

The following is a list of terms used in NSW EPA's report:

- *A hash (#)* - indicates that the result has been determined not to be statistically significant at the 95% confidence limit.
- *The All, 1986-on and Pre-1986 groups* - contain results from vehicles in the BF, BFS and LTIS 2 categories in the post-tune condition only.
- *Pre-Tune* - contains results from vehicles in the BFS and LTIS 2 categories in the pre-tune condition (1986 and 1986-on combined),
- *Post-Tune* - contains results from vehicles in the BFS and LTIS 2 categories in the post-tune condition; (pre-1986 and 1986-on combined*)*.
- *LTIS 1* - contains results from vehicles in the LTIS 1 category in the post-tune condition (pre-1986 and 1986-on combined).
- *LTIS 2* - contains results from vehicles in the LTIS 2 category in the post-tune condition (pre-1986 and 1986-on combined).

TABLE 5-4: TOXICS AND ALDEHYDES - CHEMICAL FORMULAE

C_4H_6	1,3-butadiene
C_6H_6	Benzene
C_7H_8	Toluene
C_8H_{10}	Xylenes

CH_2O	Formaldehyde
C_2H_4O	Acetaldehyde
C_3H_4O	Acrolein

Different types of statistical analysis can be applied to the results collected by NSW EPA for the following purposes:

1. to test a given hypothesis concerning some observed characteristic;
2. to represent a physical situation functionally; or,
3. to determine a reliable estimate of some factual value.

Method 1 is primarily used by NSW EPA and is described in their report as follows:

"For each parameter, the difference (i.e. the impact) for the fleet was estimated as the mean difference calculated from the vehicle sample tested, while the associated confidence interval was determined by using the t *statistic based on the pair differences in the sample. When reporting on the significance of the increase or decrease, a 95% two-tailed test was used. Such a test detects a change in either direction".*

Method 2 is termed "Linear Regression" and is applied herein by Apace when a significant relationship between paired results exists. It is a method of statistical analysis used in engineering for developing mathematical models to represent physical situations. In this report the regression analysis has been forced through zero for all data sets. The R^2 (sample coefficient of determination) is also presented and indicates how well the data fits the linear regression line.

NSW EPA's findings from their analysis of the results using Method 1 are labelled "NSW EPA Key Findings" and Apace's findings from analysis of the results using Method 2 are labelled "Apace Linear Regression". In some cases Apace has modified/filtered the data set. In such cases the new data sets have been analysed by Apace using Method 1. These are shown and labelled accordingly.

5.7.2 Regulated Exhaust Emissions

The regulated exhaust emissions of THC, NOx and CO together with the unregulated emission of CO_2 as reported by NSW EPA are summarised in Table 5-5. FORS Study results have been included where appropriate. City cycle and Highway cycle fuel consumption summaries are also included.

The correlation of neat petrol results to those in the FORS Study is close (especially for pre-1986 vehicles) indicating that the vehicle selection for this project is representative of the Australian vehicle population.

The "Metropolitan Air Quality Study – Outcomes and Implications for Managing Air Quality" , NSW EPA (1996){31} reported levels of Volatile Organic Compounds (VOC's), NOx, CO and CO_2 for the Sydney Metropolitan area. The results from the study are quoted in the following discussion under the relevant headings.

5.7.2.1 Total Hydrocarbons (THC)

In 1995 Sydney's mobile fleet accounted for 49% of the VOC emission, with passenger vehicles being responsible for 74% of the mobile fleet emission {31}.

Hydrocarbon emissions are present in both the evaporative and exhaust emissions. The main concern over hydrocarbon emission is its involvement in low-level ozone formation, which may exacerbate asthma and other respiratory difficulties.

Linear regression analysis by Apace of the THC emission results is shown in Figure H-1 (Appendix H). The trend lines indicate that the use of E10 results in a reduction in exhaust THC emission of 13% for 1986-on and 9% for pre-1986 vehicles.

The key findings from NSW EPA's report and corresponding linear regression analysis findings by Apace are shown in Table 5-6.

TABLE 5-5: SUMMARY OF EXHAUST EMISSIONS AND FUEL CONSUMPTION (NSW EPA REPORT)

	Exhaust (ADR37/00 - 3 Bag Results)					AS 2877			
Results Group	No. of Tests	THC (g/km)	NO_x (g/km)	CO (g/km)	CO_2 (g/km)	No. of Tests	City Fuel (ℓ/100 km)	No. of Tests	Hwy. Fuel (ℓ/100 km)l
Petrol (All)	59	1.02	1.53	11.71	261.6	59	12.3	54	8.9
E10 (All)	59	0.90	1.57	7.98	264.3	59	12.6	54	9.1
Petrol (1986-on)	41	0.66	1.39	8.45	264.4	41	12.1	36	8.8
(FORS)		*(0.54)*	*(1.15)*	*(7.83)*					
E10(1986-on)	41	0.57	1.46	6.18	266.2	41	12.5	36	9.0
Petrol(Pre-1986)	18	1.86	1.84	19.13	255.1	18	12.6	18	9.1
(FORS)		*(1.84)*	*(1.88)*	*(19.03)*					
E10(Pre-1986)	18	1.66	1.83	12.06	259.9	18	12.7	18	9.3
Petrol(Pre-Tune)	22	1.24	1.68	14.95	254.7	22	12.2	20	8.8
E10(Pre-Tune)	22	1.15	1.77	12.36	256.4	22	12.5	20	9.1
Petrol(Post-Tune)	22	1.05	1.65	10.13	259.5	22	12.0	20	8.8
E10(Post-Tune)	22	0.95	1.72	6.92	261.2	22	12.3	20	9.1
Petrol(LTIS 1)	10	0.49	1.30	5.67	264.9	10	11.9	8	9.3
E10(LTIS 1)	10	0.40	1.42	3.93	264.0	10	12.2	8	9.5
Petrol(LTIS 2)	10	0.49	1.43	6.83	266.7	10	12.1	8	9.1
E10(LTIS 2)	10	0.42	1.62	5.00	268.6	10	12.5	8	9.4

TABLE 5-6: EFFECT OF E10 ON EXHAUST EMISSION OF THC

Result Group		NSW EPA Key Findings	Apace Linear Regression
Tuned	All	- 12 ± 4%	-12% (1999)
	1986-on	- 13 ± 5%	- 13% $R^2 = 0.97$
	Pre-1986	- 11 ± 5%	- 9% $R^2 = 0.68$
Servicing	Neat Petrol	- 16 ± 22%#	
	(FORS)	*(-16%)*	
	E10	- 17 ± 17%#	
12 months	Neat Petrol	+ 0 ± 15%#	
	E10	+ 4 ± 14%#	

5.7.2.2 Oxides of Nitrogen (NO_X)

In 1995 Sydney's mobile fleet accounted for 82% of the total NO_x emission, with passenger vehicles being responsible for 49% of the mobile fleet emission {31}.

NO_x is considered to be a precursor to ozone formation in conjunction with VOC and can exacerbate respiratory illness, particularly asthma.

Linear regression analysis by Apace of the NOx emission results is shown in Figure H-2 (Appendix H). The trend lines indicate that the use of E10 results in an increase in NOx emissions of 2% for 1986-on and a decrease of 1% for pre-1986 vehicles.

The key findings from NSW EPA's report and corresponding linear regression analysis findings by Apace are shown in Table 5-7.

TABLE 5-7: EFFECT OF E10 ON EXHAUST EMISSION OF NO_X

Result Group		NSW EPA Key Findings	Apace Linear Regression
Tuned	All	+ 3% ±4%#	+1% (1999)
	1986-on	+ 5% ±7%#	+ 2% R^2 = 0.90
	Pre-1986	- 1% ±6%#	- 1% R^2 = 0.88
Servicing	Neat Petrol	- 2% ±10%#	
	(FORS)	*(-9%)*	
	E10	- 3% ±10%#	
12 months	Neat Petrol	+ 10% ±26%#	
	E10	+ 14% ±24%#	

5.7.2.3 Carbon Monoxide (CO)

In 1995 the CO emission from mobile transport equated to 91% of the total CO emission in Sydney, with passenger vehicles making up 79% of the CO emission from mobile transport {31}. CO increases the risk of heart disease and is fatal at high concentrations. High risk zones are proximity to traffic, vehicle cabins and confined spaces where engines are running, such as enclosed carparks. The Workcover Authority of NSW has expressed concerns over the incidence of high CO levels.

Linear regression analysis by Apace of the CO emission results is shown in Figure H-3 (Appendix H). The trend lines indicate that the use of E10 results in a reduction in CO emissions of 30% for 1986-on and 38% for pre-1986 vehicles.

The key findings from NSW EPA's report and corresponding linear regression analysis findings by Apace are shown in Table 5-8.

TABLE 5-8: EFFECT OF E10 ON EXHAUST EMISSION OF CO

Result Group		NSW EPA Key Findings	Apace Linear Regression
Tuned	All	*- 32% ±9%*	-32% (1999)
	1986-on	*- 27% ±11%*	- 30% R^2 = 0.92
	Pre-1986	*- 37% ±10%*	- 38% R^2 = 0.84
Servicing	Neat Petrol	*- 32% ±35%#*	
	(FORS)	*(-25%)*	
	E10	*- 44% ±48%#*	
12 months	Neat Petrol	*+ 20% ±18%*	
	E10	*+ 27% ±28%#*	

5.7.3 Non-regulated Exhaust Emissions

5.7.3.1 Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) is a product of complete combustion, and is generally considered benign compared to carbon monoxide which is formed as a result of incomplete combustion. Nevertheless, CO_2 emission from fossil fuels is a major contributor to the "greenhouse effect" and in 1995 motor vehicles contributed approximately 24% of unnatural CO_2 production in Sydney {31}.

Linear regression analysis by Apace of the CO_2 emission results is shown in Figure H-4 (Appendix H). The trend lines indicate that the use of E10 results in an increase in CO_2 emissions of 1% for 1986-on and 2% for pre-1986 vehicles.

The key findings from NSW EPA's report and corresponding linear regression analysis findings by Apace are shown in Table 5-9.

TABLE 5-9: EFFECT OF E10 ON EXHAUST EMISSION OF CO_2

Result Group		NSW EPA Key Findings	Apace Linear Regression
Tuned	All	+ 1% ±1%	+ 1% (1999)
	1986-on	+ 1% ±1%#	+ 1% R^2 = 0.96
	Pre-1986	+ 2% ±1%	+ 2% R^2 = 0.99
Servicing	Neat Petrol	+ 2% ±3%#	
	E10	+ 2% ±2%#	
12 months	Neat Petrol	+ 1% ±3%#	
	E10	+ 2% ±3%#	

The increase in exhaust mass emission of CO_2 when using E10 is primarily due to the volumetric increase in fuel consumption of 3% compared to neat petrol. However, when the full carbon cycle is taken into account it is estimated there is a net reduction of from 5.1 to 7.6% in the mass emission of CO_2 compared to neat petrol. Refer to Appendix I for sample calculations.

The FORS study did not report CO_2 emission specifically, however an overall reduction of 1.5% in fuel consumption was noted following vehicle servicing.

5.7.4 Exhaust Emission of "Toxics" and Aldehydes

The exhaust emission of "toxics" and aldehydes as reported by NSW EPA are summarised in Table 5-10.

Table 5-11 shows an additional data set formed by Apace comprised of the emissions from post-tune vehicles from the BF, BFS, LTIS 2 categories, plus LTIS 1. The scatter graphs for the aldehydes and toxics are in Appendix H. The LTIS 1 group was included to increase the sample size. It should also be noted that the regression lines in the scatter graphs have been forced through zero.

Risk factors are applied to this additional data set in section 5.10.2 in order to assess the health impacts of the changes in aldehydes and toxics emissions due to E10.

TABLE 5-10: AVERAGED MASS EXHAUST EMISSION OF TOXICS & ALDEHYDES (NSW EPA REPORT)

		1,3-Butadiene Mg/km	**Acetaldehyde** mg/km	**Acrolein** Mg/km	**Benzene** Mg/km	**Formaldehyde** Mg/km	**Toluene** mg/km	**Xylenes** mg/km
Petrol	All	4.80	3.95	1.866	23.54	13.59	36.21	28.94
E10	All	3.79	12.46	2.089	18.16	17.24	28.50	23.11
Petrol	post'86	1.35	2.24	1.138	14.36	5.64	19.21	16.17
E10	post'86	1.23	7.00	1.227	10.35	7.16	14.17	12.29
Petrol	pre'86	18.60	7.58	3.493	64.83	31.85	112.71	86.43
E10	pre'86	14.02	24.04	4.017	53.30	40.38	93.02	71.77
Petrol	Pre-tune	1.68	4.79	2.417	18.80	16.88	28.83	25.16
E10	Pre-tune	1.38	16.35	2.156	15.66	17.57	24.06	20.40
Petrol	Post-tune	1.77	4.40	2.217	17.87	16.05	26.66	22.20
E10	Post-tune	1.47	13.87	2.118	13.65	18.80	20.47	17.60
Petrol	LTIS 1	11.67	1.82	-0.031	30.46	5.52	43.52	36.12
E10	LTIS 1	10.10	5.06	0.552	23.74	6.90	34.37	30.39
Petrol	LTIS 2	1.77	1.09	0.598	17.87	5.38	26.66	22.20
E10	LTIS 2	1.47	4.30	0.865	13.65	6.75	20.47	17.60

TABLE 5-11: APACE DATA GROUP (POST-TUNE, BF, BF(S), LTIS 1 AND LTIS 2)
EXHAUST EMISSION OF TOXICS & ALDEHYDES

	Pre1986		1986-on	
	Petrol	E10	Petrol	E10
1,3-Butadiene (mg/km)	28.84	24.41	4.19	3.56
Benzene (mg/km)	88.20	65.79	18.08	13.61
Toluene (mg/km)	169.82	128.80	22.74	16.90
Xylene (mg/km)	140.88	105.03	19.70	15.29
Formaldehyde (mg/km)	31.12	39.27	5.22	6.56
Acrolein (mg/km)	3.38	3.95	1.22	1.20
Acetaldehyde (mg/km)	7.55	24.20	2.15	6.30

5.7.4.1 Exhaust Aldehydes

5.7.4.1.1 Formaldehyde

The key findings from NSW EPA's report are shown in Table 5-12 along with a summary of the linear regression analysis findings by Apace (Figure H-5, Appendix H).

TABLE 5-12: EFFECT OF E10 ON EXHAUST EMISSION OF FORMALDEHYDE

Result Group		NSW EPA Key Findings	Apace Average increase (includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	+ 27% ± 12%	+25% (1999)	+ 25% (1999)
	1986-on	+ 27% ± 24%	+25%	+ 25% R^2 = 0.86
	Pre-1986	+ 27% ± 12%	+26%	+ 25% R^2 = 0.88
Servicing	Neat Petrol	- 5% ± 26%#		
	E10	+ 7% ± 38%#		
12 months	Neat Petrol	- 2% ± 18%#		
	E10	- 2% ± 14%#		

5.7.4.1.2 Acetaldehyde

The key findings from NSW EPA's report are shown in Table 5-13 along with a summary of the linear regression analysis findings by Apace (Figure H-6, Appendix H). The R^2 value does not show a strong relationship for the pre-1986 vehicles, while the R^2 value for the 1986-on vehicles shows that a reasonable correlation does exist.

TABLE 5-13: EFFECT OF E10 ON EXHAUST EMISSION OF ACETALDEHYDE

Result Group		NSW EPA Key Findings	Apace Average increase (Includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	*+ 215% ± 58%*	200% (1999)	+ 181% (1999)
	1986-on	*+ 213% ± 93%*	193%	+ 171% $R^2 = 0.71$
	Pre-1986	*+ 217% ± 47%*	220%	+ 212% $R^2 = 0.52$
Servicing	Neat Petrol	*- 8% ± 24%#*		
	E10	*- 15% ± 39%#*		
12 months	Neat Petrol	*- 40% ± 78%#*		
	E10	*- 15% ± 49%#*		

5.7.4.1.3 Acrolein

The key findings from NSW EPA's report are shown in Table 5-14 along with a summary of the linear regression analysis findings by Apace (Figure H-7, Appendix H).

TABLE 5-14: EFFECT OF E10 ON EXHAUST EMISSION OF ACROLEIN

Result Group		NSW EPA Key Findings	Apace Average increase (Includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	+ 12% ± 18%#	+3% (1999)	- 3% (1999)
	1986-on	+ 8% ± 19%#	-2%	- 5% $R^2 = 0.90$
	Pre-1986	+ 15% ± 30%#	+17%	+ 2% $R^2 = 0.46$
Servicing	Neat Petrol	- 8% ± 38%#		
	E10	- 2% ± 35%#		
12 months	Neat Petrol	-		
	E10	+ 57% ± 49%#		

5.7.4.2 Exhaust Toxics

5.7.4.2.1 1,3-Butadiene

The key findings from NSW EPA's report are shown in Table 5-15 along with a summary of the linear regression analysis findings by Apace (Figure H-8, Appendix H). The linear regression lines for 1,3-butadiene show decreases of 14% for pre-1986 vehicles and 21% for vehicles 1986-on. The R^2 value shows very good correlation in this trend. However, the number of Pre-1986 vehicles tested for 1,3-butadiene is very low.

TABLE 5-15: EFFECT OF E10 ON EXHAUST EMISSION OF 1,3-BUTADIENE

Result Group		NSW EPA Key Findings	Apace Average increase (includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	- 21% ± 36%[#]	-15% (1999)	- 19% (1999)
	1986-on	- 9% ± 23%[#]	-15%	- 21% R^2 =0.93
	Pre-1986	- 25% ± 210%[#]	-15%	- 14% R^2 = 0.96
Servicing	Neat Petrol	+ 5% ± 40%[#]		
	E10	+ 6% ± 39%[#]		
12 months	Neat Petrol	- 85% ± 68%		
	E10	- 85% ± 76%		

5.7.4.2.2 Benzene

The key findings from NSW EPA's report are shown in Table 5-16 along with a summary of the linear regression analysis findings by Apace (Figure H-9, Appendix H). The regression lines for benzene show decreases of 29% for pre-1986 vehicles and 26% for vehicles 1986-on. The R^2 value shows very good correlation in the trend for 1986-on vehicles and a reasonable correlation for pre-1986 vehicles with low number of data points.

5.7.4.2.3 Toluene

The key findings from NSW EPA's report are shown in Table 5-17 along with a summary of the linear regression analysis findings by Apace (Figure H-10, Appendix H). The regression lines for toluene show decreases of 28% for pre-1986 vehicles and 31% for vehicles 1986-on. The R^2 value shows good correlation in the trend for pre-1986 and 1986-on vehicles.

TABLE 5-16: EFFECT OF E10 ON EXHAUST EMISSION OF BENZENE

Result Group		NSW EPA Key Findings	Apace Average increase (Includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	- 23% ± 12%	-25% (1999)	- 27% (1999)
	1986-on	- 28% ± 15%	-25%	- 26% R^2 =0.99
	Pre-1986	- 18% ± 85%[#]	-25%	- 29% R^2 = 0.77
Servicing	Neat Petrol	- 5% ± 13%[#]		
	E10	- 13% ± 15%[#]		
12 months	Neat Petrol	- 41% ± 37%		
	E10	- 43% ± 36%		

TABLE 5-17: EFFECT OF E10 ON EXHAUST EMISSION OF TOLUENE

Result Group		NSW EPA Key Findings	Apace Average increase (includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	*- 21% ± 13%*	-25% (1999)	- 30% (1999)
	1986-on	*- 26% ± 15%*	-26%	- 31% R^2 =0.82
	Pre-1986	*- 17% ± 34%*[#]	-24%	- 28% R^2 = 0.80
Servicing	Neat Petrol	*- 8% ± 24%*[#]		
	E10	*- 15% ± 26%*[#]		
12 months	Neat Petrol	*- 39% ± 45%*[#]		
	E10	*- 40% ± 50%*[#]		

5.7.4.2.4 Xylenes

The key findings from NSW EPA's report are shown in Table 5-18 along with a summary of the linear regression analysis findings by Apace (Figure H-11, Appendix H). The regression lines for xylenes show decreases of 28% for pre-1986 vehicles and 27% for vehicles 1986-on. The R^2 value shows very good correlation in the trend for pre-1986 vehicles and a reasonable correlation for vehicles 1986-on.

TABLE 5-18: EFFECT OF E10 ON EXHAUST EMISSION OF XYLENES

Result Group		NSW EPA Key Findings	Apace Average increase (includes LTIS1 Group)	Apace Linear Regression (Includes LTIS 1 Group)
Tuned	All	*- 20% ± 12%*	-23% (1999)	- 27% (1999)
	1986-on	*- 24% ± 12%*	-22%	- 27% R^2 =0.79
	Pre-1986	*- 17 ± 45%#*	-25%	- 28% R^2 = 0.96
Servicing	Neat Petrol	*- 12% ± 29%#*		
	E10	*- 14% ± 27%#*		
12 months	Neat Petrol	*- 39% ± 39%#*		
	E10	*- 42% ± 43%#*		

5.7.4.3 Correlation Between Exhaust "Toxics" and Total Hydrocarbons

The key findings from NSW EPA's report are:

- The correlation between exhaust toxics and total hydrocarbons are essentially the same for E10 and petrol.
- Good correlation exists between exhaust benzene and THC, exhaust toluene and THC, and exhaust xylene and THC for both E10 and petrol.
- Relatively poor correlation exists between exhaust 1,3-butadiene emissions and THC for both E10 and petrol.

5.7.5 Regulated Evaporative Emissions

Only total hydrocarbon evaporative emissions are regulated. As already noted in Section 5.7.2.1, the main concern with HC emission is its involvement in low-level ozone formation, which may exacerbate asthma and other respiratory difficulties.

Table 5-19 shows a summary of NSW EPA's results from the evaporative emissions tests obtained using the ADR37 SHED test method.

TABLE 5-19: SUMMARY OF EVAPORATIVE EMISSIONS
(NSW EPA Report)

Results Group	No. of Tests	Diurnal (g)	Hot-Soak (g)	Total (g)
Petrol (All)	56	8.19	5.08	13.27
E10 (All)	56	9.53	7.30	16.83
Petrol (1986-on)	39	7.50	3.03	10.54
(FORS)		*(3.98)*	*(1.81)*	*(5.76)*
E10(1986-on)	39	8.78	4.06	12.84
Petrol(Pre-1986)	17	9.78	9.76	19.54
(FORS)		*(5.76)*	*(7.98)*	*(13.64)*
E10(Pre-1986)	17	11.25	14.73	25.98
Petrol(Pre-Tune)	21	6.88	3.12	10.00
E10(Pre-Tune)	21	7.86	4.42	12.28
Petrol(Post-Tune)	21	6.38	3.09	9.47
E10(Post-Tune)	21	6.91	4.60	11.51
Petrol(LTIS 1)	0	NA	NA	NA
E10(LTIS 1)	0	NA	NA	NA
Petrol(LTIS 2)	11	5.43	2.95	8.39
E10(LTIS 2)	11	5.43	3.63	9.06

The correlation of evaporative emissions to the FORS study cannot be established for the diurnal phase of the SHED test due to changes in the test protocol and the different RVP of the petrol used in this project (ULP 80.6, LP 82.3) compared to that used in the FORS Study (ULP 76.5, LP 73.5). However correlation between hot soak emissions is considered valid by Apace due to the similarity of the distillation curves.

While the results obtained from the SHED test are valid under the ADR37 protocol used, it is considered that the test method, which involves direct heating the fuel tank contents to a prescribed temperature, is unsuitable for comparing fuels having differing physico-chemical properties. The concerns regarding the diurnal phase are discussed more fully in Appendix F.

TABLE 5-20: EVAPORATIVE EMISSIONS
(NSW EPA report)

Result Group		NSW EPA Key Findings
Diurnal		
	1986-on	+ 17% ± 16%
	Pre-1986	+ 15% ± 15%
Hot-Soak		
Tuned	1986-on	+ 34% ± 28%
	Pre-1986	+ 51% ± 30%
Diurnal + Hot-Soak		
Tuned	All	+ 27% ± 12%
	1986-on	+ 22% ± 17%
	Pre-1986	+ 33% ± 17%
Servicing	Neat Petrol	- 5% ± 17%#
	E10	- 6% ± 14%#
12 months	Neat Petrol	-
	E10	-

5.7.5.1 Hot Soak Evaporative Emissions

Analysis of the FORS data (Table 5-21) showed good correlation between NSW EPA's results for this project and the FORS study. NSW EPA's FORS study data differs significantly to that obtained by the other two laboratories involved in that study. The reason for the discrepancy has not been established. However, no compensation will be made in the analysis of the results obtained in this study for the lower values obtained by the other laboratories involved in the FORS study.

It can, however, be assumed that this project's test fleet is representative of the general vehicle population in NSW.

TABLE 5-21: COMPARISON OF HOT SOAK EVAPORATIVE EMISSIONS

	LP	ULP
NSW EPA	9.76	3.03
FORS Study		
NSW EPA	9.17	3.08
EPA Vic	6.39	0.90
Ford	7.69	1.34

5.7.5.2 Diurnal Evaporative Emissions

No comparison can be made with the FORS Study results due to changes in test protocol and RVP of the test fuels.

The mass of evaporative emissions from an "In-Service" vehicle is typically composed of three parts:

- losses to the atmosphere originating from the fuel system i.e. fuel tank, fuel lines and charcoal canister;
- leakages of engine and transmission oil, brake fluid, coolant; and,
- vehicle materials of construction such as tyres, rubber seals, plastics and upholstery.

Comparison of evaporative emissions from E10 with those from neat petrol is concerned with Item 1 only, however true comparison will be affected by the other two items. Typically for an "In-Service" vehicle Item 3 will be very low and can be considered insignificant, however Item 2 could have some impact on the results.

Throughout the project great care was taken by NRMA in preparing the vehicles for testing followed by a rigorous checking procedure by NSW EPA. However, in spite of the care exercised, several vehicles exhibited significant variations in the results. It is noted that widely varying results were also reported in the FORS study.

The evaporative emissions control system is relatively simple, typically being comprised of a sealed fuel tank, vapour/liquid separator, flow check valve, a purge valve, a charcoal canister and the necessary interconnecting pipework. The following is a description given in Gregorys Workshop manual for a Holden Commodore VS system:

> *" Evaporative Control System*
>
> *This system controls fuel vapours which would normally escape from the fuel tank. The fuel tank cap is not vented to atmosphere, but is fitted with a valve to allow both pressure and vacuum relief.*
>
> *Fuel vapour is routed from the fuel tank vent pipe system to a canister filled with activated charcoal. The canister four port design (sic) and is located in the engine compartment, mounted to the front end support panel.*
>
> *The fuel vapour is absorbed by the charcoal. When the engine is running at above idle speed, air is drawn into the canister through the atmospheric port at the bottom of the canister assembly. The air mixes with the vapour and the mixture is drawn into the intake manifold via the canister."*

The deliberately chosen simplistic description given above belies the difficulties in achieving a system exhibiting a high level of integrity and it must be recognised that accurate and repeatable performance of the system may be impossible to achieve without constant monitoring and evaluation as each test proceeds.

The mass of emissions from the fuel system to the atmosphere during the diurnal phase is dependent on:

- the vapour pressure;
- mass of vapour generated;
- capacity and efficiency of the charcoal canister; and,
- size and type of leakage path.

In comparing E10 with neat petrol the only obvious variables are the vapour pressure and mass of vapour generated, however the following factors must be recognised:

- Mechanical failure between tests - fuel tank cap sealing inadequate resulting in variation of vapour leakage rates.

  For example, the fuel tank is often pressurised to about 7 kPa by means of a flow check valve or a relief valve located within the fuel tank cap. Failure of this valve to seal will result in approximately 40% increase in fuel vapour generation which must be absorbed by the charcoal canister or which could be vented directly to the atmosphere.

- Canister "break through" - excessive vapour generation due to overheating, insufficient purge rate, or degraded canister capacity.

  The canister capacity is designed to conform to ADR37 requirements which stipulate the RVP of the test fuel as 60 - 63.4 kPa. However, the test fuels used in this project are in excess of 80 kPa resulting in more than 100% increase in vapour generation.

- Variation in test conditions - temperature rise, time, etc.;

  ADR37 permits variations in absolute fuel temperature (start temperature 14-16°C), the temperature rise (12.8-13.8°C) and the duration of the test (58-62 minutes). The most critical are the latter two. A 1°C change in the temperature rise can result in a 13% change in vapour generation and the 4 minute time variation in the duration of the test can vary the final measurement by more than 100%.

- Variation in test fuel volatility.

  The test fuels were stored in 205L drums at the BP Auburn depot under cover and were subject to extreme ambient temperatures, however samples taken from freshly opened drums indicated a reduction of 2-3 in RVP. Test fuel transferred to NSW EPA's storage facility at Lidcombe was stored at 10°C in the coldroom. On usage as the vapour space within the drum increased the RVP was reduced. It is estimated, on the basis of measuring one drum only, that the RVP could be reduced by up to 5 kPa (-16%). Errors can therefore be introduced when switching from an empty drum to a full drum for consecutive tests.

- External influences such as "fresh" engine and transmission oil leaks.

Figures H-12 to H-15 (Appendix H) show some of the characteristics determining whether a true comparison between E10 and neat petrol has been achieved. Note that:

- that there is some time delay between temperature rise and measurement of the THC emission; and,
- the vapour pressure is calculated from the test fuel RVP and temperature rise, see Appendix F Graph 10 (a) & (b), {11}.

Figure H-12 shows a sudden increase in THC emission for neat petrol at the 50-55 minute interval. Analysis shows that:

- Temperature rise is well controlled.
- The emissions for neat petrol and E10 are almost identical for vapour pressures up to 15 kPa indicating that to this point there was no change in system leakage rate, however leakage increased rapidly for neat petrol above 18 kPa.
- The THC value for neat petrol was recorded as ~2.6 gm, however it was only 1.5 gm at the 58 minute mark and could have been as high as 3.5 gm at the 62 minute mark.

It can be conjectured that a seal or relief valve commenced opening at approximately 15 kPa and could have been almost fully open at 19 kPa. It is not believed to be due to canister "break through". The result is not considered valid.

Figure H-13 shows only a small increase in the final THC emission for E10 compared with neat petrol. It can be seen that:

- temperature rise is very well controlled.
- the emissions for neat petrol and E10 are almost identical for vapour pressures up to 15 kPa indicating that to this point there was no change in system leakage rate. However at higher vapour pressures higher emissions for neat petrol are evident.

Although the result points to some discrepancy in the tests being biased toward E10 the result is nevertheless considered valid.

Figure H-14 shows the equivalent of theoretical increase when comparing neat petrol with E10. It should however be noted that:

- Temperature for E10 shows a decrease at the 45-50 minute mark leading to the “beak” present in the Figure H-14 c & d.
- The emissions for neat petrol and E10 are identical for vapour pressures up to 20 kPa indicating that to this point there was no change in system leakage rate.

The results are considered valid showing no obvious discrepancies for the two test fuels.

Figure H-15 shows the other extreme with emissions due to E10 being substantially higher than for neat petrol. Analysis of the results indicates that:

- Temperature control suffers from hysteresis with the temperature rise end points being at the extreme range of the permitted temperature rise. The approach to the end point for E10 causes a significant increase in HC emissions as shown on the temperature rise Figure H-15 c. It is conjectured that convection circulation within the fuel tank may be such as to cause higher fuel surface temperature than that measured at the geometric centre.
- The emissions for neat petrol and E10 are identical for vapour pressures up to only 2.5 kPa. The leakage rates at the higher vapour pressure levels indicate that the size, or type, of the leakage path was not identical for the two fuels tested.

The result is considered invalid.

A re-assessment by Apace of NSW EPA results (Diurnal and Hot-Soak) ignoring the three lowest and three highest outliers for vehicles 1986-on and the two lowest and two highest outliers for pre-1986 are presented in Table 5-22 along with a summary of the findings of the linear regression analysis by Apace.

TABLE 5-22: EFFECT OF E10 ON EVAPORATIVE EMISSION OF THC

Result Group	Original NSW EPA Key Findings	Outliers Removed Key Findings	Apace Linear Regression (Outliers Removed)
Diurnal			10% (1999)
1986-on	*+ 17% ± 16%*	*+ 17% ± 15%*	+ 9% R^2 = 0.89
Pre-1986	*+ 15% ± 15%*	*+ 17% ± 15%*	+ 14% R^2 = 0.97
Hot-Soak			40% (1999)
Tuned 1986-on	*+ 34% ± 28%*	*+ 42% ± 31%*	+ 33% R^2 =0.85
Pre-1986	*+ 51% ± 30%*	*+ 58% ± 29%*	+ 60% R^2 =0.92

5.7.6 Evaporative Toxic Emissions

Summary of Results from NSW EPA's report

"Evaporative toxic emissions results were obtained from 24 test pairs (E10 and petrol) on 13 test vehicles (see Table 8). Twenty of the test pairs were excluded from the analyses for the reasons given in the clarification below. Statistical analyses were not carried out as only four test pairs remained.

Owing to the very limited data set, no valid findings can be made. The use of E10 resulted in the evaporative toxic emissions being higher for some vehicles and lower for others. No consistent trends are apparent."

5.7.7 Exhaust and Evaporative Emissions Reactivity

The CSIRO report titled "Quantifying Ozone Impacts for the Petrohol Study" is presented as Appendix 7 of NSW EPA's report and contains an explanation of the terms along with the results presented in this section.

The Reactivity Adjustment Factors (RAF) from the CSIRO report are shown in Table 5-23 and Table 5-24. The RAF number is the ratio of the grams of ozone produced per grams of NMOG emitted using E10 to grams of ozone produced per grams of NMOG emitted using neat petrol (see Equation 1 below).

TABLE 5-23: EXHAUST RAF
(CSIRO REPORT)

		RAF
ALL (Post-Tune)	1986-on	0.99
	Pre-1986	1.02
Pre-Tune	1986-on	0.98
	Pre-1986	0.99

TABLE 5-24: EVAPORATIVE RAF
(CSIRO REPORT)

		RAF All Data included	RAF Data with significant background contribution excluded
Diurnal	1986-on	0.98	0.96
	Pre-1986	0.80	0.80
Hot-Soak	1986-on	0.98	0.92
	Pre-1986	0.95	0.95

EQUATION 1:RAF CALCULATION

$$RAF(E10) = \frac{gO_3/gNMOG\ \text{emit.}\ (\text{E10})}{gO_3/gNMOG\ \text{emit.}\ (\text{Petrol})}$$

In all test categories a reduction in ozone formation potential of the exhaust emissions for E10 compared to neat petrol was observed (Table 5-25). The reduction is reported as mainly being due to the reduction in NMOC emitted when operating on E10 compared to neat petrol, there being little difference in emission reactivity. Key Findings as reported by NSW EPA for exhaust ozone formation potential are shown in Table 5-26.

TABLE 5-25: OZONE FORMATION POTENTIAL OF EXHAUST EMISSIONS (NSW EPA REPORT)

Results Group	No. of Tests	NMOC (g/km)	Emission Reactivity	Ozone Formation (g/km)
Petrol (All)	22	0.59	4.03	2.43
E10 (All)	22	0.46	4.02	1.93
Petrol (1986-on)	18	0.34	3.96	1.34
E10(1986-on)	18	0.27	3.92	1.04
Petrol(Pre-1986)	4	1.69	4.36	7.34
E10(Pre-1986)	4	1.35	4.45	5.98
Petrol(Pre-tune)	11	0.49	4.20	2.14
E10(Pre-tune)	11	0.46	4.14	2.01
Petrol(Post-Tune)	11	0.51	4.15	2.21
E10(Post-Tune)	11	0.39	4.13	1.71
Petrol(LTIS 1)	11	0.66	3.91	2.66
E10(LTIS 2)	11	0.53	3.89	2.16
Petrol(LTIS 2)	11	0.51	4.15	2.21
E10(LTIS 2)	11	0.39	4.13	1.71

TABLE 5-26: OZONE FORMATION POTENTIAL OF EXHAUST EMISSIONS (NSW EPA Report)

Result Group		NSW EPA Key Findings
Tuned	All	- 20 %
	1986-on	- 23 %
	Pre-1986	- 19 %
Servicing	Neat Petrol	+ 3 %
	E10	- 15 %
12 months	Neat Petrol	- 17 %
	E10	- 21 %

Note: *Tuned* - Results were obtained from vehicles that were in a tuned state

Servicing - The effect of servicing on emissions (pre-tune – post-tune)

12 months - The effect of 12 months vehicle operation on emissions (post-tune – post-tune)

In all test categories an increase in ozone formation potential of the evaporative emissions for E10 compared to neat petrol was observed (Table 5-27). There is a decrease in the reactivity of THC released but this is outweighed by the larger mass of THC released by E10 compared to neat petrol. Key Findings as reported by NSW EPA for the evaporative ozone formation potential is shown in Table 5-28.

TABLE 5-27: OZONE FORMATION POTENTIAL OF EVAPORATIVE EMISSIONS (NSW EPA REPORT)

	Diurnal				Hot-Soak			Total		
	No. of Tests	THC (g)	Emiss. React.	Ozone (g)	THC (g)	Emiss. React.	Ozone (g)	THC (g)	Emiss. React.	Ozone (g)
Pet.(All)	56	8.19	2.80	22.98	5.08	3.17	16.10	13.27	2.95	39.08
E10(All)	56	9.53	2.52	24.06	7.30	2.95	21.56	16.83	2.71	45.62
Pet.(1986-on)	39	7.50	2.66	19.96	3.03	3.37	10.22	10.54	2.86	30.18
E10(Post-1986)	39	8.78	2.56	22.48	4.06	3.10	12.59	12.84	2.73	35.07
Pet(Pre-1986)	17	9.78	3.06	29.93	9.76	3.03	29.57	19.54	3.05	59.50
E10(Pre-1986)	17	11.25	2.46	27.68	14.73	2.86	42.13	25.98	2.69	69.81

TABLE 5-28: OZONE FORMATION POTENTIAL OF EVAPORATIVE EMISSIONS (NSW EPA REPORT)

Result Group		NSW EPA Key Findings
Tuned	All	+ 17 %
	1986-on	*+ 16 %*
	Pre-1986	*+ 17 %*

NSW EPA notes in its report that the effect of ethanol content on reactivity calculations was not assessed and that the results should be treated with caution. It was also noted that in order to perform a more comprehensive analysis it would be ideal to have a sampling and analysis system for ethanol, however this was outside the scope of the project.

NSW EPA's report concludes:

> *"2. Since ethanol was not measured in these tests care should be taken to consider how it may influence the results. It may be present in significant concentrations in the evaporative emissions. However given its relatively low MIR value of 1.34, and its proportion (10%) in the petrohol fuel its impact on the calculated reactivity is likely to be small."*

In SAE paper 952748 "Gasoline Evaporative Emissions - Ethanol Effects on Vapor Control Canister Sorbent performance", Ames A, Grisanti et al. reported that vapour from an E10 blend at 21.1°C contained 13% w/w ethanol.

However it also reported that canisters exhibit preferential absorption for ethanol and that diurnal SHED test speciation varied 0.8%-2.9% w/w. Ethanol concentration for combined diurnal and hot soak phases of the SHED test are reported as varying from 5 to 16% w/w with E10 blends.

In SAE paper 912429 "Composition and Reactivity of Fuel Vapor Emissions from Gasoline-Oxygenate Blends", Robert L. Furey and Kevin L. Perry, reported 6.6 to 7.1% w/w ethanol concentration in diurnal vapour.

In SAE paper 901114 "Volatility Characteristics of Blends of Gasoline with Ethyl Tertiary - Butyl Ether (ETBE)", Robert L. Furey and Kevin L. Perry, noted that

> *"Hot-Soak Vapour Generation - The mass of vapor generated in a hot carburetor is related to the distillation characteristics of the fuel, rather than to the vapor pressure."*

and reported that good correlation was achieved between the mass of hot soak vapour collected with the percentage of fuel evaporated at 70°C.

In SAE paper 912429 "Composition and Reactivity of Fuel Vapor Emissions from Gasoline-Oxygenate Blends", Robert L. Furey and Kevin L. Perry, also reported that the vapour generated at 75.6°C contained 22.2% w/w ethanol.

There is sufficient evidence available to state that diurnal evaporative emissions respond more directly to vapour pressure whereas hot soak emissions are linked to the distillation characteristics of the fuel. (NSW EPA report, Impacts of Petrohol, Pages 54-55).

Figure 5-5 and Figure 5-6 show the relationship between the neat petrol and E10 distillations for LP and ULP respectively and the estimated concentration of ethanol in the vapour (condensate). The estimate of ethanol content from a distillation curve is based on the following available information:

- the volume of ethanol in 100 ml of E10 cannot be higher than 10ml at any point on the distillation curve;
- the boiling point of neat ethanol is 78.4°C;
- the volume of ethanol at initial boiling point is zero;
- the difference in distillation volume at 100°C between E10 and the base petrol is due to azeotropes formed by the base petrol and ethanol;
- the densities of speciation components between C4-olefins and n-heptane; and
- the molecular weights of speciation components between propane and n-heptane.

Figure 5-5 and Figure 5-6 indicate that the maximum ethanol concentration of 24% w/w (21.9 % v/v) for ULP and 27% w/w (24.5% v/v) for LP occurs at 65°C. The graphs also show the percent difference in the volume evaporated against temperature enabling the effective hot-soak temperatures to be estimated as 65-70°C for pre-1986 vehicles and 55-58°C for 1986-on vehicles. The ethanol concentration in the vapour was thus assessed as 22.5% w/w for pre-1986 vehicles and 16.5% w/w for 1986-on vehicles.

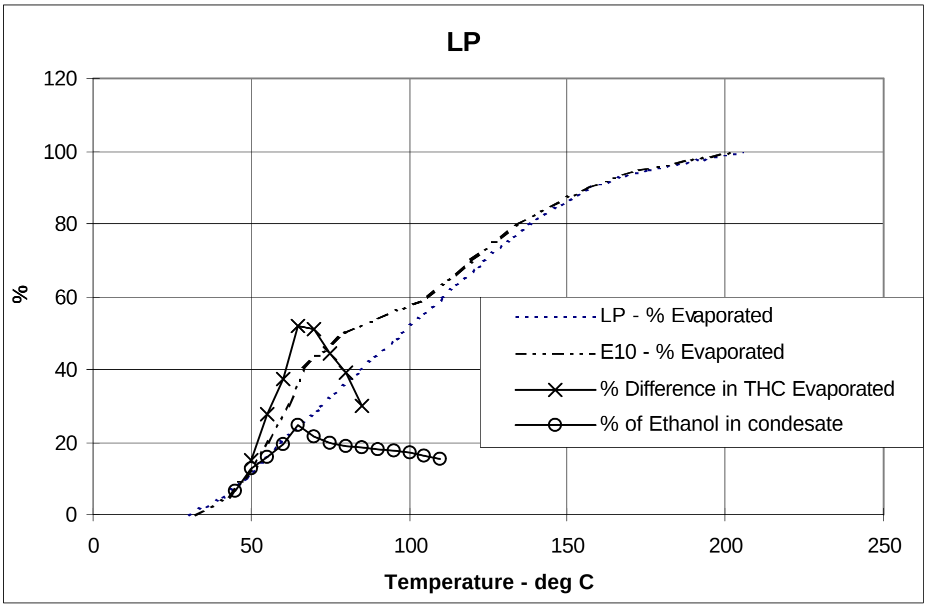

FIGURE 5-5: LP DISTILLATION CURVES

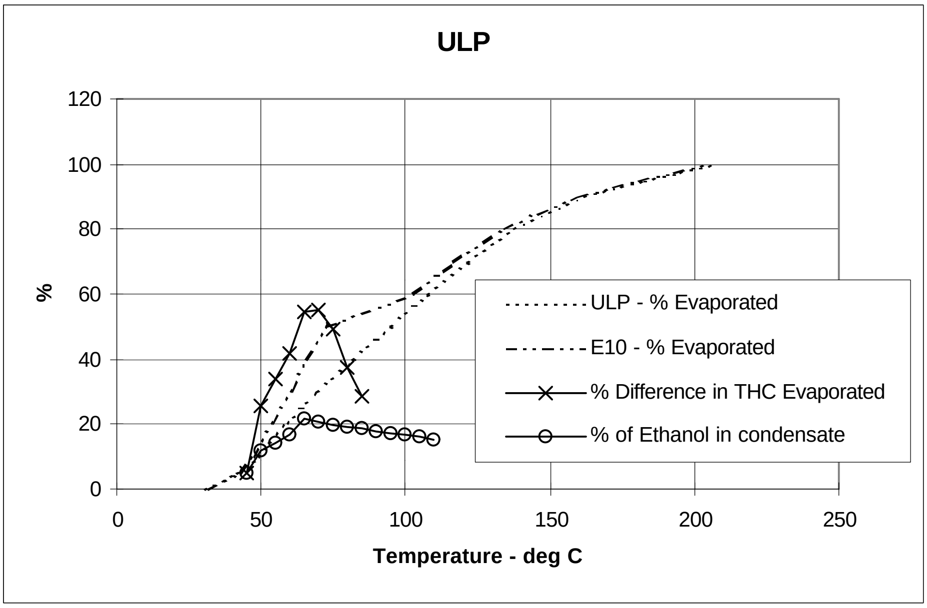

FIGURE 5-6: ULP DISTILLATION CURVES

Table 5-29 shows the effect of including ethanol on MIR calculations for the hot soak phase of the SHED test. The calculations are based on the assumption that the ethanol is additional to the other species and does not form part of the residual hydrocarbons.

The effect on Reactivity Adjustment Factor (RAF) of including ethanol in the speciation is shown in Table 5-30. No allowance/re-assessment has been made for the ethanol concentration in the diurnal phase.

TABLE 5-29: EFFECT OF ETHANOL ON HOT-SOAK MIR

	B4 (All data)	B8 (All data)	B12 (excl data)
Fuel	LP/E10	ULP/E10	ULP/E10
% ethanol in vapour	MIR		
0 *	2.86	3.47	3.10
22.5	2.52	-	-
16.5	-	3.12	2.81
% change	-11.9	-10.0	-9.4

* NSW EPA (CSIRO) Report

TABLE 5-30: EFFECT OF ETHANOL ON HOT-SOAK RAF

	Vehicles	RAF		Change
		Vapour containing		
		No ethanol	ethanol	%
Hot soak	pre-1986	0.95	0.83	-12.5
	1986-on (all)	0.98	0.88	-10.5
	1986-on (excl data)	0.92	0.83	-9.4

5.8 Effect of Maintenance & Time

The following are table summaries from NSW EPA's report. The items marked with # are stated by NSW EPA not to be statistically significant at the 95% confidence level.

5.8.1 Effect of Maintenance

TABLE 5-31: EFFECT OF SERVICING ON EXHAUST EMISSIONS (NSW EPA Report)

	Neat Petrol	E10
HC	- 16% ±22%#	- 17% ±17%#
NO_x	- 2% ±10%#	- 3% ±10%#
CO	- 32% ±35%#	- 44% ±48%#

TABLE 5-32: EFFECT OF SERVICING ON EXHAUST EMISSIONS OF ALDEHYDES (NSW EPA Report)

	Neat Petrol	E10
Formaldehyde	*- 5% ± 26%#*	*- 7% ± 38%#*
Acetaldehyde	*- 8% ± 24%#*	*- 15 % ± 39%#*
Acrolein	*- 8% ± 38%#*	*- 2% ± 35%#*

TABLE 5-33: EFFECT OF SERVICING ON EXHAUST EMISSION OF TOXICS (NSW EPA REPORT)

	Neat Petrol	E10
1,3-Butadiene	+ 5% ± 40%#	+ 6% ± 39%#
Benzene	- 5% ± 13%#	- 13 % ± 15%#
Toluene	- 8% ± 24%#	- 15 % ± 26%#
Xylenes	- 12% ± 29%#	- 14 % ± 27%#

TABLE 5-34: EFFECT OF SERVICING ON EVAPORATIVE EMISSIONS OF THC (NSW EPA REPORT)

	Neat Petrol	E10
THC	- 5% ± 17%#	- 6% ± 14%#
Diurnal	- 7% ± 24%#	- 12% ± 18%#
Hot-Soak	- 1% ± 24%#	+ 4% ± 14%#

5.8.2 Effect of Time

The following is an extract from the NSW EPA report dealing with emission deterioration over a 12 month (approximately) period.

TABLE 5-35: EFFECT OF TIME ON EXHAUST EMISSIONS (NSW EPA REPORT)

	Neat Petrol	E10
HC	0% ±15%#	4% ±14%#
NO_x	10% ±26%#	14% ±24%#
CO	20% ±18%	27% ±28%#
CO_2	1% ± 3%#	2% ±3%#

TABLE 5-36: EFFECT OF TIME ON EXHAUST EMISSION OF ALDEHYDES AND TOXICS (NSW EPA REPORT)

An examination of the results found substantial apparent increases in acrolein and decreases in most of the other exhaust aldehydes and toxics, both on petrol and on E10, from vehicles in the LTIS category over the 12-month period. However, few of these results are statistically significant due to the small sample size (only 8 or 9 vehicles) and the large variations in the individual results.

TABLE 5-37: EFFECT OF TIME ON EVAPORATIVE EMISSIONS (NSW EPA REPORT)

No evaluation could be performed on the evaporative toxic emission in relation to change over a 12-month period due to the change in protocol between the first round of tests and the second round at the end of the 12-month period.

5.9 Effects of E10

5.9.1 NSW EPA Key Findings

The key findings from NSW EPA's report are:

In summary, the use of E10 yielded the following impacts:

TABLE 5-38: EFFECT OF E10 ON EXHAUST EMISSIONS (NSW EPA REPORT)

	1986-on	Pre-1986
HC	- 13% ±5%	- 11% ± 5%
NO_x	+ 5% ±7%#	- 1% ± 6%#
CO	- 27% ±11%	- 37% ± 10%

TABLE 5-39EFFECT OF E10 ON EXHAUST EMISSION OF ALDEHYDES (NSW EPA REPORT)

	1986-on	Pre-1986
Formaldehyde	+ 27% ± 24%	+ 27% ± 12%
Acetaldehyde	+ 213% ± 93%	+ 217% ± 47%
Acrolein	+ 8% ± 19%#	+ 15% ± 30%#

TABLE 5-40: EFFECT OF E10 ON EXHAUST EMISSION OF TOXICS (NSW EPA REPORT)

	1986-on	Pre-1986
1,3-Butadiene	- 9% ± 23%#	- 25% ± 210%#
Benzene	- 28% ± 15%	- 18% ± 85%#
Toluene	- 26% ± 15%	- 17% ± 34%#
Xylenes	- 24% ± 12%	- 17% ± 45%#

TABLE 5-41: EFFECT OF E10 ON EVAPORATIVE EMISSION OF THC
(NSW EPA REPORT)

	1986-on	Pre-1986
Total	+ 22% ± 17%	+ 33% ± 17%
Diurnal	+ 17% ± 16%	+ 15% ± 15%
Hot-Soak	+ 34% ± 28%	+ 51% ± 30%

TABLE 5-42: EFFECT OF E10 ON OZONE FORMATION POTENTIAL (NSW EPA REPORT)

	1986-on	Pre-1986
Exhaust	*- 23%*	*- 19%*
Evaporative	*+ 16%*	*+ 17%*

5.9.2 Apace Linear Regression Findings

TABLE 5-43:EFFECT OF E10

	1986-on	Pre-1986
HC	-13%	-11%
CO	-30%	-38%
NO_X	+2%	-1%
CO_2	+1%	+2%
Formaldehyde	+25%	+25%
Acetaldehyde	+171%	+212%
Acrolein	-5%	+2%
1,3-Butadiene	-21%	-14%
Benzene	-26%	-29%
Toluene	-31%	-28%
Xylenes	-27%	-28%
Evaporative		
Diurnal	+9%	+14%
Hot soak	+33%	+60%

5.10 Impacts of E10

5.10.1 Ozone Formation Potential

The assessment of ozone formation potential requires appropriate weighting of vehicle operation factors which incorporate exhaust, diurnal and hot soak THC emissions. Other factors, such as running and resting losses, were not measured and are not included in any assessment

The Metropolitan Air Quality Study (MAQS){31} assumes that for the evaporative emissions the average vehicle makes 3.5 trips with a total distance of 38.9 km travelled each day. The MAQS model uses Reddy calculations for the evaporative emission phase and does not take into account the actual SHED test results of "In Service" vehicles. Thus the use of the model itself would be inappropriate. It is assumed by Apace that the 3.5 trips/day and 38.9 km/day applied to the evaporative emissions results also apply to the exhaust emissions.

Table 5-44 lists the assumed breakdown of the 3.5 trips.

TABLE 5-44: BREAK DOWN OF 3.5 TRIPS OVER 38.9 KM

	No.	Km
Diurnal	1.00	
Hot-Soak	3.50	
CT(5.8 km ea.)	1.00	5.80
HT(5.8 km ea.)	2.50	14.50
S		18.60
Total		38.90

For the purpose of this analysis it has been further assumed that, for the exhaust emissions, the 3.5 trips comprise 1 cold start (Bag 1-CT, ADR37), 2.5 hot starts (Bag 2 - HT, ADR37) with the remaining distance travelled assigned to the stabilised phase (Bag 3 - S, ADR37). It is also assumed that the evaporative emissions are comprised of 1 diurnal and 3.5 hot soak phases of the SHED test.

The following cold start/stabilised/hot start ratios are used in the references shown in Table 5-45.

TABLE 5-45: SPLIT OF EXHAUST EMISSIONS

Source	Cold start %	Stabilised %	Hot start %
ADR37 (fixed)	21.5	50	28.5
US EPA (flexible)	40	30	30
Apace	14.9	47.8	37.3

The effect of the ethanol component on Reactivity Adjustment Factor (RAF) was discussed in Section 4.7.7. CSIRO provided the following comment on the issue of THC measurement in the SHED test:

> *"A second issue is the effect of the presence of ethanol on the total VOC or THC measurement in the evaporative measurements. I presume that the THC (or VOC) measurement was conducted with a continuous HC analyser based on the flame ionisation detector (FID) principle. The FID has a response to hydrocarbons which is very nearly proportional to the mass of C in any hydrocarbon. Hence this detector can be used to determine THC by calibration with a single HC (usually propane, C_3H_8) since all other HC species will respond similarly. However oxygenated compounds can give a much lower response; formaldehyde (HCHO), for example, gives essentially no responses. A rough rule of thumb is that one O atom eliminates the response due to one C atom, and ethanol (CH_3CH_2OH), on this basis, would be expected to have a response only about 50% of that observed for ethane, C_2H_6.*
>
> *A consequence of this is that if ethanol really contributes more than 20% to the weight of hot soak evaporative emissions then the HC results measured by the continuous analysers would significantly underestimate the HC emissions from the E10 fuel (perhaps by as much as 10%)."*

In view of the above comment the measured Hot soak THC mass emissions have been readjusted to reflect the low response of ethanol (THC/0.885 for pre-1986 and THC/0.9175 for 1986-on vehicles).

Table 5-46 and Table 5-47 show that when ethanol reactivity in the hot soak phase of evaporative emissions is taken into account then there is a slight decrease in ozone formation potential (-3.2%) for 1986-on vehicles and an increase (7.8%) for pre-1986 vehicle. The 1999 fleet assessment in Table 5-48 shows that there is no change (0.24%) in the ozone formation potential despite the greatly increased mass of evaporative emissions measured using the ADR37 test protocol.

TABLE 5-46: THC EMITTED IN A DAY BY "1986-ON" VEHICLES (EXHAUST + EVAPORATIVE)

ULP	Neat Petrol	E10	Multiplier	Neat MIR g	E10 MIR g	Neat Ozone g	E10 Ozone g
Diurnal	7.94	9.26	1.00	2.60	2.50	20.64	23.15
Hot-Soak	2.50	4.27*	3.50	3.37	2.81	29.49	40.52
CT	2.29	2.00	5.80	3.96	3.92	52.60	45.47
HT	1.74	1.61	14.50	3.96	3.92	99.91	91.51
S	1.69	1.59	18.60	3.96	3.92	124.48	115.93
Total						327.12	316.58
% change							-3.22

* Adjusted to allow for FID insensitivity to ethanol.

TABLE 5-47: THC EMITTED IN A DAY BY "PRE-1986" VEHICLES (EXHAUST + EVAPORATIVE)

ULP	Neat	E10	Multiplier	Neat MIR g	E10 MIR G	Neat Ozone g	E10 Ozone g
Diurnal	10.20	11.88	1.00	3.06	2.46	31.21	29.22
Hot-Soak	10.54	18.89	3.50	3.03	2.52	111.78	166.63
CT	2.29	2.00	5.80	4.36	4.45	57.91	51.62
HT	1.74	1.61	14.50	4.36	4.45	110.00	103.89
S	1.69	1.59	18.60	4.36	4.45	137.05	131.60
Total						447.95	482.97
% change							7.82

TABLE 5-48: 1999 FLEET ASSESSMENT - 1:3 RATIO FOR LP TO ULP

	LP	ULP	Total
Neat Petrol	447.95	981.35	1429.31
E10	482.97	949.57	1432.72
% Difference			0.24

Taking into consideration the concerns raised in regard to the "real world" applicability of the ADR37 test protocol compared to the US EPA Multiday Diurnal test procedure, the use E10 is expected to result in a real decrease in ozone formation potential compared to neat petrol.

Studies using E10 reformulated to the same RVP as the base petrol reported a reduction of THC evaporative emissions under the ADR37 test protocol {34}.

5.10.2 Health Risk Assessment

The exhaust emission of "toxics" and aldehydes are reported in section 5.7.4 and are re-presented in Table 5-49. Risk assessment has not been carried out on the evaporative emissions due to the small sample size.

Air toxics and aldehydes are air pollutants that cause adverse health effects. The health problems may be acute, chronic or carcinogenic. The acute and chronic health effects can cause respiratory, reproductive and neurological problems.

Some air toxics have been proven to cause cancer in humans. However, most air toxics are identified through laboratory experiments in which animals receive very high doses of the compound being studied. People almost never breathe such high doses.

Motor vehicles emit several pollutants that are classified as known or probable human carcinogens. Benzene, for instance, is a known human carcinogen, while formaldehyde, acetaldehyde, and 1,3-butadiene are probable human carcinogens.

Some toxic compounds are present in petrol and are emitted to the air when petrol evaporates or passes through the engine as unburned fuel. Benzene, for example, is a component of petrol. Vehicles emit small quantities of benzene in unburned fuel, or as vapour when petrol evaporates.

A significant amount of vehicle benzene comes from the incomplete combustion of compounds in petrol such as toluene and xylenes that are chemically very similar to benzene. Like benzene itself, these compounds occur naturally in petroleum and become more concentrated when petroleum is refined to produce high-octane petrol.

Formaldehyde, acetaldehyde, acrolein and 1,3-butadiene are not present in fuel but are by-products of incomplete combustion.

In calculating the risk to human health and the environment of toxic emissions, scoring systems have been developed by organisations to prioritise the toxics (including aldehydes). The scoring systems are based on toxicity exposure of the substance.

Apace reports the calculations for Health Risk Assessment based on the Environment Defence Fund (EDF) data. California Air Resources Board (CARB) data is shown for comparison.

EDF uses a scoring system to help identify environmental releases of toxic chemicals that are likely to pose the greatest risk to human health. This system adjusts the amount of a chemical that is released using a weighting factor (a chemical's "toxic equivalency potential"), so that chemical releases can be compared on a common scale taking into account differences in toxicity and exposure potential.

The EDF developed its risk scoring system in collaboration with the School of Public Health at the University of California at Berkeley. Similar scoring systems are used by Minnesota's Pollution Control Agency, major chemical manufacturers like ICI, and national environmental agencies in Europe.

EDF’s risk scoring system was designed as a means comparing releases of toxic chemicals, so that engineers can compare the environmental impacts of alternatives when they practice design-for-environment. EDF's risk scoring system has been developed after careful review of several similar scoring systems that also attempt to meet these needs. These systems all share a risk assessment framework; they utilise environmental fate and exposure models to predict the dose organisms receive after a toxic chemical is released into an environmental compartment, and then compare this dose with indicators of chemical toxicity to produce a risk index. The systems vary in the extent to which they focus on specific types of releases, address ecological as well as human health impacts, and rely on different sources of data.

EDF takes both toxicity and exposure potential into account. Human toxic equivalency potentials express the release of a chemical in terms of an equivalent (equally toxic) mass release of a reference chemical.

The EDF method uses the carcinogen benzene as a reference chemical for measuring human health effects. All chemical releases are converted into benzene-equivalents using a potency factor based on the occupational exposure standard for this chemical in the United Kingdom.

EDF's benzene-equivalents include consideration of exposure potential and not just toxicity, and EDF compares the toxicity of chemicals to benzene using cancer potency factors and not occupational standards.

The non-cancer risk assessment factors use toluene as a reference chemical for measuring human health effects.

TABLE 5-49: TOXIC AND ALDEHYDES EXHAUST EMISSIONS

		1986 –on (mg/km)			Pre-1986 (mg/km)			Combined(1999) (mg/km)		
Exhaust		Petrol	E10	%	Petrol	E10	%	Petrol	E10	%
Toxics	**1,3-Butadiene**	4.19	3.56	-15.01	28.84	24.41	-15.37	10.35	8.77	-15.26
	Benzene	18.08	13.61	-24.70	88.20	65.79	-25.41	35.61	26.66	-25.14
	Toluene	22.74	16.90	-25.67	169.82	128.80	-24.15	59.51	44.88	-24.59
	Xylenes	19.70	15.29	-22.39	140.88	105.03	-25.45	50.00	37.73	-24.54
Aldehydes	**Formaldehyde**	5.22	6.56	25.74	31.12	39.27	26.19	11.70	14.74	26.04
	Acrolein	1.22	1.20	-2.06	3.38	3.95	17.13	1.76	1.89	7.13
	Acetaldehyde	2.15	6.30	193.03	7.55	24.20	220.50	3.50	10.78	207.84

The EDF weighting factors are shown in Table 5-50, the higher the value the higher the associated health risk on exposure to that chemical. The values are based on the assumption that the toxic is air released.

The omission of weighting factors from the table does not indicate that there is no associated risk, only that insufficient data is available, to EDF, to formulate a weighting factor.

TABLE 5-50: EDF RISK ASSESSMENT WEIGHTING FACTORS (AIR RELEASE)

		Carcinogenic	Non Carcinogenic
Toxics	1,3-Butadiene	0.33	1.2
	Benzene	1.00	17
	Toluene		1
	Xylenes		0.82
Aldehydes	Formaldehyde	3.00E-03	7
	Acrolein		2.10E+03
	Acetaldehyde	3.50E-03	3.8

The risk assessment weighting is obtained by multiplying the mass of the emission by the weighting factor. The results for the carcinogenic and non-carcinogenic weighted emissions are shown in Table 5-51 and Table 5-52 respectively. The results are summed and the percentage differences between the totals are shown.

5.10.2.1 Carcinogenic

There is a 24% decrease in the carcinogenic risk when using E10 compared to neat petrol based on the combined fleet, with a 24% decrease for both 1986-on vehicles and pre-1986 vehicles. Figure 5-7 shows the mass of each individual compound as a percentage of the total mass of the carcinogenic compounds, compared to the risk level of each compound as a percentage of the total risk level. It gives a visual indication of the impact a change in the mass of a carcinogen will have on the overall risk of the exhaust emissions. For example it can be seen that although the mass emission of acetaldehyde has increased significantly using E10, its effect on overall carcinogenic risk is negligible.

TABLE 5-51: CARCINOGENIC ASSESSMENT

		1986-on		Pre-1986		Combined (1999)	
		Petrol	E10	Petrol	E10	Petrol	E10
Toxics	1,3-Butadiene	1.38	1.17	9.52	8.06	3.42	2.89
	Benzene	18.08	13.61	88.20	65.79	35.61	26.66
	Toluene						
	Xylenes						
Aldehydes	Formaldehyde	0.02	0.02	0.09	0.12	0.04	0.04
	Acrolein						
	Acetaldehyde	0.01	0.02	0.03	0.08	0.01	0.04
Sum		19.48	14.83	97.84	74.05	39.07	29.63
Difference			-23.89		-24.32		-24.16

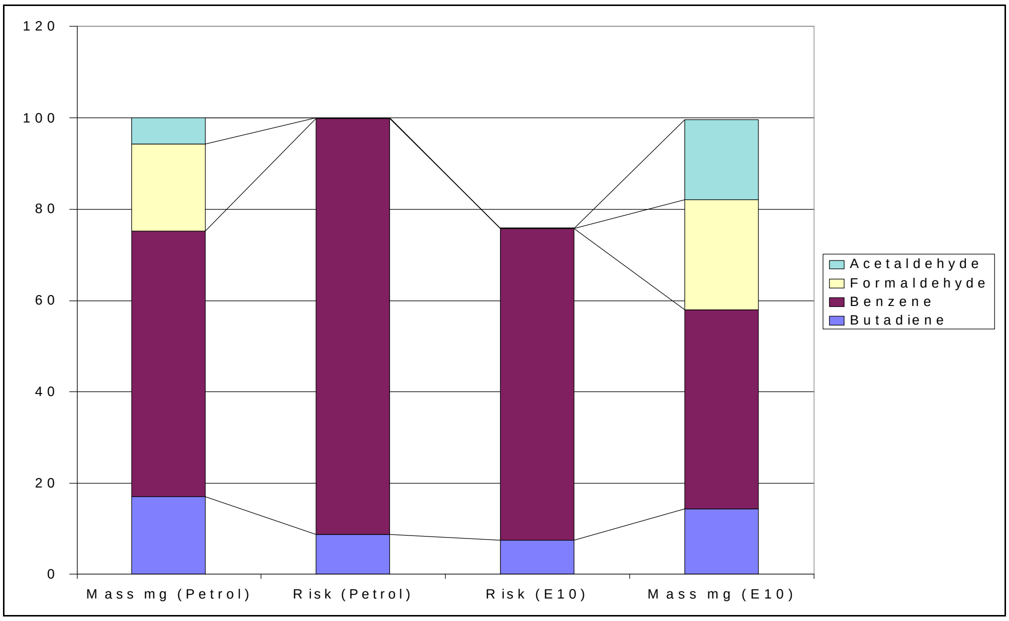

FIGURE 5-7: CARCINOGENIC (MASS - RISK)

5.10.2.2 Non-carcinogenic

As shown in Table 5-52, there is a 3% increase in the non-carcinogenic risk when using E10 compared to neat petrol based on the combined fleet, with 1986-on vehicles experiencing a 4% decrease and pre-1986 vehicles experiencing a 10% increase.

The slight increase of 3% in the non-carcinogenic risk factor due to E10 in the combined fleet is almost entirely due to the increase in acrolein in pre-1986 vehicles(see Table 5-52 and Figure 5-8). Although acetaldehyde mass emission increased by 208% the contribution to the risk factor is small, whereas the contribution of the estimated 7% increase in acrolein mass emission amounted to over 80% of the total non-carcinogenic risk. The large increase due to acrolein is offset by the significant decrease in the mass emission of toxics.

This analysis must be viewed with great caution as the determination of acrolein was inconclusive. This is highlighted by the linear regression finding (Table 5-14**) which shows a 3% reduction in the mass emission of acrolein rather than the estimated 7% increase shown in** Table 5-47 **based on the simple average mass difference.Additional research and improved aldehyde sample collection protocols are needed to predict the risk more accurately.**

TABLE 5-52: NON-CARCINOGENIC ASSESSMENT

		1986-on		Pre-1986		Combined	
		Petrol	E10	Petrol	E10	Petrol	E10
Toxics	1,3-Butadiene	5.02	4.27	34.61	29.29	12.42	10.52
	Benzene	307.33	231.42	1499.36	1118.40	605.34	453.16
	Toluene	22.74	16.90	169.82	128.80	59.51	44.88
	Xylenes	16.16	12.54	115.52	86.12	41.00	30.94
Aldehydes	Formaldehyde	36.54	45.95	217.85	274.90	81.87	103.19
	Acrolein	2572.30	2519.20	7088.96	8303.60	3701.47	3965.30
	Acetaldehyde	8.17	23.95	28.69	91.95	13.30	40.95
Sum		2968.26	2854.23	9154.81	10033.07	4514.90	4648.94
Difference			-3.8%		9.6%		3.0%

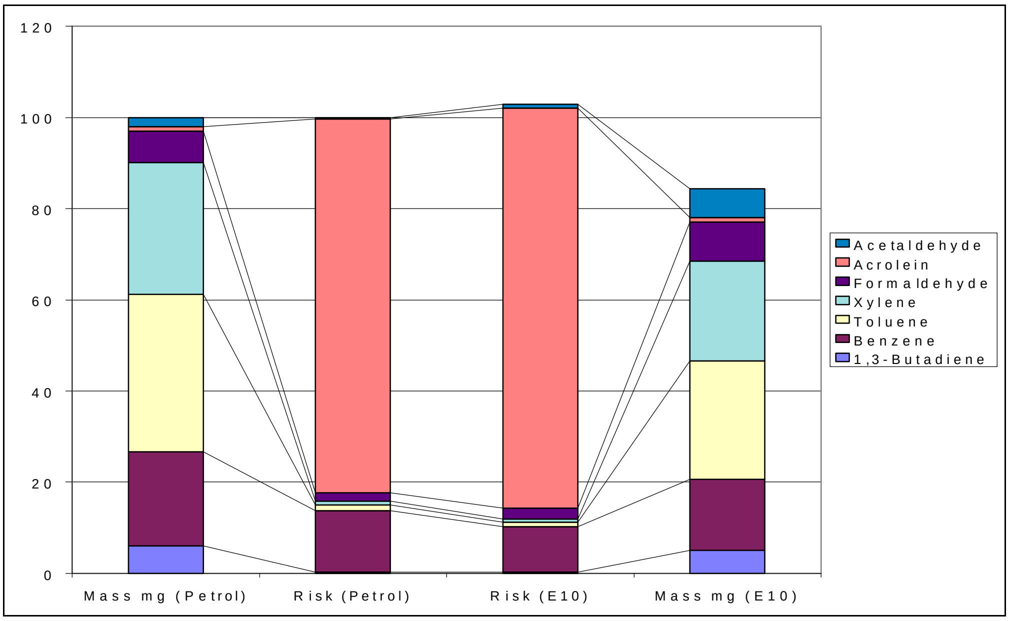

FIGURE 5-8: NON-CARCINOGENIC (MASS - RISK)

5.10.2.3 California Air Resources Board (CARB) Comparison

The risk assessment based on CARB risk assessment factors is shown in Table 5-53. It should be noted that CARB factors further break down the non-carcinogenic risk into acute and chronic health problems and that the compounds used differ, as shown in Table 5-54.

Again, the increase in acute and chronic risk based on the CARB risk assessment factors is almost entirely due to the increase in acrolein and as such, the analysis must be viewed with great caution.

TABLE 5-53: RISK ASSESSMENT BASED ON CARB FACTORS

	1986-ON	pre-1986	Combined
Carcinogenic	-17.05	-17.08	-17.07
Acute	-1.47	16.72	7.45
Chronic	-0.85	17.91	8.30

TABLE 5-54: RISK FACTORS AVAILABLE FOR USE

		EDF		CARB		
		Carcinogenic	Non-carcinogenic	Carcinogenic	Acute	Chronic
Toxics	**1,3-Butadiene**	✓	✓	✓		
	Benzene	✓	✓	✓		✓
	Toluene		✓			✓
	Xylenes		✓		✓	✓
Aldehydes	**Formaldehyde**	✓	✓	✓	✓	✓
	Acrolein		✓		✓	✓
	Acetaldehyde	✓	✓	✓		✓

5.11 Findings and Conclusions

10% v/v ethanol/petrol blend (E10) offers significant benefits in terms of reductions in exhaust and greenhouse gas emissions with no apparent detrimental effect on other aspects of engine or vehicle performance.

When measured according to the ADR37 SHED test method there is a significant increase in evaporative emissions with 10% v/v ethanol/petrol blend compared to neat petrol. However, based on the ADR37 protocol, there is no increase in ozone forming potential with 10% v/v ethanol/ petrol blend.

In the United States the ADR37 SHED test method for evaporative emissions measurement has been replaced by the Multiday Diurnal SHED test method which is considered by U.S. EPA to more accurately model "real world" conditions. United States reports suggest that, when tested using the Multiday Diurnal SHED test method, the mass of evaporative emissions {39} from 10% v/v ethanol/petrol blend is not significantly different to that from neat petrol.

Further work needs to be undertaken to determine the "real world" evaporative emission from 10% v/v ethanol/petrol blend.

It is estimated that the 1999 passenger vehicle fleet will consume approximately 25% leaded petrol (LP) and 75% unleaded petrol (ULP). The results of this project for the projected 1999 fleet consumption show that, when compared to use of neat petrol, use of 10% v/v ethanol/petrol blend has the following effects:

- Regulated exhaust emission of:
  - CO decreases by approximately 32%;
  - THC decreases by approximately 12%; and
  - NOx increases by approximately 1%.

- Non-regulated exhaust emission of:
  - 1-3 butadiene decreases by approximately 19%;
  - benzene decreases by approximately 27%;
  - toluene decreases by approximately 30%;
  - xylenes decrease by approximately 27%;
  - acrolein decreases by about 3%;
  - formaldehyde increases by approximately 25%; and,
  - acetaldehyde increases by approximately 181%;
  - CO_2 increases by 1%; but,
  - net CO_2 emission decreases by up to 7% on a full carbon cycle basis.

  Note:

  The value for acrolein is indicative only and must be treated with extreme caution.

  The large increase in acetaldehyde emission does not result in an overall increase in ozone formation potential or health risk assessments.

- Evaporative emission (SHED test method - ADR37 protocol) of:
  - ~ "diurnal" HC increases by approximately 17% ;
  - ~ "hot soak" HC increases by approximately 39%;

  Note: It is reported that there is little or no change in evaporative emissions with the Multiday Diurnal SHED test method in force in the United States since January 1996 {39}.

- Ozone formation potential

  There is little or no change on ozone formation potential.

- Health risk assessment
  - ~ carcinogenic risk is reduced by approximately 17-24% (CARB, EDF); and,
  - ~ acute and chronic health (respiratory, reproductive and neurological) risks increase by 3-8%(EDF, CARB).

  Note: The increase in acute and chronic health risk is almost entirely due to an estimated increase in acrolein. Because the determination of acrolein was inconclusive, this finding must be treated with great caution.

5.12 Recommendations

It is recommended that further research be conducted to:

- determine the level of evaporative emissions from 10% v/v ethanol/petrol blend under "real world" conditions such as by using the Multiday Diurnal test procedure in force in the United States since January 1996; and,
- improve measuring methods for the determination of toxic and aldehyde compounds in exhaust and evaporative emissions.

6 FUEL CONSUMPTION

Ethanol has a lower calorific value than petrol which results in the E10 blend having a lower calorific value than neat petrol. The effect of this on fuel economy needs to be studied to ascertain the benefit of the E10 blend.

The approach taken for this study to measure fuel consumption involved the collection of data from "In-service" vehicles and dynamometer evaluation.

6.1 Theoretical Basis for Fuel Economy Changes Due to Ethanol

Fuel economy theoretically decreases when ethanol is used, primarily due to its lower energy content. The energy content of petrol is approximately 30,500 kJ/ℓ (LHV) and that for ethanol is 21,200 kJ/ℓ (LHV).

Table 6-1 shows the theoretically expected decrease in fuel energy as a result of ethanol use in the 5.7% to 10% v/v range when compared to neat petrol. Providing there is no change in thermal efficiency, the decrease in energy must be compensated by an equivalent increase in fuel consumption. This corresponds to approximately 0.2ℓ to 0.3ℓ for a car that averages 10ℓ/100 km.

TABLE 6-1: THEORETICAL EFFECT OF ETHANOL ON FUEL ENERGY

	O_2	Ethanol	Petrol	LHV	Ethanol	Petrol	Total	Change
	% w/w	% v/v	% v/v	kJ/ℓ	kJ/ℓ	kJ/ℓ	kJ/ℓ	% reduction
Ethanol	34.8	100	-	21,200			21,000	-
Petrol	-	-	100.0	30,500	-	30,500	30,500	-
Eth/Pet	2.0	5.7	94.3	-	1208	28,761	29,969	1.8
Eth/Pet	2.7	7.7	92.3	-	1632	28,151	29,783	2.4
Eth/Pet	3.5	10.0	90.0	-	2120	27,450	29,570	3.1

6.2 In-service Vehicles

The large number of variables affecting "In-service" vehicle fuel economy prevents accurate measurements in anything short of a tightly controlled test or a large well documented fleet study. Variables in "In-service" fuel consumption are:

- Measurement variability
- Ambient temperature effects
- Seasonal fuel composition

6.2.1 Measurement Variability

The variables that are inherent in fuel economy measurements include:

- differences in personal driving habits;
- weather conditions (temperature, wind effects, rain and snow);
- traffic patterns (e.g., rush hour versus midday or weekends, highway driving versus city driving, etc.);
- vehicle technology, state of tune, use of air conditioners and changes in tyre pressure;
- temperature effect on fuel volumes when refuelling; and even,
- whether the vehicle is level each time it is filled, which in itself can distort fuel economy readings by several percent.

6.2.2 Ambient Temperature Effects

Wintertime driving can result in significant decreases in fuel economy when compared to other times of the year. These large decreases can be attributed to:

- increased stop and go driving,
- more friction between vehicle mechanical parts;
- idling to heat up the vehicle prior to a trip;
- increased rolling resistance;
- a greater power load on the engine; and,
- longer periods spent in cold engine operating modes at richer fuel/air mixtures.

6.2.3 Seasonal Fuel Composition

Seasonal changes made to petrol for drivability issues influences the energy content of the fuel and hence the fuel economy. Winter grade fuels with their higher volatility generally have less energy per volume than summer grade fuels, varying by approximately 3-4% throughout the season {1} and with summer grade fuel having a seasonal energy variation of as much as 5%.

A combination of the above variables can have a profound effect on fuel economy. For example, the difference between city versus highway driving can cause a variation in fuel economy in the range of 20 to 30%. This, together with the cumulative effect of the other variables, can account for as much as a 35 to 40% difference in expected fuel economy and far outweigh the effect of the small change in fuel energy density that is shown in Table 6-1.

Two approaches were adopted for the collection of “In-service” fuel consumption data, as follows:

- Polling approximately 250 regular users of E10 ethanol/petrol blends from BOGAS account customers, compared with a similar number of regular users of petrol only.
- Requesting "LTIS" fleet participants to maintain a fuel consumption log book and, when possible, to operate on neat petrol for comparison.

6.3 Dynamometer Evaluation

The dynamometer evaluation drive cycle consumption tests were carried out in accord with Australian Standard AS 2877 "Methods of Test for Fuel Consumption of Motor Vehicles Designed to Comply With Australian Design Rules 37 and 40" during emission testing, conducted by NSW EPA.

Fuel consumption figures obtained from city and highway cycles are not intended to be representative of true on-road driving {13}. However, they do provide a controlled operating environment that eliminates the variables associated with “In-service” fuel consumption and gives a clear indication of the difference in fuel economy between neat petrol and E10.

There were three groups of vehicles that underwent different levels of testing, the groups are as follows:

- ♦ Long Term In-service Fleet (LTIS)
- ♦ Base Fleet subfleet (BF(s))
- ♦ Base Fleet (BF)

The LTIS fleet was tested three times on both E10 and neat petrol, in the following order:

- ♦ "post-tune" (Post 1 tune) condition at the commencement of the emissions test program;
- ♦ "pre-tune" condition following approximately 12 months of operation; and
- ♦ "post-tune" (Post 2 tune) condition immediately following step 2.

The BF(s) fleet was tested twice, on both E10 and neat petrol, in the following order:

- ♦ “Pre-tune” vehicle tested in “as received condition”; and,
- ♦ “Post-tune” condition immediately following step 1.

The BF fleet was tested only once, on both fuels, in a tuned condition.

6.4 Results

6.4.1 In-service Results

♦ Polling approximately 250 regular users of E10 ethanol/petrol blends from BOGAS account customers, compared with a similar number of regular users of petrol only.

Although mailouts were made on two separate occasions, the response was extremely poor, significantly below that required for meaningful analysis. Consequently no results are presented.

♦ Requesting "LTIS" fleet and other participants to maintain a fuel consumption log book and, when possible, to operate on neat petrol for comparison.

Table 6-2 shows the fuel consumption figures collected, the percentage change between neat and E10 where applicable, and DPIE “In-service” figures {13}. Looking at the percentage change between E10 and neat petrol there is no trend evident.

The table also clearly shows the difficulty in achieving accurate and repeatable results. The variation in fuel consumption from a 6.8% improvement to 7.8% deterioration is not unexpected and can be explained as being partly due to changes in drivability.

TABLE 6-2: IN-SERVICE FUEL CONSUMPTION

Vehicle	Year	Fuel consumption ℓ/100 km		% change	DPIE ℓ/100 km
Make		E10	Petrol		
Ford Falcon	1992	12.3	13.2	-6.8	13.36
Ford Falcon	1992	12.3			13.36
Ford Laser	1994	11.4			
Toyota Camry*	1993	10.8			
Mits. Magna	1995	12.2	11.4	7.8	12.09
Holden Ute	1994	11.0			
Mits. Magna	1995	11.1			11.91
Ford Falcon	1985	12.6	12.2	3.3	
Toyota Camry	1993	8.24	8.75	-5.8	9.53

* V6

Note: % change ‘+’ positive equal increase in fuel consumption using E10

‘- ’ minus equal decrease in fuel consumption using E10

6.4.2 Dynamometer Results

The dynamometer evaluation of fuel consumption (FC) has been divided into the following:

- LTIS Fleet
- BF(s) + LTIS Fleets
- BF + BF(s) + LTIS Fleets

6.4.2.1 LTIS Fleet (9 ULP, 2 LP)

Table 6-3 reflects the effect of the two ULP fuels and the vehicle condition. The results presented are based on 7 of the 9 ULP LTIS vehicles, due to two vehicles having no data on one of the highway cycles. The average increase in fuel consumption from neat petrol to E10 of 2.8 % city and 3.2% highway are close to the theoretical energy reduction of 3.1%.

TABLE 6-3: FUEL CONSUMPTION LTIS FLEET (ULP)

Condition	City cycle				Highway cycle		
	Neat FC ℓ/100km	E10 FC ℓ/100km	% Change		Neat FC ℓ/100km	E10 FC ℓ/100km	% Change
Post 1-tune	12.11	12.40	2.4		9.07	9.34	3.0
Pre-tune	12.13	12.50	3.1		8.87	9.12	2.9
Post 2-tune	12.19	12.56	3.0		8.88	9.20	3.6
Average increase %			2.8				3.2

It should be noted that the fuel economy was unaffected by neither the period of operation between tests (approx. 12 months, Post 1-Post 2) nor by "tuning" (Pre-Post 2) to manufacturers specification.

Table 6-4 shows the change in fuel economy due to:

- deterioration of engine tune over twelve months (Post1 to Pre tune);
- change in fuel economy due solely to ageing of the vehicle over twelve months, other than tuning (Post1 to Post2 tune); and
- effect of tuning.

For both neat petrol and E10 the city cycle shows little change over all the conditions. The highway cycle shows an improvement in fuel consumption for both the 12 month conditions on both fuels.

The effect of tuning has had little influence on fuel consumption for the fleet. The difference between city and highway cycles is put down to test repeatability error and the small sample size.

TABLE 6-4: CHANGE IN FUEL CONSUMPTION DUE TO TIME AND TUNING (LTIS, ULP)

Condition	City cycle		Highway cycle	
	Neat % Change	E10 % Change	Neat % Change	E10 % Change
Deterioration of tune over 12 months	0.15	0.84	-2.18	-2.33
Vehicle Ageing over 12 months	0.65	1.30	-2.10	-1.50
Effect of Tuning	0.50	0.45	0.10	0.80

Caution should be taken in interpreting the results in Table 6-6 due to the small sample size.

Table 6-5 reflects the effect of the two LP fuels, and the vehicle condition, on fuel consumption. The sample consists of only two vehicles for the LTIS LP fleet, so caution should be taken interpreting the results. Unlike the ULP comparisons, the increase in fuel consumption from neat petrol to E10 for the city cycle is small (0.13%), and does not reflect the energy difference between the two fuels. The fuel consumption increase in the highway cycle of 2% is closer to the theoretical difference of 3%.

An explanation for the decreased difference in fuel consumption is the enleanment that E10 causes. LP vehicles are older vehicles incorporating older mixture control technology and do not adjust to the extra oxygen in the E10, so they run leaner than if they were on neat petrol. A leaner running engine tends to be more fuel efficient although, if an engine runs too lean, it may experience drivability problems. The enleanment effect does not occur in the majority of ULP vehicles, due to newer vehicle technology that corrects for the stoichiometric requirements of the fuel used. Hence in LP vehicles the 3.1% energy loss with E10 is partially masked by the leaning effect of the fuel.

Caution should be taken in interpreting the results in Table 6-6 due to the small sample size.

TABLE 6-5: FUEL CONSUMPTION LTIS FLEET (LP)

Condition	City cycle				Highway cycle		
	Neat ℓ/100km	E10 ℓ/100km	% Change		Neat ℓ/100km	E10 ℓ/100km	% Change
Post1-tune	13.79	13.84	0.4		10.32	10.56	1.4
Pre-tune	13.19	13.27	0.6		9.33	9.53	2.1
Post2-tune	14.04	13.96	-0.6		9.75	9.99	2.4
Average increase %			0.13				2.0

TABLE 6-6: CHANGE IN FUEL CONSUMPTION DUE TO TIME AND TUNING (LTIS, LP)

Condition	City cycle		Highway cycle	
	Neat % Change	E10 % Change	Neat % Change	E10 % Change
Deterioration of tune over 12 months	-4.29	-4.14	-9.54	8.92
Vehicle Ageing over 12 months	1.90	0.90	-5.50	-4.60
Effect of Tuning	6.40	5.20	4.50	4.80

6.4.2.2 BF(s) Fleet (5 ULP, 5 LP)

The BF(s) fleet was tested in "pre-tune" condition and then immediately retested in a "post-tune" condition. The sample size was small and therefore the LTIS results (Pre-tune and Post 2-tune) have been added, giving a total of 12 ULP and 7 LP vehicles.

Table 6-7 shows the average fuel consumption increase for the ULP vehicles from neat petrol to E10. The increase of 2.97% for city cycle, and 3.24% for the highway cycle, are close to the theoretical increase of 3.1%. The change in fuel consumption due to tuning, Table 6-8, are insignificant.

TABLE 6-7: FUEL CONSUMPTION BF(S) AND LTIS FLEETS COMBINED (ULP)

Condition	City cycle				Highway cycle		
	Neat ℓ/100km	E10 ℓ/100km	%		Neat ℓ/100km	E10 ℓ/100km	%
Pre-tune	12.96	12.46	2.52		8.74	9.01	3.06
Post-tune	12.04	12.45	3.41		8.74	9.04	3.41
Average increase %			2.97				3.24

TABLE 6-8: CHANGE IN FUEL CONSUMPTION DUE TO TUNING (ULP)

Condition	City cycle		Highway cycle	
	Neat % Change	E10 % Change	Neat % Change	E10 % Change
Effect of Tuning	-0.97	-0.11	0.01	0.35

The average fuel consumption increase for LP vehicles of 1.96% for the city cycle and 2.29% for the highway cycle is shown in Table 6-9.

TABLE 6-9: FUEL CONSUMPTION BF(S) AND LTIS FLEETS COMBINED (LP)

Condition	City cycle				Highway cycle		
	Neat ℓ/100km	E10 ℓ/100km	%		Neat ℓ/100km	E10 ℓ/100km	%
Pre-tune	12.93	13.38	3.49		9.1	9.25	1.65
Post-tune	12.97	13.03	0.43		9.09	9.36	2.93
Average increase %			1.96				2.29

Per Table 6-10, on neat fuel the effect of tuning has made little difference in fuel consumption. By comparison the E10 has reduced fuel consumption for the city cycle and increased fuel consumption on the highway cycle.

TABLE 6-10: CHANGE IN FUEL CONSUMPTION DUE TO TUNING (LP)

Condition	City cycle		Highway cycle	
	Neat % Change	E10 % Change	Neat % Change	E10 % Change
Effect of Tuning	0.31	-2.65	-0.04	1.22

6.4.2.3 All vehicles (39 ULP, 17 LP)

The remainder of the vehicles were tested only once, in a "post-tune" condition.

Table 6-11 and Table 6-12 show the average increase in fuel consumption for E10 for the ULP and LP test fleets respectively. The same trends are evident with the ULP vehicles fuel consumption around the theoretical value and the LP lower than theoretical due to enleanment.

TABLE 6-11: FUEL CONSUMPTION ALL VEHICLES (ULP)

Condition	City cycle				Highway cycle		
	Neat ℓ/100km	E10 ℓ/100km	%		Neat ℓ/100km	FC ℓ/100km	%
Post-tune	12.19	12.56	3.0		8.82	9.05	2.6

TABLE 6-12: FUEL CONSUMPTION ALL VEHICLES (LP)

Condition	City cycle				Highway cycle		
	Neat ℓ/100km	E10 ℓ/100km	%		Neat ℓ/100km	E10 ℓ/100km	%
Post-tune	12.67	12.83	1.3		9.13	9.35	2.4

The scatter graphs of neat petrol vs E10 for city and highway cycle are shown in Figure 6-1, Figure 6-2, Figure 6-3 and Figure 6-4. An attempt was made to analyse the results of the two outliers as shown in Figure 6-1 but no acceptable explanation was determined.

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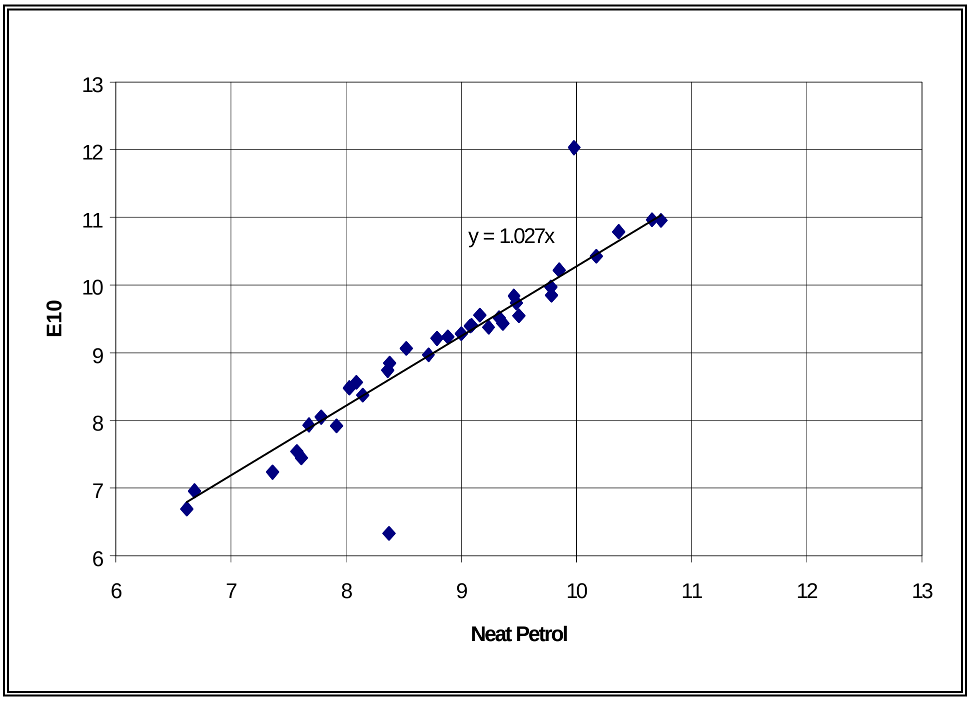

FIGURE 6-1: NEAT VS E10 - HWY. FUEL CONSUMPTION FOR ULP VEHICLES

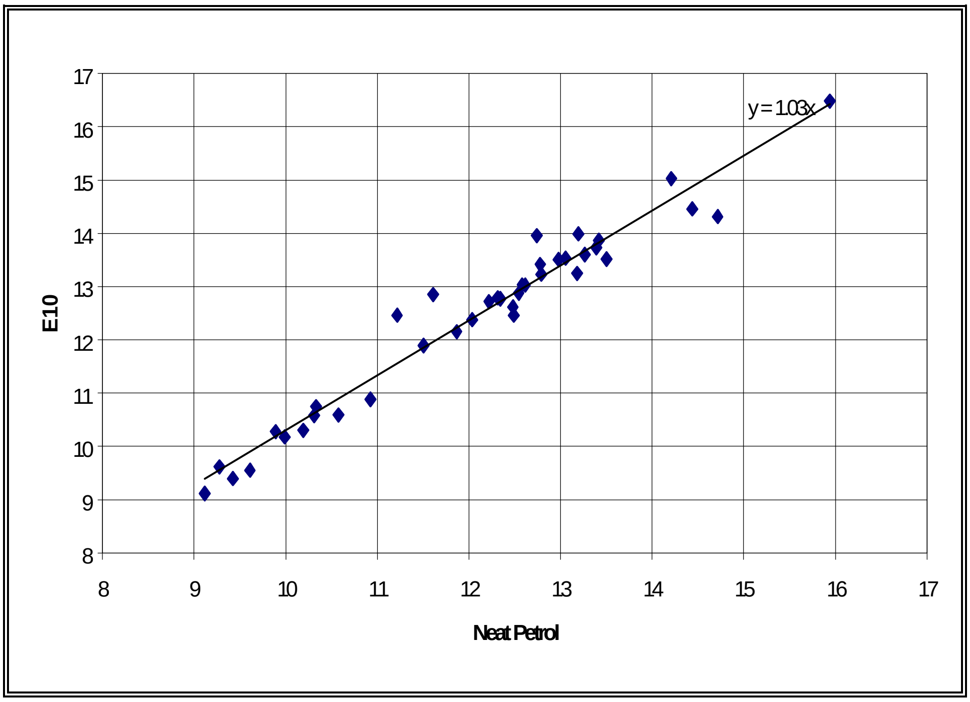

FIGURE 6-2: NEAT VS E10 - CITY FUEL CONSUMPTION FOR ULP VEHICLES

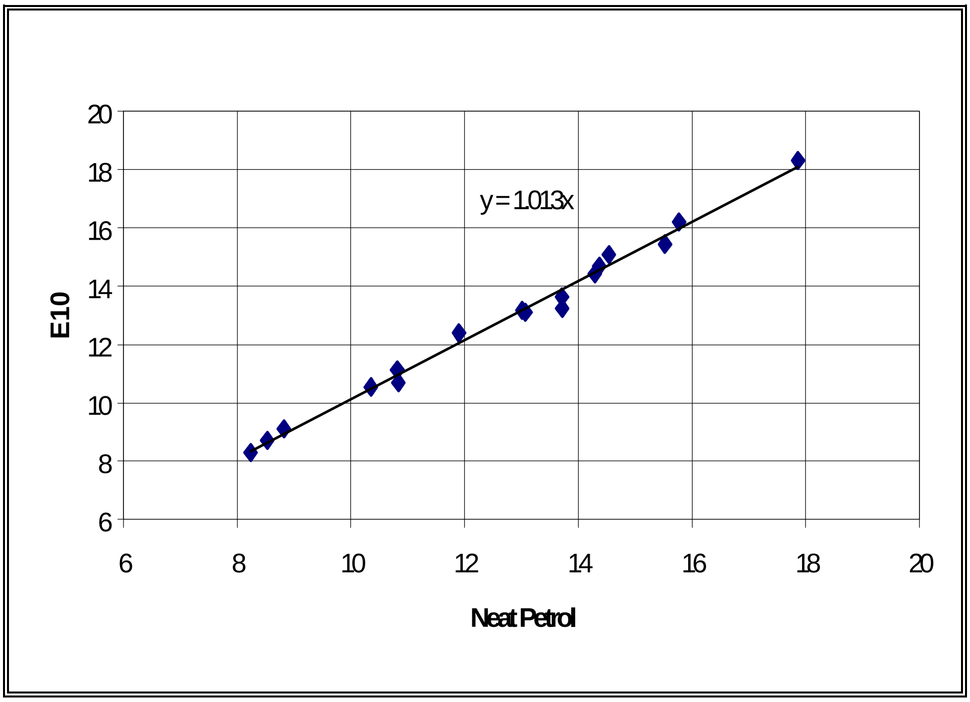

FIGURE 6-3: NEAT VS E10 - CITY FUEL CONSUMPTION FOR LP VEHICLES

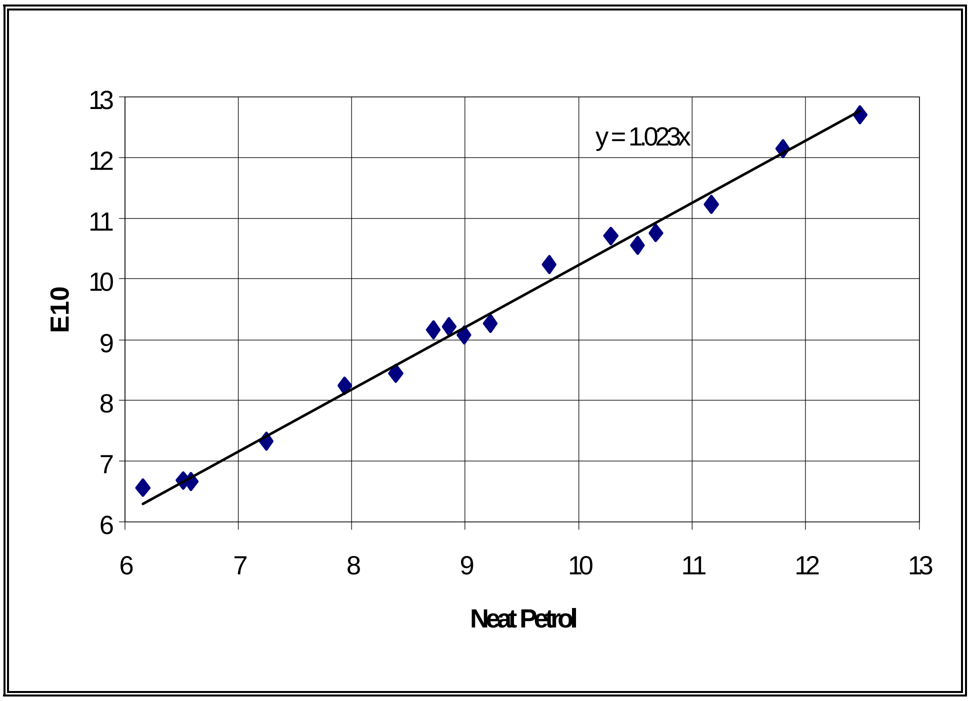

FIGURE 6-4: NEAT VS E10 - HWY. FUEL CONSUMPTION FOR LP VEHICLES

When manufactures report a model's fuel consumption to the National Average Fuel Consumption compilation they use a 55/45 city/highway weighting. Table 6-13 shows the combined city and highway fuel consumption for this study's test fleet.

TABLE 6-13: COMBINED CITY AND HWY. FUEL CONSUMPTION (55/45 CITY/HWY. WEIGHTING)

	Neat ℓ/100km	E10 ℓ/100km	% Change (E10/Neat)
ULP	10.61	10.91	2.8
LP	11.08	11.26	1.6

Using the fuel consumption data shown in Table 6-11 and Table 6-12, the substitution of petrol with 10% ethanol on a volume/volume basis results in fuel consumption increases ranging from 1.3% to 3% . Due to the increase in fuel consumption, the reduction in petrol usage is not 10% but 8.9% to 7.3% (Table 6-14).

As can be seen from the works cited in Appendix C, research in this area agrees with results presented and indicates that fuel economy loss experienced as a result of ethanol use agrees closely with the theoretical prediction for fuel energy loss.

TABLE 6-14: PERCENTAGE SAVING IN PETROL AS A RESULT OF USING E10

	City Cycle % Savings	Highway Cycle % Savings	Combined(55/45) % Savings
ULP	7.3	7.7	7.5
LP	8.9	7.8	8.5

6.5 Conclusion

A fuel consumption increase of 2.8% from neat ULP to E10 ULP appears consistent with both the theoretical energy loss of approximately 3% and other fuel consumption studies conducted in the US. The 1.6% fuel consumption increase, from neat LP to E10 LP, can be explained by the enleaning effect that E10 has on older vehicle technology (as discussed in section 1.1.2 Stoichiometric Requirement (Enleanment)).

While fuel consumption has increased on E10, there is still a net saving on the consumption of petrol; 8.5% for LP and 7.5% for ULP.

7 VEHICLE DRIVABILITY

To assess the drivability of vehicles running on E10, three evaluations were sought:

- Observations and comments from general users at BOGAS service stations;
- Observation and comments from experienced drivers recommended by NRMA and IAME;
- Formal testing under specific climatic conditions by experienced drivers drawn from FCAI and NRMA.

7.1 Background

Factors that influence vehicle drivability are engine design/technology, engine calibration, fuel characteristics and ambient air conditions.

Performance problems can occur for a variety of reasons, and tracing performance problems to a specific cause is difficult, and often impossible. Some of the potential engine performance problems resulting from fuel-related sources include:

- starting difficulty;
- stalling;
- hesitation during acceleration;
- rough engine operation;
- vapour lock;
- plugged fuel filters; and,
- fouled spark plugs;

While the fuel characteristics of E10 are similar to neat petrol they are not identical, differences include:

- volatility;
- stoichiometric requirement;
- motor octane;
- latent heat of vaporisation; and,
- susceptibility to water contamination.

7.1.1 Volatility

As fuel is metered in liquid form and then vaporised/atomised before/while entering the cylinders, volatility is an important characteristic of the fuel used. The effects of volatility on vehicle drivability performance are listed in Table 7-1.

If the fuel volatility is too low, drivability problems such as poor cold starts, poor warm up drivability, as well as unequal distribution of fuel to the cylinders in carburetted vehicles will result.

Fuel which has high volatility, may vaporise (boil) in fuel pumps, lines or carburettors at high operating temperatures. The result is a decrease in fuel flow, or vapour lock, leading to loss of power, rough engine operation or even complete engine stoppage.

TABLE 7-1: EFFECTS OF VOLATILITY ON VEHICLE PERFORMANCE{2}

Volatility Too Low	Volatility Too High
Poor cold start	Hot Drivability problems
Poor warm-up performance	Vapour lock
Poor cool weather drivability	
Unequal fuel distribution in carburetted vehicles	

Petrol is a complex mixture of hundreds of hydrocarbons. The mixture of hydrocarbons in petrol determines its physical properties and engine performance characteristics. Ethanol is a pure compound containing carbon, hydrogen and oxygen, and its introduction will change many of the characteristics of the base petrol.

The addition of ethanol changes the volatility of the base petrol. Figure 7-1 shows the vapour pressure change of the ethanol/neat petrol blend with ethanol concentration. It can be seen that maximum vapour pressure of the blend is achieved at relatively low ethanol concentrations (3 to 15% v/v) peaking at about 5-10%. Figure 7-2 depicts typical distillation curves, one of neat petrol and the other of E10. The vapour pressure change with temperature is shown in Figure 7-3. The base fuel for E10 is the same as the neat petrol shown and it is evident that the addition of 10% ethanol to the base neat petrol has altered the midrange volatility of the base fuel (neat petrol).

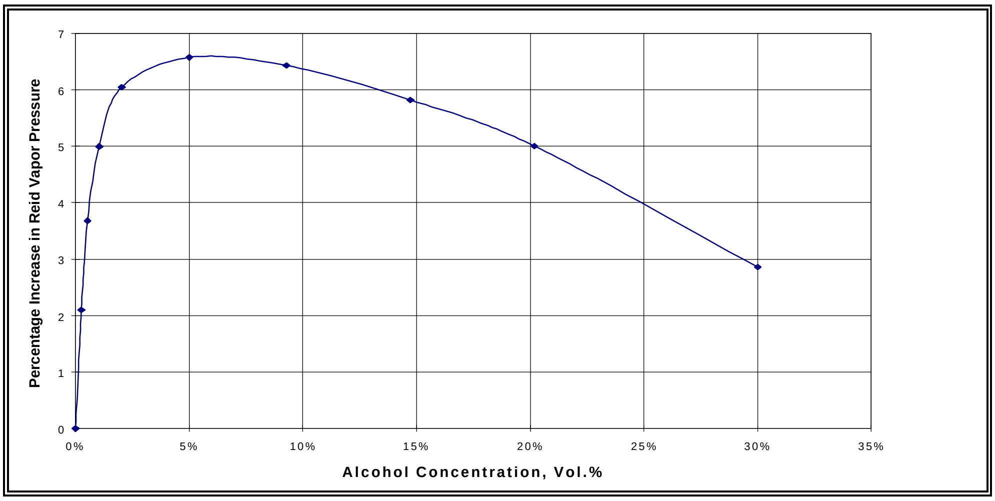

FIGURE 7-1: INCREASE IN VAPOUR PRESSURE VS ETHANOL CONCENTRATION {32}

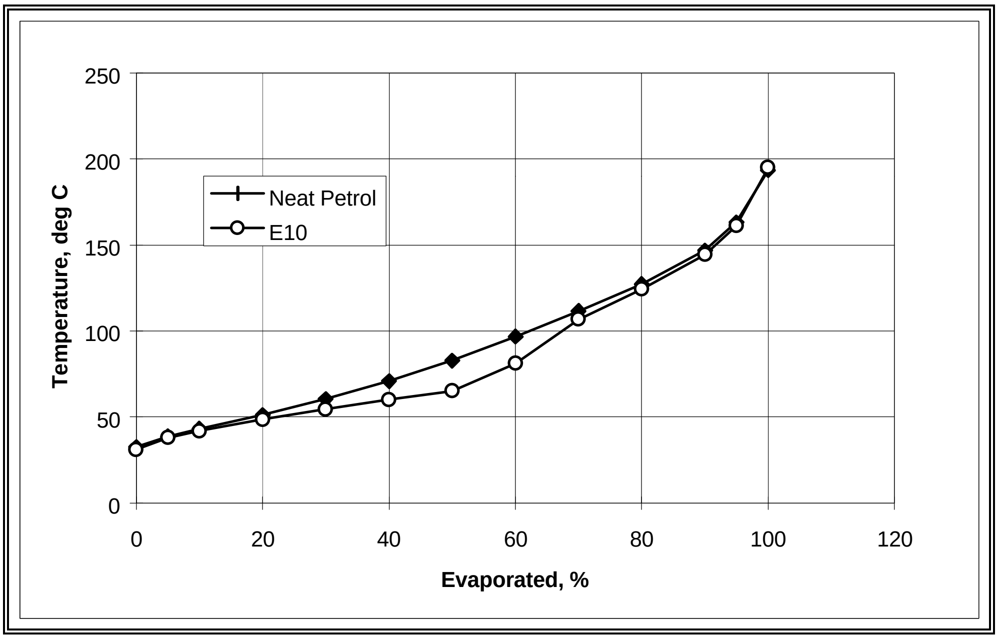

FIGURE 7-2: TYPICAL DISTILLATION CURVES{11}

Certain parts of the distillation curve are associated with drivability characteristics. For instance the 10% evaporated temperature must be low enough to provide easy cold starting but high enough to reduce vapour lock and hot drivability problems. The 50% evaporated temperature should be low enough to provide acceptable cool drivability and warm-up but not so low as to promote hot drivability and vapour lock problems.

Accordingly, and based on this and the comparison of the neat petrol and E10 distillation (Figure 7-2), one would expect similar starting characteristic between neat petrol and E10, better warm-up and cool weather drivability from E10 but with an increased possibility of hot weather and vapour lock drivability problems.

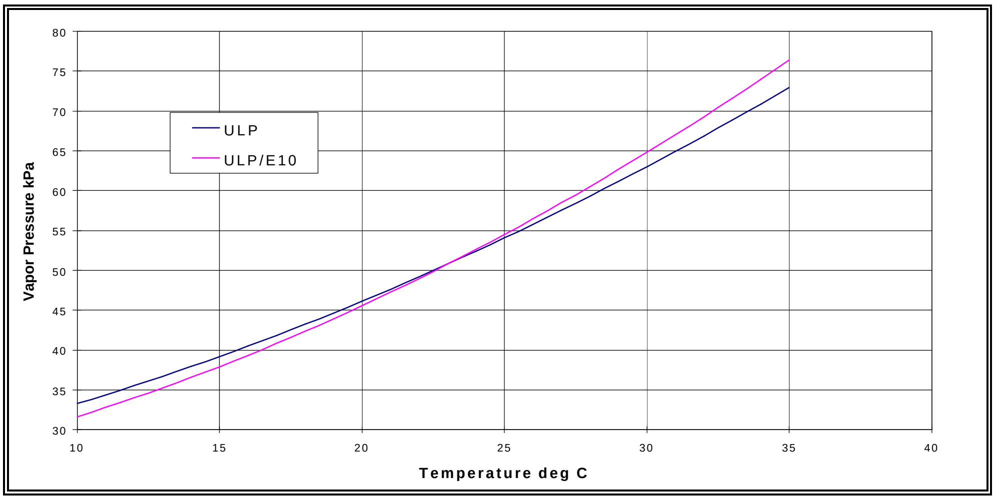

FIGURE 7-3: VAPOUR PRESSURE VS TEMPERATURE{11}

7.1.2 Stoichiometric Requirement (Enleanment)

Neat petrols are mixtures of many hydrocarbon compounds that consist of hydrogen and carbon whereas ethanol consists of hydrogen, carbon and oxygen. The addition of ethanol, and hence oxygen, to a hydrocarbon-only fuel results in a change in the proportion of fuel to air that is required to provide complete combustion of the fuel to water and carbon dioxide. The exact air-to-fuel ratio needed for complete combustion of neat petrol is called its "stoichiometric air-fuel ratio" and is about 14.7 grams of air to one gram of fuel (14.7:1) for neat petrol.

$$\boxed{\text{Fuel + Air(Oxygen + Nitrogen)} \Rightarrow CO_2 + H_2O + N_2}$$

FIGURE 7-4: GENERALISED COMBUSTION EQUATION

For E10, less air is required because oxygen is contained in the fuel and some of the hydrocarbons have been displaced. For example, an ethanol/petrol blend containing 3.5% w/w oxygen (E10) would require 14.1 grams of air per gram of fuel (based on ethanol A/F ratio of 9 and neat petrol A/F of 14.7){5}. The effect of this type of fuel change on an engine is called "enleanment."

The air-fuel ratio requirement is an important factor in the design of engines and fuel metering controls. Vehicles that use some form of "closed loop" fuel system that continuously monitors and adjusts the amount of fuel delivered to the engine to maintain the stoichiometric air-fuel ratio do not experience any enleanment effects from oxygenated fuels such as E10{4}. These vehicles have an operation range that accommodates oxygenated fuels when operating in the "closed loop" mode.

During cold start and at full throttle, these systems operate in an "open loop" mode that provides a rich fuel mixture that is necessary for those conditions. In the rich mixture, "open loop" mode, vehicles do experience some enleanment effects from E10.

Vehicles that operate open loop system, such as older carburetted models, provide the same ratio of air to fuel for both E10 and neat petrol and do not automatically compensate for changes in fuel oxygen content. As a result, the air-fuel mixture is enleaned when oxygenated fuel is used and some change in engine operation is possible. In general, the dynamic operating range of most engine air-fuel ratios is large relative to the small change caused by enleanment and the change is normally imperceptible to the operator.

Vehicle drivability characteristics are not normally affected by switching between E10 and neat petrols, whether or not a vehicle is using a "closed loop" fuel control system. In a situation where a vehicle is not properly adjusted and is operating in a "too lean" condition or where the original engine design was to a "lean burn" philosophy, switching to a fuel with increased oxygen content would increase the risk of a drivability problem. The symptom most likely to appear in this situation is a hesitation during acceleration. A compromise idle and acceleration mixture adjustment should eliminate any drivability problems whether operating on neat petrol or E10 ethanol/petrol blend.

Whilst one can identify such differences between E10 and neat petrol, and thereby postulate the resultant effect on the drivability performance, the final say is best achieved by actual comparative drivability tests on the two fuels and public perception of the fuel.

7.1.3 Road Octane

“Knocking” is the sound of abnormal combustion. Normal combustion in a spark ignition engine is initiated by a spark. The flame front fans out from the spark plug and travels across the combustion chamber rapidly and smoothly until all the fuel is consumed. When combustion is abnormal, the last part of the unburned mixture auto ignites and burns rapidly causing a rapid increase in pressure within the cylinder which creates a characteristic knocking sound. The octane rating of a fuel is measured in a CFR engine under two different operating conditions that determine the "research" (RON) and "motor" (MON) octane numbers for the fuel. The "motor" method differs from the "research" method by using preheated mixtures, higher engine speeds and variable ignition timing thus placing more severe demands on the fuel being tested. MON values are lower than for RON.

Because RON and MON are measured in a single cylinder laboratory engine, they do not completely predict antiknock performance in multi-cylinder engines. There is a procedure for measuring Road Octane Number (RdON), however a good approximation is (RON+MON)/2 also known as the Anti Knock Index.

The octane rating of a fuel must be higher than the minimum "road" octane requirement of the engine in order to avoid damage to engine components. It should be noted that the "high speed" knock, although not necessarily audible, leads to significantly more severe engine damage than the possibly more audible "low speed" knock.

Ethanol has blending octane numbers in petrol in the order of 120-135 BRON and 95-106 BMON (Blending Research and Motor Octane Numbers respectively). These values can vary considerably with the quality of the petrol with which ethanol is blended. The Australian Institute of Petroleum reports much lower blending octane numbers, 105-120 BRON and 90-95 BMON. Caltex Oil

Australia advised that in their experience with ethanol blends, ethanol gave a positive contribution to blend RON but its contribution to MON varied from positive to negative, tending to confirm the low numbers given by AIP{35}.

The 10% v/v ethanol/petrol test fuels used in the emission and drivability tests indicate a blending octane number for ethanol of 125 for BRON and 96 for BMON.

7.1.4 Latent heat of vaporisation

Cold start and drivability can be impaired by ethanol blends due to ethanol's high latent heat of vaporisation.

Cold starting may be impaired by the increased enthalpy of evaporation of ethanol and additional enrichment may be required. Drivability with petrol can be correlated to a combination of the distillation points, particularly the temperature (T50) at which 50% is distilled. Addition of ethanol will tend to depress T50 which would indicate an improved drivability with petrol. However this potential improvement is offset in blends by ethanol's high latent heat of vaporisation, suggesting the conventional correlation does not hold with blends. Drivability problems will tend to be more common in carburettor vehicles without closed loop oxygen sensors.

7.1.5 Susceptibility to Water Contamination

The polarity of ethanol causes the blend to absorb water. An excess of water in the blend results in the separation of an ethanol/water rich phase causing misfire and stalling.

Water generally is introduced into the blend through the water contained in the ethanol after manufacture or absorbed by the ethanol or blend during storage and transportation. The quantity of water which can be tolerated will depend on:

- The composition of the petrol, particularly aromatic and olefin contents.
- Temperature - less water can be tolerated at lower temperatures (Figure 7-5).
- Ethanol content - the higher the ethanol content, the more water can be tolerated.

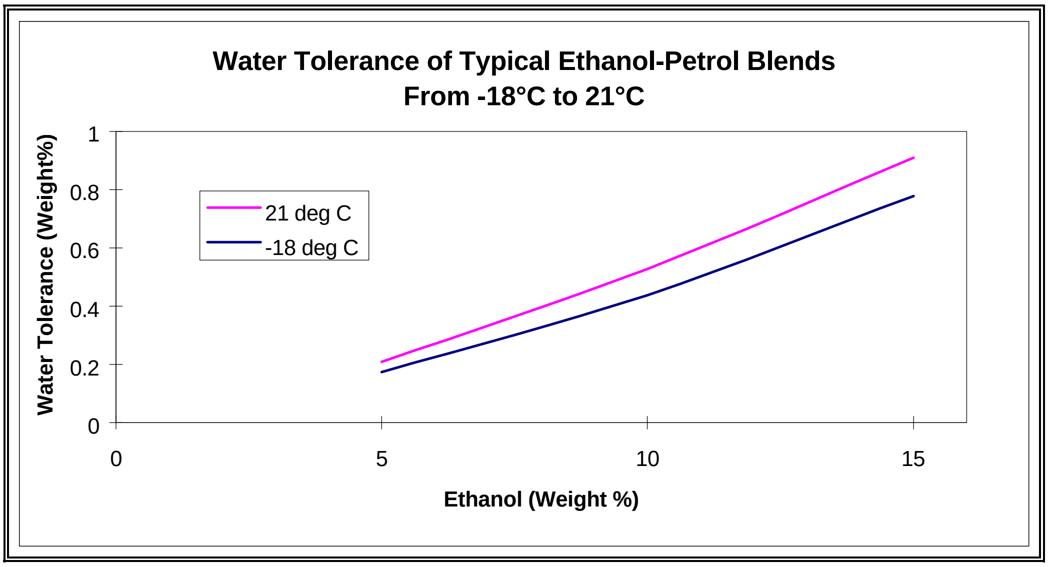

FIGURE 7-5: WATER TOLERANCE

7.2 Public Observations and Comments

Throughout this project there was a great deal of public interaction in the course of sourcing vehicles for the emission testing phase. This enabled gathering from the experience of BOGAS customers a general public perception of 10% v/v ethanol/petrol blend.

It may have gone without saying that BOGAS customers must be satisfied with E10 otherwise they would not continue using the product. However, from the public contact, it became apparent that public's awareness of the fuel they are using varies:

- Some users were oblivious to the fact that BOGAS fuel contained ethanol, even though the BOGAS bowsers advertised that fact. These people perceived no vehicle performance difference.

- The majority of customers, whilst aware of the fact that ethanol is contained in the BOGAS fuel they purchase, also state that they perceive no difference in the running of their vehicles. Just as for any other service station, they use BOGAS as a matter of convenience and price.

- There are, however, some users who assert that they get better fuel economy, and/or their vehicle runs smoother, using E10.

While the general public are not trained nor sufficiently experienced to notice subtle differences in vehicle performance, their perception and acceptance of E10 indicates satisfactory performance.

7.3 Experienced Drivers Observations and Comments

Throughout the emission testing phase, three experienced drivers were employed to ferry the test vehicles to and from the Central Coast to the NRMA facility in Villawood Sydney.

Vehicles were collected from the Central Coast and driven to NRMA. The fuel type on collection was assumed to be E10, due to the selection process stipulating that E10 was the majority of the fuel used by the vehicle. After completion of testing the vehicles were fuelled with E10 for the return journey to the Central Coast. It can be assumed therefore that the ferry drivers would be experiencing the drivability of the vehicles on E10 blend.

The typical ferry route involved both urban and highway driving conditions, placing the test vehicles under a range of operating conditions for the driver to experience.

At the completion of the emission testing phase the drivers were asked to comment on the vehicles they drove throughout the period in regard to drivability performance. All the drivers reported that no detectable difference was noted while running the vehicles on E10. While a comparative observation was not made between the two fuels, the drivers did not raise any concern over the performance of the vehicles they drove on E10.

7.4 Formal Drivability Testing

Formal testing of vehicle drivability is broken up into two main performance areas, as outlined in SAE J312, “Automotive Gasolines”. These are:

- Cold Weather
  - Cold Start;
  - Cold drivability; and,
  - Carburettor Icing.
- Hot Weather
  - Hot Start
  - Hot Drivability; and
  - Vapour Lock.

7.4.1 Drivability Grading

The main factors determining vehicle drivability are characterised in Table 7-2 below:

TABLE 7-2: CLASSIFICATION OF DRIVABILITY FACTORS{6}

Startability	The ease of engine starting
Idle Stability	The degree of smoothness of the engine at idle
Stalling	Engine failure to continue running
Stumble	A short, sharp reduction in acceleration
Hesitation	Temporary delay in response to the throttle being opened
Surging	Fluctuation of engine power output while under steady load

The above drivability phenomena are judged throughout the cold and hot test cycles and are subjectively graded as per Table 7-3.

TABLE 7-3: DRIVABILITY GRADING

5	Excellent	No problem, Insensible
4	Good	Problem hardly sensed
3	Average	Not without problem
2	Poor	Problem distinctly sensed
1	Extremely poor	Uncomfortable

The grade for each test vehicle's performance is recorded on data sheets for cold and hot drivability.

The drivability rating is the sum of the awarded points; the higher the rating the better the performance. For rating cold drivability, a weighting factor is applied before summing, as is explained in the next section.

7.4.2 Cold-Start & Cold Drivability

The cold weather trial sought a comparison of vehicle drivability under cold climate conditions on E10 as against neat petrol.

The different physical properties of E10 compared with petrol, such as oxygen content and vapour pressure variances, may be anticipated due to their effects on A/F ratio (lean-off) and fuel vaporisation to affect drivability parameters. The aim of the trial was to ascertain whether these differences in physical properties translate to an adverse effect on the Cold Start and Cold Drivability of vehicles types now commonly in public use.

7.4.2.1 Protocol

The test protocol adopted for evaluating Cold-Start Drivability was based on Cold-Start Drivability procedures from SAE{8}, Co-ordinating Research Council (CRC){7}, and Federal Chamber of Automotive Industries (FCAI){12}.

The trial involved testing one vehicle per day, with the same driver evaluating all vehicles.

The test procedure is outlined as follows:

- Test Vehicle preparation - The mechanical and electrical system condition of each test vehicle was prepared and tested as described in Appendix A. Engine oil was changed to a grade recommended by the vehicle manufacturer for operation at low ambient conditions;

- Minimum of a 12 hour cold soak - The vehicle was placed in a refrigerated container and cooled to -2°C over a 12 hr period;

- Cold Startability evaluation - Evaluating cold startability involved assessing the start time of the test vehicle following the 12 hour cold soak. The practice used for starting each engine was taken from the cold start procedure recommended by the vehicle's operating manual. The total cranking time was recorded, then 5 seconds after starting, idle rpm and idle vacuum were also recorded; and,

- Cold Drivability evaluation - The cold drivability cycle, carried out over a distance of 1 kilometre, involved accelerating and decelerating within a speed range of 0-60 km/hr. Over this period the vehicle's performance was noted and at the end of the cycle it was brought to a standstill and idled. For each test, the drivability cycle is carried out four times.

Figure 4 shows the drivability cycle for the test vehicles. It should be noted that due to differences in acceleration, distances travelled for each part of the cycle will vary from vehicle to vehicle.

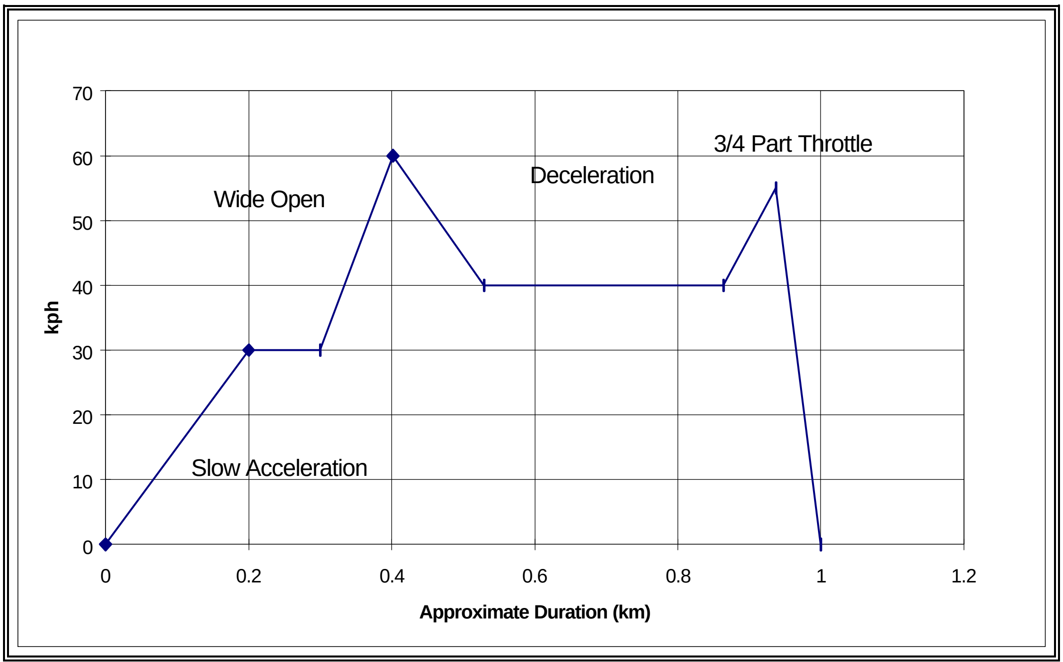

FIGURE 7-6: COLD DRIVABILITY TEST CYCLE

Throughout each cycle, a vehicle's drivability is graded as described in Table 7-3. Of the four cycles comprising a test, each has an additional weighting factor applied to its grades as follows:

- First cycle 9
- Second cycle 5
- Third cycle 2
- Fourth cycle 1

These declining weights compensate for the vehicle's operating temperatures increasing throughout the test. After the relevant weighting factor has been applied to the grading of each phenomenon, they are totalled for the 4 drivability cycles. The total constitutes the test result for a particular fuel.

Note: No specific driving conditions were set to evaluate carburettor icing and no such icing was noted nor expected.

7.4.2.2 Test Fleet

For the cold weather trial, a test fleet of four vehicles, see Table 7-4, were selected as a representative cross section of commonly available vehicles.

TABLE 7-4: COLD WEATHER TEST FLEET

Make	Model	Year	Petrol Type	Fuel System	Cylinders	Trans
Ford	Falcon	1985	leaded	carburettor	6	Man. 4
Ford	Laser	1994	unleaded	carburettor	4	Man. 5
Toyota*	Lexcen*	1995	unleaded	fuel injection	6	Auto. 4
Mitsubishi	Magna	1995	unleaded	fuel injection	4	Auto. 4

*Holden Commodore

7.4.2.3 Trial Conditions

The problems of stumble, stalling, hesitation, and surge can occur at any ambient temperature, though their severity and frequency increase with the lower ambient temperatures associated with cold weather. Cold weather trial conditions were designed to simulate Australian winter conditions.

The SAE J1635 "Cold Start and Driveability" states that the procedure may be carried out at any ambient temperature. However, as this trial is testing drivability for winter conditions, an ambient air temperature between -1°C° and 13°C was chosen. This temperature range is based on CRC testing practices (2°C to 10°C){7}, and carburettor icing promotion (-1°C to 13°C){6}.

Testing was carried out at Workcover's Occupational Safety Centre, Londonderry, and the surrounding roads. Ambient air temperatures of -2°C to 2°C were expected at the time of testing, sunrise, for the month July{9}.

It is CRC experience that the "soak" temperature is more influential than the "run" temperature in terms of vehicle drivability performance. CRC recommends that the soak temperature of the test vehicle be within a few degrees of the run temperatures{7}.

To achieve desirable and constant soak temperature, a refrigerated cargo container was used to condition the test vehicle. This eliminated weather unpredictability, ensured a constant starting condition, and reduced the influence of ambient air temperatures at the time of testing.

The coldroom temperature was set at -8 °C for air supply and -4.25 °C for the return air. These temperatures were experimented with before actual testing and achieved an engine block temperature of between -3 °C and -2°C after a twelve-hour cold soak.

As a result of using a coldroom the actual ambient air temperatures at the time of test raised little concern, providing the range of -1 to 13 °C was met, as the cold soak had significantly greater influence over the drivability.

7.4.2.4 Results/Discussion

The data sheets, with driver's comments, are located in Appendix A. A summary and review of the data collected follows below.

7.4.2.4.1 Test Fuel

For each test vehicle, there was prepared a supply of both petrol and E10 in both 10 litre and 20 litre containers. These were stored under refrigerated conditions until needed for testing.

At the time of preparation and again at the time of filling the test vehicle, fuel samples were taken. On preparation, the neat petrol was analysed to ensure that it represented a typical fuel for the winter months, FVI 115-120. Again at the time of filling a test vehicle, the fuels were sampled to determine whether storage had affected the fuel's properties as previously analysed at the time of preparation.

Figure 7-7 shows the results of the fuel analysis. Note that the FVI for the neat petrol is scattered compared with the E10 FVI, despite both fuels having been prepared from the same batch of base fuel at the same time, stored in the same type of containers and under the same conditions. The procedure used ensured no opportunity of contamination of the neat petrol with ethanol. If there had been any problem with preparation or storage, scattering of the E10 FVI would also have been expected.

One possible explanation, not proven, suggests a problem with the procedure/technique used to analyse the fuel samples. Small traces of ethanol can influence FVI; any contamination of analysis apparatus with E10, would cause a skewing of the FVI data for the respective neat petrol sample.

It is generally found that, for E10, FVI is usually 17-18 points higher than the base fuel from which it was blended{19}{20}{21}. It can also be assumed, that the E10 FVI analyses are reliable due to their relative stability. Given that the average E10 FVI is 132, a base fuel FVI 115 (17 points lower) is expected. This is at the lower limit of FVI values for the refinery production at this (winter) time of the year.

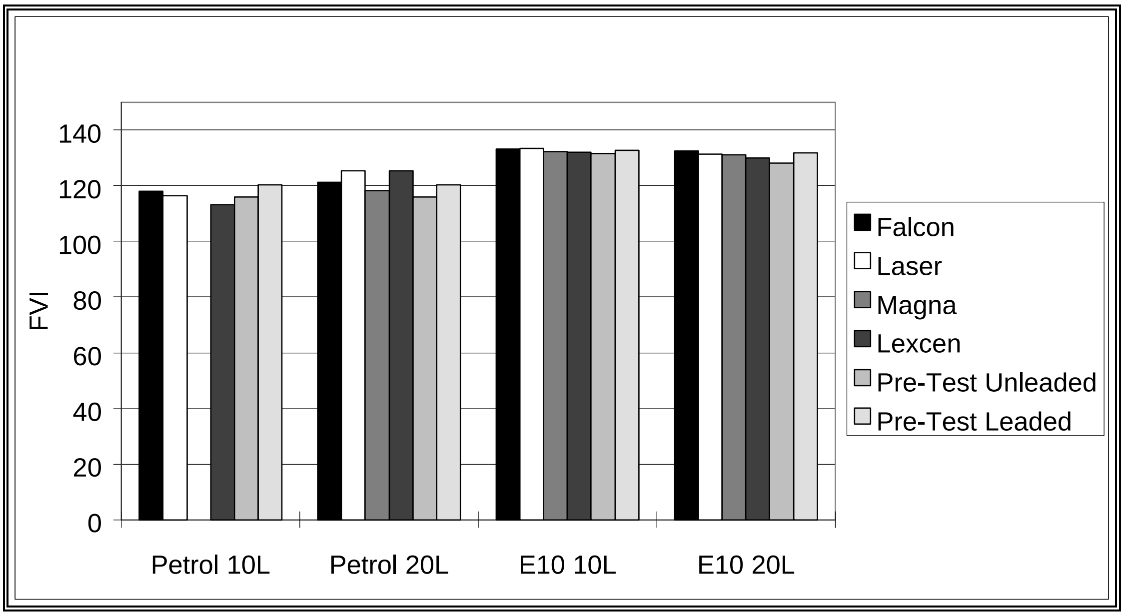

FIGURE 7-7: FVI ANALYSIS OF COLD WEATHER TEST FUEL

7.4.2.4.2 Test Results

Toyota Lexcen (= Holden Commodore)

The two test days on the Lexcen had similar conditions, with the ambient temperatures being 4.5°C and 3.5°C for petrol and E10 respectively, (see Figure 7-14).

As between fuels, there was no detectable difference in starting the Lexcen, with both engine starts having a cranking time of 2 seconds, (Figure 7-15).

All drive cycles for the Lexcen on petrol and E10 were stated as running impeccably, with no penalty points being given to either fuel.

Acceleration times for the 30-60 Km/h are all reasonable (Figure 7-8). For the first cycle the acceleration time is slightly longer for both fuels. The other three cycles were similar, varying between 2.5-3.0 seconds, see Figure 7-8.

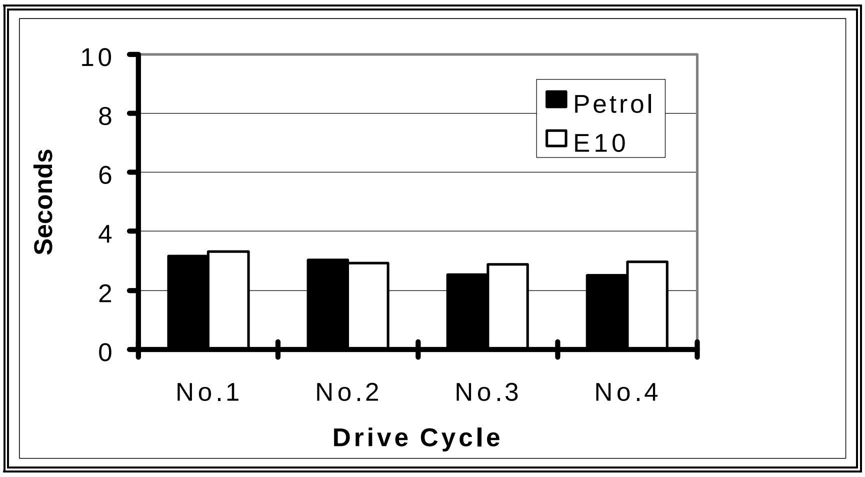

FIGURE 7-8: LEXCEN ACCELERATION TIMES

Magna

Ambient temperatures during the Magna tests were 6 °C for petrol and 12 °C for E10, (see Figure 7-14). While the difference in temperatures is not ideal for the comparison, any inherent problem would have been present in the respective first cycles due to the cold soak and the bias that it has over testing. Given cold soak temperature consistency and its predominant influence over test results, and given the weighting applied to the first cycle, these variations in ambient temperature have minimal influence on the comparison.

There was no detectable difference between fuels in starting of the Magna with both engine starts having a cranking time of 2 seconds, see Figure 7-15.

The Magna had no problems detected during the drive cycles for each fuel with no penalty points being awarded.

Laser

On the test days ambient temperatures were 4 °C and 7.5 °C for petrol and E10 respectively (see Figure 7-14).

Engine cranking time on petrol was 9 seconds but only 2 seconds on E10, (see Figure 7-15). The battery state appears not to be factor in this discrepancy of cranking time since, prior to both tests, its voltage, specific gravity and soak temperature were all similar. The difference of 3.5 °C in the ambient air temperature between the two tests is also most unlikely to have influenced the results.

On both fuels the Laser experienced problems over the drive cycle. The drivability rating points are shown in Figure 7-10.

Note that in Figure 7-11 the first cycle acceleration on neat petrol was extrapolated from the actual 30-50 kph to approximate that for 30-60 kph. This adjustment to the result was necessary because of a traffic impediment during the test.

From the starting times and drivability rating points it would appear that the Laser performed marginally better on E10 than on neat petrol.

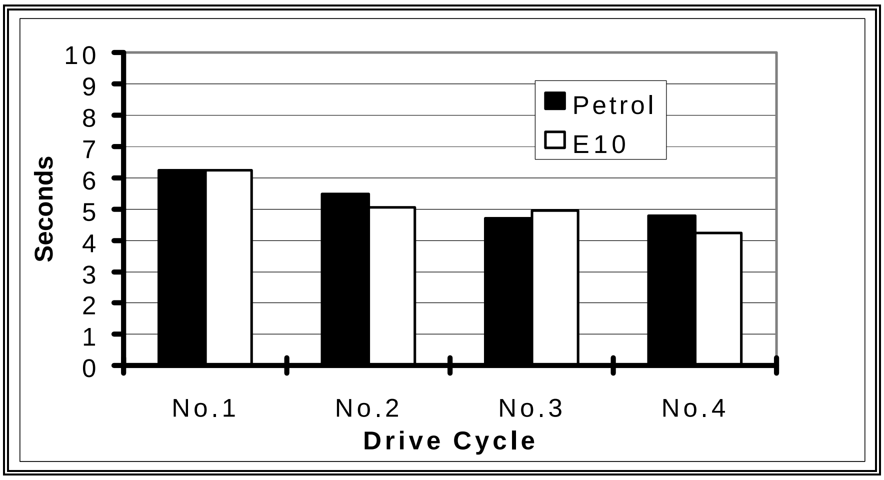

FIGURE 7-9: MAGNA ACCELERATION TIMES

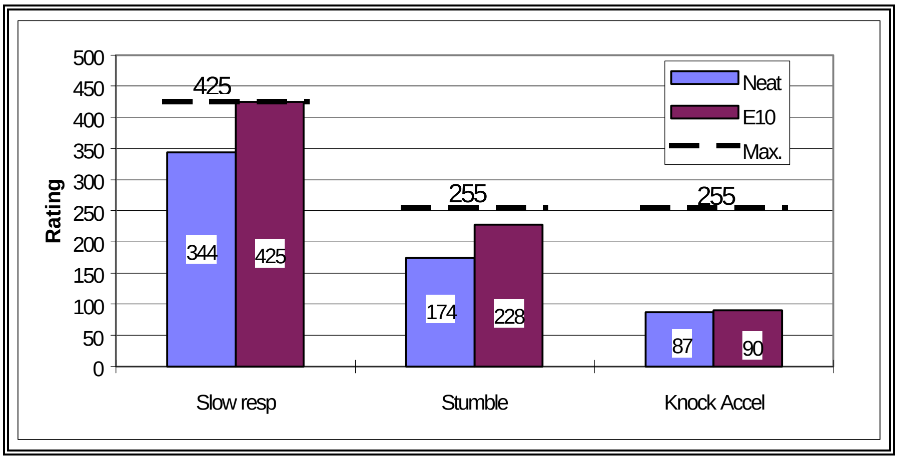

FIGURE 7-10: LASER DRIVABILITY RATING

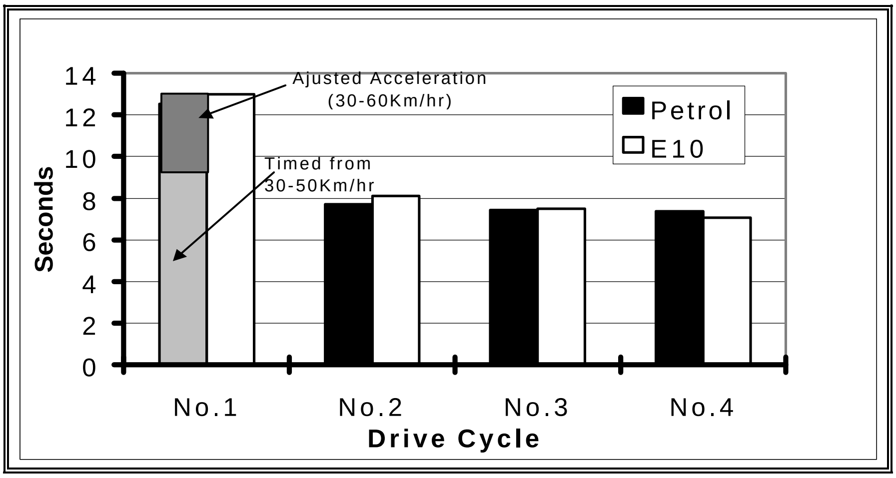

FIGURE 7-11: LASER ACCELERATION TIMES

Falcon

For the Falcon the two test days had similar ambient air temperatures being 12.5 °C for petrol and 11 °C for E10, (see Figure 7-14).

Engine cranking times for the Falcon were 1 second for petrol and 2 seconds E10, (see Figure 7-15). The difference is considered insignificant in relation to any performance difference between the two fuels.

On both fuels the Falcon experienced problems while performing the drive cycle. The drivability rating points are shown in Figure 7-12.

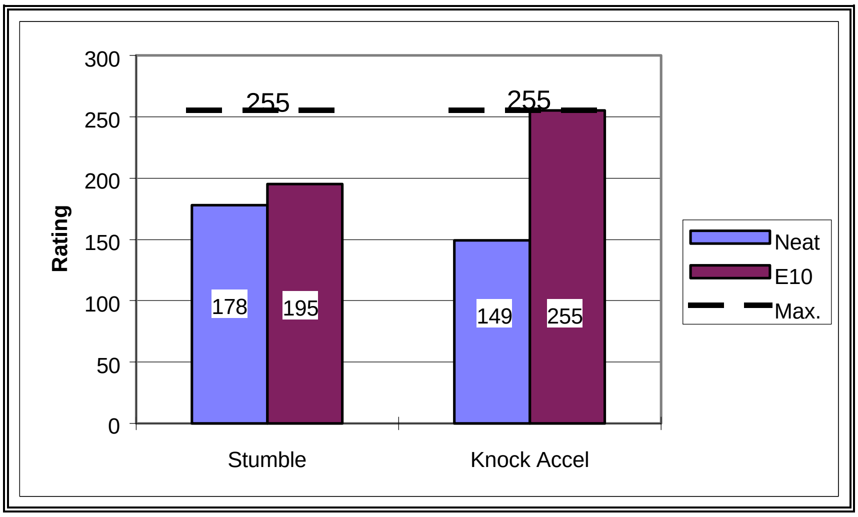

FIGURE 7-12: FALCON DRIVABILITY RATING

The acceleration times for the Falcon, (Figure 7-13), show no sign of detectable performance difference between the two fuels.

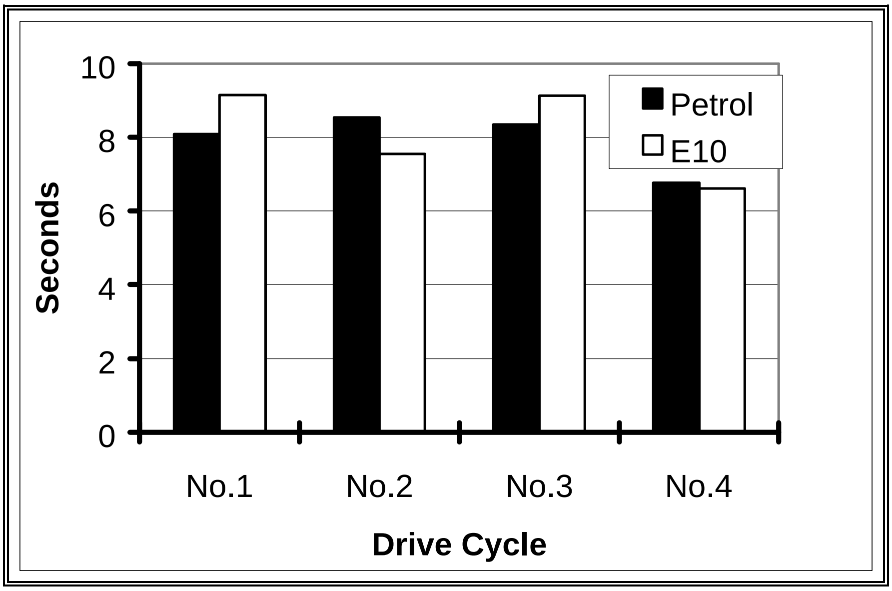

FIGURE 7-13: FALCON ACCELERATION TIMES

Acceleration and cranking times reflect no discernible performance difference between the two fuels. The drivability rating points, however, suggest that the Falcon was less susceptible to stumble and knock when running on E10. This difference could be attributed to the octane rating of E10 being higher than neat petrol.

7.4.2.4.3 General

On all test days during the trial the range of the ambient air temperatures fell within maximum and minimum temperatures prescribed for Cold Drivability evaluations (Figure 7-14). Also noted are the respective soak temperatures which were maintained constant within 2°C by use of the cold room for vehicle preconditioning.

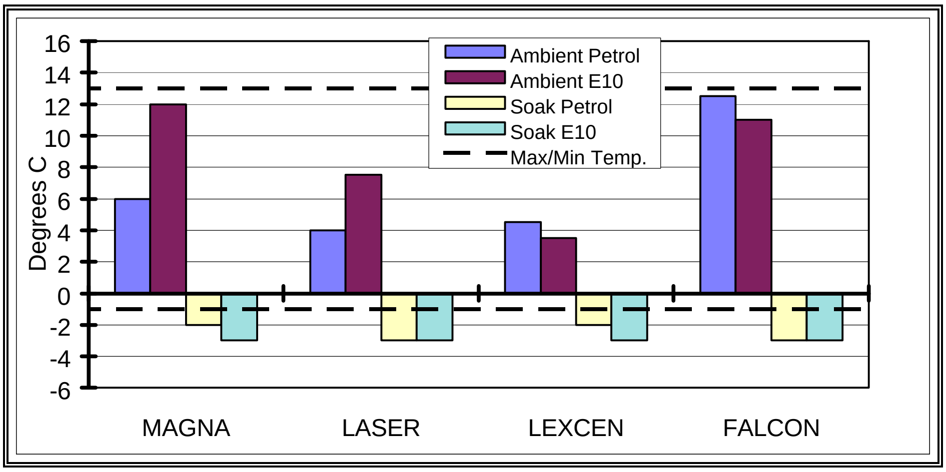

FIGURE 7-14: AMBIENT SOAK TEMPERATURES ON TESTING

Apart from the Laser when tested on neat petrol, cranking times (Figure 7-15), are all reasonable. In the case of the Laser, not only were soak temperatures recorded as being the same but the battery state was also found similar for both fuels.

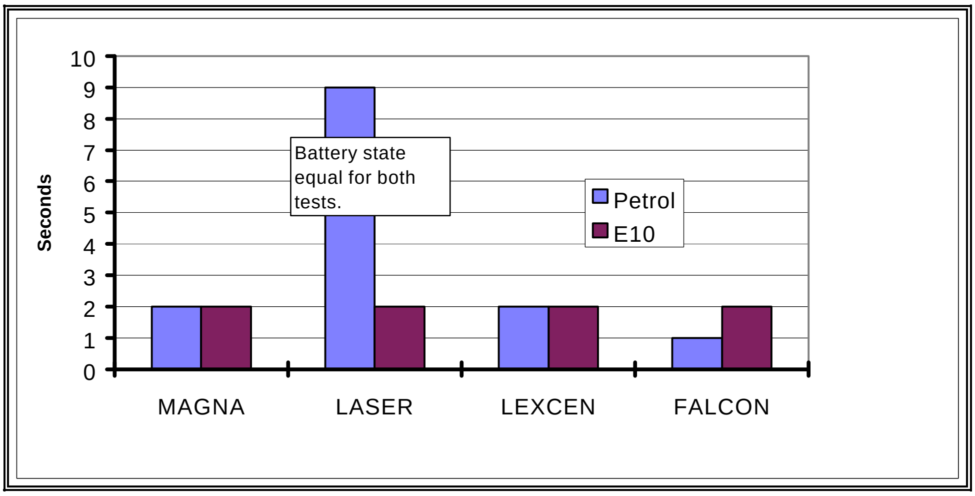

FIGURE 7-15: COLD-START CRANKING TIME

7.4.2.5 Conclusion

The Lexcen and Magna, both fuel injected vehicles, exhibited no discernible performance differences running on E10 when compared with neat petrol.

Both the carburetted vehicles however experienced performance problems on both fuels. E10 performed marginally better than neat petrol but, to all intents and purposes, the difference to an everyday driver would not be noticed.

7.4.3 Hot Start, Hot Drivability and Vapour Lock - Broken Hill

The purpose of this trial was to evaluate the performance characteristics of 10% v/v ethanol petrol blend as compared to those of neat petrol under hot climate conditions.

Given the differences as between E10 and neat petrol, in fuel properties such as vapour pressure, oxygen content, and combustion temperature, drivability characteristics need to be compared in assessing whether E10 has any effect on vehicle performance.

The hot drivability evaluation consists of two main parts. The first, Hot Drive (HD), consists of driving the test vehicle through a range of accelerations and decelerations, assessing its performance characteristics for:

- Idling/Throttle response — Lean-off of A/F ratio
- Warm-up drivability — Lean-off of A/F ratio
- Acceleration — Lean-off of A/F ratio
- Steady state surge — Inlet quenching &/or A/F ratio lean-off

The second part, Hot Fuel Handling (HFH), is primarily designed to determine the vehicle's:

- Tendency to form vapour lock — Vapour Pressure

To minimise variation in subjective evaluation of drivability, all the Hot Drive and Hot Fuel Handling tests were carried out and rated by an FCAI representative.

7.4.3.1 Protocol

The hot drivability protocol used for the trial was provided by FCAI. The protocol is designed to evaluate drivability in a vehicle placed under specific demands/criteria when in a hot climate environment.

Prior to the commencement of any testing, each test vehicle was checked for:

- road worthiness;
- tyre pressures; and
- state of engine tune.

The fuel filter on one of the test vehicles (Mitsubishi Magna 1985) was replaced. The others were known to have been replaced shortly before commencement of the tests. The test procedure is outlined as follows:

- Warm-up - to warm the engine (and drive train), the test vehicle is driven over 5 km at either 100 km/h with 4th speed (or range D) or, in case road conditions make this impossible, at 70 km/h with 3rd speed (or range 2).

♦ Hot Drive - the test procedure follows the data sheets, provided by FCAI, as shown in Appendix B. The test vehicle’s performance is critiqued over a range of speeds with varying types accelerations, decelerations and steady state drives designed to localise problems in a vehicle's performance such as:

~ slow throttle response;
~ stumble;
~ surge;
~ backfire;
~ jerk;
~ shock;
~ knock; etc.

♦ Hot Fuel Handling - this protocol details the test method for evaluating a vehicle's vapour lock resistance. The specification is applicable to an environmental chamber test as well as a road test.

The Hot Fuel Handling Test Cycle, Figure 7-16, involves:

~ A preliminary 40 minute drive at 140 kph to heat stress the test vehicle;
~ The test vehicle is then placed in a wind shelter for a 15 minute dead soak, engine stopped;
~ On completing the 15 minute soak, the vehicle performs a timed acceleration from 0 to 120 kph under WOT, recorded as T1, then brought to a stop and idled for 5 minutes;
~ Another WOT acceleration to 120 kph is then timed and recorded as T2.
~ After again reaching 120 kph, the vehicle is slowed to and held at a constant 60 kph over 10 minutes for stabilising before a third and final WOT acceleration from 0 to 120 kph is performed and the time recorded as T*.

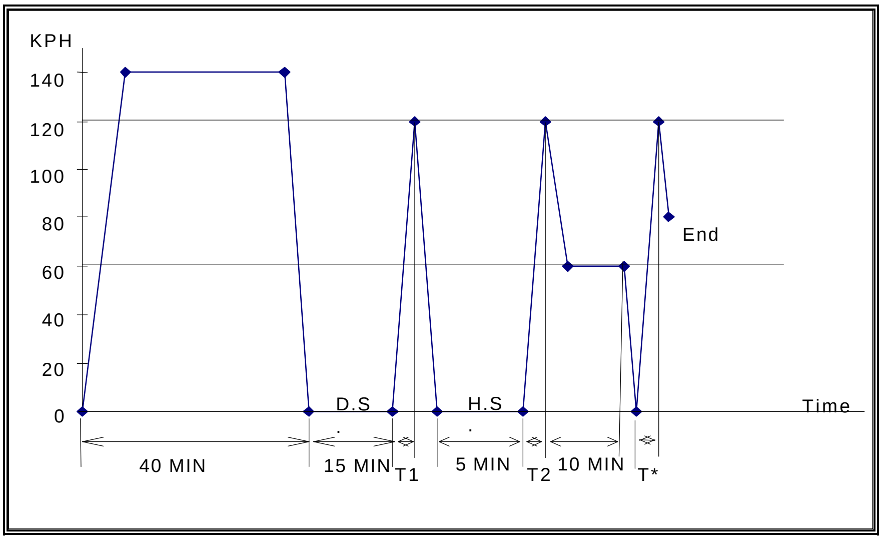

FIGURE 7-16: HOT FUEL HANDLING TEST CYCLE

- Vapour lock resistance is evaluated principally by reference to the objective measurements of both T1/T* and T2/T*. The value T* is the acceleration time recorded for the test vehicle in a stabilised (non-stressed) state; T1 and T2 are the acceleration times recorded for the vehicle whilst heat stressed following the preliminary 40 minute drive at 140 kph. A vapour lock problem is considered evident when:
  - ~ T1/T* and T2/T* are greater than 1.5;
  - ~ Vehicle slows during the WOT acceleration to 120 km/hr; and,
  - ~ Surge rating for the drive cycle is less than 3^- - based on a scale of 1 to 5 (worst to best - Refer Table 7-3).

7.4.3.2 Test Fleet

Four vehicles were used in the trial. See Table 7-5 for vehicle details. Three of the vehicles were rented and their condition was average for the make, model and year. The fourth vehicle (Mitsubishi Magna 1995) was one of the project's courtesy cars and again its condition was typical of the model and year.

TABLE 7-5: HOT WEATHER TEST FLEET

Make	Model	Compliance Year	Cylinders & Displacement	Fuel	Fuel Delivery	Trans
Mitsubishi	Magna	1985	4 2.6L	LP	Carb.	3 Auto.
Ford	Falcon XF Wagon	1986	6 3.3L	ULP	Carb.	4 Man.
Mitsubishi	Magna	1995	4 2.6L	ULP	EFI	4 Auto.
Toyota	Lexcen	1995	6 3.8L	ULP	EFI	4 Auto.

For each part of the hot drivability evaluation the test vehicle was first drained of all fuel and refuelled with 30 litres of the relevant test fuel. Each test vehicle was then subject to the protocol once on each test fuel and the respective drivability noted. For each vehicle, both Hot Drive and Hot Fuel Handling were consecutively performed on neat petrol first. The two tests were then repeated on E10. As a small percentage of ethanol can alter the FVI of neat petrol, testing in this order ensured that the neat petrol did not become contaminated with ethanol.

7.4.3.3 Test Fuels

The test fuels used at Broken Hill trial were locally sourced and the E10 test fuel blended on site. The following test fuel handling procedure was adopted to minimise vapour losses or, at the very least, synchronise any vapour losses for each fuel.

- An equal number of 15 L and 10L plastic containers was allocated to neat petrol and E10.
- The containers allocated to E10 were filled to 10% of their nominal capacity with anhydrous ethanol.

- The petrol dispensing bowser (ULP or LP as appropriate) was started and all containers were filled to their nominal capacity with neat petrol. Container lids were replaced immediately on filling.
- Prior to filling the vehicle with test fuel, the fuel tank was drained as much as possible by siphoning and then driven until all of the remaining fuel was consumed.
- Test fuel samples were taken just prior to filling of the test vehicles for later analysis by Ampol Refinery, Kurnell.

Figure 7-17 depicts the test fuel FVIs for each vehicle. The neat test fuel has an approximate FVI of 92 and the E10 test fuel has an FVI of 110. Typical FVI for January at Broken Hill is approximately 90.

7.4.3.4 Results/Discussion

The data sheets, with driver's comments, are located in Appendix B. A summary and review of the data collected follows below.

7.4.3.4.1 Test Fuel

It should be noted that FVI of the test fuels show little scatter and deviation from petrol typical for that time of year (max. 89 for South Australia, 98 for NSW) suggesting that the fuel handling, sampling and analysis were satisfactory.

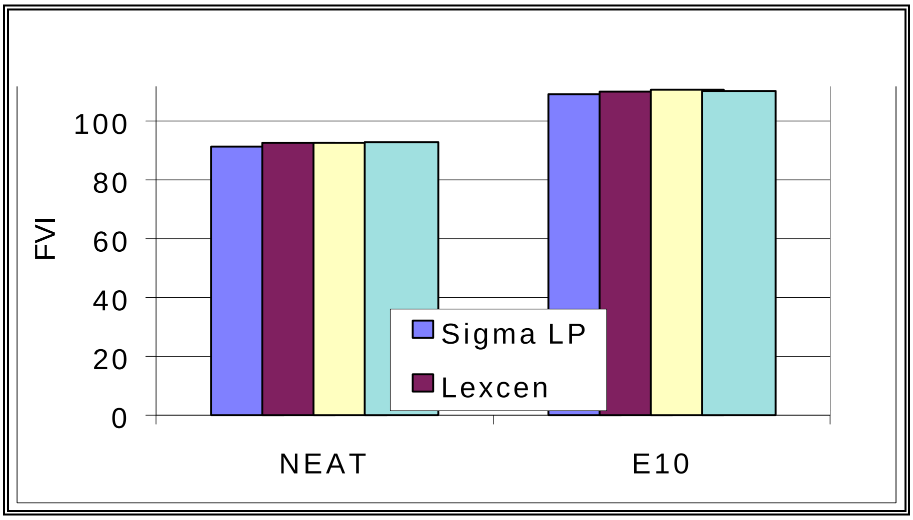

FIGURE 7-17: FVI OF TEST FUEL FOR EACH VEHICLE

7.4.3.4.2 Hot Drive

Drivability Rating

The drivability rating scored for each vehicle in Hot Drive is summarised in Figure 7-18. The rating is as previously defined in Table 7-3 and Table 7-2 and higher rating indicates better performance. As between E10 and neat petrol the differences for each vehicle were minimal and insignificant, appearing no more than would ordinarily be expected in replicating testing on any one fuel, whether E10 or neat petrol.

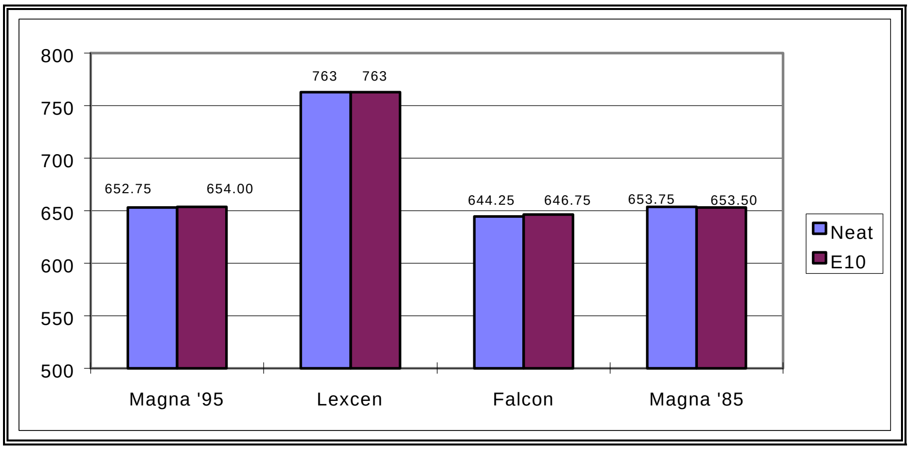

FIGURE 7-18: DRIVABILITY RATING

1995 Magna

The 1995 Magna experienced a rating difference of 1.25 points between E10 and Neat petrol, with E10 drivability marginally the better out of the two; see Figure 7-18. A breakdown of the performance difference between the two fuels is summarised in Table 7-6.

The lesser points on neat petrol reflect a rough idle with air conditioning on, rough while creep running, and a slight shock on the 60 km/hr down to 40 km/hr tip-in.

TABLE 7-6: MAGNA 95 - HIGHLIGHTS OF RATINGS

	Good	Jerk	Shock	Total
Magna '95 Neat	131.25	41.75	41.75	652.75
Magna '95 E10	132.00	42.00	42.00	654.00
Difference	-0.75	-0.25	-0.25	-1.25

Lexcen 1995

Referring to Figure 7-18, on the Hot Drive test runs for the Lexcen there was no detectable difference between the two fuels.

Falcon 1985

Figure 7-18 above reflects a difference of 2.5 points between the two fuels , with performance marginally better on E10. Details of the evaluation are set out in Table 7-7 below. On both fuels, but to slightly varying degrees, problem areas for this vehicle were:

- ♦ surging whilst at constant speed running, and
- ♦ rabbit hopping under both acceleration and deceleration.

An area of noticeable difference between E10 and neat petrol was that, under some wide open throttle conditions, engine knock was observed only on neat petrol. This was most likely due to the octane value of neat petrol being lower than that of E10.

TABLE 7-7: FALCON HIGHLIGHTS OF RATINGS

	Surge	Shock	Accel	Rabbit hops	Decel	Total
Falcon Neat	76.50	40.50	21.75	15.50	16.50	644.25
Falcon E10	75.75	42.00	24.00	15.75	15.75	646.75
Difference	0.75	-1.5	-2.25	-0.25	0.75	-2.5

1985 Magna

The Hot Drive rating of the 1985 Magna differed by 0.25 points, performing slightly better on neat petrol. On both fuels, though at different stages of the test cycle, points were deducted on detection of a slight surge.

Acceleration Times

As a component of the Hot Drive testing, times were recorded for accelerating from a constant 30 km/hr up to 60 km/hr under a rapid wide open throttle, see Figure 7-19.

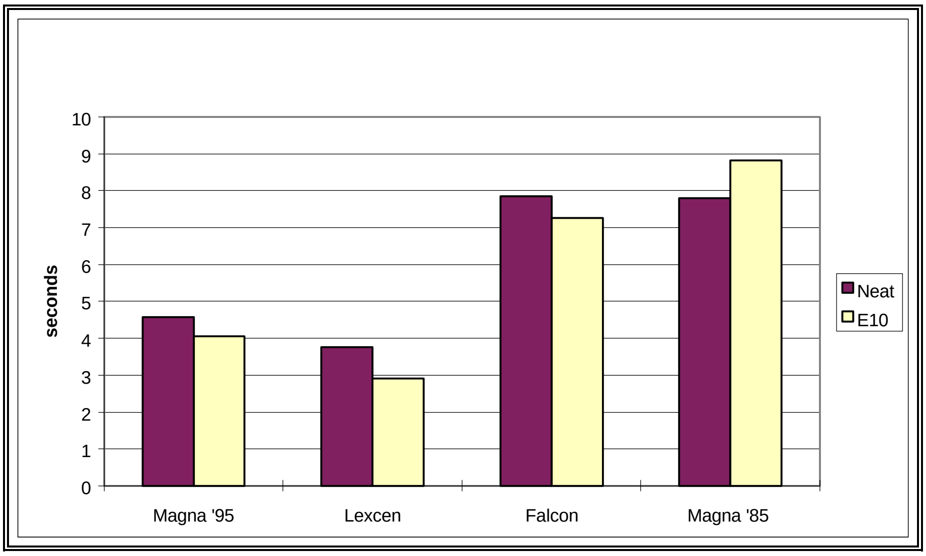

FIGURE 7-19: ACCELERATION TIMES - HOT DRIVE

7.4.3.4.3 Hot Fuel Handling

The ambient air temperature recommended for hot fuel handling is 35°C minimum. This temperature was not reached on some test days but, given project time constraints, the recommendation had to be compromised. Following discussions and reaching agreement with the FCAI representative, 32.5°C was the lowest temperature under which vapour lock resistance testing was conducted for this project.

The hot drivability protocol for evaluating hot fuel handling lists three acceptability criteria points, they are:

- T1/T* and T2/T* are greater than 1.5;
- Vehicle slows during the WOT acceleration to 120 km/hr; and,
- Surge rating for the drive cycle is less than 2.75 based on a scale of 1 to 5

The three acceleration times recorded during the hot fuel handling (T1, T2 and T*) and the temperature at the time of testing are set out in Figure 7-20 and Figure 7-21. Note that, for the 1985 Magna no E10 results are presented due to this vehicle's testing having been aborted because of a mechanical failure unrelated to fuel.

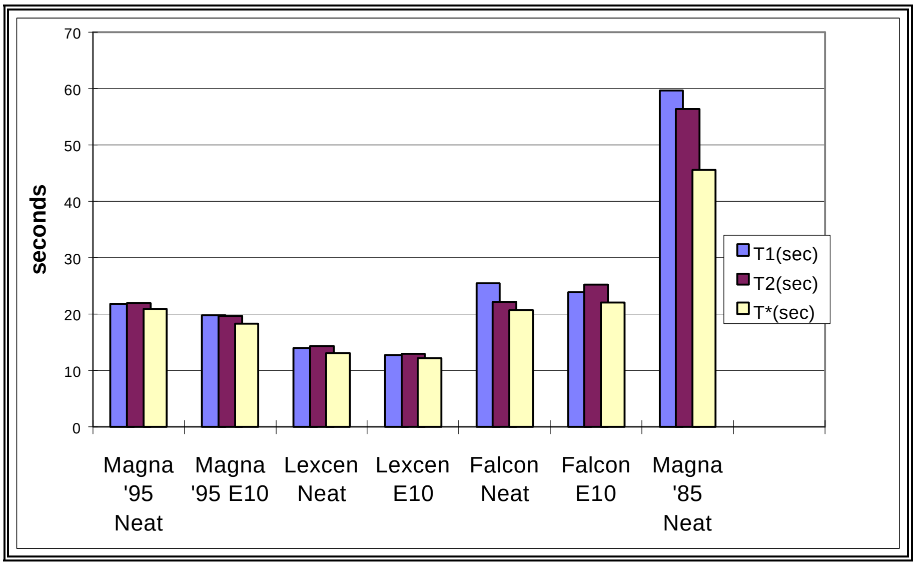

FIGURE 7-20: ACCELERATION TIMES - HOT FUEL HANDLING

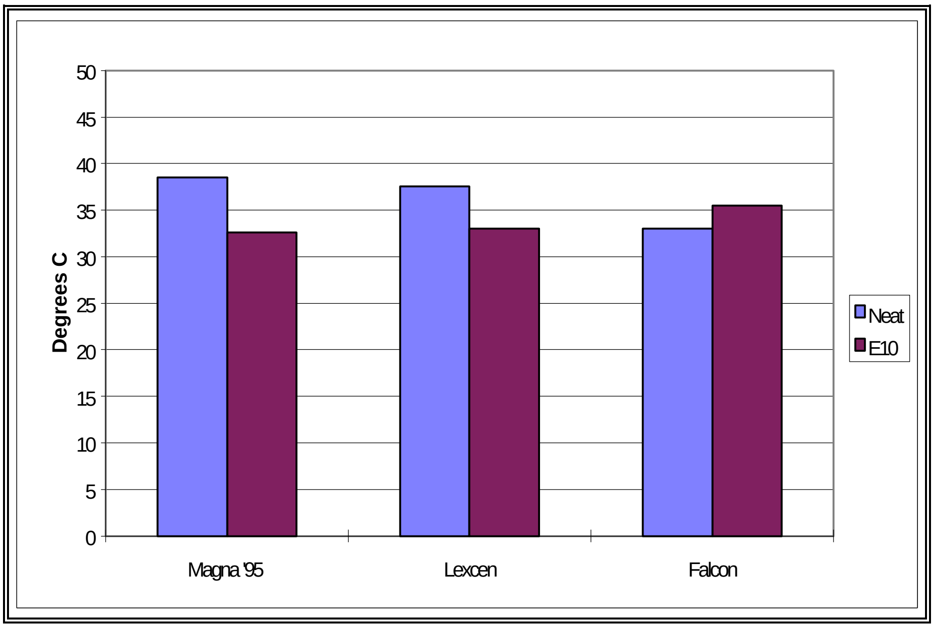

FIGURE 7-21: TEST AMBIENT TEMPERATURES - HOT FUEL HANDLING

Figure 7-22 sets out the values T1/T* and T2/T* for the tested vehicles. For both fuels, all values emerged as being within the 1.5 ratio which determines the limit of an acceptable resistance to vapour lock.

There was no evidence of deceleration or surge for the tested vehicles during the Hot Fuel Handling.

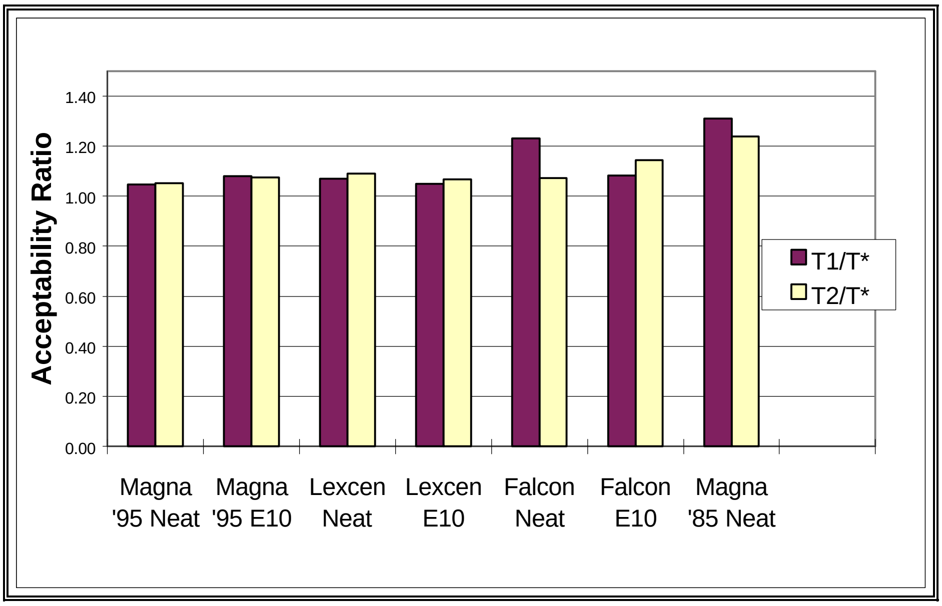

FIGURE 7-22: VAPOUR LOCK RESISTANCE

Magna 1995

The 1995 Magna experienced a slight power down during the initial wide open throttle acceleration (T1) on both fuels, and no other points were noted.

Lexcen 1995

The Lexcen experienced no problems.

Falcon 1985

The Falcon experienced a rough idle during the hot soak following T1 on neat petrol, and stumbled on take-off for T2 on E10.

Magna 1985

Comparative testing was not completed for Hot Fuel Handling. The E10 evaluation was cancelled due to tyre failure during the latter half of 140 km/hr heat stress drive. However this vehicle's operation on neat petrol suffered from:

- rough idle and engine stalling twice immediately following the 15 minute dead soak period (stumble rating 2);
- severe power down during T1 acceleration (acceleration rating 2)
- reduced power during T2 acceleration

During the heat stress drive on E10 (prior to tyre failure) there was evidence of fuel starvation (vapour lock) and speed had to be reduced to 120 km/hr. Although the heat stress drive is not part of the Hot Fuel Handling evaluation, it can be conjectured that this vehicle's performance on E10 would have been similar and possibly marginally worse than it was with neat petrol.

7.4.3.4.4 Summary

The trial sought a comparison of drivability as between neat petrol and E10, a blend of 10% v/v ethanol with neat petrol, under hot weather conditions. The variations noted in testing were minor. In most instances the respective test vehicle experienced stress in the same area on both fuels. Only slight variations (subtle differences) in comparative performance were found.

The ambient temperatures (32.5°C+) were not so extreme as recommended (35°C+) for such testing. Nevertheless there was no indication of any problem being greater for E10 than for neat petrol. Given E10's theoretically greater susceptibility to vapour lock, the lack of any such clear variation suggests no practical difference in the serviceability of E10 and neat petrol under hot weather conditions.

7.4.3.4.5 Conclusion

All three vehicles fully tested for hot fuel handling met the criteria for an acceptable resistance to vapour lock. However, it should be noted vehicle design in the placement of fuel lines and fuel pumps has a large influence on vapour lock characteristics.

Although there were differences between the two fuels these did not reflect any consistent variation favouring one or the other. On that basis it can be concluded there is no practical difference between the two fuels.

7.4.4 Hot Drivability - Bourke

The protocol used for the Bourke hot drivability trial was essentially similar to the Broken Hill protocol. Nevertheless, distinguishing aspects of the Bourke trial were matters of assessors, vehicle selection and fuel preparation/handling/storage.

7.4.4.1 Assessors

The Technical Support section of NRMA, namely Mr. Owen Johnstone, Manager, and Mr. Andrew Skidmore, Technical Officer carried out all of the evaluation functions needed to assess the vehicle performance.

7.4.4.2 Vehicle Selection

The test fleet was comprised of all late model and low kilometre vehicles, details being as shown in Table 7-8.

TABLE 7-8: VEHICLE DETAILS

	Built Date	Cylinders	Fuel System	Trans.
Toyota Camry	1995	4	ULP Injected	Auto.
Toyota Lexcen	1995	6	ULP Injected	Auto.
Mitsubishi Magna	1995	4	ULP Injected	Auto.
Ford Falcon	1995	6	ULP Injected	Auto.

7.4.4.3 Test Fuel

Fuel preparation - the neat petrol used for all the tests was sourced from Shell Depot at Bourke. The procedure adopted was as follows:

- Clean 205 L drums were allocated two each to neat petrol and E10.
- 20 L of anhydrous ethanol was placed in each of the drums allocated to E10.
- All the drums were filled to 200 L with neat ULP and quickly closed.

Vehicle fuelling - in order to avoid contamination of neat petrol by ethanol, vehicles were always tested with neat petrol first. The procedure for fuelling the test vehicle was:

- 10L of test fuel were drawn from the 205 L drum into a 10L plastic container using a drum pump.
- The vehicle was driven until all of the fuel previously in the vehicle fuel tank was consumed.
- The 10L of test fuel was then poured into the vehicle fuel tank and the vehicle driven to the Shell Depot where the rest of the required quantity of test fuel was pumped into the vehicle fuel tank.

Samples of the test fuels were taken from the drums on completion of testing at Bourke and analysed by Ampol Laboratories. The FVI of the fuel was 82 and 103 for neat and E10 respectively. The FVI for the neat/base fuel is considered to be significantly lower than the normal production value from the Sydney refineries for that time of year (98 FVI max.), however the fuel available from South Australia is 89 FVI.

In view of the fact that the difference in the FVI of E10 and neat petrol test fuels used is 22 FVI compared with the normal 17 FVI, it is considered that the comparison for the two fuel holds true. It is recognised that any problems experienced with either fuel will be reduced due to the lower absolute vapour pressure and FVI.

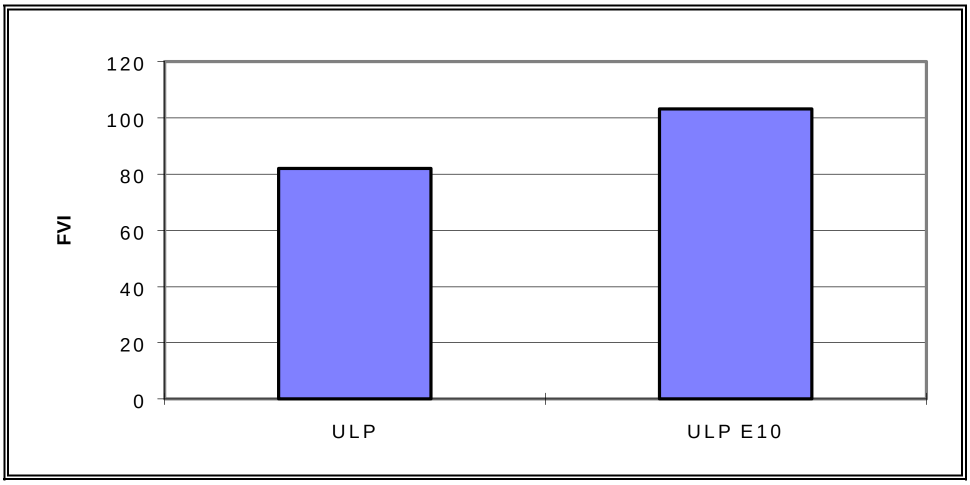

FIGURE 7-23: FVI FOR BOURKE TEST FUEL

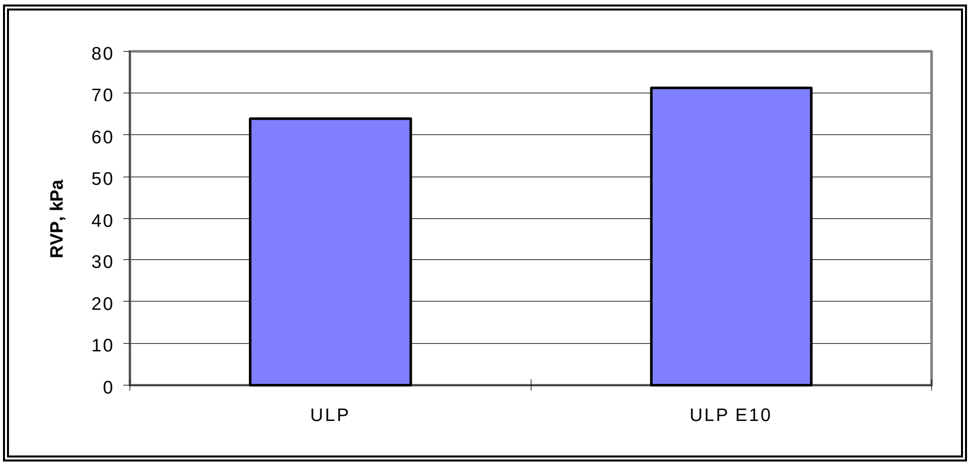

FIGURE 7-24: RVP FOR BOURKE TEST FUEL

7.4.4.4 Results/Discussion

7.4.4.4.1 Hot Drive

The drivability rating of the vehicles tested can be seen in Figure 7-25. The Falcon and the Camry performed marginally better on the E10 fuel, while the Lexcen and the Magna performed marginally better on neat petrol.

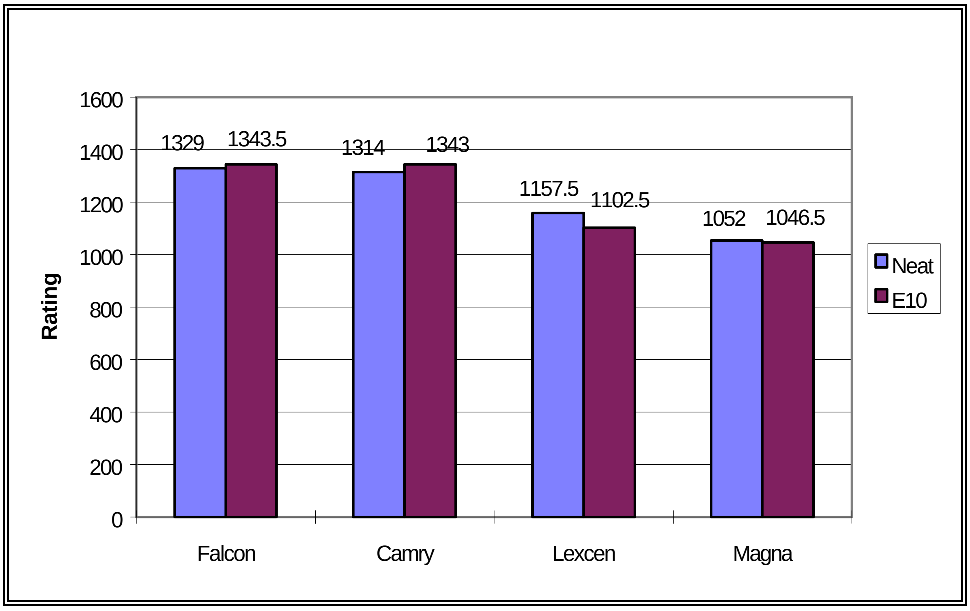

FIGURE 7-25: DRIVABILITY RATING

Falcon

The Falcon running on E10 received reduced drivability rating for a surge at a constant speed (40 kph), most likely being due to air conditioning cycling. In all other areas no demerits were allocated.

Running on neat petrol the Falcon experienced surging while running at constant speeds (40, 60, 80, 100, 120 kph). Also slight stumbles and jerks were experienced during some tip-in procedures. Stumbles were also noted in the varying accelerations from 60 kph to 90 kph.

TABLE 7-9: FALCON DRIVABILITY HIGHLIGHTS

	Stumble	Surge	Jerk	Total
Falcon Neat	155.5	161.5	67	1329.0
Falcon E10	165.0	163.5	70	1343.5
Difference	-9.5	-2.0	-3	-14.5

Camry

The Camry running on E10 experienced surge, slow response, and stumble symptoms. The surge was experienced under a constant speed of 60 kph in 2nd gear. The slow response was experienced in the 40 kph down to 20 kph tip-in, and the stumble was also experienced in two incidents while carrying out the tip-in tests.

The Camry's performance running on neat petrol was slightly worse than on E10, experiencing surge, slow response, stumble, jerk, and shock symptoms. Surge was noted on all constant speed runs. Slow response was noted in the majority of tip-in tests as was the stumble, jerk and shock symptoms. Jerk was also noted for all the acceleration/deceleration phase.

TABLE 7-10: CAMRY DRIVABILITY HIGHLIGHTS

	Slow Res	Stumble	Surge	Jerk	Shock	Total
Camry Neat	154.5	156.5	157.5	61.5	74	1314
Camry E10	159.0	163.0	166.0	70.0	75	1343
Difference	-4.5	-6.5	-8.5	-8.5	-1	-29

Lexcen

Neat and E10 fuels showed signs, to differing degrees, of slow response, stumble, surge, jerk, shock, knock on acceleration, acceleration performance, and deceleration (see Table 7-11).

TABLE 7-11: LEXCEN DRIVABILITY HIGHLIGHTS

	Good	Safety	Slow Res	Stumble	Surge	Jerk	Shock	Accel Knock	Accel Perform	Decel	Total
Lexcen Neat	224.75	27.0	123.75	143.5	136.5	60	58	54.5	53.5	16	1157.5
Lexcen E10	201.50	25.50	120.00	139.5	136.0	48	50	55.0	52.0	15	1102.5
Difference	23.25	1.5	3.75	4.0	0.5	12	8	-0.5	1.5	1	55.0

Magna

The Magna experienced differing degrees of jerk, shock, and rabbit hops throughout its testing, as shown in Table 7-12.

TABLE 7-12: MAGNA DRIVABILITY HIGHLIGHTS

	Good	Jerk	Shock	Rabbit hops	Total
Magna Neat	198.5	50	50	30	1052.0
Magna E10	200.0	48	48	27	1046.5
Difference	-1.5	2	2	3	5.5

7.4.4.4.2 Acceleration Times

As a component of the Hot Drive testing, times were recorded for accelerating from a constant 30 kph up to 60 kph under a rapid wide open throttle, see Figure 7-26.

Only minor differences in acceleration times for each vehicle were recorded between the two fuels and present no concern to the use of E10 blend.

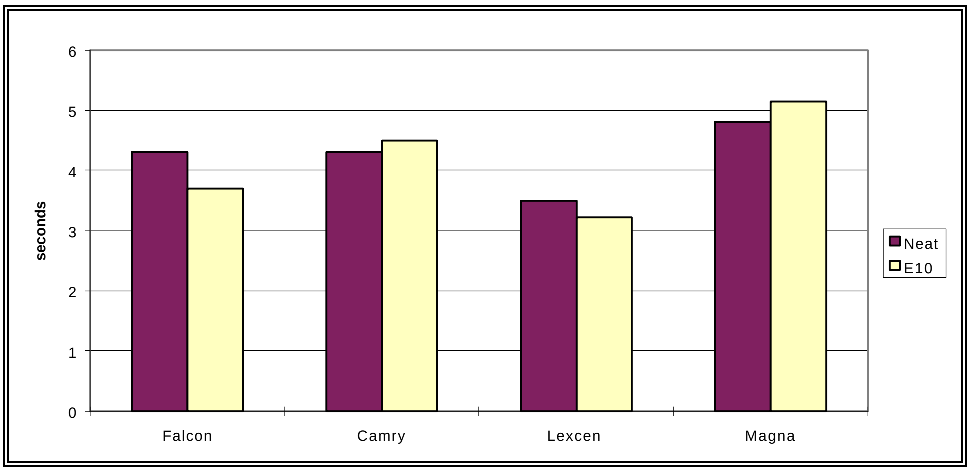

FIGURE 7-26: ACCELERATION TIMES - HOT DRIVE

7.4.4.5 Hot Fuel Handling

The acceleration times (T1, T2 and T*) for the hot fuel handling are shown in Figure 7-27 indicating there is little difference between fuels for each vehicle.

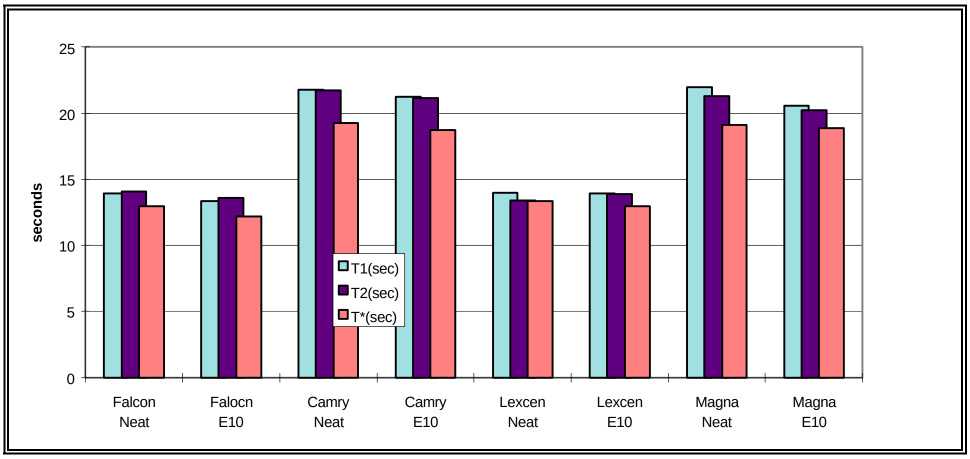

FIGURE 7-27: ACCELERATION TIMES - HOT FUEL HANDLING

The acceptability criteria (T1/T*, T2/T* < 1.5) for the acceleration times are seen in Figure 7-28. Both fuels for all vehicles met the criteria easily showing little difference between heat stressed acceleration times and stabilised temperatures acceleration times.

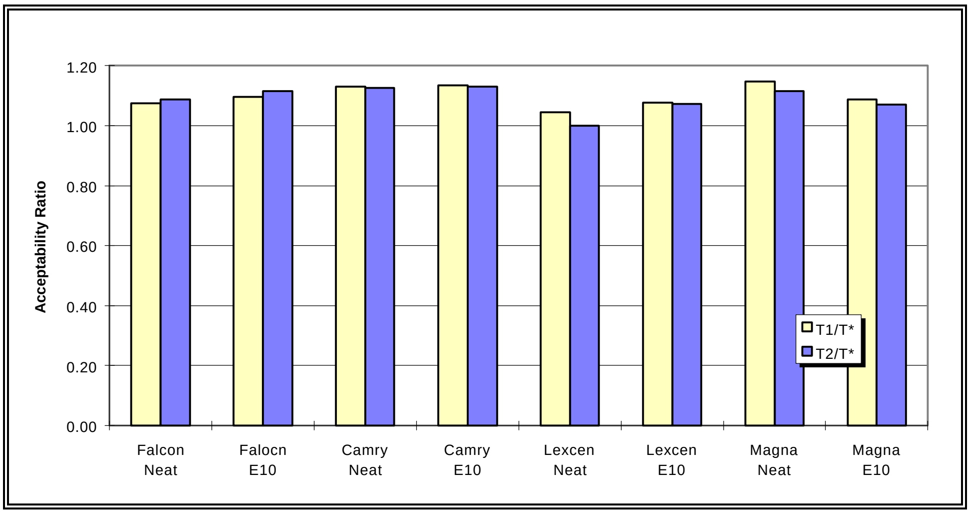

FIGURE 7-28: VAPOUR LOCK RESISTANCE

7.4.4.6 Conclusion

The criteria applied by both assessors was such that that the deficiencies in vehicle performance noted were very minor and they would not be apparent to the average driver.

The vehicles' differences on each fuel displayed no trend in favour of either fuel. The Magna and the Lexcen performed slightly better on the neat fuel and the Falcon and the Camry performing marginally better on the E10 for the Hot Drivability part of the tests while the Magna performed better on E10 during the Hot Fuel Handling tests. Acceleration times tended to favour the use of E10 for all vehicles.

No clear differences could be isolated and therefore the conclusion reached is that there is no practical difference between the two fuels under hot drivability conditions.

7.5 Conclusion

7.5.1 Cold Drivability

7.5.1.1 Londonderry

The Lexcen and Magna, both fuel injected vehicles, exhibited no discernible performance differences running on E10 when compared with neat petrol.

Both the carburetted vehicles however experienced performance problems on both fuels. E10 performed marginally better than neat petrol but, to all intents and purposes, the difference to an everyday driver would not be noticed.

7.5.2 Hot Drivability

7.5.2.1 Broken Hill

All three vehicles fully tested for hot fuel handling met the criteria for an acceptable resistance to vapour lock. However, it should be noted vehicle design in the placement of fuel lines and fuel pumps has a large influence on vapour lock characteristics.

Although there were differences between the two fuels these did not reflect any consistent variation favouring one or the other. On that basis it can be concluded there is no practical difference between the two fuels.

7.5.2.2 Bourke

The criteria applied by both assessors was such that that the deficiencies in vehicle performance noted were very minor and they would not be apparent to the average driver.

The vehicles' differences on each fuel displayed no trend in favour of either fuel. The Magna and the Lexcen performed slightly better on the neat fuel and the Falcon and the Camry performing marginally better on the E10 for the Hot Drivability part of the tests while the Magna performed better on E10 during the Hot Fuel Handling tests. Acceleration times tended to favour the use of E10 for all vehicles.

No clear differences could be isolated and therefore the conclusion reached is that there is no practical difference between the two fuels under hot drivability conditions.

8 MATERIALS COMPATIBILITY

8.1 Introduction

Materials in direct contact with fuel must exhibit a resistance to deterioration by that fuel in order not to impair safety and reliability of the fuel system. These materials include metals, plastics and elastomers.

The Australian vehicle market cannot be assumed to be compatible with ethanol/petrol blends (E10), especially vehicles that are more than 10 years old. In practice it is virtually impossible to ascertain the extent of E10 incompatible materials in the market place as only the vehicle manufacturing industry and component suppliers are privy to that information. Even then much of that information has been lost over time or was never available in the first place.

The quality of ethanol and any fuel additives, such as corrosion inhibitor, will also exert an influence on the extent of materials deterioration over time.

Detailed studies of materials compatibility with ethanol have been carried out by others {2,14,15}, and they have not been repeated for this project. Rather, in establishing E10 material compatibility with the Australian vehicle population, vehicles on the Central Coast that use E10 have been focused on to ascertain if any materials compatibility problems have developed.

The following approach was adopted to ascertain if any material compatibility problems have become apparent to regular users of E10:

- Request for information to FCAI with respect to both domestically produced and imported current vehicles;
- Frequent liaison with E10 distributors, namely Bowen Petroleum Services Pty. Ltd (BOGAS) and Marina Petroleum Pty. Ltd.;
- Request to aftermarket parts suppliers; and
- Inspection of parts

8.2 Background

8.2.1 Types of Material

Fuel system materials in direct contact with the fuel are varied and Appendix D shows some of the more commonly used materials. The majority of these materials have been tested with ULP and E10 by others and it was found that there was no significant difference in the effect of the fuel on the material.

8.2.2 Types of Failure

Some materials used in fuel systems tend to degrade over time, such as the elastomeric materials used to make hoses and seals. Other fuel system components are made of metals and plastics and must also be compatible with the wide range of fuels. Degradation can occur for many reasons, such as repeated heating and cooling cycles, normal oxidation by the atmosphere and corrosion by other substances. Fuel composition can also affect deterioration rates. For example, aromatics (a natural component of petrol) can cause some parts to swell. In addition, degradation of some older elastomeric fuel distribution components may be accelerated by exposure to E10.

However, overseas material manufacturers, principally in the United States, found it necessary in the early to mid 1980's to upgrade several of the materials used in their fuel system to achieve acceptable operation with E10 and the increased aromatic content of base petrol.

There are two distinct types of materials compatibility problems:

- *Acute failure* - a substance causes a part to fail within a very short period of time; and
- *Accelerated deterioration* - a substance causes a part to fail noticeably faster than would have been the case had the part not been exposed to that substance.

8.2.3 Metal components

Accelerated deterioration of metal components can result from corrosion, chemical reactions between the fuel and the affected material, or permeation of the fuel through the material. Most metal components in automobile fuel systems will corrode or rust in the presence of water, air or acidic compounds.

The petrol distribution system usually contains water, and additional moisture may collect in storage and the vehicle tank from condensation. Petrol may also contain traces of sulphur and organic acids and has always been recognised as potentially corrosive. Pipelines that distribute petrol are constructed of plain steel and appropriate corrosion inhibitors have been added to petrol for many years.

The presence of ethanol and traces of water may result in accelerated corrosion by chloride ions and acetic acid. Prior tests conducted on vehicles running on E10 for an extended period have studied vehicle fuel tanks and fuel system components. These tests have generally concluded that E10 does not increases corrosion in normal, everyday operation{2}.

American automotive manufactures do not see corrosion as a problem so long as an effective corrosion inhibitor is added to the fuel{2}. All marketers of E10 in Australia use a corrosion inhibitor, DCI11 or similar, thus greatly reducing the possibility of corrosion.

8.2.4 Elastomer Components

Elastomer compatibility is more difficult to generalise; material may swell, soften, become permeable, or harden on drying out. Petrols with high levels of aromatics, notably benzene, toluene, and xylene, accelerate material degradation to a similar degree as fuels containing ethanol{2}. However, no increase in the rate of materials failures has been reported over the past several decades despite substantial increases in aromatics levels in order to maintain desired octane levels{4}.

Numerous tests have indicated that materials compatibility with E10 is no more a concern than comparable hydrocarbon fuels and should not present any unique problem{1}.

8.2.5 Other

Occasionally, in older model vehicles, deposits in fuel tanks and fuel lines were loosened by E10 blends. When this occurs, vehicle's fuel filter may become blocked, however this is easily remedied by a filter change. It is not likely that such problems will be experienced on late model vehicles.

8.3 United States Experience

Ethanol blends have been sold in the US for the last 15-20 years, and the U.S. has built up experience with the use of E10 and the effect it has on older vehicles of the late 1970's through to the present vehicles of today.

Ethanol-based oxygenated petrols in the U.S. have generally presented no significant difficulty for fuel systems in vehicles manufactured after the early 1980's as a result of the use of fluoroelastomeric components. The issue of using E10 in vehicles earlier than the 1980's also did not present significant materials compatibility problems.

Fluoroelastomers have been used in automotive and non-automotive engines since the mid-1980s. These materials are specifically designed to handle all modern petrols, including high-aromatic, ethanol-containing and ether-containing petrols within these substances' legally permissible levels, without experiencing any materials compatibility concerns. Fluoroelastomers are also far more resistant to permeation and ozone degradation than were earlier elastomers.

8.4 Results

8.4.1 FCAI

FCAI were requested to assist in determining the position adopted by the vehicle manufacturing industry to the use of E10.

Based on the response from FCAI (Appendix D) it is understood that:

- The Australian motor industry currently follows the global material standards that are E10 compatible.
- Imported vehicles also follow the global material standards and are E10 compatible.

Although not stated in FCAI’s response it is believed that imported vehicles have been E10 compatible since the introduction of ULP in 1986.

The main concern raised by FCAI was how the older proportion of the Australian vehicle population would stand up to E10 material compatibility issues.

It should be noted that FCAI's advice was generally heeded, but some of the suggested test protocols i.e. measuring elastomer hardness or hose burst pressure, were not carried out.

8.4.2 BOGAS Customers

Throughout the project there was a great deal of interaction with BOGAS customers in the course of sourcing vehicles for the emission testing phase. This enabled gathering of a general public experience of E10.

In relation to materials compatibility no concerns were raised by BOGAS customers of the ones questioned. However BOGAS itself highlighted several material compatibility issues brought to its attention. They are as follows:

- Some model Victa lawn mowers with fuel gauges have encountered the problem of the ethanol melting the fuel gauge unit;
- Australian manufactured aftermarket fibreglass fuel tanks for motorcycles (Ducati) have had problems with the resin migrating and causing carburettor blockage. A warning advising affected users has been posted at all BOGAS outlets. The fuel tank manufacturer is aware of the problem and is now using ethanol resistant resins.
- Fuel delivery tankers have had problems with their discharge pump seals swelling in the presence of E10. These have been replaced by ethanol compatible seals.
- A small number of Ford Falcon vehicles fitted with a capacitive type fuel sender unit can indicate incorrect readings with E10 compared to neat petrol. This type of sender unit exhibits sensitivity to water and water ingress into the unit is controlled by porous plugs. It is conjectured that the water ingress is aided by E10 (change in surface tension), however removal of the sender unit from the vehicle followed by thorough hot air drying usually eliminates the problem.

8.4.3 Inspection of parts

Throughout the emission testing phase of the project, vehicles that were prepared for testing had fuel tank, fuel sender and seal, fuel lines and fuel filters inspected as part of their preparation. The inspection was carried out by NRMA Service Department personnel and a representative from Apace Research.

8.4.3.1 Fuel tanks

In preparation of each test vehicle for emission testing by NSW EPA the fuel gauge sender unit was removed for installation of the in-tank thermocouple. This provided opportunity for visual inspection of the fuel tank's internal condition. On all vehicles inspected no visible signs of corrosion were noted. The Ford plastic fuel tanks were also unaffected by E10.

The fuel gauge sender units and seals from the majority of vehicles that underwent emission testing displayed no signs of being affected by E10.

However, the sender unit seal from Ford Falcon station wagons showed high levels of deterioration (Figure 8-1). The Ford Falcon station wagons that were examined and showed deterioration of the fuel sender unit seal ranged from May 1988 (EA) to Oct. 1992 (EB). No Ford Falcon wagons later than 1992 were tested. The seal showed deterioration on the majority of Falcon wagons that were inspected and were within the above range. While severe deterioration was noted in some cases, the integrity of the seal was maintained.

FIGURE 8-1: FORD FALCON SENDER UNIT SEAL - OVER 200,000 KM EXCLUSIVELY ON E10

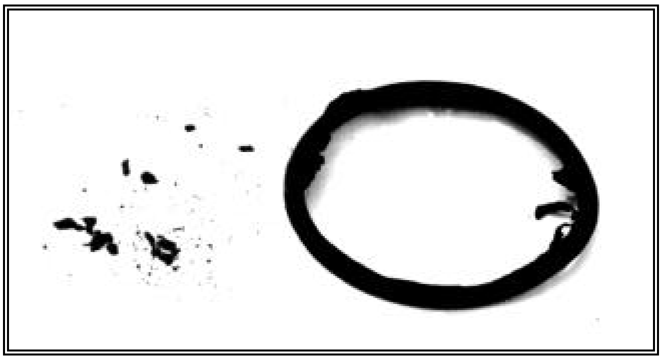

FIGURE 8-2: FORD FALCON SENDER UNIT SEAL -OVER 140,000 KM EXCLUSIVELY ON NEAT PETROL

On following up on this problem, a Sydney based Ford Falcon vehicle known never to have been exposed to E10 was inspected, and revealed similar deterioration of the sender unit seal suggesting that petrol in general is the cause of the seal deterioration, and not due to the material having a low E10 tolerance (Figure 8-2).

The equivalent Ford Falcon sedans in the above range have a different sender unit arrangement, with the sender unit located on top of the tank compared with the wagon's being mounted low on the side. The unit design is also different, incorporating a different seal. The seals on the Falcon sedans did not show signs of deterioration. Whether this is due to the seal being on top of the tank and hence having limited contact with the fuel or whether the composition of the seal is different was not determined.

8.4.3.2 Fuel line hoses

All tested vehicles had at least one fuel hose, usually the return line hose, replaced. The hose was inspected, at time of removal, for any excessive swelling or softening and then placed in a plastic bag for later inspection in order to establish cracking or hardening on drying out. No deterioration was noted as being due to E10, with the majority of degradation being evident on the outside hose cover. NSW EPA noted that a number of tank filler hoses were perished causing excessive diurnal evaporative emissions. This information was supplied belatedly and therefore it was not possible to identify whether E10 was the cause of such deterioration.

SAE Standard for Fuel and Oil hoses (SAE J30) specifies the fuel hose resistance to ethanol under Section 6.5.13 "Ethanol Modified Fuel Resistance".

8.4.3.3 Fuel pumps (EFI)

During the course of the trial, two pump "failures" were experienced. The pumps were cut open for inspection but no definite conclusion could be reached as to the cause of the failure. It is conjectured that significant quantities of dirt were responsible for suction filter blockage resulting in pump cavitation and hence low fuel pressure. In addition, there was some evidence that some of that dirt passed through the pump and may have caused a temporary pump motor jam. None of the pump parts, including the nylon strainers and motor brushes, appeared to be affected by E10.

8.4.3.4 Fuel filters

All fuel filters fitted to test vehicles were replaced and the removed filters were examined. No detrimental effect due to E10 was noted on any of the filters inspected.

Four after-market suppliers of fuel filters were approached for confirmation of their filter's suitability for use with E10.

- Direct response was received only from GUD Manufacturing Company (RYCO filters) who confirmed that their fuel filters can be used with E10 as well as many other compounds. See Appendix D for their test results. These filters are sold nationally under the RYCO labels by K-Mart and Big W.

- International Auto Parts Pty. Ltd. filters found in some Big W stores prohibit the use of any alcohols as well as other compounds. The warning is clearly marked on the packaging. No direct response was received from this company.

- The other two companies polled, Pro Kit Pty. Ltd. and Cooper's Filter Co. (Westfil Filters) did not respond.

8.4.3.5 Catalytic converter

A catalytic converter was removed from a Ford Falcon 1992, one of the LTIS fleet (and in fact one of BOGAS's own fleet), which had covered in excess of 200,000 km almost exclusively using E10.

The converter was inspected and tested by the School of Chemistry, Macquarie University under the direction of Professor Noel. W. Cant. The full report detailing test protocol and results is shown in Appendix D. The tentative diagnosis from the inspection and testing are:

- *"Based on past experience we believe that the deterioration of the catalyst honeycomb on the APACE vehicle was most likely due to normal wear and tear attributable to the high number of kilometres travelled by the vehicle."*
- *"There are three special features of the test results for the APACE samples which warrant some comment.*
  - ~ *The performance at the rear of the converter is worse than at the front which is the reverse of the normal pattern.*
  - ~ *The surface areas are relatively uniform throughout rather than showing a sharply lower area at the front as is usual.*
  - ~ *The deterioration in performance for NO removal is considerably greater than for CO and C_3H_6."*

- *One possible explanation is that the exhaust gas temperature was a little lower than normal and the rise in temperature along the converter, which accompanies the pollution control reactions, was more gradual than usual. This could have two effects. Firstly the rear of the converter could run hotter than the front third, the reverse of normal......"*

  ".....additional work could provide extra assurance that nothing untoward had occurred in the APACE converter. However we think it highly unlikely that the extra data would be of a form which would cause us to alter the tentative diagnosis expressed above......"

Apace proposed to monitor the catalytic converter temperatures after it was noted that differing results were being obtained in HC emissions for the differing parts of the exhaust emissions drive cycle. These results suggested significant differences in catalytic converter temperature as between neat petrol and E10. However NSW EPA opposed the proposal and therefore no temperature readings were recorded.

8.5 Conclusion

While there was no evidence of adverse effect on the parts inspected there may possibly be a slight increase in deterioration of the parts due to the use of E10, but no concern is warranted. However, it should be recommended when switching to the use of E10 that, as part of normal vehicle maintenance, vehicle owners should inspect their engine and fuel distribution system for leaks and replace older or leaking components. Owners of pre-1986 vehicles with possibly degraded elastomers and other engine parts should consider replacing these with parts which are engineered to assure compatibility with all modern petrols, including petrols containing ethanol.

In conjunction with on-the-job inspection, parts such as fuel lines, fuel sender unit seals and fuel filters were removed and inspected by independent inspectors (NRMA Technical Services, N. Gillies, and N. Webber).

Reports from the inspectors can be seen in Appendix D. The general consensus reached by the inspectors was that ethanol appeared to have no adverse effect on the parts inspected.

While materials that are ethanol intolerant are known and well documented, the presence of these materials in Australia's vehicle population is not well documented.

US experience from engine and elastomer manufacturers have indicated that even in older vehicles, any materials compatibility or deterioration problems that may be encountered would not result in immediate, acute failures of elastomeric components but rather would result in an increase in deterioration rates in-use.

Investigation of the BOGAS retail area has revealed no concerns with material compatibility and there is no knowledge of acute failures on light duty vehicles. Investigation of vehicle parts that have run on E10 have revealed no concerns. This is in agreement with US studies, with areas covered by the Oxygenated Gasoline program not having reported higher rates of materials degradation or failure than other areas receiving conventional petrols.

9 ENGINE AND FUEL SYSTEM WEAR

Studies, such as "Enhanced Extension of Petrol with Aqueous Ethanol", CSR Chemicals Ltd., (1984) {17}, on vehicles running on ethanol petrol blends have reported higher than normal corrosion in carburettor bowls, metal fuel lines and metal fuel tanks. However, the blends have differed from the E10 being used for this project in percentage of ethanol, the absence of a corrosion inhibitor and higher water content.

The effect of E10 on lubricity and corrosion of engine parts has raised little concern and in the United States where E10 is commonplace no concern has developed regarding wear following normal vehicle operating and maintenance procedure{4}. SAE Information Report J1297 Mar 93 "Alternative Automotive Fuels" states no unusual engine wear problems have been observed using E10, and SE and SF grades of oil have satisfactorily lubricated engines{26}. The current standard is SG which provides better oxidation stability and sludge protection than the SE and SF oils.

In this project two approaches were taken to evaluate engine and fuel system wear. The main approach was the dismantling and inspection of 5 LTIS vehicle's engines that were examined for unusual wear and deterioration characteristics. The other approach involved analysing engine oil samples taken from the LTIS Fleet for oil quality and wear metal materials in the oil.

9.1 Engine Inspection

A total of 5 vehicles from the fleet of 11 LTIS test vehicles were inspected for abnormal wear and deterioration of parts. The vehicles chosen had their engine's stripped by NRMA workshop at Villawood so that following parts were accessible for inspection:

- Fuel delivery system (Injectors/carburettor)
- Fuel Lines, tank, filter, pressure regulator
- Fuel sender unit and seal
- Inlet and exhaust valves
- Cylinder Heads/Piston
- Cylinder Walls
- Crank pins/Bearings

Three independent parties were involved in the inspection and are listed in Table 9-1. On examining components from the vehicles the inspectors were asked to comment whether there was any abnormal wear or deterioration evident that could be related to E10. Vehicle's age and distance travelled were taken into account, with their comments being based on their experience in the industry.

TABLE 9-1: VEHICLE INSPECTORS

Neville Webber		MIAME, MSAEA Automobile Engineering Consultant, Licensed Loss Assessor & Forensic Engineer
Neil Gillies		BE, Grad Dip, ME, FIEAust, MIMechE, FSAEA Consultant in Mechanical Engineering, Vehicle Engineering, Design Synthesis, Failure Investigation.
NRMA	Edward Wardell	Inspecting Engineer, Automotive Technical Services
	Owen Johnstone	B.E., PEng, MSAEA Manager Technical Support

9.1.1 Vehicles Inspected

TABLE 9-2: VEHICLES INSPECTED

Make	Model	Year	Petrol Type	Fuel Delivery	Cylinders	Trans	Odom. (km)
Ford	Falcon	1985	leaded	carburettor	6	Man. 4	102,000
Ford	Falcon EB1	1992	unleaded	fuel injection	6	Auto. 4	205,500
Toyota* *Holden Commodore	Lexcen*	1995	unleaded	fuel injection	6	Auto. 4	45,000
Mitsubishi	Magna Sedan	1995	unleaded	fuel injection	4	Auto. 4	42,000
Holden	Commodore VH	1981	leaded	carburettor	6	Auto. 3	128,500

9.1.1.1 Vehicle History

Ford Falcon 1985

Predominantly used for commuter trips around Gosford, it has travelled the last 35,000 km on a majority of E10.

Ford Falcon 1992

A BOGAS fleet car that has travelled over 200,000 km on E10 with a mixture of highway and town driving.

Toyota Lexcen 1995

Courtesy vehicle with a mix of city and Highway driving and majority of fuel used was E10. Had engine rebuild at 5000 km due to initial incorrect assembly at factory.

Mitsubishi Magna 1995

Courtesy vehicle with a mix of city and Highway driving and the majority of fuel used was E10.

Holden Commodore 1981

Predominantly used for commuter trips around Gosford it has travelled the last 35,000 km on a majority of E10.

9.1.2 Inspection Comments

The following are extracts from reports written by the inspectors. The reports are located in Appendix E.

9.1.2.1 1992 Ford Falcon

NRMA -

> *"The fuel pump/sender unit tank seal displayed advanced deterioration of its fuel contact areas."*[1]
>
> *"From the inspection of the components sighted, it is considered that the engine displays no evidence of abnormal wear, other than the top compression rings which is of some concern.*
>
> *Until further engines running on the same fuel type are inspected, a reserved judgement as to the prime cause of the top ring wear is held."*[2]

Neil Gillies –

> *"No unusual condition of any of the fuel hoses or seals on the vehicle were noted."*
>
> *"Although possibly different from that expected with petrol only, there were no significant problems found with the engine condition and thus none which could be attributed to the ethanol."*

N. Webber –

> *"The examination of components available for inspection did not reveal any significant deterioration within the motor."*
>
> *"There was no evidence of serious seal deterioration at injectors, sender unit or pressure regulator."*

[1]Throughout the trial this was a common problem with Ford Falcon sender unit seals, and no other vehicles involved in the trial experienced this deterioration. On further investigation a vehicle running on local Sydney fuel experienced the same sender unit deterioration. Materials Compatibility, Section 8

[2] The other vehicles inspected showed no indication of the same abnormal compression ring wear.

FIGURE 9-1: FUEL PRESSURE REGULATOR SHOWING NO SIGNS OF DETERIORATION

9.1.2.2 1985 Ford Falcon

NRMA –

> *"No evidence of major deterioration of the carburettor gaskets, fuel bowl or fuel hose or emission component hoses. The fuel sender unit and associated fuel lines displayed no abnormal deterioration or corrosion damage."*
>
> *"None of the wear present as listed in this report can be attributed to the Ethanol fuel blend used by the vehicle."*

N.Gillies –

> *"No unusual condition of any of the fuel hoses or seals on the vehicle were noted."*
>
> *"Although possibly different from that expected with petrol only, there were some problems found with the engine condition but these are regarded as attributed to inadequate lubrication and overheating and not to the ethanol."*

N.Webber-

> *"Fuel lines, carburettor and ancillary items did not reveal any significant deterioration or chemical reaction.*
>
> *The fuel tank, sender unit and ancillary fuel lines were also found to be in serviceable condition."*

9.1.2.3 1981 Holden Commodore

NRMA –

> *".... it is my opinion that the engine displays general wear consistent with indicated distance travelled.*
>
> *No evidence could be attributable to the use of an Ethanol fuel blend."*

N.Gillies –

> *"No unusual condition of any of the fuel hoses or seals on the vehicle were noted."*
>
> *"Although possibly different from that expected with petrol only, there were some problems found with engine condition but these are regarded as attributed to inadequate lubrication and conditions of use and not to the ethanol."*

N.Webber –

> *"Fuel tank seals and filter were serviceable."*
>
> *"There was no evidence of corrosion having formed within the fuel tank."*
>
> *"The wear factor acknowledged is what one would reasonably expect from normal operation considering the age of the vehicle and the kilometres travelled."*

9.1.2.4 1995 Toyota Lexcen

N.Webber –

> *"Fuel pump, fuel tank and filler cap were free from corrosion or seal deterioration."*
>
> *"The six injectors were checked. Delivery and spray pattern were found to be satisfactory in both facets of operation."*
>
> *"The examination of component parts available did not reveal any major operational problems."*

NRMA –

> *"From the items inspected from the dismantled engine it is my opinion that no detrimental wear has taken place due to the usage of an 'Ethanol' blend fuel."*

N.Gillies –

> *"Although possibly different from that expected with petrol only, there were some problems found with the engine condition but these are regarded as attributed to the conditions of use and not to the ethanol."*

9.1.2.5 1995 Mitsubishi Magna

N.Webber –

> *"Ancillary fuel hose appeared serviceable with no apparent deterioration.."*

NRMA –

> *"From the items inspected it is my opinion that no abnormal wear was detected that could be associated with usage of an 'Ethanol' blend fuel."*

9.1.3 Conclusion - Engine Inspection

The inspectors found nothing untoward in the examination of the five vehicles that have run on E10. There was no indication that E10 had promoted any abnormal, detrimental, accelerated, or excessive wear in the inspected vehicles' engines. All fuel system components, seals, injectors and gaskets, showed little to no abnormal wear compared to the inspectors' experiences of neat petrol driven vehicles.

This is in agreement with SAE Information Report J1297 Mar 93 "Alternative Automotive Fuels" where no unusual engine wear problems have been observed using E10.

9.2 Oil Analysis

All the Long Term In-Service (LTIS) fleet had periodic oil samples taken and analysed. Analysis of the engine oil enables abnormal wear and oil deterioration trends to be observed. While other studies have not reported engine wear troubles on similar blends to E10, confirmation on the Australian fleet is required.

9.2.1 LTIS Fleet

TABLE 9-3: LTIS FLEET

Make	Model	Year	Petrol Type	Fuel Delivery	Cylinders	Trans	Odom. (km)
Ford	Falcon EB1	1992	unleaded	fuel injection	6	Auto. 4	205,500
Ford	Falcon EB2	1992	unleaded	fuel injection	6	Auto. 4	242,500
Ford	Falcon XF	1985	leaded	Carburettor	6	Man. 4	102,000
Ford	Laser KF	1994	unleaded	Carburettor	4	Man. 5	60,500
Holden	Commodore VH	1981	leaded	carburettor	6	Auto. 3	128,500
Holden	Commodore VR	1994	unleaded	fuel injection	6	Auto. 4	54,500
Mitsubishi	Magna TS (Sedan)	1995	unleaded	fuel injection	4	Auto. 4	42,000
Mitsubishi	Magna TS (Wagon)	1995	unleaded	fuel injection	4	Auto. 4	42,000
Toyota	Camry	1993	unleaded	fuel injection	4	Auto. 4	87,500
Toyota	Corolla	1992	unleaded	fuel injection	4	Auto. 4	70,000
Toyota* *Holden Commodore	Lexcen*	1995	unleaded	fuel injection	6	Auto. 4	45,000

9.2.2 Oil Sampling

Samples were taken using Patmar Industries Pty. Ltd. sample pump and they were labelled with vehicle identification, date, and odometer reading. Prior to taking an oil sample the engine was run to ensure a uniform mix of the engine oil. The sample was then taken at a point so as to avoid contamination of residue on the bottom of the sump.

9.2.3 Requirements of an Engine Oil

A modern engine oil is expected to perform the following:Clean engine surfaces to prevent build up of contaminants.

- Disperse these contaminants.
- Provide correct lubrication film thickness through the temperature ranges encountered to lubricate and remove heat from the sites of potential wear.
- Provide a slippery coating of anti-wear material on moving surfaces.
- Counteract corrosive materials in the oil.

- Rapidly eliminate the possibility of air entrapment caused by agitation.
- Remain fluid at normal cold start conditions.

9.2.4 Tests Conducted

Analysis of the oil was carried out by Oilcheck Pty. Ltd.

As stated previously, no concerns have risen with regard to any adverse effect of E10 on engine oil and its properties. The oil samples collected were fully analysed for all the following properties to confirm previous findings:

- Viscosity
- Oxidation
- Nitration
- Pentane Insolubles
- Dispersancy
- Acid Index
- Total Base Number
- Water Content
- Fuel
- Dilution
- Wear Metals
  - ~ iron
  - ~ chromium
  - ~ copper
  - ~ lead
  - ~ aluminium
  - ~ tin
  - ~ silicon
  - ~ sodium

In the analysis of the oil results there are two areas that are looked at for possible influences by E10. Firstly the quality of the actual oil may be degraded by E10 and secondly E10 may influence the wear rate of the engine. By examining the physical, chemical, contamination and wear metals properties of the oil across the range of test vehicles the effect of E10, if any, can be established if trends exist.

9.2.5 Viscosity and Viscosity Index

Viscosity measurements of new and used oil characterise the lubricant as to its grade. Viscosity grades are listed as SAE or ISO.

ISO grades for lubricants are calculated as the Viscosity in mm2/s (Centistokes) at 40°C. SAE grading establishment is controlled at 100°C. A typical new oil used would have an SAE 20W-40 grade with 5.6 cSt minimum and a 16.3 cSt maximum at 100°C.

The viscosity values at 100 °C, shown in Figure 9-2, are reasonable, with all vehicles within acceptable limits with the exception of the Commodore VR. There is no trend to indicate viscosity is being influenced by E10. It should be noted that viscosity is not a measure of the oil’s quality.

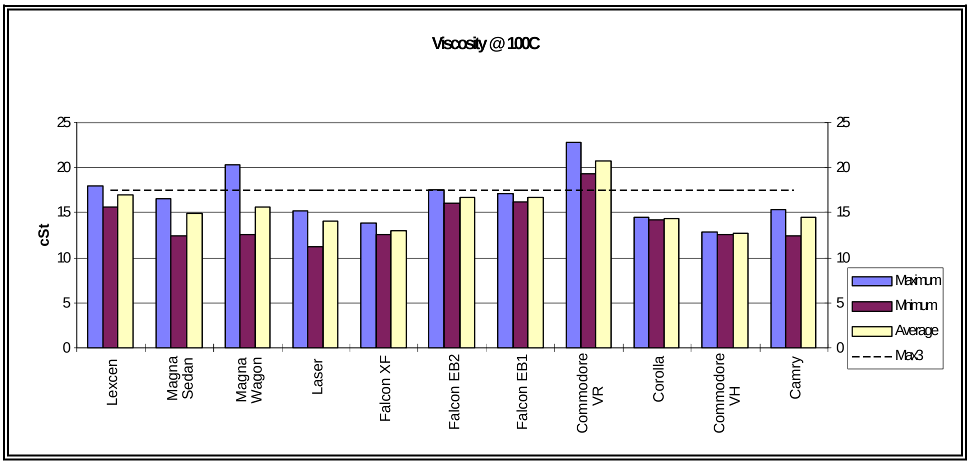

FIGURE 9-2: VISCOSITY @ 100 °C

9.2.6 Total Base Number for Engine Oils

Corrosion inhibitors are added to counter acidic effects on metals. In engine oils, reserve alkalinity is included in the formulation to neutralise acids formed by combustion. This is reflected by the Total Base Number (TBN) of an engine oil.

The TBN value of an oil is calculated from the amount of acid that is required to counteract its basic characteristics. The TBN is expressed as the equivalent mass in milligrams (mg) of potassium hydroxide (KOH) per gram of the oil.

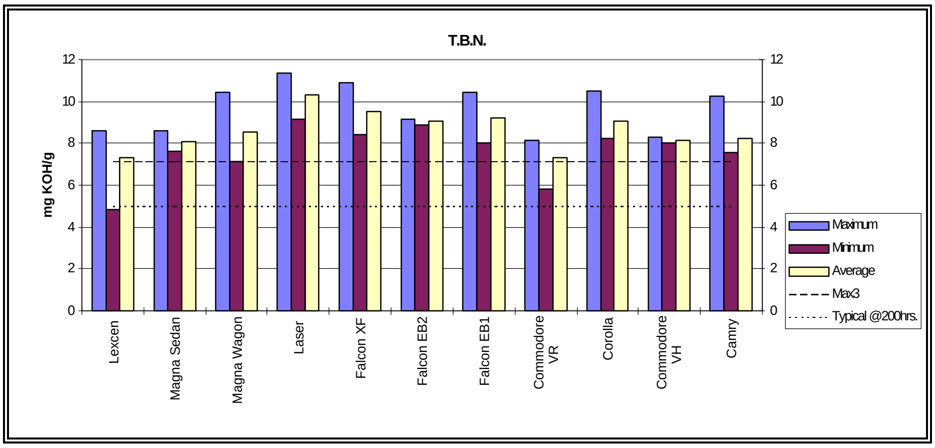

FIGURE 9-3: TOTAL BASE NUMBER

Figure 9-3 shows the spread of TBN for the long term in-service test fleet. When the TBN reaches 50% of the oils original TBN rating it is considered unusable. The MAX 3 has a TBN rating of 8.9, which the Magna Sedan and Lexcen were using, and their values are above a TBN of 4.5 indicating no problems. The other test vehicles are run on any of the commercial automotive oils.

Oilcheck Pty. Ltd. state that a 50 % TBN of 5 is representative of most common commercial oils, and reveals no problems with the other test vehicles.

9.2.7 Acid Index.

The TBN value above employs detection of the neutralisation point of the oil by means of a colour change. Acid Index test procedure utilises the acid that can be extracted from the oil by water containing an indicator solution, which is very sensitive to acid content, to effect a colour change through 5 separate steps. The ratings are listed below:

- Typical of new oil with little or no water extractable acid. Oil is suitable for use.
- Typical of a used oil with low acidity level. Oil is suitable for further use.
- Typical of used oil with a medium acidity level. Oil is suitable for further use.
- Typical of a used oil whose acidity level has increased to a point where the oil requires changing.
- Typical of used oil with significant acidity level. The oil is overdue for a change.

The acidity reflects blow-by gas condensations, oil oxidation and other sources of acidity.

The high acidity levels being experienced, Figure 9-4, are normally associated with oxidation of the engine oil and/or contamination of the oil by combustion products. Another factor that can affect the acid index is storage, with the possibility of acidity levels increasing {29}. The large majority of samples collected were stored over two months before being analysed and it is a high possibility that this is the cause for the high levels as other reports have not reported this problem.

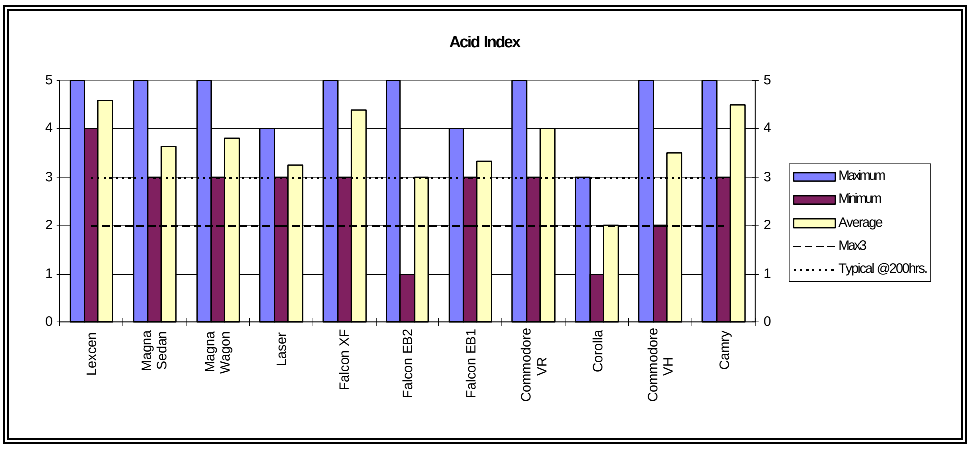

FIGURE 9-4: ACID INDEX

9.2.8 Water Content

Contamination of an oil-based lubricant, by water, can damage the metal to metal surfaces that the lubricant is designed to protect. Water will promote oxidation in the oil as well as possible corrosion in the compartment. Ingress of moisture can be sourced from atmospheric condensation sucked into the compartment on cooling of the oil, condensation of engine blow-by gases and possible leakage from cooling systems.

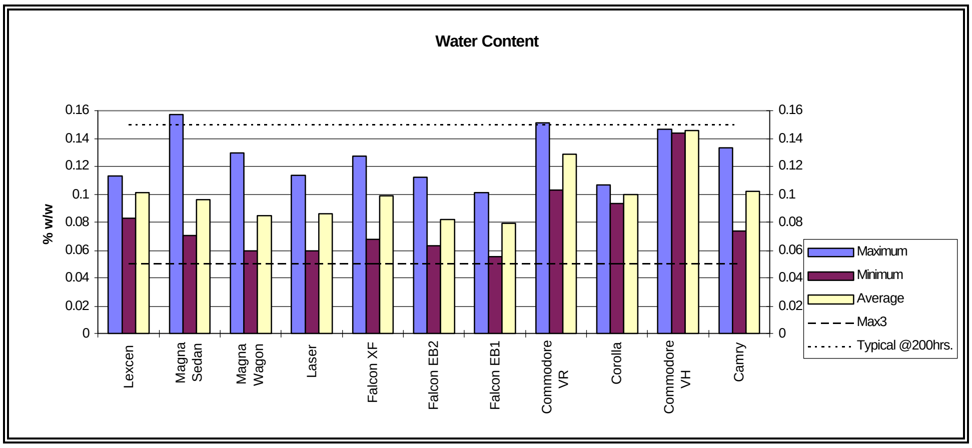

FIGURE 9-5: WATER CONTENT

Figure 9-5 shows the water content of the test vehicles. All except for the Magna Sedan fall within acceptable limits of below 0.15 % w/w. The Magna Sedan had one sample at 0.157 % w/w of water, but raises no concern as, on subsequent samples the value had fallen within the established limit.

9.2.9 Fuel Dilution

Figure 9-6 shows fuel dilution of the samples taken. It is seen that the Falcon XF and Commodore VH have a relative high percent fuel dilution and are above the typical value. These two vehicles are carburetted and are the oldest vehicles in the fleet. The vehicles have covered considerable kilometres(102,117km, 128,465km). The dilution problem is likely to be poor ring seal resulting in unburned fuel being blown past the rings. Also, both vehicles are mainly driven for short commuting trips, which does not promote the normal evaporation of the fuel from the oil, as in medium to long commuting trips.

The other test vehicles have some minor deviation above the expected value of 3.5 % w/w but not to any large extent and general trends do not suggest any concerns developing.

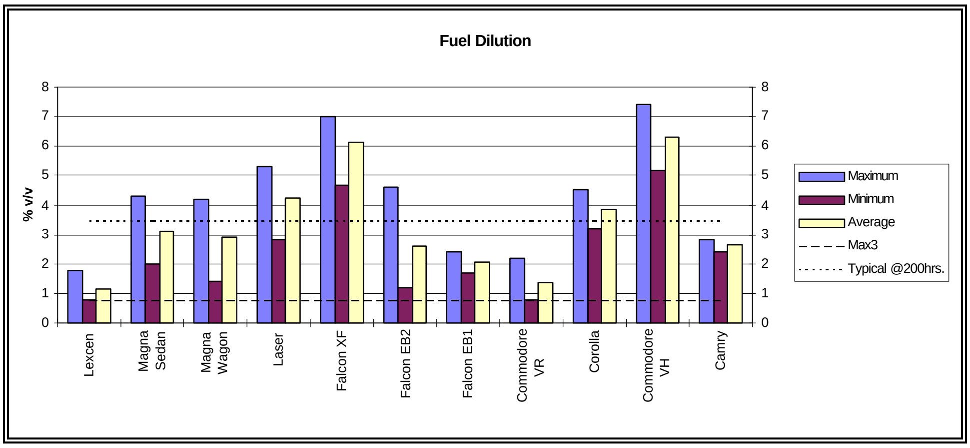

FIGURE 9-6: FUEL DILUTION

9.2.10 Dispersancy

Dispersant additives are incorporated in engine oil formulations to ensure that minimal accumulation of contaminants causing sludging will occur. Sludging is the combination of mainly moisture and soot or wear debris from the engine. It can adversely affect the engine operation through filter plugging, deposition on moving surfaces and by thickening of the oil to an extent that incorrect lubricant supply will result.

Dispersancy is assessed as;

- ♦ GOOD — Satisfactory dispersant properties in oil.
- ♦ FAIR — Unsatisfactory dispersant properties. An oil change is required. Normally, other parameters of analysis will be adverse.
- ♦ POOR — Totally unacceptable or no dispersant properties in oil. Oil in this state will be considered overdue for change and will also be reflected in adverse test results in other areas.

All vehicles except the Commodore VR had good dispersancy. The Commodore VR received three “poor” ratings out of four samples analysed for the vehicle, the fourth received a “good” result.

On two occasions, when samples were taken from the Commodore VR, the oil level was noted as being below the low level maker on the oil dip stick. This indicates that the vehicle has been running on a small amount of oil. Whether due to an oil leak or poor servicing, an increased deterioration of the oil would be expected. The “Poor” dispersancy also ties in with the high viscosity.

9.2.11 Pentane Insolubles or Soot Content.

Levels of about 0.02 % by weight indicate a slight detrimental effect on the oil and gives evidence of "sooting" usually caused by poor ring seal. The root causes of these problems could be excessive periods of idle running, cold running, or fuel washing the oil seal away in cases of defective injectors.

When levels above 0.2 % by weight are experienced, a definite problem has occurred and renders the oil unsuitable for further use.

Analysis of the oil for pentane insolubles, Figure 9-7, reveals no indication of any problem present or developing.

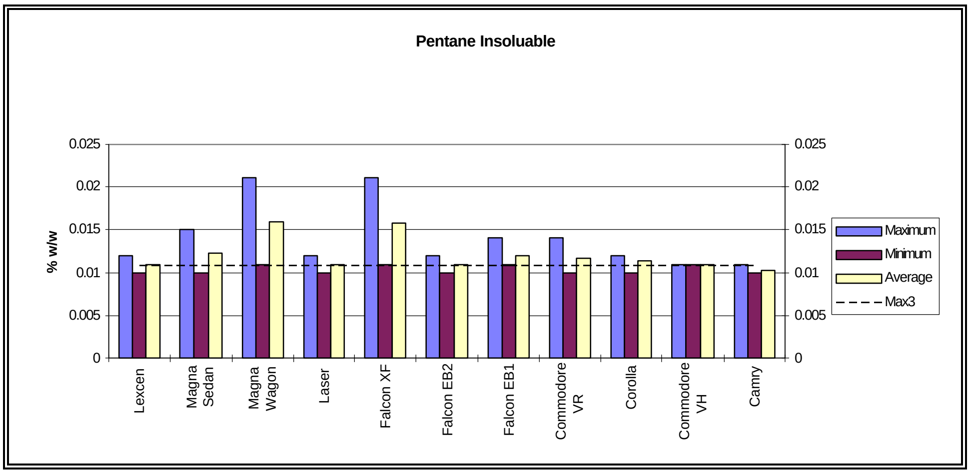

FIGURE 9-7: PENTANE INSOLUBLES

9.2.12 Nitration

Nitrogen oxides formed in the combustion process are mostly vented to the atmosphere, with the rest of the exhaust, but some will combine with soot, oxidation and sulphation products that are absorbed and remain in the oil. These form part of the pentane insolubles.

Typically new oil has a Nitration value of around 10. Values up to approximately 20 are considered normal for used oil{29}. All Nitration values, Figure 9-8, fall within normal values for used oil.

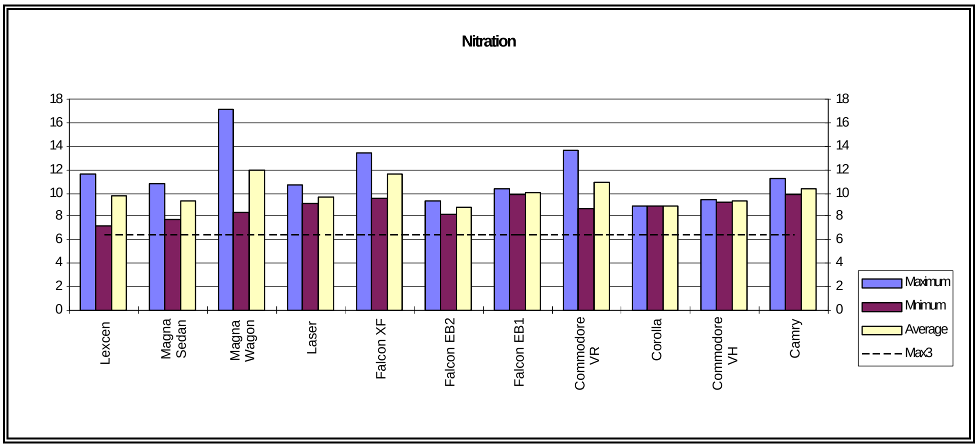

FIGURE 9-8: NITRATION

9.2.13 Oxidation

Lubricants will oxidise when exposed to air or products of combustion in engine oils. An increase in oxidation from the "new oil" value (typically 18), is a measure of how the oil is standing up to the harsh environment in which it must operate. The smaller the number the lower the amount of oxidation.

Oxidation-preventing additives, called oxidation inhibitors, are generally incorporated into most formulations to counteract the effect that oxygen and heat, the major cause of the oxidation, have on the lubricant.

For used oil, values below 40 are considered normal. In Figure 9-9 it can be seen that all values are below 40, indicating no adverse influence of E10 on the oxidation.

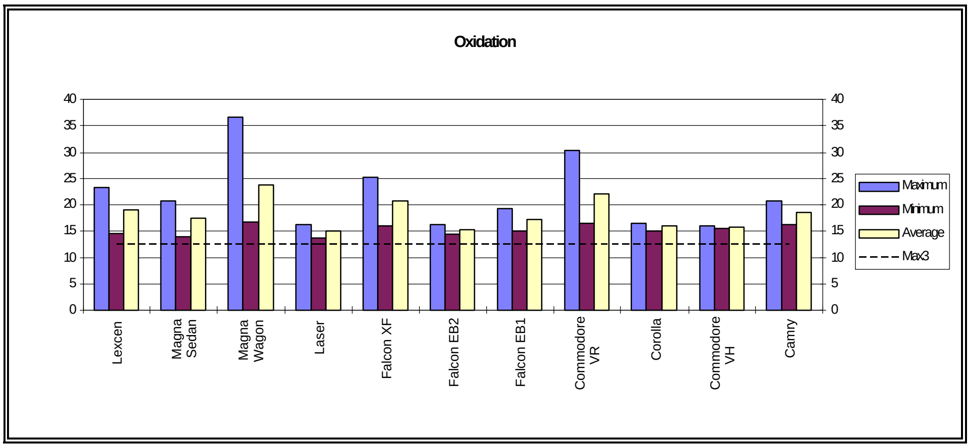

FIGURE 9-9: OXIDATION

9.2.14 Wear Metal Analysis

9.2.14.1 Lead

Six of the LTIS vehicles show signs of questionable lead levels, namely the Lexcen, Magna Wagon, Falcon XF, Falcon EB1, Commodore VR and Commodore VH as seen in Figure 9-10.

The Falcon XF and Commodore VH are both leaded petrol vehicles and have extreme levels of lead above 800 ppm and are not fully shown in Figure 9-10. The majority of the lead traces in these two vehicles would most likely be from the high fuel dilution levels (Section 9.2.9) and the lead contained in the fuel. The amount of lead obtained from other sources, if any, is not determinable for these two leaded vehicles.

For the other unleaded vehicles (Lexcen, Magna Wagon, Falcon EB1 and Commodore VR) lead elevation may indicate wear of the slipper bearing.

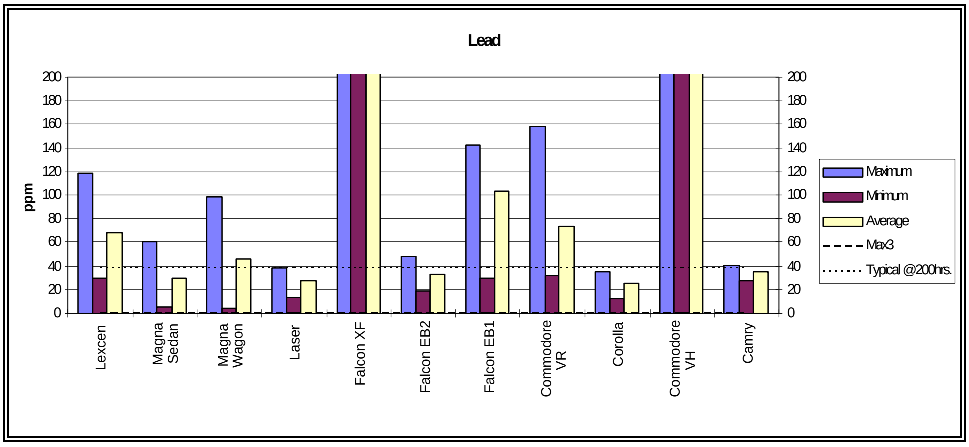

FIGURE 9-10: LEAD - WEAR METAL ANALYSIS

9.2.14.2 Iron

Figure 9-11 shows the iron levels of the LTIS fleet, the Falcon XF has extremely high levels of iron in its samples. The Magna Wagon and Falcon EB1 show some signs of high iron levels with both only having one sample with an elevated level and not raising any concern. The iron levels are normally sourced from cylinder liner/rings in engines, and bearings.

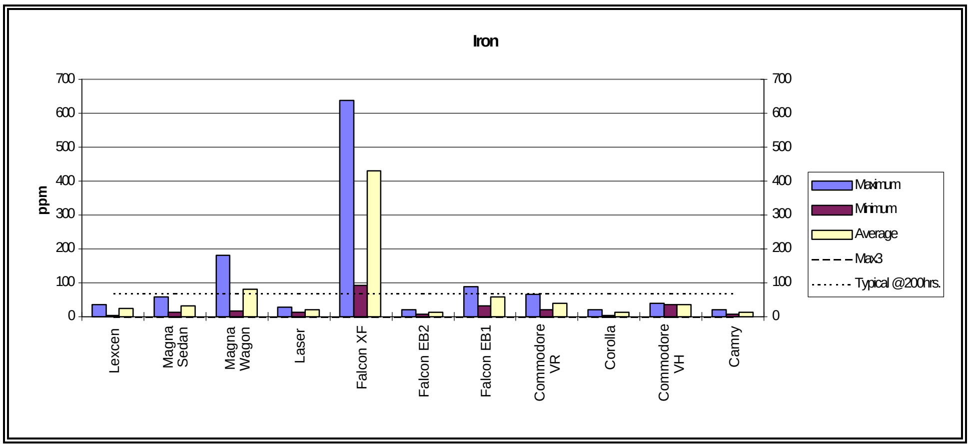

FIGURE 9-11: IRON - WEAR METAL ANALYSIS

9.2.14.3 Chromium

Only the Falcon XF showed elevated levels of Chromium, again indicating possible signs of wear

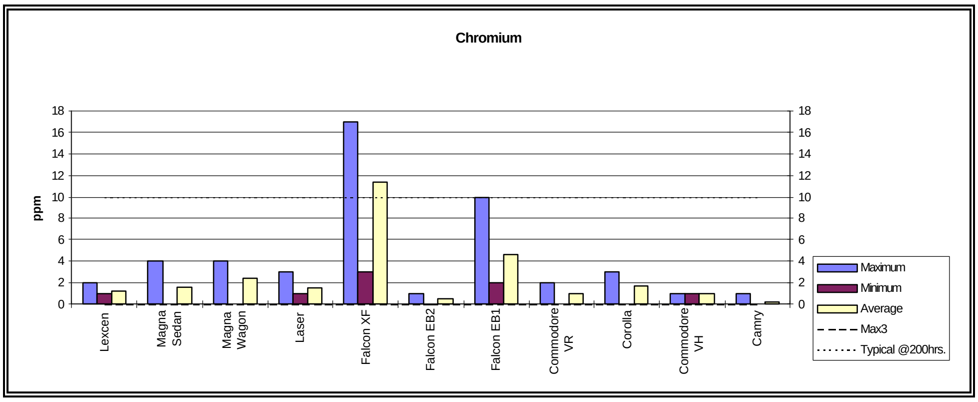

FIGURE 9-12: CHROMIUM - WEAR METAL ANALYSIS

9.2.14.4 Copper

Four vehicles are shown to have elevated copper levels in their oil samples, (Figure 9-13). The Lexcen, Falcon XF and Commodore VR have values that are all above typical copper levels expected. As with elevated lead values elevated copper values indicate possible slipper bearing wear.

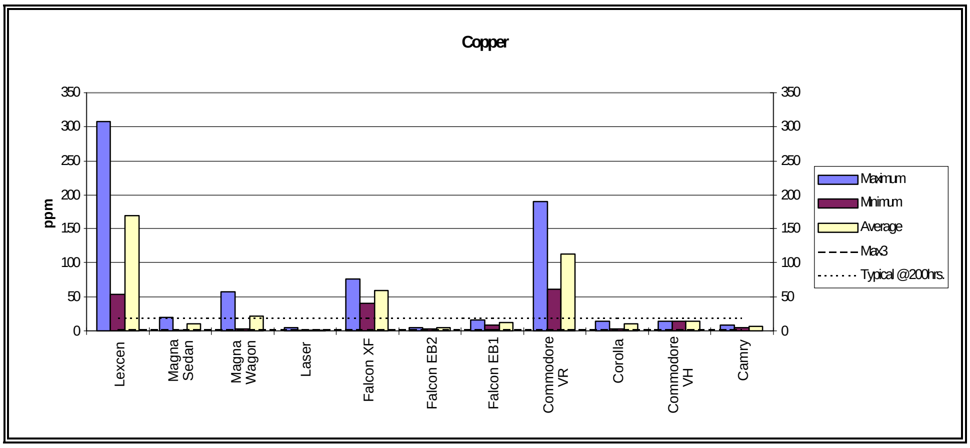

FIGURE 9-13: COPPER - WEAR METAL ANALYSIS

9.2.14.5 Tin

The Lexcen had one sample that had an elevated tin level, Figure 9-14. This one sample presents no concern as subsequent samples were normal. Elevated tin level is again a sign of possible slipper bearing wear

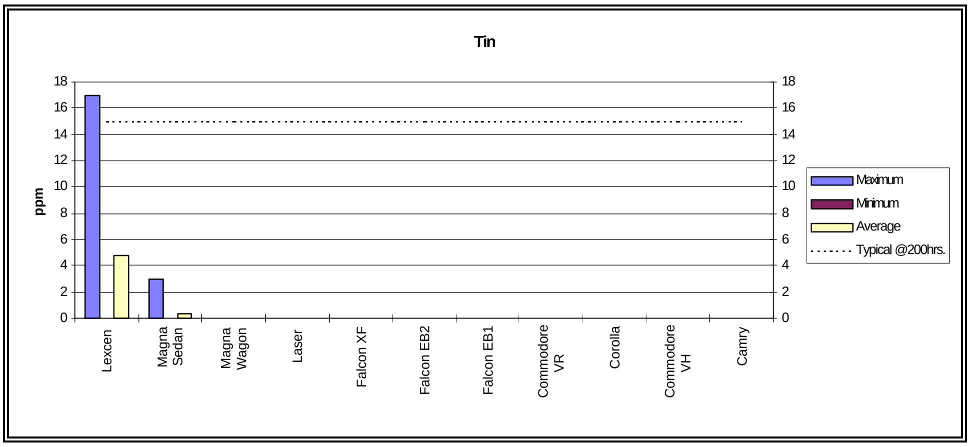

FIGURE 9-14: TIN - WEAR METAL ANALYSIS

9.2.14.6 Aluminium

Elevated levels of aluminium are present in three vehicles, Magna Sedan, Magna Wagon, and Falcon XF as seen in Figure 9-15. Aluminium is associated with piston material in engines, and bearings in some instances.

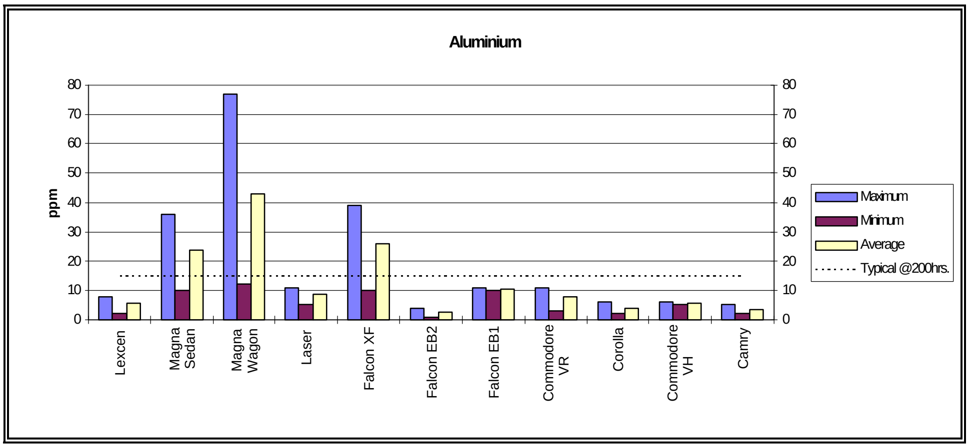

FIGURE 9-15: ALUMINIUM - WEAR METAL ANALYSIS

9.2.14.7 Silicon

Silicon is an indication of contamination of the oil by dirt that may lead to accelerated wear. Dirt may enter the oil during oil filling, engine maintenance, or via the air intake where the air filter is faulty or incorrectly fitted. An additive of silicon or silicon sealant may also be reflected, typically around 10 ppm.

From Figure 9-16 the Lexcen, Magna Sedan, Magna Wagon, Falcon XF, Commodore VR and Camry show signs of elevated silicon contamination.

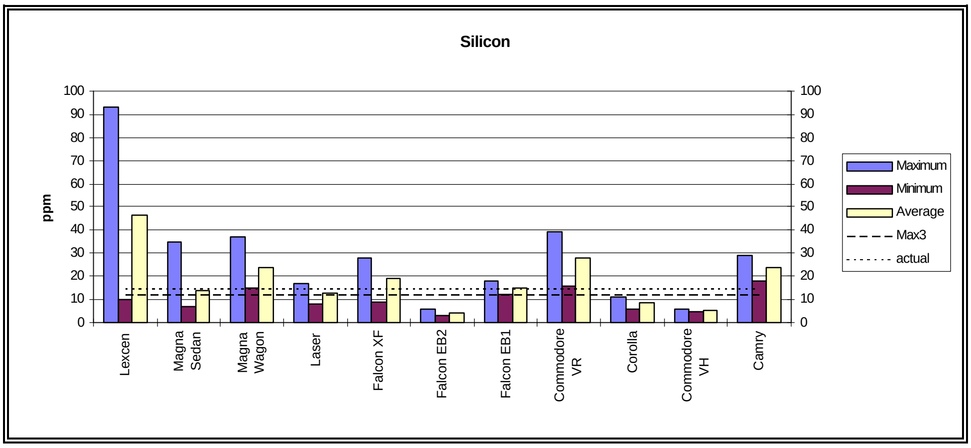

FIGURE 9-16: SILICON - WEAR METAL ANALYSIS

9.2.14.8 Sodium

Sodium traces within the sample normally indicate coolant leakage - though it can be consistent with some oil formulations. All vehicles show some sign of sodium traces. The Corolla has a consistently high sodium level, Lexcen and Magna Sedan have one sample each that is high but other samples show acceptable values. The Commodore VR's sodium levels are all above the typical but only one is considered high.

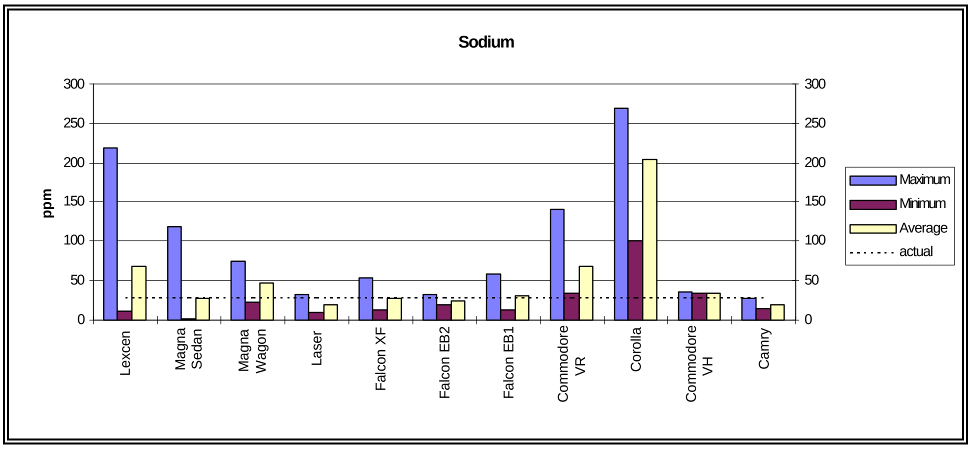

FIGURE 9-17: SODIUM - WEAR METAL ANALYSIS

9.2.15 Conclusion - Oil Analysis

The oil properties are all within normal ranges indicating that the E10 is not having any adverse reaction with the oil.

A summary of high readings on the wear metal analysis and contamination products are shown in Table 9-4: Wear Metal Summary. The Lexcen, Magna Sedan, Falcon XF, Falcon EB1 and Commodore VH had their engines stripped down and inspected, and revealed no metal wear that could be attributed to E10.

TABLE 9-4: WEAR METAL SUMMARY

	FUEL DILUTION	IRON	CHROMIUM	COPPER	LEAD	ALUMIUM	TIN	SILICON
Camry								X
Commodore VH*	X				X			
Lexcen*				X	X		X	X
Commodore VR				X	X			X
Corolla								
Falcon EB1*					X			X
Falcon EB2								
Falcon XF*	X	X	X	X	X	X		X
Magna Sedan*						X		X
Magna Wagon					X	X		X
	2	2	1	3	6	3	1	7

*Engines were stripped and inspected

10 WATER TOLERANCE ISSUES

While neat petrol and neat ethanol mix, they may separate in the presence of water or addition of water. Therefore, in the blending, storage, and distribution of E10, water contamination issues must be addressed.

10.1 Phase Separation

The laboratory derived ternary mutual solubility diagram for petrol, ethanol and water at 20 °C is shown in Figure 10-1. The water tolerance characteristics can be seen with both neat petrol and E10 being susceptible to phase separation with the addition of water. The actual occurrence of phase separation is rare. However, the water absorption that can eventually lead to phase separation is less rare and is most commonly caused by improper fuel storage practices at the fuel distribution or retail level, or due to the accidental introduction of water during vehicle refuelling.

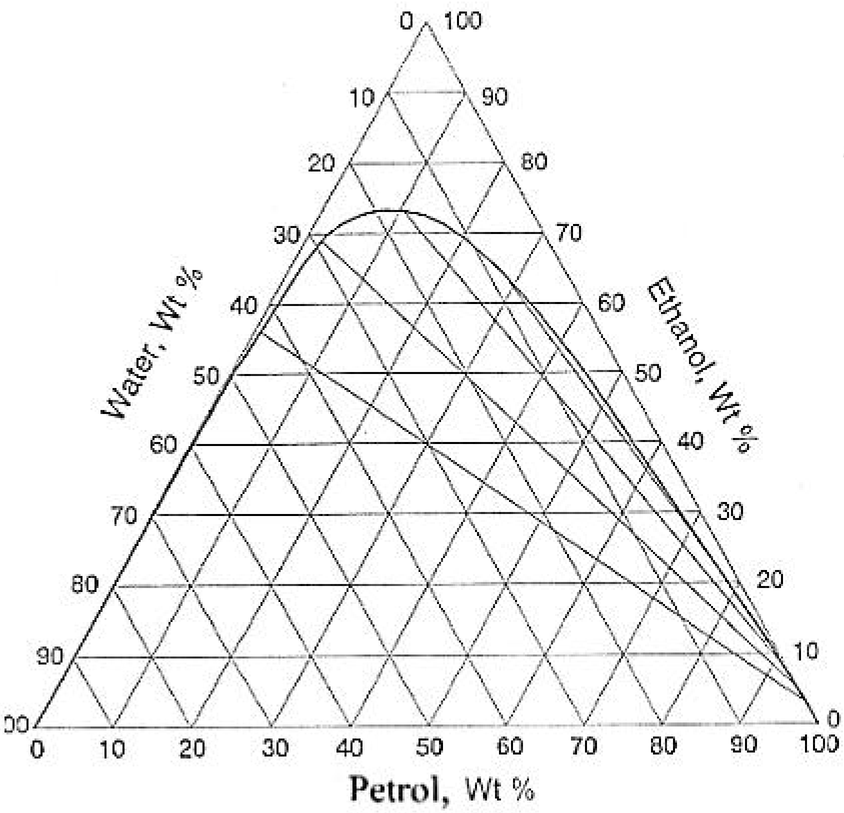

FIGURE 10-1: TERNARY MUTUAL SOLUBILITY DIAGRAM AT 20°C

10.1.1 Neat Petrol

The ability of neat petrol to absorb water, its water tolerance, is small. When phase separation occurs in neat petrol, water having a higher density than petrol will form a layer below the petrol. As most engines obtain their fuel from at, or near, the bottom of their fuel tank, engines will experience vehicle drivability troubles or complete stoppage once separation has occurred depending on the quantity of water separated.

10.1.2 E10

The situation is more complicated for E10. E10 can absorb significantly more water without phase separation occurring and can actually dry out fuel tanks by absorbing the water and allowing it to be drawn harmlessly into the engine with the fuel.

However, if too much water is introduced into an ethanol-containing petrol, the water and most of the ethanol (typically 60-70%) will separate from the petrol and the remaining ethanol. The amount of water that can be absorbed by ethanol-blended petrols without phase separation, varies from 0.3 to 0.5 volume percent, depending on temperature, aromatics and ethanol content{4}. If phase separation does occur, the ethanol/water mixture would be drawn into the engine. In general, no petrol engine can run on this mixture (except those also designed to run on high ethanol content blends).

When E10 separates due to contamination by 0.5% water, two phases will exist, one a 93% petrol and the other a 7% water (0.5%) and ethanol phase at the bottom of the tank. If similar amount of water was introduced to neat petrol only a 0.5% phase of water would exist at the bottom of the tank. The 10% ethanol/water blend would be more likely to cause engine stoppage/drivability problems, than just a 0.5% water phase, due to a larger volume of unusable phase.

10.2 E10 Blending

Splash blending is the mixing of ethanol with petrol meeting the industry codes of practice. The mixing may be done in a number of ways:

- in storage tanks;
- in-line blending; or
- blending in a truck prior to delivery.

BOGAS carries out its blending of E10 in road tankers using industry practice as follows:

- Temperature of neat ethanol and neat petrol taken and used for precise measure of quantities.
- Road tanker (25,000*l*) filled to 10% of capacity with neat ethanol.
- Neat petrol is then bottom filled into the tank to make the remaining 90% volume capacity of the tank.

The agitation of bottom filling the tank ensures a reliable mix, and no problems have been encountered by BOGAS with this method. Blend quantities are considered important, hence the temperature consideration in blending.

Anhydrous ethanol is used in the blend for E10 with water content maintained below 1.25% w/w{23}, which equates to 0.1ℓ of water in 10ℓ of neat ethanol. A fifty litre (50ℓ) tank of uncontaminated E10 would contain about 50 ml of water at most, and would be able to absorb a further 100-110 ml of water at 10°C before phase separation.

10.3 E10 Storage

E10 is particularly sensitive to poor handling and storage practices because of the possibility of phase separation. Basic precautions must be followed when introducing ethanol-containing fuels in a fuel distribution system for the first time. An example for underground storage preparation is shown in Figure 10-2. In general, water must be removed from fuel tanks and fuel lines to prevent water absorption and possible subsequent phase separation.

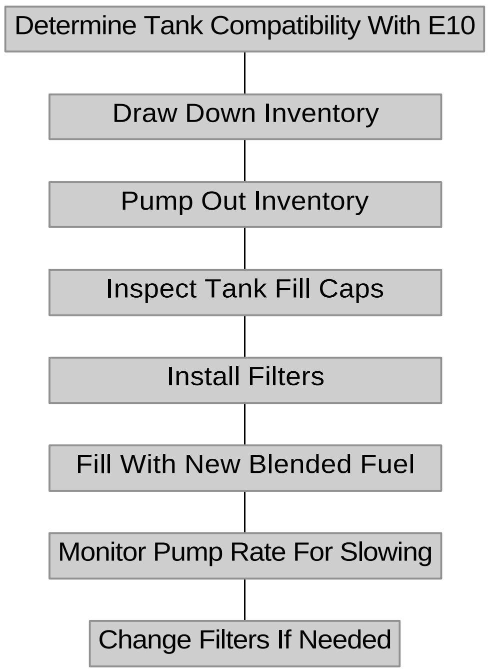

FIGURE 10-2: UNDERGROUND TANK CHANGE OVER PROCEDURE{18}

Once storage tanks and delivery systems have been cleared of water E10 may be used and the continued use will ensure no water build up, unless there is water ingress into the system through leaks.

It has been BOGAS' experience that good housekeeping practices (Table 10-1) are sufficient to control any water-related issues with use of E10. Ensuring seals are in good condition, no water build up around ground tank fill holes which may be drawn into the tank, and daily testing for water in the tanks (water testing paste has to be ethanol resistant), are all standard practices for distribution centres. Storage tanks should be checked regularly for water/ethanol bottoms.

Note: The usual water testing pastes are ineffective in the presence of ethanol (and most other alcohols).

TABLE 10-1: HOUSEKEEPING CHECKLIST FOR E10 BLENDS

Inspect manhole covers and fill pipe manholes for standing water. Follow recommended procedure to have all water removed.
Dip underground tanks with special ethanol blend water testing paste. If any water bottom is detected follow the recommended procedure to have it removed.
Monitor pump rates for any slowing and replace spin micron filter if required.
Keep fill caps tight all times unless the tank is being dipped or fuel is being delivered.

If a water/ethanol bottom exists in a storage tank, it should be pumped out as soon as possible, it may be necessary to pump out the tank completely and install fresh ethanol blend. An investigation should be made to determine the source of any water in the storage tank.

Some manufacturers in United Sstates expressed concern that ethanol-blended petrols might absorb water vapour from the atmosphere, leading to phase separation. However, evidence for this phenomenon occurring is limited at best. American States with extensive ethanol programs, have not reported problems with phase separation due to absorption of water from the atmosphere. Limited testing with ethanol blends suggests that the rate of water absorption from the atmosphere is very slow; it requires several months for open-vented marine fuel tanks to accumulate sufficient water to make phase separation possible, and another source of water is needed before separation will actually occur {4}. Of far greater concern is the accidental introduction of water, by splash or spray, during fuelling or the presence of water in the fuel tank prior to the addition of ethanol-blended petrols.

10.4 E10 Distribution

Water normally exists in the system interfacing with hydrocarbon products. This is common in port terminals where water is used for ship ballasting, pipeline product interfacing and is also common in Australian refineries. To avoid separation problems ethanol/petrol blending should occur in the final stages of distribution.

Distribution of E10 to retail outlets is the same as for neat petrol, in road tankers. The possibility of water contamination of E10 via tanker transport is small if the tankers are only and regularly used for E10 and neat petrol transport. There is evidence of successful transportation of E10 blends via pipelines{22}, but it is not recommended by the American Petroleum Institute.

The regular use of E10 will absorb and remove water from the tanker assuring no build up of a critical water mass for phase separation. If the tanker is transporting neat petrol any water present will settle on the bottom of the tank as a separate phase and since transport trucks deliver from the bottom of the tanker compartment, any accumulated water or contaminants will be dispensed into the neat petrol storage tanks where water bottoms are not unusual.

BOGAS distributes E10 by road tanker along the Central Coast and have reported no problems with the procedure, apart from an initial material compatibility problem relating to their discharge pump seals swelling in the presence of E10 that were replaced with ethanol/petrol compatible seals.

10.5 Regional Temperature Guidelines

The amount of water that can be absorbed by E10 before phase separation occurs decreases as temperature decreases. Hence an E10 blend that is stable at one temperature may separate into two phases at another lower temperature. Figure 10-3 shows the relationship of water content and temperature with phase separation for E10. A phase separation diagram such as Figure 10-3 gives a good indication of E10 and water against temperature, but actual characteristics will vary according to the base petrol used.

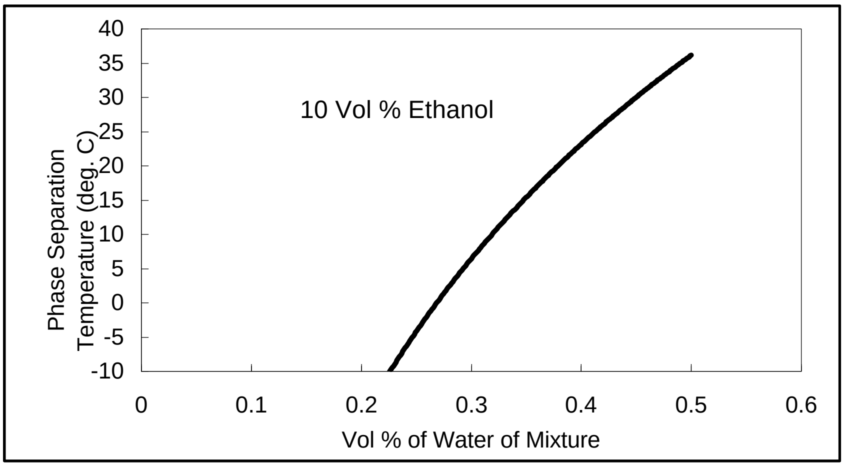

FIGURE 10-3 PHASE SEPARATION IN E10-WATER MIXTURES{16}

Phase stability of a blend can be improved by adding higher alcohols such as propanol and butanol to the E10 blend{16}. These higher alcohols reduce the temperature at which phase separation occurs. Figure 10-4 shows the effect of blending butanol to an E10 blend that has 0.4%v/v water content. To date no concern of phase stability has been raised by BOGAS (as long as good practices are in place) and hence the use of higher alcohols have not been studied within this trial.

There is some evidence that addition of higher alcohols to increase stability may be a problem with regard to materials compatibility. This was raised in a CSR study in the early 1980's{17}. Since then, automotive and material manufacturers have started using materials that are more tolerant to alcohols. Hence the concern may not be an issue today, but further study would need to be done to confirm this.

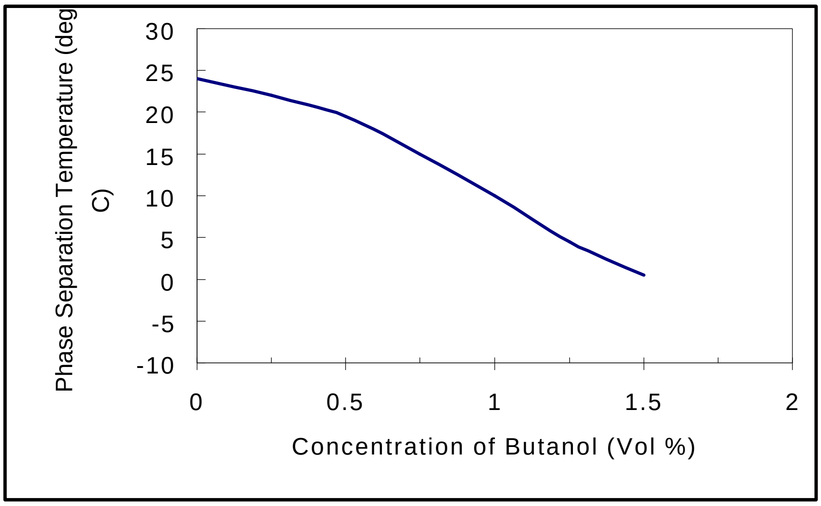

FIGURE 10-4 THE EFFECT OF BUTANOL ON THE PHASE SEPARATION OF E10 (0.4% WATER CONTENT){16}

ASTM D4814-97b "Standard Specification for Automotive Spark-Ignition Fuel" outlines a test procedure for testing oxygenated petrol to help minimise/reduce the chance of phase separation due to low temperatures. In short the blend is tested at the lowest temperature that it may be subjected to for signs of phase separation. This ensures (reduces the possibility) that uncontaminated fuel will not separate on colder days of the month. However, the blend may become contaminated after testing and increase the possibility of phase separation.

The minimum temperature used for the ASTM test is dependent on time and place of intended use, and is the 10th percentile 6-h minimum temperature (highest temperature of the six coldest consecutive hourly temperature readings of a 24 hour day). A maximum temperature limit of 10°C is in place to allow for cool underground storage during the hotter months. The 6-h minimum temperature provides information on the cold-soak temperature experienced by the fuel.

The ASTM lists United States regions with their 10th percentile 6-h minimum temperature for every month. A contour map of Australia for July 1997 lowest temperatures is shown in Figure 10-5. While these are not the 10th percentile 6-h minimum as in the ASTM, they give a good idea of the lower temperatures that E10 would experience in Australia and represent more extreme values than would be seen in the 10th percentile 6-h minimum for Australia. The lowest contour shown is -6°C, although places such as Cooma have had July minimums of -12°C. E10 blends are used successfully in the United States in areas that are below -12°C.

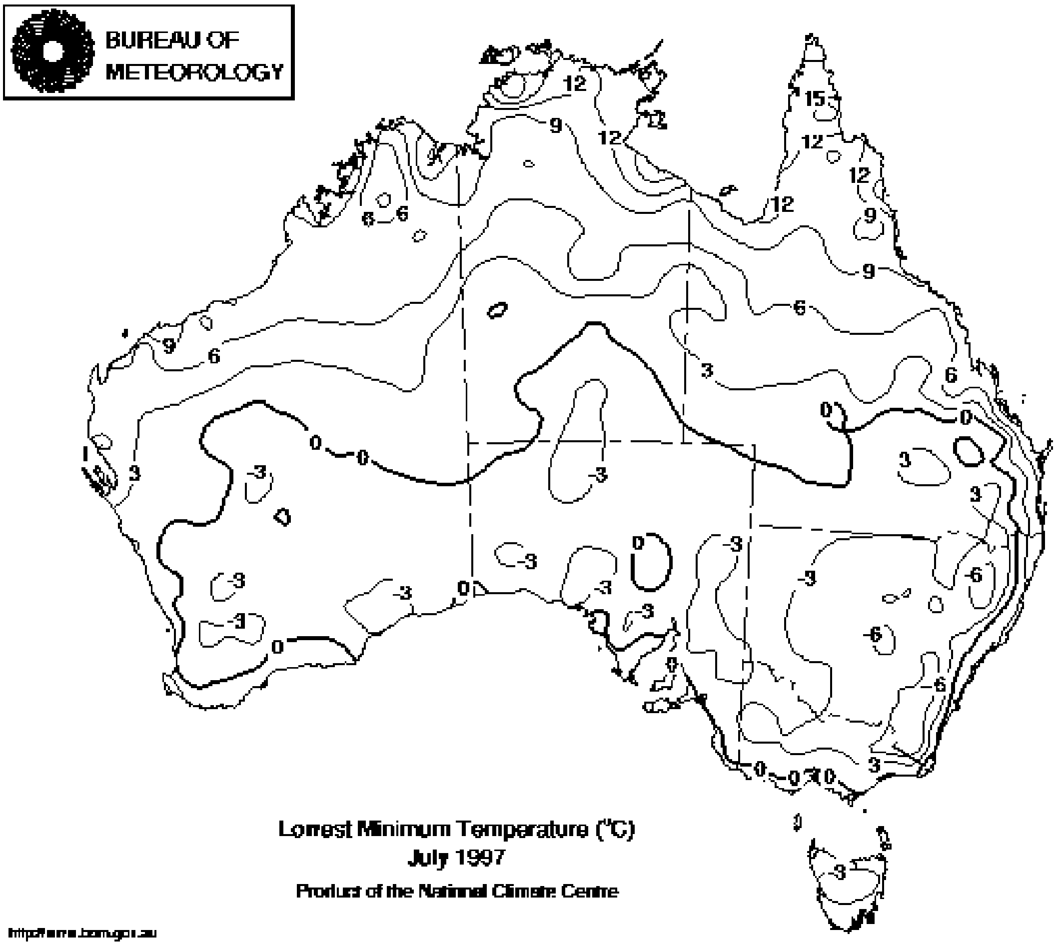

FIGURE 10-5: TEMPERATURE CONTOUR MAP BASED ON JULY 1997 LOWEST TEMPERATURES

If a similar standard is proposed for Australia it is suggested that the already existing boundaries for FVI zones be used for the minimum temperature requirements for E10 blends.

10.6 Conclusion

The phase stability of E10 is an important issue that cannot be overlooked. Being aware of E10 water tolerance characteristics, and taking the necessary precautions, will greatly reduce the possibility of phase separation.

The use of anhydrous ethanol with a water content of no more than 1.25%w/w{23} in the blending of E10, will enable E10 to absorb a significant amount of water before phase separation occurs. Ensuring storage and distribution facilities are free from water before the introduction of E10, and good house-keeping practices, reduces the possibility of phase separation affecting the end user.

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