# Market Barriers to the Uptake of Biofuels Study

# A Testing Based Assessment to Determine Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Passenger Vehicle Fleet

## Report to Environment Australia

**March 2003**

**Orbital Engine Company**

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## APPENDICES

# 1 Executive Summary

This document presents the findings of vehicle testing completed by the Orbital Engine Company in order to assess the impact of gasoline containing 20% by volume ethanol on the Australian passenger vehicle fleet. The program is an initiative of the Environment Australia project “Market Barriers to the Uptake of Biofuels – Testing Petrol Containing 20% Ethanol (E20)”. The program comprised two components, these being a desktop study and an experimental study. Both components have run in parallel with the desktop study reports submitted to Environment Australia in October and November 2002.

The desktop studies were undertaken with the intent of providing further focus and substantiation to the experimental study work scope. These studies resulted in the submission of reports to Environment Australia covering: 1) “A Literature Review Based Assessment on the Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Vehicle Fleet”; and 2) “A Technical Assessment of a Failure Mode and Effects Analysis Output for the Application of the E20 Petrol Ethanol Blend Fuel into the Australian Vehicle Fleet”. These reports have confirmed that the proposed experimental program is sufficiently broad in terms of capturing the potential issues identified.

The experimental study work scope has three major components reported:
- Vehicle performance and operability testing
- Vehicle durability testing
- Component material compatibility testing.

A number of other elements to this study included in this report are:
- An assessment of the impact on greenhouse gas emissions.
- A literature review on Well to Wheel greenhouse gas emissions evaluations.
- An assessment of the impact on the paint work on the fuel filler area of new vehicles.

The vehicle durability testing is not reported in this document, as this testing has been categorised as a separate phase and has just been initiated. The planned completion timing of this activity is May 2004. This activity is considered crucial, as it will provide detailed data related to the impact of the E20 fuel blend on the durability of many vehicular systems, in particular the catalyst in terms of regulated emissions, air toxic emissions and greenhouse gases.

The vehicle testing program included nine different vehicle makes or models, and was comprised of 5 new vehicles and 4 old vehicles (model year 1985 to 1993). The vehicles were selected in consultation with The Department of Transport and Regional Services and Environment Australia to ensure adequate representation of the Australian passenger vehicle fleet.

## 1.1 Vehicle Performance Impacts.

Vehicle operability testing was performed to determine the impact of E20 on general vehicle operation, including the impact on vehicle acceleration, driving quality, fuel economy and emissions.

### 1.1.1 Engine Power Evaluation.

For both the new and old vehicles, the result of the acceleration testing indicates that there is no evidence of a detriment in power caused by the use of E20 fuel. However increases in exhaust gas temperature were measured in five of the nine vehicles tested with three showing increases in catalyst temperature. Enleanment was found to occur on six of the nine vehicles tested, with three of these vehicles having closed loop type control systems (closed loop refers to feedback control technique used to control inputs to achieve desired outputs). In general the increase in exhaust gas temperature was found to follow those vehicles with enleanment. The enleanment and rise in exhaust gas temperature is of concern as the rise in exhaust gas temperature has the potential to impact on engine and aftertreatment durability.

### 1.1.2 Tailpipe Emissions Evaluation.

#### 1.1.2.1 Regulated Tailpipe Emissions for New Vehicles.

The results from the 5 new vehicles when tested to the relevant emissions standard (ADR37/01) of the effect of E20 on regulated emissions showed:

- Total unburnt Hydrocarbon (THC) emissions were generally reduced, with an average reduction over all vehicles of 30%.
- Carbon monoxide (CO) emissions were generally reduced, with an average reduction over all vehicles of 29%.
- Oxides of Nitrogen (NOx) emissions were generally increased, with an average increase over all vehicles of approximately 48%.
- The magnitudes of the changes in emissions levels were substantially different for each individual vehicle when compared to the average for all vehicles.

Because of the large differences in magnitude of change in emissions between vehicles when using E20, a simple calculation was performed to estimate the impact on city cycle regulated emissions from new vehicles of E20 compared to gasoline only fuel. This estimate is based on the new car volumes of several different vehicle classes, and estimated the impact of E20 to be:

- THC reduction of approximately 28%
- CO reduction of approximately 21%
- NOx increase of approximately 34%

#### 1.1.2.2 Regulated Tailpipe Emissions for Old Vehicles.

The results from the 4 old vehicles when tested to the relevant emissions standard (ADR27C & ADR37/00) of the effect of E20 on regulated emissions showed:

- THC emissions changes varied from vehicle to vehicle, with an average reduction over all vehicles of only 4%.

- CO emissions were generally reduced, with an average reduction over all vehicles of 70%. One of the four old vehicles tested featured close loop fuelling control, and as such did not show CO emissions reductions of this magnitude when operated on E20.
- NOx emissions were generally increased for the vehicles without closed loop control. The NOx emissions were reduced for the vehicle with closed loop fuelling control. The average NOx emissions over all vehicles was increased by approximately 9%.
- The magnitudes of the changes in emissions levels (and even the direction of the change when the closed loop vehicle is included in the analysis) were substantially different for each individual vehicle when compared to the average for all vehicles.

#### 1.1.2.3 New Vehicle Highway Tailpipe Emissions

The effect on tailpipe emissions over the highway cycle of E20 for the 5 new vehicles were:

- THC emissions were generally reduced, with an average reduction over all vehicles of 25%.
- CO emissions were generally reduced, with an average reduction over all vehicles of 48%.
- NOx emissions showed no clear trend when using E20 fuel. This was due to 2 of the 5 vehicles operating lean during the highway cycle. These 2 vehicles showed particularly high tailpipe NOx emissions when compared to the vehicles that maintained closed loop operation during the highway cycle. Reductions in the tailpipe NOx were measured for these lean operating vehicles, and as these emissions were substantially higher than the closed loop calibration vehicles, these reductions dominated the average change in emissions, resulting in an overall reduction in NOx emissions over all vehicles of approximately 9%.

#### 1.1.2.4 Old Vehicle Highway Tailpipe Emissions.

The effect on tailpipe emissions over the highway cycle of E20 for the 4 old vehicles were:

- THC emissions changes varied from vehicle to vehicle, with an average reduction over all vehicles of approximately 10%.
- CO emissions were generally reduced, with an average reduction over all vehicles of 76%. One of the four old vehicles tested featured close loop fuelling control, and as such did not show CO emissions reductions of this magnitude when operated on E20.
- NOx emissions showed no general trend when considering each individual vehicle. The average NOx emissions over all vehicles were increased by approximately 10%.
- The magnitudes of the changes in emissions levels (and even the direction of the change) were substantially different for each individual vehicle when compared to the average for all vehicles.

#### 1.1.2.5 Tailpipe $CO_2$ Emissions

The results from the 5 new vehicles of the effect on $CO_2$ emissions from E20 showed the following:

- $CO_2$ emissions were generally reduced over the city cycle, with an average reduction over all vehicles of approximately 1%.
- $CO_2$ emissions were generally reduced over the highway cycle, with an average reduction over all vehicles of approximately 1%.
- The reduction in $CO_2$ emissions for these type of vehicles is consistent with the automotive literature.

The results from the 4 old vehicles of the effect on $CO_2$ emissions from E20 showed the following:

- $CO_2$ emissions showed no general trend over the city cycle when considering individual vehicle results. Large reductions in CO emissions for two of the vehicles, however, resulted in increased $CO_2$ emissions, which dominated the overall $CO_2$ emissions change, resulting in an overall increase for all vehicles in $CO_2$ emissions of approximately 2%.
- $CO_2$ emissions again showed no general trend over the highway cycle. Large reductions in CO emissions for two of the vehicles resulted in increased $CO_2$ emissions, which dominated the overall $CO_2$ emissions changes, resulting in an overall increase across all vehicles in $CO_2$ emissions of approximately 1%.

### 1.1.3 Engine Management System and Calibration.

All new vehicles were found to maintain closed loop control while operating on the E20 fuel blend, however the exhaust emissions changes due to the E20 fuel blend prior to treatment by the catalyst were found to be vehicle specific. The adaptation of the vehicles engine management systems to the E20 fuel was also found to be specific to the vehicle manufacturers control strategy. The impact on the catalyst efficiencies was found to be small, however the catalysts are new and until the 80,000 km mileage accumulation (now underway) is complete and the catalysts aged, the longer term impact is unknown.

The old vehicles without closed loop engine management all displayed the enleanment expected from the E20 fuel. The effect on exhaust emissions was found to be a function of the base calibration (mixture strength) of the vehicle. The one old vehicle which has closed loop fuelling control was found to operate similarly to the new vehicles.

### 1.1.4 Unregulated Tailpipe Toxics Emissions for New and Old Vehicles.

During regulated emissions testing of the vehicles, samples were taken for analysis to determine the tailpipe aldehyde group emissions and the air toxics emissions for both gasoline and E20 fuel.

#### 1.1.4.1 Aldehydes for New Vehicles

Following the sample analysis from the new vehicle testing, the following effects of E20 were found on the Aldehyde emissions:

- Propionaldehyde and Acrolein concentrations were found to be below the measurable range of the instrument and therefore are not considered.
- Formaldehyde emissions remained unchanged. This result compares favourably to other studies.
- Acetaldehyde emissions generally show very large increases for E20, when compared with results from gasoline only.
- The majority of Acetaldehyde emissions are emitted during the warm-up phase of the drive cycle. Once the vehicle is fully warm, the Acetaldehyde emissions become negligible.

#### 1.1.4.2 Aldehydes for Old Vehicles.

Following analysis of samples of exhaust gas from the old vehicle testing the following effects of the E20 fuel were found on Aldehyde emissions.

- Overall there was a large increase in Aldehydes from the ADR27C vehicles when operated on E20, of the order of 700%.
- There was also an increase in Aldehydes with the ADR37/00 vehicles, in this case the absolute level is significantly lower than for the ADR27C vehicles, from a percentage perspective the ADR37/00 vehicles are approximately 900% lower than the ADR27C with aldehyde emissions.
- The increase comes predominately from an increase in Acetaldehyde.
- This trend compared favourably with other studies

#### 1.1.4.3 Exhaust Toxics for New Vehicles

Following sampling of the tailpipe emissions, the following effects of the E20 fuel were found on exhaust toxic emissions.

- Overall decreases in exhaust toxics were measured when the vehicles are operated on E20 fuel: Benzene 40%, Hexane 40% and Toluene 30%.
- These trends compare favourably with other studies.
- There is a good correlation between exhaust Benzene, Hexane, Toluene and THC on both gasoline and E20, this substantiates the claim that a significant source of toxics is by products of combustion and un-combusted gasoline.
- The largest impact is in the cold transient phase, further confirming that the major source of toxics is by products of combustion and un-combusted gasoline.

#### 1.1.4.4 Exhaust Toxics for Old Vehicles.

- Overall there was a decrease in exhaust toxics when the vehicles are operated on E20 as follows, 1,3 Butadiene 15%, Benzene 20% and Toluene 10%.
- The un-catalysed vehicles emitted the same output of toxics regardless of the phase of the drive cycle i.e. cold or hot.
- These trends compare favourably with other studies.

### 1.1.5 Evaporative Emissions for New Vehicles.

- Overall the evaporative total hydrocarbon emissions increased when vehicles are operated on E20
- This data measured shows a similar result to other studies.

### 1.1.6 Evaporative Emissions for Old Vehicles.

- The average result for the pre 1985 vehicles tested showed the evaporative emissions increased when operated on E20.
- The average result for the pre 1995 vehicles tested showed the evaporative emissions decreased when operated on E20. This result, however, is skewed by the high gasoline diurnal emissions from the Toyota Camry.
- The carburetted vehicle that does not have the float chamber vented to the carbon canister showed a large increase in hot soak evaporative emissions when operated on E20 fuel, eg. approximately 100% increase.

### 1.1.7 Toxic Evaporative Emissions for Old Vehicles.

- Overall there will be an increase in evaporative air toxics when the old vehicles are operated on E20.
- The increase in air toxics concurs with the increase in THC measured during the evaporative test.

### 1.1.8 Fuel Consumption for New Vehicles.

Fuel consumption was increased when operating the vehicles with the E20 fuel, however the increases measured were only in some cases as high as the theoretical 6% predicted, based on the decrease in energy content of the fuel when adding 20% by volume ethanol.

- In general there was an increase in fuel consumption when the vehicles tested are operated on E20 ranging. This increase in fuel consumption ranges from 2.5% to 7% depending on the cycle and the vehicle.
- The increase in fuel consumption on average across all the vehicles was approximately 5%. This increase was less than expected. It is thought the differences might be due to subtleties in the adaptation strategies of the various vehicle control systems.
- Increases in fuel consumption of 5% or more are considered to be recognisable to the average driver.

### 1.1.9 Fuel Consumption for Old Vehicles.

In general there was a minor increase (less than 2%) in fuel consumption when the open loop fuelled vehicles were operated on E20.

- The closed loop fuelled vehicle behaved similarly to the new vehicles tested with an increase in fuel consumption when operated on E20 ranging from 3.5% to just over 6% depending on whether operated over the city or highway cycle.

### 1.1.10 Driveability for New Vehicles.

Driveability assessments are a subjective measure to evaluate engine starting behaviour and driveability characteristics of the vehicle. Assessments have been made for cold, hot and ambient conditions temperatures. For all starting assessments, a level of objectivity can be applied as a measurement is taken.

#### 1.1.10.1 Ambient Conditions Assessment.

The vehicles were assessed under ambient conditions of approximately $25^{o}$ Celsius. This is the most common condition that the majority of vehicle owners would be exposed to in terms of the potential impacts of the E20 fuel. In general, startability was maintained or slightly improved at $25^{o}$ Celsius with E20, however these improvements were considered not discernable to the average driver. Idle quality was also assessed and though slight improvements and degradations were found, these were considered to be not obvious to the average driver.

The outcome of the general vehicle performance assessment indicated both slight improvements and reductions in the acceleration performance evaluation when operated on E20 fuel. In all, the differences were slight and most likely not observable by the average driver.

The final assessment was of warmed-up driveability where the vehicles are operated until up to normal operating temperatures and then assessed for driveability. In general the vehicles performance on the E20 fuel was assessed as substantially the same as when operating on gasoline.

#### 1.1.10.2 Hot Conditions Assessment.

In general all vehicles were assessed as not having significant changes to hot start times and idle performance when operated on the E20 fuel blend. This however does not apply to the one of the vehicles where start times of three seconds or more were measured for both the hot start and hot re-start times with E20. This was identified as being discernable to the average driver.

The hot conditions extended idle testing with the E20 fuel blend showed no substantial differences when compared to gasoline only fuel.

Following the hot conditions tests, the vehicles were driven out onto the open road to assess their driveability while heat soaked. For all the vehicles, when operating them on E20 fuel, the driveability was considered to be substantially similar to the gasoline baseline.

#### 1.1.10.3 Cold Conditions Assessment.

The cold start tests were performed after having soaked the vehicle for eight hours at approximately $-10^{o}$ Celsius. Two vehicles displayed long start times with E20; some in excess of three seconds, which is well beyond the one and a half second production development targets. This increase is considered to be identifiable to the average driver. One of these two vehicles stalled upon crank and fire on both test occasions. This is considered by the rating system as very poor and is judged as undermining the drivers confidence and conveying poor reliability. In general the idle stability and roughness changes was found to change slightly when the vehicles were operated on E20 fuel but not to the extent of being discerned by the average driver

The assessment of warm-up driveability after the cold start found the vehicles to be similar for both gasoline and the E20 fuel blend.

### 1.1.11 Driveability for Older Vehicles.

#### 1.1.11.1 Ambient Conditions Assessment.

In general, potentially significant startability problems with old open loop carburetted vehicles, such as long starting times, may occur. Idle quality may potentially degrade on open loop vehicles to the point where the driver experiences stability and roughness.

The outcome of the general vehicle performance assessment indicated slight reductions in the acceleration performance evaluation when operated on E20 fuel. Issues such as hesitation to throttle demand and mediocre WOT launchability performance may also occur which are more significant when the engine is cold.

For some of these impacts, the average driver will believe a disturbing defect are present and is likely to seek corrective action but will still have confidence of continual operation.

#### 1.1.11.2 Hot Conditions Assessment.

Startability for some of the older vehicles may display stalling and rough running to such a degree that the driver will believe that the vehicle will fail to stay running and not operate consistently. In the other vehicles startability was still noticeably worse than the gasoline baseline.

The hot conditions extended idle testing with the E20 fuel blend showed at least two of the vehicles would stall following the 20 minute idle. These would likely result in the driver seeking corrective action and undermine the drivers confidence due to unreliability.

Following the hot conditions tests, the vehicles were driven out onto the open road to assess their driveability while heat soaked. For most of the vehicles (except Camry), when operating them on E20 fuel, there was significant hesitation to WOT demand along with hesitation at cruise speeds of 50 to 70 km/h. The average driver would notice these changes.

#### 1.1.11.3 Cold Conditions Assessment.

The cold start tests were performed after having soaked the vehicle for eight hours at approximately $–10^{o}$ Celsius. Two vehicles displayed very long start times with E20; one in excess of 65 seconds which represented a significant increase over the gasoline baseline of 22.5 seconds. Idle quality may also degrade to a level of stalling and rough operation such that the drivers confidence is undermined. One of the vehicles stalled upon crank and fire on both test occasions.

The assessment of warm-up driveability after the cold start found that some of the vehicles degraded significantly, although in some cases the baseline gasoline vehicle had poor driveability as well. Hesitation at cruise speed of 50 km/h was also noted for most vehicles, with some of the vehicles (Holden Commodore) performance likely to cause the driver to seek corrective action.

## 1.2 Well to Wheel Greenhouse Gas Impact.

A desktop study and literature review was performed to determine the Well to Tank component of the lifecycle greenhouse gas emissions. One publication, written by the CSIRO, was specifically utilised to make the lifecycle greenhouse gas emissions conclusion as reported here. The data within this publication was considered to be most relevant as it contained specific Australian related information.

The data required for the Tank to Wheel component of the lifecycle emissions was measured as part of the vehicle exhaust gas emissions and fuel consumption testing component of the program of work reported herein.

These two components were then summed to provide an estimation of the potential of the E20 fuel blend in terms of the impact on the greenhouse gas emissions. The following tables summarise the city and highway driving cycle outcome in terms of the potential impact due to:

- The new vehicle fleet.
- The old vehicle fleet
- The combined vehicle fleet.

The assessment terminology used within the tables is as follows:

- Better – decrease in well to wheel greenhouse gas emissions
- Same – no change
- Worse – increase in well to wheel greenhouse gas emissions

| Comparison of Transport Fuels CSIRO base Well To Tank Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **ADR WTW Emissions City Cycle** | **Gasoline** | **E20** | | | | | | |
| | Reference (PULP) | Azeotropic (wood waste) | Azeotropic (wheat) fired with wheat straw | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (wheat) | Azeotropic (molasses - Sarina - Economic Allocation) | Azeotropic (ethylene) |
| New Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |
| Old Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Same*** | ***Same*** | ***Worse*** |
| **Overall – E20 to Petrol Assessment** | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |

**Table 1.1 - City Cycle Well to Wheel Greenhouse Gas Outcome.**

| Comparison of Transport Fuels CSIRO base Well To Tank Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **AS2877 WTW Emissions Highway Cycle** | **Gasoline** | **E20** | | | | | | |
| | Reference (PULP) | Azeotropic (wood waste) | Azeotropic (wheat) fired with wheat straw | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (wheat) | Azeotropic (molasses - Sarina - Economic Allocation) | Azeotropic (ethylene) |
| New Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |
| Old Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Same*** | ***Same*** | ***Worse*** |
| **Overall – E20 to Petrol Assessment** | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |

**Table 1.2 - Highway Cycle Well to Wheel Greenhouse Gas Outcome.**

The conclusion that can be drawn from this summary is there is a clear statistically significant potential benefit to the total greenhouse gas emissions in utilising a fuel comprising gasoline and 20% by volume ethanol. The benefit however is highly dependent on the production and process methods utilised to produce the ethanol. The production of ethanol from wood waste provides the most significant advantage with a potential approximate 11% reduction in well to wheel greenhouse gas mass emissions per unit distance travelled over all vehicles for both city and highway driving.

## 1.3 Materials/Component Compatibility Test Interim Conclusions.

Interim findings of the materials/component compatibility testing schedule are summarised below. A final report on the assessment of the testing when all components complete the 2000 hour immersion is planned for early May 2003.

Corrosion of metallic fuel system components by the E20 test fluid has been found and is considered as unacceptable as the potential exists for the oxide to dislodge and deposit in fuel filters and fuel metering devices causing blockage. Further the dislodged oxide has the potential to settle in areas where mechanical movement of components occurs, such as bearings in fuel pumps and fuel injectors potentially accelerating the wear of these components.

The potential impact on the vehicle fleet from corrosion of the metallic fuel system components may be premature component failure, degraded driveability and operability followed by engine operation failure, the details of which are described within the material/component compatibility section of this report.

Nearly all brass and copper components have displayed significantly increased tarnishing when in contact with the E20 test fluid. This corrosion is considered a concern as it presents the potential for changing the fuel metering performance of fuel metering jets, may cause premature component failure of rubbing components such as the fuel pump commutator and may cause changes in the electrical performance of components due to changes in the contact resistance of electrical connections within fuel submerged pumps for example.

In general, rubber components are experiencing a greater change in weight and hardness when immersed in the E20 test fluid then in neat gasoline. Of significant concern is the distortion and swelling of the fuel pressure regulator diaphragms from the EFI fuel systems tested. These components are under stress in operation and coupled with the findings of the immersion tests the potential for premature failure exists. Such failure may render the vehicle inoperable and has the potential to result in fuel leakage. A carburettor diaphragm displayed distortion and swelling, indicating the potential premature failure of this diaphragm. These impacts are considered as unacceptable due to the increased potential for fuel leakage.

Most of the plastic materials tested have experienced little or no changes when immersed in the E20 test fluid. An E20 effect was found on the two PCV valves tested, the plastic part of the valve was found to completely separate from the metal part of the valve. This is a concern as the potential exists for degraded driveability and operability due to a significant engine air leak should the separation be experienced on the vehicle. This would potentially result in the loss of the fuel and air metering accuracy required for normal engine operation.

The final findings of the materials component compatibility tests are planned to be reported in early May 2003 when all the engine and fuel systems components and materials under test complete the 2000 hour immersion schedule. However, based on the interim findings of the materials/component compatibility testing, there are a number of materials utilised in the vehicles components tested to provide sufficient evidence that the potential impacts on the Australian vehicle fleet are of sufficient magnitude to consider them as unacceptable.

## 1.4 Fuel Filler Area Paint Work Impact.

The application of the test fluid gasoline and E20 fuel to vehicle fuel filler door test samples presently shows:

- No evidence of paint peeling
- No evidence of blistering
- No evidence of crazing
- No evidence of dulling
- Some evidence of staining (white painted fuel filler door only)

The staining is only evident on the white painted fuel filler door sample. To the naked eye the staining shown is slightly more prominent on the sample exposed to E20 than to the baseline ULP sample.

Testing is to continue for the remaining period of materials/components compatibility testing program and the final report on this testing is planned for early May 2003.

# 2 Introduction

The Commonwealth Government of Australia, represented by Environment Australia, is investigating the effects of higher ethanol blends in fuel on the Australian vehicle fleet. This investigation is to provide information to the Government on the impacts of noxious and greenhouse emissions, vehicle performance and durability from the use of 20% by volume ethanol blended with gasoline (E20). This study will then be used to aid the Government to set the national fuel standards as provided by the *Fuel Quality Standards Act 2000*.

Environment Australia, under the auspices of the Ethanol task force, commissioned an issues paper with the aim of seeking public comment on setting the appropriate ethanol limit in automotive fuel (2). This paper extensively covered the issues related to using ethanol as an automotive fuel. In particular it refers to two earlier trials conducted in Australia. The first trial in 1980-83 (5) examined the impacts of E15 (15% ethanol). The second in 1998 (6) comprised an intensive field trial of ethanol/gasoline blend E10 (10% ethanol) in vehicles. The data from these trials, plus evidence from the submissions to the issues paper, lead to the conclusion that generally blends up to 10% are accepted as being suitable for the Australian fleet. Currently, however, there is not general consensus on the applicability of higher ethanol concentration blend fuels for the Australian vehicle fleet.

One of the conclusions that can be drawn from the submissions to the issues paper was the lack of current Australian data on the effects of higher ethanol blends (E20) on the Australian fleet. In order to rectify this, Environment Australia has commissioned testing on vehicles and components under tender No. 34/2002. Subsequently, Orbital Engine Company has been contracted by Environment Australia to undertake an engineering program related to the use of 20 percent ethanol blend fuel in the Australian market.

A second phase to the total program has been recently commenced at Orbital Engine Company, this phase is focussed on revealing the potential longer term impacts the E20 fuel blend may have on the new Australian vehicle fleet. The new vehicle pairs will be operated for 80,000 km on mileage accumulation chassis dynamometers one on standard pump gasoline the other on the E20 fuel blend thus providing the means for a comparison to be made.

## 2.1 Program Goals

The program goals were to target and identify data and information detailing the impacts of a 20 percent ethanol blend fuel on the Australian vehicle fleet through both desktop and experimental studies.

### 2.1.1 Desktop Studies

The desktop studies investigated two areas both designed to provide focus and substantiation for the experimental studies. The first was a Failure Mode and Effects Analysis (FMEA) of ethanol gasoline fuel blends on the fuel systems types representing the majority of fuel systems utilised in modern passenger vehicles. This document (3) contains design FMEA's focussing on the two fuel systems types, it served to confirm that the related experimental testing program was ideally focussed and not deficient in any areas.

The second desktop study was an "Analysis of Impacts" review (4), comprising a literature review study aimed at understanding the reasons supporting, and the potential impacts of, the use of the E20 blend fuels in automotive gasoline engines.

Both desktop studies have been completed and submitted to Environment Australia.

### 2.1.2 Experimental Studies

The goal of the experimental studies was to perform a series of structured tests designed to gather data on the effect of the baseline gasoline and the E20 blend fuels on the following key parameters.

- Tailpipe emissions
- Evaporative emissions
- Greenhouse gas emissions
- Fuel consumption
- Vehicle operability
- Durability
- Fuel system components, base engine hardware and engine management systems

The information gathered from the desktop studies was utilised in designing the program experiments in an effort to ensure that all the potential aspects received the best possible coverage within the framework of the program constraints.

## 2.2 Methodology Adopted

The methodology adopted for this program of work was to conduct an assessment of both vehicle performance and vehicle durability on new and old vehicles, representative of the Australian vehicle fleet. The testing was undertaken using representative baseline gasolines and 20 percent ethanol blended with the baseline gasoline.

### 2.2.1 Test Fuels Management

The test program required Orbital to procure sufficient quantities of a variety of fuel types. The methodology adopted was to source the necessary baseline gasoline and ethanol from various refiners. These fuels were then used as blend constituents to produce test fuel blends for use throughout the program. Fuel identification and usage was strictly controlled in accordance with internal Quality Assurance procedures.

### 2.2.2 Vehicle Performance Assessment

The methodology adopted to gather the experimental data was to firstly obtain an understanding of the performance of the engines on the baseline gasoline.

Following this baseline, the engines were tested according to the same procedures except that the E20 ethanol blend fuel was utilised. This provides two back-to-back data sets enabling the direct comparison of the performance of each vehicle.

#### 2.2.2.1 Tailpipe Emissions

The procedure adopted for measurement of regulated emissions of carbon monoxide, (CO) total hydrocarbons, (THC) and oxides of nitrogen (NOx) is the Australian Design Rule (ADR) pertinent to the particular model year of the vehicle being tested, (16, 17 & 18).

#### 2.2.2.2 Evaporative Emissions

The pertinent ADR's covering emissions measurement calls for both a hot soak and a diurnal test, (16, 17 &18). The testing is to be undertaken in a special purpose Sealed House for Evaporative Determination (SHED) facility.

#### 2.2.2.3 Greenhouse Gas Emissions

Greenhouse gas and air-toxic emissions were measured concurrently with the measurement of the tailpipe and evaporative emissions.

#### 2.2.2.4 Fuel Consumption

Vehicle fuel consumption was determined from the tailpipe emissions and calculated for both the city and highway cycles of the driving cycle, following the relevant Australian Standard (AS), (7).

#### 2.2.2.5 Vehicle Operability and Performance

Where possible, industry standard testing procedures have been adopted within this area of vehicle assessment.

### 2.2.3 Vehicle Durability Assessment

Extended vehicle durability testing and specific bench tests will be used to assess the impact of E20 blend fuel on fuel system components and base engine wear. Only the new vehicles will undergo the vehicle durability testing due to the inherent difficulties in operating old vehicles for extended mileage accumulation.

#### 2.2.3.1 Fuel System Components

The vehicle activity involved the functional testing of the major fuel system components (fuel pump, fuel filter, fuel regulator and fuel injectors) according to the relevant Society of Automotive Engineers (SAE) standards, (14, 13, 15 & 12).

An assessment of other fuel system components (fuel tank, fuel filler, area filler cap, carbon canister, etc.) is planned following the durability testing program.

The potential impact of spillage of the E20 fuel blend on vehicle paintwork adjacent to the fuel filler area was assessed following the relevant International Standards Organisation (ISO) standard, (11).

#### 2.2.3.2 Engine Wear

An assessment of the base engine wear was to be undertaken on the new vehicle pool only.

### 2.2.4 Fuel System Material Compatibility

Materials compatibility was determined by a comparative assessment of the immersion performance of metallic, elastomeric and plastic fuel system components/samples in 0% ethanol and 20% ethanol gasoline mixes. The methodology for testing these samples was to adopt as much as possible of the two relevant SAE standards, (9) and (10) that cover the materials compatibility testing. Relevant sections of the SAE standard (8) covering the details of test fuels for materials compatibility testing were also adopted where possible. The adoption was to the point of fulfilling the engineering requirement of ensuring potential incompatibility had a high probability of being identified, however the adoption was not to the point of qualification of the materials or components, this being outside the scope of the project.

# 3 Test Fuel Management

The test program required Orbital to procure sufficient quantities of fuel grade Ethanol, Unleaded Petrol (ULP), Premium Unleaded Petrol (PULP), and Lead Replacement Petrol (LRP) in both summer and winter grades including ULP and PULP in bulk storage on Orbital's site. These fuels were used as the blend stocks for the preparation of the various ethanol blended fuels required for both the vehicle and materials compatibility testing phases of the program.

Details as to the specification of and/or the actual quality of the procured fuels, along with independent analyses confirming gasoline quality and blend quality and strength can be found in Appendix M.

## 3.1 Hot and Operability Test Gasoline

The hot and operability test gasoline was required in ULP, PULP and LPR grades and was sourced from the Caltex Kurnell refinery in New South Wales through the Caltex Broadmeadows terminal. The fuel was delivered at the beginning of November 2002 in 205 litre drums. A total of eight drums of ULP, two drums of PULP and four drums of LRP was received. Each drum was well labelled and accompanied with a Material Safety Data Sheet (MSDS).

The fuel was renamed for the purposes of standardization with company quality procedures and the individual drums were identified according to the following naming convention. The hot and operability test gasolines were renamed AEN Summer ULP, AEN Summer PULP and AEN Summer LRP. The individual drums have been identified with the prefix S for summer and numbered according to the number of drums in the group, ie. AEN Summer ULP S1 - S8, AEN Summer PULP S1 – S2, etc. All operability testing except for the cold tests were completed with AEN Summer ULP, PULP and LRP neat and the ethanol blended with AEN Summer ULP, PULP and LRP respectively to produce the E20 fuel blends.

A second batch of hot and operability test gasoline in ULP and LRP grades was procured from the same source and delivered at the end of December 2002 in 205 litre drums. A further nine drums of ULP and four drums of LRP were received. The individual drums were identified as batch two and labelled with the prefix S2, i.e. AEN Summer ULP S2/1 – S2/9 and AEN Summer LRP S2/1 – S2/4.

## 3.2 Cold Test Gasoline

The cold test gasoline was required in ULP, PULP and LRP grades and was sourced from the Shell Newport operation in Victoria. These fuels were delivered at the beginning of November 2002 in 205 litre drums. Four drums of ULP, one drum of PULP and two drums of LRP were received. Each drum was well labelled and accompanied with a MSDS.

The fuel was renamed in accordance with the identification protocol. The individual drums have been identified with the prefix W for winter and numbered according to the number of drums in the group, ie. AEN Winter ULP W1 - W4, AEN Winter PULP, etc.

## 3.3 Stabilisation Gasoline

Specific test gasoline is only required for the vehicle operability assessment testing. For general testing throughout the vehicle stabilisation phase and the 20,000 km mileage accumulation phase, pump grade gasoline is suitable. Existing supply of locally available ULP and PULP sourced from the BP Kewdale terminal in Western Australia, as stored on Orbitals site in bulk, was used for this purpose. LRP for stabilisation purposes was sourced from a local BP service station, as it is not stored in bulk on Orbitals site.

## 3.4 Engine and Fuel System Materials/Component Compatibility Gasoline

The fuel system component compatibility gasoline had no specific requirements, apart from being representative of domestic fuel supply. Accordingly, the fuel used for the fuel system component compatibility testing is the locally available ULP sourced from the BP Kewdale terminal in Western Australia and the LRP as sourced from a local BP service station.

## 3.5 Ethanol

The fuel grade ethanol was sourced from the Manildra Group in New South Wales and CSR Ltd. Yarraville Distillery in Victoria. This fuel was delivered at the end of October 2002. A total of five 205L drums were received. The packaging identified the contents as SMS 100 F21, containing one percent by volume ULP as a denaturant. The drums were marked according to the identification protocol as E1 – E5.

A further batch of fuel grade ethanol was sourced from CSR Ltd. This fuel was delivered during December 2002. A total of four drums were received and marked according to the identification protocol as E6 – E9.

## 3.6 Gasoline/ Ethanol Mixing Process

The process used for achieving accurate, repeatable blends of the various fuel mixtures was developed by Orbital following a review of information available from organisations such as CSR, Manildra Group, American Coalition for Ethanol, Governors Ethanol Coalition and the Alternative Fuels Data Centre. The lack of explicit technical information and references to the avoidance of “splash blending” when mixing ethanol and gasoline, led Orbital to develop a mixing process based on gravimetric measurement of the blend constituents.

Drummed fuel was stored externally under a covered bunded area surrounding the bulk fuel storage facility. The drums containing the necessary blend stocks of gasoline and ethanol were transported to the fuel preparation area and soaked at 20°C for 24 hours prior to opening and decanting of fuels. The mixing process required that the densities of the fuel constituents were measured and the mass of each constituent calculated based upon the volume required to achieve the requested blend concentration. Scales were purchased with a load cell capable of measuring large masses with a high degree of accuracy. Once measured each constituent was then decanted into the blend drum. A re-circulating pump was fitted and run for a pre-determined period of time to ensure blend homogeneity. Once blended, the drum was then labelled according to the identification protocol. The batched fuel was then stored at 20°C in the fuel storage area until required for use.

## 3.7 Fuel Control

There were a total of 16 new fuels and blends evaluated in the various test phases of the program. An inventory of fuels specific to this program was created in an excel workbook to assist with the management and control of fuel use and location.

Of particular concern was control of the blended ethanol fuel concentrations. In order to qualify the blending process, a one-litre sample was taken from each drum of blended fuel for in-house density measurement, this was compared to a calculated value based on the density of the individual constituents. The ethanol volume of the blends was checked in house using a basic water extraction method. A second one-litre sample for some blends was taken by a representative from the Australian Taxation Office and sent to a testing agency appointed by Environment Australia for independent analysis. Details confirming the blend strengths and densities of the fuels used throughout this program along with independent quality data are tabulated in Appendix M.

Analysis of the data in Appendix M confirms the quality of the supplied test gasoline, demonstrates the mixing process adopted by Orbital is valid and shows the effect ethanol has on the base gasoline distillation curve when blended as E20.

## 3.8 Engine Oils Used

Each vehicle was operated with the respective manufacturer specified engine oil. Servicing intervals were followed as per manufacturers specification and completed by the respective manufacturers authorised service technician.

# 4 Vehicle Selection and Preparation.

A summary of the vehicle selection and preparation processes prior to engaging each vehicle into the test program proper is provided.

## 4.1 Vehicle Selection.

A thorough analysis of the Australian market was undertaken to assign vehicle selection based upon a range of criteria including vehicle class, vehicle type, manufacturer, country of manufacturer and fuel type. A mix of new and old vehicles was chosen to reflect the age distribution of the on-road registered fleet. New vehicle types were selected primarily on the basis of sales volume in the Australian market for 2001, see Table 4.1. Old vehicle types were selected primarily on the basis of the applied fuel system, with emphasis placed on selecting vehicles released just prior to, and shortly unleaded petrol into the Australian market (1985), as well as encompassing representation of non-locally built vehicles, see Table 4.2.

The Department of Transport & Regional Services and Environment Australia reviewed the vehicle selection process and endorsed the choice of recommend vehicles. A total of 14 vehicles were selected and subsequently procured for the experimental study, of which there are ten new vehicles (five vehicle pairs) and four old vehicles. For the purposes of overall quality control, each vehicle has been assigned a vehicle code. These codes will be the primary reference used throughout this report, with the last two digits referring to vehicle number. The selected test vehicles are listed in Table 4.3.

| Manufacturer/Model | Vehicle Class | 2001 Production Numbers§ | Percentage of Vehicle Class | Percentage of Fleet |
|---|---|---|---|---|
| **Holden Commodore** | Large | 85,422 | 44.9 | 16.1 |
| **Ford Falcon** | Large | 53,534 | 28.1 | 10.1 |
| **Toyota Camry** | Medium | 18,256 | 47.7 | 3.5 |
| **Hyundai Accent** | Small/Light | 21,054 | 9.2 | 3.9 |
| **Subaru Impreza WRX*** | Sports | 6,592 | 70.0 | 1.3 |

* Subaru represents a high performance turbocharged vehicle requiring PULP.
§ Source: ABS passenger vehicles 2000-2001.

### Table 4.1 - New Vehicle Fleet Representation

| Age Group* | Percentage of Fleet | Manufacturer/Model | Model Year | Class | Fuel | Fuel and Aftertreatment Technology |
|---|---|---|---|---|---|---|
| **6 – 10** | 23 | Toyota Camry | ‘93 | Medium | ULP | EFI TWC |
| **11 – 15** | 19 | Mitsubishi Magna | ‘86 | Medium | ULP | Carburettor Oxidation Catalyst |
| **> 15** | 26 | Holden Commodore VK | ‘85 | Large | LRP | Carburettor |
| **> 15** | 26 | Ford Falcon XF | ‘85 | Large | LRP | EFI |

*. Based on year 2001.

### Table 4.2 - Old Vehicle Fleet Representation

| Test Phase | Vehicle Code | Vehicle Type | Vehicle Age | Comments |
|---|---|---|---|---|
| Phase 2A Vehicle Operability & Limited Vehicle Durability | AENHO01 | Holden Commodore | New | ULP to E20 test plus<br>E20 20,000 km durability |
| | AENFO02 | Ford Falcon | New | ULP to E20 test only |
| | AENTO03 | Toyota Camry | New | ULP to E20 test only |
| | AENHY04 | Hyundai Accent | New | ULP to E20 test only |
| | AENSU05 | Subaru Impreza WRX | New | PULP to E20 test only |
| | AENHO06 | Holden Commodore | New | ULP 20,000 km durability only |
| Phase 2B Vehicle Durability (80,000 km) | AENFO07 | Ford Falcon | New | No testing being carried out |
| | AENTO08 | Toyota Camry | New | No testing being carried out |
| | AENHY09 | Hyundai Accent | New | No testing being carried out |
| | AENSU10 | Subaru Impreza WRX | New | No testing being carried out |
| Phase 2A Vehicle Operability | AENFO11 | Ford Falcon | Old (MY ’85) | LRP to E20 test only |
| | AENHO12 | Holden Commodore | Old (MY ’85) | LRP to E20 test only |
| | AENMI13 | Mitsubishi Magna | Old (MY ’86) | ULP to E20 test only |
| | AENTO14 | Toyota Camry | Old (MY ’93) | ULP to E20 test only |

**Table 4.3 - Selected Test Vehicles**

The initial experimental program proposed to Environment Australia via the tender submission (1) included both vehicle operability and extended vehicle durability assessment. The scope of work was subsequently amended such that testing focussed primarily on operability, with an assessment of exhaust emissions limited durability on one new vehicle pair (AENHO01 and AENHO06) only to 20,000kms, as opposed to the original proposal of multiple vehicle pair durability tests to 80,000kms each. In order to differentiate this change to the work scope, vehicle operability assessment is referred to as Phase 2A and extended vehicle durability assessment as Phase 2B. Progression with Phase 2B will be contingent upon approval from Environment Australia at a later date. Without the completion of Phase 2B, only very limited exhaust gas emissions, engine wear, fuel system, and other durability related data was available and reported herein. However, should phase 2B be approved, this data will be available in the reports issued as part of the Phase 2B program.

## 4.2 Vehicle Preparation.

A summary of the vehicle preparation process undertaken prior to engaging each vehicle into the performance testing program activity is outlined below. There are differences in preparation of the new and old vehicles and these are clearly detailed in the following section.

### 4.2.1 Vehicle Inspection Tasks.

All vehicles were thoroughly inspected in order to establish the best possible locations for the sensors necessary to make the required measurements of the various pressures and temperatures during the performance testing of the vehicle pool. At this juncture, all vehicles were appropriately identified with the appropriate vehicle code and each vehicle was assigned a bound and protected book containing details of the testing schedule and sign off criteria that were to be met prior to engaging the vehicle in the performance testing component of the program.

#### 4.2.1.1 Engine Disassembly, Inspection and Rebuild.

This process is undertaken on all the new vehicles subject to test. The purpose of this exercise was to obtain the baseline data set for the analysis of base engine condition and component wear. Following engine disassembly, the relevant engine components were inspected, measured and photographed as required. The engine was then rebuilt.

The respective manufacturer's authorised service technicians conducted all engine disassembly and rebuild activity.

The baseline data was recorded and is complied for each vehicle in the appropriate appendices.

#### 4.2.1.2 Dealer Refurbishment.

This process is undertaken on all the old vehicles subject to test. Typically, older vehicles will have accrued high mileage, therefore necessitating a thorough inspection to gauge vehicle condition. This inspection covers key components of a range of critical vehicle systems (engine, fuel, EMS, aftertreatment, transmission, suspension, brake and clutch) and is used to determine the level of refurbishment required to return the vehicle to a similar as-new functional and roadworthy condition as possible. This was necessary to complete the vehicle operability assessment without influence of substandard function and condition.

The respective manufacturer's authorised service technicians conducted the refurbishment activity.

Following dealer refurbishment, the old vehicles were run over the appropriate driving cycle and emissions tested according to the ADR specified for the vehicle. This was found necessary to ensure that the vehicles were in-tune to met the regulated exhaust emissions levels specified for each vehicle model year. One vehicle in particular, the Holden Commodore AENHO12 required a number of tests and adjustments before meeting the regulated emissions levels specified for this model year vehicle type.

#### 4.2.1.3 Vehicle Instrumentation.

In order to analyse the environmental and vehicle operating conditions, a variety of sensors and gas sample pipes are installed to measure system temperatures, pressures and exhaust Air Fuel Ratio (AFR) and to measure tailpipe emissions.

#### 4.2.1.4 Fuel System Assessment.

Once the vehicles have completed their 6,400km stabilisation, the major fuel systems components (fuel pump, fuel filter, fuel regulator and fuel injectors) were functionally tested according to the relevant SAE standards, (14, 13, 15 & 12). All bench testing was undertaken using test fluids as specified in the relevant standard. Furthermore, the condition of the abovementioned components was recorded by photographic and written assessment. This assessment was confined to the new vehicles only.

This provides a baseline of the performance of these components. If the Phase 2B 80,000 km mileage accumulation is completed, then the major fuel systems components will be tested once again.

#### 4.2.1.5 Inspection and Maintenance (IM) 240 Test.

The IM240 test procedure, (20), was selected to verify the vehicle emissions and combustion quality before and after any disruption to a vehicle's engine, fuel, engine management or aftertreatment system. This test was confined for use with the new vehicles only.

The IM240 test was also used to measure the vehicles tailpipe emissions and fuel consumption at each scheduled service stop during mileage accumulation to 20,000 km. The purpose of this testing was to quickly confirm the vehicle was performing as expected by comparing previously measured emissions and fuel consumption, thus eliminating the possibility of extensive mileage accumulation on a malfunctioning vehicle.

The IM240 test is an inspection and maintenance drive cycle is used in the USA to verify emission quality of in-use light duty vehicles. The test was designed to detect high emitting in-use vehicles that require maintenance on inadequately performing emission control systems. The IM240 has a duration of 240 seconds, representing a 3.1 km route with an average speed of 47.3 km/h and a maximum speed of 91.2 km/h. The test also includes procedures for checking pre OBD-II (On-board Diagnostics 2) evaporative emission systems and fuel cap integrity, however only the IM240 vehicle tailpipe emissions procedure was used during the vehicle testing, fuel consumption is an automatic measurement outcome of the emissions test procedure.

#### 4.2.1.6 6,400km Mileage Accumulation.

In order to break-in the new and rebuilt engines and to stabilise the aftertreatment systems, the vehicles need to be operated for a set distance. For this project, all new vehicles and the refurbished older vehicles are scheduled to accumulate 6,400km. All mileage accumulation will be via ADR79/00, (21), Appendix 1 Annex VIII and run on Orbitals mileage accumulation chassis dynamometer (MACD) facility.

#### 4.2.1.7 New and Old Vehicle Preparation.

Table 4.4 and Table 4.5 present the respective preparatory tests and procedures that each new and old vehicle underwent, the data recorded was assessed for consistency and to ensure the vehicle was operating normally with no system or component failures. All new vehicles were found to meet these criteria and were then cleared for the performance assessment component of the program.

| Preparation sequence | Source vehicle | Pre-test inspection | Pre-disassembly emission test -IM 240 | Engine disassembly, component measurement & engine rebuild | Vehicle Instrumentation | Post-rebuild emission test - IM240 | 6,400km mileage accumulation |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| **Test fuel** | **Gasoline** | | | | | | |

**Table 4.4 - New Vehicle Preparation Sequence.**

| Preparation sequence | Source vehicle | Dealer refurbishment | Orbital hardware check | Vehicle Instrumentation | ADR emissions check | 6,400km mileage accumulation |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| **Test fuel** | **Gasoline** | | | | | |

**Table 4.5 - Old Vehicle Preparation Sequence.**

Both the Mitsubishi Magna (AENMI13) and the Holden Commodore (AENHO12) old vehicles required tuning before they passed the ADR emissions check; prior to the 6,400km mileage accumulation process.

The Toyota Camry did not require an engine overhaul as the ADR emissions check revealed the vehicle to be well within exhaust emissions requirements. Based on this data the Toyota Camry was not processed through the 6,400km mileage accumulation as it was deemed to be stable with a road mileage of

All old vehicles were cleared for performance assessment.

# 5 Vehicle Performance Results.

## 5.1 New Vehicles

A summary of the performance and evaluation tests for both neat gasoline and the E20 fuel blend undertaken on the new vehicles is discussed below. Test reports for each vehicle test are included in the appendices to this report.

### 5.1.1 Engine Power Evaluation.

This assessment evaluated the wide-open throttle (WOT) or full load performance of a power train installed in a vehicle. The test procedure adopted is based on SAE J1491 (19), measuring acceleration from both a standing start and from a stabilised speed of 64km/h. All testing was carried out at Orbital's MACD facility. Details of the test procedure can be found in WOT performance test reports in the vehicle appendices. The full load tests with E20 were conducted after the E20 snap test. Following the E20 snap tests, the vehicle was run on E20 blend fuel for a distance of 200 km on an open road circuit in order to ensure that engine management system (EMS) adaptation had occurred on E20 blend fuel. An IM240 emissions and driveability assessment test were also conducted before the full load. It is therefore reasonable to assume that if any adaptation of the EMS was going to take place it would have occurred.

For the standing start tests, three WOT accelerations were performed from a standing start to a speed of no less than 100km/h, and covering no less than 402m. The vehicle speed, exhaust temperatures and exhaust lambda were logged. Lambda, or relative air fuel ratio, often expressed as the symbol $\lambda$ being defined as:

$$\lambda = \text{(Actual air fuel ratio)}/\text{(Stoichiometric air fuel ratio)}$$

(Further details on definitions and the properties of ethanol can be found in (4)).

For the 64 km/h test, the vehicle was held at a constant speed of 64km/h and then accelerated at WOT to 97km/h. Separate tests for manual transmission vehicles were run in top gear, and top gear less one, and not downshifted during the acceleration. Automatic transmission vehicles were allowed to downshift as determined by the vehicle transmission controller. Again the vehicle speed, exhaust temperatures and exhaust lambda were logged.

Figure 5.1 and Figure 5.2 shows the results for the two tests conducted for all the new vehicles tested. Overall there is little difference between gasoline and E20. The largest difference recorded for standing start acceleration was for the Toyota Camry (AENTO03) with a 10% improvement. However, for the acceleration from 64km/h E20, this vehicle was marginally worse with E20, with the elapsed time increasing by approximately 5%. From Figure 5.2, for the acceleration from 64km/h the Hyundai Accent (AEHNY04) and Subaru Impreza WRX (AENSU05) both appear to have improved with the use of E20. However the WOT acceleration test data indicated a degradation of performance up to a speed of 97 km/h when using E20. When the full acceleration curves are examined, the different gear shifting techniques employed by the two drivers can account some of the reduction in performance. If the acceleration time lost on gearshifts is removed the acceleration times are relatively close.

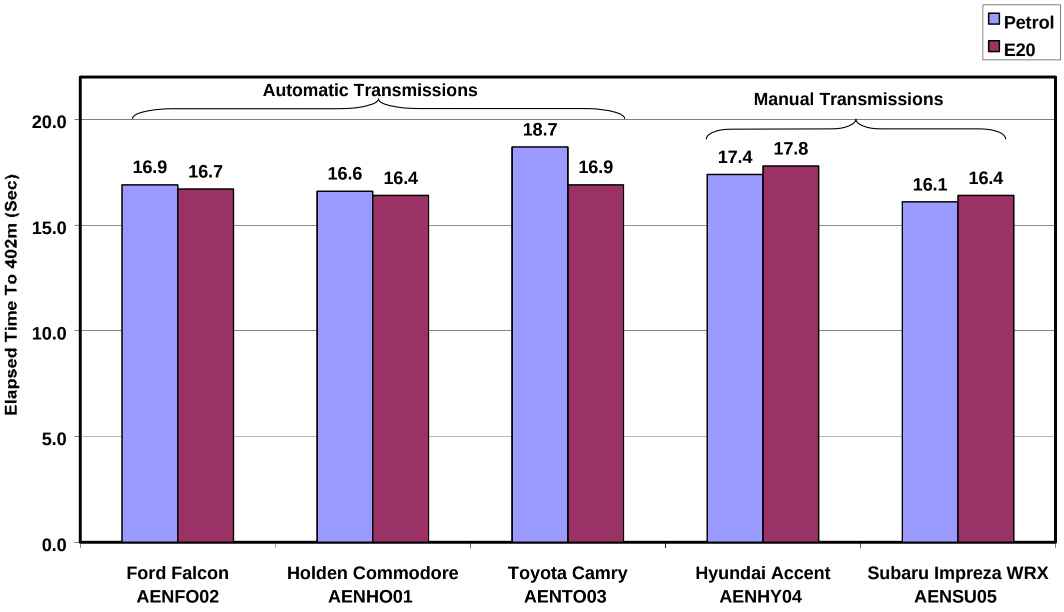


Figure 5.1 - Elapsed Times to 402m All New Vehicles

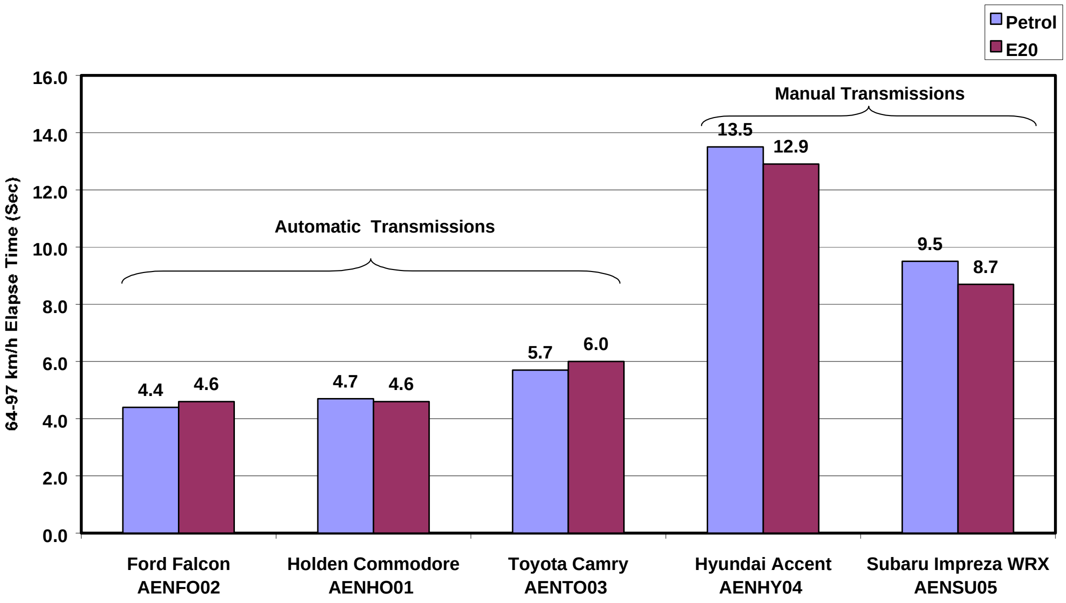


Figure 5.2 - 64-97 km/h Elapsed Times Top Gear (Manual Transmission) All New Vehicles

The exhaust lambda data from the full load performance is of more significance. This data gives some insight into how the vehicle EMS adjusts to the different fuel types. Typically in full load operation an engine will be calibrated to run richer than stoichiometry ($\lambda<1$). In this mode the closed loop controller, using feedback from the oxygen sensor, is no longer operational. Therefore, during open loop operation there will be no correction applied to the fuelling. In the literature review (4) the various aspects of a closed loop control were broadly covered. One of the principle aspects covered was that of adaptation. Adaptation is the adjustment of the base fuelling level (fuel injection duration) determined from information acquired during closed loop operation. This is in addition and complementary to any adjustment made to the fuelling level by the closed loop control action using the oxygen sensor. Adaptation is used to compensate globally for various changes in the EMS (deviations in fuel injector response), environmental conditions, fuel types etc. It is possible that adaptations determined during closed loop operation can be carried across and applied to the areas of engine operation which are open loop including full load, engine start up and warm-up and trailing throttle, if the EMS is so configured. This discussion is further covered in section 5.1.3. It is this aspect that can be determined from studying the exhaust lambda values from the WOT tests on gasoline and E20.

Figure 5.3 and Figure 5.5 show the lambda value ($\lambda$) in the exhaust for the Subaru WRX (AEHSU05) and the Toyota Camry (AENTO03) as measured by a wideband oxygen sensor (UEGO). It appears the both vehicles engine management systems have compensated for the addition of ethanol. For the Subaru WRX (AEHSU05) it can be seen that the lambda value when running on petrol or E20 is nominally the same across the whole test. The Toyota Camry (AENTO03) appears initially to have no compensation showing a lambda value difference of approximately 7%. This difference is expected from the 20% ethanol in the fuel without any EMS compensation (4). The E20 lambda trace then approaches the same levels as the gasoline trace, in a similar manner to the Subaru WRX (AEHSU05). It is reasonable to assume that the EMS system in the Toyota Camry (AENTO03) has in some part compensated for the additional oxygen. The variation beyond 12 seconds might be variability in load, slightly different operation of the transmission during the test or test variability/measurement. For clarification the parts of the traces which have a sharp inflection on the trace and in the case of Figure 5.3 go off scale are the positions where a gear change has occurred during the acceleration.

For the other new vehicles (Hyundai Accent (AEHNY04) Figure 5.7 Holden Commodore (AENHO01) Figure 5.11 and the Ford Falcon AU (AENFO02) Figure 5.11) all indications are that their respective EMS do not compensate the fuelling level at full load. The net affect for all three of these vehicles is that the exhaust lambda value is lean by approximately 7% over the target lambda value set by the manufacture. With this level of enleanment it is expected to measure a concomitant increase in the exhaust temperature. This can be seen in Figure 5.8, Figure 5.10 and Figure 5.12. Normally it is expected for the post catalyst temperatures to exceed the pre-catalyst temperatures due to the exothermic reaction caused by the oxidation of CO and THC's. Figure 5.6, Figure 5.8, Figure 5.10 and Figure 5.12 clearly show this trend to begin with then the trend is reversed as the vehicle is accelerated. This occurs predominantly as the lambda value decreases (i.e. richer) as there is less oxygen available in the exhaust for oxidation. There will also be some secondary affect from the residence time of the exhaust gas on the catalyst, i.e. the amount of time the pollutants have to react with any oxygen as the engine speed increases.

For the vehicles which appear to have adapted, the Toyota Camry (AENTO03) shows a slight increase in exhaust temperature when operating on E20. The Subaru WRX (AEHSU05) also shows an increase in temperature of a similar order to the vehicles which appear not to adapt. This is an unexpected result. It should be noted that the Subaru has two catalysts in the exhaust system a close coupled catalyst and an under body catalyst. The pre catalyst temperature was measured down stream of the turbo-charger turbine and upstream of the pre catalyst and the post catalyst temperature is downstream of the under body catalyst, the most likely reason the post catalyst temperature never exceeds the pre-catalyst temperature is because the main exothermic reaction is occurring across the pre-catalyst. Any temperature rise is lost as the gas travels down the exhaust into the under body catalyst. It is quite likely there is little oxygen in the exhaust at this stage hence little or no reaction on the under body catalyst.

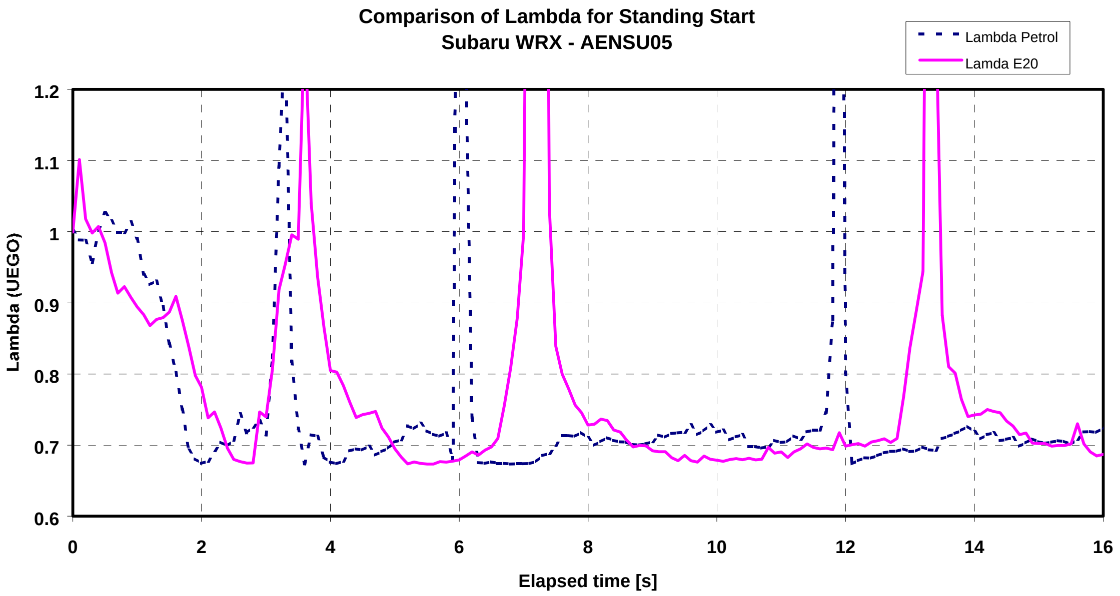


**Figure 5.3 - WOT Air Fuel Ratio Subaru WRX-AENSU05**

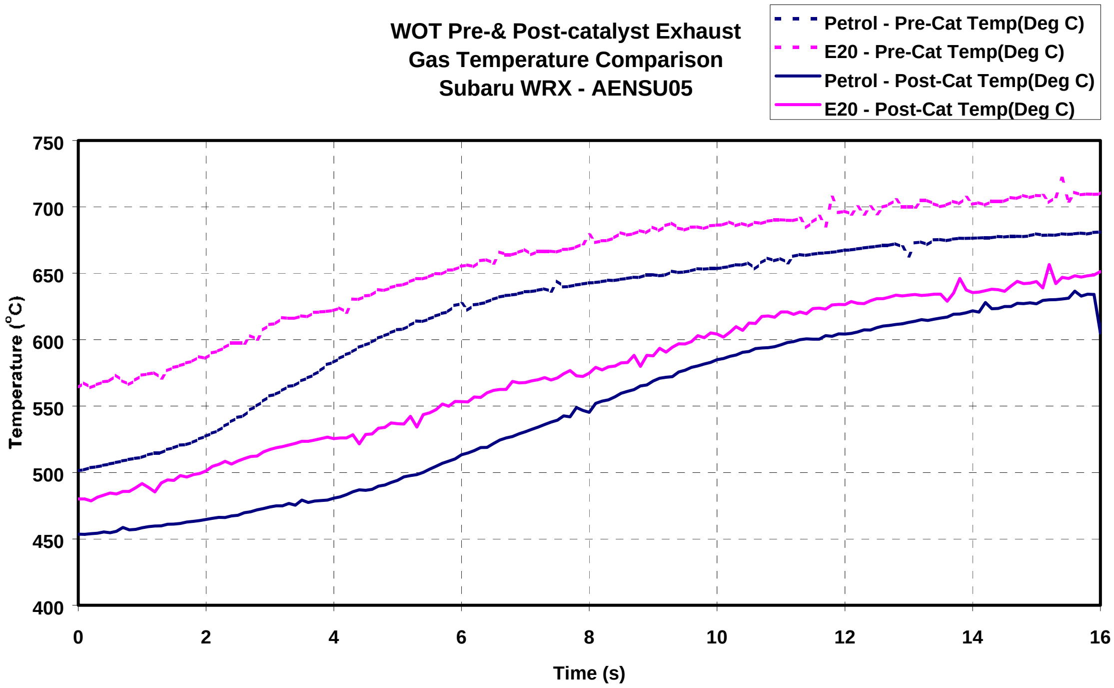


Figure 5.4 - WOT Exhaust Temperatures Subaru WRX - AENSU05

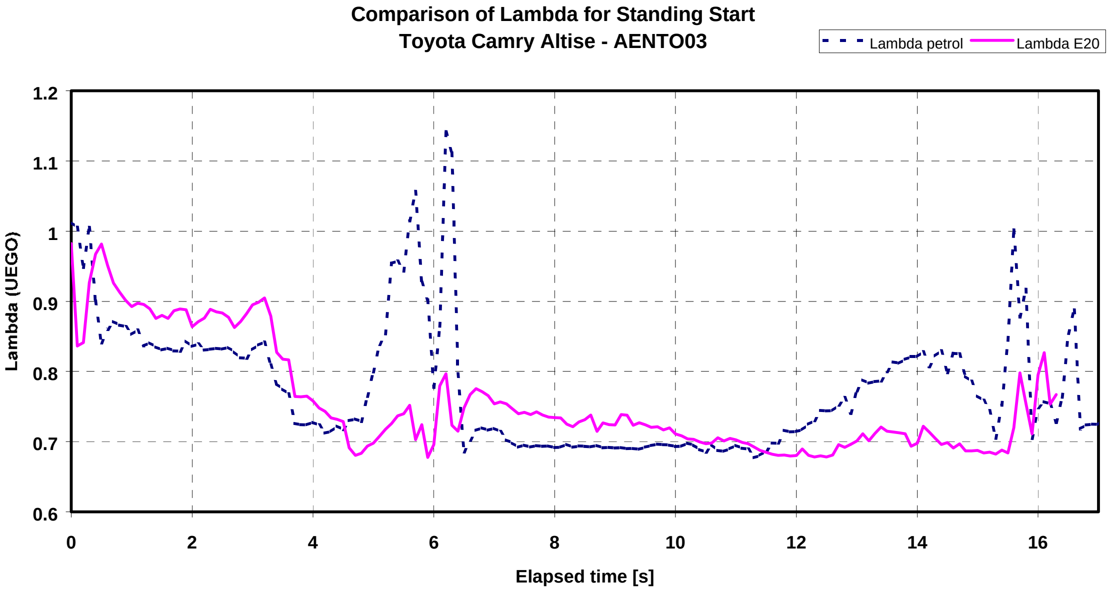


Figure 5.5 - WOT Air Fuel Ratio Toyota Camry Altise - AENTO03

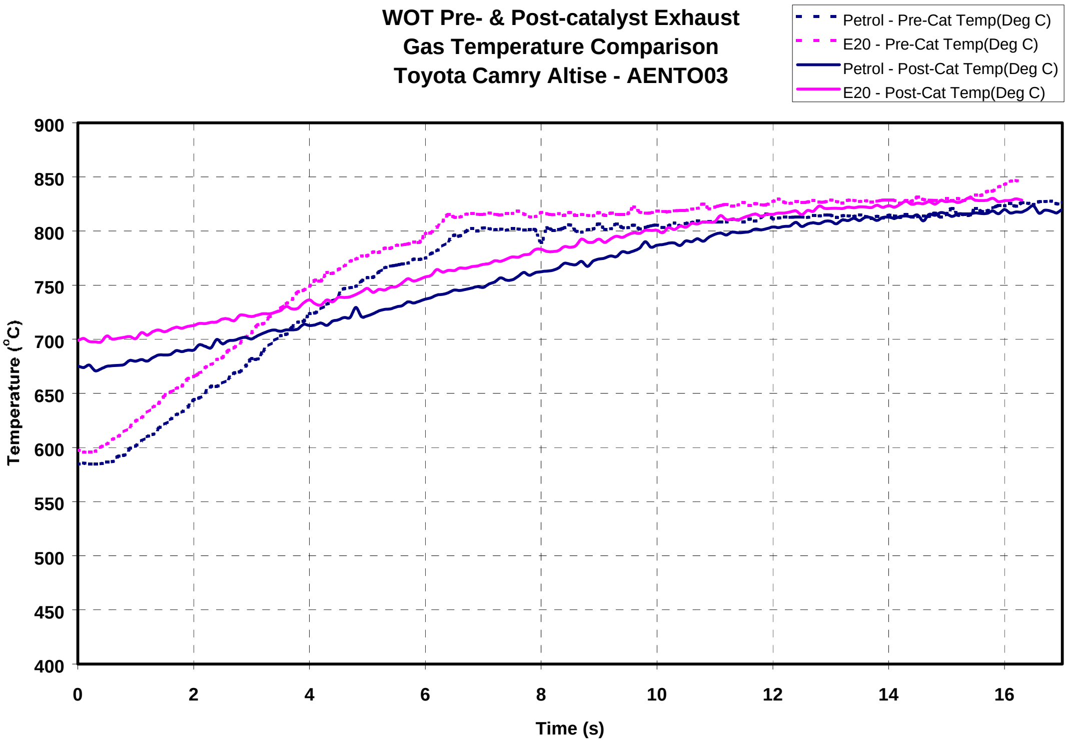


Figure 5.6 - WOT Exhaust Temperatures Toyota Camry Altise - AENTO03

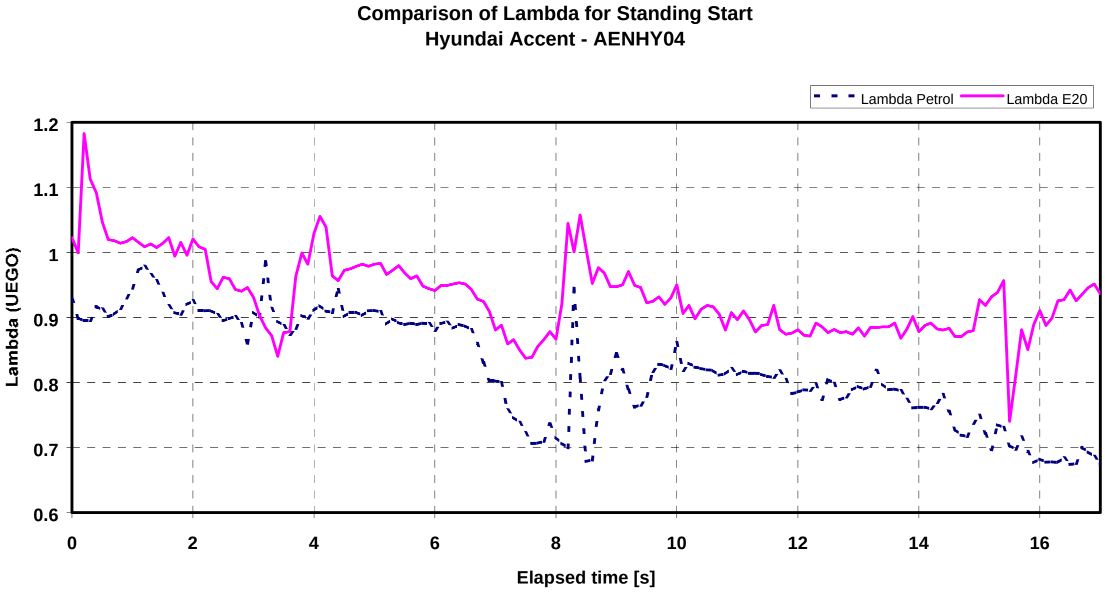


Figure 5.7 - WOT Air Fuel Ratio Hyundai Accent - AENHY04

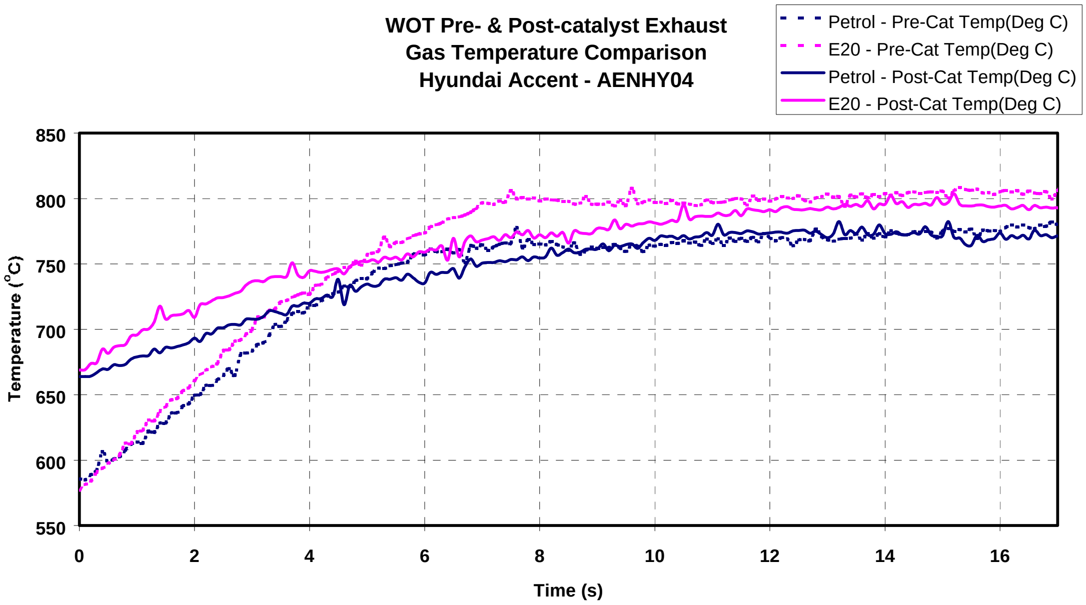


Figure 5.8 - WOT Exhaust Temperatures Hyundai Accent - AENHY04

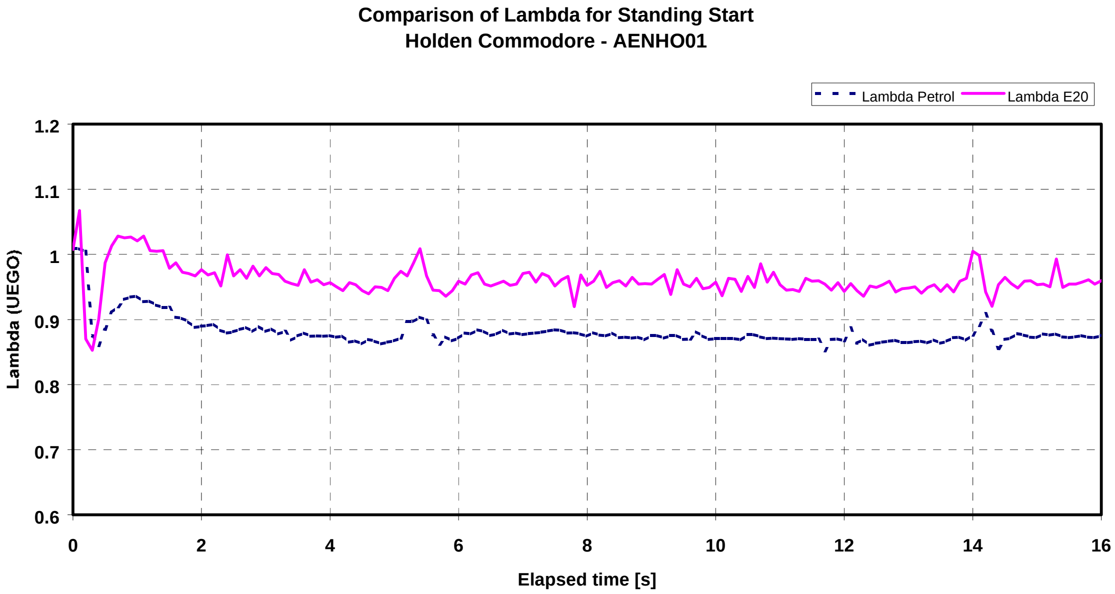


Figure 5.9 - WOT Air Fuel Ratio Holden Commodore - AENHO01

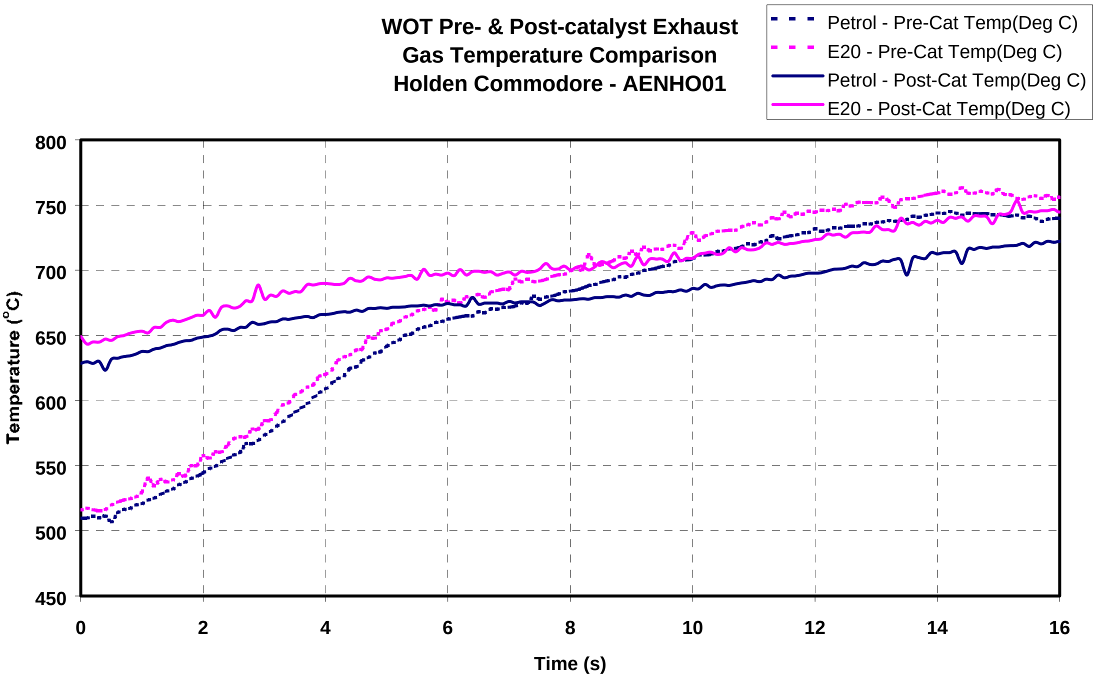


Figure 5.10 - WOT Exhaust Temperatures Holden Commodore - AENHO01

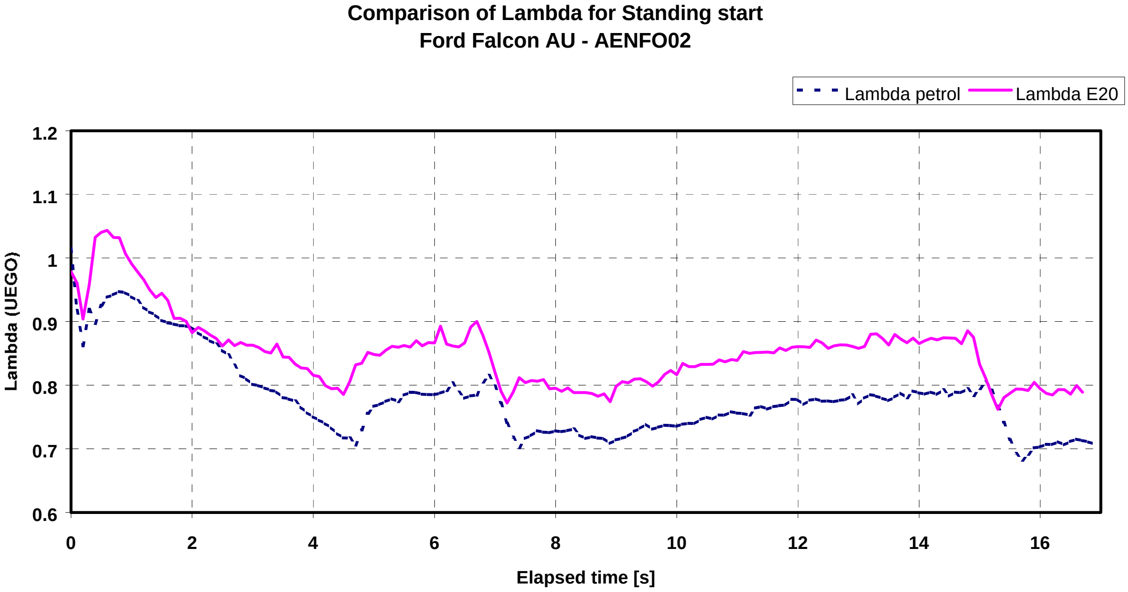


Figure 5.11 - WOT Air Fuel Ratio Ford Falcon AU - AENFO02

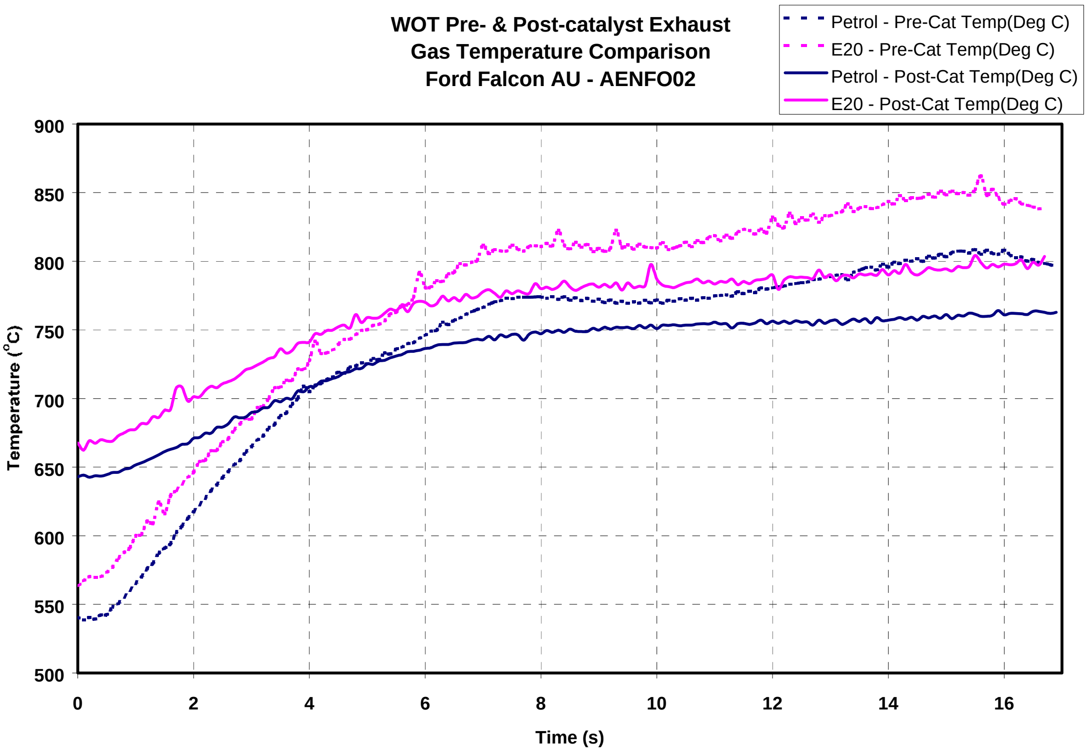


Figure 5.12 - WOT Exhaust Temperatures Ford Falcon AU - AENFO02

#### 5.1.1.1 Conclusion Engine Power Evaluation.

The WOT acceleration results on the new vehicles tested indicate there is no significant evidence of a detrimental effect caused by the use of E20 on the WOT performance. The variation in how the different vehicle EMS compensates for the ethanol is however noteworthy. Three of the vehicles tested appeared to have no compensation at full load and hence ran lean when operated on E20. There was concomitant rise in exhaust temperature for these three vehicles when operated on E20. It should be noted that the exhaust temperature also increased on the vehicles, which did adapt, when running on E20. In the case of the Toyota Camry (AENTO03) the increase in exhaust temperature was small. In the case of the Subaru WRX (AEHSU05) there was a marked increase in exhaust temperature when operated on E20, which was an unexpected result considering the vehicle was clearly running at a similar lambda value to that when operated on gasoline.

The gasoline full load lambda calibration is predominately set to control operating temperatures of engine and exhaust aftertreatment components for durability reasons. An increase exhaust gas temperature has the potential to lead to engine and aftertreatment system durability issues.

### 5.1.2 Tailpipe Emissions Assessment.

The regulated emissions from all the new vehicles where tested according to ADR 37/01 (18). During the test, measurement of air-toxic and greenhouse gas emissions were also taken. This data will be discussed in sections 5.1.4 and 7.3. The tests were undertaken with both baseline gasoline and E20 blend fuel and occurred after the vehicles had completed the low mileage

stabilisation distance of 6400km. Test reports detailing the procedures used and the detailed results for each vehicle test are included in the appendices to this report.
Also included in this section are the emissions data taken from the vehicles when they were tested over the AS2877 highway cycle, (7).

#### 5.1.2.1 ADR37/01 Weighted Regulated Tailpipe Emissions

The average weighted tailpipe emissions for all the new vehicles tested on both straight gasoline and 20% ethanol over the ADR37/01 cycle are given in Table 5.3 and pictorially shown in Figure 5.13, Figure 5.14, Figure 5.15 and Figure 5.16. The data is summarised in Figure 5.17. From (4), for closed loop systems, where the relative air fuel ratio, lambda (λ) is maintained in normal driving conditions, the effect on noxious emissions from a change in oxygen content in the fuel is minimised so long as the controller is able to maintain the desired lambda value. Also from (4) a review of published emissions data was made. The conclusion being that generally, for modern vehicles with closed loop fuel delivery systems and three way catalyst (TWC) aftertreatment systems, the addition of up to 20% ethanol results in a reduction in CO emissions and an increase in NOx emissions. There was conflicting data with respect to THC emissions. On further review of the sources of data in (4) it is thought that the data from (35) is the most relevant as the vehicles used are 1990 to 1995 model year US Federal vehicles. The emissions legislation that these vehicles complied to was the same as ADR37/01. From this study, (35) the difference in emissions from gasoline to E20 are shown in Table 5.1

| Exhaust Emission | Average percentage change from Gasoline to E20 |
|---|---|
| THC Emissions | -25% |
| CO Emissions | -27% |
| NOx Emissions | +29% |

**Table 5.1 - Percentage Change in Emissions (35)**

Figure 5.17 indicates that when operating the vehicles on E20 the trend presented in Table 5.1 was followed with an overall simple commulative average reduction of 29% in CO emissions, a reduction of 30% in THC emissions, and an increase of approximately 48% in NOx emissions. These results compare favourably with the results presented in Table 5.1 with the overall average change in CO and THC emissions being very similar, and the increase in NOx emissions being higher than those measured in (35). Note that in (35), the average of all the vehicles emissions was also used. In this paper the comment is made that all the vehicles had similar baseline gasoline emissions. This is certainly not the case with the vehicles in this study with three of the vehicles having substantially lower tailpipe emissions. Table 5.2 shows the baseline data reported in (35) and standard deviation compared to the mean data and standard deviation for the vehicles tested in this trial. From this data it is surprising that in (35) that the comment was made that the base fuel (gasoline) emissions characteristics for all vehicles is very similar, particularly for the CO emissions data.

| Parameter | Mean Gasoline(35) | Mean Gasoline | Mean E20 | Standard Deviation Gasoline(35) | Standard Deviation Gasoline | Standard Deviation E20 |
|---|---|---|---|---|---|---|
| THC (g/km) | 0.119 | 0.087 | 0.061 | 0.047 | 0.060 | 0.032 |
| CO (g/km) | 1.251 | 0.986 | 0.702 | 0.821 | 0.943 | 0.570 |
| NOx (g/km) | 0.278 | 0.089 | 0.132 | 0.114 | 0.060 | 0.108 |
| $CO_2$ (g/km) | 252.2 | 242.3 | 239.8 | 21.03 | 37.2 | 38.5 |

**Table 5.2 - Average Emissions Data from (35) Compared to Average Emissions Data for All New Vehicles from the Present Trial**

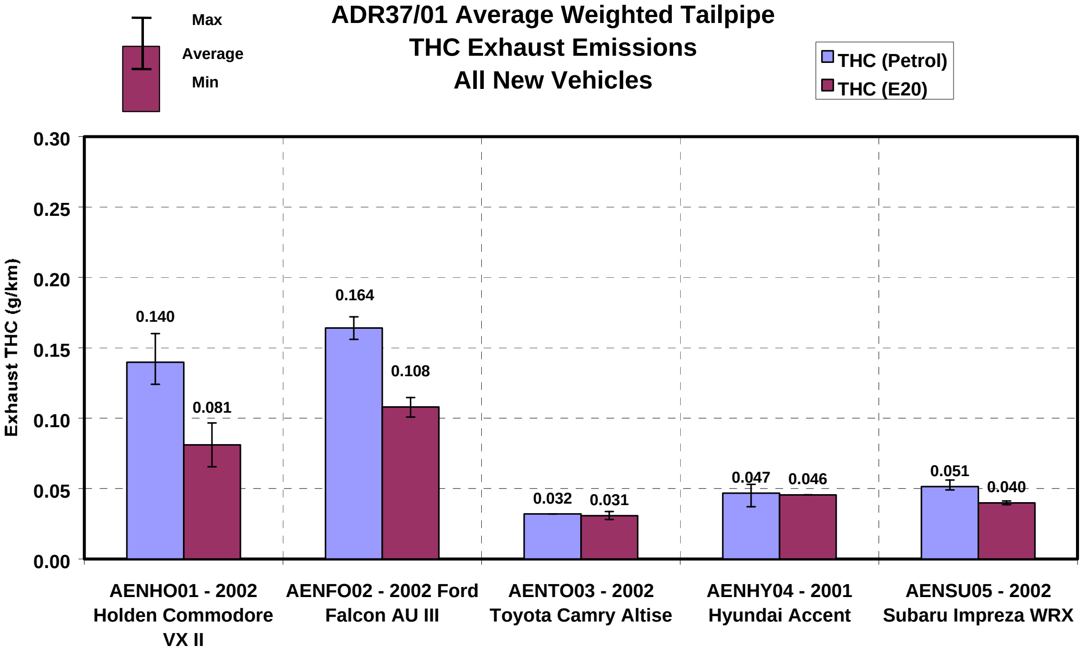
The individual vehicle percentage change in tailpipe emissions between gasoline and E20 has been plotted to understand if the trend remains on an individual vehicle basis, Figure 5.18. The hydrocarbon and CO emissions generally reduce when operating on E20 compared with gasoline only fuel. The largest reductions are seen for the vehicles with the highest absolute emissions to begin with. The vehicles with comparatively low tailpipe emissions show a smaller change, with some vehicles showing virtually showing no difference in tailpipe HC and CO levels on the two different fuels. Examples of this are the Holden Commodore and Hyundai Accent which show virtually no change in the tailpipe CO emissions when operated on the different fuels. The vehicle control systems characteristics and how they respond to changes in the fuel properties are thought to have a large bearing on the magnitudes of the emissions changes measured in the testing program.

The tailpipe NOx emissions show a general increase across all vehicles except for the Holden Commodore vehicle, which shows virtually no change in tailpipe NOx emissions. The tailpipe NOx emissions are strongly influenced by the closed loop controller affecting the NOx conversion efficiency of the three-way catalysts that are fitted to all new vehicles. The closed loop controller operating characteristics on the two different fuels can therefore lead to large differences in the changes in NOx emissions caused by the change in fuel properties between the different vehicles. This is discussed in more detail in the subsequent section (see 5.1.3).

It should also be noted here that some of the tailpipe emissions measured are extremely, low particularly the THC emissions of the Toyota Camry, Hyundai Accent and Subaru WRX and the NOx emissions of the Toyota Camry and Subaru WRX. The percentage change in emissions for these vehicles, although measurable, have only a small significance when compared to the other vehicles with higher emissions, due to the low level of emissions which are considerably under the legislated ADR limits on either fuel

| Vehicle Type | Vehicle code | THC (Gasoline) g/km | THC (E20) g/km | CO (Gasoline) g/km | CO (E20) g/km | NOx (Gasoline) g/km | NOx (E20) g/km | CO2 (Gasoline) g/km | CO2 (E20) g/km |
|---|---|---|---|---|---|---|---|---|---|
| **Holden Commodore VX** | AENHO01 | 0.140 | 0.081 | 0.740 | 0.728 | 0.085 | 0.083 | 268.4 | 267.6 |
| **Ford Falcon AU** | AENFO02 | 0.164 | 0.108 | 2.651 | 1.677 | 0.152 | 0.300 | 261.0 | 256.2 |
| **Toyota Camry Altise** | AENTO03 | 0.032 | 0.031 | 0.666 | 0.457 | 0.024 | 0.044 | 252.0 | 248.4 |
| **Hyundai Accent** | AENHY04 | 0.047 | 0.046 | 0.342 | 0.345 | 0.148 | 0.180 | 176.6 | 172.0 |
| **Subaru Impreza WRX** | AENSU05 | 0.051 | 0.040 | 0.531 | 0.303 | 0.037 | 0.053 | 257.1 | 256.2 |

## Table 5.3 - ADR37/01 Weighted Tailpipe Emissions All New Vehicles.



## Figure 5.13 - ADR37/01 Weighted Tailpipe THC Emissions All New Vehicles

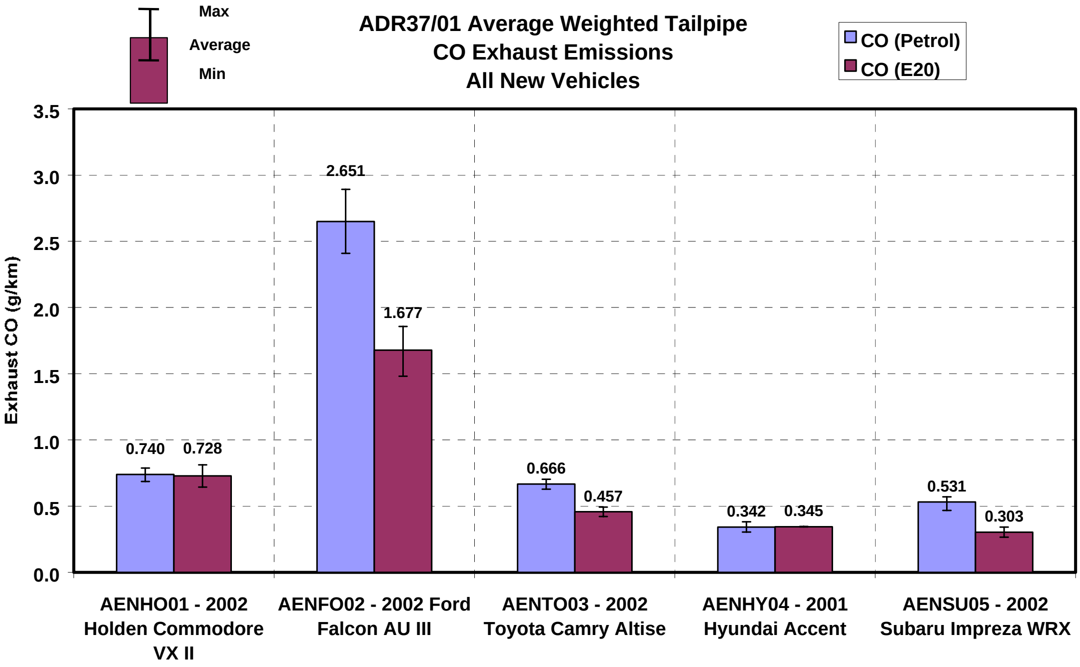


Figure 5.14 - ADR37/01 Weighted Tailpipe CO Emissions All New Vehicles

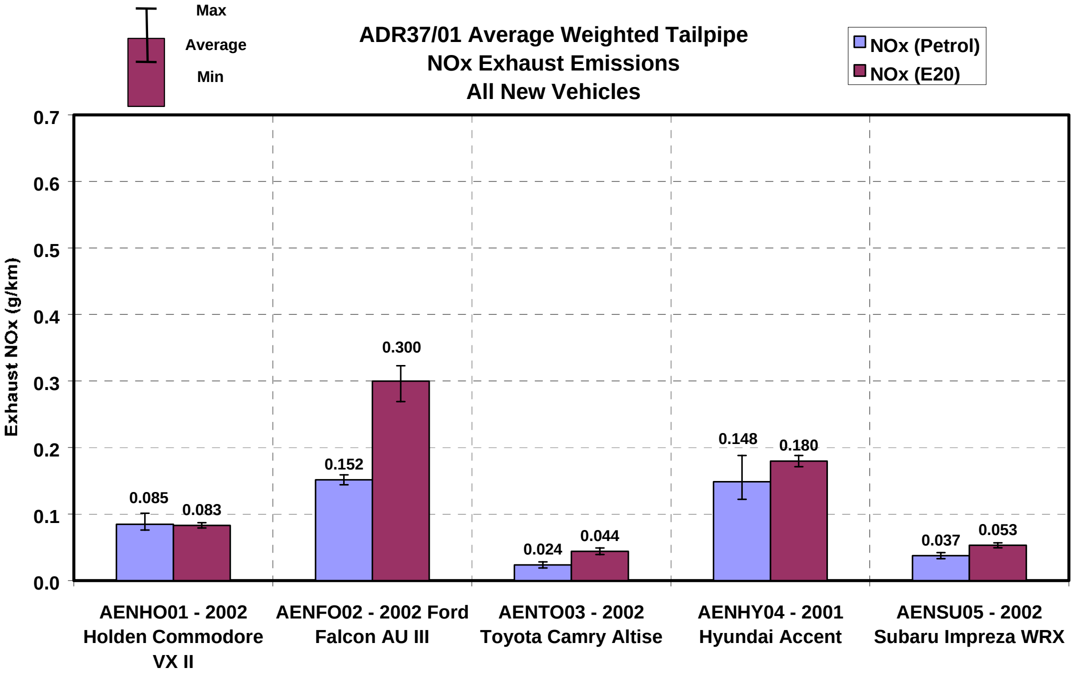
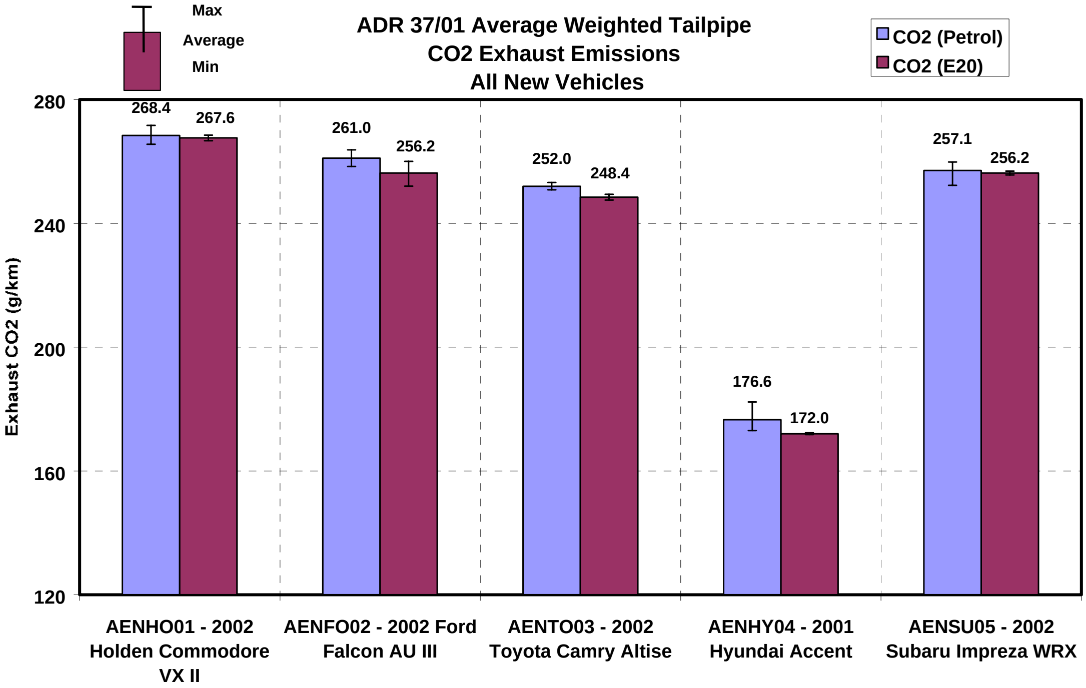
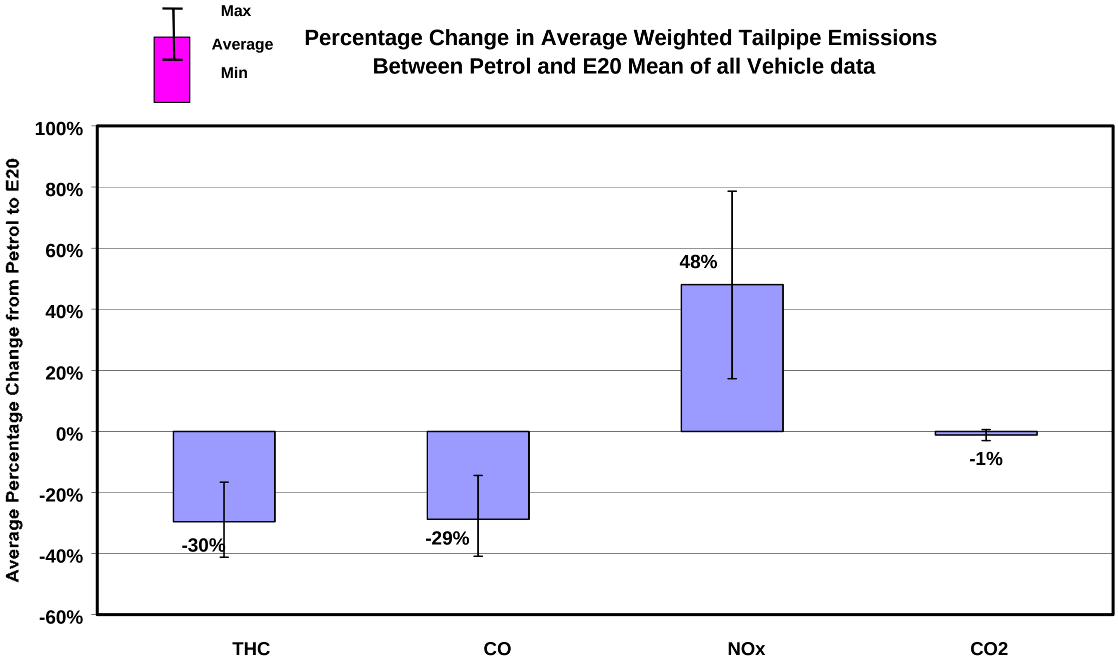


Figure 5.15 - ADR37/01 Weighted Tailpipe NOx Emissions All New Vehicles



## Figure 5.16 - ADR37/01 Weighted Tailpipe CO2 Emissions All New Vehicles



## Figure 5.17 - Percentage Change in ADR37/01 Average Weighted Tailpipe Emissions Between Gasoline and E20 Mean of All the New Vehicles

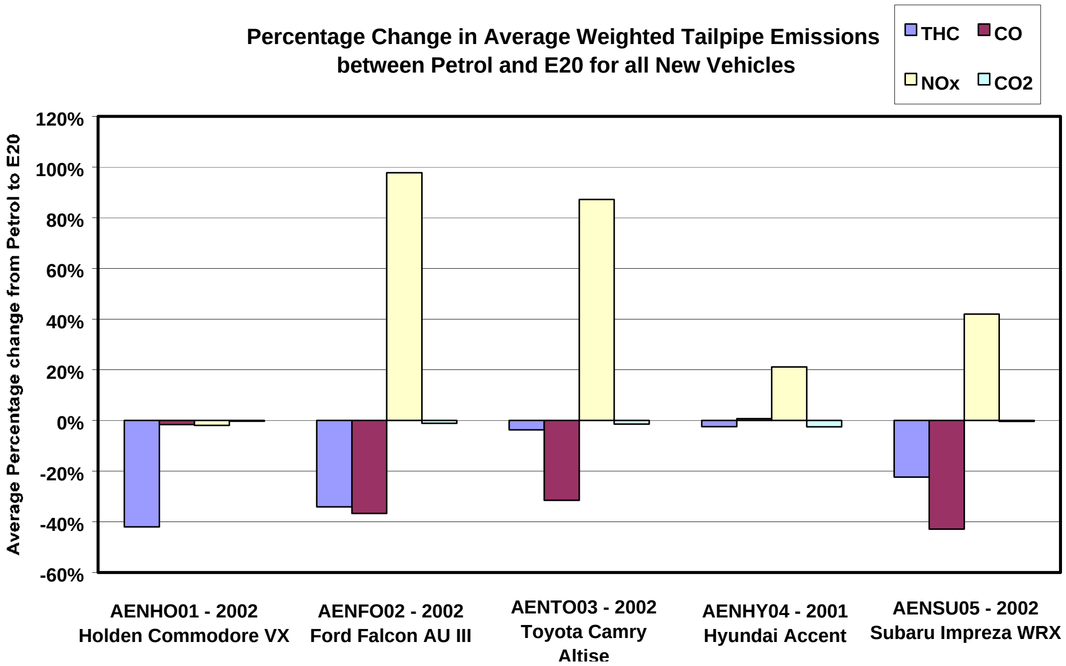


**Figure 5.18 - Percentage Change in ADR37/01 Weighted Tailpipe Emissions Between Gasoline and E20 for All the New Vehicles**

### 5.1.2.1.1 New Vehicle Impact of E20 on Regulated Tailpipe Emissions

In order to approximate the impact on regulated emissions for city driving, an analysis has been performed which includes the relative contribution of each vehicle type to the total emissions. By examining the new passenger car volumes for 2001, and by considering 4 classes of vehicles, an approximate estimate can be established. The four passenger car classes that were considered are:

1. Large – approximately 41% of the new car fleet. These vehicles are represented by the Holden Commodore and Ford Falcon test vehicles. The contribution of the Commodore and the Falcon to this class was based on the relative volumes of these two vehicles for the year 2001.
2. Medium – approximately 8% of the new car fleet. This category is represented by the Toyota Camry.
3. Small/Light – approximately 49% of the new car fleet. This category is represented by the Hyundai Accent.
4. Sports – approximately 2% of the new car fleet. This category is represented by the Subaru Impressa WRX.

Other classes such as prestige, compact all terrain vehicles etc are not included in this analysis, as there was no representation from the test vehicles chosen. The classes which are represented, however, account for approximately 90% of the Australian new passenger car fleet.

In order to produce an approximate impact on new car emissions, an assumption was made that all new cars travel approximately the same distance per year. This assumption is likely not correct, with the larger vehicles (Falcon and Commodore) accumulating more mileage per year than the other categories. However, even with this assumption, the large vehicles with the higher tailpipe emissions can contribute more than 70% of the total emissions even though the volumes account for 40% of the new car fleet. The effect of E20 on these large vehicles is therefore still highly weighted and therefore important to the overall impact on regulated emissions during city driving.

Table 5.4 shows a summary of the impact on regulated emissions over the ADR37/01 drive cycle of E20 fuel compared to gasoline only. Each test vehicle has been assigned a weighting factor which is the combination of the representative of the contribution to its respective class (in most cases this is 100% as there was only one vehicle to represent the class except in the case for the large vehicles) and the contribution of the class to the total new vehicle fleet.

| Regulated Emission | Fuel Type | | Percentage Change (%) |
|---|---|---|---|
| | Gasoline | E20 | |
| THC (g/km) | 0.088 | 0.063 | -27.9 |
| CO (g/km) | 0.835 | 0.659 | -21.1 |
| NOx (g/km) | 0.121 | 0.161 | 33.5 |

**Table 5.4 Impact of E20 on Regulated City Cycle Emissions of New Vehicle Fleet**

The approximation of the impact on the new vehicle fleet is seen to be similar to the simple average, with the HC and CO emissions reducing by approximately 28% and 21% respectively, and the NOx emissions increasing by approximately 34%. Although these impacts are similar to those calculated from the simple averaging of all vehicles, the magnitude of the NOx increase is less. This is primarily due to the reduced effective contribution of the Ford Falcon due to its sales volume weighting compared to the Holden Commodore.

#### 5.1.2.1.2 Conclusions ADR37/01 Weighted Regulated Tailpipe Emissions

Based on the analysis presented in the previous section, the following conclusions can be draw:

- There is a general trend of reduced HC and CO emissions, and an increase in NOx emissions due to operation on E20 compared with gasoline only fuel.
- The overall average changes in emissions summed across all vehicles are not representative of the change for each individual vehicle in the study. Although the general trend follows for the majority of the vehicles, the magnitude of the change is substantially different. This is largely a function of engine control system, and its ability to compensate accurately for the change in fuel properties.
- A simple prediction of the overall impact on regulated emissions of the new car vehicle fleet has been performed which shows that the HC and CO emissions would be reduced by approximately 28% and 21% respectively, while the NOx emissions would be increased by approximately 33%.

- The average percentage change of all the vehicles from gasoline to E20 compares favourably with other studies of vehicles of similar emissions compliance, however as stated, this average can give a false impression of each of the individual vehicle emissions outcome.

#### 5.1.2.1.3 Impact on $CO_2$ Emissions of New Vehicles from E20

Although carbon dioxide is not classified as a regulated emission, it is a greenhouse gas contributor, and therefore needs to be included in the analysis of the impacts of E20 on the Australian passenger vehicle fleet. From Figure 5.16 it can been seen that there is a general trend of reduced $CO_2$ emissions with the use of E20 when compared with gasoline only fuel. The trend is consistent across the range of vehicles tested, with only small $CO_2$ reductions measured between 0.3 to 2.6%. When averaged over all the vehicles, the $CO_2$ emissions reduction was approximately 1%. This small reduction is consistent with the findings from the literature-based study for vehicles of similar type (4).

### 5.1.2.2 AS2877 Highway Tailpipe Emissions (Not regulated)

The tailpipe emissions for all the vehicles tested on both gasoline only and 20% ethanol over the AS2877 Highway cycle are given in Table 5.5 and pictorially in Figure 5.19, Figure 5.20, Figure 5.21 and Figure 5.22.

From the data, there is seen a general trend of reduced HC and CO emissions when using E20 compared to gasoline only fuel. The magnitudes of these reductions are again significantly different between the vehicles, with the largest reductions generally occurring to the vehicles with the largest absolute emissions to begin with. These trends are similar to what was found for the ADR37/01 test results.

The NOx emissions changes are seen to be quite different between the new vehicles, with no general trend of reduced or increased emissions levels over the highway cycle when the vehicles were operated on E20. The NOx emissions were found to reduce for the Commodore and Falcon, and generally increase for the other vehicles. The general increase in NOx emissions with E20 is what would have been expected, as measured for the ADR37/01 cycle. The magnitudes of the tailpipe NOx emissions were also found to be substantially different. On further investigation, it was found that the Commodore and Falcon ran lean (open loop) during the highway cycle with both gasoline and E20 fuels. This operation results in very poor conversion efficiency of NOx generated while the engine is in lean operation. The lean operation with gasoline as the baseline also helps to explain the reduction in NOx that was measured with E20. With the engine running on E20 with a calibration, which was already lean of stoichiometric operation with gasoline, there would be further enleanment leading to a possible reduction in the NOx generation. The other vehicles continued to run at stoichiometric operation in closed loop control, and as such the NOx emissions were significantly lower on both gasoline and E20.

The $CO_2$ emissions on average across all vehicles shows a small reduction of approximately 1% when using E20 compared to gasoline only fuel (see Figure

5.23). The individual vehicles, however, so show the same general trend, with both increases and reductions shown for the different vehicles when operating on E20. It is believed that the differences in the vehicle results are due to specific vehicle calibrations, including the control system, and the way it adapts to the different fuel properties. The effect on engine operation due to the control system function is presented in more detail in section 5.1.3).

The average change in emissions over all the vehicles tested is summarised in Figure 5.23. This shows an average reduction in HC and CO emissions of 25 and 48% respectively. The NOx emissions, on average, are also reduced by approximately 9%. This reduction is due to the reductions from the open loop lean operating vehicles which dominate this average due to the large magnitudes of the absolute NOx emissions levels.

| **Vehicle Type** | **Vehicle code** | **THC (Gasoline) g/km** | **THC (E20) g/km** | **CO (Gasoline) g/km** | **CO (E20) g/km** | **NOx (Gasoline) g/km** | **NOx (E20) g/km** | **CO2 (Gasoline) g/km** | **CO2 (E20) g/km** |
|---|---|---|---|---|---|---|---|---|---|
| **Holden Commodore VX** | AENHO01 | 0.020 | 0.016 | 0.101 | 0.021 | 0.844 | 0.758 | 163.3 | 160.6 |
| **Ford Falcon AU** | AENFO02 | 0.042 | 0.029 | 0.918 | 0.384 | 3.327 | 3.003 | 177.0 | 174.2 |
| **Toyota Camry Altise** | AENTO03 | 0.023 | 0.016 | 0.955 | 0.539 | 0.015 | 0.025 | 167.5 | 162.8 |
| **Hyundai Accent** | AENHY04 | 0.011 | 0.009 | 0.088 | 0.087 | 0.058 | 0.084 | 125.3 | 126.7 |
| **Subaru Impreza WRX** | AENSU05 | 0.006 | 0.006 | 0.101 | 0.100 | 0.006 | 0.008 | 179.8 | 182.5 |

**Table 5.5 - AS2877 Highway Tailpipe Emissions All New vehicles**

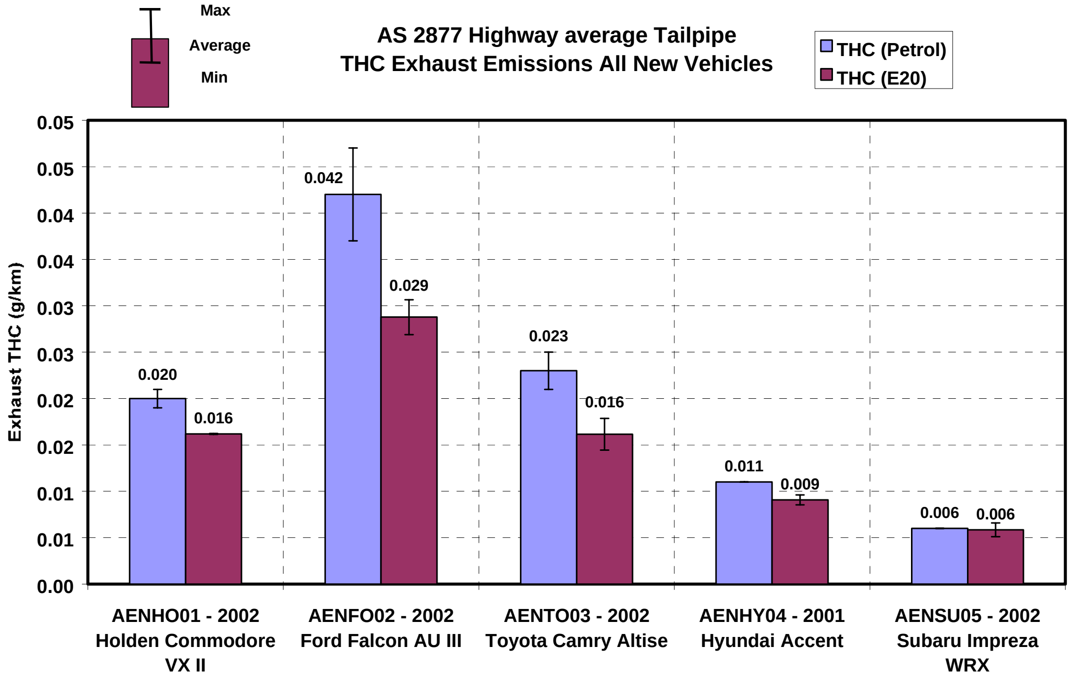


**Figure 5.19 - AS2877 Highway Tailpipe THC Emissions All New Vehicles**

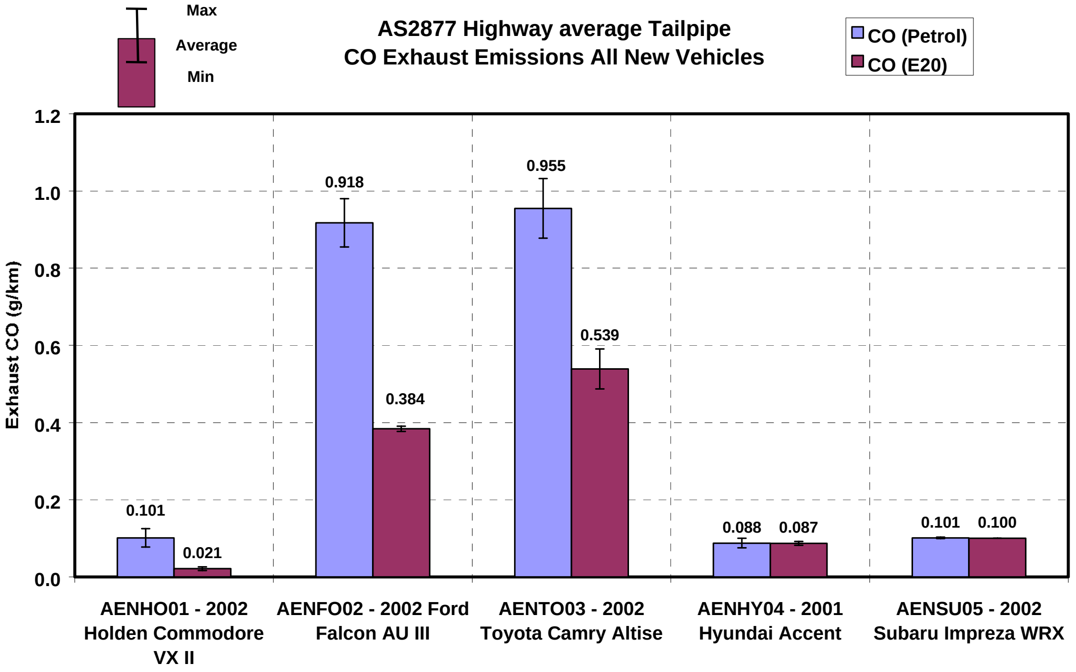


Figure 5.20 - AS2877 Highway Tailpipe CO Emissions All New Vehicles

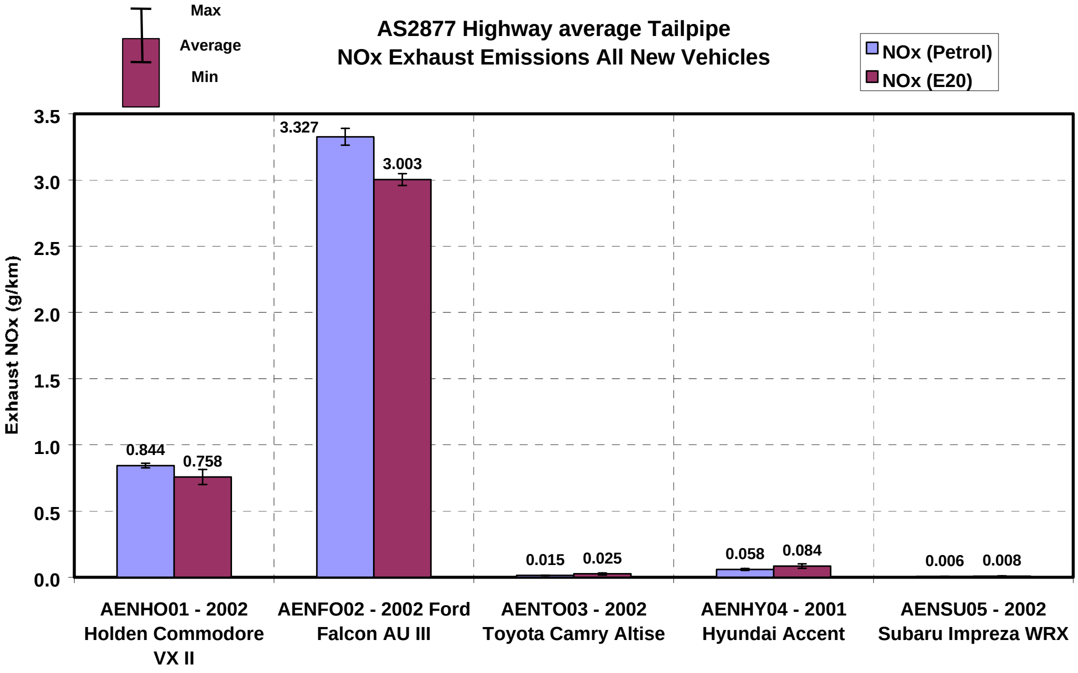


Figure 5.21 - AS2877 Highway Tailpipe NOx Emissions All New Vehicles

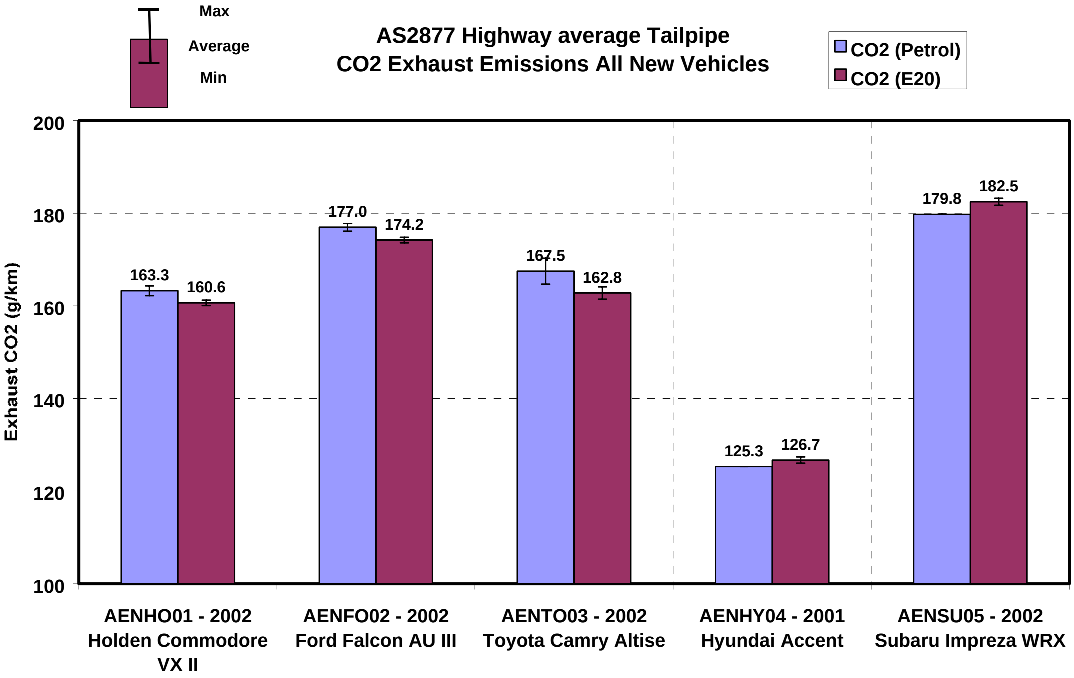


Figure 5.22 - AS2877 Highway Tailpipe CO2 Emissions All New Vehicles

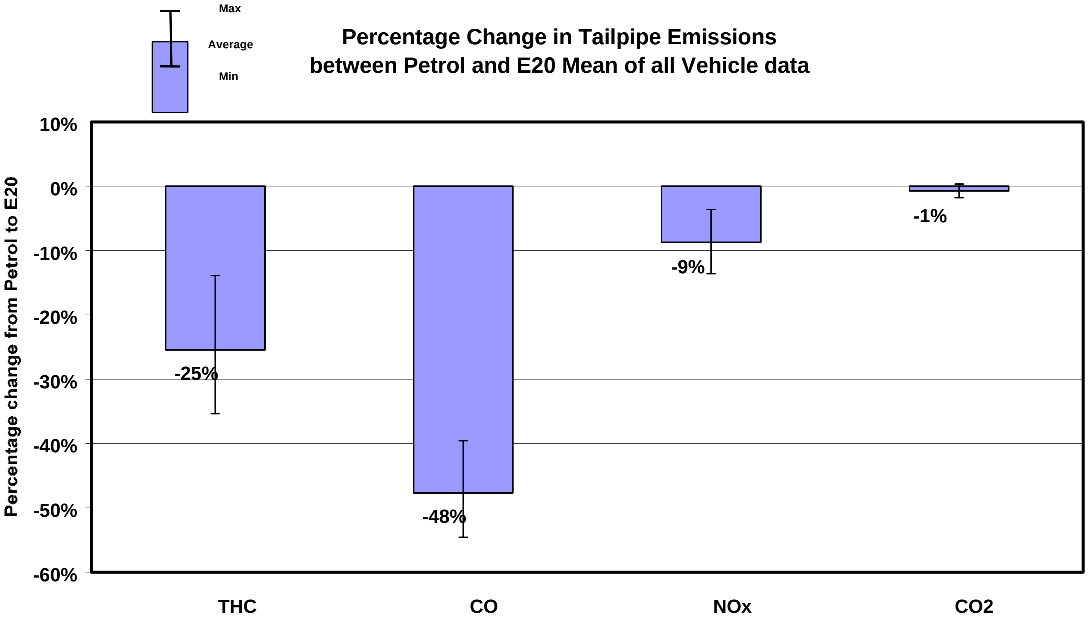


Figure 5.23 - Percentage Change in AS2877 Highway Average Tailpipe Emissions Between Gasoline and E20 Mean of All the New Vehicles

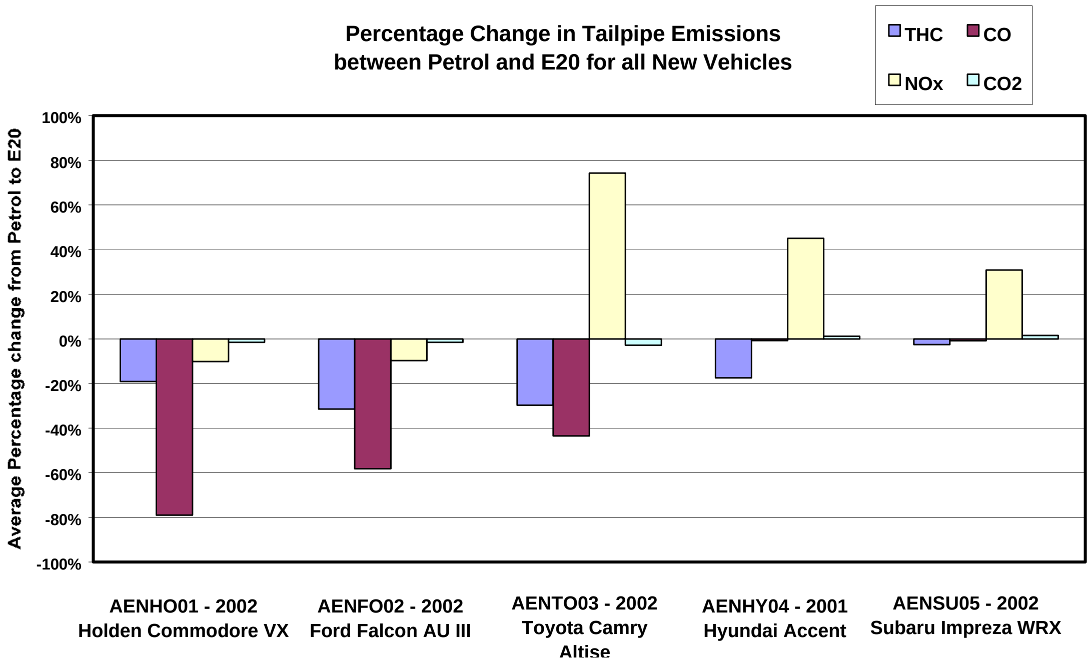


**Figure 5.24 - Percentage Change in AS2877 Highway Tailpipe Emissions Between Gasoline and E20 for All the New Vehicles**

#### 5.1.2.2.1 Conclusions AS2877 Highway Tailpipe Emissions.

The following conclusions can be made based on the preceding analysis:

- There is a general trend across all vehicles of reduced HC and CO emissions when operating on E20 compared with gasoline only fuel.
- Tailpipe NOx emissions changes are varied depending on the vehicle with no clear trend evident. This was due to some of the vehicles operating lean without closed loop control, and hence had comparatively high NOx emissions with both gasoline and E20 fuels.
- The overall average changes in emissions summed across all vehicles are not representative of the change for each individual vehicle. Differences in control and calibration strategies and characteristics result in different tailpipe emissions changes when using E20 compared to gasoline only fuel.
- The average change across all vehicles in tailpipe emissions shows a reduction in HC, CO and NOx of 25%, 48% and 9% respectively.
- The average $CO_2$ emissions across all vehicles was reduced by approximately 1% for E20 when compared with gasoline only fuel. The reduction in $CO_2$ emissions with E20 was not consistent for all vehicles tested.

### 5.1.3 Engine Management Systems Impacts

This section presents an analysis of engine out and tailpipe emissions data focussed on understanding the impact the E20 fuel blend has on the engine management system.

#### 5.1.3.1 Pre-Catalyst Emissions Data (Not Regulated)

Section 5.1.2.1 concentrated on the effect of a 20% ethanol blend on regulated tailpipe emissions. To better understand the effect of a 20% ethanol blend on vehicle tailpipe emissions it is necessary to study the change in fuel has on the pre-catalyst or engine out emissions. This data for all the new vehicles studied is presented in Figure 5.25, Figure 5.29, Figure 5.32, Figure 5.35 and Figure 5.39. The data is split into the three phases of the ADR37/01 test cycle, phase one cold transient, phase two hot stabilised and phase three hot transient. This makes it possible to differentiate any changes in emissions performance between gasoline and E20 that might occur between hot and cold start, steady state and transient performance

From Figure 5.18 it appears that the Holden Commodore (AENHO01) and Hyundai Accent (AENHY04) do not have the expected improvement in tailpipe CO emissions typically associated with operating an engine with an oxygenated fuel. Figure 5.25 clearly shows that in fact the pre-catalyst CO emissions in phase one actually increases for the Holden Commodore. Whilst for the Hyundai Accent Figure 5.35 the CO emissions remains approximately the same as for gasoline for phase one. For all the other vehicles there is a marked decrease in pre-catalyst CO emissions in phase one and for all vehicles there is decrease in the phase two and three CO emissions. The result from the Holden Commodore is unexpected, one of the reasons to oxygenate fuel is to reduce the cold start CO emissions. Also from Figure 5.18 the tailpipe NOx emissions for the Holden Commodore has not increased in line with the other vehicles tested. The Hyundai Accent tailpipe NOx emissions has increased but not to the same extent as the other vehicles. Again this is an unexpected result. There are a number of possible reasons for these results but the most probable is that when the EMS adapts for the increased oxygen content of the fuel, it either over compensates or biases (lambda shifts) the closed loop controller (36). Figure 5.26 shows the percentage of oxygen in the exhaust pre-catalyst for the Holden Commodore. It appears from this data that when the vehicle is operated on E20 there is a marked decrease in the oxygen in the exhaust, particularly when the vehicle is idling. Comparison of this data to the data in Figure 5.33 for the Toyota Camry shows that for the Toyota the percentage oxygen is virtually coincident for gasoline and E20. The data for the Ford Falcon Figure 5.30 and Subaru Figure 5.40 show similar coincidence. However the Hyundai Figure 5.36 appears to behave in a similar manner to the Holden with a marked decrease in the exhaust oxygen content when operated on E20, particularly at idle and light load regions. It is this decrease in oxygen or rich bias which has increased the CO emissions in phase one whilst at the same time maintained the NOx emissions levels to be similar between gasoline and E20 for both the Holden Commodore and Hyundai Accent. It should be noted that the rich bias need not necessarily be rich of stoichiometry, the base gasoline calibration could be lean of stoichiometry and the adaptation to E20 has removed this lean bias. To investigate if this was occurring the modal lambda was calculated for the Holden Commodore Figure 5.27 and Hyundai Accent Figure 5.37. From these figures it can be seen than when operating on gasoline both of these vehicles have a lean bias at idle. When these two vehicles are operated on E20, the adaptation process removes the lean bias. Note all the vehicles maintained closed loop control while operating on E20 through the drive cycle, any differences seen in the percentage oxygen in the exhaust have occurred as a function of how the EMS has adapted to the change to E20.

Plots of accumulated or integrated mass of engine out oxygen over the ADR37/01 drive cycle are shown for each vehicle in Figure 5.28, Figure 5.31, Figure 5.34, Figure 5.38 and Figure 5.41. If the accumulated plot shows the lines for gasoline and E20 to be virtually coincident then it can be assumed the closed loop controller is operating in a similar manner regardless of the fuel. Clearly from Figure 5.28 for the Holden Commodore and Figure 5.38 for the Hyundai Accent this is not true with both vehicles having a lower value of accumulated engine out oxygen (i.e. rich biased) over the drive cycle. The Ford Falcon, Figure 5.31, appears to have a lean bias to the controller, this is not apparent from the modal plot of pre-catalyst exhaust oxygen content, Figure 5.30, but certainly accounts for the large increase in tailpipe NOx emissions. This is also supported by a significant drop in the catalyst NOx conversion efficiency Figure 5.43, (97.9% to 91.3%).

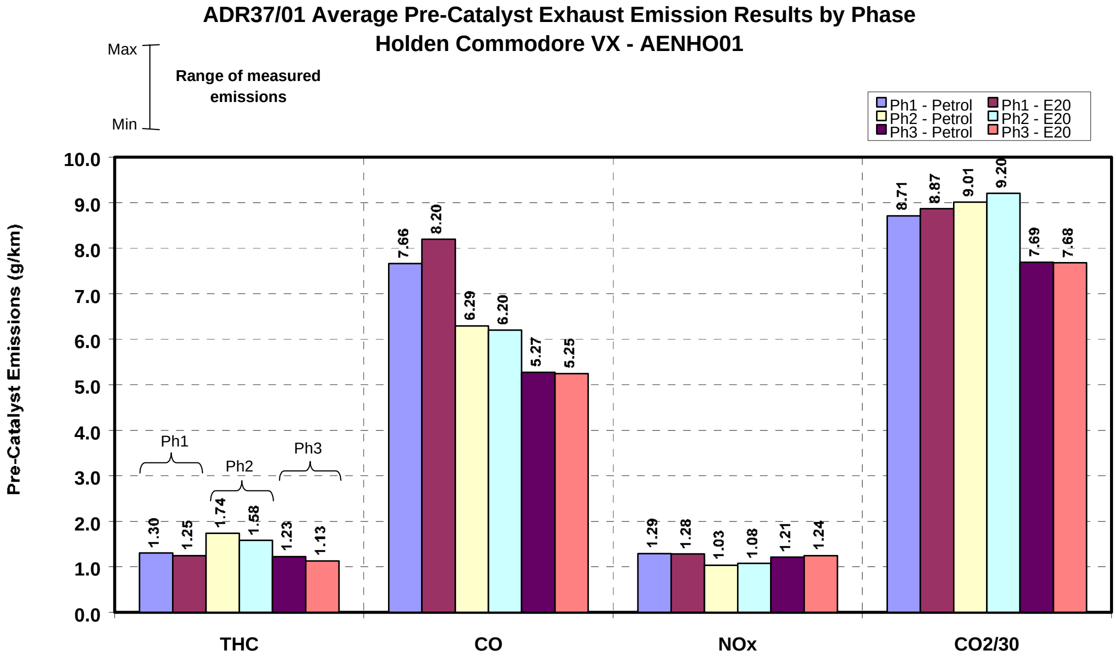


Figure 5.25 - Average Pre Catalyst Emissions Holden Commodore VX - AENHO01.

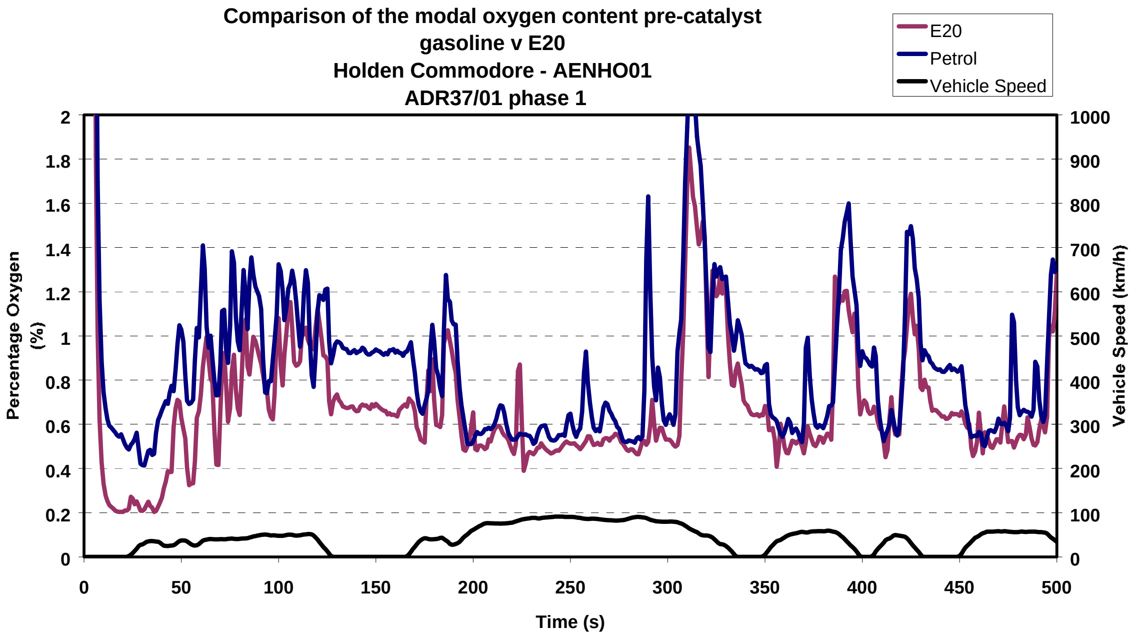


Figure 5.26 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Holden Commodore (AENHO01).

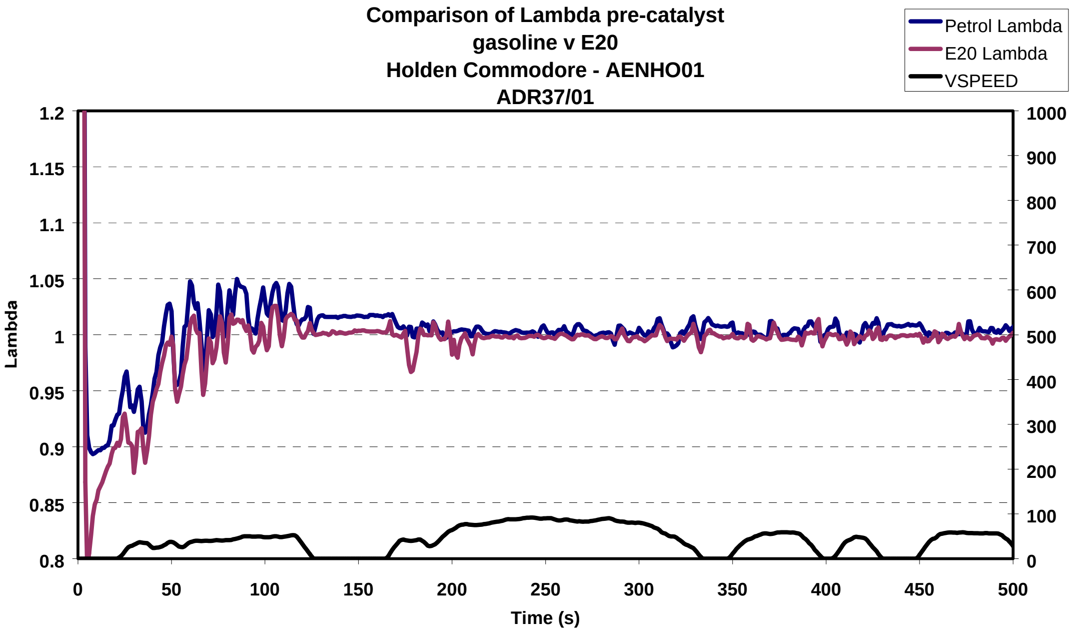


Figure 5.27 - Comparison of Lambda for Gasoline vs. E20 Holden Commodore (AENHO01).

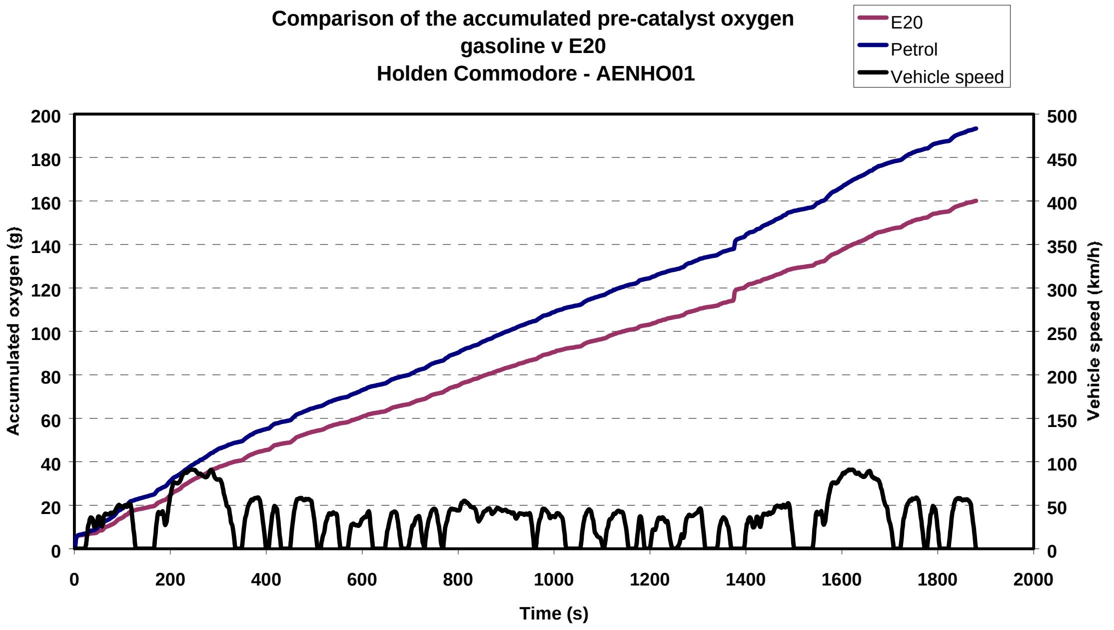


Figure 5.28 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Holden Commodore (AENHO01).

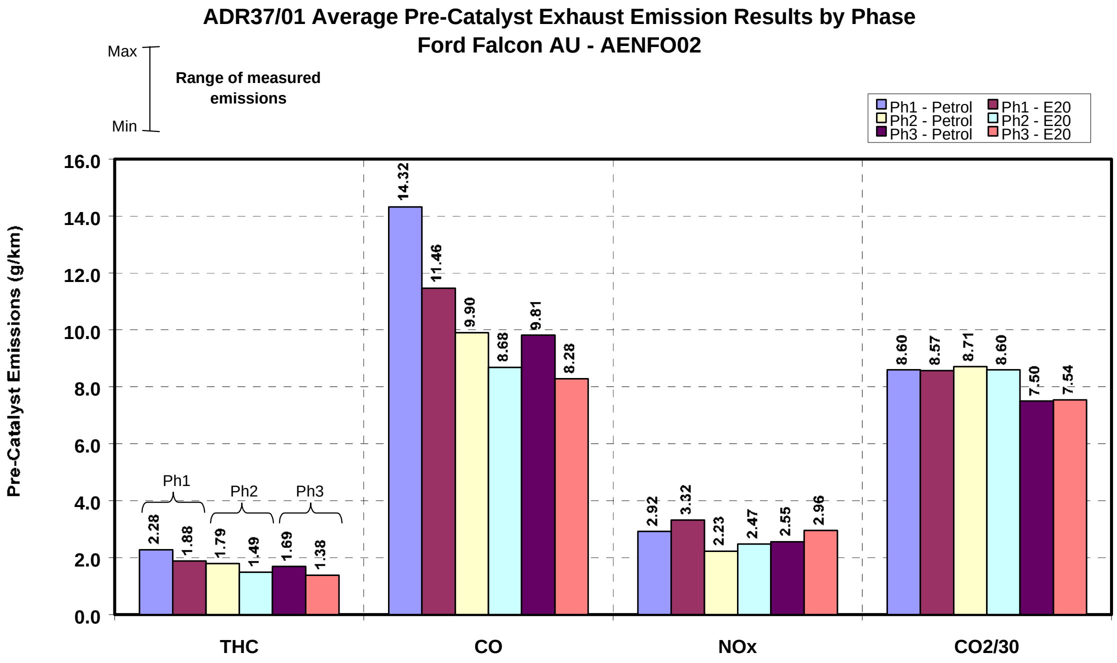


Figure 5.29 - Average Pre Catalyst Emissions Ford Falcon AU AENFO02.

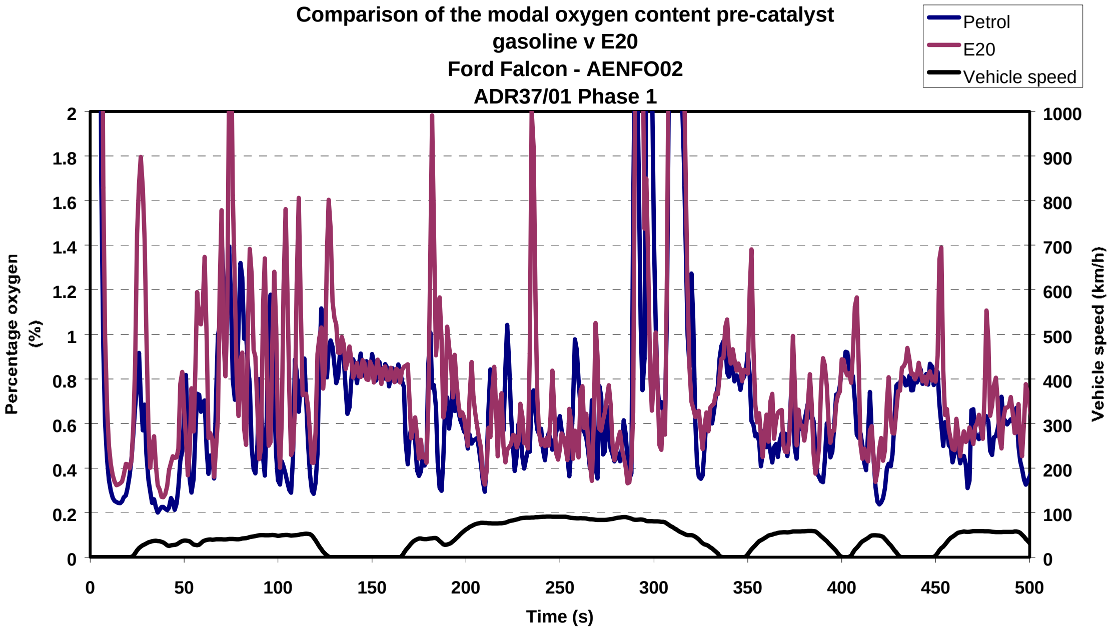


Figure 5.30 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Ford Falcon (AENFO02).

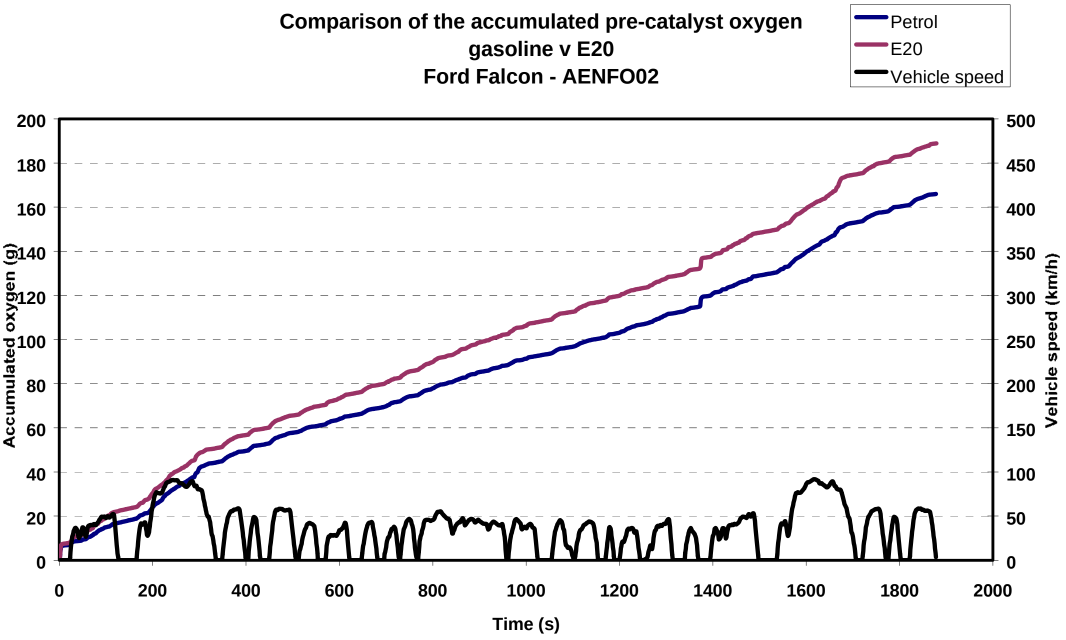


Figure 5.31 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Ford Falcon (AENFO02)

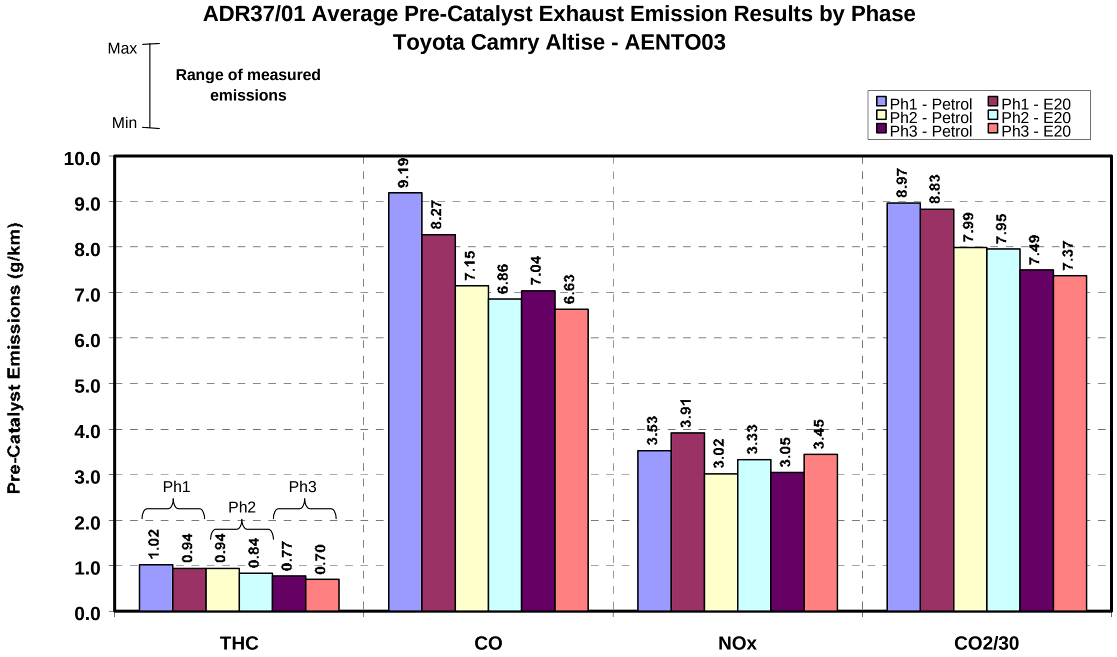


Figure 5.32 - Average Pre-Catalyst Emissions Toyota Camry Altise AENTO03

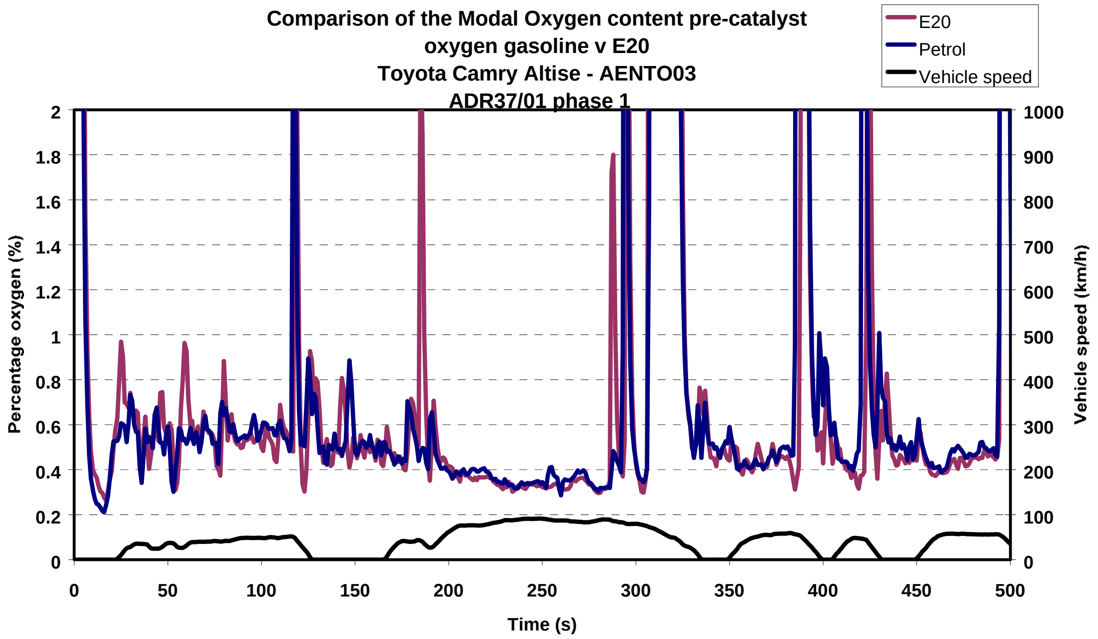


Figure 5.33 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Toyota Camry Altise (AENTO03)

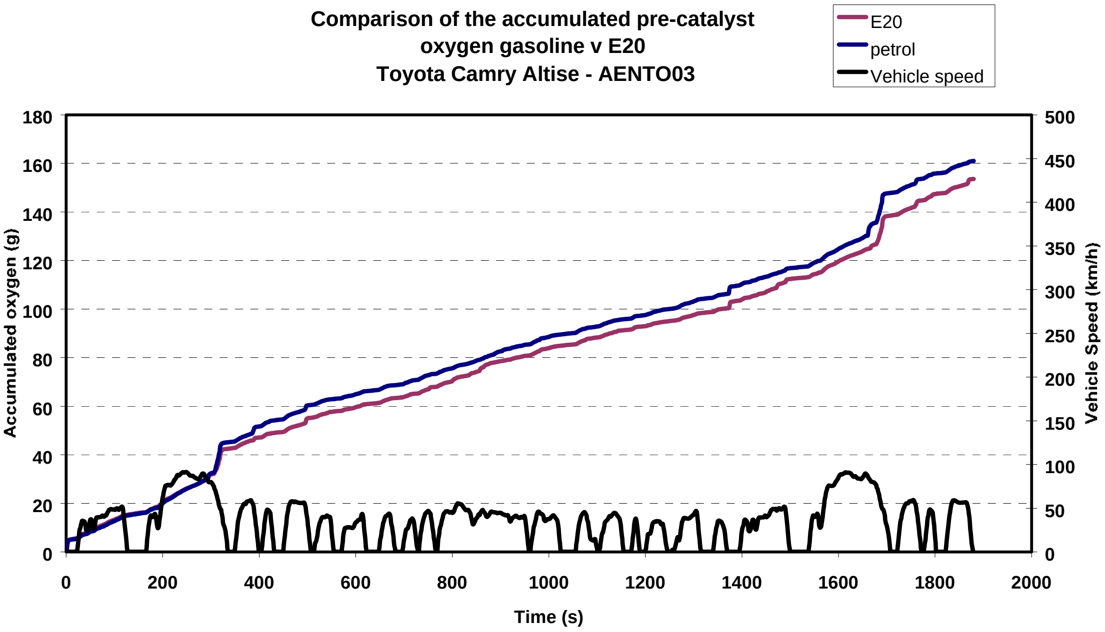


Figure 5.34 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Toyota Camry Altise AENTO03

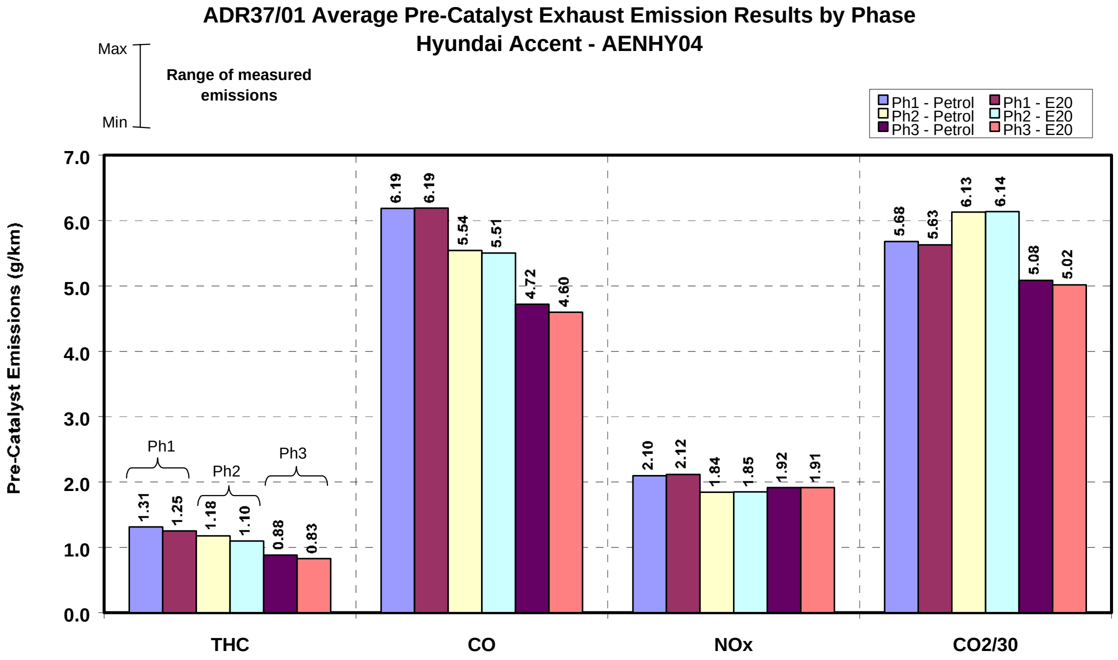


Figure 5.35 - Average Pre-Catalyst Emissions Hyundai Accent AENHY04

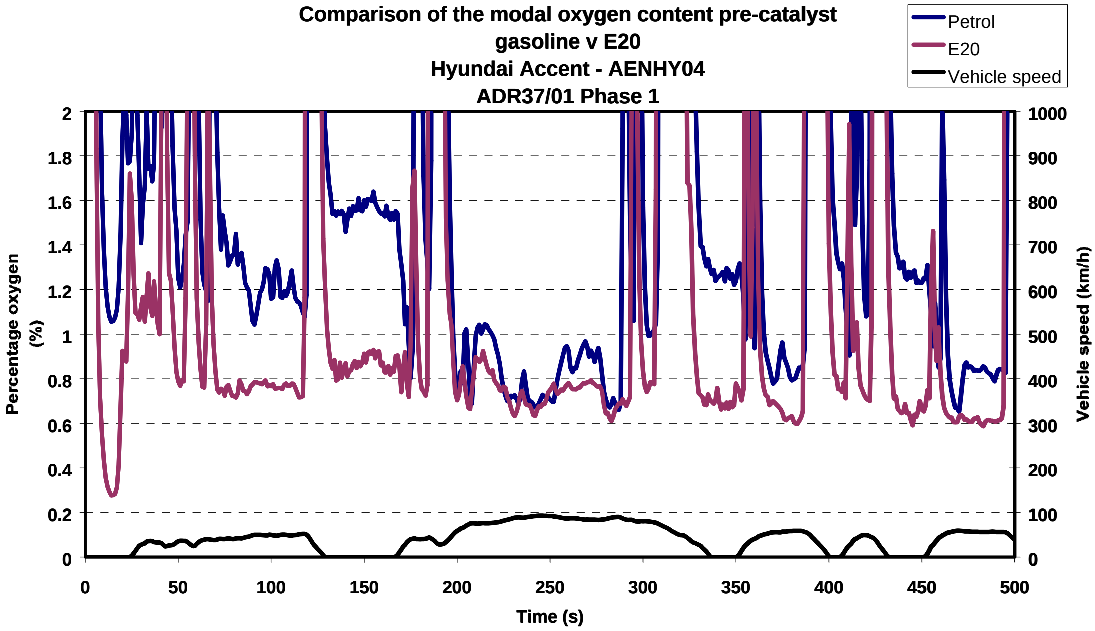


Figure 5.36 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Hyundai Accent (AENHY04).

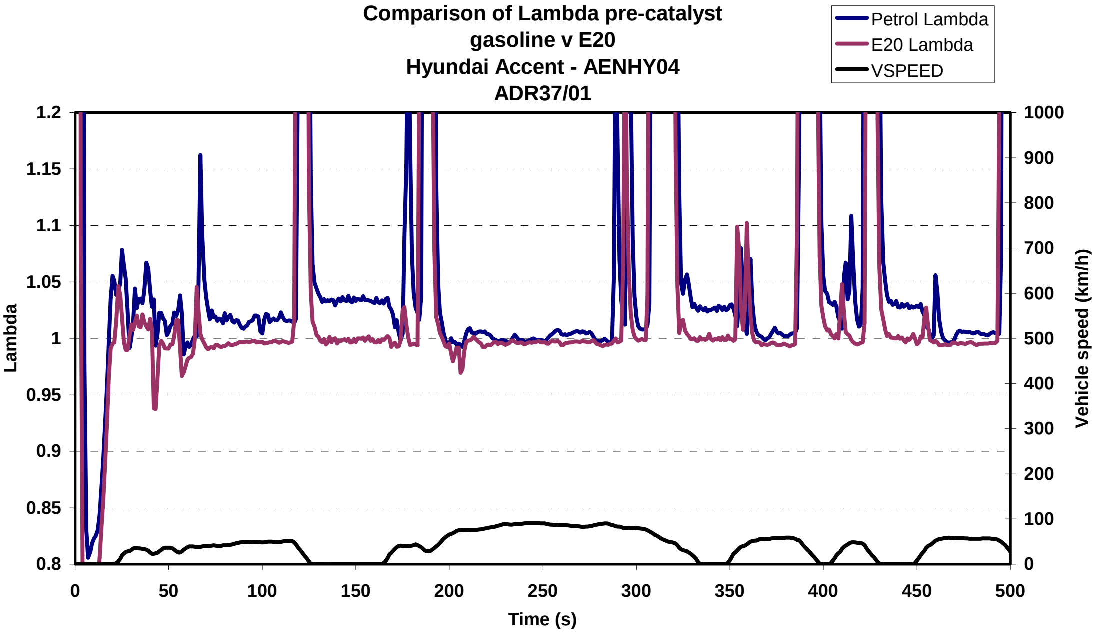


Figure 5.37 - Comparison of Lambda for Gasoline vs. E20 Hyundai Accent (AENHY04).

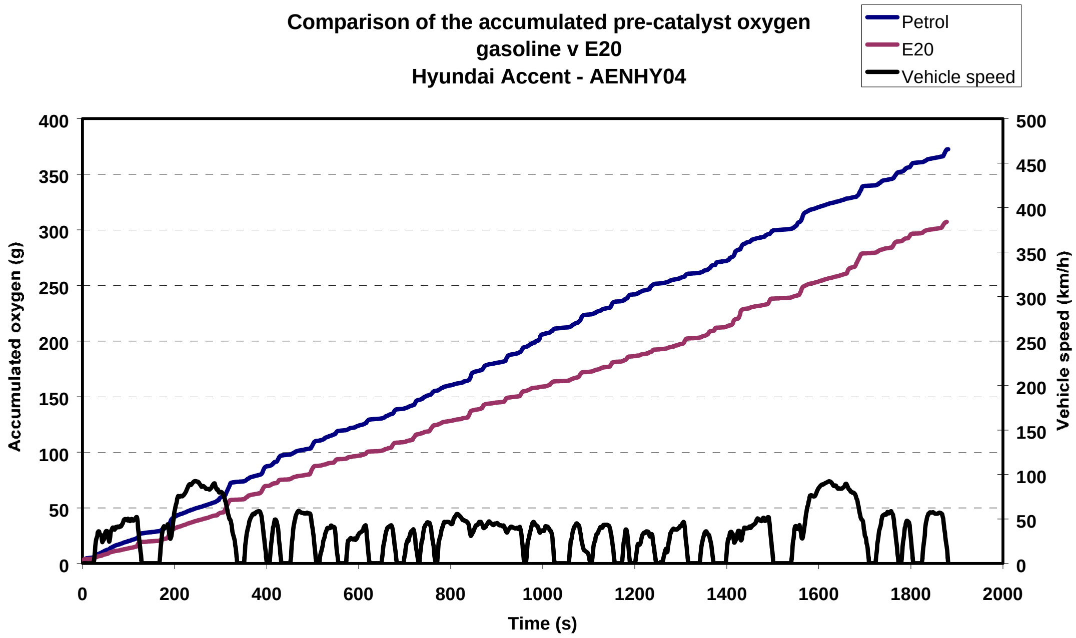


Figure 5.38 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Hyundai Accent (AENHY04).

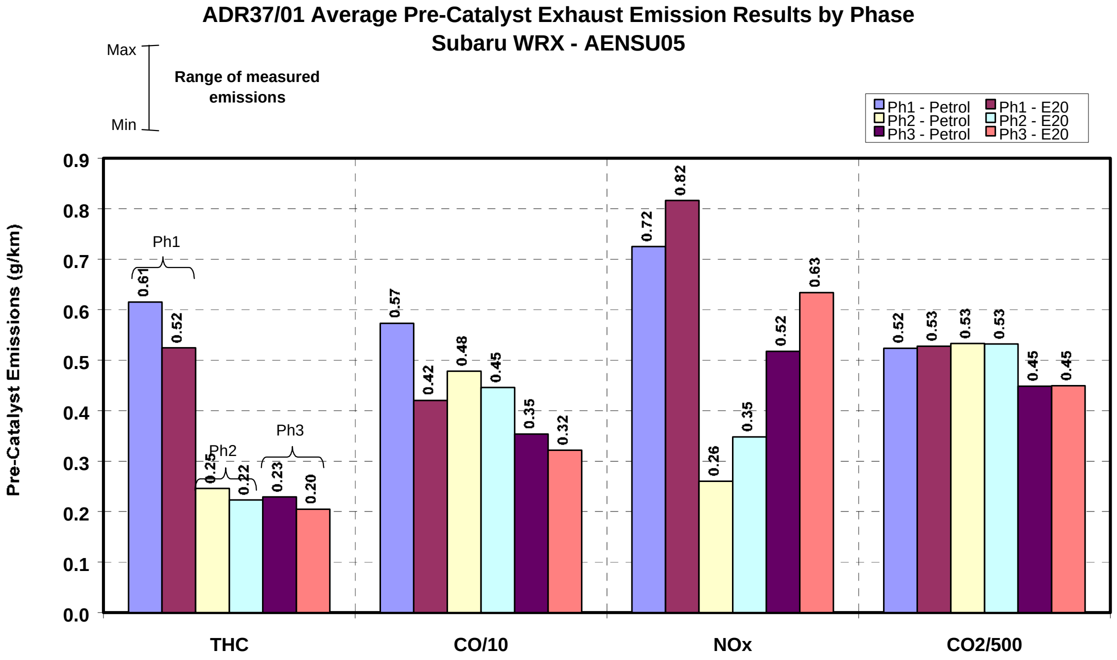


Figure 5.39 - Average Pre-Catalyst Emissions Subaru WRX AENSU05.

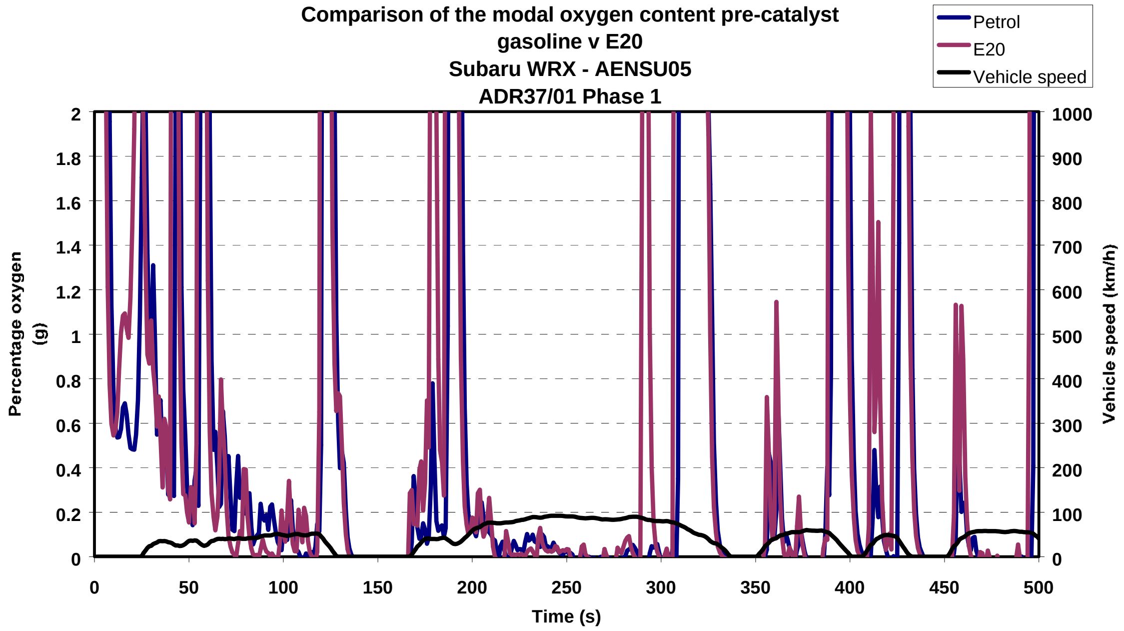


Figure 5.40 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Subaru WRX (AENSU05)

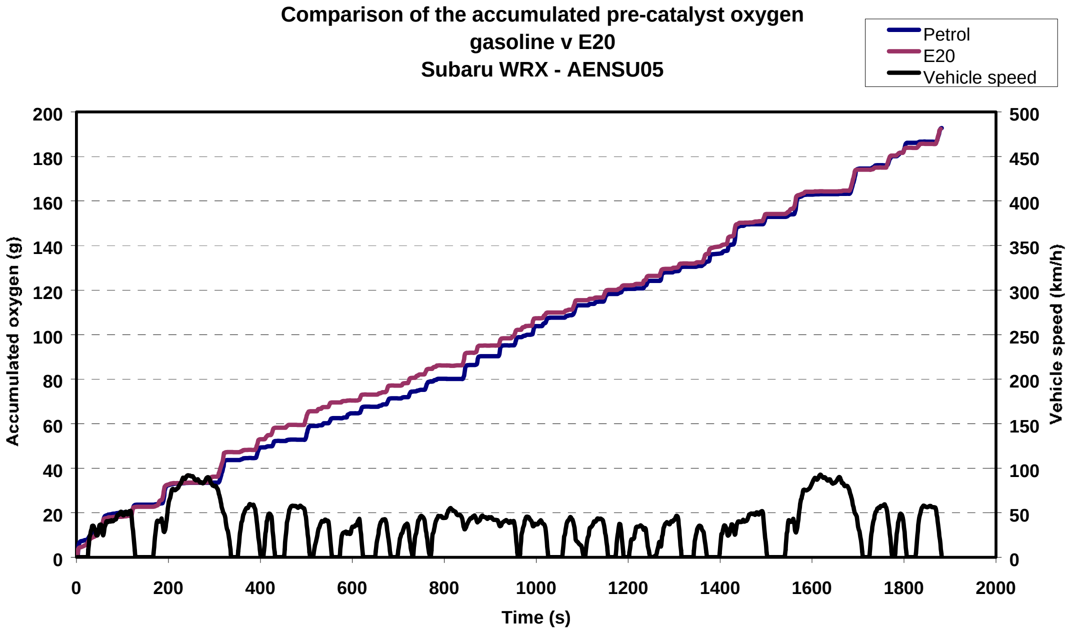


Figure 5.41 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Subaru WRX (AENSU05).

### 5.1.3.1.1 Conclusions Pre-catalyst Emissions Data

It can be concluded from analysis within the previous section that:

- All vehicles maintained closed loop control while operating on E20 during the ADR37/01 test procedure.
- Based on the data presented, individual vehicles have very different pre catalyst emissions outcomes when switched from straight gasoline to E20.

- The differences are a function of how the EMS for the particular vehicle adapts the closed loop controller.
- It appears from the data measured, the adaptation process that occurs with the Commodore and Hyundai does not have the same bias applied to the closed loop controller as when operated on gasoline. The difference in control is such that when operated on E20 it has either increased the CO emissions or maintained the same level. The nett affect of this has been to maintain the pre-catalyst NOx emissions at similar levels to gasoline.
- For the Toyota Camry and Subaru WRX the adaptation of the fuelling has occurred and clearly shows that the oxygen levels in the exhaust for gasoline and E20 are very similar. The nett affect on pre-catalyst emissions for these vehicles is a decrease in CO and an increase in NOx emissions predominately in the first phase.
- The Ford Falcon appears to be operating lean of the stoichiometric point, the effect on pre-catalyst emissions is similar to the other vehicles which are running slightly rich of the stoichiometric point. However it is well known that optimal catalyst efficiency is fractionally rich of stoichiometry ($\lambda$=0.99 …1.0)(36), for the Ford Falcon this has resulted in a reduction in the catalyst performance, see Section(5.1.3.2)

#### 5.1.3.2 Aftertreatment (Catalyst) System Performance

The following section assesses the phase-by-phase performance of the vehicle aftertreatment systems, Figure 5.42, Figure 5.43, Figure 5.44, Figure 5.45 and Figure 5.46. All the vehicles tested are fitted with TWC's. The Subaru (AENSU05) is fitted with a pre-catalyst plus an under-body catalyst. At a mileage of 6400km there be will be little or no degradation of the catalyst performance. Overall there is little difference in catalyst efficiency between operating the vehicles on gasoline and E20 during the second and third phases. There are minor differences in the oxidation capability of the catalysts during the first phase, however at this mileage the differences are not thought to be significant. The only point of significance is the decrease in NOx conversion for the Ford Falcon Figure 5.43 particularly during the second and third phases of the drive cycle, when the catalyst is hot and should be operating at highest efficiency. It is assumed that this purely due to the closed loop control action as discussed in 5.1.3.1 and not any decrease in the catalysts ability to reduce NOx when operating the vehicle on E20.

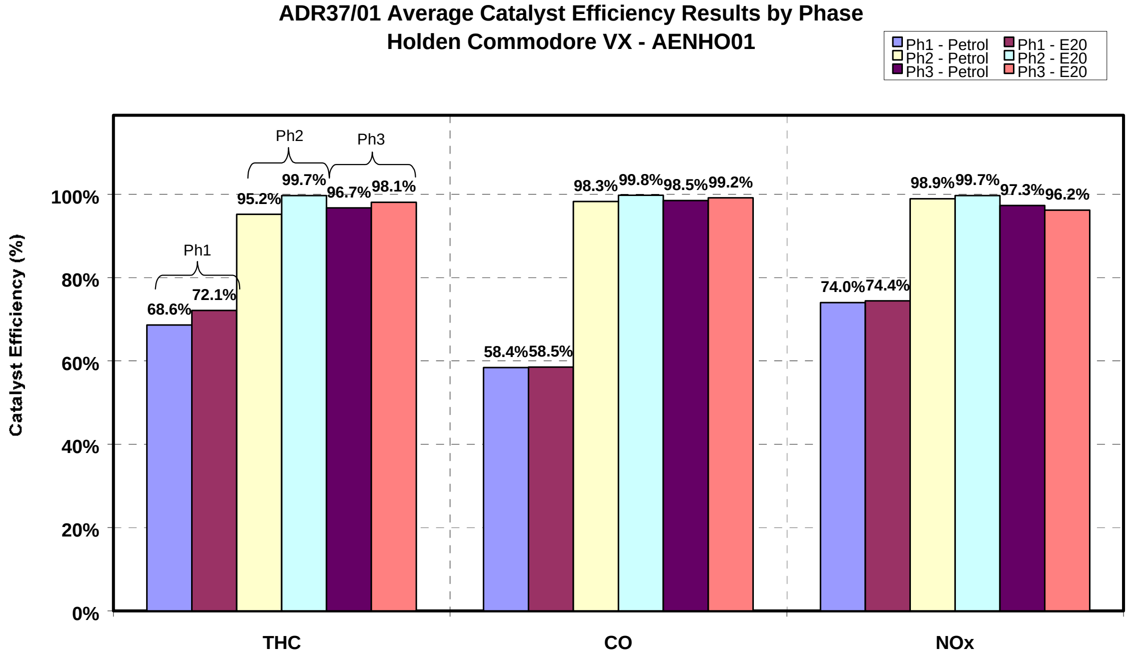


Figure 5.42 - Average Catalyst Efficiency Holden Commodore AENHO01

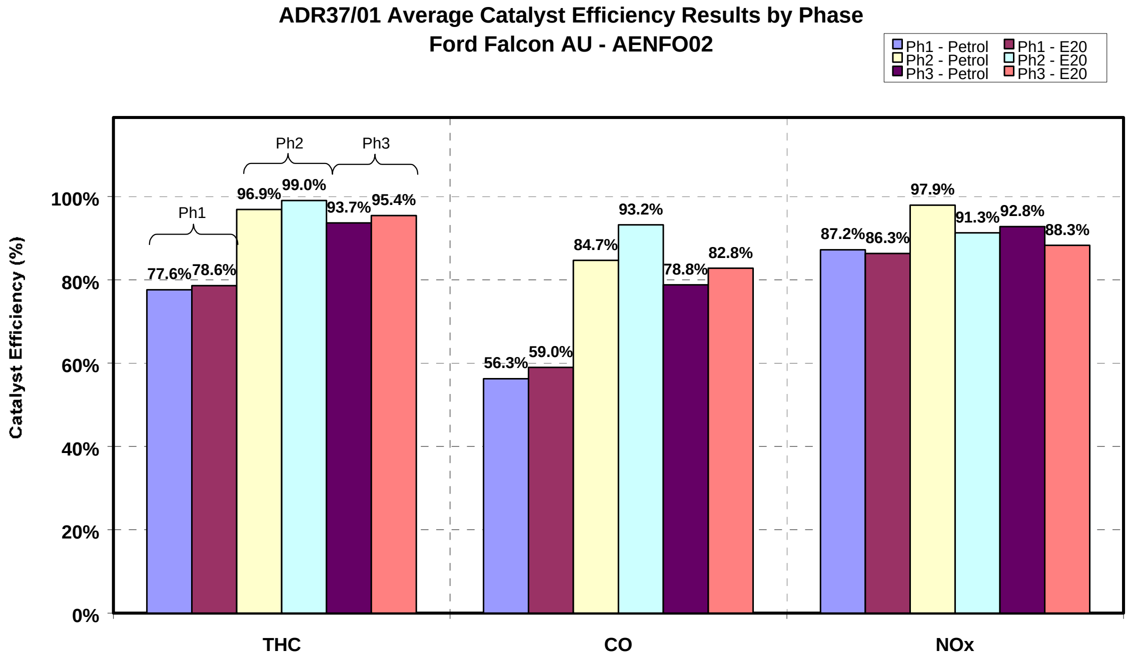


Figure 5.43 - Average Catalyst Efficiency Ford Falcon AENFO02

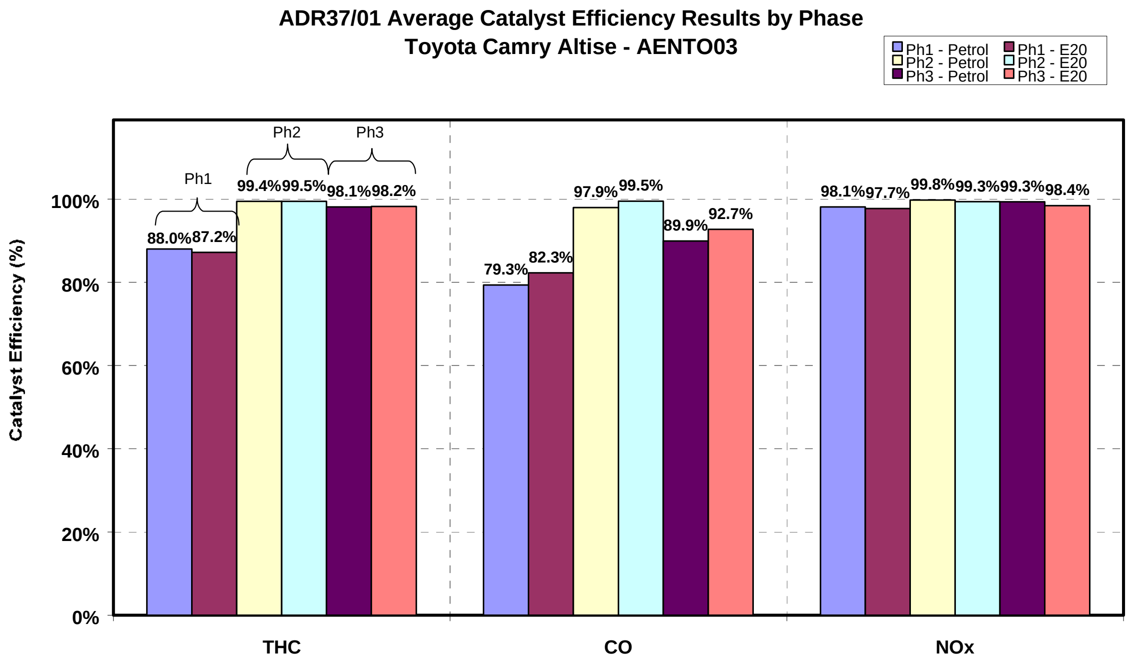


Figure 5.44 - Average Catalyst Efficiency Toyota Camry Altise AENTO03

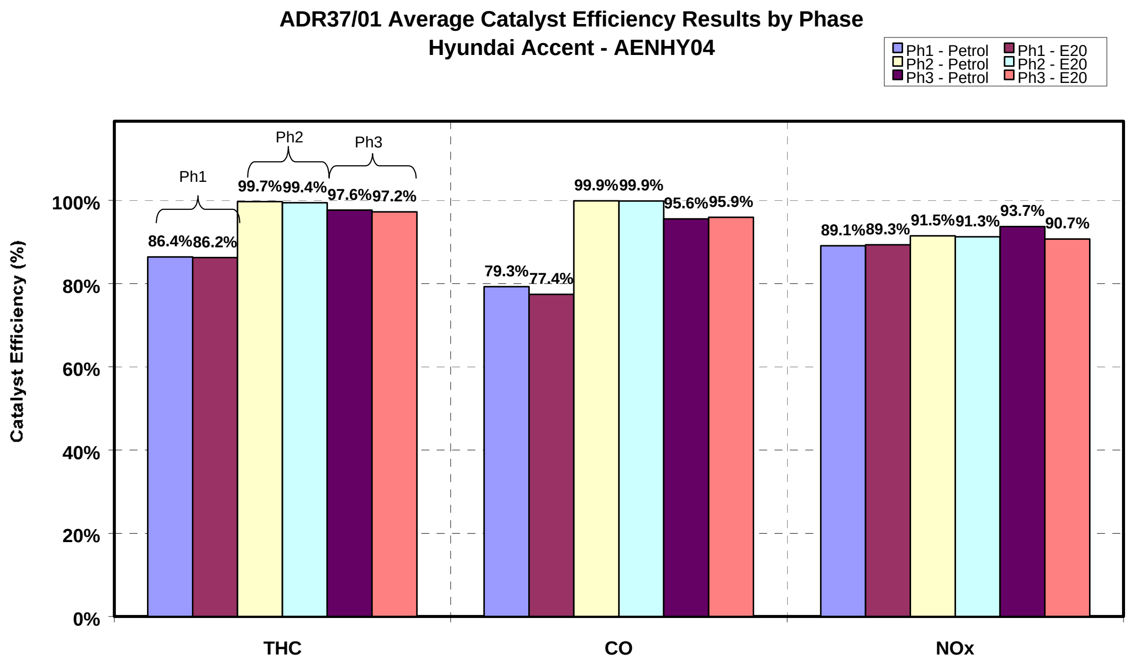


Figure 5.45 - Average Catalyst Efficiency Hyundai Accent AENHY04

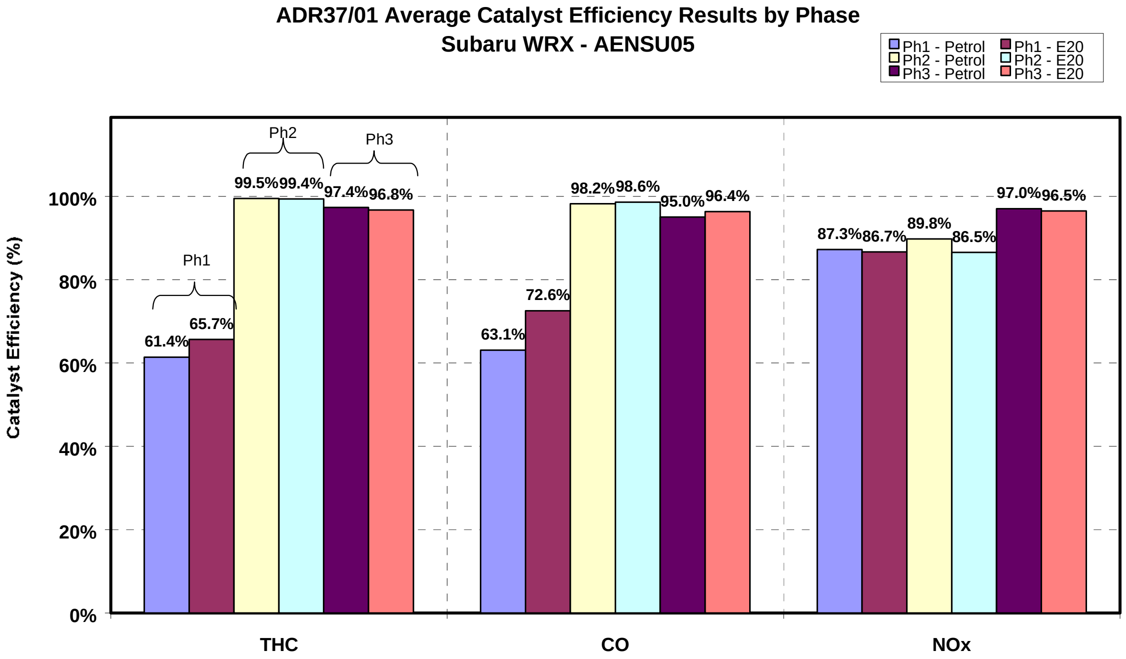


**Figure 5.46 - Average Catalyst Efficiency Subaru WRX AENSU05**

#### 5.1.3.2.1 Conclusion Aftertreatment System Performance

The vehicle aftertreatment system analysis has revealed the following conclusions:

- Overall there is little difference in catalyst efficiency between operating the vehicles on gasoline and E20 during the second and third phases.
- There are minor differences in the oxidation capability of the catalysts during the first phase, however at this mileage the differences are not thought to be significant.
- There is a decrease in NOx conversion for the Ford Falcon in the second and third phases of the drive cycle, when the catalyst is hot and should be operating at highest efficiency. It is assumed that this purely due to the closed loop control action as discussed in Section 5.1.3.1 and not any decrease in the catalysts ability to reduce NOx emissions when operating the vehicle on E20.

### 5.1.4 Unregulated Toxic Tailpipe Emissions Assessment.

During the regulated tailpipe emissions testing samples where extracted for analysis to determine the tailpipe aldehyde emissions and BTEX emissions. Due to the nature of the analysis two samples where taken, one for analysis by GC (Gas Chromatography) and one for analysis by HPLC (High Performance Liquid Chromatography). Four samples where taken per test, one per phase and one background. From the samples taken the concentrations of the compounds listed in Table 5.6 were determined.

| Compound | | Analysis technique |
|---|---|---|
| Formaldehyde | $CH_2O$ | HPLC |
| Acetaldehyde | $C_2H_4O$ | HPLC |
| Acrolein | $C_3H_4O$ | HPLC |
| Propionaldehyde | $C_3H_6O$ | HPLC |
| 1,3 Butadiene | $C_4H_6$ | GC |
| Benzene | $C_6H_6$ | GC |
| Hexane | $C_6H_{14}$ | GC |
| Toluene | $C_7H_8$ | GC |
| P-Xylene | $C_8H_{10}$ | GC |
| O-Xylene | $C_8H_{10}$ | GC |

**Table 5.6 Summary of Air Toxics analysed**

Acetaldehyde is one of the primary decomposition products from ethanol combustion and is expected to be higher from ethanol than from other fuels, (38).

### 5.1.4.1 Exhaust Aldehydes

For the new vehicles tested the levels of Aldehydes were very low and in many cases below the measurable range of the instruments used, for both gasoline and E20. In the case of Acrolein there was no measurable quantity from any of the vehicle emissions samples. Because of the extremely low values some individual results are also negative due to higher background level for that test sample. All emissions samples were corrected for the background or ambient emissions. In the cases of a negative result these have been excluded. It is thought the extremely low levels are due to the aldehydes being oxidised on the catalyst. This should become apparent as the vehicles are progressively aged in the 80,000 km mileage accumulation program phase.

Figure 5.47, Figure 5.48 and Figure 5.49 show the weighted aldehyde emissions for all the vehicles. Due to low levels of Formaldehyde and Propionaldehyde it is not possible to discern a clear trend between the two fuels. This is not the case for acetaldehyde in which there is an increase for all vehicles. This concurs with the data found in the literature survey (4) though the percentage increase in acetaldehyde reported in that case was of the order of 200%, which is considerably less than determined in this study however the absolute values measured are relatively small and errors in the absolute numbers can result in large differences in percentage.

Figure 5.50, Figure 5.51 and Figure 5.52 are the first, second and third phases respectively of the ADR37/01 cycle. It is quite clear that the majority of the increase in acetaldehyde when operating on E20 fuel occurs during the cold phase (phase 1). Note that for the y-axis scale, there is virtually an order of magnitude difference between the first and third phase emissions. Considering that Formaldehyde and Acetaldehyde are not present in fuel but are by products of incomplete combustion this result should not be surprising as phase 1 includes the emissions from the cold start.

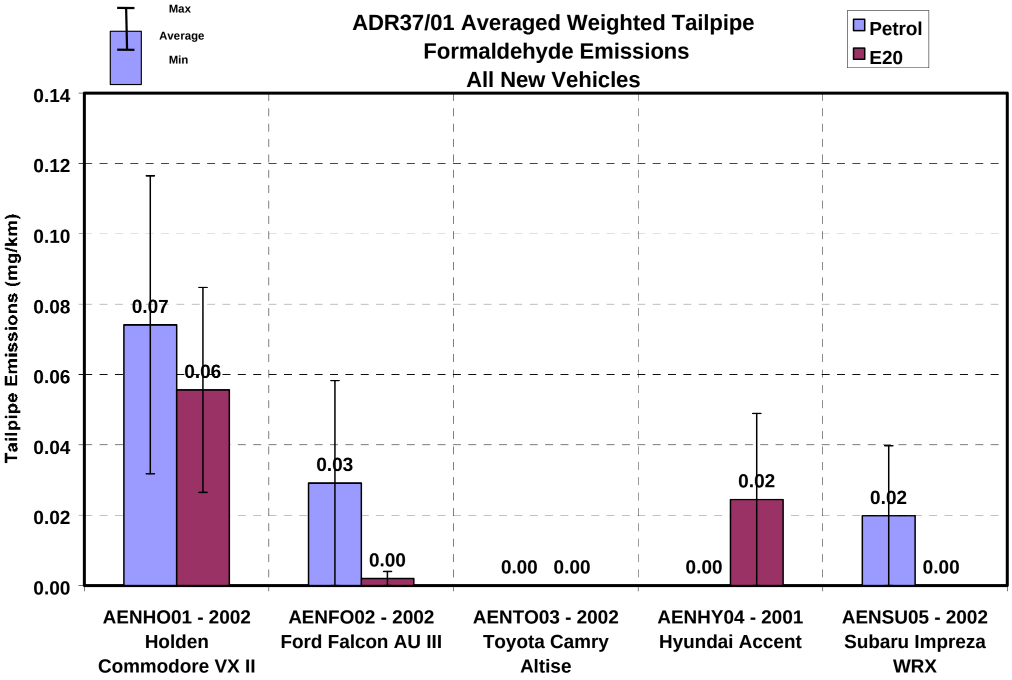


Figure 5.47 - ADR37/01 Average Weighted Tailpipe Formaldehyde Emissions all New Vehicles

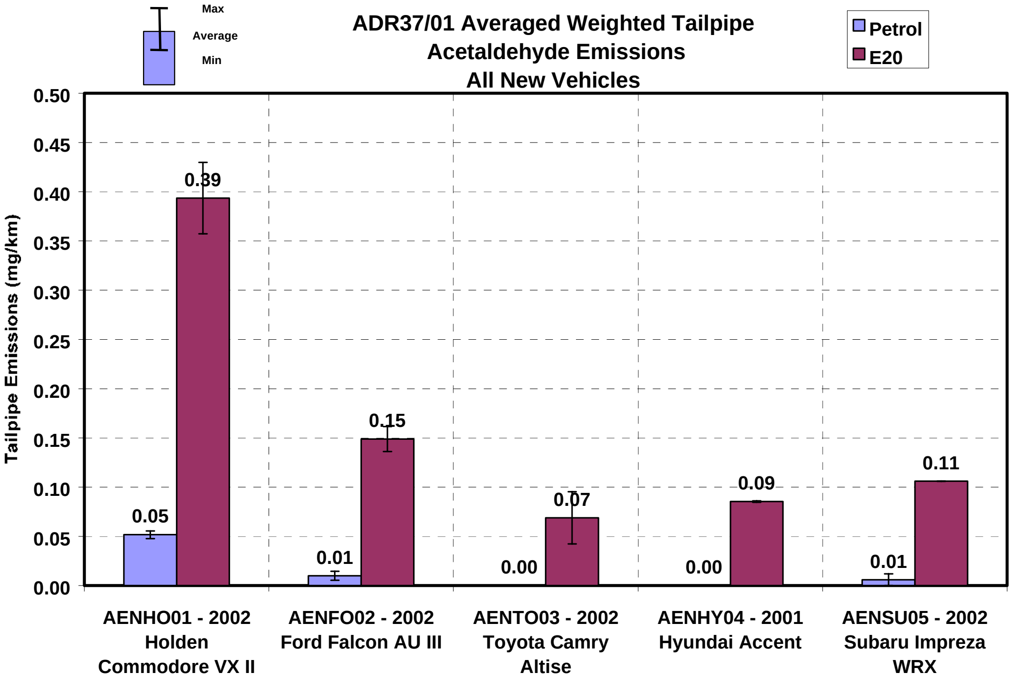


Figure 5.48 - ADR37/01 Average Weighted Tailpipe Acetaldehyde Emissions all New Vehicles

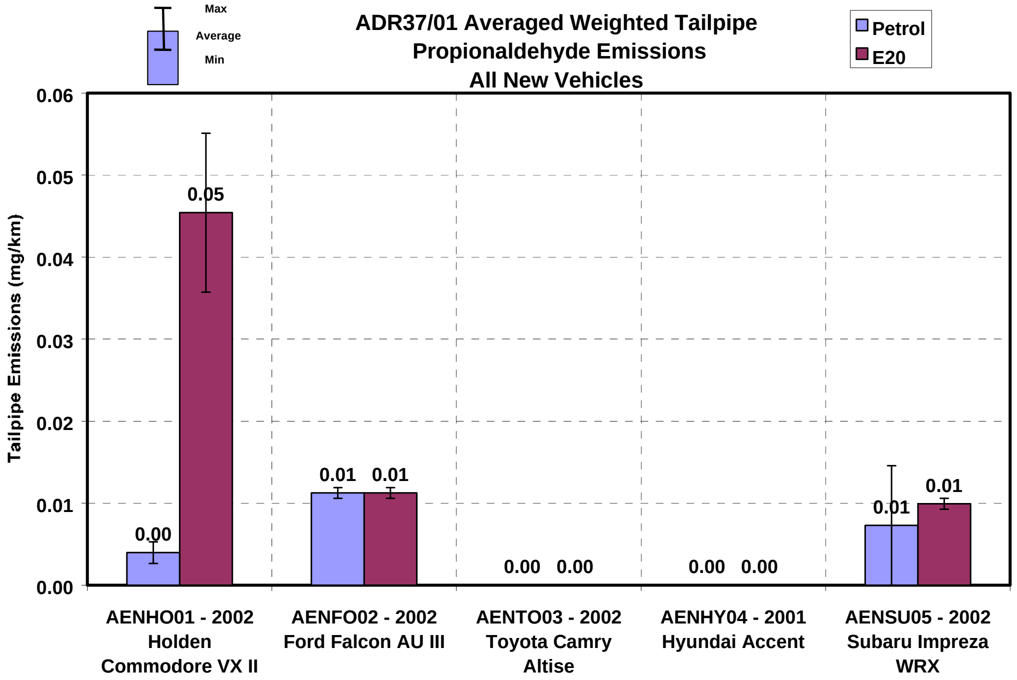


Figure 5.49 ADR37/01 Average Weighted Tailpipe Propionaldehyde Emissions all new vehicles

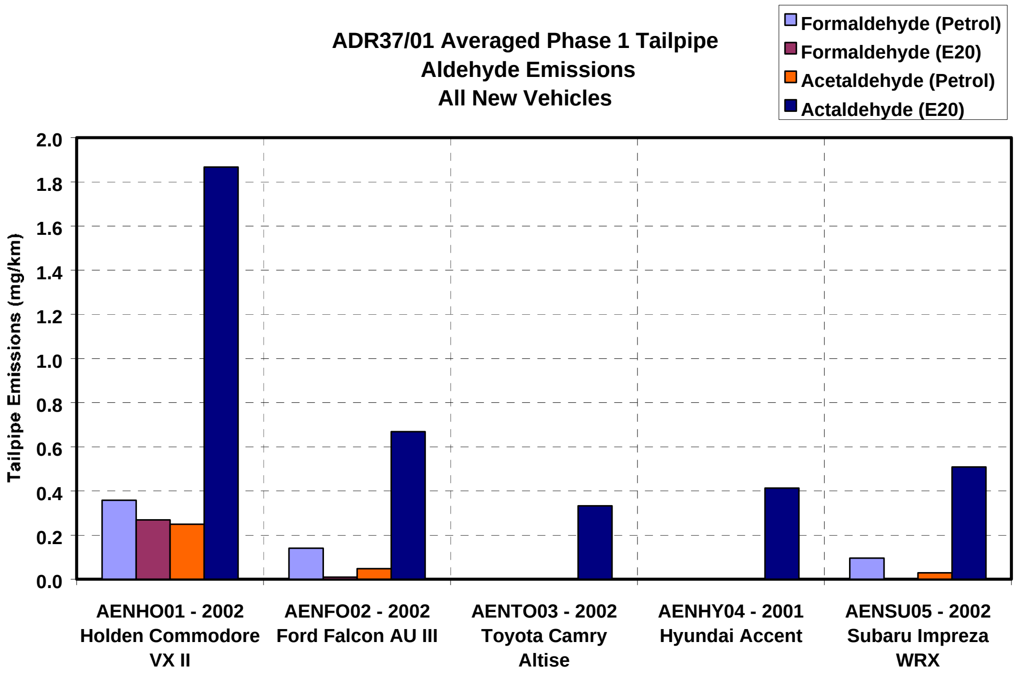


Figure 5.50 - ADR37/01 Phase 1 Aldehyde Tailpipe Emissions all New Vehicles.

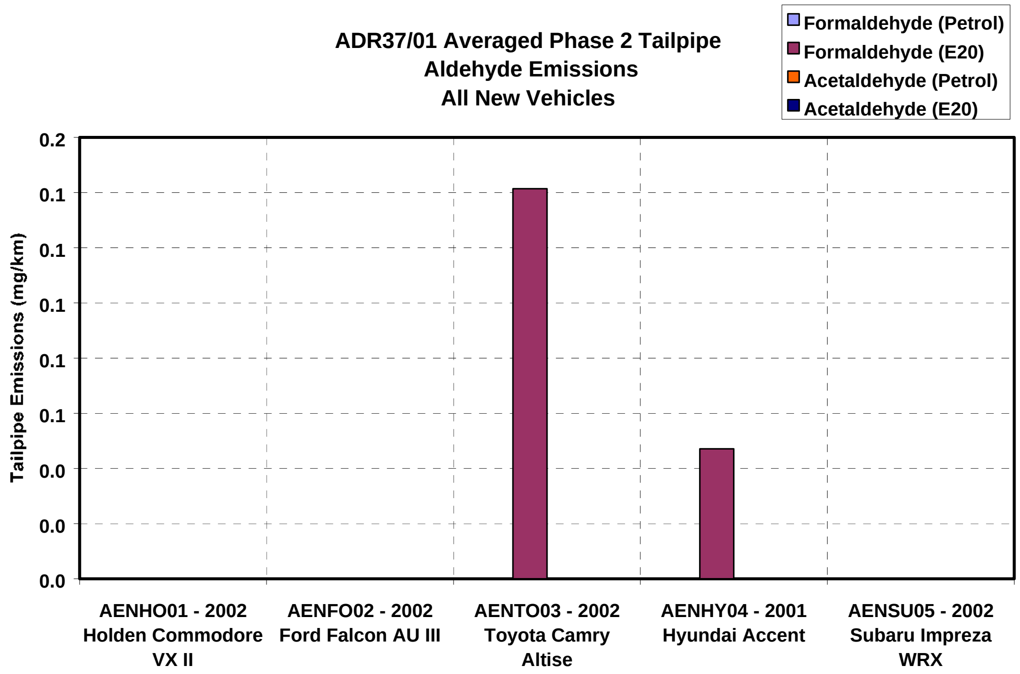


**Figure 5.51 - ADR 37/01 Phase 2 Aldehyde Tailpipe Emissions all New Vehicles.**

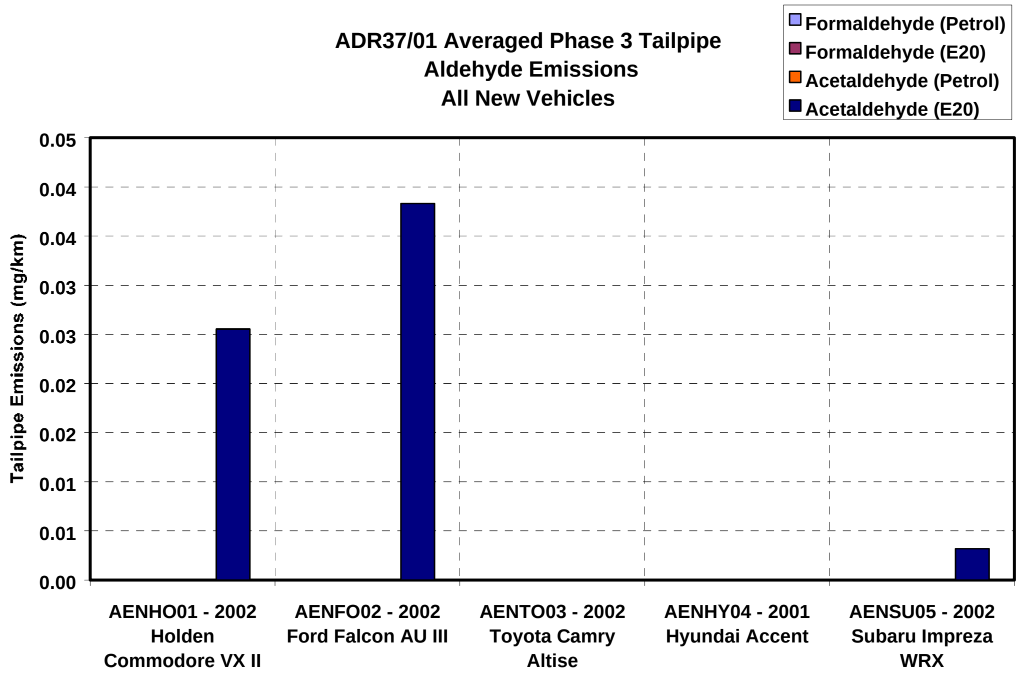


**Figure 5.52 ADR 37/01 Phase3 Average Aldehyde Tailpipe Emissions all New Vehicles.**

### 5.1.4.2 Conclusion Exhaust Aldehydes

It can be concluded from the previous section that:

- Overall there will be an increase in Aldehydes when the vehicles are operated on E20, though the measured values are very low.
- The increase comes predominantly from an increase in Acetaldehyde.
- The largest impact is in the first phase of the drive cycle, which includes the cold start.
- The trends reported here compare favourably with other studies.

#### 5.1.4.3 Exhaust Toxics

Figure 5.53, Figure 5.54, Figure 5.55, Figure 5.56 and Figure 5.57 show the tailpipe exhaust toxics 1,3 Butadiene, Benzene, Hexane, Toluene and Xylene for all the new vehicles. Xylene as displayed is the summation of P-Xylene and O-Xylene. From the literature survey (4) the general consensus was that as this group of emissions was largely the by-products of combustion or un-combusted gasoline the exhaust toxics should decrease with increasing ethanol content. Overall this is clearly the case Figure 5.58 with all compounds other than 1,3 Butadiene and Xylene showing a marked reduction in emissions. It should be noted that both of these compounds have fairly low values compared to other published data for gasoline or an ethanol blend (6). What is interesting from the figures displaying the individual compounds is the difference between the vehicles. The Holden Commodore and Ford Falcon vehicles have substantially higher exhaust toxics emissions compared with other vehicles when operating on gasoline however, these vehicles also exhibit large reductions in Benzene, Hexane and Toluene when operated on E20 fuel. Figure 5.59, Figure 5.60 and Figure 5.61 show the tailpipe Toluene emissions for the first, second and third phases respectively of the ADR37/01 cycle. It is quite clear that the majority of the exhaust toxics occur in the cold transient phase (phase 1), typically when the pre-catalyst engine out emissions are highest. The other toxics measured follow a similar trend. Note that for the y-axis scale, there is virtually an order of magnitude difference between the first phase and the other two phases of the test. To substantiate that significant amounts of these compounds come from incomplete combustion, each toxic measured has been plotted against the tailpipe THC, Figure 5.62, Figure 5.63, Figure 5.64, Figure 5.65 and Figure 5.66. Good correlation exists between exhaust Benzene and THC, exhaust Hexane and THC and exhaust Toluene and THC. There was a poor correlation between 1,3 Butadiene and THC and Xylene and THC. These relationships are similar those found (6) other than for Xylene.

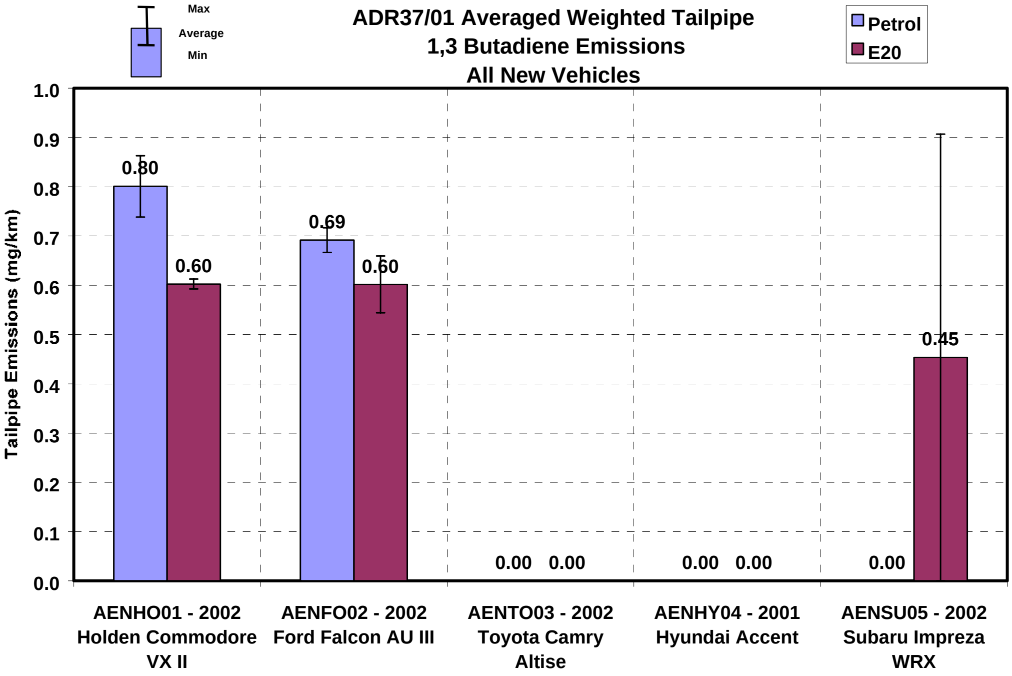


Figure 5.53 - ADR37/01 Average Weighted Tailpipe 1,3 Butadiene Emissions all New Vehicles

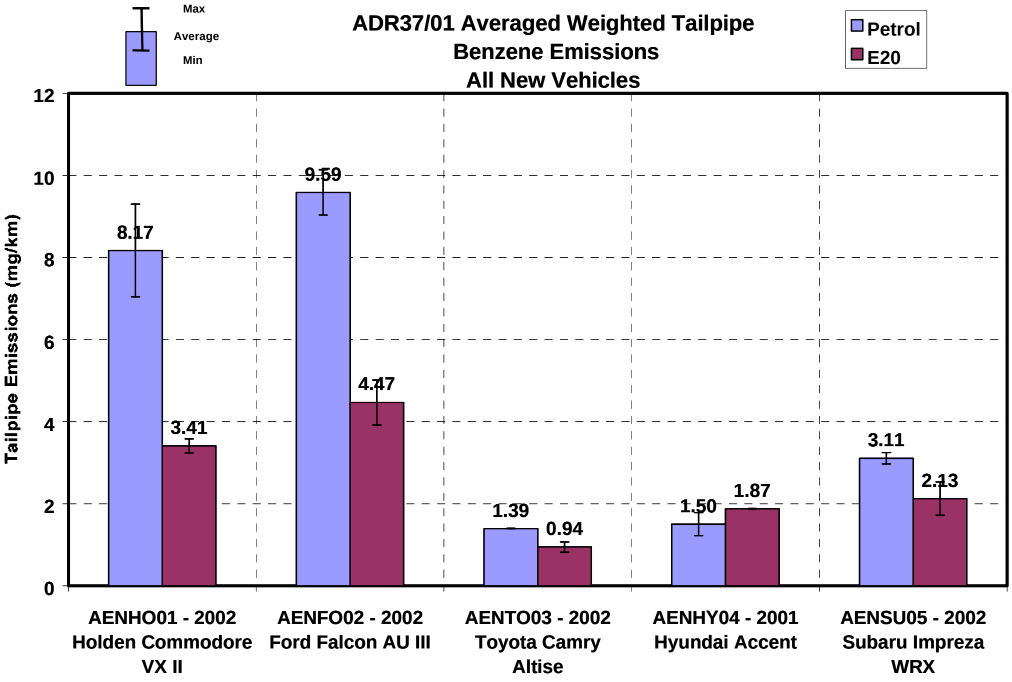


Figure 5.54 ADR37/01 Average Weighted Tailpipe Benzene Emissions all New Vehicles.

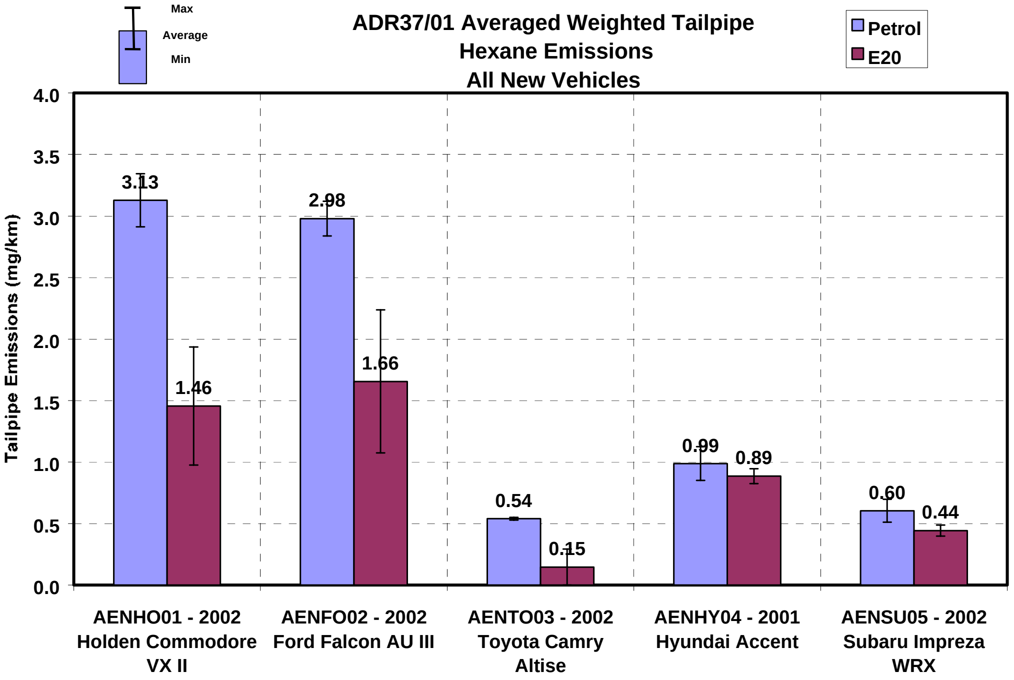


Figure 5.55 - ADR37/01 Average Weighted Tailpipe Hexane Emissions all New Vehicles.

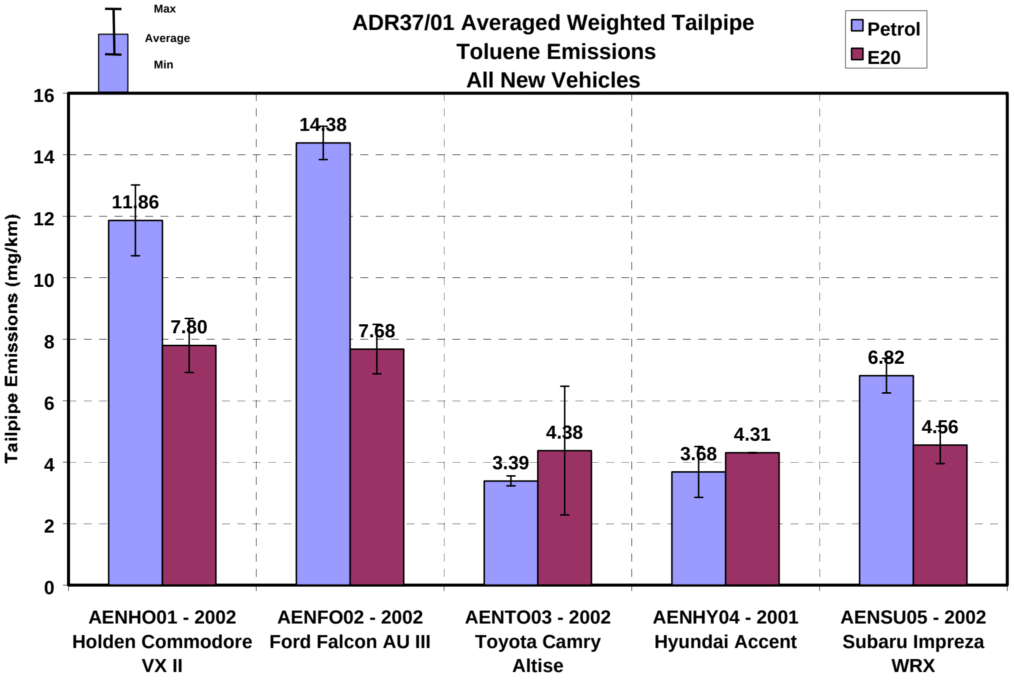


Figure 5.56 - ADR37/01 Average Weighted Tailpipe Toluene Emissions all New Vehicles.

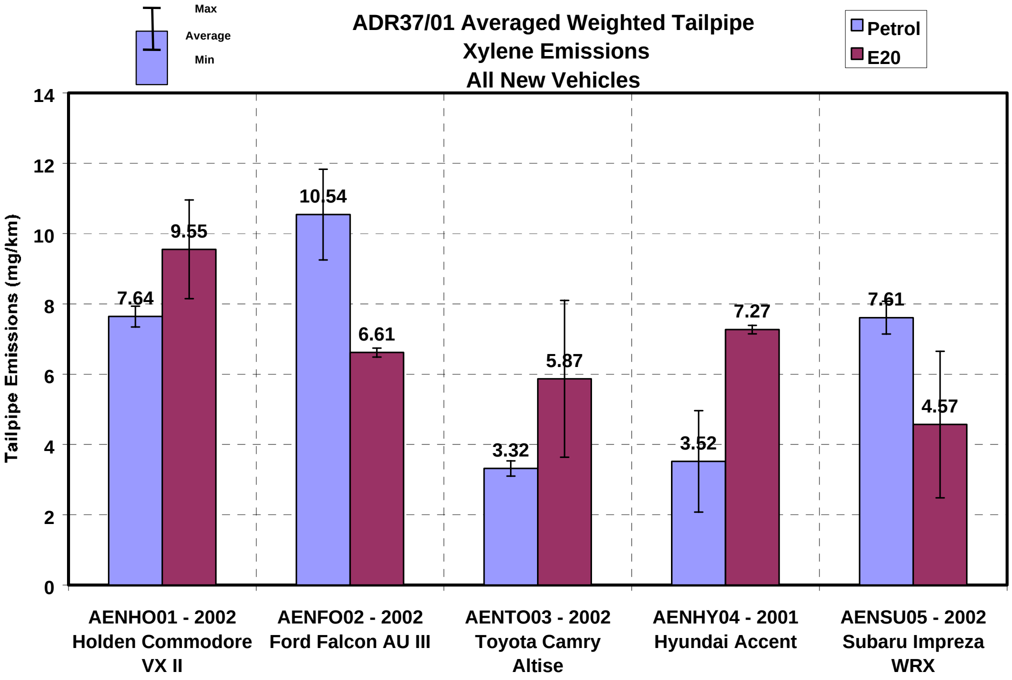


Figure 5.57 - ADR37/01 Average Weighted Tailpipe Xylene Emissions all New Vehicles.

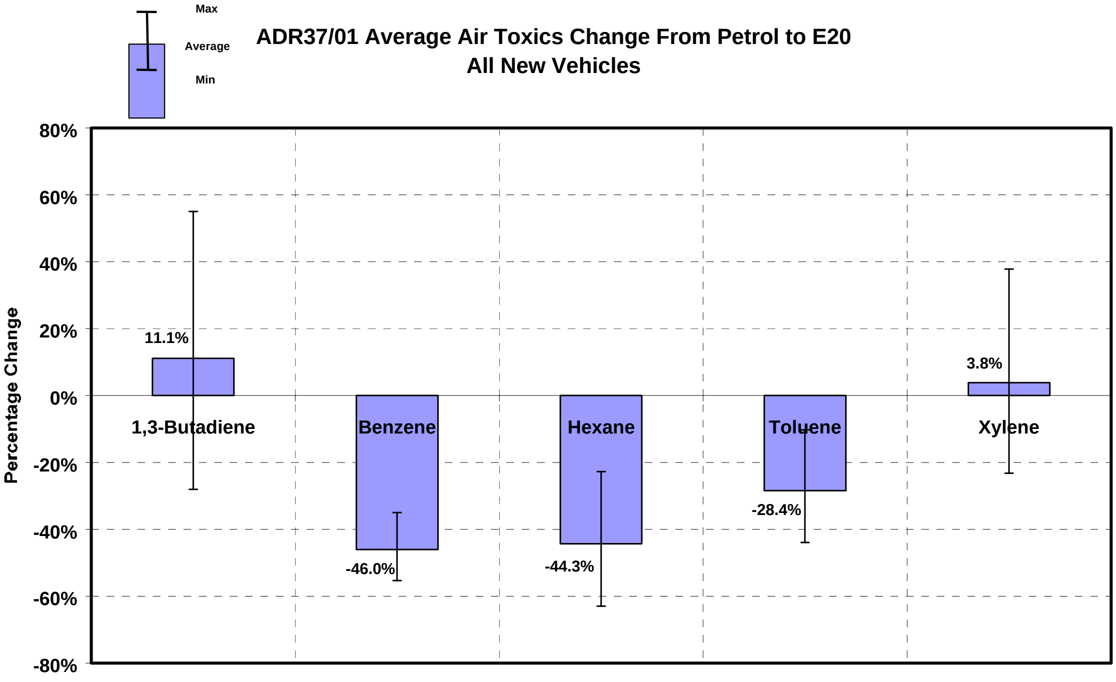


Figure 5.58 - ADR37/01 Average Air Toxics Percentage Difference Gasoline to E20 for all New Vehicles.

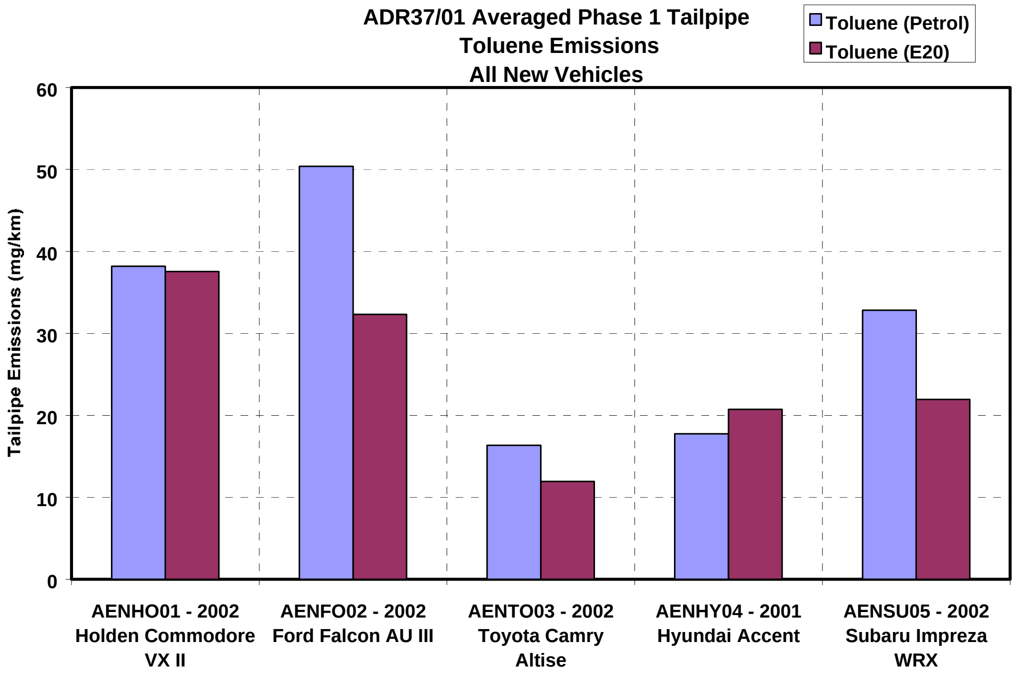


Figure 5.59 - ADR 37/01 Phase 1 Average Toluene Tailpipe Emissions all New Vehicles.

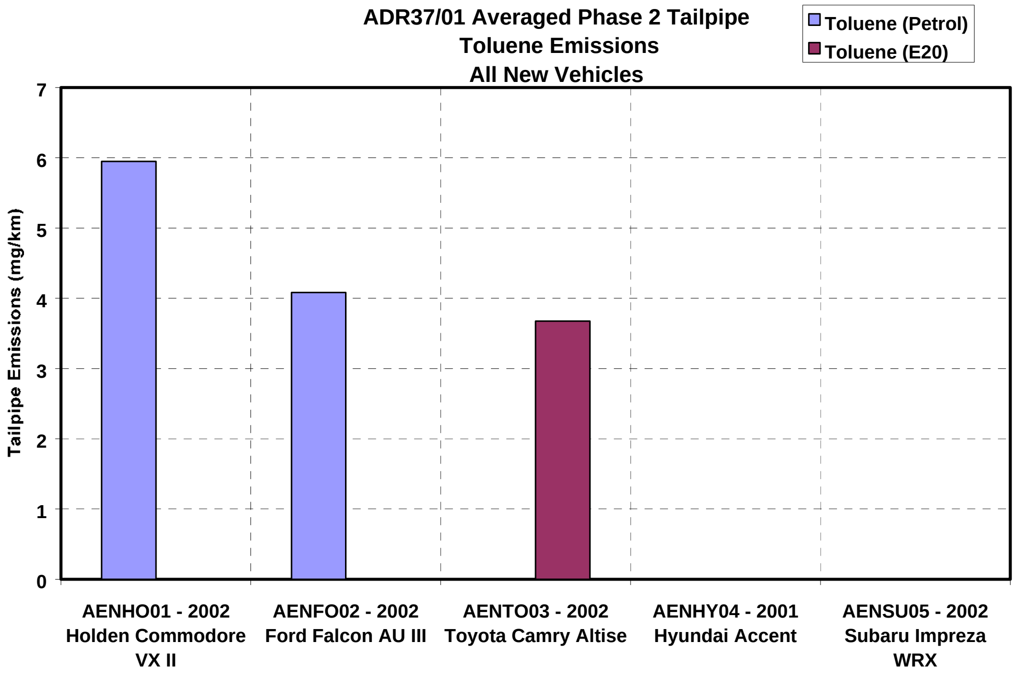


Figure 5.60 - ADR 37/01 Phase 2 Average Toluene Tailpipe Emissions all New Vehicles

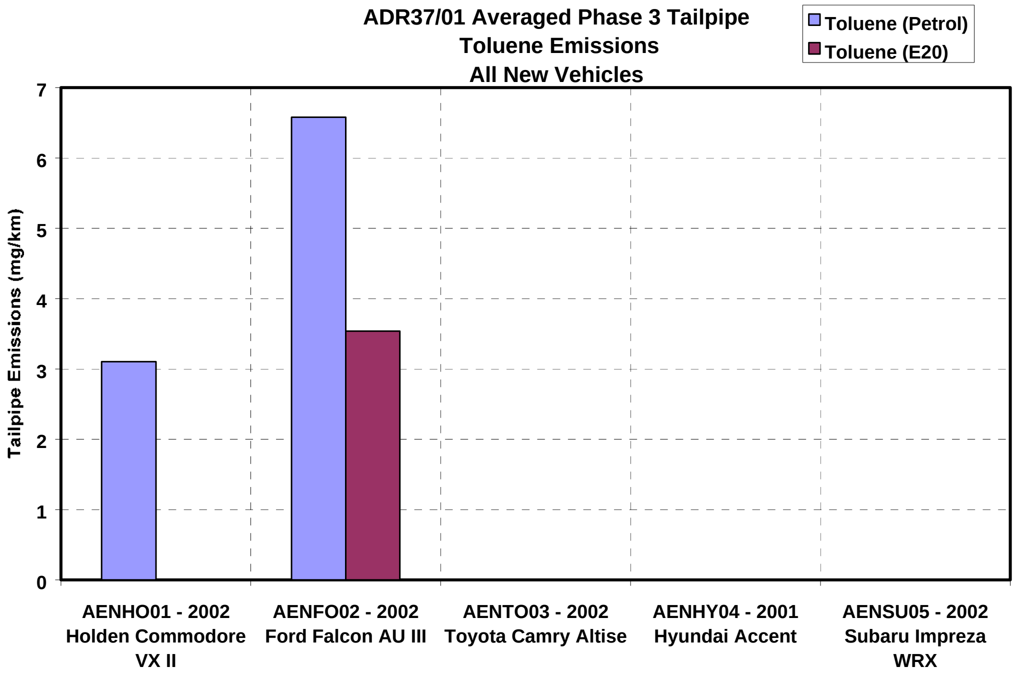


Figure 5.61 - ADR 37/01 Phase 3 Average Toluene Tailpipe Emissions all New Vehicles.

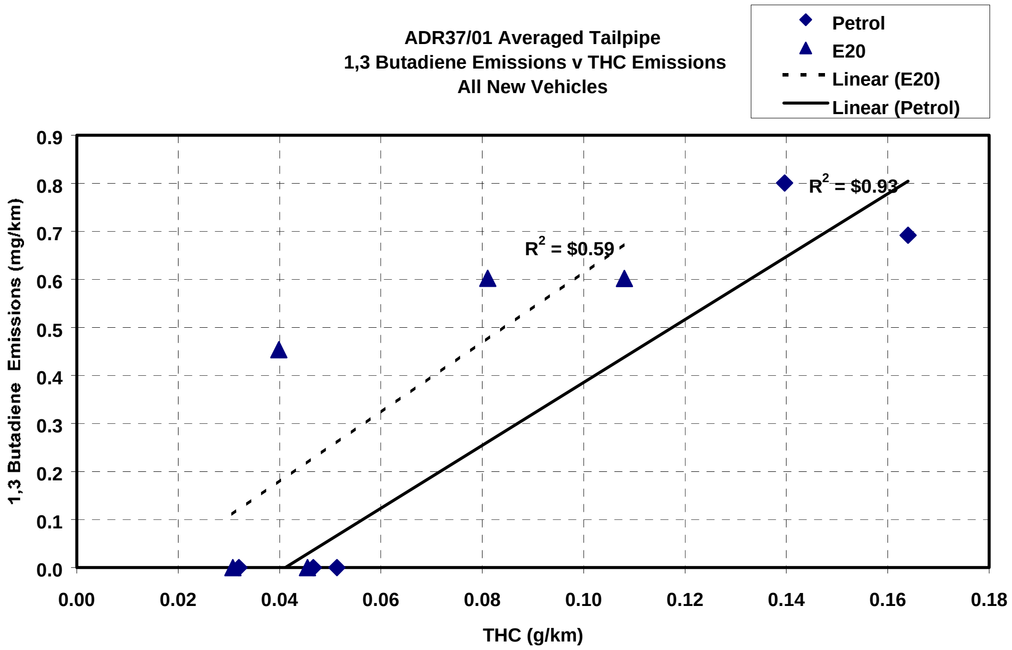


Figure 5.62 Relationship Between 1,3 Butadiene and THC Tailpipe Emissions.

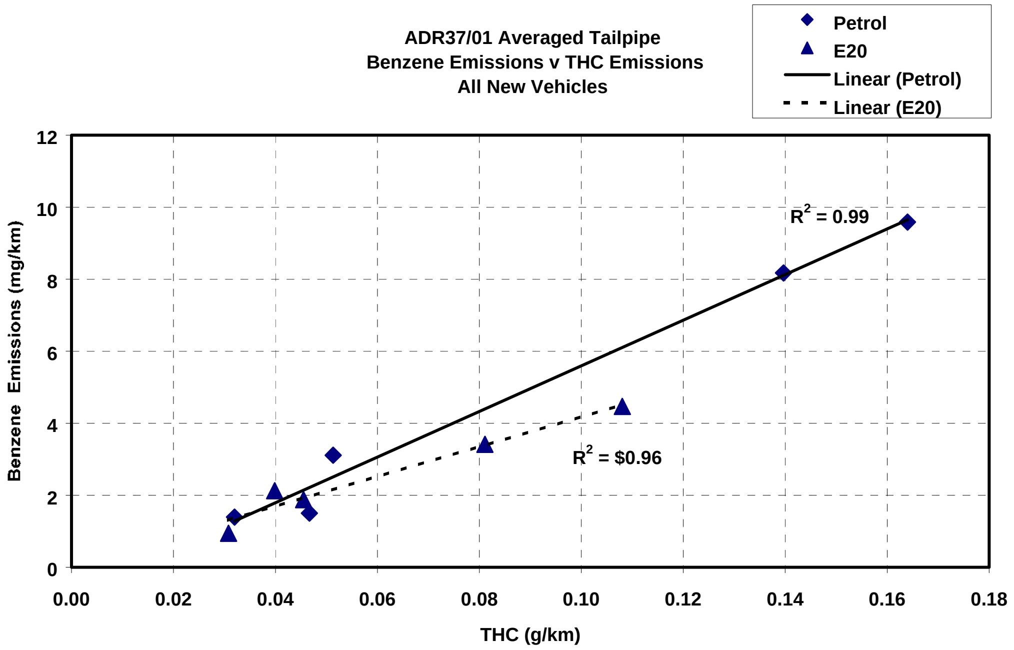


Figure 5.63 - Relationship Between Benzene and THC Tailpipe Emissions

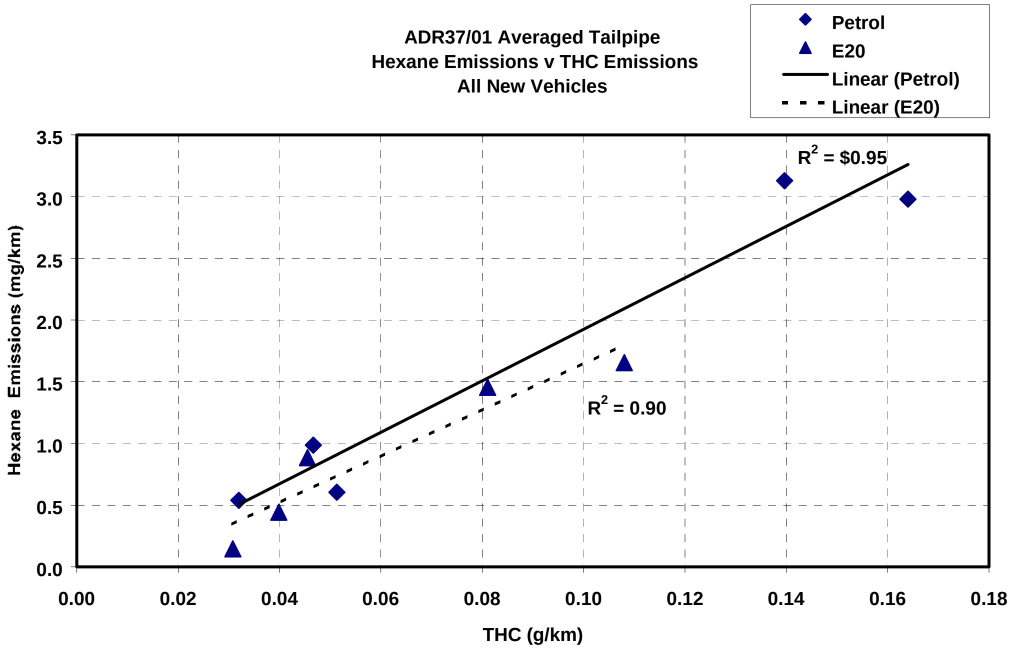


Figure 5.64 - Relationship Between Hexane and THC Tailpipe Emissions

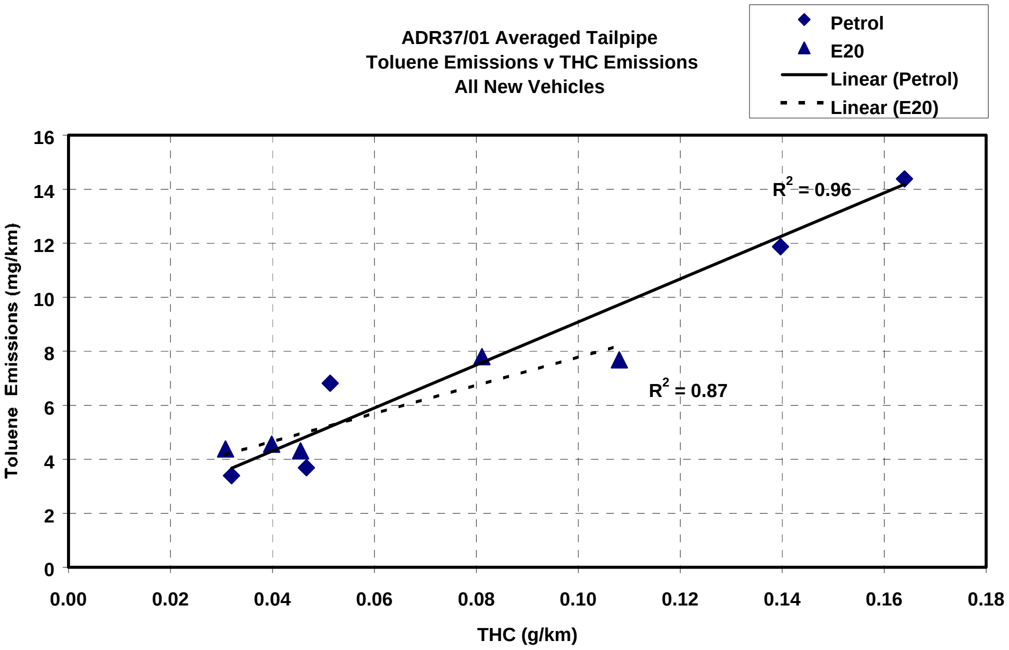


Figure 5.65 - Relationship Between Toluene and THC Tailpipe Emissions

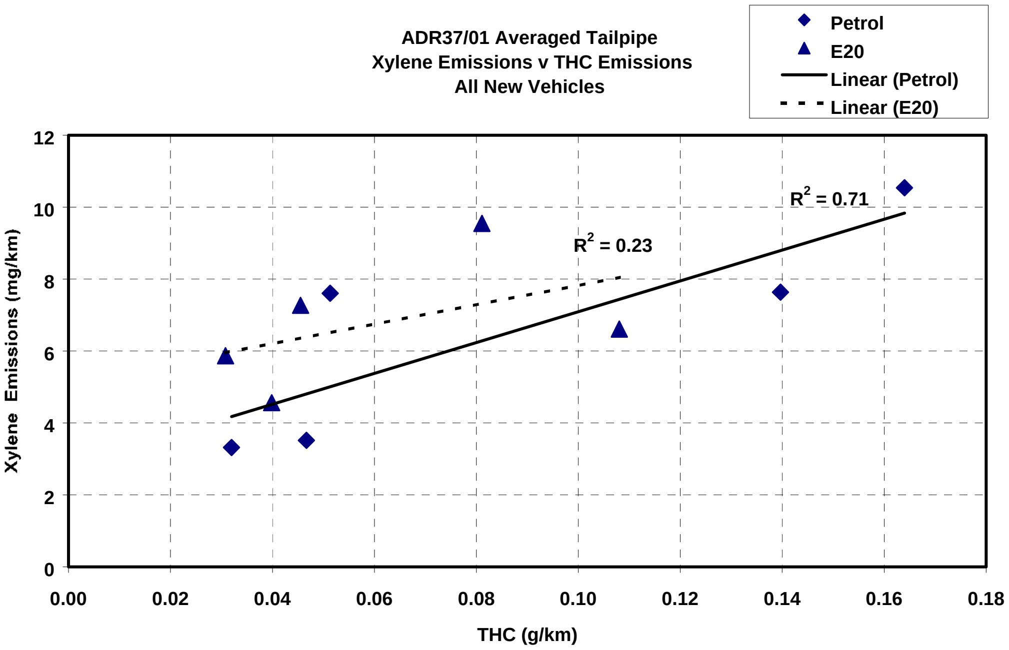


Figure 5.66 Relationship Between Xylene and THC Tailpipe Emissions.

#### 5.1.4.4 Conclusion Exhaust Toxics.

It can be concluded from the previous section that:

- The following overall decreases in exhaust toxics were measured when the vehicles are operated on E20: Benzene 40%, Hexane 40% and Toluene 30%.
- These trends compare favourably with other studies.
- There is a good correlation between exhaust Benzene, Hexane, Toluene and THC on both gasoline and E20, this substantiates the claim that a significant source of toxics is by products of combustion and un-combusted gasoline.
- The largest impact is in the cold transient phase, further confirming that the major source of toxics is by products of combustion and un-combusted gasoline.

### 5.1.5 Regulated Evaporative Emissions Assessment.

The regulated evaporative emissions from all the new vehicles where tested according to ADR 37/01 (18). During the test, measurement of air-toxic during the hot soak portion of the test where made this data will be discussed in section 5.1.6. The tests were undertaken with both baseline gasoline and E20 blend fuel and occurred after the vehicles had completed the low mileage stabilisation distance of 6400km. Test reports detailing the procedures used and the detailed results for each vehicle test are included in the appendices to this report.

#### 5.1.5.1 Evaporative Emissions data

The evaporative emissions data for all the new vehicles tested on both straight gasoline and 20% ethanol are given in Table 5.7 and pictorially in Figure 5.67. It should be noted that the values measured for all vehicles are very low. The total value of emissions for all vehicles is considerably under the legislated limit of 2.0g/test. All the evaporative emissions data has been averaged together and plotted in Figure 5.68.

In the literature review conducted (4) the effect of a 20% ethanol blend on the evaporative emissions was discussed in detail. In summary the largest affect comes from the distortion of the distillation curve downwards compared to straight gasoline in the mid range of the curve (Appendix M). This will predominately affect the hot soak portion of the evaporative emissions test as the fuel temperatures are substantially higher than for the diurnal testing, and in the region where the percentage of evaporated fuel is higher for the ethanol blend fuel compared with gasoline only. There is the possibility that at the diurnal test temperature (start at 15 deg C and finish at 29 deg C) the percentage of gasoline evaporated is similar or slightly higher than that of a 20% ethanol blend due to the vapour pressure of an oxygenated fuel decreasing more rapidly with a reduction in temperature. Therefore it is possible that the oxygenated fuel can have a lower vapour pressure than gasoline at the diurnal test temperatures. Hence the diurnal emissions could be the same or slightly less.

This data measured compares favourably with other studies referenced in (4) with a decrease in the diurnal emission and an increase in the hot soak emissions when tested on E20. There was some variance to the results on a vehicle-by-vehicle basis. However considering the levels measured and the scatter in the results these differences are not thought to be significant. The only unexpected result is the hot test on the Subaru WRX in which there appears to be a considerable decrease in the hot test emission when operating on E20. This decrease has brought the total evaporative emission value for the Subaru WRX to be less on E20 than gasoline.

It was thought that there might be some discernable differences between the vehicles with return less fuel systems (Toyota Camry and Hyundai Accent) and the conventional return systems. In theory a returnless system should return less heat energy to the fuel tank hence there should be less evaporation of the fuel. Any reduction in bulk fuel temperature is helpful from an evaporation standpoint point however with a 20% ethanol blend, the distortion of the distillation curve, it is even more desirable to reduce the bulk fuel temperature. The carbon canisters on the vehicles tested are brand new and hence have not lost any working volume so any subtle changes from different fuel systems are difficult to discern. Should a running loss test have been conducted it is more likely differences may have been revealed.

It should be noted that this testing was conducted on summer grade fuel with no adjustment to the base fuel volatility. The distillation curves for some of the fuels used can be found in Appendix M.

| Vehicle Type | Vehicle code | Diurnal (Gasoline) | Diurnal (E20) | Hot soak (Gasoline) | Hot soak (E20) | Total (Gasoline) | Total (E20) |
|---|---|---|---|---|---|---|---|
| **Holden Commodore VX** | AENHO01 | 0.070 | 0.075 | 0.183 | 0.185 | 0.250 | 0.260 |
| **Ford Falcon AU** | AENFO02 | 0.13 | 0.160 | 0.11 | 0.207 | 0.24 | 0.367 |
| **Toyota Camry Altise** | AENTO03 | 0.185 | 0.075 | 0.11 | 0.16 | 0.295 | 0.235 |
| **Hyundai Accent** | AENHY04 | 0.195 | 0.165 | 0.080 | 0.29 | 0.275 | 0.455 |
| **Subaru Impreza WRX** | AENSU05 | 0.15 | 0.07 | 0.28 | 0.15 | 0.355 | 0.22 |

**Table 5.7 Average Evaporative Emissions (g/test) for All New Vehicles.**

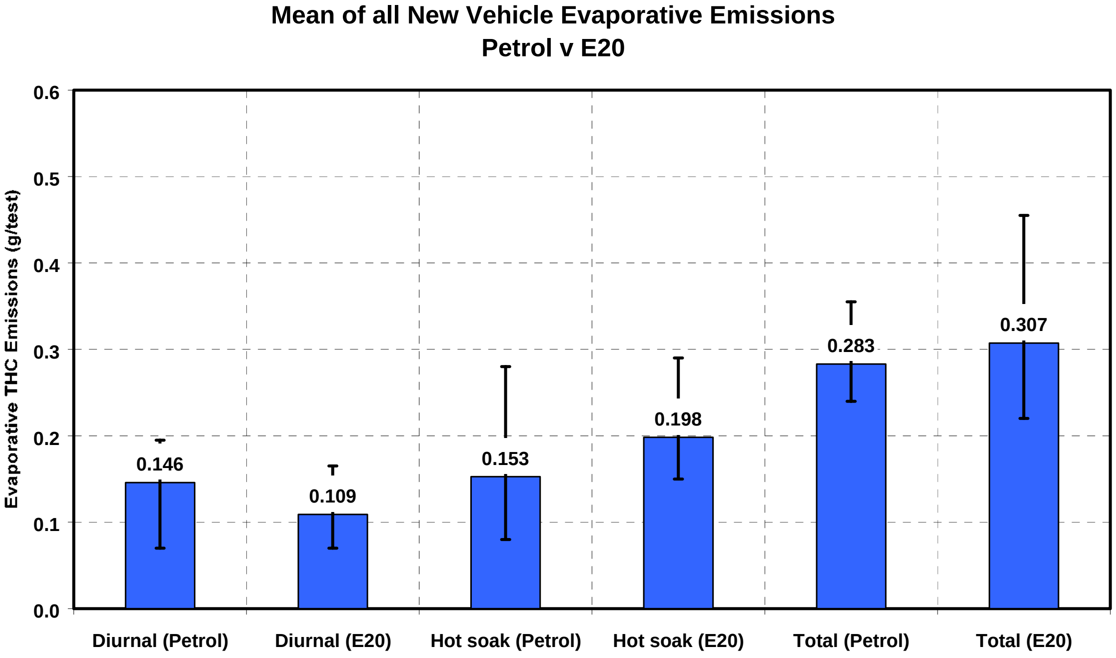


Figure 5.67 Average Evaporative Emissions for All New Vehicles.

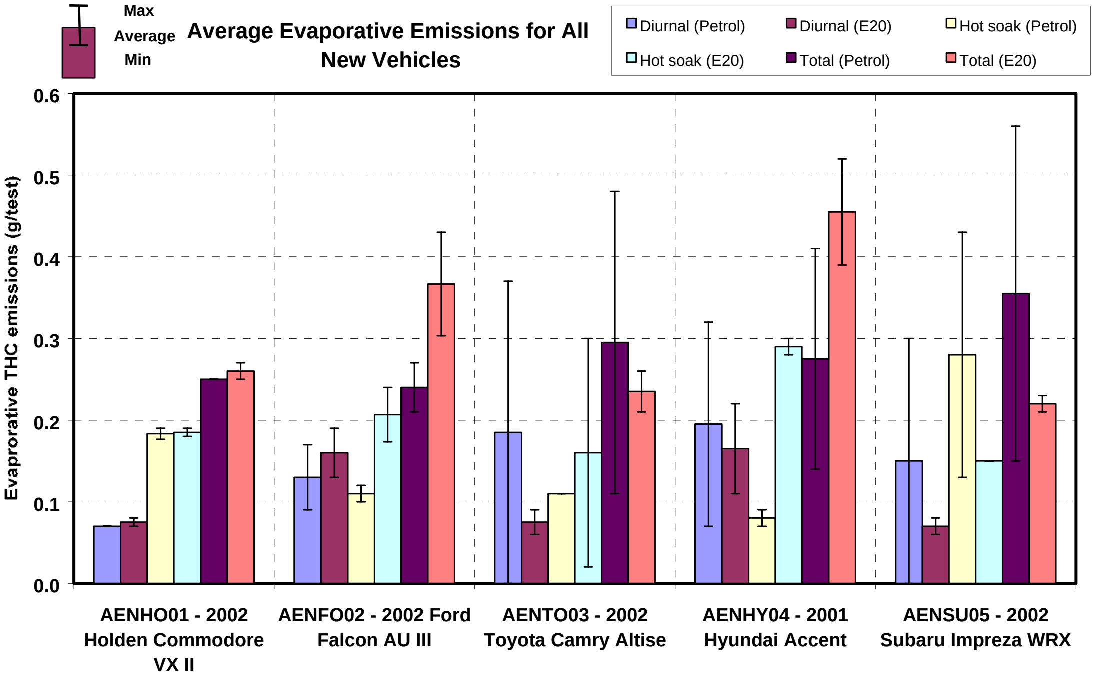


Figure 5.68 Mean of All the Evaporative Emissions Data for the New Vehicles

### 5.1.5.1.1 Conclusion Evaporative Emissions Assessment.

It can be concluded from the previous section that:

- In general the diurnal THC emissions decreased when the vehicles are operated on E20.
- In general the hot soak THC emissions increased when the vehicles are operated on E20.
- Overall the total evaporative emissions increased when vehicles are operated on E20
- This data measured compares favourably with other studies.
- As the SHED (Sealed Housing for Evaporative Determination) test is primarily a “go no-go” test and gives no indication of the impact on the vehicle evaporative emissions system it maybe preferable to conduct running loss tests in the future to improve the understanding of the evaporative emissions impact.

### 5.1.6 Air Toxic Evaporative Emissions Assessment.

During the ADR37/01 evaporative emissions testing, a sample was taken during the hot soak portion for analysis to determine air toxics. The toxics measured are Benzene, Toluene and Xylene. Xylene as displayed is the summation of P-Xylene and O-Xylene. Due to the reduced fuel temperature for the diurnal test, start fuel temperature 15 Celcius and final fuel temperature of 29 Celcius it was thought that any differences between the gasoline air toxics and E20 air toxics would probably be minimal. Also from studying the data in (6), the diurnal air toxics appears to be quite variable. As the potential mechanism for differences between gasoline and E20 fuel evaporation appears to be related to the distortion of the distillation curve, the present study concentrated on toxics measurements from the hot soak test.

Figure 5.69, Figure 5.70 and Figure 5.71 display the comparison of the air toxics measured against straight gasoline and E20 for all the new vehicles tested. Figure 5.72 is the average air toxics for all the vehicles tested. This indicates that on average the air toxics will increase when the vehicle is operated on ethanol. This result appears reasonable, as above approximately 60 C bulk fuel temperature an E20 blended fuel will start to evaporate at a significantly faster rate than a straight gasoline see distillation curves in Appendix M.

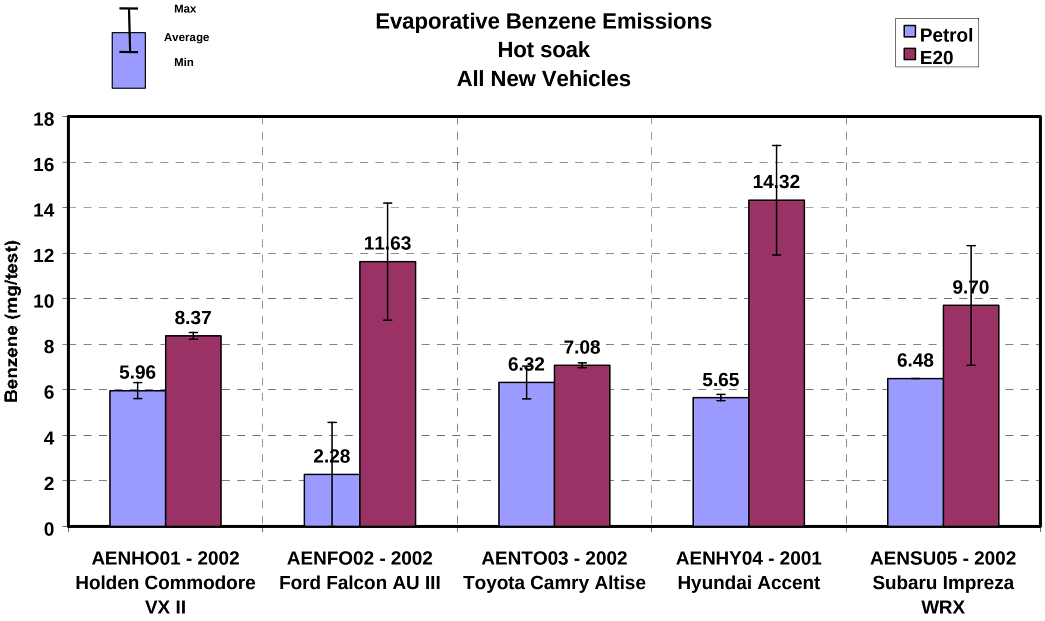


Figure 5.69 - Hot Soak Evaporative Benzene Emissions All New Vehicles

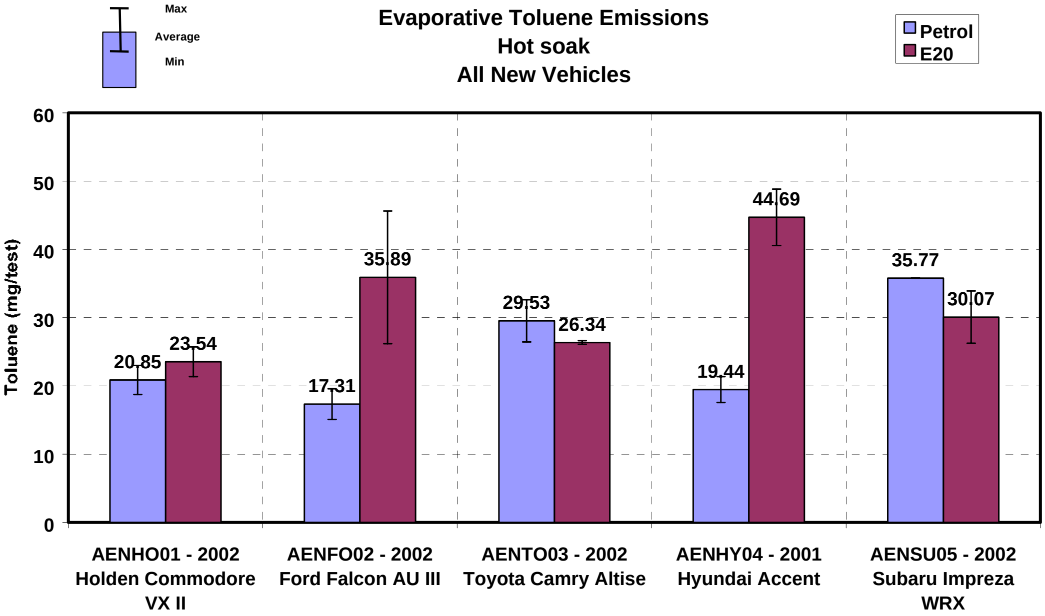


Figure 5.70 - Hot Soak Evaporative Toluene Emissions All New Vehicles

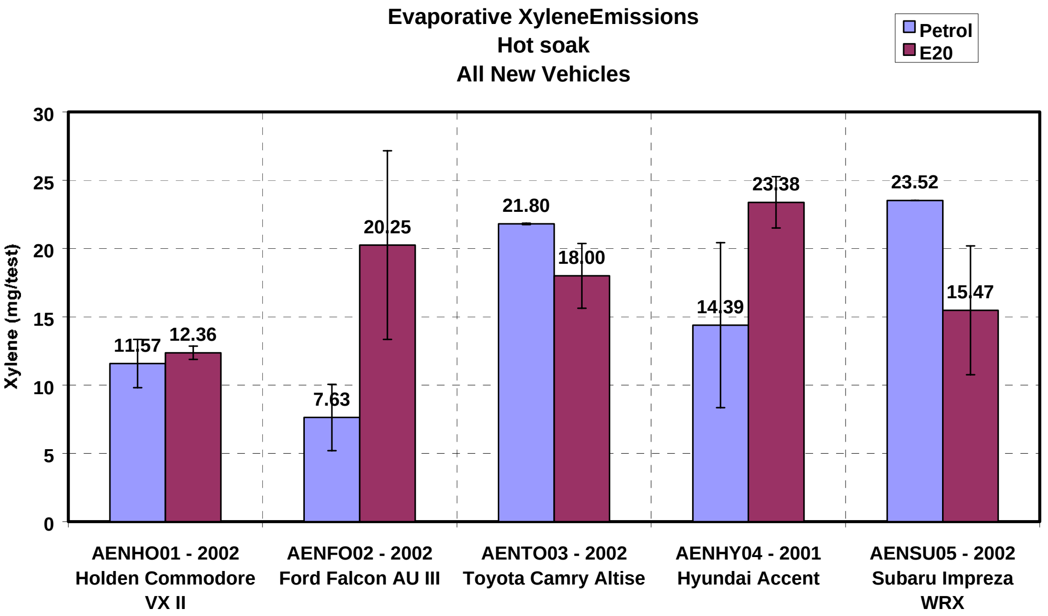


Figure 5.71 - Hot Soak Evaporative Xylene Emissions All New Vehicles

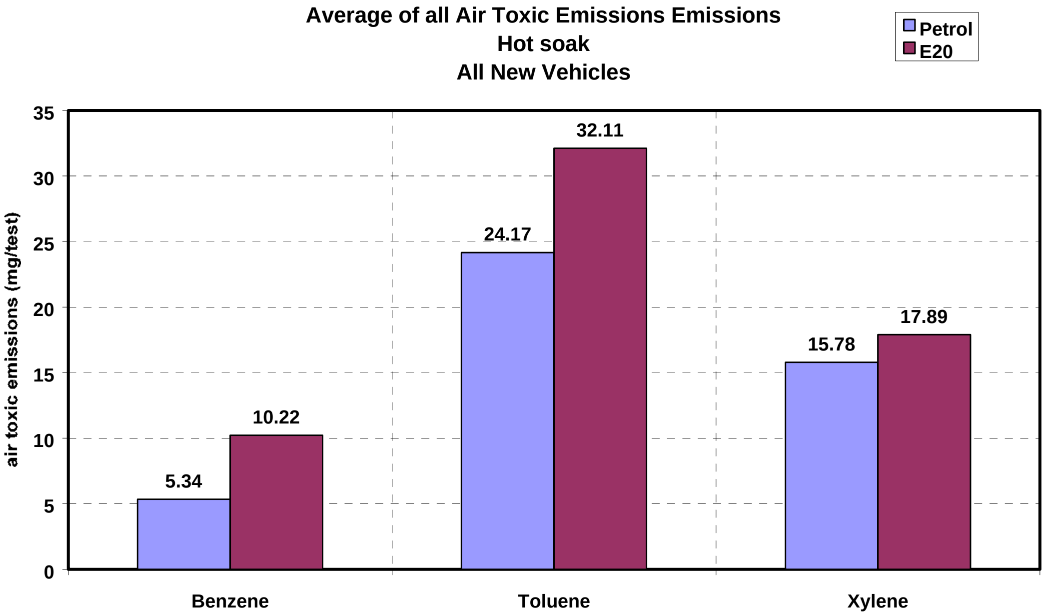


Figure 5.72 - Average Hot Soak Evaporative Emissions All New Vehicles

### 5.1.7 Conclusion Unregulated Evaporative Emissions

It can be concluded from the previous section that:

- Overall there will be a increase in evaporative air toxics when the new vehicles are operated on E20.
- The increase in air toxics concurs with the increase in THC measured during the evaporative test.

### 5.1.8 Fuel Consumption Assessment.

The fuel consumption for all the new vehicles was determined according to AS2877 (7) for both straight gasoline and for 20% ethanol blend. The data is presented in Table 5.8 and pictorially in Figure 5.73 and Figure 5.74. The Metro – Highway (M-H) fuel consumption has also be calculated. This is a weighted composite figure determined from both the ADR37/01 and AS2877 Highway cycle.

Fuel consumption theoretically increases when oxygenates are blended with gasoline due to the lower energy content of the oxygenate. The results from (35) determined that for a 20% ethanol blend a fuel consumption increase of the order of 7% would be expected. The literature review based study (4) concluded that an increase of approximately 6% should be theoretically evident when using E20. This assumes that the closed loop controller was able to maintain stoichiometric combustion conditions (i.e. the oxygen content of the E20 fuel blend is within the range of adaptation authority) over the drive cycle. It has been shown in section 5.1.10 that all the vehicles had sufficient adaptation authority over the ADR37/01 cycle. From Figure 5.74 it is clear that difference in fuel consumption between gasoline and E20 is somewhat less than expected for most of the vehicles on either drive cycle. The 6% fuel consumption increase assumes that stoichiometric combustion would be maintained, however it appears that on the highway cycle this is not the case with enleanment strategies being used on some of the vehicles to reduce the fuel consumption. For these vehicles, it is expected that the fuel consumption increase when operating on E20 should be less than the vehicles where stoichiometric, closed loop operation was maintained for the complete cycle. Interestingly the fully imported vehicles, which are probably designed to conform to US or European legislation, appear to have increased their fuel consumption when operated on E20 by approximately 6%. With respect to the ADR37/01 or city fuel consumption it is thought that the difference between the expected 6% and the actual measured result is likely due to subtle differences in the way the EMS systems adapt.

| Vehicle Type | Vehicle code | City FC (Gasoline) l/100km | City FC (E20) l/100km | % Difference City | Highway FC (Gasoline) l/100km | Highway FC (E20) l/100km | % Difference Highway | M-H (Gasoline) l/100km | M-H (E20) l/100km | % Difference M-H |
|---|---|---|---|---|---|---|---|---|---|---|
| **Holden Commodore VX** | AENHO01 | 11.629 | 12.342 | 6.13% | 6.992 | 7.278 | 4.08% | 8.956 | 9.399 | 4.94% |
| **Ford Falcon AU** | AENFO02 | 11.447 | 11.892 | 3.89% | 7.636 | 7.919 | 3.71% | 9.347 | 9.702 | 3.79% |
| **Toyota Camry Altise** | AENTO03 | 10.904 | 11.437 | 4.89% | 7.232 | 7.411 | 2.48% | 8.876 | 9.190 | 3.54% |
| **Hyundai Accent** | AENHY04 | 7.636 | 7.936 | 3.92% | 5.367 | 5.745 | 7.04% | 6.416 | 6.773 | 5.57% |
| **Subaru Impreza WRX** | AENSU05 | 11.107 | 11.645 | 4.84% | 7.744 | 8.283 | 6.97% | 9.291 | 9.847 | 5.98% |

**Table 5.8 – New Vehicle Fuel Consumption Data, City, Highway and Metro-Highway.**

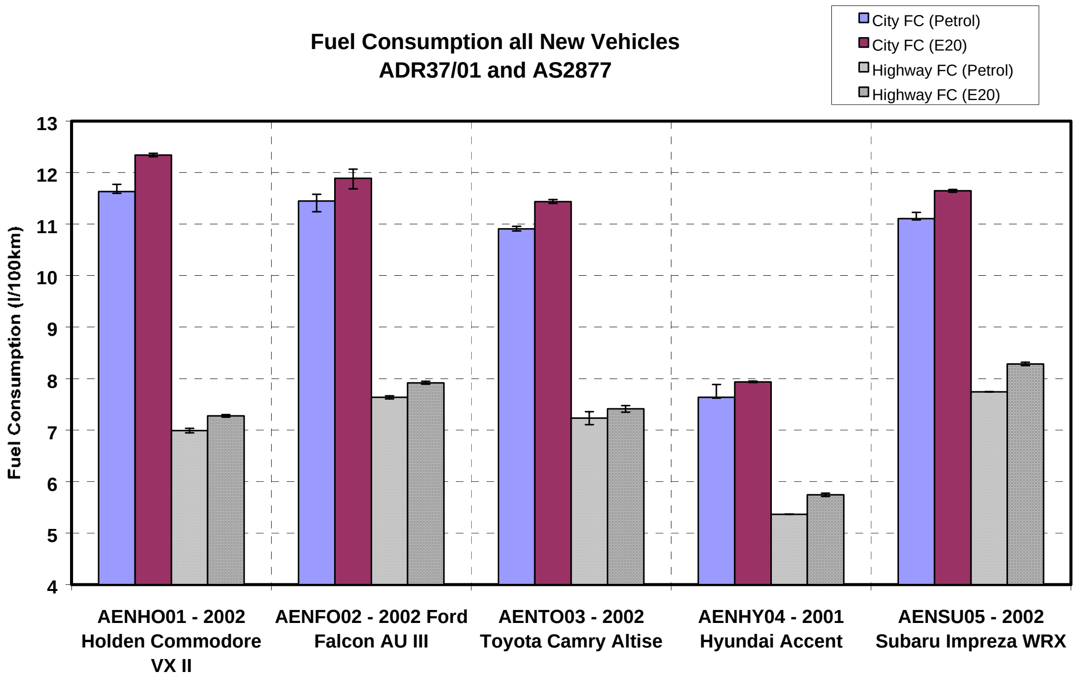


**Figure 5.73 – New Vehicle Fuel Consumption Comparison.**

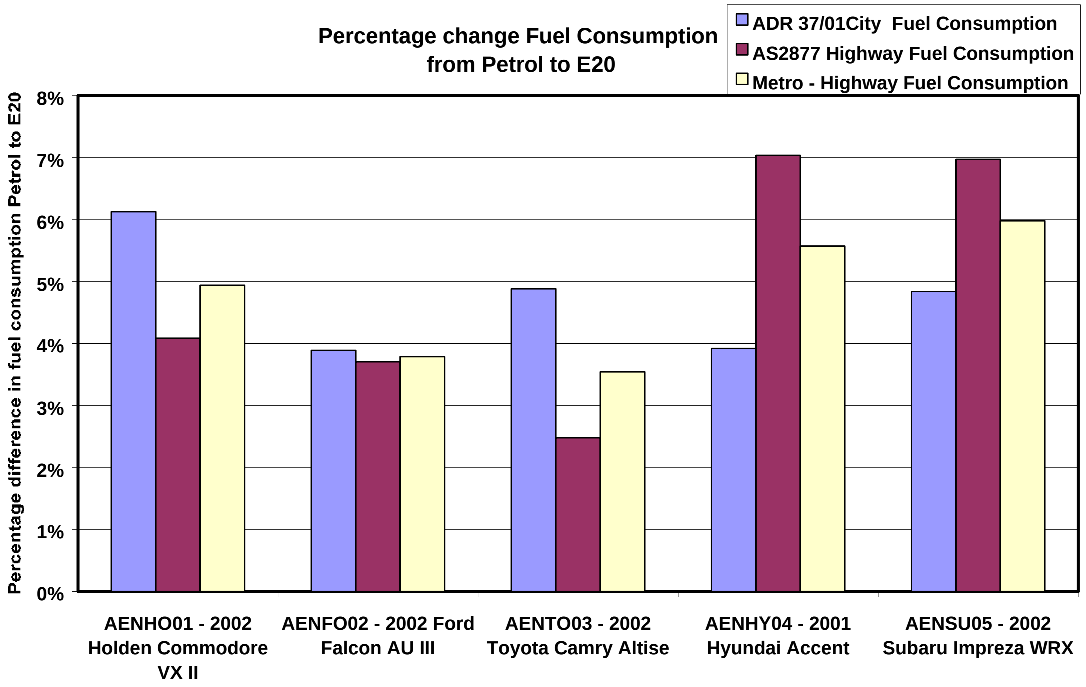


**Figure 5.74 – New Vehicle Fuel Consumption Differences.**

#### 5.1.8.1.1 Conclusions Fuel Consumption.

It can be concluded from the previous section that:

- In general there is an increase in fuel consumption when the vehicles tested are operated on E20 ranging from 2.5% to 7% depending on the cycle and the vehicle.
- The average fuel consumption increase across all vehicles was approximately 5% when operating on E20 compared to gasoline only fuel.
- The level of increase on average was less than expected. It is thought the differences are due to subtleties in both the calibration strategies and the adaptation strategies of the various vehicles control systems.

### 5.1.9 Vehicle Driveability Assessment.

The driveability assessments are a subjective measure to evaluate engine starting behaviour and driveability characteristics of the vehicle. The vehicle driveability was evaluated by means of an open road test based on industry standards. The assessments are made for ambient, hot and cold temperature weather conditions. The cold and hot conditions for vehicle assessment were simulated in the extreme environmental test chamber simulating the weather condition. Vehicle driveability is a “worse case” judgement of how the vehicle/engine performs. The assessment is made on a scale of 1 to 10 as described in Table 5.9.

| Rating | | Assessment comments |
|---|---|---|
| 10 | Excellent | Excellent driveability. No defects, user is truly impressed. |
| 9 | Very good | No trace of defects, solid/responsive |
| 8 | Good | No noticeable defects, less responsive or flat performance. User is pleased. |
| 7 | Satisfactory | One or more slight defects present barely noticeable. All minor in nature |
| 6 | Agreeable | One or more defects present, very noticeable, not objectionable. User does not consider objectionable. User is generally satisfied |
| 5 | Mediocre | Obvious defects present, irritating, will probably generate complaints. User not particularly happy with car operation and is likely to seek corrective action |
| 4 | Poor | Disturbing defects present, but still confident of continual operation. User would seek corrective action |
| 3 | Very poor | Undermines driver confidence, not reliable |
| 2 | Bad | Failure to stay running, will not operate consistently |
| 1 | Very bad | Uncontrollable, unpredictable operation |

**Table 5.9 - Drive Ratings Table.**

The vehicle performance related to the acceleration, launch and passing performance of the vehicle is also evaluated and Table 5.10 provides the different interpretations of the ratings when assessing the vehicle performance.

With starting, some level of objectivity can be applied by the measurement of start time. Ratings for starting and idle quality are also given in Table 5.11 to provide interpretations of the ratings that may have been awarded, the ratings comments from Table 5.9 apply to the ratings number in Table 5.11.
The procedures for the three distinct tests are included in the specific test reports in the vehicle appendices. Two independent test engineers repeat each of the three distinct tests, this occurs for both baseline gasoline and E20 fuel blend. One of the problems of any subjective testing is sample size. It is preferable in subjective testing to have a larger number of testers as outlying ratings can be removed as being not representative before the averaging process. In this study, two tests per fuel type (gasoline and E20) have been conducted for each of the driveability assessments performed. Due to the limited sample size, all the ratings are included and where appropriate, comment is made on the difference in rating should it exist. This is particularly relevant to starting, as averaging two ratings one of which is a stall rating is quite misleading.

In this study, the 7.0 rating has been defined as the typical production target.

| Rating | | Rating Comment |
|---|---|---|
| 10 | Excellent | Exceptionally good responsive feel under all conditions |
| 9 | Very good | Vehicle performance is above average |
| 8 | Good | Vehicle performance better than average.. |
| 7 | Satisfactory | Driver feels vehicles performance is what it should be |
| 6 | Agreeable | Driver feels vehicle does not perform as well as he thought it would but he would not seek corrective action |
| 5 | Mediocre | Vehicle does not perform as well as driver thought it would. Poor passing and acceleration capability under normal circumstances |
| 4 | Poor | An engine performance problem exists which is disturbing but is not serious enough to undermine the drivers confidence in the cars ability to pass another vehicle. |
| 3 | Very poor | Lack of confidence- vehicle performance is so weak that the drive lacks the confidence required to try and passing manoeuvre |
| 2 | Bad | Vehicle performance is so weak that the driver is reluctant to operate vehicle on public roads. |
| 1 | Very Bad | |

**Table 5.10 - Performance Rating Table.**

| Rating | Startability Rating | Idle Quality Rating |
|---|---|---|
| 7 | Normal | Normal |
| 5 | Rough | Rough |
| 3 | Start and Stall | Surge |
| 1 | No start | Engine Stall |

**Table 5.11 - Startability and Idle Quality Rating Table**

This is somewhat arbitrary as depending on the particular vehicles target market and price range will affect the amount of engineering development expended on the product. The assessments made here are focussed on determining the differences between the fuels rather than the differences between the vehicles. The production target was set to act as guide to help differentiate between acceptability and below which becomes an issue for the end user.

Specific gasolines for hot and cold testing were utilised with details of the various properties of the gasolines and some of the E20 blends made with the gasolines found in Appendix M.

#### 5.1.9.1 Ambient Conditions Driveability Evaluation.

The ambient vehicle driveability evaluation has been divided into three discrete areas each tested under the ambient conditions in Perth started early in November 2002 and was completed in early January 2003. In general, the ambient temperature for the startability testing was 25$^{o}$ Celcius. The test reports detailing the procedures used and the detailed results for each vehicle are included in the appendices to this report. The fuel used for the ambient condition test was summer grade ULP or PULP for gasoline and the same blended with 20% ethanol.

#### 5.1.9.1.1 Startability and Idle Quality.

For the startability assessment, the ambient start and the warmed-up startability were assessed. In general the Holden Commodore (AENHO01) and the Hyundai Accent (AENHY04) demonstrated similar startability with a small degradation in idle stability and roughness on both gasoline and the E20 fuel. The Toyota Camry (AENTO03) and the Subaru Impreza WRX (AENSU05) demonstrated small improvements in startability and idle quality with the Ford Falcon (AENFO02) having the largest improvement in startability and idle quality. The improvements and degradations are considered as small and not discernible to the average driver.

#### 5.1.9.1.2 Vehicle Performance.

The vehicle performance assessment is focussed on the various acceleration facets of normal driving. The Holden Commodore (AENHO01), Toyota Camry (AENTO03) and the Subaru Impreza WRX (AENSU05) were found to all demonstrate similar performance with both gasoline and E20 fuel. Small differences such as the Holden Commodore demonstrating an improvement in the WOT launch and the Subaru Impreza WRX with slight degradation for the passing feeling acceleration were noted. The Ford Falcon was found to demonstrate degradation in many of the vehicle performance acceleration tests, however the average driver would not necessarily notice. The Hyundai Accent also demonstrated degradation in many of the acceleration tests when operated on E20 fuel with a significant drop in the WOT passing feeling acceleration to the point where the average driver would notice the difference.

#### 5.1.9.1.3 Warmed-up Driveability.

This test effectively assesses the normal driving response of the warmed-up vehicle for a number of typical vehicle functions following the driving cycle in Figure 0.1. The details of these functions are provided in the test reports for each vehicle.

In general all vehicles performed acceptably when operated on the E20 fuel blend. In particular the Holden Commodore, the Toyota Camry and the Subaru Impreza WRX all performed with almost no detectable difference, certainly to the average driver. The Hyundai Accent was found to have a slight degradation in the tip-in and tip-out facet of the testing with a reduction in WOT torque delivery that would be noticeable to the average driver. Tip-in and tip-out is the on throttle and off throttle response of the vehicle. The Ford Falcon was found to have a small reduction in full load torque delivery with an increase in engine knocking.

#### 5.1.9.2 Hot Start and Driveability Evaluation.

This evaluation if focussed on identifying potential starting and driveability issues related to very hot mid day conditions to which the vehicle may be exposed. In order to simulate these conditions, testing was carried out in the extreme environmental chamber where three heat loadings are applied in order to simulate the actual hot mid day condition. These loadings include the ambient air temperature, the solar heat loading and a convective heating input from the surface on which the vehicle was parked, see Figure 5.75. The surface is assumed to simulate asphalt. The ambient air temperature within the environmental chamber was controlled to $40^{o}$ Celcius. The solar loading of the mid day sun was simulated by using infrared lamps capable of producing a heating radiation loading of up to 1,100 $W/m^2$. Simulation of the convective heating from the hot surface was effected by controlling the surface temperature of a thin rectangular metal tank running the length and nearly the width of the vehicle with hot water. The surface temperature was set at 60 - $65^{o}$Celcius.

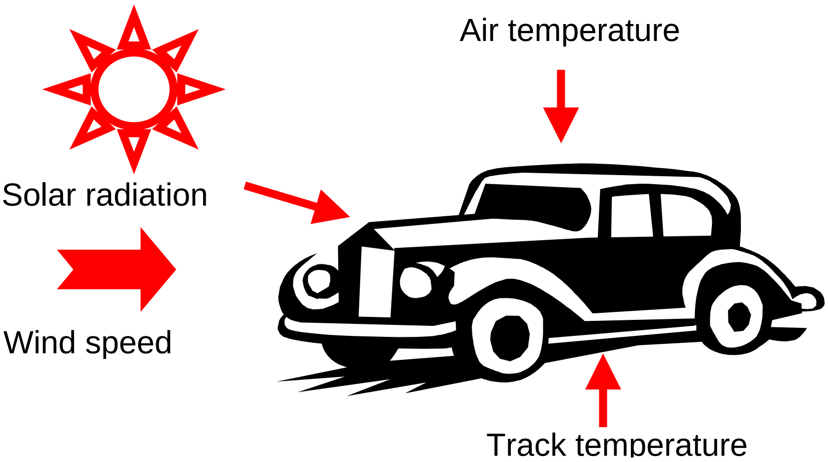


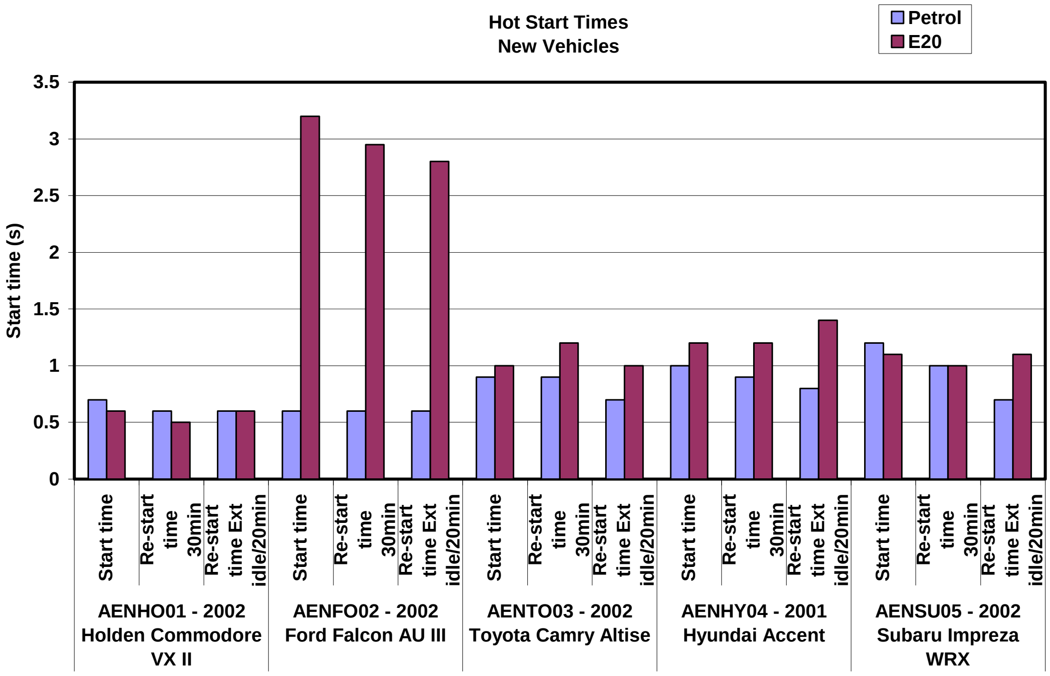
**Figure 5.75 - Hot Conditions Heat Loading**

Prior to the evaluation, the vehicles were conditioned by running them on a chassis dynamometer until the engine oil temperature reached $120^{o}$ Celcius, ensuring the vehicles engine and engine bay is fully warmed up. Immediately following this the vehicles were placed in the environmental chamber for the required soak periods as detailed in the test reports for this evaluation found in each vehicle appendix.

### 5.1.9.2.1 Startability and Idle Quality.

For all the vehicles the starting times after the ten minute hot soak either increased with E20 fuel or remained the same as for gasoline. This was the same for restart times after the 30 minute hot soak. The Ford Falcon (AENFO02) however, was found to have significantly increased start and re-start, quite obvious to the average driver. Figure 5.76 shows all the vehicles starting performance for comparison.

**Figure 5.76 - Hot Start Times for all New Vehicles**



The idle quality for the Holden Commodore, Ford Falcon, Hyundai Accent and the Subaru Impreza WRX was slightly reduced when operating on E20 fuel, this would be identifiable to the average driver. The Toyota Camry and the Hyundai Accent showed similar idle quality for gasoline and E20 fuel.

### 5.1.9.2.2 Hot Extended Idle Quality and Startability.

The Holden Commodore though starting quickly was found to misfire during the starting process with the idle degrading when operating on E20 fuel, both identifiable to the average driver. There was some increase in the time to start following the extended 20 minute idle and hot soak for the Toyota Camry, Hyundai Accent and the Subaru Impreza WRX though not significant enough to be observed by the average driver. The Ford Falcon however was found to require nearly three seconds to start after the extended idle and hot soak when operating on E20 fuel, Figure 5.76 provides the comparison. The hot extended idle quality was found to be virtually unchanged when operating on E20 fuel, however the Hyundai Accent actually demonstrated improved idle quality when operating on the E20 fuel to the point where the average driver would observe the improvement.

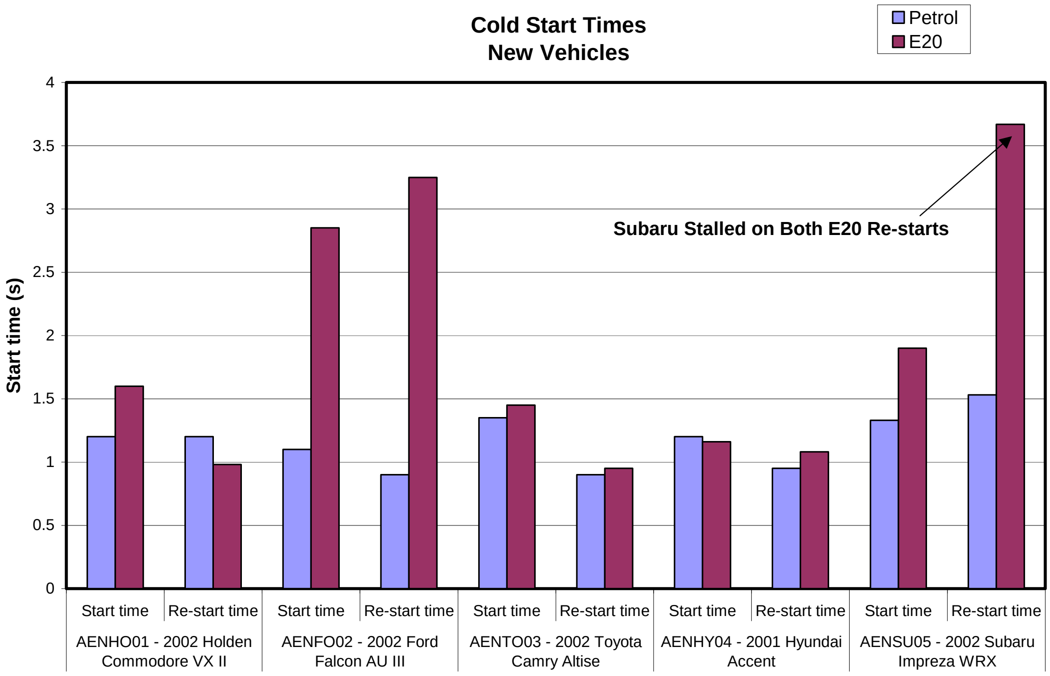
### 5.1.9.2.3 Hot Driveability.

Following the hot extended idle quality and startability testing, the vehicle is hot soaked for a further 20 minutes. Upon re-starting the vehicle it is immediately driven out onto the open road to assess the hot driveability following the driving cycle as give in Figure 0.1. All the vehicles tested were found to operate in a similar manner as on gasoline when operating on E20 fuel.

### 5.1.9.3 Cold Start and Warm-up Evaluation.

The cold start and warm-up evaluation tests were performed after having soaked the vehicles for at least eight hours at approximately –10$^{o}$ Celcius in the extreme environmental chamber. The fuel used for the cold condition testing was specific test winter grade ULP of PULP for gasoline and the same blended with 20% ethanol, the details can be found in Appendix M.

**Figure 5.77 - Cold Start and Restart Times for all New Vehicles**



Subaru Stalled on Both E20 Re-starts

### 5.1.9.3.1 Startability and Idle.

Small changes to the starting and restarting times were found for the Holden Commodore, Toyota Camry and the Hyundai Accent with the changes either increasing or decreasing, not however significantly enough to be observed by the average driver, see Figure 5.77. The Ford Falcon and the Subaru Impreza WRX both displayed significantly longer starting and restarting times some in excess of three seconds when operated on E20 fuel. The ratings given were below 7.0 and therefore noticeable to the average driver. The Subaru Impreza WRX was found to stall on both re-start tests which has resulted on a 4.0 rating indicating poor performance with an average driver viewing this as a disturbing defect present, but still confident of continual operation and would seek corrective action.

### 5.1.9.3.2 Warm-up Driveability

Immediately following the start and idle assessment in the environmental chamber, the vehicle is driven onto the open road to assess the warm-up performance. The driving cycle followed during this assessment is the same as for the hot driveability and can be found in Figure 0.1. Though there were small differences found with the E20 fuel, generally degradations, they would not be identified by the average driver.

| Vehicle | | Ambient Driveability | | Hot Driveability | | Cold Driveability | |
|---|---|---|---|---|---|---|---|
| | | Gasoline | E20 | Gasoline | E20 | Gasoline | E20 |
| **Holden Commodore VX II AENHO01** | Average | 7.7 | 7.7 | 7.8 | 7.4 | 7.9 | 7.8 |
| | Maximum | 8.5 | 8 | 8 | 8 | 8 | 8 |
| | Minimum | 6.8 | 7.2 | 7.3 | 6 | 7.3 | 7 |
| **Ford Falcon AU III AENFO02** | Average | 7.4 | 7.3 | 7.6 | 7.2 | 7.8 | 7.4 |
| | Maximum | 8 | 7.9 | 8 | 8 | 8 | 8 |
| | Minimum | 6.1 | 6.8 | 6.8 | 5.8 | 7.3 | 6.3 |
| **Toyota Camry Altise AENTO03** | Average | 7.6 | 7.8 | 7.9 | 7.7 | 7.9 | 7.6 |
| | Maximum | 8.3 | 8 | 8 | 8 | 8 | 7.8 |
| | Minimum | 7 | 7.3 | 7.8 | 7 | 7.5 | 7.3 |
| **Hyundai Accent AENHY04** | Average | 7.8 | 7.5 | 7 | 7.3 | 8 | 7.5 |
| | Maximum | 8 | 8 | 8 | 8 | 8 | 8 |
| | Minimum | 7.5 | 6.6 | 4.7 | 6.5 | 7.9 | 7.2 |
| **Subaru Impreza WRX AENSU05** | Average | 7.8 | 7.8 | 7.6 | 7.4 | 7.7 | 7.4 |
| | Maximum | 8.3 | 8.3 | 8 | 8 | 8 | 8 |
| | Minimum | 7 | 7.3 | 7 | 6 | 6.8 | 4 |

**Table 5.12 - Overall New Vehicle Driveability Summary**

#### 5.1.9.4 Driveability Conclusions.

Based on the previous sections, the following conclusions can be draw:

- Under ambient conditions some vehicles potentially may experience a noticeable degraded WOT acceleration performance.
- Under hot conditions, some vehicles potentially may experience increased starting times of up to three seconds while idle stability may be degraded such that it will be noticed by the average driver.
- Under cold conditions some vehicles potentially may experience longer starting times of up to three seconds and engine stalls once the engine fires, the driver will view this as s disturbing defect but still retain confidence of continual operation and would seek corrective action.
- These impacts are related to the changes made to the distillation curve of the gasoline by addition of 20% ethanol along with enleanment and the greater heating required to vaporise ethanol and are confirmed by the literature review completed earlier (4).

Table 5.12 summarises the overall driveability assessment.

### 5.1.10 Fuelling Adaptation (Enleanment) Assessment.

The fuelling adaptation assessment or enleanment test was a simple test designed to help establish an understanding of a particular vehicles engine managements systems, EMS, ability to accommodate the difference between gasoline and E20. This test is only relevant to the vehicles fitted with closed loop controlled fuelling systems and therefore contains data for the old Toyota Camry (AENTO14). This test is one part of understanding the capabilities of the EMS and other factors such as “snap fuelling”(see section 5.1.11), i.e. the speed of the system to adapt and how the system compensates in the areas in which closed loop operation is not used also need to be considered. These areas are cover in other sections of the report.

The aim of the test was to understand the approximate limits of the compensations/adaptation available. The data presented should not be used as an exact measure of the limits of adaptation but as a guide. The test procedure consisted of artificially offsetting the fuelling level. This was accomplished by dropping the regulated fuel pressure. The fuel injector duration was measured whilst observing the lambda sensor output. The adaptation limit being determined when the lambda sensor output became inactive. The test was conducted at idle and at an arbitrary point within the emissions speed/load operational envelop, typically this equated to a vehicle speed of 60km/h. All the test data for each vehicle can be found in the appropriate vehicle appendix.

Table 5.13 shows the results for the fuelling adaptation test for all the closed loop vehicles in the study. Clearly all the vehicles have fairly large adaptation ranges at the points tested. These ranges will adequately accommodate a 20% ethanol blend fuel. This data should be viewed in conjunction with section 5.1.1 in which the issues off full load adaptation are investigated for the new vehicles and section 5.1.3 in which the fuelling adaptation during the emissions drive cycles is examined for the new vehicles. Sections 5.2.1 and 5.2.3 are similar but examine the old vehicles.

| **Vehicle Type** | **Vehicle code** | **Percentage increase in injector pulse width** | | | |
|---|---|---|---|---|---|
| | | **Idle (gasoline)** | **Idle (E20)** | **Off idle (gasoline)** | **Off idle (E20)** |
| **Holden Commodore VX** | AENHO01 | 41.0% | 30.5% | 47.7% | 32.7% |
| **Ford Falcon AU** | AENFO02 | 40.1% | 52.2% | 62.4% | 65.4% |
| **Toyota Camry Altise** | AENTO03 | 17.0% | 16.8% | 18.0% | 21.3% |
| **Hyundai Accent** | AENHY04 | 54.9% | 45.1% | 52.3% | 47.6% |
| **Subaru Impreza WRX** | AENSU05 | 25.2% | 25.1% | 38.1% | 41.1% |
| **Toyota Camry Ultima** | AENTO14 | 0.3[§]% | 0.1[§]% | 31% | 14.2% |

**Table 5.13 - Percentage Increase in Fuel Injector Pulse Width.**

§ The result for the old Toyota Camry (AENTO14) is somewhat misleading. The Toyota Camry (AENTO14) appears to have the ability to adapt and maintain stoichiometric air fuel ratio when operating over the ADR37/00 drive cycle, Figure 5.110 and Figure 5.111 both clearly show the EMS controlling the fuelling level. From further investigation it appears that the closed loop fuelling control is disabled after 20-30 seconds, which gives rise to the numbers tagged § in Table 5.13 for the idle test case.

#### 5.1.10.1 Conclusion Fuelling Adaptation (Enleanment) Assessment

It can be concluded from the previous section that:

- From the simple test conducted there appears to be an adequate range of adaptation for the closed loop vehicles tested when operated on E20.

### 5.1.11 Snap Fuelling Change Assessment.

This test is focussed on developing an understanding of the rate at which the vehicle EMS is capable of coping with sudden switches from gasoline to the E20 blend fuel and once adapted to the E20 fuel blend a sudden switch back to gasoline. Within the phase of the E20 program reported here the test and outcome of switching from gasoline to E20 fuel is covered. This test is only relevant to the vehicles fitted with closed loop controlled fuelling systems and therefore contains data for the old Toyota Camry (AENTO14). Following the 80,000km mileage accumulation the test of switching from E20 to gasoline will be completed. The old Toyota Camry (AENTO14) will not be included in the reverse snap fuel change test. The methodology adopted to develop the understanding was to complete back to back tests of ambient condition driveability and emissions measurement through the IM 240 procedure. It is noted that the order of process is reversed as it was thought the driveability assessment was of primary priority as it would provide information on potential driveability issues directly after the fuel snap change potentially before any adaptation process could occur. Should the emissions adversely change was considered of secondary importance.

#### 5.1.11.1 Driveability Assessment.

In general all the new vehicles and the old Toyota displayed equivalent driveability characteristics on gasoline and E20 fuel, as found in section **Error! Reference source not found.** and section 5.2.11.3 for the old Toyota (AENTO14). The Holden Commodore (AENHO01) was found to have slightly improved acceleration feel while the Ford Falcon (AENFO02) demonstrated increased vehicle noise under full conditions when fuelled with E20. Both the new and old Toyotas were found to drive almost identically on both the gasoline and the E20 fuel. The Subaru Impreza WRX (AENSU05) demonstrated a slightly improved idle quality with the E20 fuel. The Hyundai Accent was found to rate slightly less in more areas than the other vehicles. In terms of the average driver, it is unlikely that the small improvements or deteriorations are likely to be discerned.

#### 5.1.11.2 Emissions Assessment.

The emissions testing has revealed a similar trend to that described in section 5.1.2.1 was found, with the individual vehicle trends for all the measured exhaust emissions following similar characteristics. For the old Toyota Camry similar trends were also found, see section 5.2.2.1.

#### 5.1.11.3 Conclusion Snap Fuelling Change Assessment.

Based on the previous sections, the following conclusions can be drawn:

- The closed loop controlled vehicles appear to quickly adapt to the snap fuel change demonstrating very similar driveability characteristics when operating on both gasoline and E20 fuel.
- Exhaust emissions trends are similar to those found in the city cycle ADR37/01 and ADR37/00 test procedures.

## 5.2 Old Vehicles.

A summary of the performance and evaluation tests undertaken on the old vehicles is discussed below. Test reports for each vehicle test are included in the appendices to this report.

### 5.2.1 Engine Power Evaluation.

This assessment was carried as described in section 5.1.1. The data from both tests for all the old vehicles is presented in Figure 5.78 and Figure 5.79. Overall there is little difference between gasoline and E20.

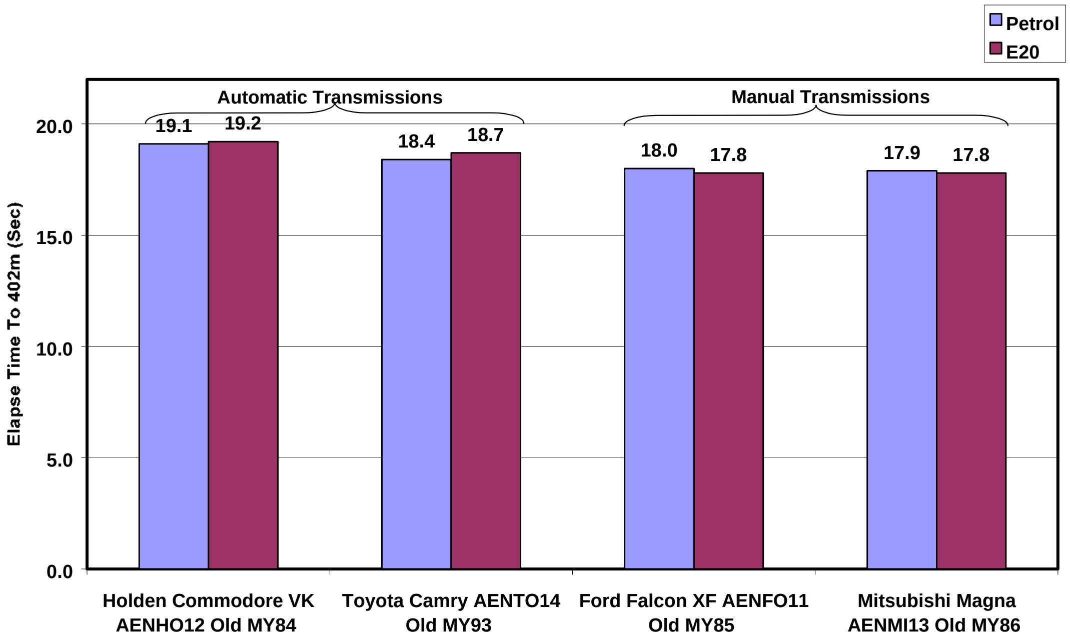


Figure 5.78 - Elapsed Times to 402m All Old Vehicles.

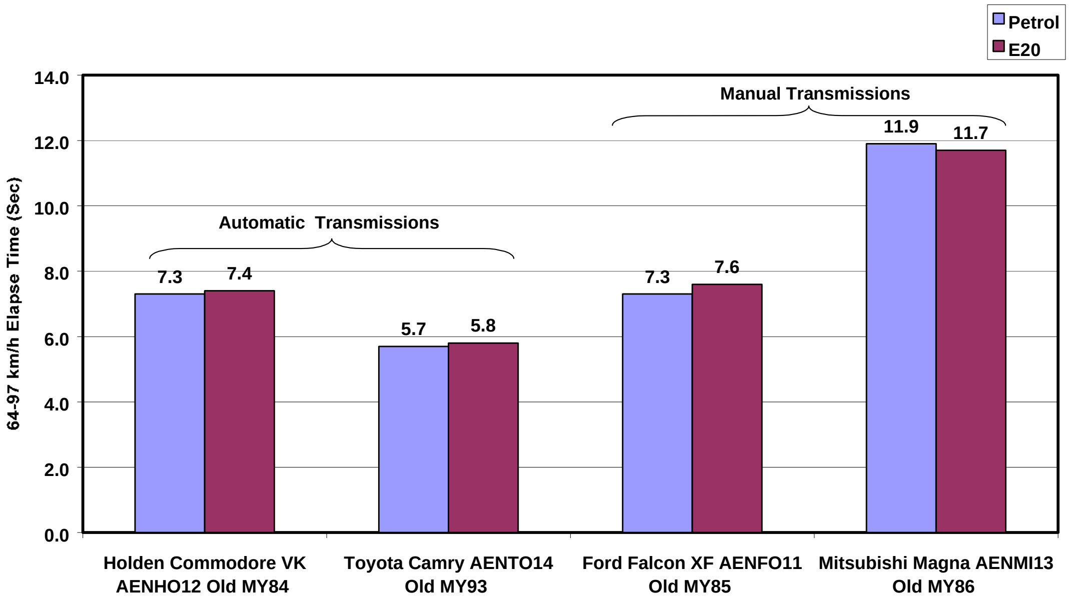


**Figure 5.79 - 64-97 km/h Elapsed Times Top Gear All Old Vehicles.**

The exhaust lambda values for full load for the old vehicles are shown in Figure 5.80 Holden Commodore VK (AENHO12), Figure 5.82 Ford Falcon XF (AENFO11), Figure 5.84 Mitsubishi Magna (AENMI13) and Figure 5.86 Toyota Camry (AENTO14). Apart from the Toyota Camry all the vehicles are open loop fuelled vehicles. Hence it is expected that there will be a lean shift in lambda when the vehicle is running on E20 of approximately 7%. This can be clearly seen for all the open loop vehicles. The value of lambda for the Holden Commodore VK (AENHO12) appears to be lean for typical WOT levels. This model of vehicle is equipped with a secondary air pump, which appears to be pumping excess air into the exhaust under all operating conditions. As the air pump operation is not affected by fuel type the difference between the lambda curves can be attributed to the operation of the vehicle on gasoline or E20. On E20, for a large proportion of the test lambda was greater than one ($\lambda > 1$) meaning there will be excess oxygen/air in the exhaust. It is assumed that it is this excess oxygen/air, which is the reason that the exhaust temperature is lower when the vehicle is operated on E20 compared to gasoline Figure 5.81. This is most likely due to the excess air absorbing energy released by the combustion thus lowering the exhaust gas temperature.

The Mitsubishi Magna (AENMI13) is also equipped with a secondary air system. However this system is a passive system, which uses the pressure pulsations in the exhaust to draw excess air into the system. These systems by their very nature are tuned to the gas dynamics of the exhaust system and therefore only operate over a limited range, usually covering the emissions speed/load area. It appears from the lambda level in the exhaust gas of the Mitsubishi Magna that the secondary air is not active during full load operation. When the vehicle is operated on E20 there is the concomitant increase in the pre-catalyst exhaust gas temperature, Figure 5.85

The exhaust temperatures for the Ford Falcon XF (AENFO11) clearly show a marked increased when the vehicle is operated in E20 Figure 5.83.

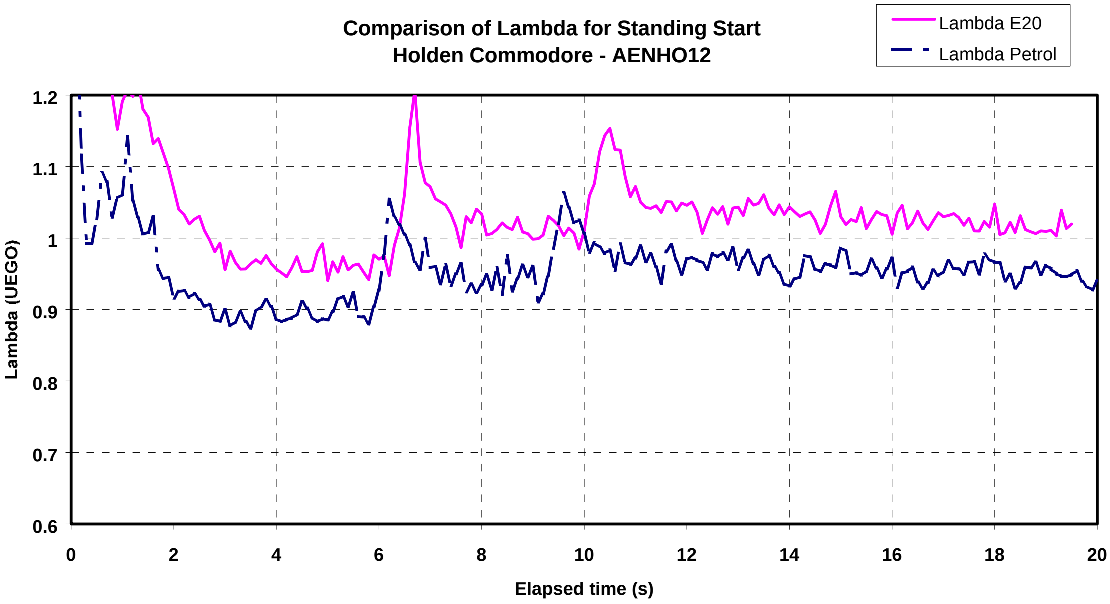


Figure 5.80 - WOT Air Fuel Ratio Holden Commodore VK – AENHO12

The Toyota Camry (AENTO14) is the only closed loop vehicle in the old vehicle group. From the exhaust lambda, Figure 5.86, it appears that the EMS system on this vehicle carries over any adaptations made when in closed loop operation into the full load region.

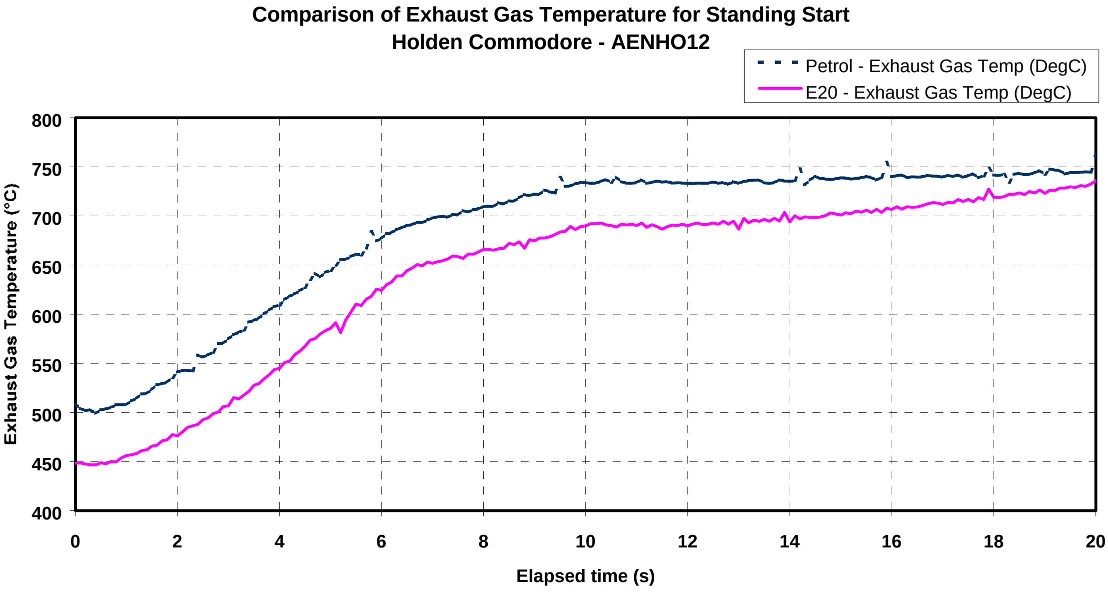


Figure 5.81 - WOT Exhaust Temperatures Holden Commodore VK – AENHO12

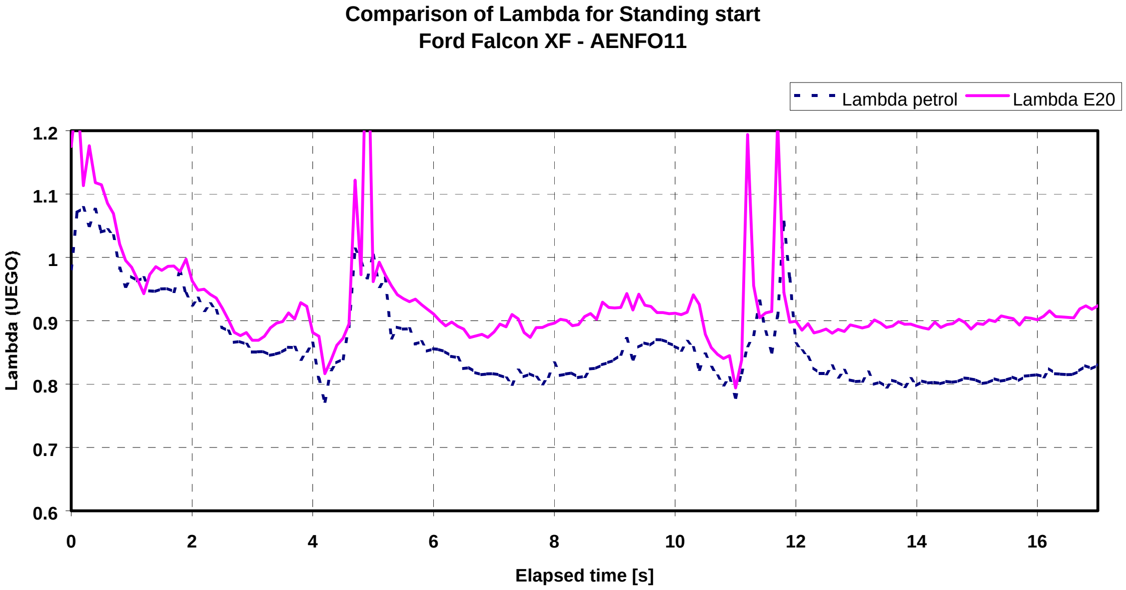


Figure 5.82 - WOT Air Fuel Ratio Ford Falcon XF - AENFO11

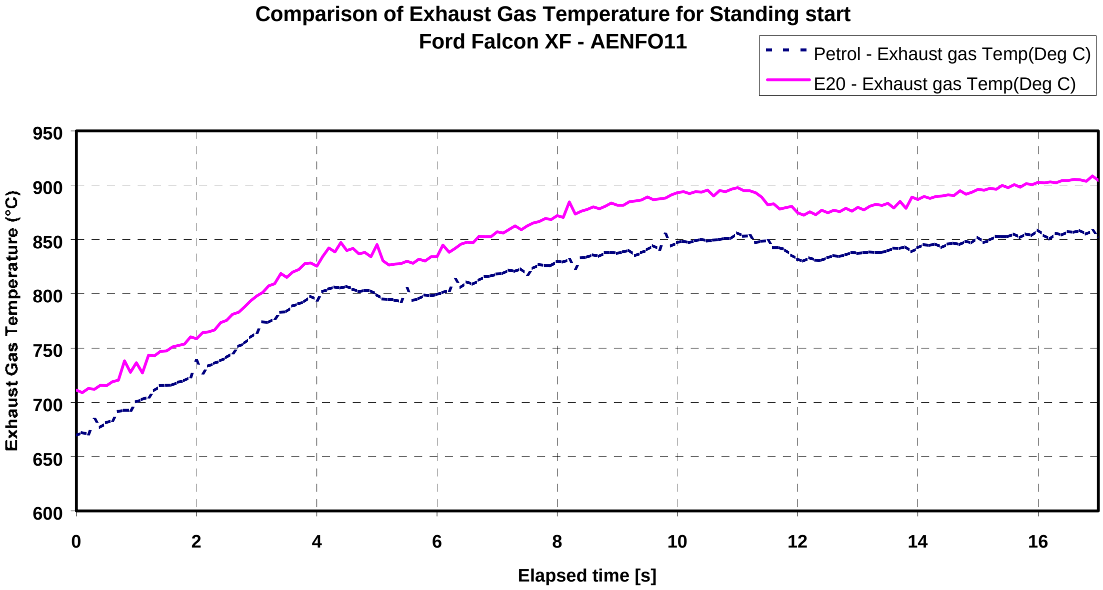


Figure 5.83 - WOT Exhaust Temperatures Ford Falcon XF - AENFO11

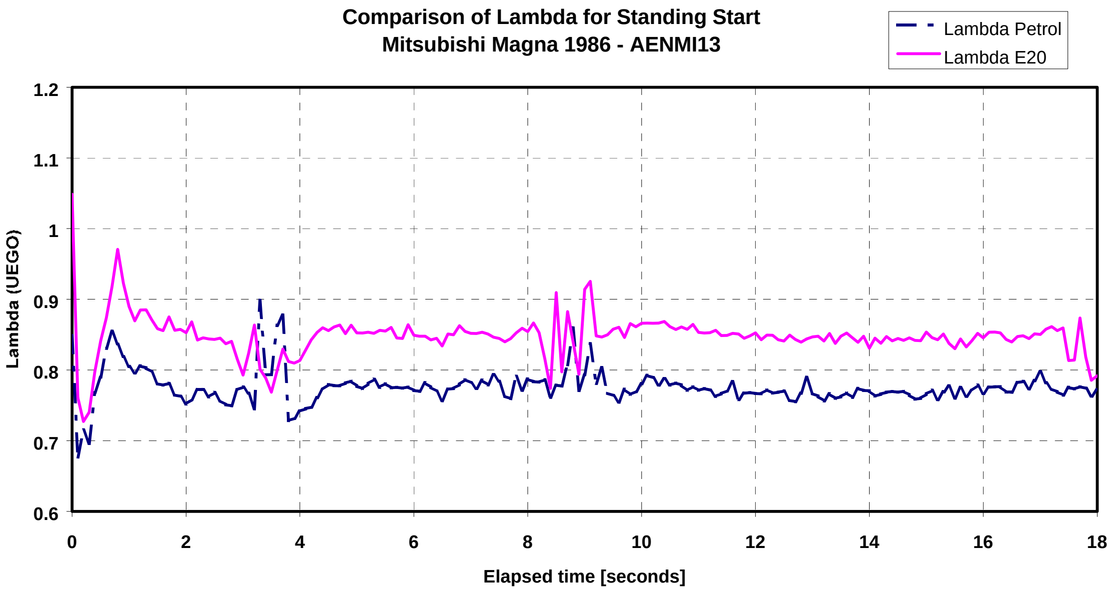


Figure 5.84 - WOT Air Fuel Ratio Mitsubishi Magna - AENMI13

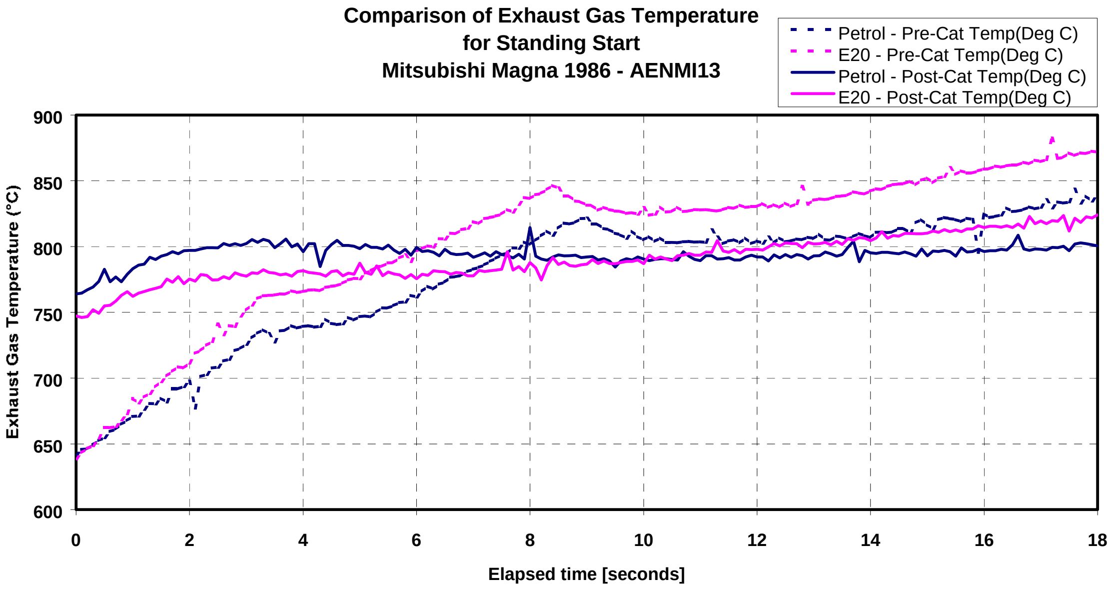


Figure 5.85 - Wot Exhaust Temperatures Mitsubishi Magna - AENMI13

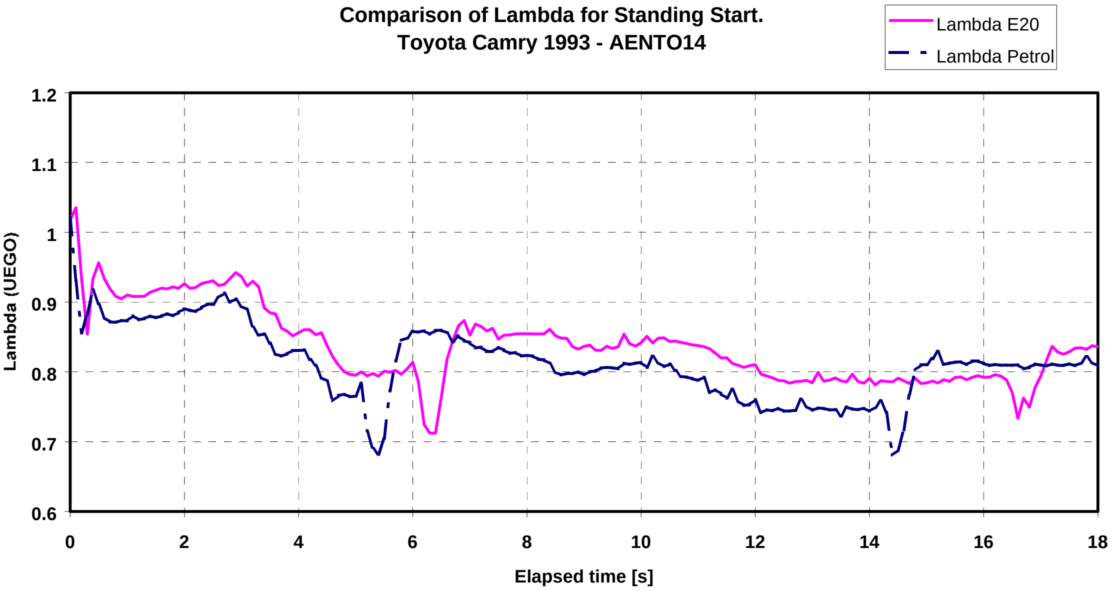


Figure 5.86 - WOT Air Fuel Ratio Toyota Camry AENTO14

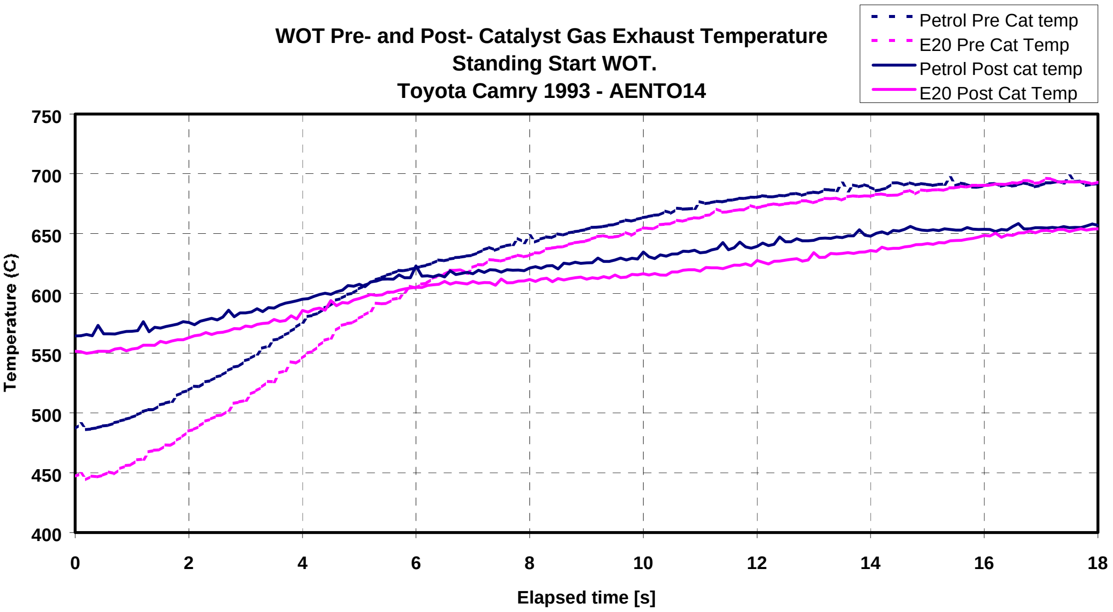


Figure 5.87 - WOT Exhaust Temperatures Toyota Camry AENTO14

### 5.2.1.1 Conclusions Engine Power Evaluation.

The WOT acceleration results from the old vehicles tested indicate there is no significant evidence of a detrimental effect in acceleration caused by the use of E20 on the WOT performance. Three of the old vehicles tested are open loop fuelled vehicles. All these vehicles exhibit an increase in lambda of approximately 7%. The Ford Falcon XF (AENFO11) increase in lambda appears to be slightly more than 7% towards the end of the standing start acceleration which might account for the significant increase in exhaust temperature when this vehicle is operated on E20. The Holden Commodore

VK (AENHO12) exhaust temperature decreases when the vehicle is operated on E20 even though the vehicle exhaust lambda has increased. It is thought that this is due to the excess air supplied by the air pump fitted to this vehicle.

The Toyota Camry (AENTO14), is the only closed loop vehicle in the old group and appears to have an EMS which carries the closed loop adaptation into the full load region.

Any deviation from the gasoline full load lambda calibration that results in increased exhaust temperatures has the potential to lead to engine durability issues. If an aftertreatment system is fitted there is the potential for durability issues with these components also.

### 5.2.2 Tailpipe Emissions Assessment.

The regulated and evaporative emissions from all the old vehicles where tested according to their respective compliance ADR i.e. ADR27C or ADR37/00 (16 or 17). During the test, measurement of air-toxic and greenhouse gas emissions where also taken, this data will be discussed in sections **Error! Reference source not found.** and 7.3. The tests were undertaken with both baseline gasoline and E20 blend fuel and occurred after the vehicles had completed the low mileage stabilisation distance of 6400km after refurbishment. The only exception to this was the Toyota Camry Ultima, which it was deemed unnecessary to rebuild the engine or replace the aftertreatment system as an emissions test showed the tailpipe emissions substantially lower than ADR37/00 the compliance regime for this vehicle. Test reports detailing the procedures used and the detailed results for each vehicle test are included in the appendices to this report.
Also included in this section will be the emissions data taken from the vehicles when they where tested over the AS2877 highway cycle

#### 5.2.2.1 ADR27C & ADR37/00 Weighted Regulated Tailpipe Emissions

The average weighted tailpipe emissions for all the old vehicles tested on both gasoline only and gasoline with 20% ethanol over the ADR27C and ADR37/01 drive cycles are given in Table 5.14 and pictorially shown in Figure 5.88, Figure 5.89, Figure 5.90 and Figure 5.91. The data is summarised in Figure 5.92 as the mean of the emissions data and Figure 5.93 as the individual vehicle percentage differences in tailpipe emissions between gasoline and E20.

Apart from the Toyota Camry all the vehicles are open loop fuelled vehicles, hence it is expected that there will be a lean shift in lambda when the vehicle is running on E20 of approximately 7%. This can be clearly seen in the pre-catalyst/engine out emissions data 5.2.3.1 where the modal data for all three open loop vehicles clearly shows an increase in exhaust oxygen content in the exhaust.

The general trend in the emissions show that the HC emissions are virtually unchanged when using E20 compared to gasoline only fuel. The Holden Commodore does show a reduction in HC emissions, but the other vehicles do not show any sensitivity in HC emissions to the different fuels. The CO emissions are reduced when using E20, with large reductions seen for all vehicles except the closed loop operation Toyota Camry. The NOx emissions are found to increase for the vehicles without closed loop control. This is consistent with the expected behaviour of these vehicles when the base calibration on gasoline operates at near (or richer than) stoichiometric air/fuel ratios.

On average across all the older vehicles without close loop control, there was a reduction in HC and CO emissions of approximately 4% and 70% respectively, while NOx emissions increased by approximately 15% when using E20. These increases are similar to the average across all vehicles (including the closed loop Toyota Camry) due to high absolute values of the older vehicles without closed loop fuelling control. Overall, the results compare favourably with the findings in (4) which concluded for open loop fuel systems there is a clear trend for a reduction in CO emissions, with the NOx and THC emissions being highly dependent on the base engine calibration.

The data for the Toyota Camry (AENTO14), with closed loop fuelling control, cannot be compared with the other open loop vehicles and is best compared to the new vehicles in 5.1.2. Similar to the Holden Commodore (AENHO01) and Hyundai Accent (AENHY04), there is no apparent reduction in CO and no increase in NOx emissions. This appears to be for exactly the same characteristic as for the newer vehicles with the closed loop controller being relatively, biased rich, by the adaptation process when the vehicle has been operated on E20 (5.2.3.1).

| Vehicle Type | Vehicle code | THC (Gasoline) g/km | THC (E20) g/km | CO (Gasoline) g/km | CO (E20) g/km | NOx (Gasoline) g/km | NOx (E20) g/km | CO2 (Gasoline) g/km | CO2 (E20) g/km |
|---|---|---|---|---|---|---|---|---|---|
| **1985 Ford Falcon XF (ADR27C)** | AENFO11 | 2.099 | 2.092 | 28.405 | 8.299 | 0.967 | 0.994 | 318.8 | 344.0 |
| **1985 Holden Commodore VK (ADR27C)** | AENHO12 | 1.606 | 1.445 | 26.989 | 6.465 | 0.811 | 1.119 | 281.1 | 288.2 |
| **1986 Mitsubishi Magna TM (ADR37/00)** | AENMI13 | 0.096 | 0.098 | 4.156 | 1.994 | 1.146 | 1.257 | 245.7 | 238.8 |
| **1993 Toyota Camry Ultima (ADR37/00)** | AENTO14 | 0.128 | 0.128 | 1.330 | 1.268 | 1.099 | 1.000 | 233.5 | 230.2 |

**Table 5.14 - ADR27C & ADR37/00 Weighted Tailpipe Emissions All Old Vehicles**

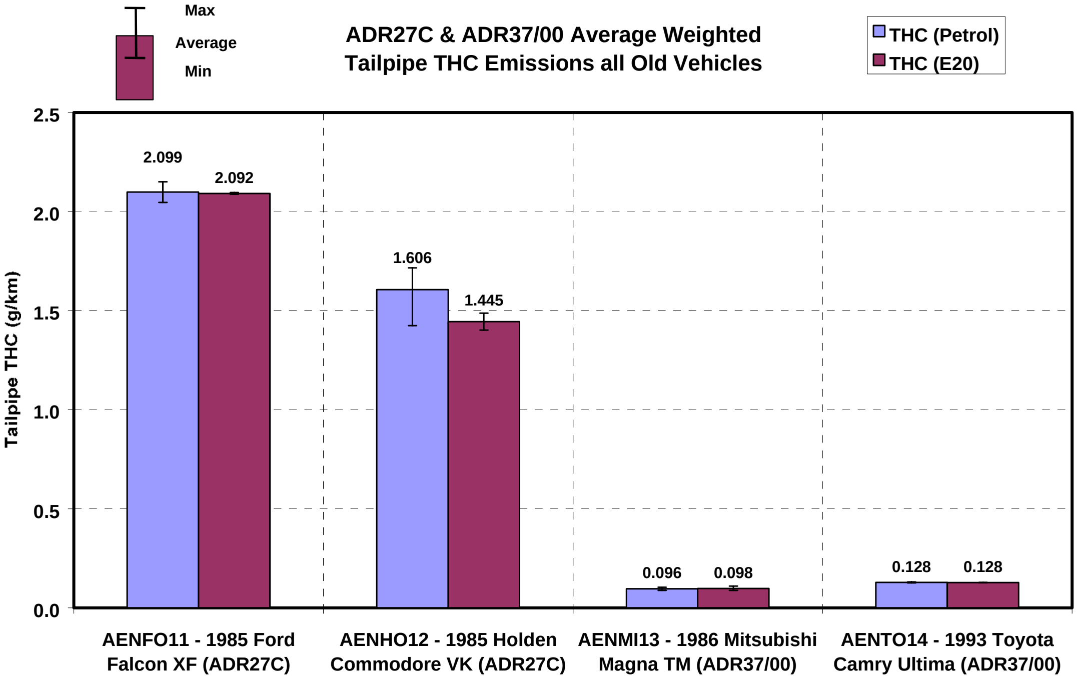


Figure 5.88 - ADR27C & ADR37/00 Average Weighted Tailpipe THC Emissions All Old Vehicles

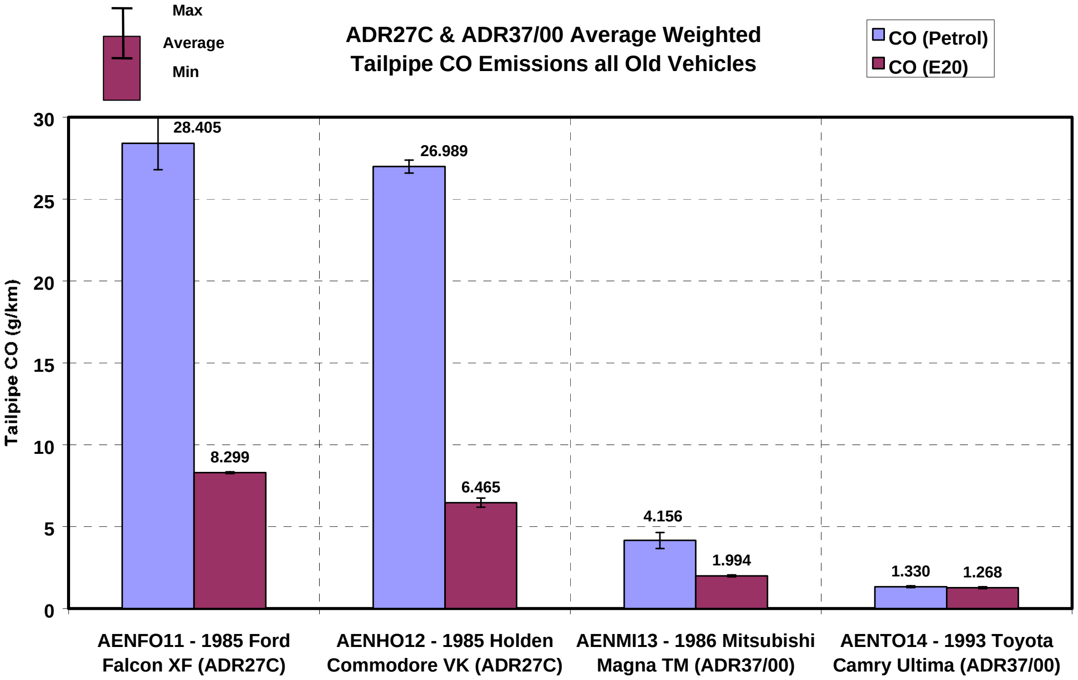


Figure 5.89 - ADR27C & ADR37/00 Average Weighted Tailpipe CO Emissions All Old Vehicles

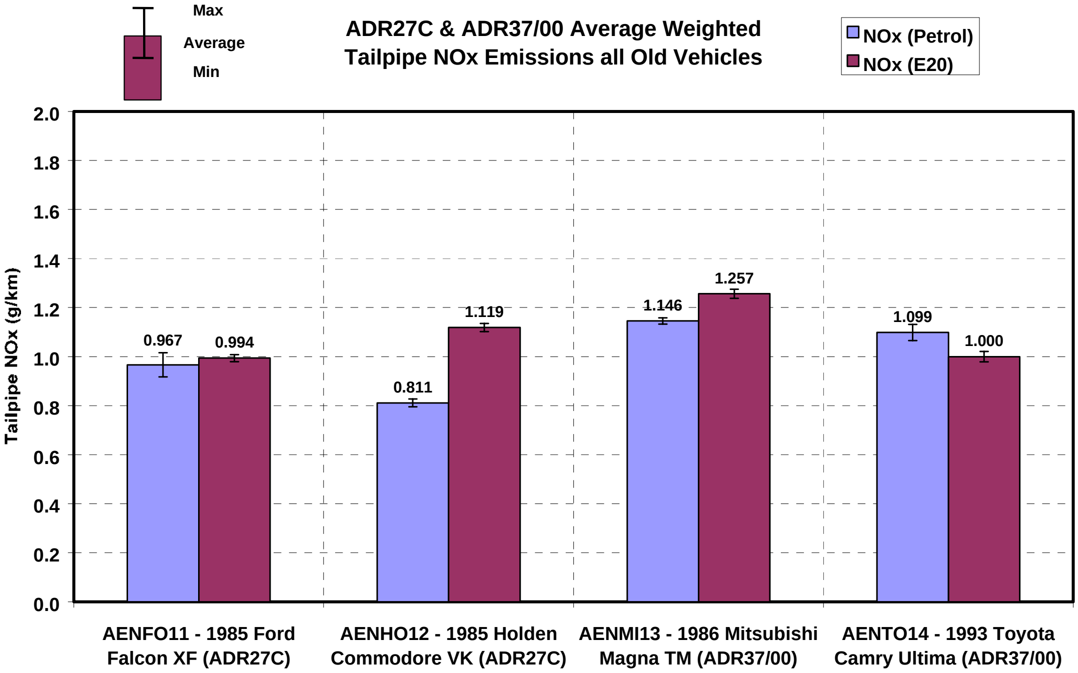


**Figure 5.90 - ADR27C & ADR37/00 Average Weighted Tailpipe NOx Emissions All Old Vehicles.**

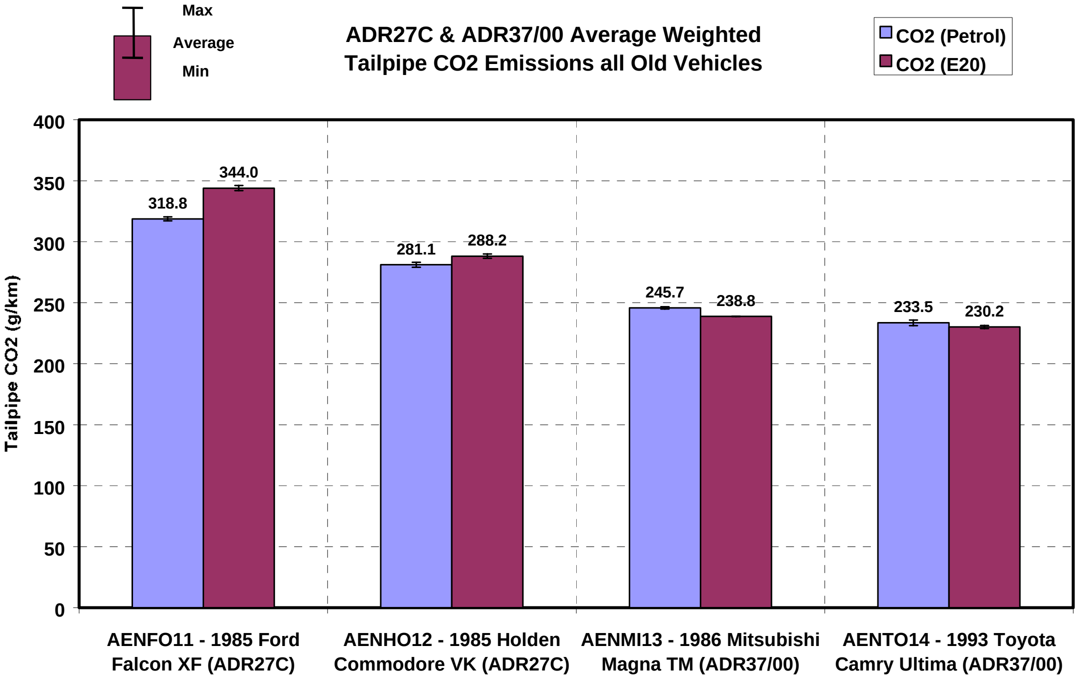


**Figure 5.91 - ADR27C & ADR37/00 Average Weighted Tailpipe CO2 Emissions All Old Vehicles**

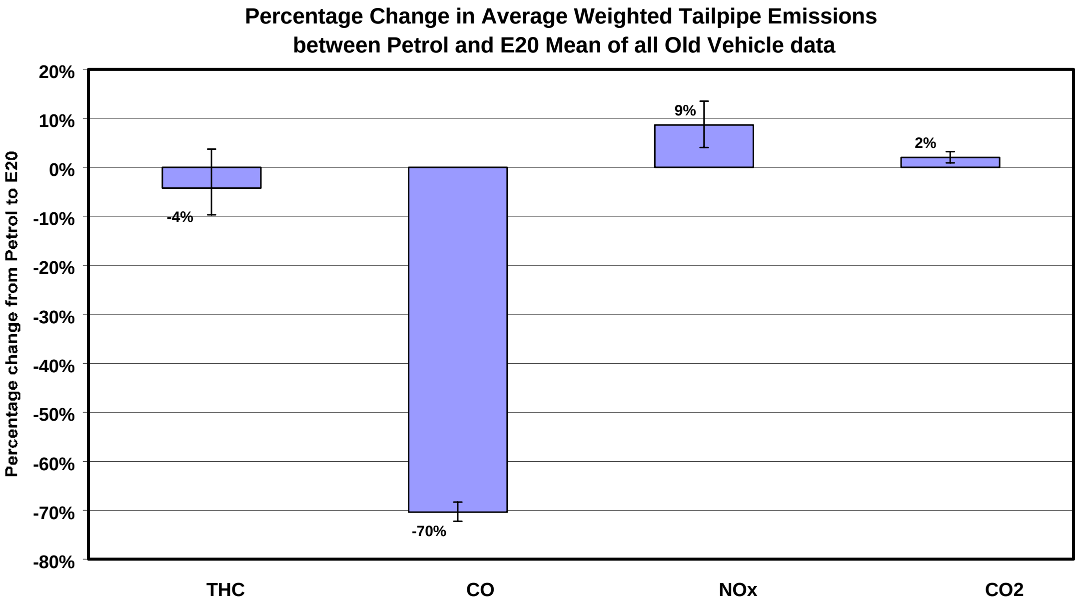


Figure 5.92 - Percentage Change in ADR27C & ADR37/00 Average Weighted Tailpipe Emissions Between Gasoline and E20 Mean of All Old Vehicles

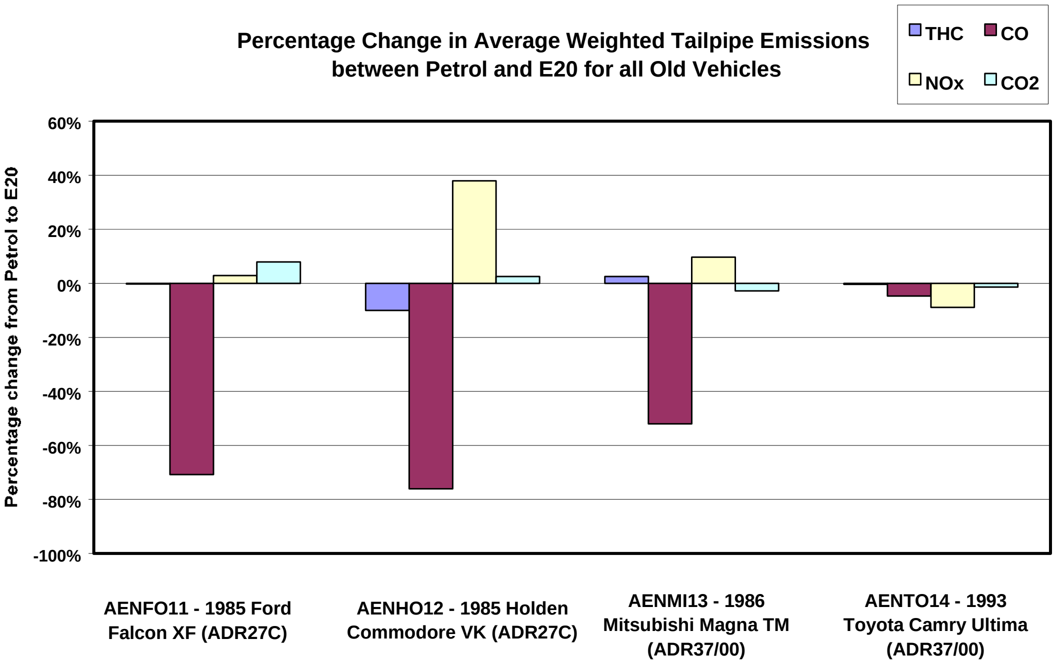


Figure 5.93 - Percentage Change in ADR27C & ADR37/00 Weighted Tailpipe Emissions Between Gasoline and E20 for All Old Vehicles

#### 5.2.2.1.1 Conclusions ADR27C & ADR37/00 Weighted Tailpipe Emissions.

From results described in the previous section, it can be concluded that:

- For older vehicles without closed loop control, there was a large reduction in CO emissions for all vehicles when operating on E20 compared with gasoline only fuel. The NOx emissions showed a general increase with E20, while the HC emissions remained relatively unchanged. This compares favourably with other studies on vehicles with similar control systems.
- The older vehicle with closed loop fuelling control (Toyota Camry) showed little change in regulated emissions when operated on E20.
- If the average percentage change of the emissions for all vehicles from gasoline to E20 is calculated, the approximate decrease in emissions of THC will be 4%, CO will be 70% and NOx will increase by approximately 9%. When including the closed loop vehicle in the older vehicle group, these average results do not represent the individual vehicle emissions change when using E20.

#### 5.2.2.1.2 Impact on $CO_2$ Emissions of Old Vehicles from E20

Although carbon dioxide is not classified as a regulated emission, it is a greenhouse gas contributor, and therefore needs to be included in the analysis of the impacts of E20 on the Australian passenger vehicle fleet. From Figure 5.91 it can been seen that there is no general trend for CO2 emissions with the use of E20 when compared with gasoline only fuel when comparing the effects for each individual vehicle. The Ford Falcon and Holden Commodore show increased $CO_2$ emissions, while the Mitsubishi Magna and the Toyota Camry both show reduced $CO_2$ emissions. Based on the literature study (4) and the findings from the new vehicle results, it may well be expected that the $CO_2$ emissions should be reduced with the use of E20.

The increases in the $CO_2$ emissions for the Falcon and Commodore are believed to be due to the large reductions seen in CO emissions of these vehicles with the use of E20. The CO emissions are reduced due to leaner operation with E20, resulting in reductions in both engine combustion generated CO emissions and potentially more post oxidation in the exhaust system. The reduction in CO leads to the higher $CO_2$ emissions as the CO is fully oxidized. When comparing the CO emissions reduction from these two vehicles as a mass equivalent $CO_2$ emissions, the CO reduction more than accounts for the increase in tailpipe $CO_2$ emissions measured for these vehicles.

The overall average across all the old vehicles for $CO_2$ emissions were found to increase by 1% for E20 when compared to gasoline only fuel. This increase is thought to be primarily due to the Ford Falcon and Holden Commodore which displayed large absolute reductions in CO emissions, leading to higher tailpipe $CO_2$ emissions.

### 5.2.2.2 AS2877 Highway Tailpipe Emissions

The tailpipe emissions for all the vehicles tested on both gasoline only and gasoline with 20% ethanol over the AS2877 Highway cycle are shown in

Table 5.15 and pictorially in Figure 5.94, Figure 5.95, Figure 5.96 and Figure 5.97. The data is summarised in Figure 5.98 and Figure 5.99.

The results are very similar to those for the ADR27C and ADR37/00 cycle. There is a general trend of large reductions in CO emissions for the open loop vehicles. The HC and NOx emissions, however, do not show any general trend when considering each individual vehicle result. The closed loop vehicle shows virtually no change in HC, a small reduction in CO emissions, with an increase in NOx emissions of approximately 60% when using E20. This is consistent of the findings for the new vehicles which continued to operate in closed loop control (stoichiometric air/fuel ratio) during the highway cycle. When averaged over all vehicles, the use of E20 results in a reduction of HC and CO emissions of 10% and 76% respectively, while the NOx emissions increase by approximately 10%. Again this data indicates that on an individual basis the vehicles have a different emissions outcome when switched from straight gasoline to E20.

The $CO_2$ emissions with E20 compared to gasoline only fuel do not show any consistent general trend for the individual vehicles in the study. The Ford Falcon and Holden Commodore show increases in $CO_2$, while the Mitsubishi Magna shows a reduction in $CO_2$. The increased $CO_2$ evident for the Falcon and Commodore is believed to be due to the large reductions in CO emissions for these two vehicles, as was also the case for the city cycle operation. Overall, the $CO_2$ emissions increase by 1% when averaged over all the vehicles, but this increase is predominantly due to the changes in $CO_2$ emissions of the Falcon and Commodore.

| Vehicle Type | Vehicle code | THC (Gasoline) g/km | THC (E20) g/km | CO (Gasoline) g/km | CO (E20) g/km | NOx (Gasoline) g/km | NOx (E20) g/km | CO2 (Gasoline) g/km | CO2 (E20) g/km |
|---|---|---|---|---|---|---|---|---|---|
| **1985 Ford Falcon XF (ADR27C)** | AENFO11 | 0.840 | 0.574 | 12.998 | 3.239 | 1.018 | 1.101 | 200.1 | 209.9 |
| **1985 Holden Commodore VK (ADR27C)** | AENHO12 | 0.643 | 0.757 | 12.198 | 2.473 | 1.280 | 1.428 | 210.2 | 211.9 |
| **1986 Mitsubishi Magna TM (ADR37/00)** | AENMI13 | 0.025 | 0.022 | 0.821 | 0.411 | 1.282 | 1.235 | 152.6 | 149.3 |
| **1993 Toyota Camry Ultima (ADR37/00)** | AENTO14 | 0.014 | 0.015 | 0.238 | 0.189 | 0.380 | 0.593 | 160.5 | 161.1 |

**Table 5.15 - AS2877 Average Tailpipe Emissions All Old Vehicles**

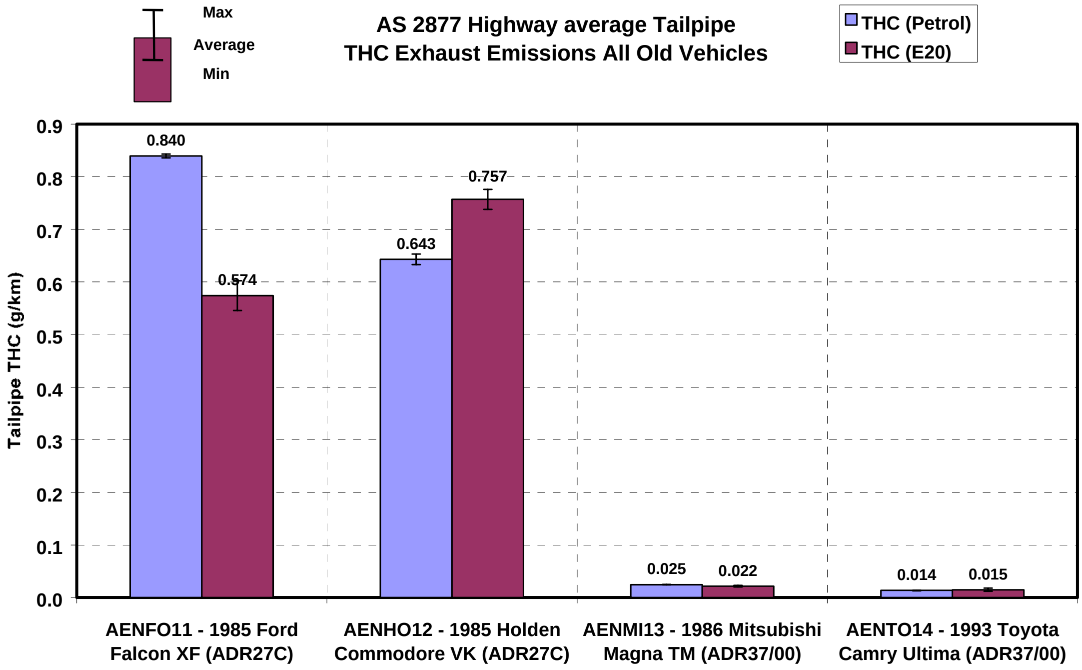


Figure 5.94 - AS2877 Highway Average Tailpipe THC Emissions All Old Vehicles.

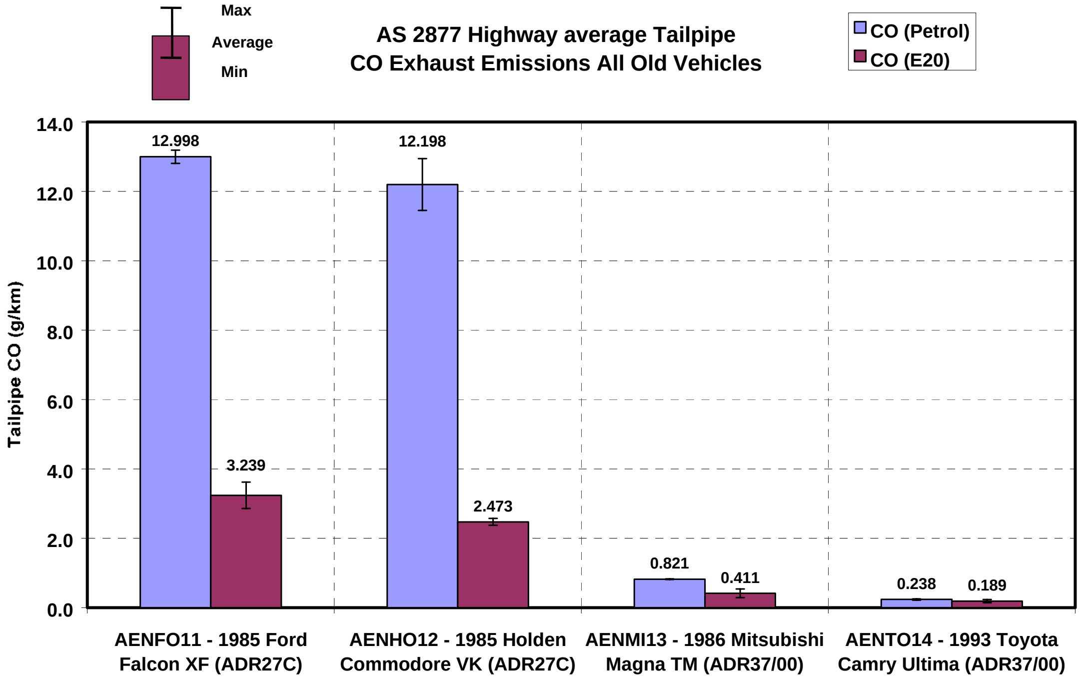


Figure 5.95 - AS2877 Highway Average Tailpipe CO Emissions All Old Vehicles.

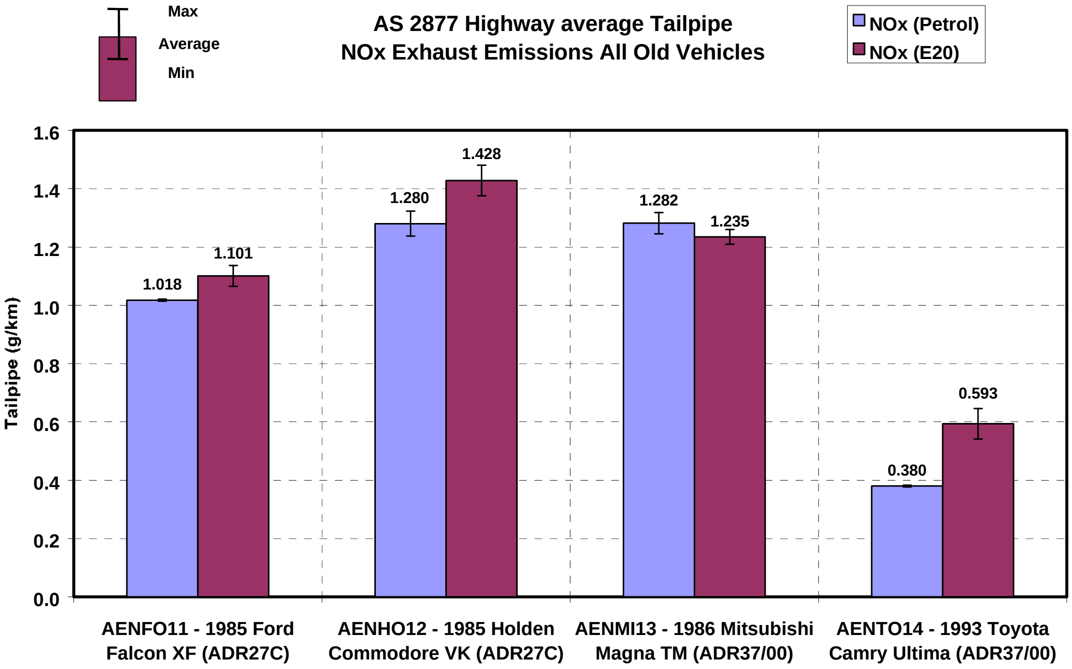


Figure 5.96 - AS2877 Highway Average Tailpipe NOx Emissions All Old Vehicles.

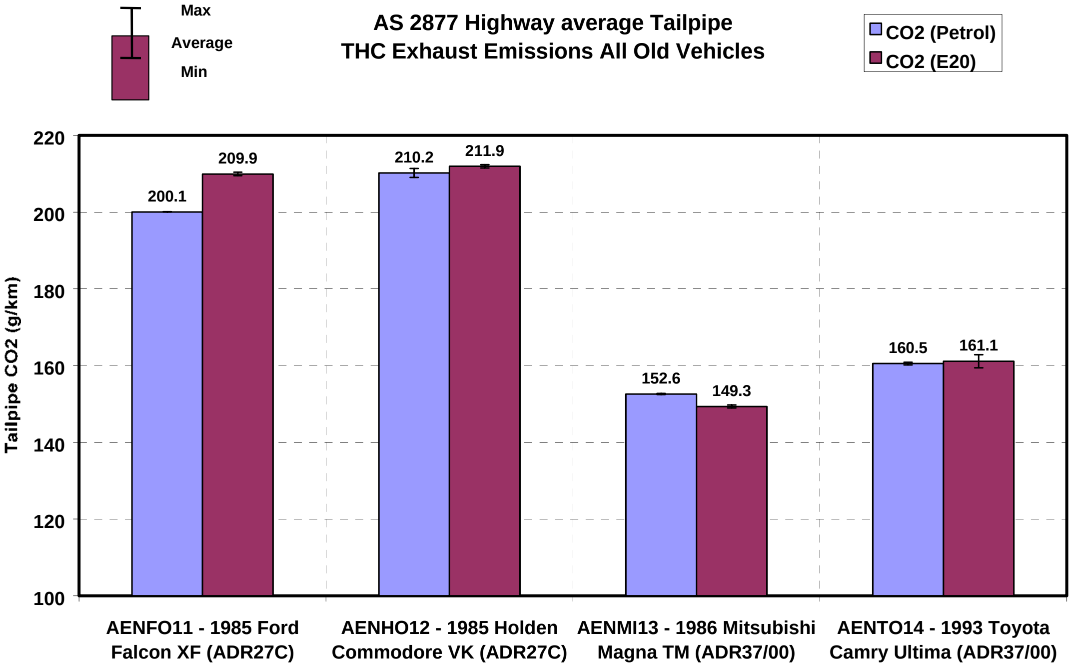


Figure 5.97 - AS2877 Highway Average Tailpipe CO2 Emissions All Old Vehicles.

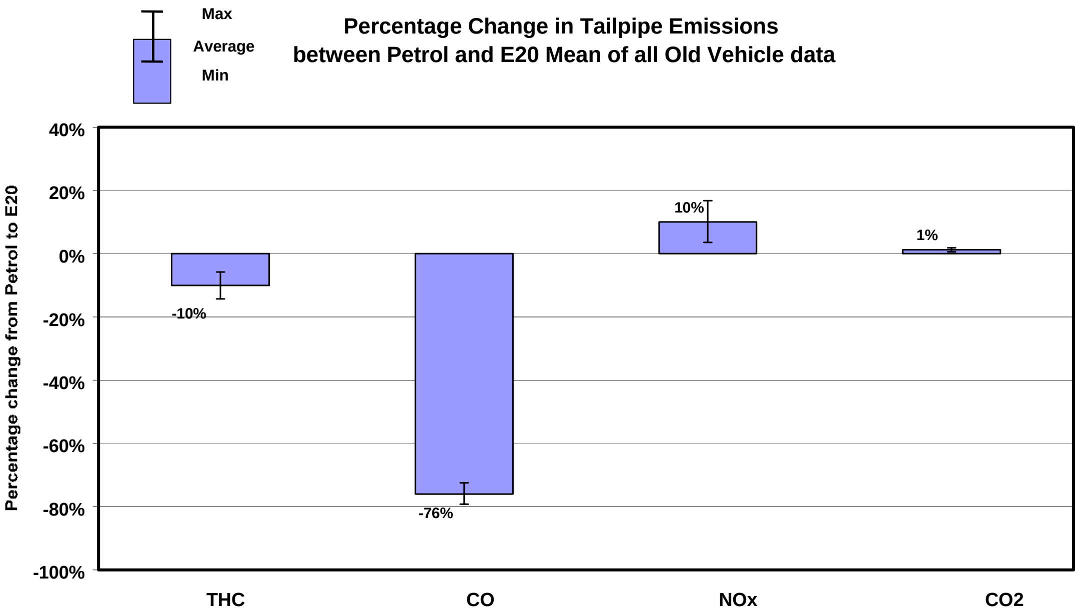


Figure 5.98 - Percentage Change in AS2877 Highway Average Tailpipe Emissions Between Gasoline and E20 Mean of All Old Vehicles.

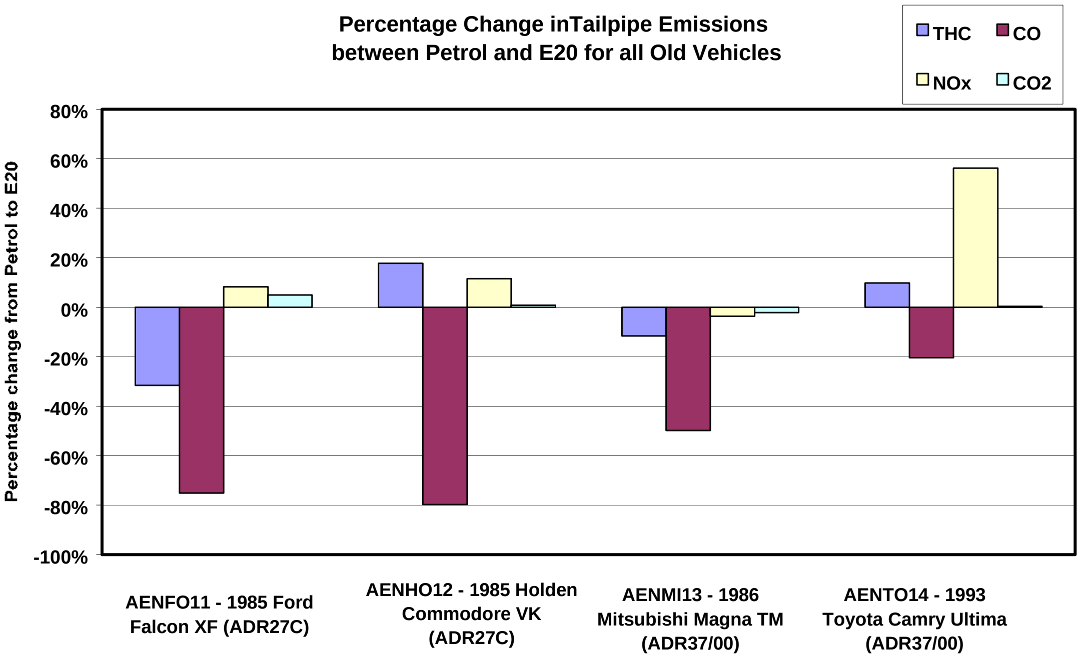


Figure 5.99 - Percentage Change in AS2877 Highway Average Tailpipe Emissions Between Gasoline and E20 for All Old Vehicles

#### 5.2.2.2.1 Conclusions AS2877 Highway Tailpipe Emissions

Based on the previous sections the following conclusions can be drawn:

- For older vehicles without closed loop control, there was a large reduction in CO emissions for all vehicles when operating on E20 compared with gasoline only fuel. The HC and NOx emissions did not display any general trend for each vehicles when using E20.
- The older vehicle with closed loop fuelling control (Toyota Camry) showed an increase in NOx emissions with a small reduction in HC emissions and negligible change in HC emissions when using E20 fuel.
- The average emissions across all vehicles show a HC and CO reduction of approximately 10% and 76% respectively, while the NOx emissions increase by approximately 10% when operating on E20 compared with gasoline only fuel. The average differences in emissions do not represent the change for each individual vehicle.
- For the open loop vehicles the difference in tailpipe CO emissions on the highway cycle are similar to the emissions differences on ADR27C and ADR37/00 cycle.

### 5.2.3 Engine Management Systems/Engine Calibration Impacts

This section presents an analysis of engine out and tailpipe emissions data focussed on understanding the impact the E20 fuel blend has on the engine management system or calibration of the open loop vehicles.

#### 5.2.3.1 Pre-Catalyst/Engine Out Emissions Data and Aftertreatment Performance.

Section 5.2.2.1 concentrated on the effect of 20% ethanol blend on the tailpipe emissions. In the case of the two ADR27C vehicles with no aftertreatment systems the data present in section 5.2.2.1 is the same as the pre-catalyst or engine out data. In this section though the data is divided into the separate phases of the test making it possible to differentiate any changes that might occur between hot and cold start and steady state and transient performance.

From Figure 5.100 for the Holden Commodore there is a marked reduction in the phase 1 CO emissions and even greater reduction in phase 2 when operated on E20. There is an increase in NOx emissions in both phases, phase one being higher due to increased engine load during this phase. Figure 5.101 shows that there has been a lean shift caused by operation on E20. Figure 5.102 shows the lean shift is consistent across the drive cycle. Note that the levels of oxygen in the exhaust of the Commodore appear high due to effect of the secondary air pump; this pump injects air into the exhaust manifold to control CO emissions. The Ford Falcon, Figure 5.103, shows very similar trends for CO emissions but the NOx emissions appears virtually unchanged. This could well be because the base calibration ran either at the lambda one or slightly lean of lambda one, if this was the case then any further enleanment would result in either the NOx emission remaining constant or reducing. The significant increase in exhaust oxygen content with the E20 fuel is an unexpected result and may have been due to an engine air leak. The Mitsubishi Magna, Figure 5.106, shows marked reductions in CO and THC emissions when operated in E20. Certainly the reductions in CO emissions are seen in the tailpipe emissions results but it appears that there is a very slight increase in tailpipe THC emissions when operating on E20. This is a somewhat surprising result as along with the decrease in engine out THC emissions the vehicle is fitted with an oxidising catalyst. Figure 5.107 shows the oxygen content in the exhaust for the Mitsubishi Magna. During the idle periods exhaust oxygen content appears to be coincident when running on gasoline or ethanol. When off idle, the expected leaner operation with the E20 fuel occurs. Considering there is no feedback mechanism the only conclusion is that the vehicle carburation must have changed between being tested on gasoline and E20.

The Toyota Camry clearly shows the same trends as the new Holden Commodore (AENHO01) and Hyundai Accent (AENHY04), with the closed loop control appearing to be biased rich. There is one major difference between this closed loop vehicle and the new vehicles studied in that at idle the closed loop controller is inoperative, see section 5.1.10. Interestingly, Figure 5.110 shows the exhaust oxygen content to be substantially lower in the idle regions indicating that the EMS has applied some correction though in an open loop manner. This certainly accounts for the large discrepancy in the accumulated oxygen plot Figure 5.112.

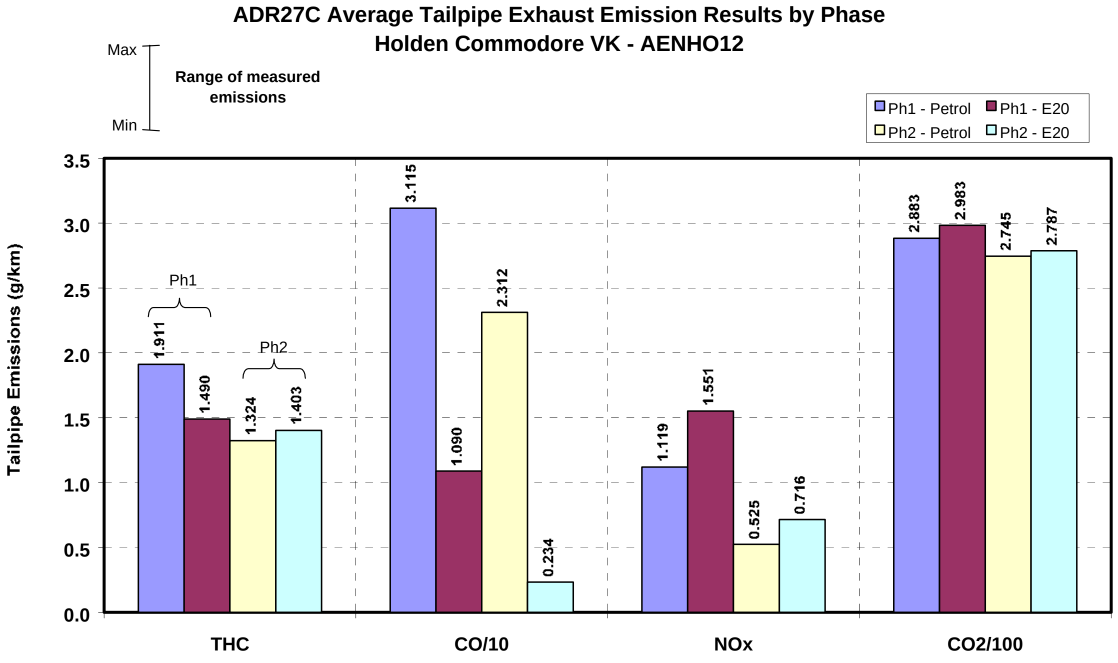


**Figure 5.100 - Average Engine Out Emissions Holden Commodore VK AENHO12.**

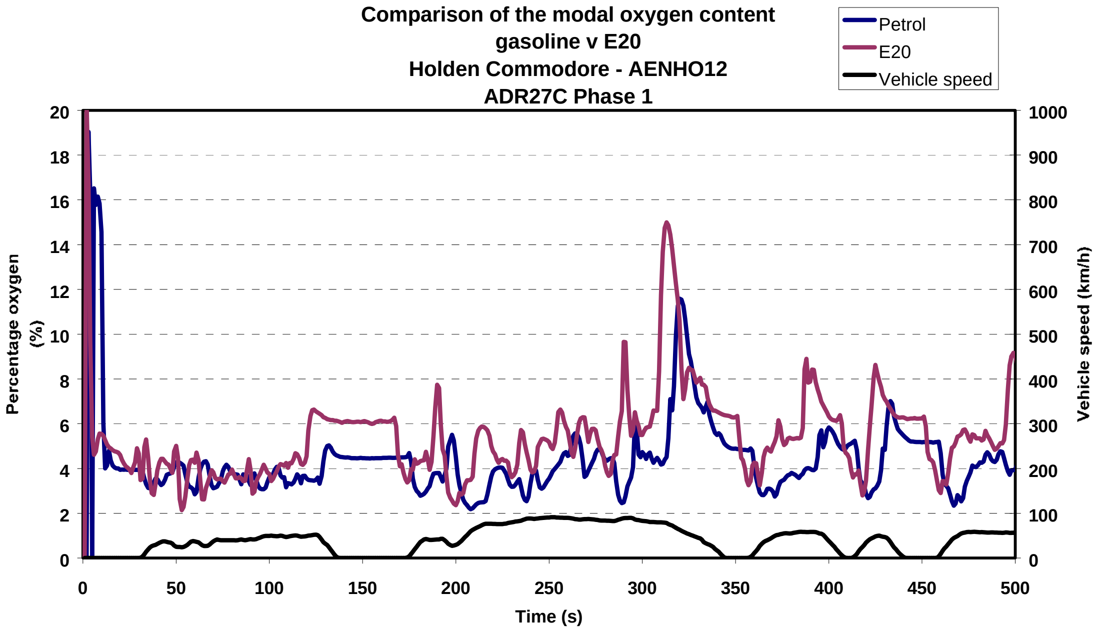


Figure 5.101 - Comparison of the Percentage Oxygen Content Gasoline vs. E20 Holden Commodore (AENHO12).

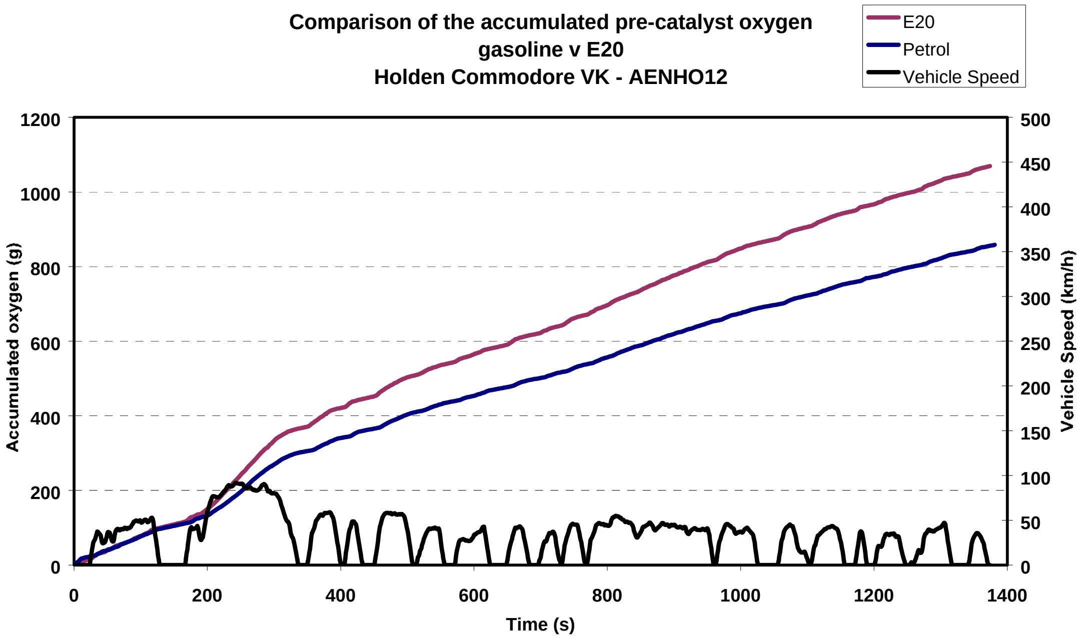
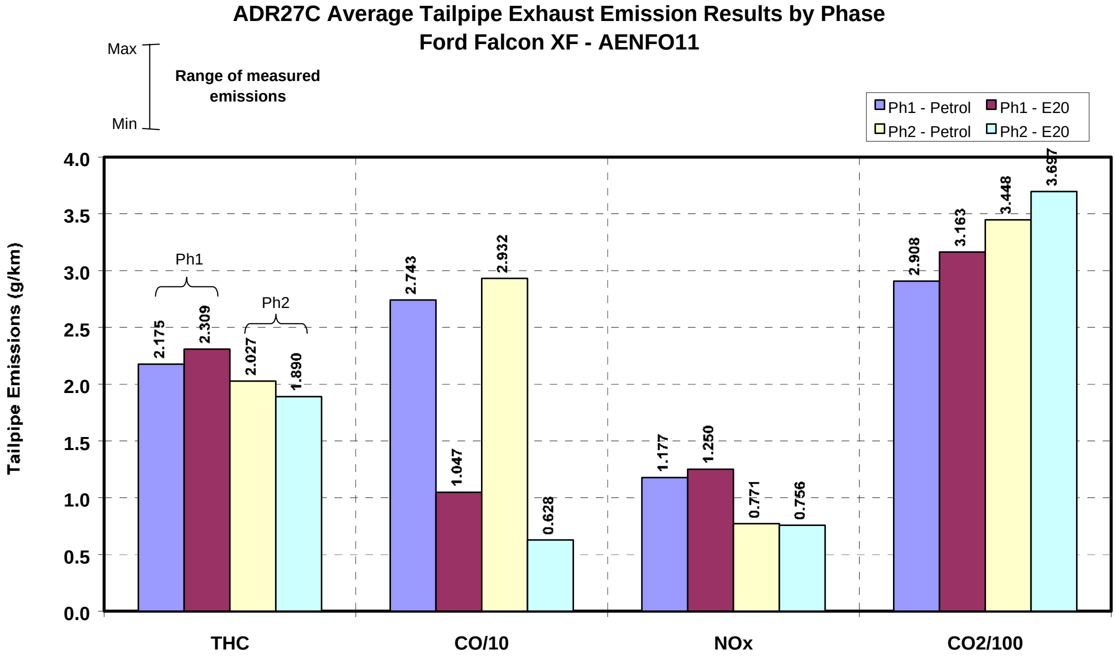
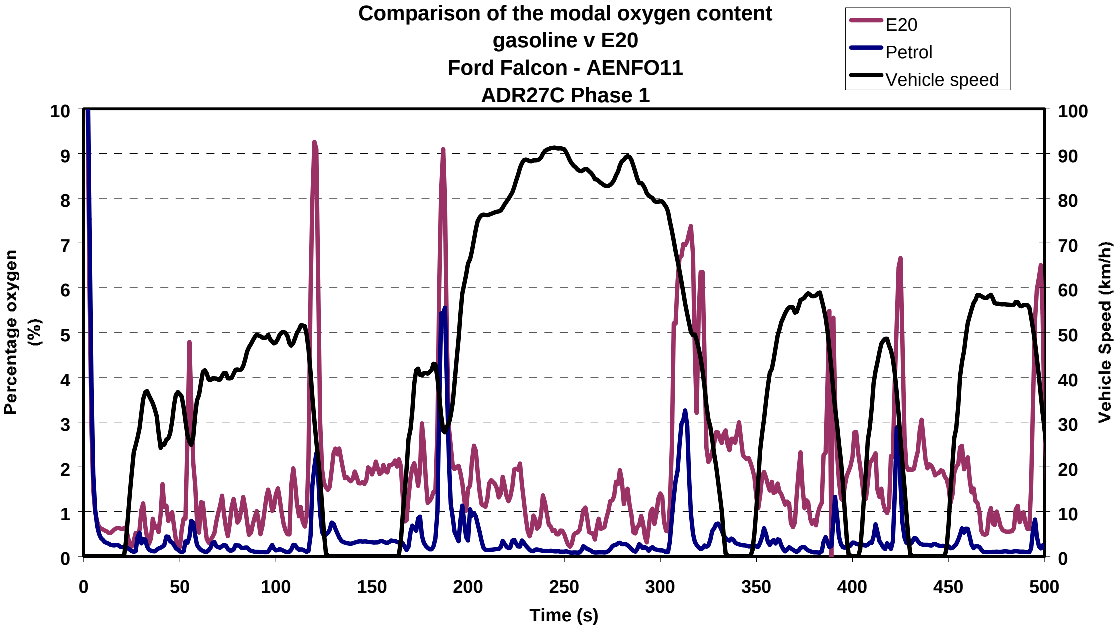


Figure 5.102 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Holden Commodore (AENHO12).



## Figure 5.103 - Average Engine Out Emissions Ford Falcon AENFO11.



## Figure 5.104 - Comparison of the Percentage Oxygen Content Gasoline vs. E20 Ford Falcon (AENFO11).

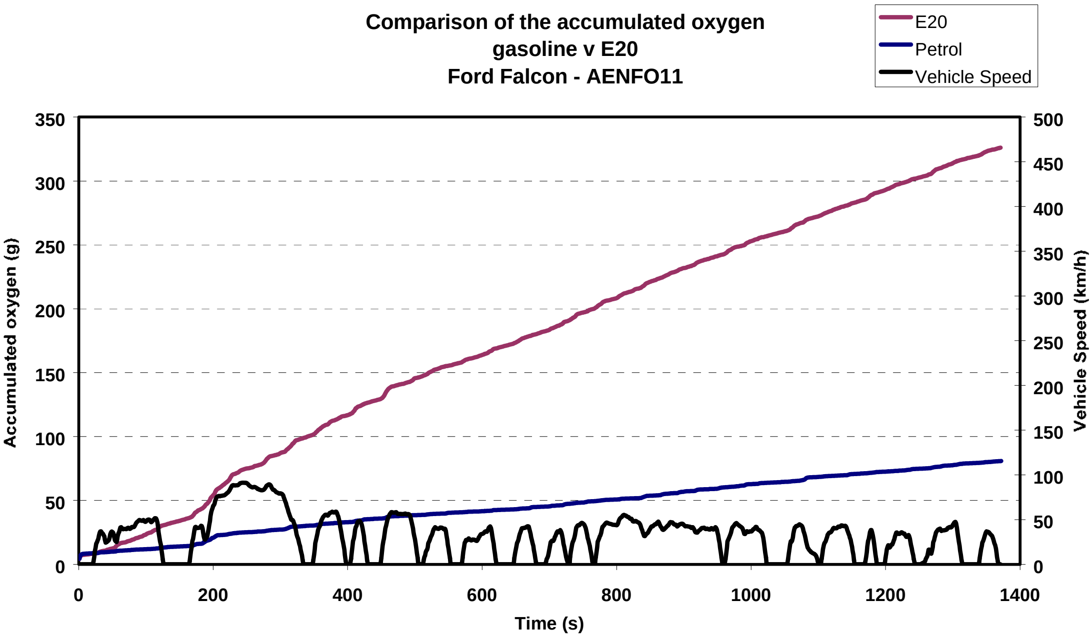


Figure 5.105 - Comparison of the Accumulated Oxygen Gasoline vs. E20 Ford Falcon (AENFO11).

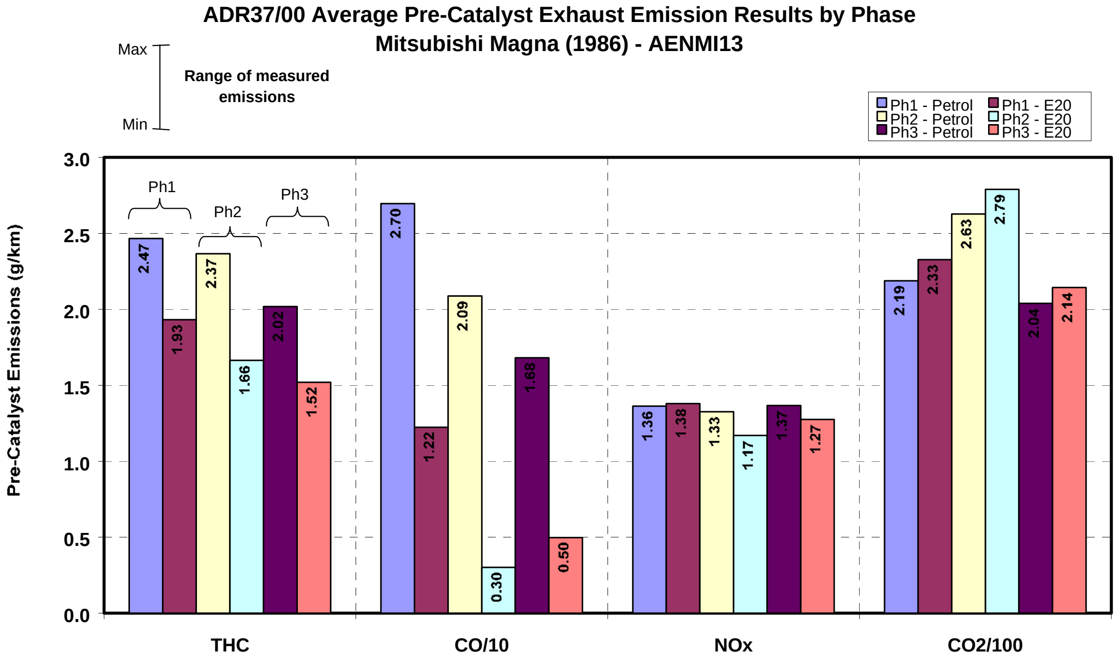


Figure 5.106 - Average Pre-Catalyst Emissions Mitsubishi Magna AENMI13.

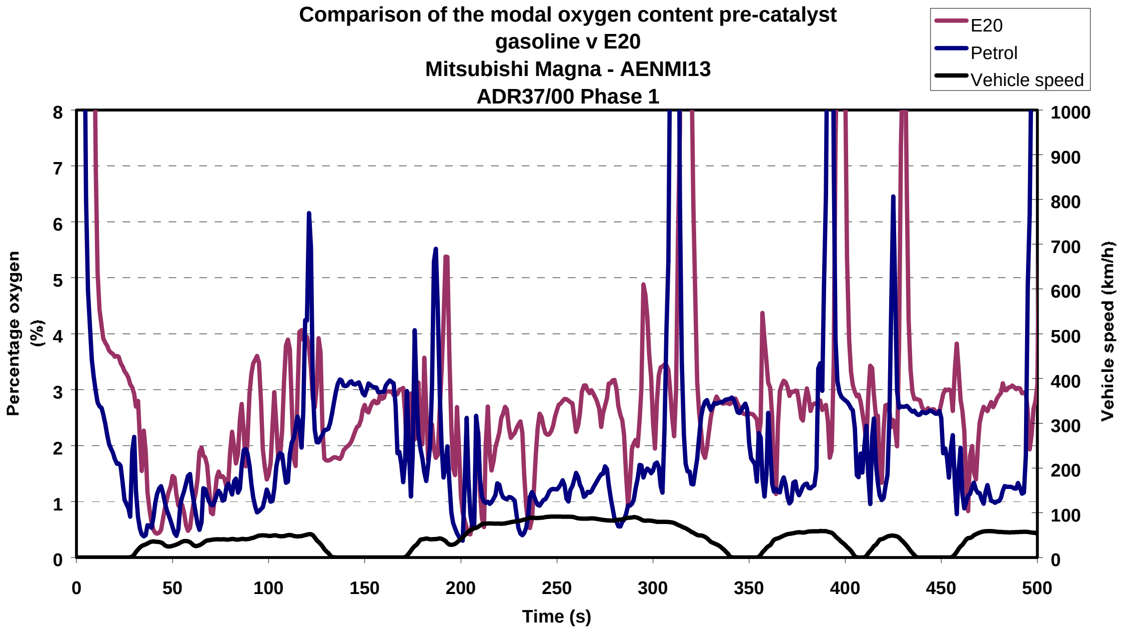


Figure 5.107 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Mitsubishi Magna (AENMI13).

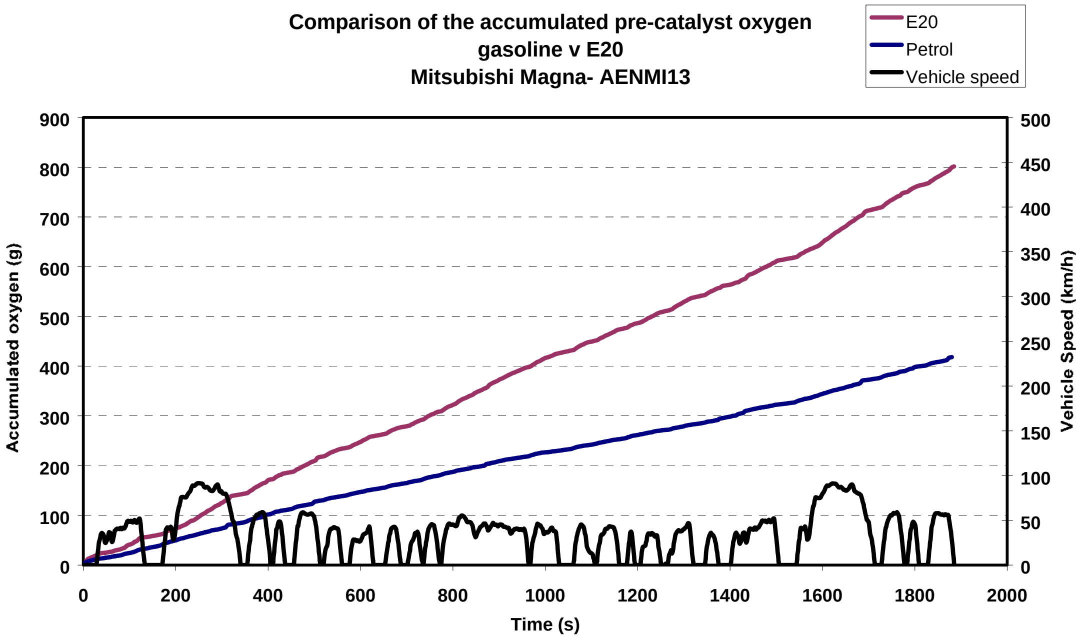


Figure 5.108 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Mitsubishi Magna (AENMI13).

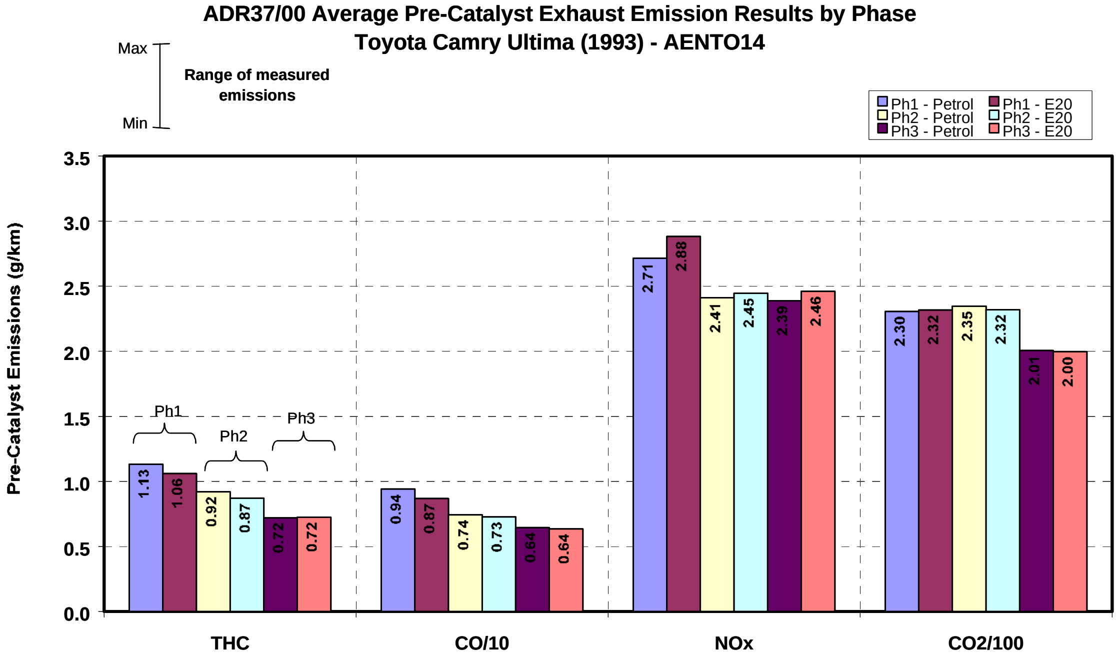


Figure 5.109 - Average Pre-Catalyst Emissions Toyota Camry AENTO14.

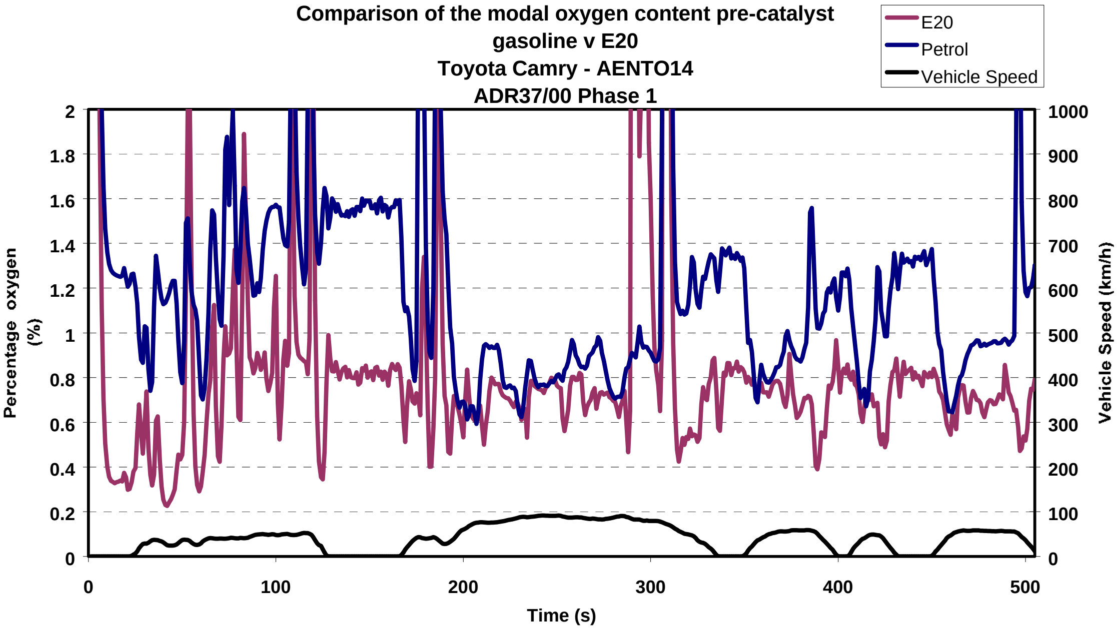


Figure 5.110 - Comparison of the Percentage Oxygen Content Pre-Catalyst Gasoline vs. E20 Toyota Camry (AENTO14).

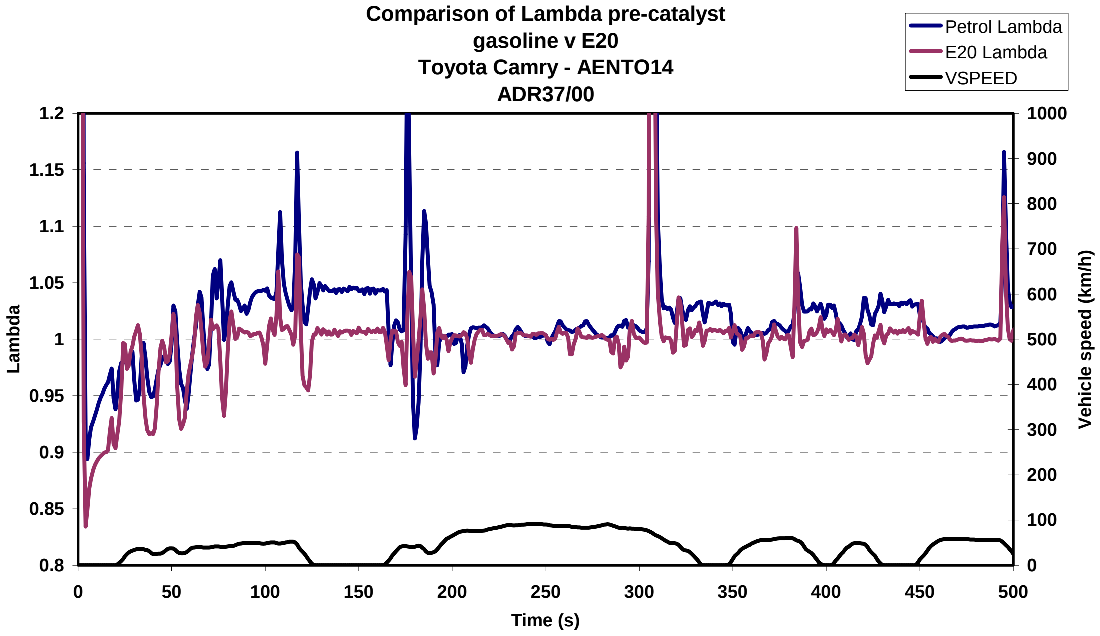


Figure 5.111 – Comparison of Lambda for Gasoline vs. E20 Toyota Camry (AENTO14).

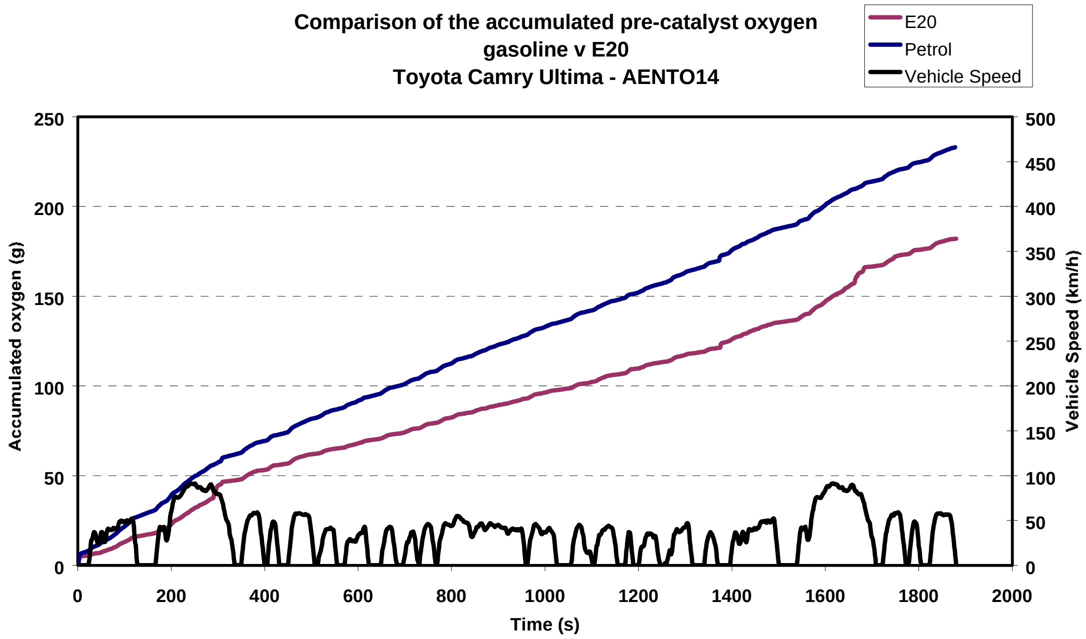


Figure 5.112 - Comparison of the Accumulated Pre-Catalyst Oxygen Gasoline vs. E20 Toyota Camry (AENTO14).

### 5.2.3.2 Conclusions Pre-Catalyst/Engine Out Emissions Data and Aftertreatment Performance.

It can be concluded from the previous section that:

- Open loop vehicles have similar pre-catalyst/engine out emissions outcomes when switched from straight gasoline to E20. The predominant difference is the reduction in CO emissions. The changes to the other regulated emissions are different from vehicle to vehicle.
- As expected all the open loop vehicles experience a lean shift when operated on E20. The effect on emissions other than CO appears to be a function of the base calibration (mixture strength) of the engine/vehicle.
- For the Toyota Camry the adaptation of the fuelling has occurred and clearly shows that the oxygen levels in the exhaust for E20 are lower than for gasoline. The overall affect on pre-catalyst emissions is an increase in CO with no change to the other regulated emissions. The exhaust lambda trace for this vehicle shows there has be a relative change in the bias of the closed loop controller between gasoline and E20.

#### 5.2.3.3 Aftertreatment System Performance

The following section assesses the phase-by-phase performance of the vehicle aftertreatment systems, Figure 5.113 and Figure 5.114. Only two of the old vehicles tested had aftertreatment (catalysts) fitted. The Mitsubishi Magna (AENMI13) is fitted with an oxidation only catalyst and the Toyota Camry (AENTO14) with a three way catalysts (TWC).

Overall there is little difference in catalyst efficiency between operating the vehicles on gasoline and E20 during any of the phases. There are minor differences in the oxidation capability of the Mitsubishi catalysts during the first phase and third phase. However the overall conversion efficiency is fairly low on either gasoline or E20 in these phases so this difference is insignificant. Interestingly there was a minor amount of NOx conversion efficiency from the oxidation only catalyst on the Mitsubishi Magna. The conversion was probably a low temperature NOx conversion across the platinum, which appears to have decreased when the vehicle is operated on E20.

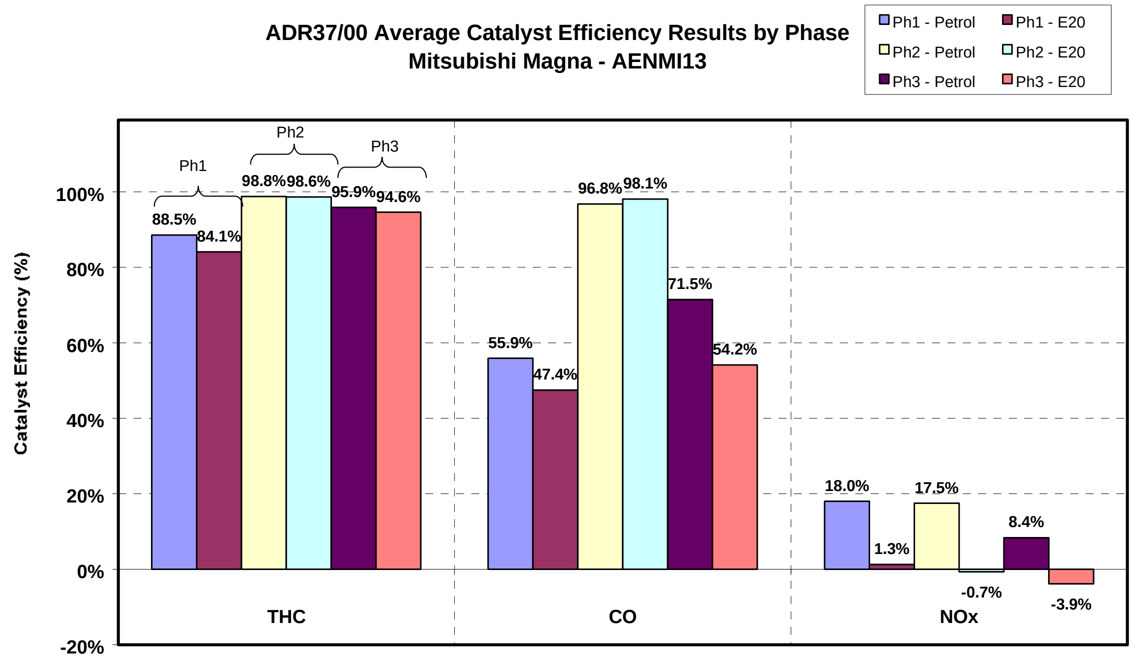


Figure 5.113 - Average Catalyst Efficiency Mitsubishi Magna AENMI13

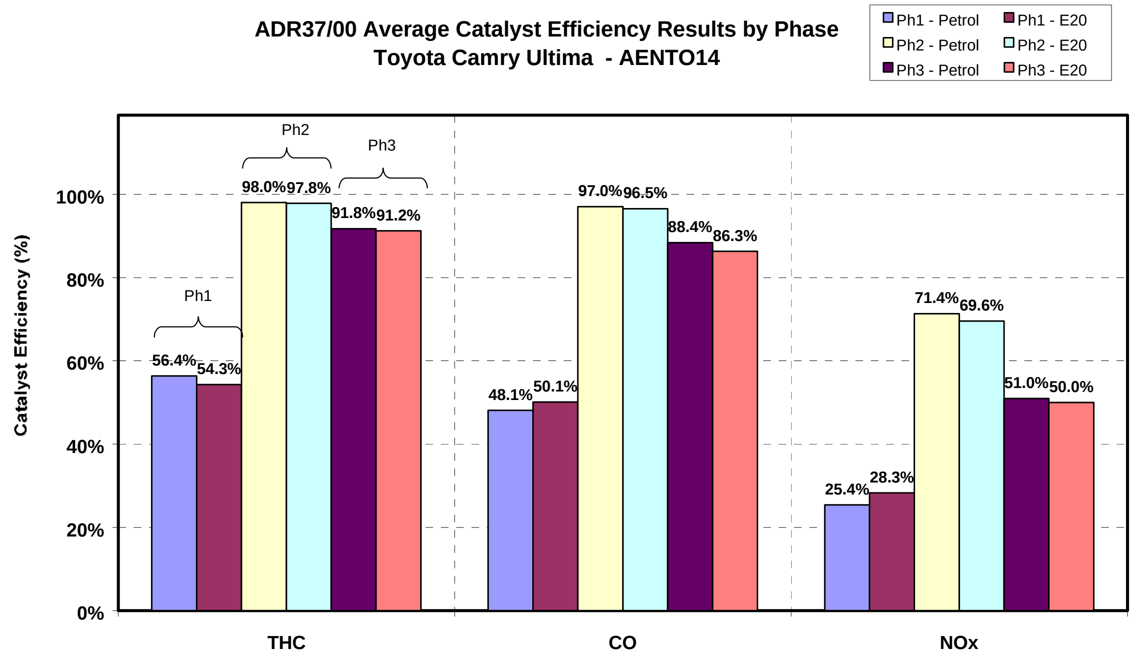


Figure 5.114 Average Catalyst efficiency Toyota Camry Ultima AENTO14

#### 5.2.3.4 Conclusion Aftertreatment System Performance.

The vehicle aftertreatment system analysis has revealed the following conclusions

Overall there is little difference in catalyst efficiency between operating the vehicles on gasoline and E20, though a change in the NOx emission conversion was found with the Mitsubishi Magna oxidation only catalyst, however the gasoline conversion is very low to start with.

### 5.2.4 Unregulated Toxic Tailpipe Emissions Assessment.

Following the same procedure as in section 5.1.4 Exhaust toxic emissions were sampled for the old vehicles.

#### 5.2.4.1 Exhaust Aldehyde Emissions

There was a considerable difference between the ADR27C vehicles and ADR37/00 vehicles in terms of the magnitude of emitted Aldehyde emissions. As such the ADR27C vehicles data have been plotted on separate graphs to the ADR37/00 vehicles. Also as per the new vehicles there was no measurable quantities of Acrolein from any of the samples taken during testing.

Figure 5.115, Figure 5.117 and Figure 5.119 present the Aldehyde emissions for the ADR27C vehicles, these vehicles are not equipped with any form of catalyst. It can be seen from these figures that both vehicles display a marked increase in all three Aldehydes measured, particularly Acetaldehyde, which is one of the primary by-products of ethanol combustion. The Ford Falcon Acetaldehyde increased by over 700% and the Holden Commodore by approximately 400%. The increases are in line with the data presented in (6).

Figure 5.116, Figure 5.118 and Figure 5.120 present the Aldehyde emissions for the ADR37/00 vehicles though both of these vehicles show increases in all three compounds measured. Though the overall levels are significantly lower, they virtually matching the ADR37/01 vehicles. Again the main increase was in Acetaldehyde with an increase in excess of 900% for the Mitsubishi Magna.

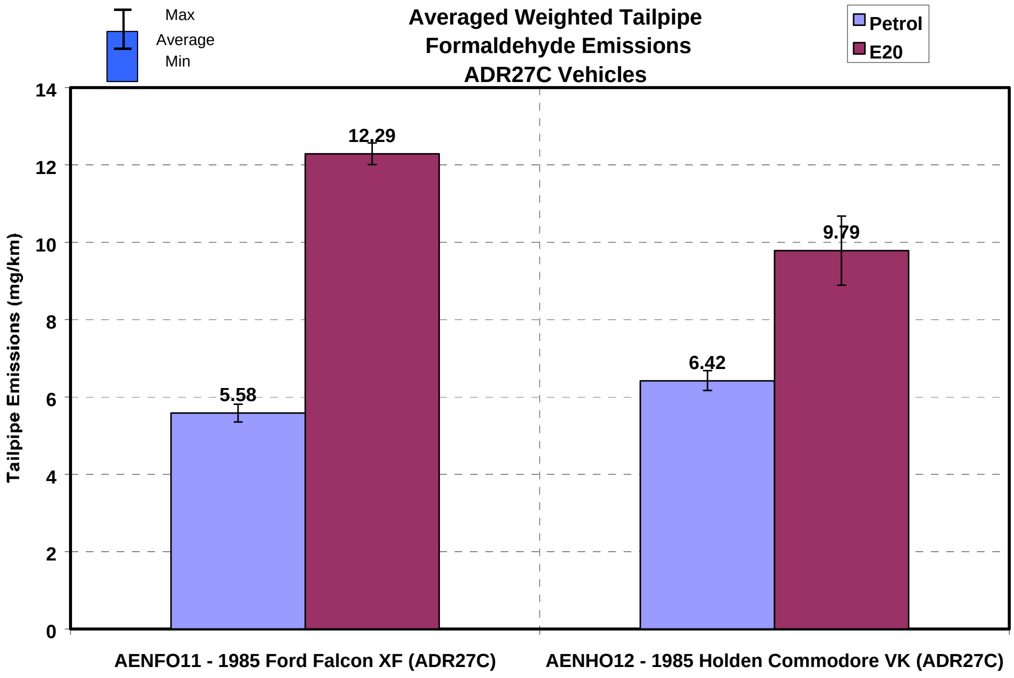


Figure 5.115 - ADR27C Average Weighted Tailpipe Formaldehyde Emissions.

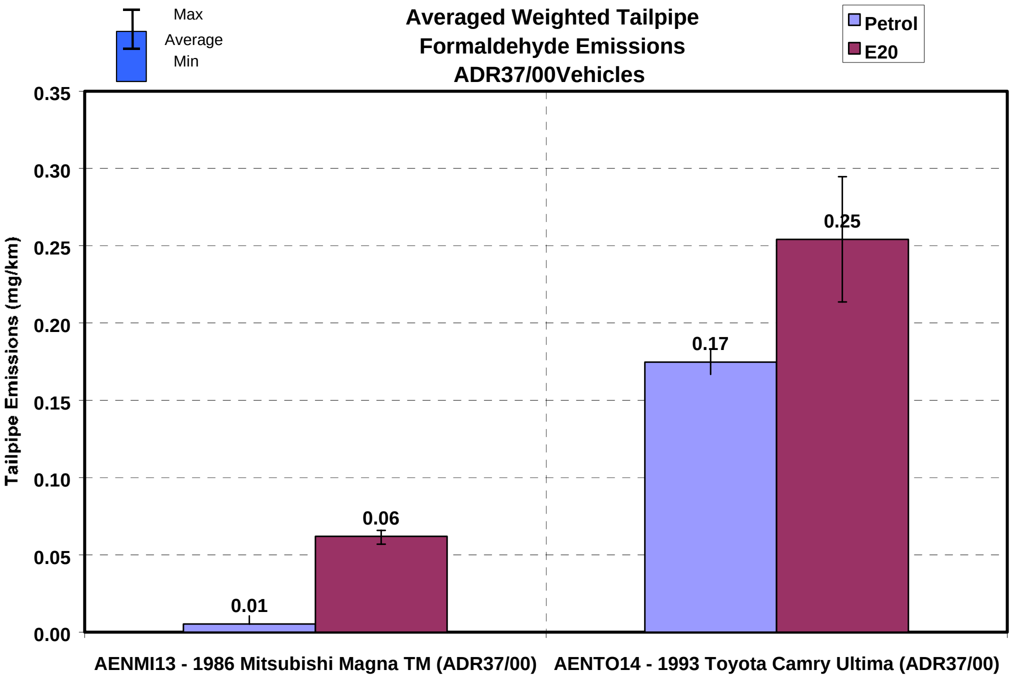


Figure 5.116 - ADR37/00 Average Weighted Tailpipe Formaldehyde Emissions

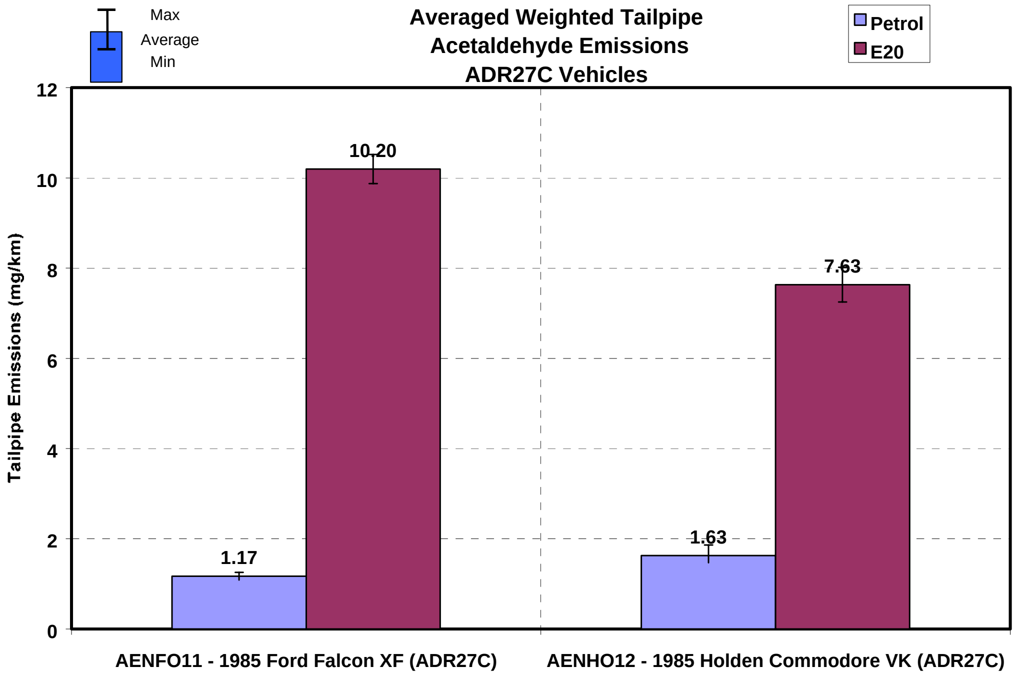


Figure 5.117 - ADR27C Average Weighted Tailpipe Acetaldehyde Emissions

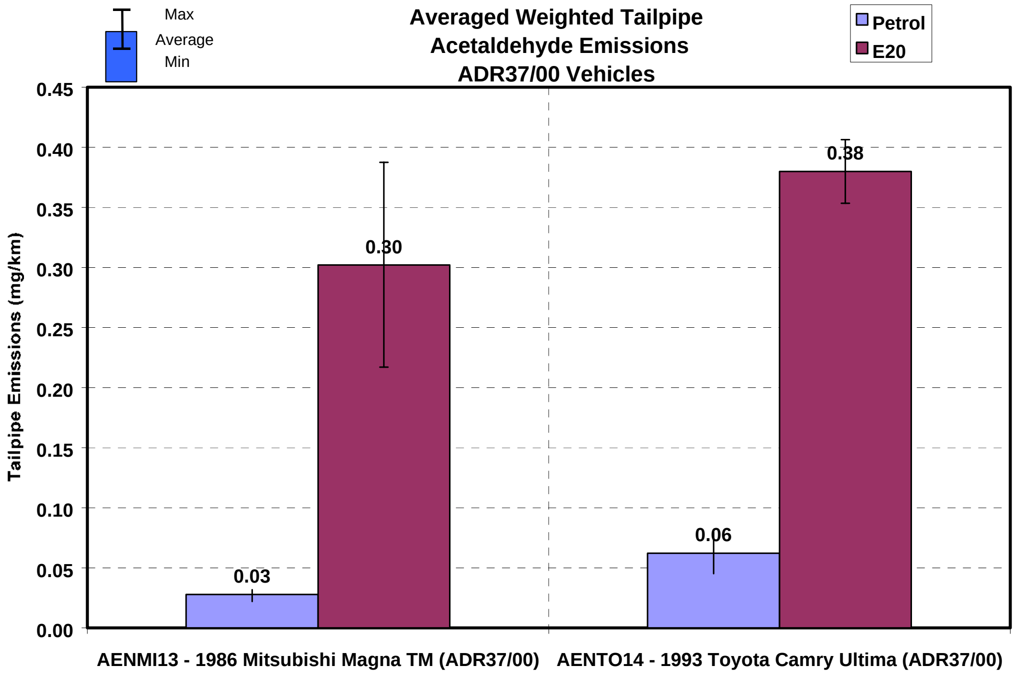


Figure 5.118 - ADR37/00 Average Weighted Tailpipe Acetaldehyde Emissions

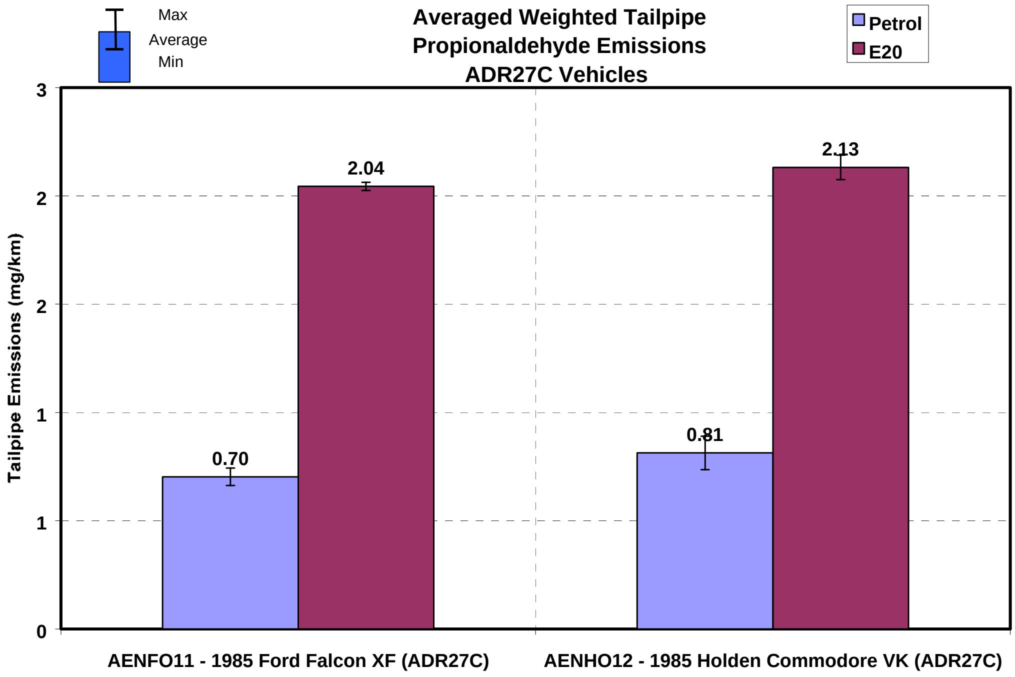


Figure 5.119 - ADR27C Average Weighted Tailpipe Propionaldehyde Emissions.

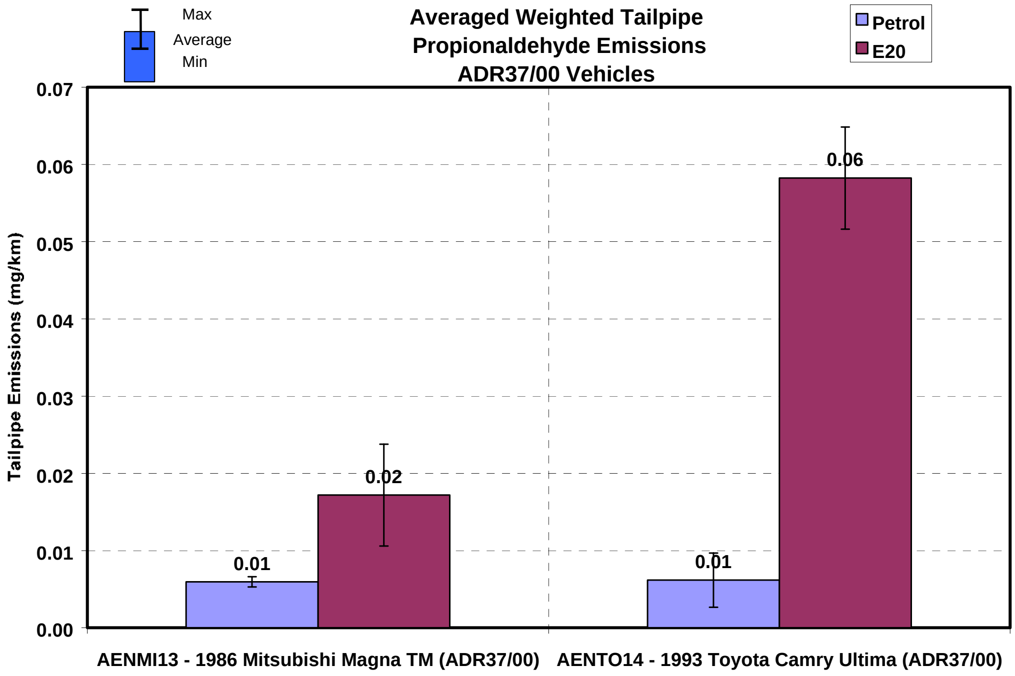


Figure 5.120 - ADR37/00 Average Weighted Tailpipe Propionaldehyde Emission.

### 5.2.4.2 Conclusions Exhaust Aldehyde Emissions

It can be concluded from the data presented in the previous sections that:

- Overall there was a large increase in Aldehydes from the ADR27C vehicles when operated on E20, of the order of 700%.
- There was also an increase in Aldehydes with the ADR37/00 vehicles, in this case the absolute level is significantly lower than for the ADR27C vehicles, from a percentage perspective the ADR37/00 vehicles are approximately 900% lower than the ADR27C with aldehyde emissions.
- The increase comes predominately from an increase in Acetaldehyde.
- This trend compared favourably with other studies.

#### 5.2.4.3 Exhaust Toxics

Figure 5.121, Figure 5.122, Figure 5.123, Figure 5.124 and Figure 5.125 show the tailpipe exhaust toxics 1,3 Butadiene, Benzene, Hexane, Toluene and Xylene for all the new vehicles. Xylene as displayed is the summation of P-Xylene and O-Xylene. From the literature survey (4) the general consensus was that as this group of emissions was largely by-products of combustion or un-combusted gasoline, the exhaust toxics should decrease with increasing ethanol content. Overall this is clearly the case Figure 5.126 with all compounds other than Hexane and Xylene showing a marked reduction in emissions. The reduction in emissions is not as great as for the ADR37/01 vehicles and this is thought to be because of the improved catalyst efficiency of the new vehicles.

Figure 5.127, Figure 5.128 show the tailpipe toxic emissions for the first, and second phases respectively of the ADR27C cycle. Compared to the ADR37/01 vehicles it is clear that without a catalyst the generation of the exhaust toxics remains fairly constant throughout the cycle

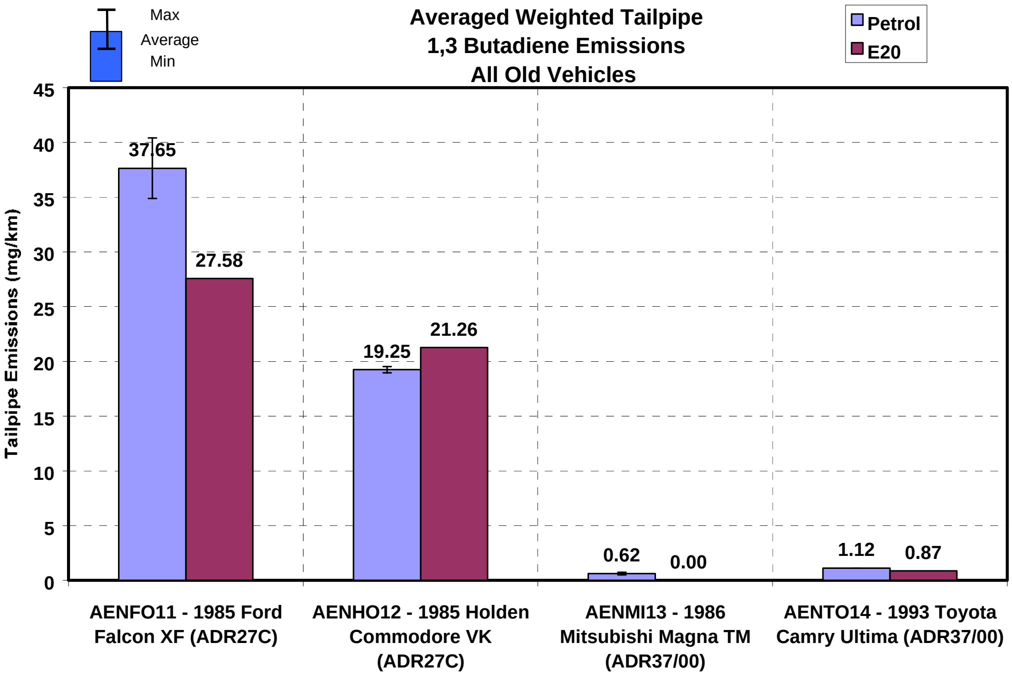


Figure 5.121 - Average Weighted Tailpipe 1,3 Butadiene Emissions all Old Vehicles.

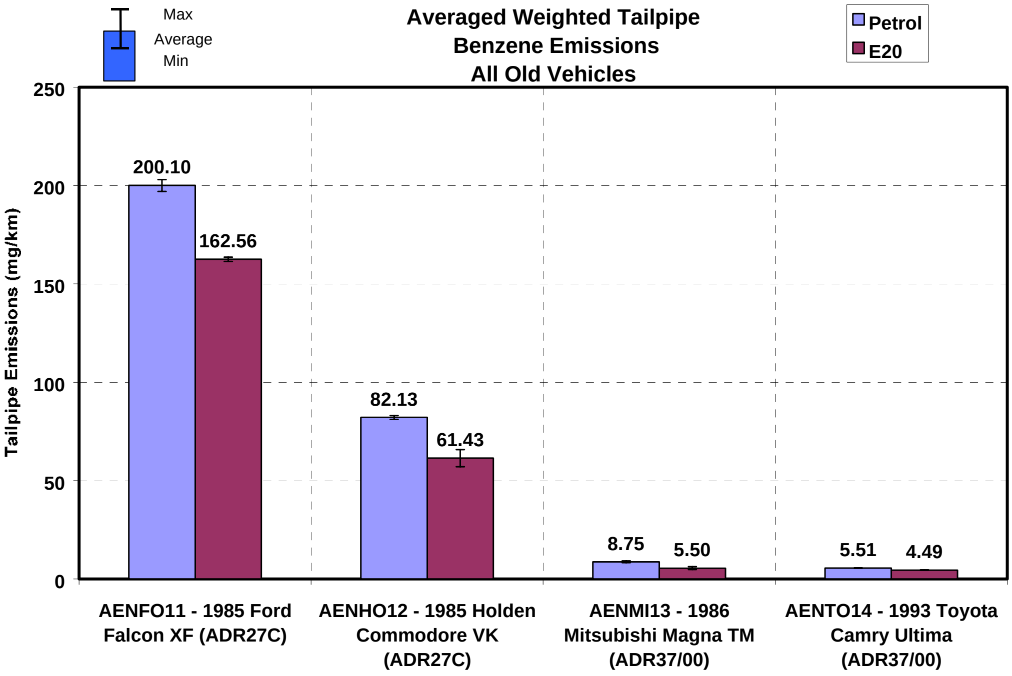


Figure 5.122 - Average Weighted Tailpipe Benzene Emissions all Old Vehicles

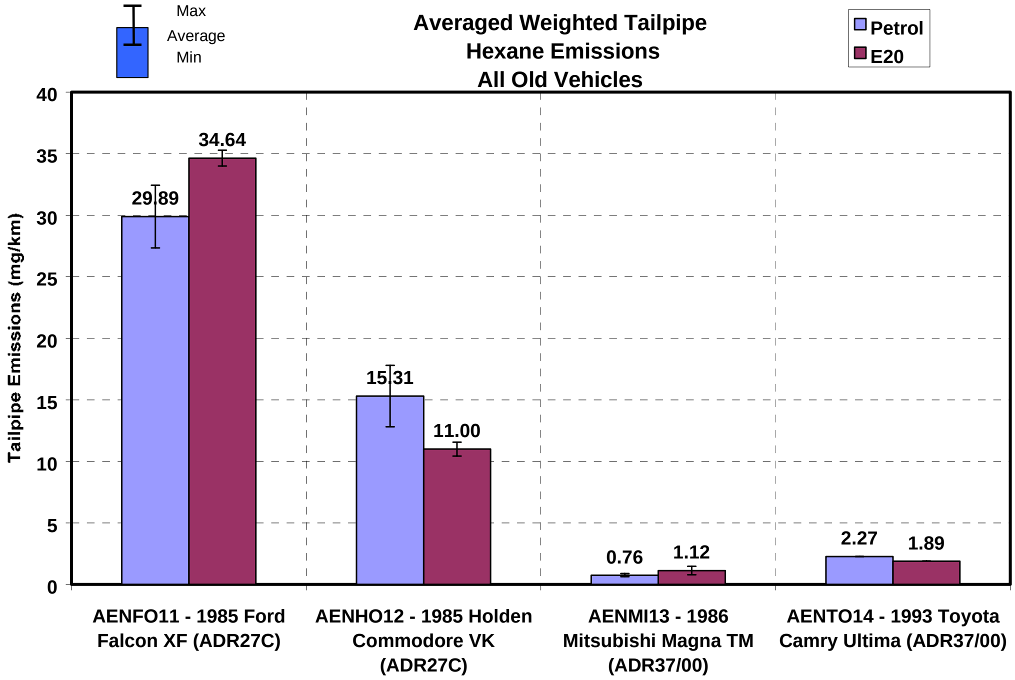


Figure 5.123 - Average Weighted Tailpipe Hexane Emissions all Old Vehicles

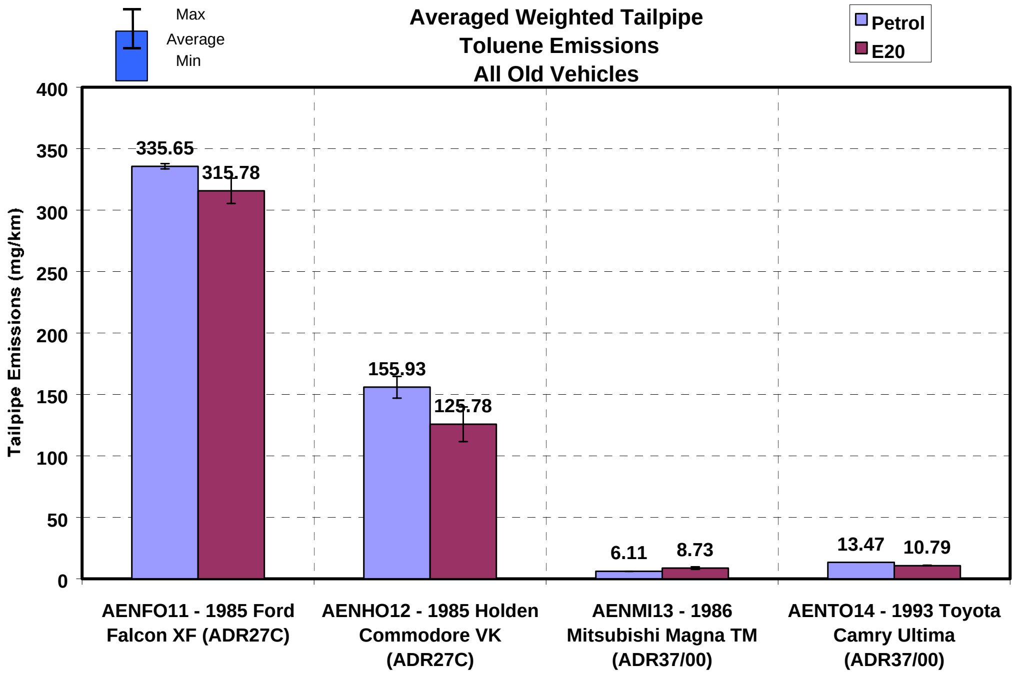


Figure 5.124 - Average Weighted Tailpipe Toluene Emissions all Old Vehicles.

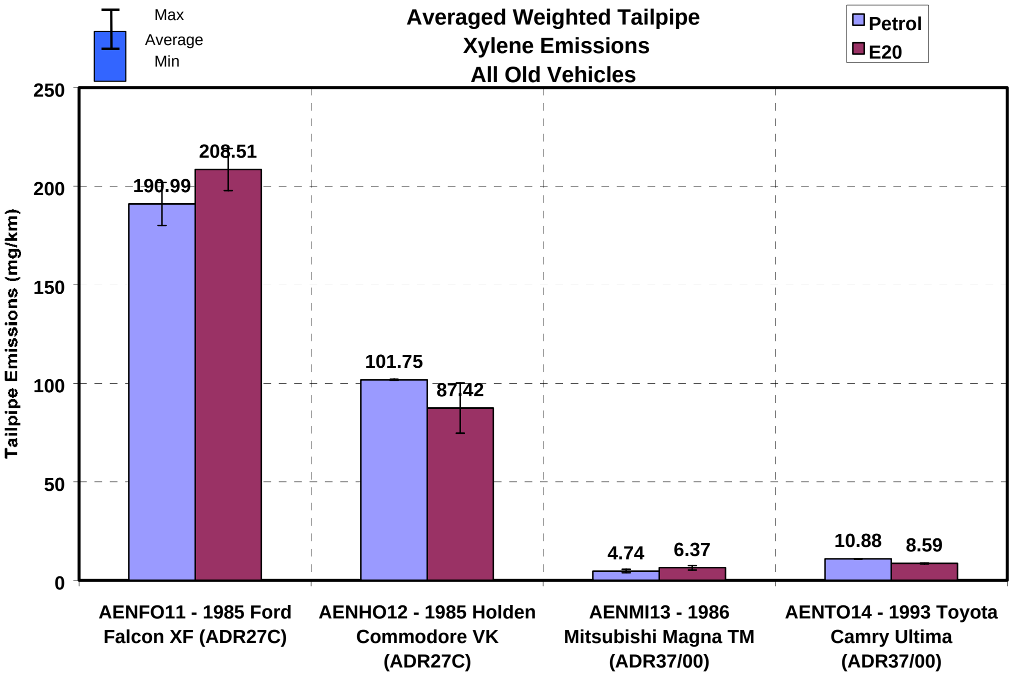


**Figure 5.125 - Average Weighted Tailpipe Xylene Emissions all Old Vehicles.**

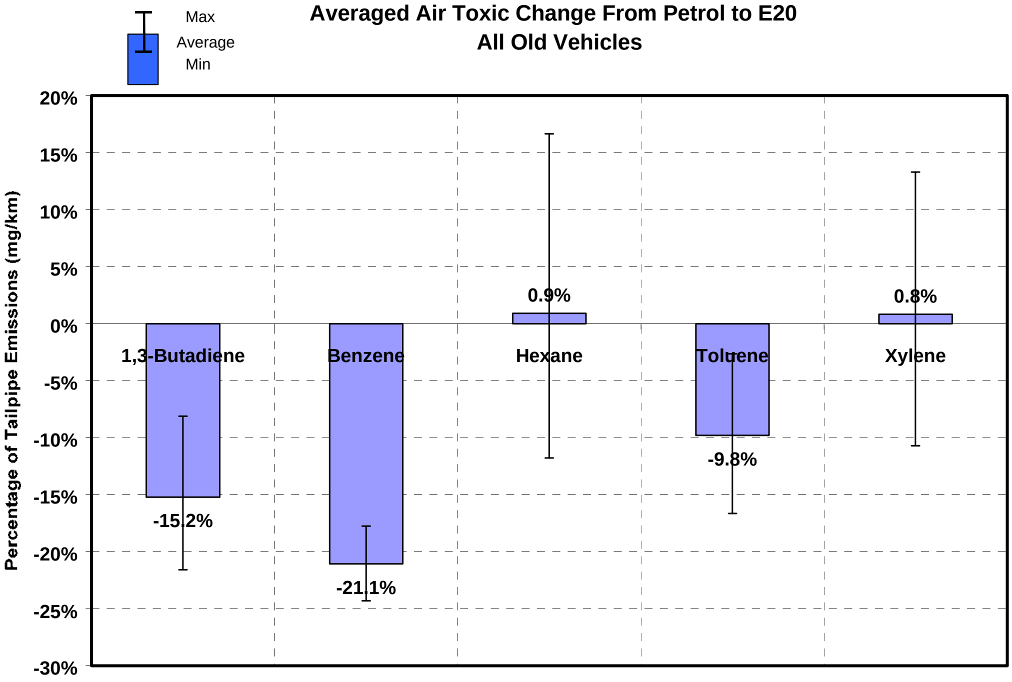


**Figure 5.126 - Average Air Toxics Percentage Difference Gasoline to E20 for all Old Vehicles.**

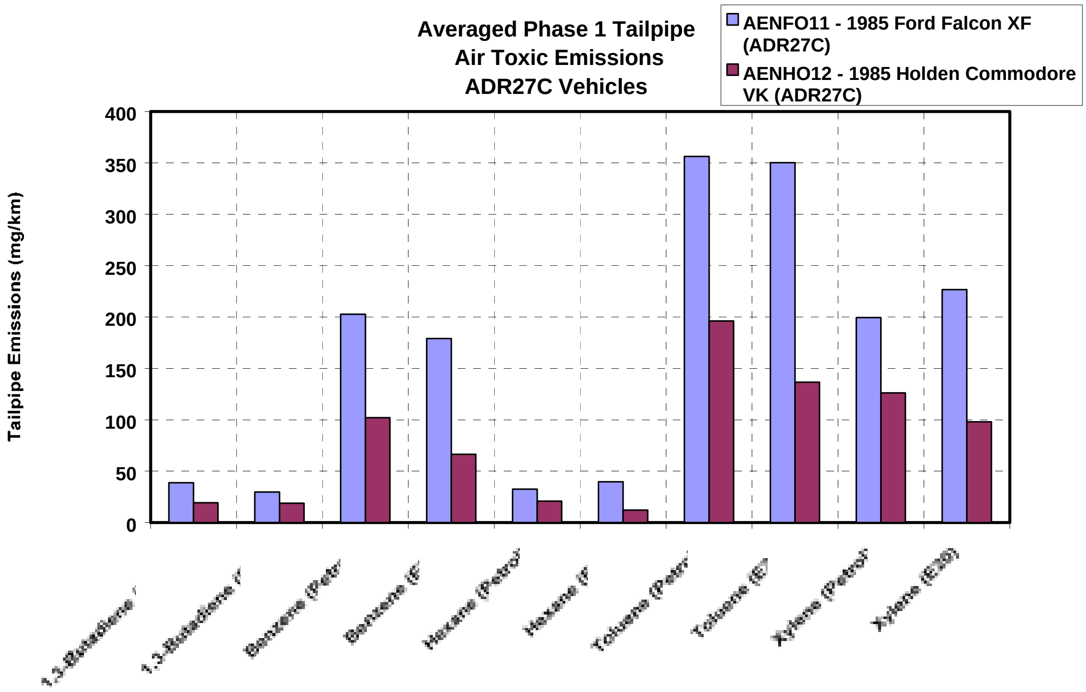


Figure 5.127 - ADR27C Phase 1 Aldehyde Emissions

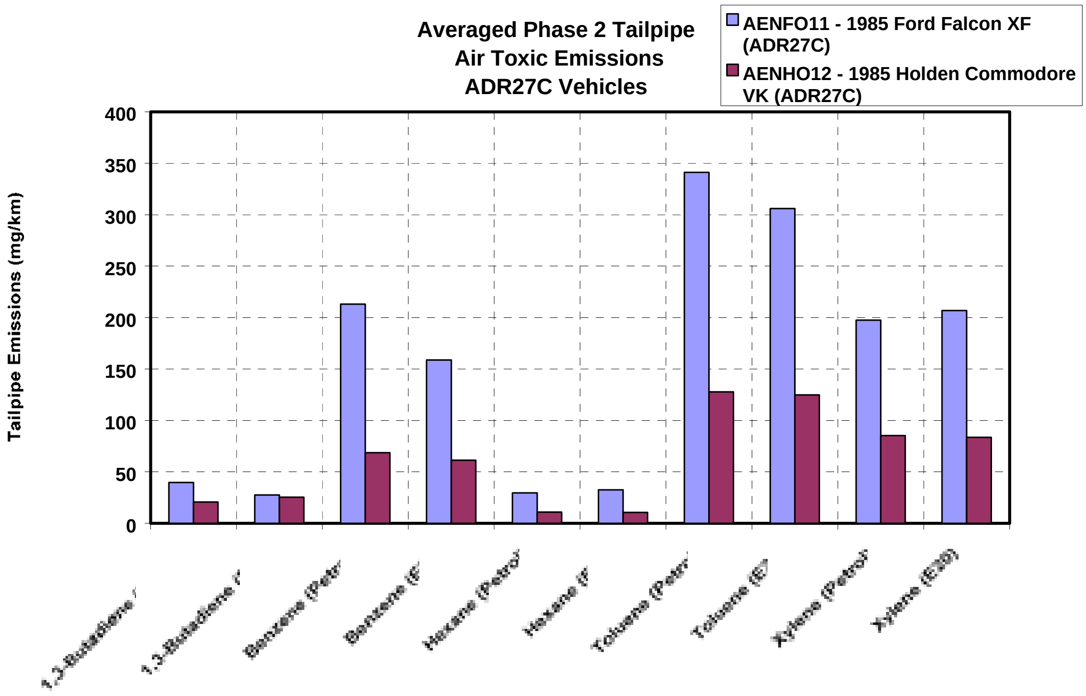


Figure 5.128 - ADR27C Phase 2 Aldehyde Emissions

#### 5.2.4.4 Conclusions Exhaust Toxic Emissions

It can be concluded from the above section that:

- Overall there was a decrease in exhaust toxics when the vehicles are operated on E20 as follows, 1,3 Butadiene 15% Benzene 20%, and Toluene 10%.
- The un-catalysed vehicles emitted the same output of toxics regardless of the phase of the drive cycle i.e. cold or hot.
- These trends compare favourably with other studies.

### 5.2.5 Unregulated Evaporative Emissions

During the ADR27C and ADR37/00 evaporative emissions testing a sample was taken during the hot soak portion for analysis to determine air toxics. The toxics measured are Benzene, Toluene and Xylene. Xylene as displayed is the summation of P-Xylene and O-Xylene. Due to the reduced fuel temperature for the diurnal test, start fuel temperature 15 Celcius and final fuel temperature of 29 Celcius it was thought that any differences between the gasoline air toxics and E20 air toxics would probably be minimal. Also from studying (6) the data for the diurnal air toxics appears to be quite variable. As the potential mechanism for difference between gasoline and E20 evaporative appear to focus on the distortion of the distillation curve the present study concentrated on the hot soak test.

Figure 5.135, Figure 5.136 and Figure 5.137 display the comparison of the air toxics measured against straight gasoline and E20 for all the new vehicles tested. Figure 5.138 is the average air toxics for all the vehicles tested. This indicates that on average the air toxics will increase when the vehicle is operated on ethanol. This result appears reasonable, as above approximately 60deg C bulk fuel temperature an E20 blended fuel will start to evaporate at a faster rate than a straight gasoline, see the distillation curves in Appendix M. The data also correlates well with the ADR37/01 testing

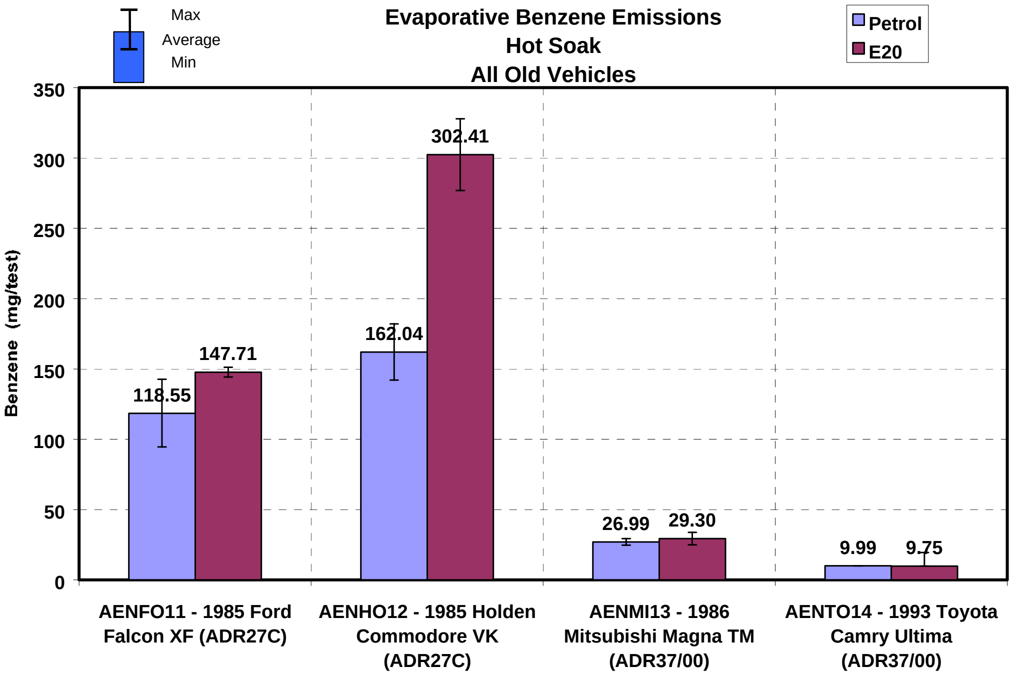


Figure 5.129 - Hot Soak Evaporative Benzene Emissions all Old Vehicles

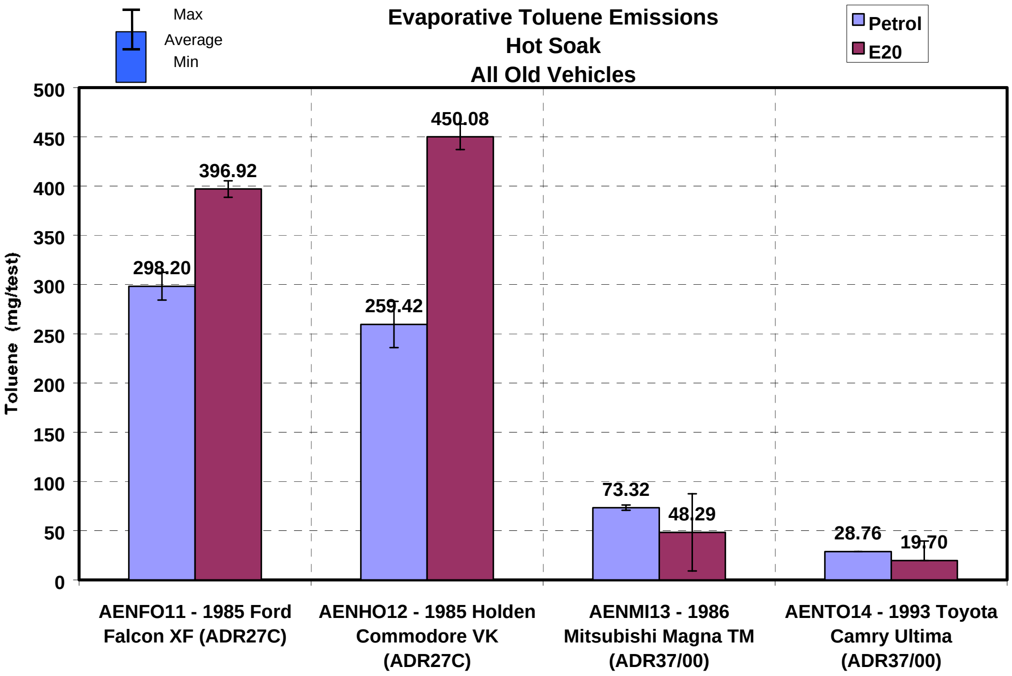


Figure 5.130 - Hot Soak Evaporative Toluene Emissions all Old Vehicles

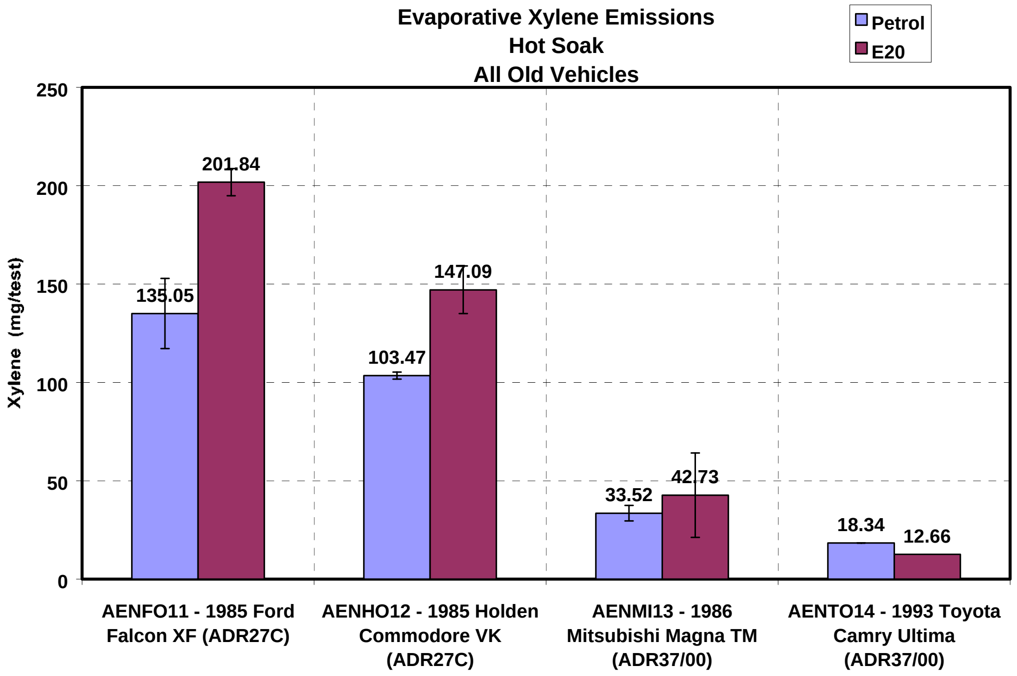


Figure 5.131 - Hot Soak Evaporative Xylene Emissions all Old Vehicles

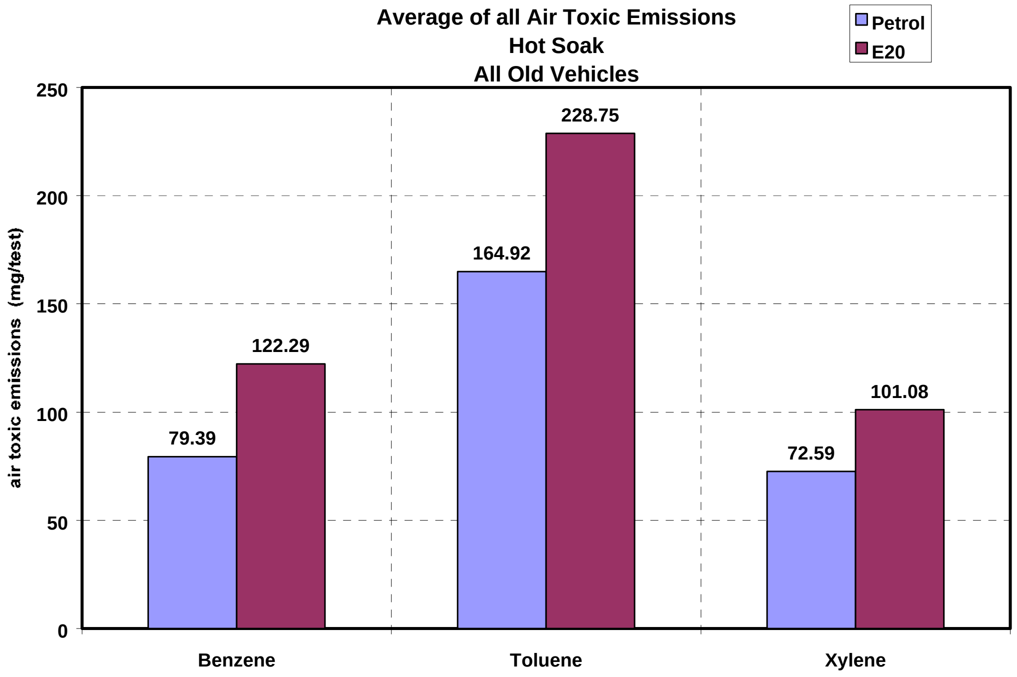


Figure 5.132 - Average Hot Soak Evaporative Emissions all Old Vehicles

### 5.2.6 Conclusion Unregulated Evaporative Emissions

It can be concluded from this section that:

- Overall there will be a increase in evaporative air toxics when the old vehicles are operated on E20,
- The increase in air toxics concurs with the increase in THC measured during the evaporative test

### 5.2.7 Regulated Evaporative Emissions Assessment.

The regulated evaporative emissions from all the old vehicles where tested according to ADR27C and ADR 37/00 (16,17). During the test, measurement of air-toxic emissions during the hot soak portion of the test were made this data will be discussed in section 5.2.8. The tests were undertaken with both baseline gasoline and E20 blend fuel and occurred after the vehicles had completed the low mileage stabilisation distance of 6400km. Test reports detailing the procedures used and the detailed results for each vehicle test are included in the appendices to this report.

#### 5.2.7.1 Evaporative Emissions Data

The evaporative emissions data for all the old vehicles tested on both straight gasoline and 20% ethanol are given in Table 5.16 and pictorially in Figure 5.133. It should be noted that the legislated target for ADR27C vehicles was 6.0g/test and for ADR37/00 vehicles 2.0g/test, hence the large discrepancy between the vehicles emissions. All the evaporative emissions data has been averaged together for the ADR27C vehicle and for the ADR37/00 vehicles and plotted in Figure 5.134.

In the literature review conducted (4) the effect of a 20% ethanol blend on the evaporative emissions was discussed in detail. In summary the largest affect comes from the distortion of the distillation curve downwards compared to straight gasoline in the mid range (Appendix M). This will predominately affect the hot soak portion of the evaporative emissions test as the fuel temperatures are substantially higher than for the diurnal testing, and in the region where the percentage of evaporated fuel is higher for the ethanol blend fuel compared with gasoline only. There is the possibility that at the diurnal test temperature the percentage of gasoline evaporated is similar or slightly higher than that of a 20% ethanol blend. Hence the diurnal emissions could be the same or slightly less.

From Figure 5.134 it can be seen that on average there is an increase in the diurnal emissions when the two ADR27C vehicles are operated on a 20% ethanol blend. Certainly the literature survey and the physical mechanism at play indicate that the diurnal emissions should remain the same or decrease. From Figure 5.133 it can be seen that there is a large discrepancy between the two vehicles in the diurnal portion of the test. Which casts doubt on the diurnal data for the Ford Falcon. However the results are similar to those reported in (6). In which vehicles of a similar type and age where tested and showed a clear increase in diurnal emissions when operated on an ethanol blend. That particular study was carried on a 10% blend so it is conceivable that the distillation curve characteristics at the diurnal test temperatures are subtly different. From Figure 5.134 it is clear to see that the hot soak emissions have increased substantially, this is mainly from the Holden Commodore Figure 5.133, which is fitted with a carburettor. This compares favourably with other studies, which have indicated that the carburettor float bowl has a strong influence on the hot soak evaporative emissions, (37).

From Figure 5.133 for the ADR37/00 vehicles the Mitsubishi Magna exhibits similar trends to the ADR37/01 vehicles tested and reported in section 5.1.5.1 with a slight decease in diurnal emissions and an increase in hot soak emissions when operated on a 20% ethanol blend. Interestingly by comparison to the only other carburetted vehicle in the trial the overall emissions are very low particularly in comparison to the hot soak test. The main reason for this being that the carburettor float bowl is vented to the carbon canister and as such collects the vapour; this backs up the findings from (37). The Toyota Camry though exhibiting the same trends of a decrease in diurnal and an increase in hot soak emissions. The overall total evaporative emissions have been skewed by the high diurnal test result on gasoline.

It should be noted that this testing was conducted on summer grade fuel with no adjustment to the base fuel volatility. The distillation curves for some of the fuels used can be found in Appendix M.

| Vehicle Type | Vehicle code | Diurnal (Gasoline) | Diurnal (E20) | Hot soak (Gasoline) | Hot soak (E20) | Total (Gasoline) | Total (E20) |
|---|---|---|---|---|---|---|---|
| **1985 Ford Falcon XF (ADR27C)** | AENFO11 | 0.930 | 4.005 | 1.750 | 2.790 | 2.680 | 6.790 |
| **1985 Holden Commodore VK (ADR27C)** | AENHO12 | 1.09 | 1.165 | 5.835 | 11.425 | 6.925 | 12.585 |
| **1986 Mitsubishi Magna TM (ADR37/00)** | AENMI13 | 0.285 | 0.245 | 0.76 | 1.19 | 1.045 | 1.43 |
| **1993 Toyota Camry Ultima (ADR37/00)** | AENTO14 | 1.870 | 0.495 | 0.115 | 0.145 | 1.985 | 0.635 |

**Table 5.16 Average Evaporative Emissions for All Old Vehicles.**

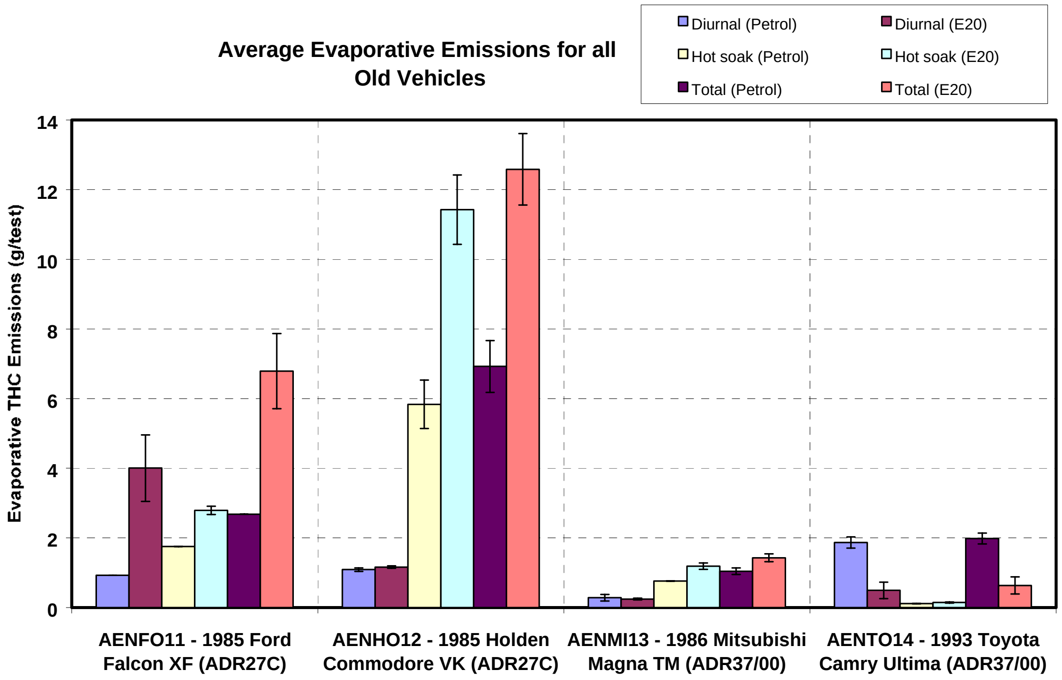


Figure 5.133 Average Evaporative Emissions for All Old Vehicles.

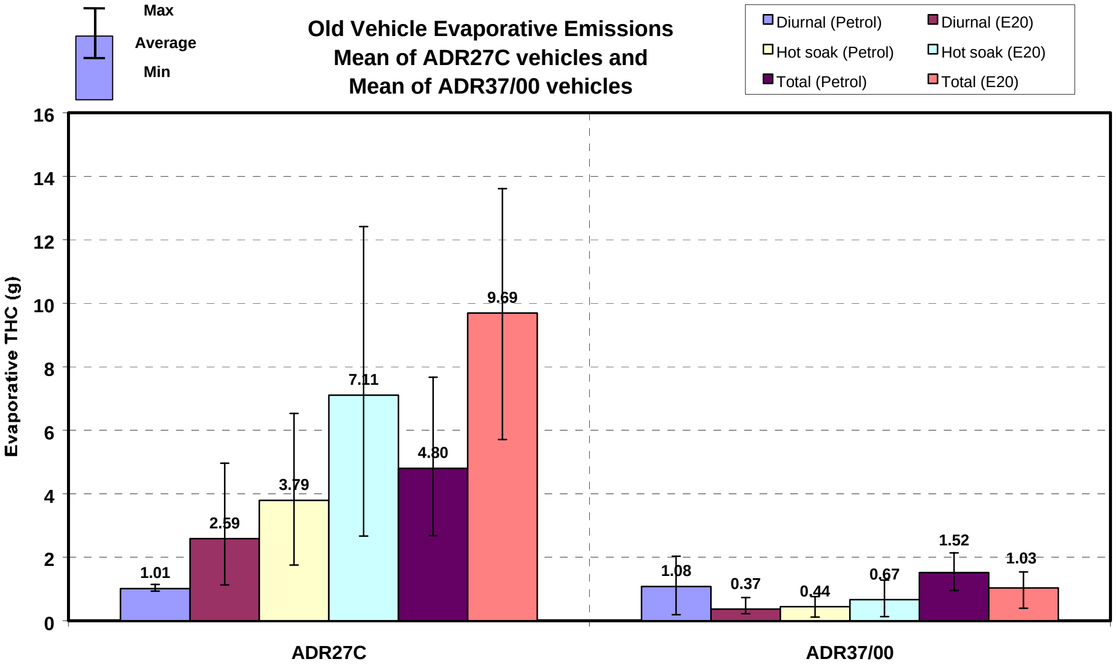


Figure 5.134 Mean of all the Evaporative Emissions Data for the ADR27C and ADR37/00 Vehicles.

### 5.2.7.1.1 Conclusion Evaporative Emissions Assessment

It can be concluded from the previous section that:

- From the measured data, in general for the ADR27C vehicles the diurnal THC emissions increased when the vehicles are operated on E20. This is contradictory to the data for the ADR37/00 and ADR37/01 vehicles, which show a decrease.
- In general the hot soak THC emissions increased for both the ADR27C and ADR37/00 vehicles when operated on E20.
- Carburetted vehicles that do not have the float chambers vented to the canister may potentially show a large increase in hot soak evaporative emissions when operated on E20 fuel.
- Overall for the ADR27C vehicles tested, the evaporative emissions increased when operated on E20.
- Overall for the ADR37/00 vehicles tested, the evaporative emissions decreased when operated on E20, however this result is potentially skewed by the high gasoline diurnal emissions from the Toyota Camry.

### 5.2.8 Air Toxic Evaporative Emissions Assessment.

During the ADR27C and ADR37/00 evaporative emissions testing a sample was taken during the hot soak portion for analysis to determine air toxics. The toxics measured are Benzene, Toluene and Xylene. Xylene as displayed is the summation of P-Xylene and O-Xylene. Due to the reduced fuel temperature for the diurnal test, start fuel temperature 15 Celcius and final fuel temperature of 29 Celcius it was thought that any differences between the gasoline air toxics and E20 air toxics would probably be minimal. Also from studying reference (6), the data for the diurnal air toxics appears to be quite variable. As the potential mechanism for difference between gasoline and E20 evaporative appear to focus on the distortion of the distillation curve the present study concentrated on the hot soak test.

Figure 5.135, Figure 5.136 and Figure 5.137 display the comparison of the air toxics measured against straight gasoline and E20 for all the new vehicles tested. Figure 5.138 is the average air toxics for all the vehicles tested. This indicates that on average the air toxics will increase when the vehicle is operated on ethanol. This result appears reasonable, as above approximately 60 Celcius bulk fuel temperature an E20 blended fuel will start to evaporate at a faster rate than a straight gasoline, see Appendix M for distillation curves.

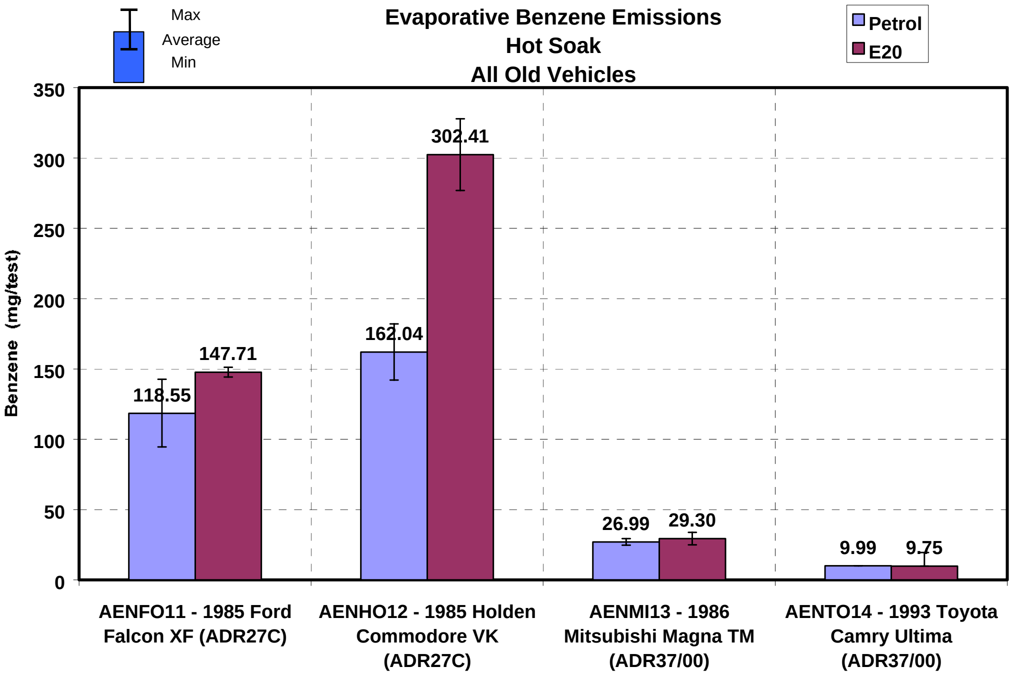


Figure 5.135 - Hot Soak Evaporative Benzene Emissions all Old Vehicles

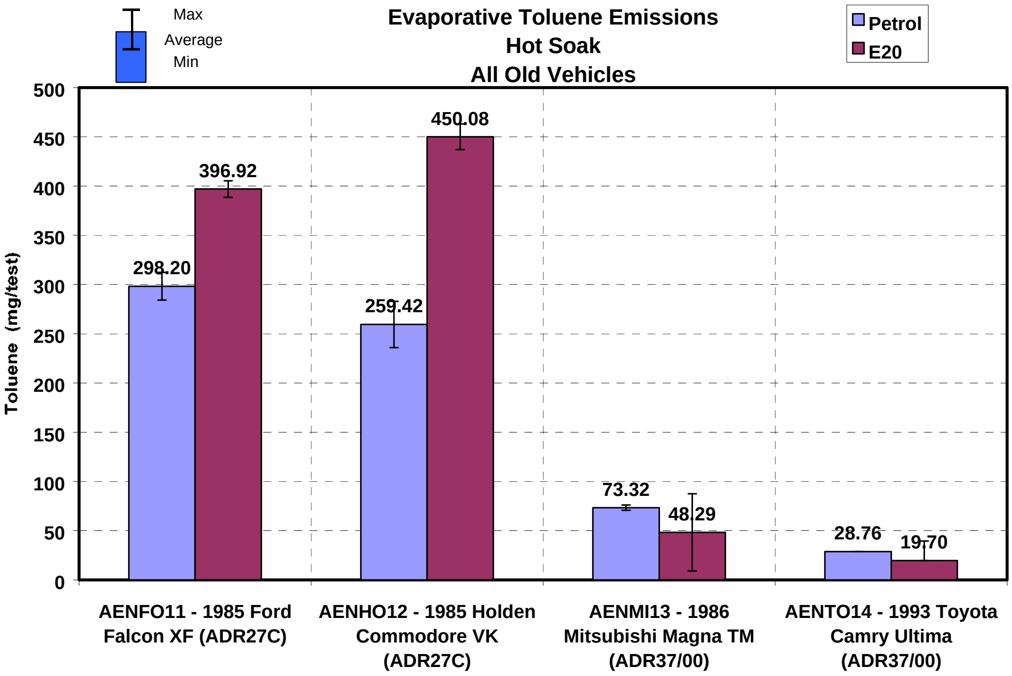


Figure 5.136 - Hot Soak Evaporative Toluene Emissions all Old Vehicles

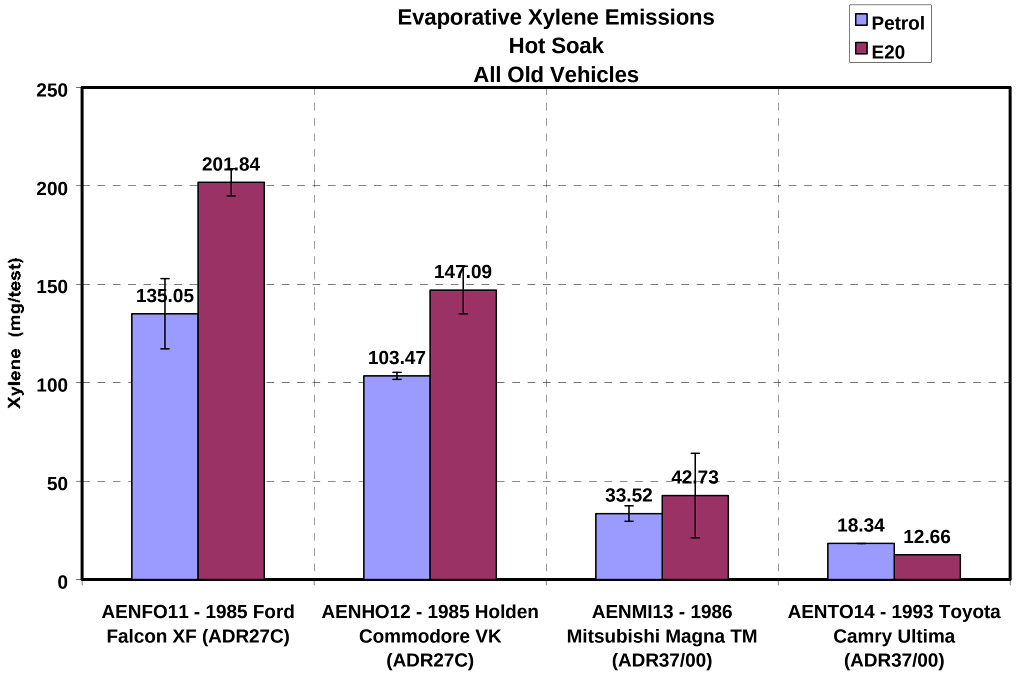


Figure 5.137 - Hot Soak Evaporative Xylene Emissions all Old Vehicles

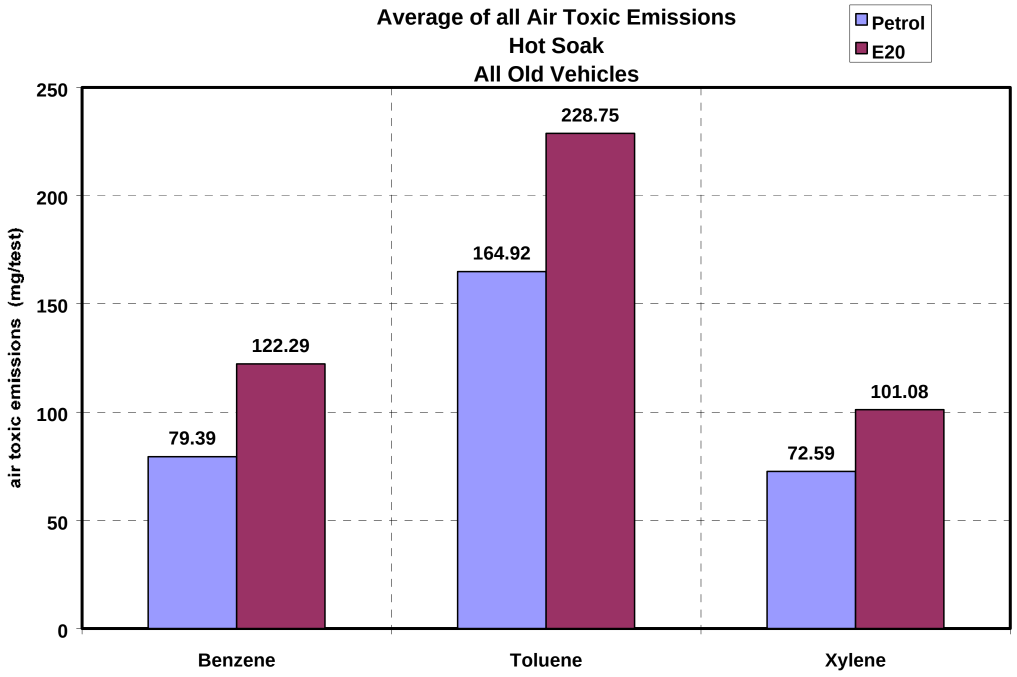


Figure 5.138 - Average Hot Soak Evaporative Emissions all Old Vehicles

### 5.2.9 Conclusion Unregulated Evaporative Emissions

It can be concluded from the previous section that:

- Overall there will be an increase in evaporative air toxics when the old vehicles are operated on E20.
- The increase in air toxics concurs with the increase in THC measured during the evaporative test.

### 5.2.10 Fuel Consumption Assessment.

The fuel consumption for all the old vehicles was determined as per AS2877 (7) for both gasoline only and for gasoline with a 20% ethanol blend. The data is presented in Table 5.17 and pictorially in Figure 5.139 and Figure 5.140. The Metro – Highway (M-H) fuel consumption has also been calculated. This is a weighted composite figure determined for both the ADR27C and AS2877 Highway cycle and the ADR37/00 and AS2877 Highway cycle.

Fuel economy theoretically increases when oxygenates are blended with gasoline due to the lower energy content of the oxygenate. This increase in fuel economy, due to the reduction in energy content, may be offset somewhat in older vehicles due to the enleanment of the fuel/air mixture when there is no closed loop fuel control (4). As three of the vehicles have open loop controlled fuelling its thought the there should be little difference in fuel consumption. Figure 5.140 shows this to be the case for the Holden Commodore AENHO12 and the Mitsubishi Magna AENMI13. The Ford Falcon AENFO11 appears to have a significant increase in fuel consumption this was a somewhat unexpected result. It is postulated that when the vehicle was running on the E20 fuel the combustion quality/engine operation had been compromised, though possibly not as a result of operating on ethanol. One of the indicators to this conclusion being drawn is the erratic behaviour of the exhaust oxygen trace shown in Figure 5.104.
The only closed loop vehicle tested in the old vehicle section appears to have behaved similarly to the new vehicles, with a larger increase in consumption for the highway cycle and than for the city cycle.

| **Vehicle Type** | **Vehicle code** | **City FC (Gasoline) l/100km** | **City FC (E20) l/100km** | **% Difference City** | **Highway FC (Gasoline) l/100km** | **Highway FC (E20) l/100km** | **% Difference Highway** | **M-H (gasoline) l/100km** | **M-H (E20) l/100km** | **% Difference M-H** |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985 Ford Falcon XF (ADR27C)** | AENFO11 | 15.409 | 16.331 | 5.98% | 9.292 | 9.774 | 5.19% | 11.887 | 12.544 | 5.53% |
| **1985 Holden Commodore VK (ADR27C)** | AENHO12 | 13.684 | 13.645 | -0.29% | 9.636 | 9.833 | 2.05% | 11.508 | 11.618 | 0.96% |
| **1986 Mitsubishi Magna TM (ADR37/00)** | AENMI13 | 10.856 | 10.969 | 1.05% | 6.584 | 6.793 | 3.18% | 8.402 | 8.592 | 2.26% |
| **1993 Toyota Camry Ultima (ADR37/00)** | AENTO14 | 10.166 | 10.529 | 3.57% | 6.884 | 7.311 | 6.21% | 8.370 | 8.788 | 5.00% |

**Table 5.17 – Old Vehicle Fuel Consumption Data.**

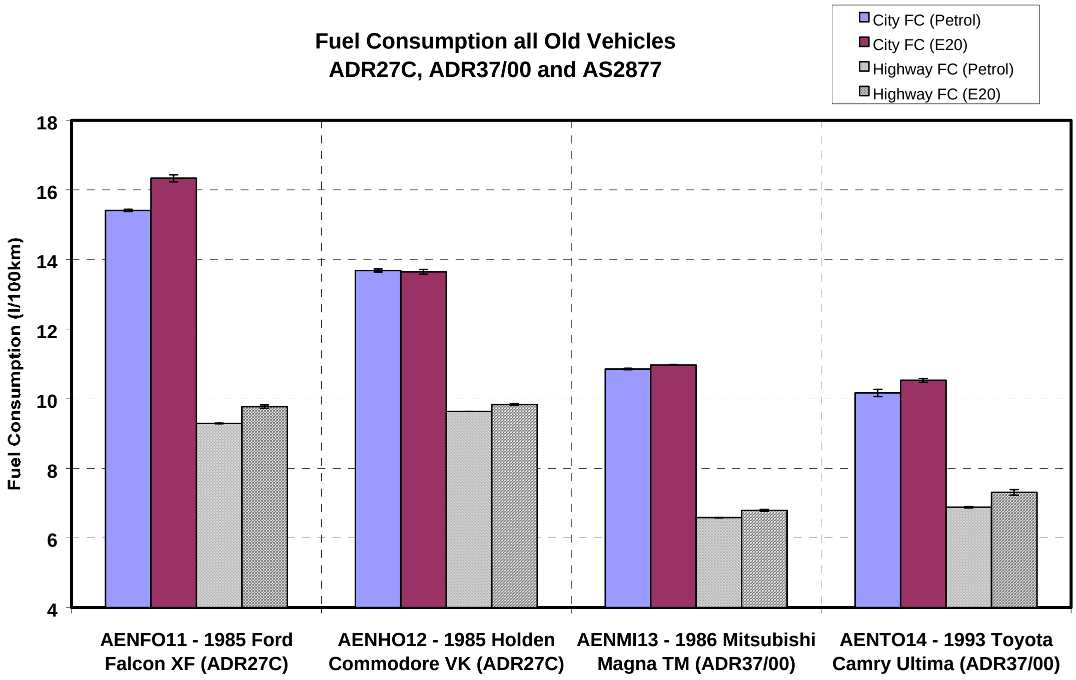


Figure 5.139 – Fuel Consumption Comparison for Old Vehicles.

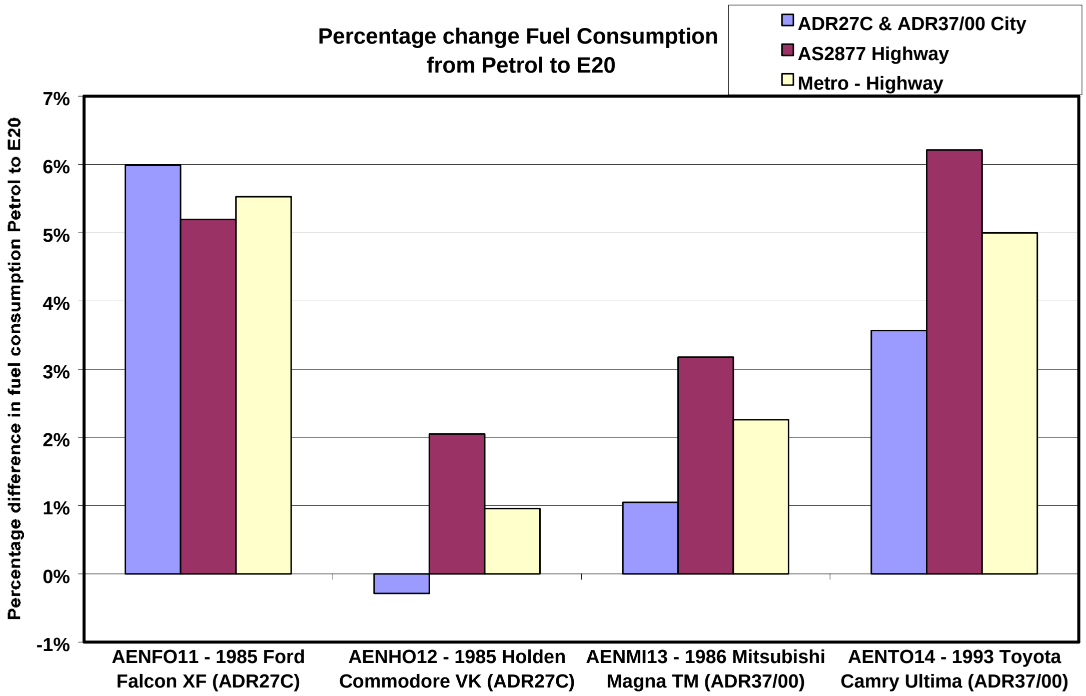


Figure 5.140 – Percentage Difference in Fuel Consumption.

### 5.2.10.1.1 Conclusions Fuel Consumption.

It can be concluded from the previous section that:

- Ignoring the Ford Falcon results, in general there was a minor increase in fuel consumption when the open loop fuelled vehicles were operated on E20 fuel.
- The closed loop fuelled vehicle behaved similarly to the new vehicles tested with an increase in fuel consumption when operated on E20 ranging from 3.5% to just over 6% depending whether operated over the city or highway cycle.

### 5.2.11 Vehicle Driveability Assessment.

The driveability assessments are a subjective measure to evaluate engine starting behaviour and driveability characteristics of the vehicle. The vehicle driveability was evaluated by means of an open road test based on industry standards. The assessments are made for cold, hot and ambient temperature weather conditions. The drive, performance, startability and idle quality ratings and assessment comment are provided in the new vehicle section 5.1.9 in Table 5.9, Table 5.10 and Table 5.11. While these ratings tables criteria are likely to be significantly beyond the capability of the old open loop vehicles, the Ford Falcon (AENFO11), the Holden Commodore (AENHO12) and the Mitsubishi Magna (AENMI13) due to their age (not condition), it is still valid to use the rating system as the objective is to compare the performance on gasoline and E20.

Further, details on the facilities utilised for the testing is provided in section 5.1.9.

The comments and discussions based on the comparison of gasoline to E20 fuel are based on the same “worse case” judgement used for the assessment, comments will only be made on issues which are significantly worse. The assumption is therefore that all other issues are either the same as gasoline or better.

Specific gasolines for hot and cold testing were utilised with details of the various properties of the gasolines and some of the E20 blends made with the gasolines found in Appendix M.

#### 5.2.11.1 Ambient Conditions Driveability Evaluation.

The ambient vehicle driveability evaluation has been divided into three discrete areas each tested under the ambient conditions in Perth started early in November 2002 and was completed in late January 2003. In general, the average ambient temperature for the startability testing was approximately 25$^{o}$ Celcius. The test reports detailing the procedures used and the detailed results for each vehicle are included in the appendices to this report. The fuel used for the ambient condition test was summer grade ULP or LRP for gasoline and the same blended with 20% ethanol.

##### 5.2.11.1.1 Startability and Idle Quality.

The two vehicles fitted with carburettors, Holden Commodore (AENHO12) and Mitsubishi Magna (AENMI13), displayed significantly degraded starting under ambient temperature conditions of approximately 25$^{o}$ Celcius with E20 fuel. On one of the start tests for the Holden Commodore it was found to stall after fire. Long cranking times were also reported for both start tests. Table 5.18 indicates the start ratings of 4.6 and 5.6 for the Holden Commodore and Mitsubishi Magna respectively indicating poor and mediocre performance. This equates to the driver of the Holden Commodore believing disturbing defects present, but still confident of continual operation and would seek corrective action. The driver if the Mitsubishi Magna would believe obvious defects present irritating, will probably generate complaints, user not happy with car operation and is likely to seek corrective action with E20 fuel.

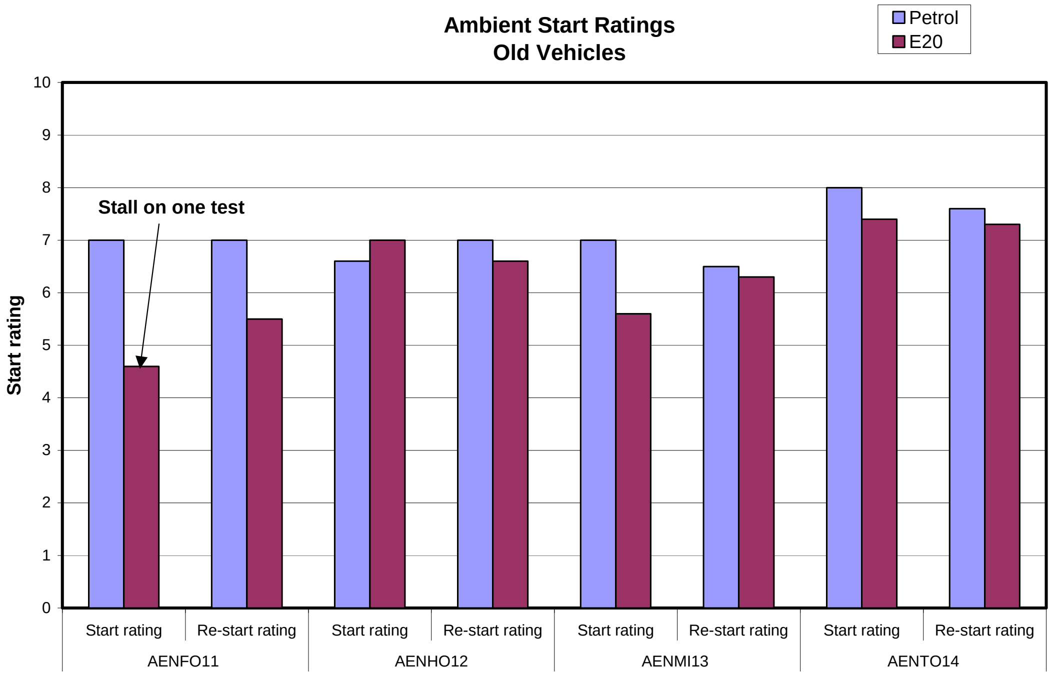


**Table 5.18 - Ambient Start Ratings Old Vehicles**

Should the worst start rating for the Holden Commodore be used, a three, this indicates very poor performance undermining the drivers confidence, vehicle is not reliable. The Holden Commodore on average was rated at 5.5 for the re-start, mediocre performance with obvious defects present irritating, will probably generate complaints, user not happy with car operation and is likely to seek corrective action when operating the vehicle on E20 fuel.

Idle quality for the Holden Commodore has also been rated in the high fives for both stability and roughness down by approximately one pint, from agreeable to mediocre. The driver has moved from the generally satisfied with gasoline to considering corrective action when E20 fuel is used. The Ford Falcon was rated with 4.3 for both the idle stability and roughness, this poor rating indicates a disturbing effect present, user would seek corrective action.

### 5.2.11.1.2 Vehicle Performance.

The WOT launchability for the Holden Commodore (AENHO12) has rated much lower with E20 fuel down to 5.0 for mediocre performance with the driver feeling the vehicle does not perform as well as the driver thought it would with poor acceleration capability under normal circumstances. This rating was given due to noticeable initial hesitation to throttle demand which when the engine is cold is very much more significant with E20 fuel.

### 5.2.11.1.3 Warmed-up Driveability.

All vehicles operated with similar driveability once warm except for the Mitsubishi Magna that rated poor (four) on tip-in (throttle on) at low speed, the user would seek corrective action. A number of other driveability areas have rated in the five group with mediocre performance with the user likely to seek corrective action. These are low speed shunt/chuggle where the vehicle is operated in high gear low speed with significant throttle demand, tip-in high gear and tip-out low gear. In general the warmed-up driveability is significantly degraded with E20 fuel to the point where the driver is likely to seek corrective action on a number of points.

## 5.2.11.2 Hot Start and Driveability Evaluation.

The vehicles were tested under hot soak conditions in the extreme environment chamber. Each vehicle was conditioned on the chassis dynamometer until the engine oil temperature was approximately $120^o$ Celcius and then placed in the environmental chamber set with an ambient temperature of approximately $40^o$ Celcius, a solar heating load of 1,100 $W/m^2$ and the track temperature of $60\text{-}65^o$ Celcius. Further details related to the simulated environmental and vehicle conditions can be found in section 5.1.9.2. The fuel used for the ambient condition test was summer grade ULP or LRP for gasoline and the same blended with 20% ethanol.

### 5.2.11.2.1 Startability and Idle Quality.

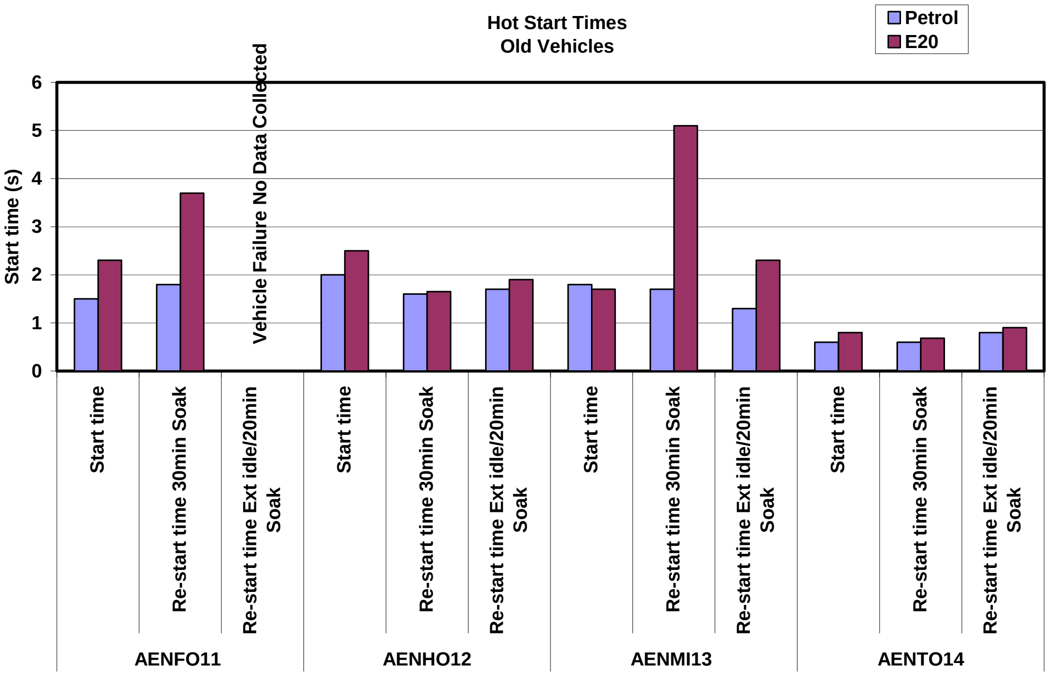


Figure 5.141 – Hot Start Times for all Old Vehicles.

Following the ten minute hot soak, all the vehicles were found to have slightly increased start times when operating on E20 fuel, except for the Mitsubishi Magna. However the Ford Falcon was found to stall upon crank and fire and subsequently rated as 4.5, poor indicating the user would be seeking corrective action. Both the Ford Falcon and Mitsubishi Magna were rated at 3.5 and 2.5 respectively for the re-start of 5.1 seconds, Figure 5.141, and stall following the 30-minute hot soak. This is interpreted as very poor, undermining the drivers confidence and not reliable for the Ford Falcon to bad and failure to stay running, will not operate consistently for the Mitsubishi Magna. The hot idle quality following the ten-minute hot soak was poor for the Ford Falcon indicating the driver would seek corrective action. Following the 30 minute hot soak, the Holden Commodore and the Mitsubishi Magna were rated as 4.8 and 4.5, poor. The Ford Falcon was rated 3.5 when operating on E20 fuel, very poor and undermining the driver confidence, not reliable.

#### 5.2.11.2.2 Hot Extended Idle Quality and Startability.

Stalling after starting following the 20 minute idle in the environmental chamber was identified on the Mitsubishi Magna rated 4.5 and the Toyota Camry rated 3.0 that stalled on both tests with the E20 fuel. The very poor rating for the Toyota Camry is seen to undermine the drivers confidence due to unreliability. Hot idle quality issues following the 20 minute soak and re-start rating mediocre, indicate the driver is not particularly happy with the vehicle and is likely to seek corrective action due to surging and rough idling performance for the Holden Commodore and Mitsubishi Magna. Starting time increase was identified for the Mitsubishi Magna, this was not highly significant when compared with the stall after fire. Extended idle testing was not possible on the Ford Falcon due to cooling system problems.

#### 5.2.11.2.3 Hot Driveability.

Upon completion of the hot extended idle quality and startability testing, the vehicle is hot soaked for a further 20 minutes. Once restarted it is driven out onto the open road for hot driveability assessment following the driving cycle shown in Figure 0.1. The most significant hot driveability impact identified with E20 fuel was with the Holden Commodore. The WOT acceleration rating was 4.5 due to significant hesitation of the engine before finally accelerating. The Holden Commodore and Mitsubishi Magna both displayed degradation in the 50 and 70 km/h cruise tests, the Mitsubishi Magna being the worst. The degradation was related to instability in combustion, the average driver would notice the changes. The Toyota Camry was only very slightly affected; the Ford Falcon was not tested due to cooling system problems.

### 5.2.11.3 Cold Start and Warm-up Evaluation.

The cold start and warm-up evaluations were completed following cold soaking the vehicle for at least eight hours at approximately –10$^{o}$ Celcius in the environmental chamber. The fuel used for the testing was specific test winter grade ULP and LRP for gasoline and the same for the E20 blend, the details can be found in Appendix M.

#### 5.2.11.3.1 Startability and Idle.

Significant differences were found in the cold startability performance of the Holden Commodore and Ford Falcon. While the cold start performance on gasoline for the Holden Commodore was very bad with an average of 22.5 seconds to start with E20 fuel the average time increased to 65 seconds, a significant outcome. The Ford Falcon required on average 3.7 seconds longer to start on E20 rated a 5.0 indicating the driver is likely to seek corrective action. Re-start time was rated 4.5 and 4.0 for the Holden Commodore for gasoline and E20 fuel with stalling occurring when E20 fuel was used.

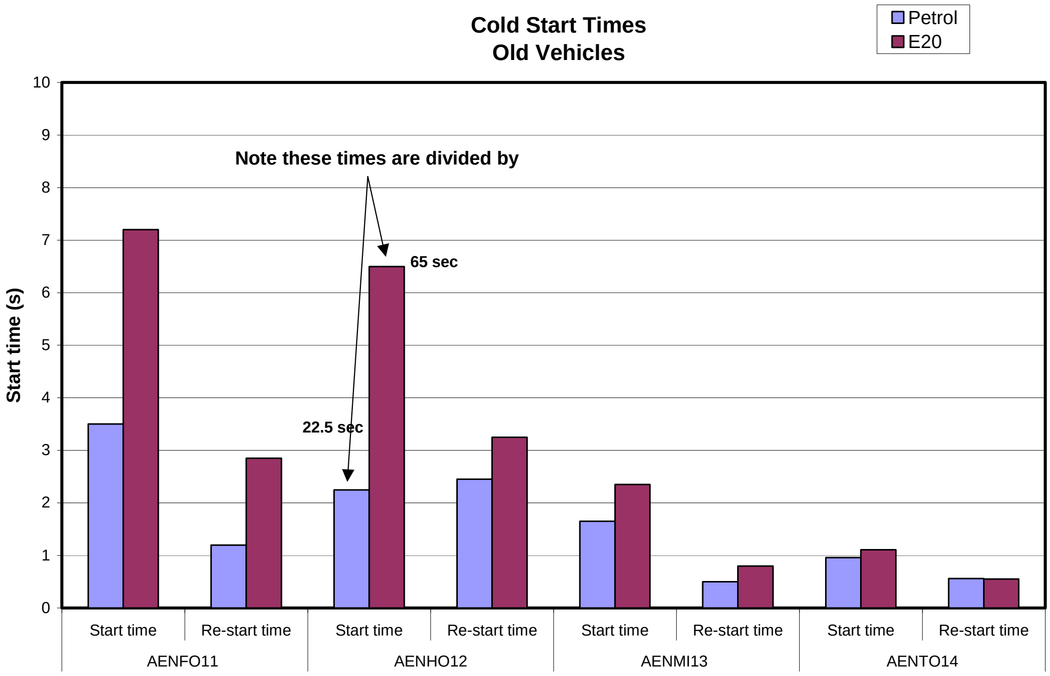


Figure 5.142 - Cold Start and Re-start Times for all Old Vehicles

Details of the starting times are given in Figure 5.142.

The idle quality was found to be very poor to poor for the Holden Commodore in all areas of assessment with stalling and roughness occurring across all tests rating from 3.8 to 4.5 with E20 fuel, some of the assessment points also rated as mediocre with gasoline.

### 5.2.11.3.2 Warm-up Driveability.

Immediately following the start and idle assessment in the environmental chamber, the vehicles were driven onto the open road for warm-up driveability assessments. The driving cycle followed for this assessment is shown in Figure 0.1. The WOT performance of the Holden Commodore was found to be very poor with severe hesitation in excess of one second upon throttle when operated on E20 fuel. Rating 3.0 and therefore undermining the confidence of the driver, as it is not reliable. Further acceleration degradation for the Holden Commodore and the Mitsubishi Magna was identified for the interrupted acceleration test. In fact the Mitsubishi Magna stalled on one of the two tests with the Holden Commodore displaying hesitation upon throttle demand. Both the Ford Falcon and the Holden Commodore were found to display degraded performance on the steady state cruise at 50km/h with a hesitation that would be noticeable to the average driver with the Holden Commodore performance likely to cause the driver to seek corrective action. The only area of any significance for the Toyota Camry was the WOT acceleration with a slight reduction in rating that would be barely noticeable to the average driver.

| Vehicle | | Ambient Driveability | | Hot Driveability | | Cold Driveability | |
|---|---|---|---|---|---|---|---|
| | | Gasoline | E20 | Gasoline | E20 | Gasoline | E20 |
| AENFO11 - 1985 Ford Falcon XF (ADR27C) | Average | 6.6 | 6.1 | 6.1 | 3.9 | 6.7 | 6.2 |
| | Maximum | 7.3 | 7 | 7.3 | 4.5 | 7.3 | 7.1 |
| | Minimum | 5.6 | 4.3 | 5 | 3.5 | 5.5 | 5 |
| AENHO12 - 1985 Holden Commodore VK (ADR27C) | Average | 7.1 | 6.6 | 6.9 | 6 | 5.8 | 4.2 |
| | Maximum | 8 | 7.8 | 8 | 7.3 | 7.4 | 6 |
| | Minimum | 6.2 | 4.6 | 4.8 | 4.5 | 1 | 1 |
| AENMI13 - 1986 Mitsubishi Magna TM (ADR37/00) | Average | 7 | 6.7 | 6.5 | 5.9 | 6.5 | 7.1 |
| | Maximum | 7.8 | 7.5 | 7.8 | 7.8 | 7.3 | 7.8 |
| | Minimum | 5.5 | 7.5 | 5 | 2.5 | 5 | 5.5 |
| AENTO14 - 1993 Toyota Camry Ultima (ADR37/00) | Average | 7.6 | 7.5 | 7.9 | 7.3 | 8 | 7.9 |
| | Maximum | 8 | 8 | 8.3 | 8 | 8.3 | 8.3 |
| | Minimum | 6.5 | 6.8 | 7.5 | 3 | 7.5 | 7.4 |

**Table 5.19 - Overall Old Vehicle Driveability Summary**

#### 5.2.11.4 Driveability Conclusions.

The following conclusions are drawn based on the previous sections.

- Under ambient conditions, potentially significant startability problems with old open loop carburetted vehicles such as long starting times with stall after firing may occur. Idle quality may potentially degrade on open loop vehicles to the point where stability and roughness are experienced. Issues such as hesitation to throttle demand and mediocre WOT launchability performance may also occur which are more significant when the engine is cold. Even when warmed-up, some cars may suffer throttle response problems along with a number of other degraded driveability issues. For some of these impacts, the average driver will believe disturbing defects are present but still have confidence of continual operation will however seek corrective action

- For hot conditions, startability of some older vehicles may display stalling and rough running to such a degree that the driver will believe the vehicle will fail to stay running and will not operate consistently. Other vehicles startability may degrade to the point where the driver believes disturbing effects are present but is still confident of continual operation and seek corrective action. Idle quality may also degrade to similar levels with unstable and rough running indicating the driver would seek corrective action. Significant hesitation to WOT demand may be experienced along with hesitation at cruise speeds of 50 to 70 km/h. Some vehicles may experience hesitation to the point of the driver seeking corrective action.
- Under cold conditions starting may become degraded to the point of stalling and rough running such that the driver seek corrective action due to the disturbing defects present. Idle quality may also degrade to a level of stalling and rough operation such that drivers confidence is undermined as it is believed the vehicle is not reliable. Further during warm-up after a cold condition start, severe hesitation to WOT throttle demand and other acceleration functions may occur such as to undermine the drivers confidence such that it is believed the vehicle is unreliable. Hesitation at cruise speed of 50 km/h was also noted that may cause the average driver to seek corrective action.
- These impacts are related to the changes made to the distillation curve of the gasoline by addition of 20% ethanol along with enleanment and the greater heating required to vaporise ethanol and are confirmed by the literature review completed earlier (4).

An overall summary is provided in Table 5.19.

# 6 Interim 20,000 Kilometre Durability Results

Upon completion of the performance based assessment on the E20 fuel blend, Holden Commodore AENHO01 (E20 vehicle) along with Holden Commodore AENHO06, (neat gasoline vehicle) were placed on the mileage accumulation chassis dynamometer facility to complete 20,000 kilometres of mileage accumulation.

Upon completion of the 20,000 kilometres, both vehicles were removed from the facility to undertake the Inspection and Maintenance 240 second emissions test in the emissions chassis dynamometer facility to compare emissions and fuel consumption. Two concurrent IM240 test cycles are performed each time the vehicle is tested to IM240 to verify consistency of the emissions data.

## 6.1 IM240 Test

Both vehicles were tested to IM240 at the stabilised mileage of 6400 kilometres to record ‘baseline’ data, subsequent to 20,000 kilometres of mileage accumulation. A service interval occurred on both vehicles at 10,000 kilometres. After completion of this service, the vehicles were tested to IM240 for performance verification. At completion of the 20,000 kilometres mileage accumulation, both vehicles were again serviced followed by IM240 testing. The results of the IM240 testing are shown in Table 6.1.

| | Gasoline Vehicle AENHO06 | | | E20 Vehicle AENHO01 | | |
|---|---|---|---|---|---|---|
| **Baseline IM240 Results (6400km)** | | | | | | |
| **Emission** | Actual | Actual | **Average** | Actual | Actual | **Average** |
| **6400km - HC** | 0.05 | 0.043 | **0.047** | 0.018 | 0.024 | **0.021** |
| **6400km - CO** | 0.409 | 0.138 | **0.274** | 0.009 | 0.024 | **0.017** |
| **6400km - NOx** | 0.02 | 0.012 | **0.016** | 0.064 | 0.034 | **0.049** |
| **6400km - CO2** | 232.98 | 233.56 | **233.270** | 234.331 | 234.030 | **234.181** |
| **6400km - FC** | 9.98 | 9.98 | **9.980** | 10.693 | 10.681 | **10.687** |
| **Service Interval (10,000km)** | | | | | | |
| **Emission** | Actual | Actual | **Average** | Actual | Actual | **Average** |
| **10,000km - HC** | 0.092 | 0.095 | **0.094** | 0.013 | 0.013 | **0.013** |
| **10,000km - CO** | 0.523 | 0.493 | **0.508** | 0.011 | 0.01 | **0.011** |
| **10,000km - NOx** | 0.033 | 0.037 | **0.035** | 0.034 | 0.056 | **0.045** |
| **10,000km - CO2** | 220.85 | 222.38 | **221.615** | 228.27 | 227.79 | **228.030** |
| **10,000km - FC** | 9.47 | 9.54 | **9.505** | 10.416 | 10.394 | **10.405** |
| **Service Interval (20,000km)** | | | | | | |
| **Emission** | Actual | Actual | **Average** | Actual | Actual | **Average** |
| **20,000km - HC** | 0.031 | 0.05 | **0.041** | 0.010 | 0.011 | **0.010** |
| **20,000km - CO** | 0.103 | 0.129 | **0.116** | 0.064 | 0.050 | **0.057** |
| **20,000km - NOx** | 0.018 | 0.045 | **0.032** | 0.063 | 0.065 | **0.064** |
| **20,000km - CO2** | 221.85 | 221.77 | **221.810** | 224.57 | 223.46 | **224.012** |
| **20,000km - FC** | 9.48 | 9.48 | **9.480** | 10.249 | 10.198 | **10.224** |

**Table 6.1 – IM240 Emission Results**

## 6.2 Conclusions.

The IM240 emissions measured over the 20,000km mileage accumulation indicate both vehicles are performing consistently, in terms of emissions, fuel consumption and general running quality.  Both vehicles are clear to continue mileage accumulation until the intermediate-mileage emissions test point as required for Phase 2B of the E20 project.

# 7 'Well to Wheel' Greenhouse Gas Emissions Comparison for E20 and Gasoline

## 7.1 Introduction

A 'Well to Wheel' greenhouse gas emissions analysis of gasoline and E20 fuel is provided in this chapter.

Reported, is an estimate and comparison of the life-cycle greenhouse gas emissions, or 'Well to Wheel' (WTW) greenhouse gas (GHG) emissions, for gasoline and E20 fuel, on the basis of 'Well to Tank' (WTT) and 'Tank to Wheel' (TTW) GHG emissions, i.e. the greenhouse gas emissions resulting from;

i) Sourcing the fuel and getting it to the vehicle fuel tank, and
ii) Consuming the fuel.

***Lifecycle ('Well to Wheel') greenhouse gas emissions = 'Well to Tank' + 'Tank to Wheel' greenhouse emissions***

The three major greenhouse gases specified in the Kyoto Protocol (22), Carbon Dioxide (CO2), Methane (CH4) and Nitrous Oxide (N2O), are taken into consideration for the 'Well to Wheel' greenhouse gas emissions. The three GHG's are combined with their respective global warming potentials (GWPs) to calculate carbon dioxide equivalent (CO2e) GHG emissions. For this report, the GWP for each of these greenhouse gases will be taken from the Second Assessment Report (SAR) in preference to the Third Assessment Report (TAR) because the data in the majority of the literature reviewed in this report is based on the SAR values (23), see Table 7.1.

| ***Compound*** | ***100 yr Global Warming Potentials (= Greenhouse gas weighting factor relative to $CO_2$ )*** | |
|---|---|---|
| | **Second Assessment Report (SAR)** | **Third Assessment Report (TAR)** |
| $CO_2$ | *1* | *1* |
| $CH_4$ | *21* | *23* |
| $N_2O$ | *310* | *296* |

**Table 7.1 – Greenhouse Gases and their Associated GWP**

The information presented here incorporates a desktop study and literature review of data sourced from contemporary scientific and engineering publications concerning the WTT GHG emissions of passenger vehicles operating on gasoline, ethanol and ethanol gasoline blends.

A number of papers were reviewed for information concerning the WTW GHG emissions of conventional and alternative fuels. Of these papers, five were selected for study and reporting. Those papers reviewed and discarded were unable to fulfil the following selection criteria.

- The paper should contain WTW data for gasoline and ethanol (including ethanol blends).
- The paper should be contemporary.
- The paper should contain data that allowed the calculation of the WTT GHG emissions.
- Where possible, the data should be relatable to the current Australian situation, e.g. the ethanol source is commercially viable within Australia.

The five selected references are from the following organisations;

- CSIRO, published in 2001, (24).
- Volvo cars, published in 1993, (25).
- Energy International Inc., published in 1994, (26).
- Amoco Oil Company, published in 1990, (27).
- General Motors Corporation, published in 2001, (28).

The WTT GHG emissions gleaned from the five literature sources were converted into terms of grams of CO2e per gram of fuel ($g_{CO2e}/g_{Fuel}$). Expressed in these terms, the WTT GHG emissions can be easily applied to each vehicle tested as part of this program in turn for determination of the WTW GHG emissions, as each vehicle has different fuel consumption that was measured in terms of grams of fuel per kilometre ($g_{Fuel}$/km). The details are presented in Section 7.2 for each literature source in turn.

The TTW GHG emissions were evaluated by direct measurement of CO2 and CH4 during ADR (city) and AS2877 (highway) drivecycle emissions testing. Included is a CH4 measurement taken during the ADR evaporative emissions test schedule. The TTW GHG data is presented in Section 7.3.

Nitrous oxide emissions were not measured during the vehicle test program and as such, the TTW GHG emission evaluation involved a literature survey to determine the likely N2O emissions based on the N2O proportion of NOx tailpipe emissions. The NOx measurement is not influenced by the concentration of N2O in the exhaust gas, (33). The resulting proportion was applied to the measured NOx tailpipe emissions for inclusion into the greenhouse gas emissions calculation.

For the work reported here, the N2O concentration of the exhaust gas, for catalysed vehicles, is assumed to be directly proportional to the measured NOx emission. The N2O to NOx ratio for both gasoline and E20 fuels for the test vehicles, obtained by referring to published, (31, 32, & 34) data on the subject, is as follows;

- 20% for vehicles fitted with 3-way catalysts
- 10% for vehicles fitted with oxidation catalysts
- 0% for non-catalysed vehicles

The Kyoto Protocol, (22) requires GHG calculations to be based on fossil fuel derived carbon dioxide or net exchange of carbon with the long-lived biosphere. Therefore, carbon dioxide that is generated as a result of the combustion of ethanol (not produced from a fossil fuel) is not included in the tailpipe GHG inventory. Hence, the TTW GHG emissions used for the WTW GHG emissions calculation is comprised of the CO2 emissions that are attributable to gasoline alone, i.e. the CO2 emission component attributable to ethanol combustion in the engine is removed because of the ruling in the Kyoto Protocol. For every gram of CO2 produced from the combustion of E20 fuel, it can be shown that 0.1381 grams of CO2 are attributable to the combustion of ethanol, see Appendix A. The vehicle tailpipe CO2 emissions measured from E20 fuel testing were therefore reduced by 13.81% for the TTW GHG assessment in line with the Kyoto Protocol for renewable fuels.

| | **GASOLINE** | **ETHANOL** | **E20** |
|---|---|---|---|
| Density (kg/l @25°C) | 0.7400 | 0.7873 | 0.7495 |
| Blend ratio (Ethanol %v/v) | — | — | 20% |
| Ethanol Content (Gasoline %w/w) | 0% | 100% | 21.01% |
| Gasoline Content (Gasoline %w/w) | 100% | 0% | 78.99% |
| H/C Ratio | 1.85 | 3.00 | 2.08 |
| O/C Ratio | 0 | 0.50 | 0.07 |
| NHV (MJ/kg) | 43.9 | 26.8 | 40.3 |
| Theoretical $g_{CO2}/g_{Fuel}$ | 3.17 | 1.91 | 2.91 |

**Table 7.2 - Assumed Fuel Properties**

The WTW analysis completed contains the impact E20 may have in terms of GHG emissions based on the new vehicle fleet, the old vehicle fleet and a combination representing the total vehicle fleet. This analysis is presented in Section 7.4 for each of the five selected WTT GHG emissions data sets.

For the analysis reported here, the properties of gasoline, ethanol and E20 given in Table 7.2 were used for calculations (29).

## 7.2 'Well to Tank' Greenhouse Gas Emissions Analysis

### 7.2.1 CSIRO Data (24).

The CSIRO report, ‘Comparison of Transport Fuels’ was written for the Australian Greenhouse Office (AGO), to compare road transport fuels in terms of;

- Full fuel cycle analysis greenhouse gas emissions
- Full fuel cycle analysis of emissions affecting air quality
- Current and near term health related issues
- Current and near term viability and function
- Current and near term environmental issues not related to GHG’s or air quality issues.

The CSIRO report examined numerous transport fuels including gasoline (PULP) and ethanol. Various forms of ethanol production were considered in the report, which are also considered in this report for the WTW evaluations. A summary of the WTT GHG emissions for gasoline and the ethanol production methods considered by the CSIRO report and converted for E20 is given in Table 7.3. The CSIRO report compared the fuels on a basis of the mass of emissions emitted per kilometre (km) travelled using SimaPro 5.0 life-cycle analysis software, (24).

The CSIRO report was the most current paper reviewed and in addition, the CSIRO report incorporates substantial Australian data for calculating the WTT GHG emissions. For these reasons, conclusions regarding the potential for E20 to produce lower WTW GHG emissions will be drawn from the results of the CSIRO based data.

| **Comparison of Transport Fuels - CSIRO** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Petrol** | **E20** | | | | | | |
| | Reference (PULP)* | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (molasses - Sarina - Economic Allocation)) | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (wheat) | Azeotropic (wheat) fired with wheat straw | Azeotropic (woodwaste) | Azeotropic (ethylene) |
| **$g_{CO2e\text{-}WTT}$ / $g_{E20}$ ($g_{Petrol}$)*** | **0.780** | **0.848** | **1.006** | **0.805** | **0.975** | **0.803** | **0.674** | **1.143** |

Table 7.3 – 'Well to Tank' Greenhouse Gas Emissions

### 7.2.2 Volvo Cars Data (25).

Agnetun et. al. of Volvo, as a part of their paper “A life-Cycle Evaluation of Fuels for Passenger Cars” evaluated the WTW GHG emissions for gasoline and E85. The paper, published in 1993, highlights the necessity to analyse a fuels impact on the environment from a life cycle perspective, rather than focus on the vehicles tailpipe emissions. The paper considers ethanol produced from the fermentation and distillation of grain crops, the WTT GHG emissions for gasoline and the ethanol production method considered converted for the E20 fuel is given in Table 7.4.

| A Life-cycle Evaluation of Fuels for Passenger Cars - Volvo | | |
|---|---|---|
| | **Petrol** | **E20** |
| **Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$** | **0.491** | **0.871** |

**Table 7.4 – 'Well to Tank' Greenhouse Gas Emissions**

### 7.2.3 Energy International Inc. Data (26).

The report prepared by Energy International Inc (EII) provided comparisons of the full fuel cycle emissions of alternative fuels for light duty vehicles including natural gas, liquefied petroleum (LPG), gasoline, reformulated gasoline, ethanol (E85), methanol (M85), and electricity. The report provides a description of the fuel cycle energy requirements, definition of fuel cycle processes, and identification of associated emission rates, estimate of changes expected in energy, technology, and emissions between 1990 (defined as current in the report) and 2000, and comparison of total United States of America and State of California fuel cycle impacts.

The EII report also provides an analysis of the greenhouse gas emissions (Carbon dioxide, Methane and Nitrous oxide) using results of a previous analysis for Gas Research Institute. The GWP values used in the EII report for determining the equivalent carbon dioxide are 11 for methane and 270 for nitrous oxide. These values differ from those used in this report (21 for methane and 310 for Nitrous oxide), hence some discrepancy will be present in the final result. Table 7.5 provides the WTT GHG emissions for gasoline and the ethanol production method considered converted for E20 fuel for both year based cases.

| Light Duty Vehicle Full Fuel Cycle Emissions Analysis - EII Report | | | | |
|---|---|---|---|---|
| | **Current Case** | | **Year 2000 case** | |
| | **Petrol** | **E20** | **Petrol** | **E20** |
| **Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$** | **0.666** | **0.973** | **0.665** | **0.846** |

**Table 7.5 – 'Well to Tank' Greenhouse Gas Emissions**

### 7.2.4 Amoco Oil Company Data (27).

This paper, prepared by Amoco Oil Company (AOC) presents an assessment of the global warming impact of gasoline and other alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), methanol and ethanol. The analysis takes into consideration all emissions sources and greenhouse gases that are associated with the entire fuel-cycle under a variety of process and engine technology scenarios. This paper examines the life cycle analysis of ethanol produced from corn. Table 7.6 contains the WTT GHG emissions for gasoline and the ethanol production method converted for E20 fuel for the technology cases.

The AOC paper was written in 1990 and is an early attempt to determine the Life Cycle Analysis (LCA) of gasoline and ethanol. The GWP values used in the paper highlight the uncertainty of the information available at the time, especially regarding the contribution of the three main GHG's considered in this report. The GHG emissions data provided by the paper were converted to revised CO2e values using the SAR GWP values to allow an equal comparison.

| Global Warming Impact of Gasoline vs. Alternative Transportation Fuels - AOC | | | | |
|---|---|---|---|---|
| | Base Technology Case | | Advanced Technology Case | |
| | Petrol | E20 | Petrol | E20 |
| Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$ | 0.801 | 1.373 | 0.683 | 1.194 |

**Table 7.6 – 'Well to Tank' Greenhouse Gas Emissions**

### 7.2.5 General Motors Corporation Data (28).

The General Motors Corporation (GMC) study was initiated to inform public and private decision makers about the impact of the introduction of advanced fuel/propulsion systems from a societal point of view. The GMC study focuses on the U.S. light duty vehicle market in 2005 and beyond.

The WTT part of the GMC study employed a version of GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) to model the emission impacts of alternative transportation fuels, including the CO2e emissions of the three major GHG's. The GMC study considered various fuels and vehicle platforms, but of interest for the purposes of this report is the data concerning conventional gasoline and ethanol. This report will apply the GMC study data for wet milled Corn by the market value method, woody biomass and herbaceous biomass, converted for E20 fuel, for comparison to gasoline as given in Table 7.7.

The GMC study provides data based on probabilistic uncertainty rather than range based values. Data presented in the 20 and 80 percentile indicates that there is a 20% chance that the value will be lower than the value indicated at the 20 percentile, and 20% likelihood that the value is higher than the value indicated at the 80 percentile. The 50 percentile value is the value that assumes there is 50% likelihood that the actual value is either higher or lower. Presented in this form, the data provides an indication of the accuracy and range of data.

| Well to Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems - North American Analysis - GMC Study | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20% | | | | 50% | | | | 80% | | | |
| | | Petrol | E20 | | | Petrol | E20 | | | Petrol | E20 | | |
| | | | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass | | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass | | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass |
| GMC Study WTT GHG Results | Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$ | 0.809 | 0.966 | 0.577 | 0.712 | 0.839 | 1.015 | 0.640 | 0.759 | 0.870 | 1.065 | 0.703 | 0.808 |

**Table 7.7 – 'Well to Tank' Greenhouse Gas Emissions**

## 7.3 'Tank to Wheel' GHG Emissions

### 7.3.1 ADR (City Cycle) Tailpipe Greenhouse Gas Emissions.

Table 7.8 and Table 7.9 provide the non-renewable TTW GHG emission results from the ADR emissions (city cycle) testing of the new and old vehicles respectively, with Figure 7.1 and Figure 7.2 providing a visual comparison. The TTW GHG emissions are related to the fuel consumption, and the major GHG contributor for each vehicle is the CO2 emissions. The N2O emissions for the two catalysed old vehicles are high, resulting from the high tailpipe NOx emissions. This result highlights the necessity to measure N2O in any future tailpipe GHG emissions assessments to verify the quantities of N2O emissions and improve the accuracy of TTW GHG assessments and potentially the WTW GHG assessment.

| NEW VEHICLES - ADR37/01 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AENHO01 | | AENFO02 | | AENTO03 | | AENHY04 | | AENSU05 | |
| | | Petrol | E20 | Petrol | E20 | Petrol | E20 | Petrol | E20 | Petrol | E20 |
| FC | g/km | 85.427 | 92.565 | 84.086 | 89.189 | 80.104 | 85.775 | 56.095 | 59.446 | 81.646 | 88.301 |
| Greenhouse Gas - CO2e | | | | | | | | | | | |
| CO2 (GWP=1) | $g_{CO2e\text{-}TTW}$/km | 268.350 | 267.566 | 261.034 | 256.185 | 251.984 | 248.408 | 176.578 | 172.044 | 257.085 | 256.188 |
| CH4 (GWP=21) | $g_{CO2e\text{-}TTW}$/km | 0.357 | 0.199 | 0.641 | 0.500 | 0.137 | 0.149 | 0.112 | 0.154 | 0.147 | 0.157 |
| N2O (GWP=310) | $g_{CO2e\text{-}TTW}$/km | 5.249 | 5.136 | 9.393 | 18.573 | 1.457 | 2.755 | 9.197 | 11.142 | 2.315 | 3.286 |
| **Total** | $g_{CO2e\text{-}TTW}$/km | **273.957** | **272.902** | **271.068** | **275.258** | **253.577** | **251.312** | **185.887** | **183.340** | **259.546** | **259.631** |
| **TOTAL Non-Renewable** | **$g_{CO2e\text{-}TTW}$/km** | **273.957** | **235.945** | **271.068** | **239.873** | **253.577** | **217.001** | **185.887** | **159.577** | **259.546** | **224.245** |

**Table 7.8 – 'Tank to Wheel' Greenhouse Gas Emissions**
***For New Vehicles – ADR37/01 (City Cycle)***

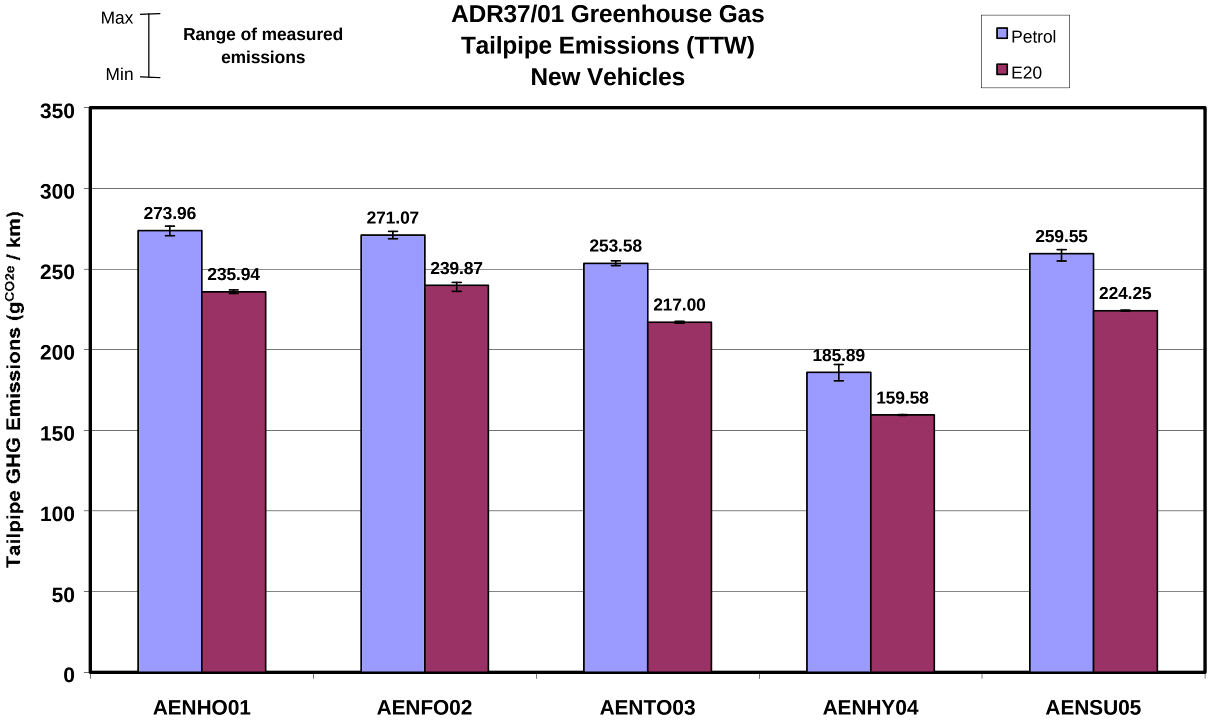


**Figure 7.1 – New Vehicle Tailpipe CO2e Emissions**
***Tested to ADR37/01 (City Cycle)***

| OLD VEHICLES - ADR27C* and ADR37/00 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | AENFO11* | | AENHO12* | | AENMI13 | | AENTO14 | |
| | | Petrol | E20 | Petrol | E20 | Petrol | E20 | Petrol | E20 |
| FC | g/km | 115.920 | 124.718 | 102.944 | 103.912 | 79.923 | 83.380 | 74.678 | 80.029 |
| Greenhouse Gas - CO2e | | | | | | | | | |
| CO2 (GWP=1) | $g_{CO2e-TTW}$/km | 318.762 | 343.966 | 281.129 | 288.156 | 245.726 | 238.839 | 233.492 | 230.159 |
| CH4 (GWP=21) | $g_{CO2e-TTW}$/km | 2.090 | 1.141 | 1.491 | 0.751 | 0.504 | 0.355 | 0.242 | 0.304 |
| N2O (GWP=310) | $g_{CO2e-TTW}$/km | 0.000 | 0.000 | 0.000 | 0.000 | 35.511 | 38.955 | 68.107 | 71.368 |
| **Total** | $g_{CO2e-TTW}$/km | **320.851** | **345.106** | **282.620** | **288.907** | **281.740** | **278.149** | **301.841** | **301.831** |
| **TOTAL Non-Renewable** | $g_{CO2e-TTW}$/km | **320.851** | **297.596** | **282.620** | **249.106** | **281.740** | **245.160** | **301.841** | **270.041** |

**Table 7.9 – 'Tank to Wheel' Greenhouse Gas Emissions for Old Vehicles – ADR27C and ADR37/00 (City Cycle)**

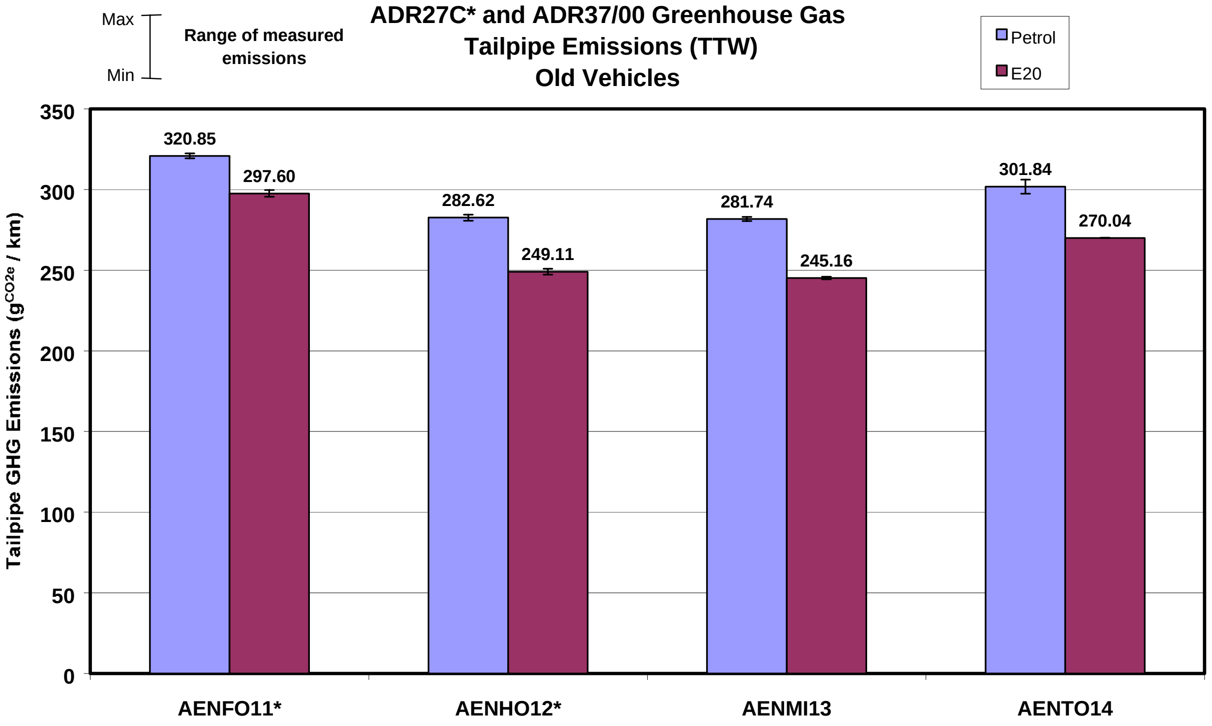


**Figure 7.2 – Old Vehicle Tailpipe CO2e Emissions Tested to ADR27C and ADR37/00 (City Cycle)**

### 7.3.2 AS2877 (Highway) Tailpipe Greenhouse Gas Emissions.

The following tables (Table 7.10 and Table 7.11) and figures (Figure 7.3 and Figure 7.4) provide the TTW GHG emission results from the AS2877 testing (Highway cycle) for the new and old vehicles. As a result of high tailpipe NOx emissions for AENHO01 and AENFO02, the tailpipe GHG emissions are strongly influenced by the estimated N2O emissions. The relatively high NOx emissions of AENHO01 and AENFO02 are the result of AFR enleanment during higher speed vehicle operation. Again, the results highlight the necessity to measure N2O in any future tailpipe GHG emissions assessments.

| NEW VEHICLES - AS2877 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AENHO01 | | AENFO02 | | AENTO03 | | AENHY04 | | AENSU05 | |
| | | Petrol | E20 | Petrol | E20 | Petrol | E20 | Petrol | E20 | Petrol | E20 |
| FC | g/km | 51.622 | 55.318 | 56.376 | 60.194 | 53.390 | 56.332 | 39.626 | 43.666 | 56.924 | 62.812 |
| **Greenhouse Gas - CO2e** | | | | | | | | | | | |
| CO2 (GWP=1) | $g_{CO2e-TTW}$/km | 163.257 | 160.644 | 176.959 | 174.206 | 167.505 | 162.775 | 125.314 | 126.708 | 179.756 | 182.484 |
| CH4 (GWP=21) | $g_{CO2e-TTW}$/km | 0.168 | 0.202 | 0.231 | 0.214 | 0.189 | 0.155 | 0.105 | 0.000* | 0.063 | 0.075 |
| N2O (GWP=310) | $g_{CO2e-TTW}$/km | 52.297 | 46.966 | 206.243 | 186.213 | 0.899 | 1.567 | 3.596 | 5.215 | 0.372 | 0.487 |
| **Total** | $g_{CO2e-TTW}$/km | **215.722** | **207.812** | **383.433** | **360.632** | **168.593** | **164.497** | **129.015** | **131.923** | **180.191** | **183.046** |
| **TOTAL Non-Renewable** | **$g_{CO2e-TTW}$/km** | **215.722** | **185.623** | **383.433** | **336.570** | **168.593** | **142.014** | **129.015** | **114.422** | **180.191** | **157.841** |

**Methane emissions not measured.*

**Table 7.10 – 'Tank to Wheel' Greenhouse Gas Emissions For New Vehicles – AS2877 (Highway)**

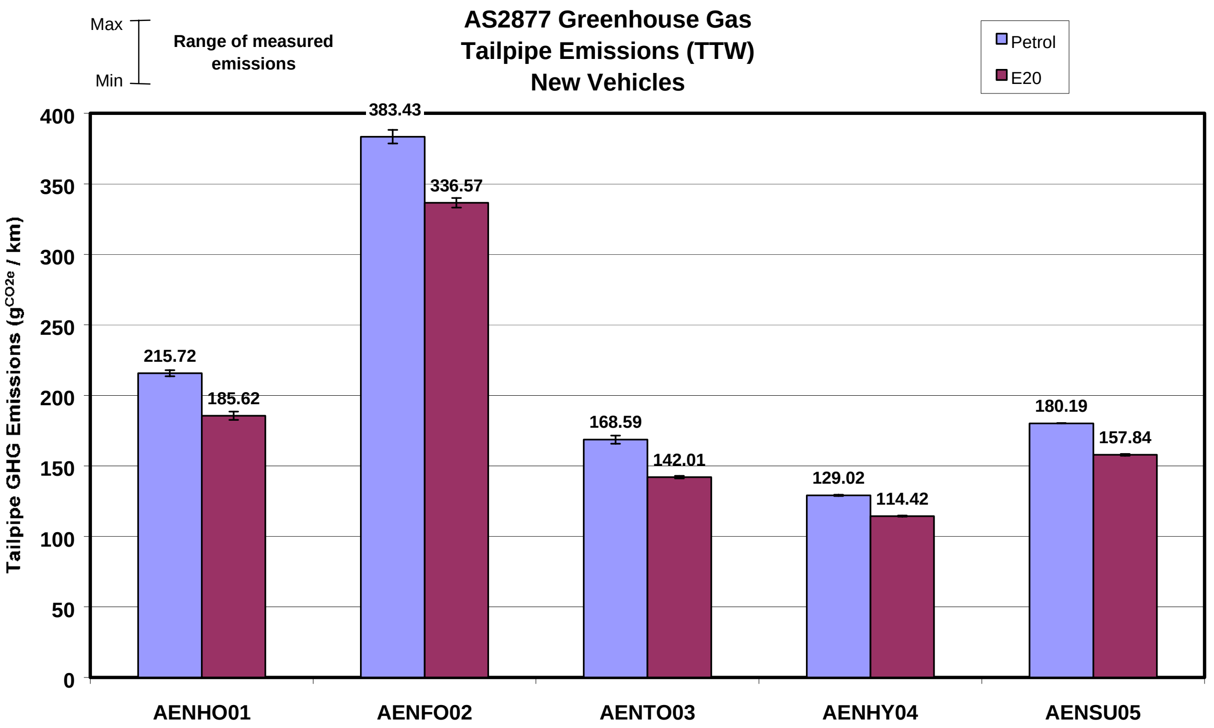


**Figure 7.3 – New Vehicle Tailpipe CO2e Emissions Tested to AS2877 (Highway)**

| OLD VEHICLES - AS2877 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | AENFO11 | | AENHO12 | | AENMI13 | | AENTO14 | |
| | | Petrol | E20 | Petrol | E20 | Petrol | E20 | Petrol | E20 |
| FC | g/km | 69.901 | 74.435 | 72.488 | 74.886 | 48.612 | 51.635 | 50.821 | 55.573 |
| **Greenhouse Gas - CO2e** | | | | | | | | | |
| CO2 (GWP=1) | $g_{CO2e-TTW}$/km | 200.067 | 209.943 | 210.214 | 211.927 | 152.580 | 149.315 | 160.528 | 161.124 |
| CH4 (GWP=21) | $g_{CO2e-TTW}$/km | 1.061 | 0.467 | 0.672 | 0.416 | 0.189 | 0.150 | 0.084 | 0.106 |
| N2O (GWP=310) | $g_{CO2e-TTW}$/km | 0.000 | 0.000 | 0.000 | 0.000 | 39.727 | 38.271 | 23.560 | 36.793 |
| **Total** | $g_{CO2e-TTW}$/km | **201.127** | **210.411** | **210.886** | **212.343** | **192.496** | **187.736** | **184.172** | **198.023** |
| **TOTAL Non-Renewable** | **$g_{CO2e-TTW}$/km** | **201.127** | **181.412** | **210.886** | **183.071** | **192.496** | **167.112** | **184.172** | **175.768** |

**Table 7.11 – 'Tank to Wheel' Greenhouse Gas Emissions For Old Vehicles – AS2877 (Highway)**

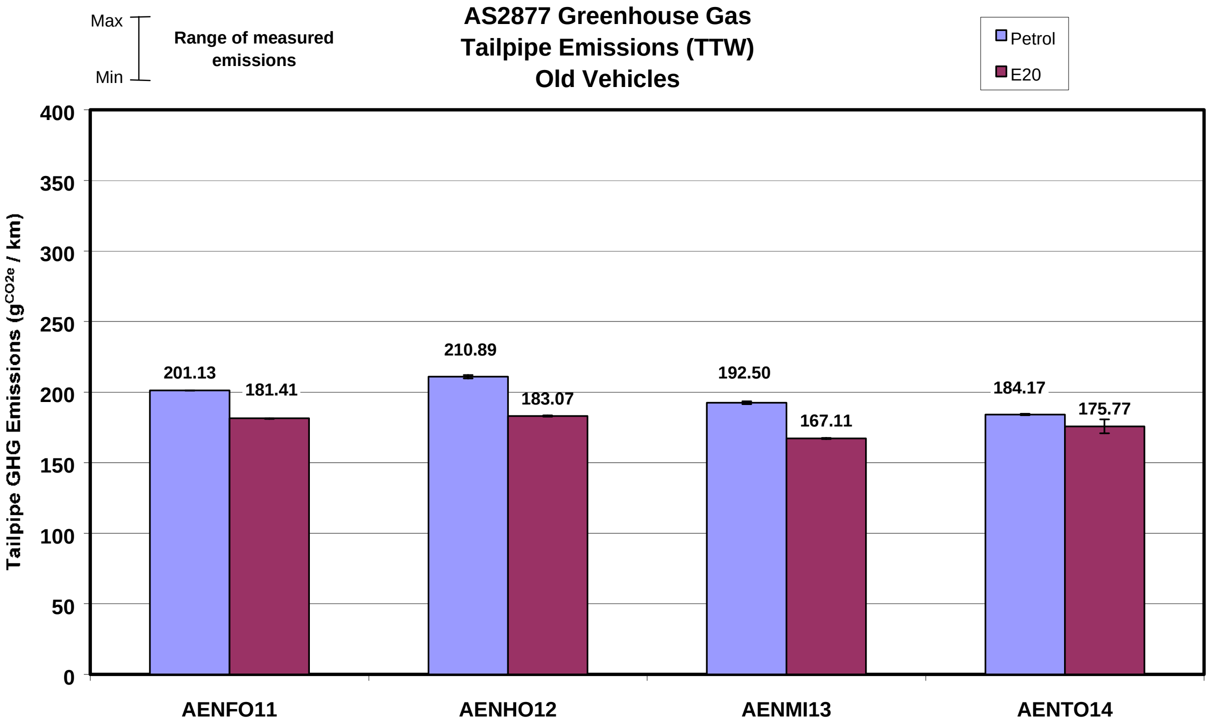


**Figure 7.4 – Old Vehicle Tailpipe CO2e Emissions Tested to AS2877 (Highway)**

### 7.3.3 Evaporative emissions

The evaporative emissions during the hot soak SHED test were sampled to measure THC and air toxics. Methane content was measured from the sampled emissions to determine the potential of GHG emissions resulting from evaporative emissions.

The resulting evaporative methane emissions were measured at, or less than, ambient concentrations (ambient concentration was generally 2.3 ppm). The average concentration differences (gasoline – E20) are small and show no correlation between the use of gasoline and E20.

Based on the measurements taken, it can be concluded that in terms of evaporative emissions;

- There was no evidence that the use of E20 influences greenhouse gas emissions when compared to gasoline.
- There was no evidence for the occurrence of CH4 greenhouse gas emissions.

It can then be assumed there was no GHG contribution from evaporative emissions by the vehicles tested, therefore evaporative emissions GHG contribution is neglected in the TTW assessment. Appendix A provides the table of CH4 measurements for the vehicles tested.

## 7.4 'Well to Wheel' GHG Emissions

The resulting WTT data from each of the five references and TTW data for E20 and gasoline as measured for the city and highway cycles was then summated to produce WTW GHG emissions for each vehicle for each WTT data set.

### 7.4.1 WTW GHG Outcome Based on CSIRO WTT Data.

For the CSIRO based outcome, WTW GHG emissions of gasoline and E20 were compared to determine the potential provided by the use of E20.

Gasoline and E20 GHG emissions were compared using the statistical outcome of the one sided paired t-test (30). The statistical analysis tests the equivalence of the mean value of each vehicles WTW GHG emission when operating on gasoline and E20. The tested vehicles are considered a sample of the Australian passenger vehicle fleet. For the CSIRO data only, the vehicles were assessed for their GHG potential based on their relative age grouping, i.e. the new and old vehicles were assessed separately.

The WTW GHG emissions comparison was assessed either 'Better', 'Same', or 'Worse' based on the following conditions.

**Better –** E20 has lower WTW GHG emissions. Probability of E20 having a mean WTW GHG emission value greater than gasoline is less than 5%.
**Same –** Cannot determine statistically if E20 WTW GHG emissions are greater or lesser than gasoline. Probability for equivalent mean values lies between 5% and 95%.
**Worse –** E20 has higher WTW GHG emissions. Probability of E20 having a mean WTW GHG emission value greater than gasoline is greater than 95%.

| **Comparison of Transport Fuels - CSIRO** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **ADR WTW Emissions City Cycle** | | **Petrol** | **E20** | | | | | | |
| | | Reference (PULP) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (molasses - Sarina - Economic Allocation) | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (wheat) | Azeotropic (wheat) fired with wheat straw | Azeotropic (woodwaste) | Azeotropic (ethylene) |
| **CSIRO WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.780** | **0.848** | **1.006** | **0.805** | **0.975** | **0.803** | **0.674** | **1.143** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 340.6 | 314.4 | 329.0 | 310.5 | 326.2 | 310.3 | 298.3 | 378.7 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 336.6 | 315.5 | 329.6 | 311.7 | 326.8 | 311.5 | 299.9 | 377.2 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 316.0 | 289.7 | 303.3 | 286.1 | 300.6 | 285.9 | 274.8 | 315.0 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 229.6 | 210.0 | 219.4 | 207.4 | 217.5 | 207.3 | 199.6 | 251.3 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 323.2 | 299.1 | 313.1 | 295.3 | 310.3 | 295.2 | 283.7 | 360.6 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 411.2 | 403.3 | 423.0 | 398.0 | 419.2 | 397.8 | 381.6 | 487.7 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 362.9 | 337.2 | 353.6 | 332.8 | 350.4 | 332.6 | 319.1 | 407.7 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 344.0 | 315.8 | 329.0 | 312.3 | 326.5 | 312.1 | 301.3 | 373.5 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 360.1 | 337.9 | 350.5 | 334.5 | 348.1 | 334.3 | 323.9 | 393.3 |
| New Vehicle - E20 to Petrol Assessment | | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |
| Old Vehicle - E20 to Petrol Assessment | | | ***Better*** | ***Same*** | ***Better*** | ***Same*** | ***Better*** | ***Better*** | ***Worse*** |
| **Overall - E20 to Petrol Assessment** | | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |

**Table 7.12 – 'Well to Wheel' ADR GHG Emissions (City Cycle)**

| **Comparison of Transport Fuels - CSIRO** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **AS2877 WTW Emissions Highway** | | **Petrol** | **E20** | | | | | | |
| | | Reference (PULP) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (molasses - Sarina - Economic Allocation) | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (wheat) | Azeotropic (wheat) fired with wheat straw | Azeotropic (woodwaste) | Azeotropic (ethylene) |
| **CSIRO WTT GHG Results** | **Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$** | **0.780** | **0.848** | **1.006** | **0.805** | **0.975** | **0.803** | **0.674** | **1.143** |
| **AENHO01** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 256.0 | 232.5 | 241.3 | 230.2 | 239.6 | 230.0 | 222.9 | 271.0 |
| **AENFO02** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 427.4 | 387.6 | 397.1 | 385.0 | 395.3 | 384.9 | 377.1 | 429.4 |
| **AENTO03** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 210.2 | 189.8 | 198.7 | 187.4 | 196.9 | 187.3 | 180.0 | 228.9 |
| **AENHY04** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 159.9 | 151.4 | 158.3 | 149.6 | 157.0 | 149.5 | 143.8 | 181.8 |
| **AENSU05** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 224.6 | 211.1 | 221.0 | 208.4 | 219.1 | 208.3 | 200.1 | 254.8 |
| **AENFO11** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 255.6 | 244.5 | 256.3 | 241.3 | 254.0 | 241.2 | 231.5 | 295.5 |
| **AENHO12** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 267.4 | 246.5 | 258.4 | 243.4 | 256.1 | 243.2 | 233.5 | 297.9 |
| **AENMI13** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 230.4 | 210.9 | 219.0 | 208.7 | 217.5 | 208.6 | 201.9 | 246.8 |
| **AENTO14** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 223.8 | 222.9 | 231.7 | 220.5 | 230.0 | 220.4 | 213.2 | 261.5 |
| New Vehicle - E20 to Petrol Assessment | | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |
| Old Vehicle - E20 to Petrol Assessment | | | ***Better*** | ***Same*** | ***Better*** | ***Same*** | ***Better*** | ***Better*** | ***Worse*** |
| **Overall - E20 to Petrol Assessment** | | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |

**Table 7.13 – 'Well to Wheel' AS2877 GHG Emissions (Highway)**

### 7.4.1.1 City Cycle WTW GHG Emissions.

Referring to Table 7.12, with the exception of Ethanol produced from ethylene, the overall City Cycle WTW results indicate E20 will provide a statistically significant WTW GHG advantage over gasoline. The E20 WTT and City Cycle TTW CO2e emissions are high for ethanol produced from ethylene because it is not considered a renewable fuel, i.e. the sequestration of CO2 produced by the combustion of ethanol is not considered in the WTW assessment.

The City Cycle WTW results indicate new vehicles using E20 will provide a statistically significant GHG advantage over gasoline, again with the exception of ethanol produced by ethylene.

For the old vehicles, the statistically significant advantage E20 will have over gasoline is dependant on the method of ethanol production, with the exception of ethanol produced from ethylene where there is a statistically significant disadvantage. E20 has an advantage in most cases except for two scenarios; where ethanol is produced from molasses with an economic allocation for the molasses and ethanol produced from premium wheat. For these two scenarios, E20 and gasoline are expected to produce similar GHG emissions. For comparative purposes, a graphical representation of the City Cycle WTW GHG emissions for a new vehicle (AENHO01) and an old vehicle (AENFO11) are shown in Figure 7.5 and Figure 7.6 respectively.

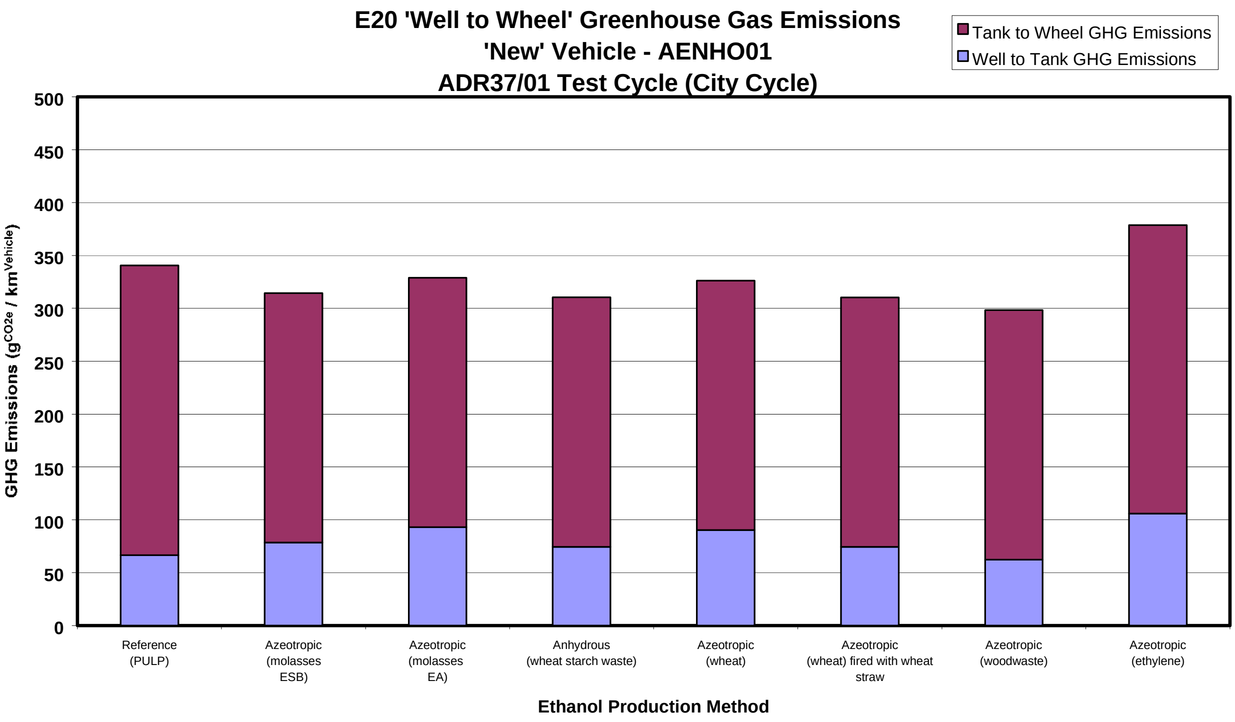


**Figure 7.5 – 'Well to Wheel' Greenhouse Gas Emissions for Holden Commodore VX – AENHO01 (City Cycle)**

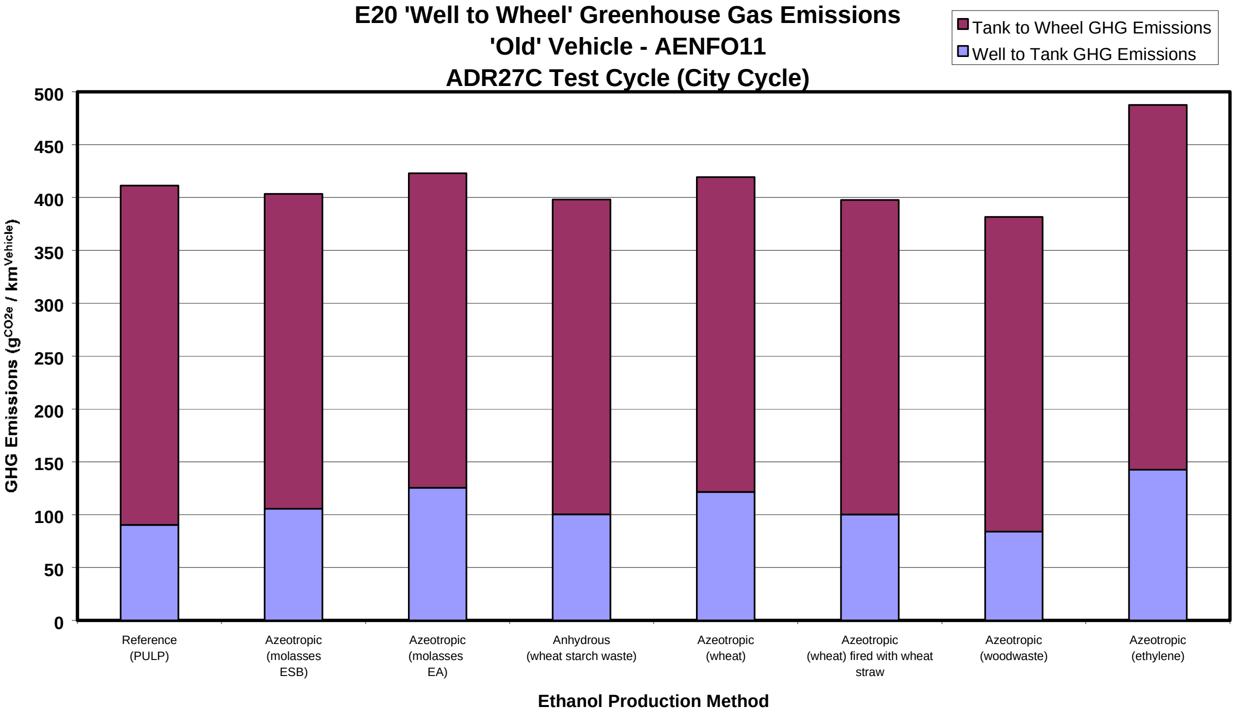


**Figure 7.6 – 'Well to Wheel' Greenhouse Gas Emissions for Ford Falcon XF – AENFO11 (City Cycle)**

### 7.4.1.2 Highway WTW GHG Emissions.

The same conclusions can be drawn for the AS2877 (Highway) WTW GHG results, Table 7.13, as those made for the City Cycle WTW GHG results for the new, old and overall fleet.

For comparative purposes, a graphical representation of the Highway WTW GHG emissions for a new vehicle (AENHO01) and an old vehicle (AENFO11) are shown in Figure 7.7 and Figure 7.8 respectively.

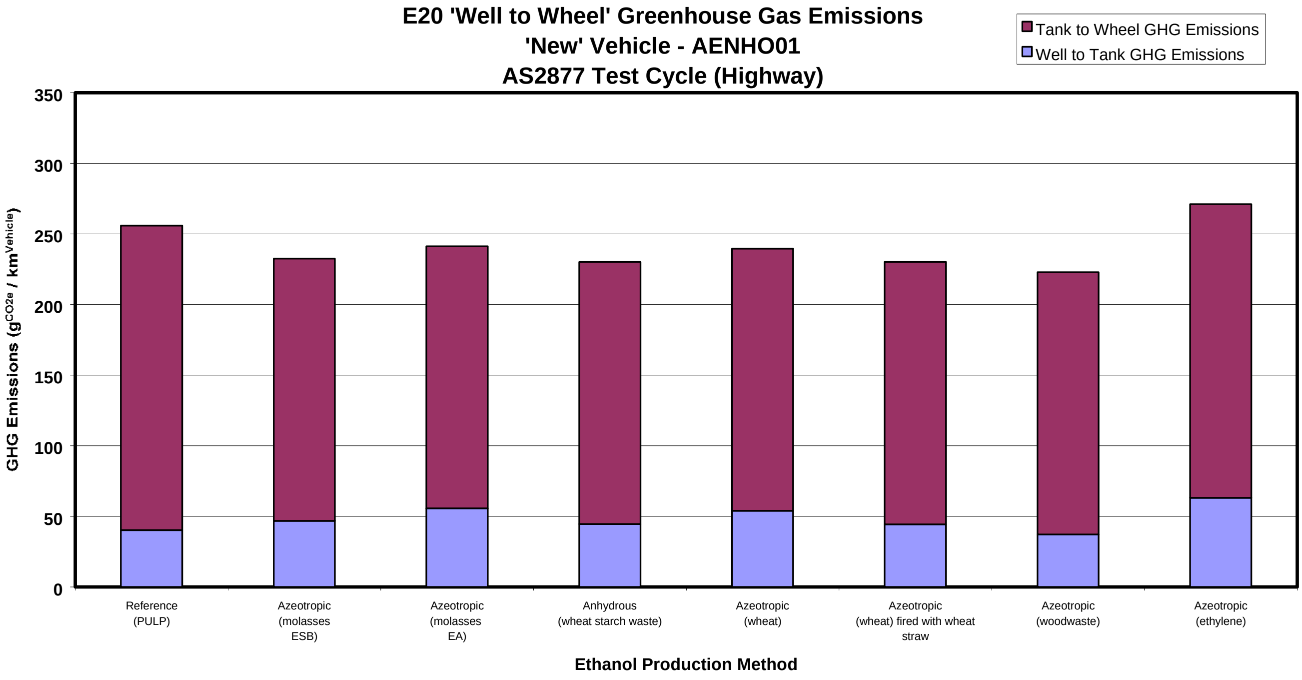


**Figure 7.7 – 'Well to Wheel' Greenhouse Gas Emissions For Holden Commodore VX – AENHO01 (Highway)**

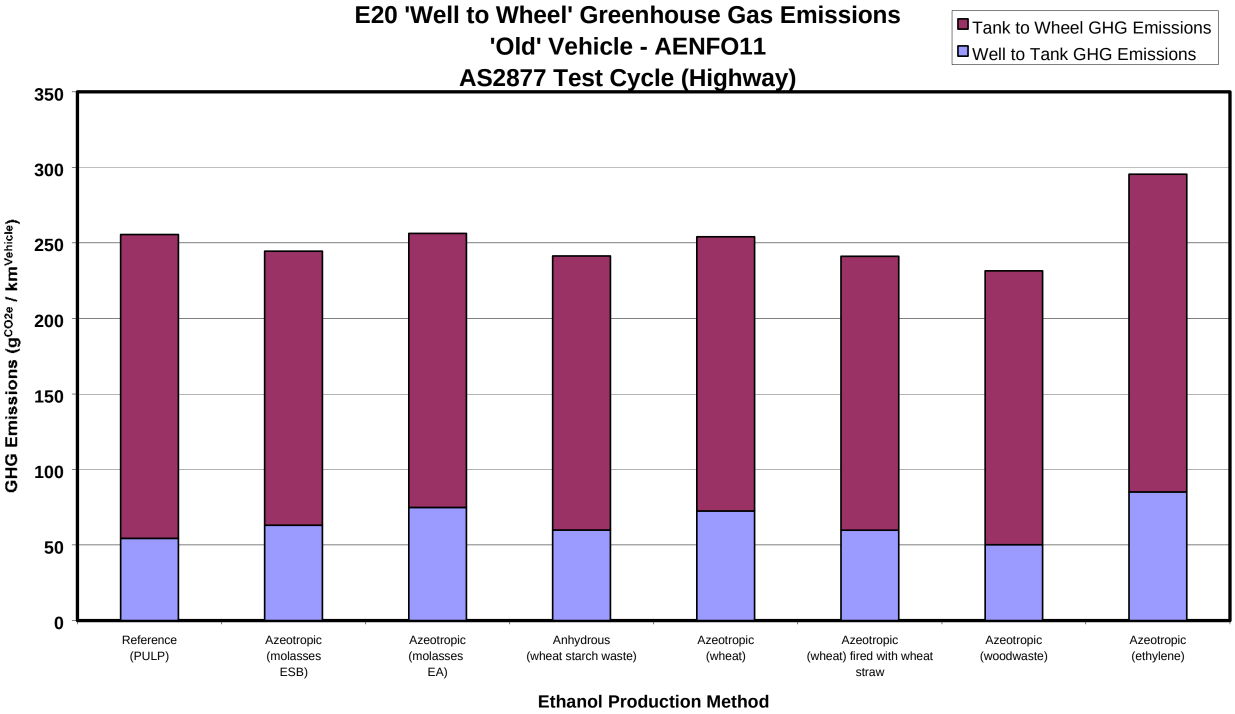


**Figure 7.8 – 'Well to Wheel' Greenhouse Gas Emissions For Ford Falcon XF – AENFO11 (Highway)**

### 7.4.1.3 Overall WTW GHG Emissions.

Considering both city and highway driving conditions, E20 will provide a statistically significant GHG emission advantage over gasoline for both new and old vehicles, when the two age groups are considered individually, so long as the ethanol is produced according to the following methods as described by the CSIRO report;

- Azeotropic ethanol from molasses – with expanded system boundaries to determine the energy allocations.
- Anhydrous ethanol from wheat starch from waste wheat.
- Azeotropic ethanol from premium wheat where the wheat waste (straw etc) is used to provide power to the plant.
- Azeotropic ethanol from lignocellulose (wood-waste).

E20 containing ethanol produced by wood-waste provides a statistically significant GHG advantage over gasoline, this being the greatest and approximately 11% on average when considering the overall fleet.

### 7.4.2 WTW GHG Outcome Based on Volvo Cars WTT Data.

| A Life-cycle Evaluation of Fuels for Passenger Cars | | | |
|---|---|---|---|
| | | Petrol | E20 (Grain Crops) |
| **Volvo WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.491** | **0.871** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 315.9 | 316.6 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 312.4 | 317.6 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 292.9 | 291.7 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 213.4 | 211.4 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 299.7 | 301.2 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 377.8 | 406.3 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 333.2 | 339.7 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 321.0 | 317.8 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 338.5 | 339.8 |

**Table 7.14 – 'Well to Wheel' ADR GHG Emissions (City Cycle)**

| A Life-cycle Evaluation of Fuels for Passenger Cars | | | |
|---|---|---|---|
| | | Petrol | E20 (Grain Crops) |
| **Volvo WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.491** | **0.871** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 241.1 | 233.8 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 411.1 | 389.0 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 194.8 | 191.1 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 148.5 | 152.5 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 208.2 | 212.6 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 235.5 | 246.3 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 246.5 | 248.3 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 216.4 | 212.1 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 209.1 | 224.2 |

**Table 7.15 – 'Well to Wheel' ADR GHG Emissions (Highway)**

The Volvo cars data for the quantity of CO2e emitted per gram of gasoline in the WTT period shows the greatest variation from the values obtained from other literature sources. The $g_{CO2e-WTT}$ / $g_{Gasoline}$ value from the Volvo paper (0.491) is approximately 35% less than the CSIRO value (0.78). The gasoline data from other sources vary by no more than 15% from the CSIRO value.

However, in comparison the E20 WTT value from the Volvo data varies by approximately 10% of typical CSIRO grain crop E20 WTT values. The relatively smaller variation in the E20 WTT value for the Volvo data from the CSIRO data, can be accounted for by the high ethanol WTT GHG emission given by the Volvo data. The Volvo data has an ethanol (E100) WTT GHG emission of 2.3 $g_{CO2e}/g_{EtOH}$ (EtOH = ethanol) compared to the CSIRO data of 0.8 $g_{CO2e}/g_{EtOH}$ (viable methods for ethanol production from grain crops)

### 7.4.3 WTW GHG Outcome Based on EII WTT Data.

| Light Duty Vehicle Full Fuel Cycle Emissions Analysis | | | | | |
|---|---|---|---|---|---|
| | | 1994 Case | | 2000 Case | |
| | | Petrol | E20 (Corn) | Petrol | E20 (Corn) |
| **EII WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.666** | **0.973** | **0.665** | **0.846** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 330.9 | 326.0 | 330.8 | 314.2 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 327.1 | 326.6 | 327.0 | 315.3 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 306.9 | 300.5 | 306.9 | 289.5 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 223.2 | 217.4 | 223.2 | 209.8 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 313.9 | 310.2 | 313.9 | 298.9 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 398.1 | 418.9 | 398.0 | 403.1 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 351.2 | 350.2 | 351.1 | 337.0 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 335.0 | 326.3 | 334.9 | 315.7 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 351.6 | 347.9 | 351.5 | 337.7 |

**Table 7.16 – 'Well to Wheel' ADR GHG Emissions (City Cycle)**

| Light Duty Vehicle Full Fuel Cycle Emissions Analysis | | | | | |
|---|---|---|---|---|---|
| | | 1994 Case | | 2000 Case | |
| | | Petrol | E20 (Corn) | Petrol | E20 (Corn) |
| **EII WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.666** | **0.973** | **0.665** | **0.846** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 250.1 | 239.4 | 250.1 | 232.4 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 421.0 | 395.1 | 420.9 | 387.5 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 204.2 | 196.8 | 204.1 | 189.6 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 155.4 | 156.9 | 155.4 | 151.3 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 218.1 | 219.0 | 218.1 | 211.0 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 247.7 | 253.8 | 247.6 | 244.4 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 259.2 | 255.9 | 259.1 | 246.4 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 224.9 | 217.3 | 224.8 | 210.8 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 218.0 | 229.8 | 218.0 | 222.8 |

**Table 7.17 – 'Well to Wheel' ADR GHG Emissions (Highway)**

### 7.4.4 WTW GHG Outcome Based on Amoco Oil Company Data.

| Global Warming Impact of Gasoline vs. Alternative Transportation Fuels - AOC | | | | | |
|---|---|---|---|---|---|
| | | Base Technology Case | | Advanced Technology Case | |
| | | Petrol | E20 (Corn) | Petrol | E20 (Corn) |
| **AOC WTT GHG Results** | **Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$** | **0.801** | **1.373** | **0.683** | **1.194** |
| **AENHO01** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 342.4 | 363.1 | 332.3 | 346.5 |
| **AENFO02** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 338.5 | 362.4 | 328.5 | 346.4 |
| **AENTO03** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 317.8 | 334.8 | 308.3 | 319.4 |
| **AENHY04** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 230.8 | 241.2 | 224.2 | 230.6 |
| **AENSU05** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 325.0 | 345.5 | 315.3 | 329.7 |
| **AENFO11** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 413.7 | 468.9 | 400.0 | 446.5 |
| **AENHO12** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 365.1 | 391.8 | 352.9 | 373.2 |
| **AENMI13** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 345.8 | 359.7 | 336.3 | 344.7 |
| **AENTO14** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 361.7 | 380.0 | 352.9 | 365.6 |

**Table 7.18 – 'Well to Wheel' ADR GHG Emissions (City Cycle)**

| Global Warming Impact of Gasoline vs. Alternative Transportation Fuels - AOC | | | | | |
|---|---|---|---|---|---|
| | | Base Technology Case | | Advanced Technology Case | |
| | | Petrol | E20 (Corn) | Petrol | E20 (Corn) |
| **AOC WTT GHG Results** | **Total $g_{CO2e\text{-}WTT}$ / $g_{Fuel}$** | **0.801** | **1.373** | **0.683** | **1.194** |
| **AENHO01** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 257.1 | 261.6 | 251.0 | 251.7 |
| **AENFO02** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 428.6 | 419.2 | 421.9 | 408.4 |
| **AENTO03** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 211.4 | 219.4 | 205.1 | 209.3 |
| **AENHY04** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 160.8 | 174.4 | 156.1 | 166.6 |
| **AENSU05** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 225.8 | 244.1 | 219.1 | 232.8 |
| **AENFO11** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 257.1 | 283.6 | 248.9 | 270.3 |
| **AENHO12** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 269.0 | 285.9 | 260.4 | 272.5 |
| **AENMI13** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 231.5 | 238.0 | 225.7 | 228.8 |
| **AENTO14** | $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$ | 224.9 | 252.1 | 218.9 | 242.1 |

**Table 7.19 – 'Well to Wheel' ADR GHG Emissions (Highway)**

### 7.4.5 WTW GHG Outcome Based on GMC WTT Data.

| Well to Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems - North American Analysis | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20% | | | | 50% | | | | 80% | | | |
| | | | E20 | | | | E20 | | | | E20 | | |
| | | Petrol | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass | Petrol | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass | Petrol | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass |
| **GMC Study WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.809** | **0.966** | **0.577** | **0.712** | **0.839** | **1.015** | **0.640** | **0.759** | **0.870** | **1.065** | **0.703** | **0.808** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 343.1 | 325.4 | 289.4 | 301.8 | 345.6 | 329.9 | 295.2 | 306.2 | 348.3 | 334.6 | 301.0 | 310.7 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 339.1 | 326.0 | 291.3 | 303.4 | 341.6 | 330.4 | 296.9 | 307.6 | 344.2 | 334.9 | 302.5 | 311.9 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 318.4 | 299.9 | 266.5 | 278.1 | 320.8 | 304.1 | 271.9 | 282.1 | 323.3 | 308.4 | 277.3 | 286.3 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 231.3 | 217.0 | 193.9 | 201.9 | 233.0 | 219.9 | 197.6 | 204.7 | 234.7 | 222.9 | 201.3 | 207.6 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 325.6 | 309.5 | 275.2 | 287.1 | 328.1 | 313.9 | 280.7 | 291.3 | 330.6 | 318.3 | 286.3 | 295.6 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 414.6 | 418.1 | 369.6 | 386.4 | 418.1 | 424.2 | 377.4 | 392.3 | 421.7 | 430.5 | 385.2 | 398.4 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 365.9 | 349.5 | 309.1 | 323.1 | 369.0 | 354.6 | 315.6 | 328.0 | 372.2 | 359.8 | 322.1 | 333.1 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 346.4 | 325.7 | 293.3 | 304.5 | 348.8 | 329.8 | 298.5 | 308.5 | 351.3 | 334.0 | 303.7 | 312.5 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 362.3 | 347.4 | 316.2 | 327.0 | 364.5 | 351.3 | 321.2 | 330.8 | 366.8 | 355.3 | 326.3 | 334.7 |

**Table 7.20 – 'Well to Wheel' ADR GHG Emissions (City Cycle)**

| Well to Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems - North American Analysis | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20% | | | | 50% | | | | 80% | | | |
| | | | E20 | | | | E20 | | | | E20 | | |
| | | Petrol | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass | Petrol | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass | Petrol | Corn, Wet Milled, Market Value | Woody Biomass | Herbaceous biomass |
| **GMC Study WTT GHG Results** | **Total $g_{CO2e-WTT}$ / $g_{Fuel}$** | **0.809** | **0.966** | **0.577** | **0.712** | **0.839** | **1.015** | **0.640** | **0.759** | **0.870** | **1.065** | **0.703** | **0.808** |
| **AENHO01** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 257.5 | 239.1 | 217.5 | 225.0 | 259.0 | 241.8 | 221.0 | 227.6 | 260.6 | 244.6 | 224.5 | 230.3 |
| **AENFO02** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 429.0 | 394.7 | 371.3 | 379.4 | 430.7 | 397.7 | 375.1 | 382.3 | 432.5 | 400.7 | 378.9 | 385.2 |
| **AENTO03** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 211.8 | 196.4 | 174.5 | 182.1 | 213.4 | 199.2 | 178.1 | 184.8 | 215.1 | 202.0 | 181.6 | 187.5 |
| **AENHY04** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 161.1 | 156.6 | 139.6 | 145.5 | 162.3 | 158.7 | 142.4 | 147.6 | 163.5 | 160.9 | 145.1 | 149.7 |
| **AENSU05** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 226.2 | 218.5 | 194.1 | 202.6 | 228.0 | 221.6 | 198.0 | 205.5 | 229.7 | 224.8 | 202.0 | 208.6 |
| **AENFO11** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 257.7 | 253.3 | 224.4 | 234.4 | 259.8 | 257.0 | 229.0 | 237.9 | 262.0 | 260.7 | 233.7 | 241.5 |
| **AENHO12** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 269.5 | 255.4 | 226.3 | 236.4 | 271.7 | 259.1 | 231.0 | 239.9 | 274.0 | 262.9 | 235.7 | 243.6 |
| **AENMI13** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 231.8 | 217.0 | 196.9 | 203.9 | 233.3 | 219.5 | 200.1 | 206.3 | 234.8 | 222.1 | 203.4 | 208.8 |
| **AENTO14** | $g_{CO2e-WTW}$ / $km_{Vehicle}$ | 225.3 | 229.5 | 207.8 | 215.3 | 226.8 | 232.2 | 211.3 | 218.0 | 228.4 | 235.0 | 214.8 | 220.7 |

**Table 7.21 – 'Well to Wheel' ADR GHG Emissions (Highway)**

## 7.5 WTW Greenhouse Gas Emissions Conclusions

A desktop study and literature review of data sourced from five publications has been analysed to determine the 'Well to Tank' greenhouse gas emissions for gasoline and E20 fuel. The CSIRO report is considered the most applicable paper reviewed as part of the work reported here, as it incorporates substantial Australian data for calculating the 'Well to Tank' emissions.

The Global Warming Potentials adopted within this report assume the Second Assessment Report values as defined by the Intergovernmental Panel on Climate Change (IPCC).

Test vehicle tailpipe emissions were directly measured for Carbon Dioxide and Methane. The Nitrous Oxide tailpipe emissions were estimated based on a relationship with the measured tailpipe Oxides of Nitrogen. Evaporative emissions were measured for methane content during the hot soak period of the ADR vehicle emissions testing. From these emission measurements, the 'Tank to Wheel' greenhouse gas emissions were determined.

The 'Well to Wheel' greenhouse gas emissions were calculated from the summation of the 'Well to Tank' data obtained from the literature reviewed and the measurements of 'Tank to Wheel' greenhouse gas emissions from the test vehicles. The 'Well to Wheel' greenhouse gases emitted by vehicles fuelled with gasoline were compared to the same vehicles fuelled with E20, to determine the advantage, if any, of E20 in terms of greenhouse gas emissions.

Data from the CSIRO report and measurements of Tank to Wheel greenhouse gas were used to draw conclusions regarding the potential for E20 to produce lower 'Well to Wheel' greenhouse gas emissions. The specifics of the 'Well to Wheel' analysis data are summarised as follows:

- E20, consisting of ethanol produced from wood waste, will produce lower quantities of greenhouse gas per unit of fuel, when compared to gasoline, during the 'Well to Tank' period.
- It can be concluded that E20, with the exception of E20 consisting of ethanol produced from wood waste, will produce higher quantities of greenhouse gas per unit of fuel, when compared to gasoline, during the 'Well to Tank' period. This same conclusion can be drawn from the GMC data.
- Future measurement of tailpipe greenhouse gas emissions should utilise the direct measurement of N2O thereby improving the accuracy and understanding of the behaviour of N2O formation from the vehicle fleet.
- Neither E20 nor gasoline emits CH4 gas as a result of evaporative losses from the vehicle.
- E20 consisting of ethanol produced from ethylene emits with statistical significance greater 'Well to Wheel' greenhouse gas emissions than gasoline for old and new vehicles, and the Australian vehicle fleet.

- E20, consisting of ethanol produced by any method other than from ethylene, emits with statistical significance less 'Well to Wheel' greenhouse gas emissions than gasoline for new vehicles, and when the entire Australian vehicle fleet is considered.
- E20, with the exclusion of ethanol produced from ethylene, from molasses with an economic allocation and from premium wheat, emits with statistical significance less 'Well to Wheel' greenhouse gas emissions than gasoline for the old vehicles.
- E20, consisting of ethanol produced from molasses with an economic allocation and from premium wheat, can be considered to emit statistically similar 'Well to Wheel' greenhouse gas emissions when compared to gasoline for old vehicles.
- E20 containing ethanol produced by wood-waste provides with statistical significance the greatest GHG advantage over gasoline, approximately 11% on average when considering the overall fleet and both city and highway driving.

| **Comparison of Transport Fuels - CSIRO** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **ADR WTW Emissions City Cycle** | | **Petrol** | **E20** | | | | | | |
| | | Reference (PULP) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (molasses - Sarina - Economic Allocation) | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (wheat) | Azeotropic (wheat) fired with wheat straw | Azeotropic (woodwaste) | Azeotropic (ethylene) |
| **AENHO01** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 66.6 | 78.5 | 93.1 | 74.5 | 90.3 | 74.3 | 62.3 | 105.8 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 274.0 | 235.9 | 235.9 | 235.9 | 235.9 | 235.9 | 235.9 | 272.9 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **340.6** | **314.4** | **329.0** | **310.5** | **326.2** | **310.3** | **298.3** | **378.7** |
| **AENHFO02** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 65.6 | 75.6 | 89.7 | 71.8 | 87.0 | 71.6 | 60.1 | 101.9 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 271.1 | 239.9 | 239.9 | 239.9 | 239.9 | 239.9 | 239.9 | 275.3 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **336.6** | **315.5** | **329.6** | **311.7** | **326.8** | **311.5** | **299.9** | **377.2** |
| **AENTO03** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 62.4 | 72.7 | 86.3 | 69.1 | 83.6 | 68.9 | 57.8 | 98.0 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 253.6 | 217.0 | 217.0 | 217.0 | 217.0 | 217.0 | 217.0 | 217.0 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **316.0** | **289.7** | **303.3** | **286.1** | **300.6** | **285.9** | **274.8** | **315.0** |
| **AENHY04** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 43.7 | 50.4 | 59.8 | 47.9 | 58.0 | 47.7 | 40.0 | 67.9 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 185.9 | 159.6 | 159.6 | 159.6 | 159.6 | 159.6 | 159.6 | 183.3 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **229.6** | **210.0** | **219.4** | **207.4** | **217.5** | **207.3** | **199.6** | **251.3** |
| **AENSU05** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 63.7 | 74.8 | 88.8 | 71.1 | 86.1 | 70.9 | 59.5 | 100.9 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 259.5 | 224.2 | 224.2 | 224.2 | 224.2 | 224.2 | 224.2 | 259.6 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **323.2** | **299.1** | **313.1** | **295.3** | **310.3** | **295.2** | **283.7** | **360.6** |
| **AENFO11** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 90.4 | 105.7 | 125.4 | 100.4 | 121.6 | 100.2 | 84.0 | 142.6 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 320.9 | 297.6 | 297.6 | 297.6 | 297.6 | 297.6 | 297.6 | 345.1 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **411.2** | **403.3** | **423.0** | **398.0** | **419.2** | **397.8** | **381.6** | **487.7** |
| **AENHO12** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 80.3 | 88.1 | 104.5 | 83.7 | 101.3 | 83.4 | 70.0 | 118.8 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 282.6 | 249.1 | 249.1 | 249.1 | 249.1 | 249.1 | 249.1 | 288.9 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **362.9** | **337.2** | **353.6** | **332.8** | **350.4** | **332.6** | **319.1** | **407.7** |
| **AENMI13** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 62.3 | 70.7 | 83.9 | 67.1 | 81.3 | 67.0 | 56.2 | 95.3 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 281.7 | 245.2 | 245.2 | 245.2 | 245.2 | 245.2 | 245.2 | 278.1 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **344.0** | **315.8** | **329.0** | **312.3** | **326.5** | **312.1** | **301.3** | **373.5** |
| **AENTO14** | $g_{CO2e-WTT}$ / $km_{Vehicle}$ | 58.2 | 67.8 | 80.5 | 64.4 | 78.0 | 64.3 | 53.9 | 91.5 |
| | Non-Renewable $g_{CO2e-TTW}$ / $km_{Vehicle}$ | 301.8 | 270.0 | 270.0 | 270.0 | 270.0 | 270.0 | 270.0 | 301.8 |
| | **Non-Renewable $g_{CO2e-WTW}$ / $km_{Vehicle}$** | **360.1** | **337.9** | **350.5** | **334.5** | **348.1** | **334.3** | **323.9** | **393.3** |

**Table 7.22 – Summarised City Cycle Gasoline and E20 Greenhouse Gas Emissions.**

A summary of each of the vehicles city and highway WTT, TTW and WTW GHG emissions based on the CSIRO, (24) data is provided in Table 7.21 and Table 7.22 respectively. This is provided should specific vehicle related E20 GHG potentials for city and highway and the combination be required.

| Comparison of Transport Fuels - CSIRO | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| AS2877 WTW Emissions Highway | | Petrol | E20 | | | | | | |
| | | Reference (PULP) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (molasses - Sarina - Economic Allocation) | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (wheat) | Azeotropic (wheat) fired with wheat straw | Azeotropic (woodwaste) | Azeotropic (ethylene) |
| **AENHO01** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 40.2 | 46.9 | 55.6 | 44.5 | 53.9 | 44.4 | 37.3 | 63.2 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 215.7 | 185.6 | 185.6 | 185.6 | 185.6 | 185.6 | 185.6 | 207.8 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **256.0** | **232.5** | **241.3** | **230.2** | **239.6** | **230.0** | **222.9** | **271.0** |
| **AENHFO02** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 44.0 | 51.0 | 60.5 | 48.5 | 58.7 | 48.3 | 40.5 | 68.8 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 383.4 | 336.6 | 336.6 | 336.6 | 336.6 | 336.6 | 336.6 | 360.6 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **427.4** | **387.6** | **397.1** | **385.0** | **395.3** | **384.9** | **377.1** | **429.4** |
| **AENTO03** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 41.6 | 47.8 | 56.7 | 45.4 | 54.9 | 45.2 | 37.9 | 64.4 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 168.6 | 142.0 | 142.0 | 142.0 | 142.0 | 142.0 | 142.0 | 164.5 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **210.2** | **189.8** | **198.7** | **187.4** | **196.9** | **187.3** | **180.0** | **228.9** |
| **AENHY04** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 30.9 | 37.0 | 43.9 | 35.2 | 42.6 | 35.1 | 29.4 | 49.9 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 129.0 | 114.4 | 114.4 | 114.4 | 114.4 | 114.4 | 114.4 | 131.9 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **159.9** | **151.4** | **158.3** | **149.6** | **157.0** | **149.5** | **143.8** | **181.8** |
| **AENSU05** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 44.4 | 53.2 | 63.2 | 50.6 | 61.2 | 50.4 | 42.3 | 71.8 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 180.2 | 157.8 | 157.8 | 157.8 | 157.8 | 157.8 | 157.8 | 183.0 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **224.6** | **211.1** | **221.0** | **208.4** | **219.1** | **208.3** | **200.1** | **254.8** |
| **AENFO11** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 54.5 | 63.1 | 74.9 | 59.9 | 72.6 | 59.8 | 50.1 | 85.1 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 201.1 | 181.4 | 181.4 | 181.4 | 181.4 | 181.4 | 181.4 | 210.4 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **255.6** | **244.5** | **256.3** | **241.3** | **254.0** | **241.2** | **231.5** | **295.5** |
| **AENHO12** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 56.5 | 63.5 | 75.3 | 60.3 | 73.0 | 60.1 | 50.4 | 85.6 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 210.9 | 183.1 | 183.1 | 183.1 | 183.1 | 183.1 | 183.1 | 212.3 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **267.4** | **246.5** | **258.4** | **243.4** | **256.1** | **243.2** | **233.5** | **297.9** |
| **AENMI13** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 37.9 | 43.8 | 51.9 | 41.6 | 50.3 | 41.5 | 34.8 | 59.0 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 192.5 | 167.1 | 167.1 | 167.1 | 167.1 | 167.1 | 167.1 | 187.7 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **230.4** | **210.9** | **219.0** | **208.7** | **217.5** | **208.6** | **201.9** | **246.8** |
| **AENTO14** | $g_{CO2e\text{-}WTT}$ / $km_{Vehicle}$ | 39.6 | 47.1 | 55.9 | 44.7 | 54.2 | 44.6 | 37.4 | 63.5 |
| | Non-Renewable $g_{CO2e\text{-}TTW}$ / $km_{Vehicle}$ | 184.2 | 175.8 | 175.8 | 175.8 | 175.8 | 175.8 | 175.8 | 198.0 |
| | **Non-Renewable $g_{CO2e\text{-}WTW}$ / $km_{Vehicle}$** | **223.8** | **222.9** | **231.7** | **220.5** | **230.0** | **220.4** | **213.2** | **261.5** |

**Table 7.23 – Summarised Highway Gasoline and E20 Greenhouse Gas Emissions.**

The City Cycle and Highway 'Well to Wheel' greenhouse gas emissions for E20 consisting of ethanol produced from wood waste are shown in Figure 7.9 and Figure 7.10 respectively.

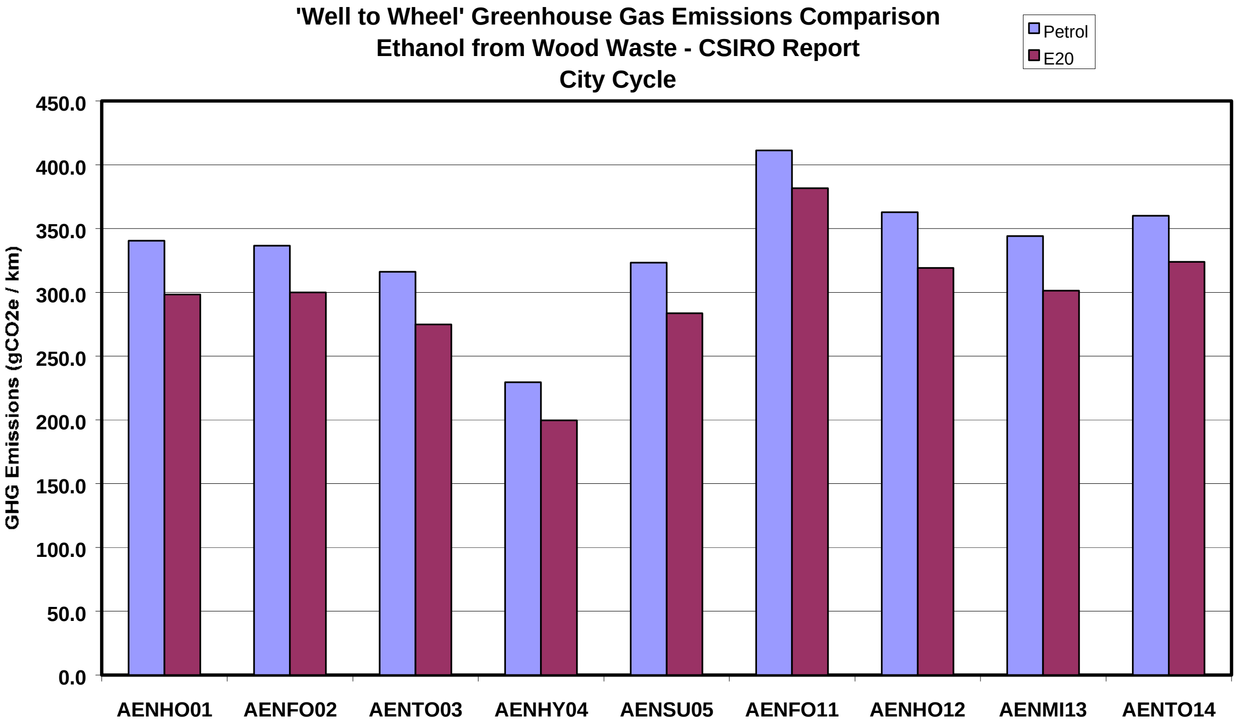


**Figure 7.9 – 'Well to Wheel' City Cycle Greenhouse Gas Emissions from E20 based on Ethanol Production from Wood Waste.**

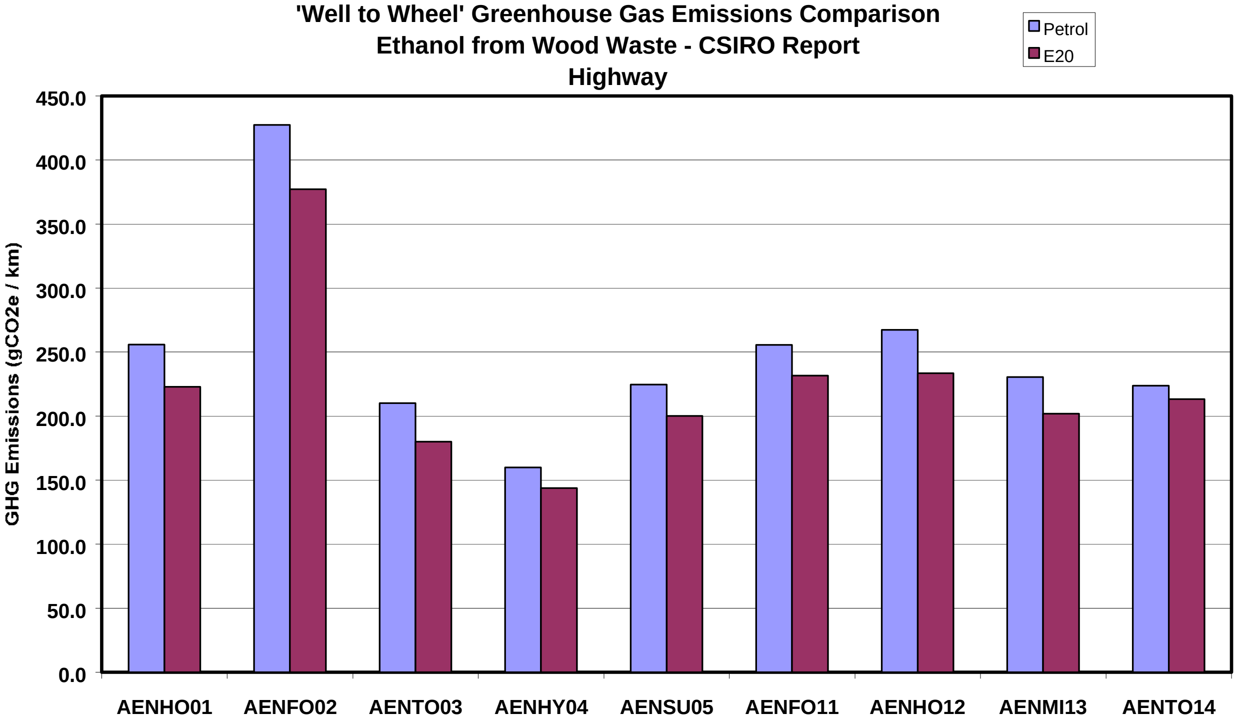


**Figure 7.10 – 'Well to Wheel' Highway Greenhouse Gas Emissions from E20 based on Ethanol Production from Wood Waste.**

# 8 Materials Compatibility Test Activity.

## 8.1 Overview.

This activity is focussed on conducting materials/component compatibility testing following as closely as possible the relevant SAE standards J1748 (10) (polymeric material) and J1747 (9) (metallic material). SAE standard J1681 (8) was followed as closely as possible in defining the test fluids utilised for material/component immersion testing.

The testing and experimental design is not an attempt to fulfil the requirements for material qualification, actual product or process validation for the materials or components. The experiments and testing are in fact designed to highlight any non-compatibility between a material or component and the E20 blend fuel.

The materials/components for immersion testing were selected on the basis of them having contact with fuel and having a high potential risk of failure, as identified by the FMEA, (3). The vehicles from which the material/components were selected were chosen as representative of the Australian vehicle fleet in terms of fuel system and aftertreatment technology as well as covering available gasolines.

The vehicles chosen were:

- Holden Commodore VN, 1990 MY.
    - Electronic Fuel Injection, Three Way Catalyst and ULP gasoline.
- Ford Falcon XE, 1985 MY.
    - Electronic Fuel Injection and LRP gasoline.
- Holden Commodore VK, 1985 MY.
    - Carburettor and LRP gasoline.

## 8.2 Component Test Preparation

### 8.2.1 Test Fluids

As proposed in the tender submission, testing is occurring with 0% ethanol and 20% ethanol/gasoline fuel blends. The fuel blends containing the 20% ethanol will be based on standard pump fuels plus 1% corrosive water, similar to that specified in (8).

- ULP and LRP (WA pump gasoline) as required for the above vehicles.
- ULP and LRP as above with 20% ethanol and 1 % corrosive water.

### 8.2.2 Test Temperatures

The specified temperatures for material testing are as follows:

- Metals at 45+/-2$^o$C
- Elastomers at 55+/-2$^o$C
- Plastics at 55+/-2$^o$C

Fuel sample containers are normally held in a temperature-controlled oven. Due to safety issues identified with the ovens and also due to the number of containers (90) required for this program, testing is being conducted in a fire protected environmental engine test cell (heated room). In order to facilitate testing of all samples at the same time, the test temperature has been standardised to 55+/-2$^{o}$C. This will not adversely affect the validity of findings for the metals testing. The higher temperature is considered to be more closely aligned with the normal vehicle related operating temperature of many of the components under test.

### 8.2.3 Test Containers

The containers for this testing are specified by the SAE standards. The containers are made of high density polyethylene, with a minimum rated burst pressure of 202.7 kPa and a volume of one litre. These unique requirements have necessitated procurement from the USA. Delay in the supply of these containers was the primary reason for delaying the test program until late-December 2002.

### 8.2.4 Facilities

The heated room (environmental test cell) and adjacent anteroom have been configured to enable testing to be undertaken in an effective and safe manner.

- The heated room is controlled to 55+/-2$^{o}$C (SAE standard for material testing) and the anteroom is controlled to 23+/-2$^{o}$C (SAE standard for component measurement). Temperature control of the heated room and anteroom has been validated over an extended period.
- The anteroom has been modified to incorporate a bench with fume hood and extraction system (see Figure 8.1). This bench is used for sample preparation and condition assessment throughout the test period.
- Fuel drums (with taps) and racks have been fitted to the bench to facilitate replenishment of each fuel type. A waste fuel drum on wheels is located next to the bench.

| Anteroom – fume hood, fuels and scales | Container Racks stored in Heated Room |
|---|---|
|  |  |

**Figure 8.1 Materials Compatibility Test Facilities**

### 8.2.5 Procedures

Procedures covering test method, facilities control and safety have been documented.

### 8.2.6 Sample Preparation

The SAE and ASTM test specifications are written assuming the testing of unformed (raw) material. Due to the unavailability of multiple samples of raw (unformed) material as required by the specification, testing was conducted on samples taken from formed parts or the formed parts themselves (eg O-rings and diaphragms). For some parts, complete assemblies were immersed in the fluid (eg fuel pumps). It was felt that this would replicate the in field situation. The components included a large number of metal and non-metal parts from the fuel systems themselves, plus the engine valve stem seals. A number of test pieces were cut from larger items, for example fuel tank test pieces, while the constituent components of other parts were used (eg. carburettor service kits). The metal components generally were not included for immersion in neat ULP or LRP as these components were assumed to be compatible with these fuels and were not expected to present any useful results. Thus some metal components were tested in E20 only, while polymeric components were tested in both ULP and LRP and E20 fluids. From a logistical point of view this enabled the samples to be kept to a reasonable number.

The following measurements and recording of characteristics of the test samples were taken where applicable to establish the initial condition of each sample.

- Weight
- Dimensions
- Hardness (rubber and plastics)
- Photographic record.

These sample measurements and recordings are again taken where possible at interim periods within the test period of 200 hours.

## 8.3 Test Status

All facilities preparations were completed in December, test procedures documented and component samples purchased and prepared (see Figure 8.2).

Figure 8.2 Test Samples in Containers

The tests on the automotive components were started in mid-December. The test duration is three months, primarily driven by the necessary time to complete the corrosion tests (2000 hours). Accordingly, the planned completion date for this activity is revised to early May 2003. The current status of the accumulated immersion hours as the time of writing this report is as follows:

- Holden Commodore VN, 1670 hours.
- Ford Falcon XE, 830 hours.
- Holden Commodore VK, 530 hours.

## 8.4 Experimental Data

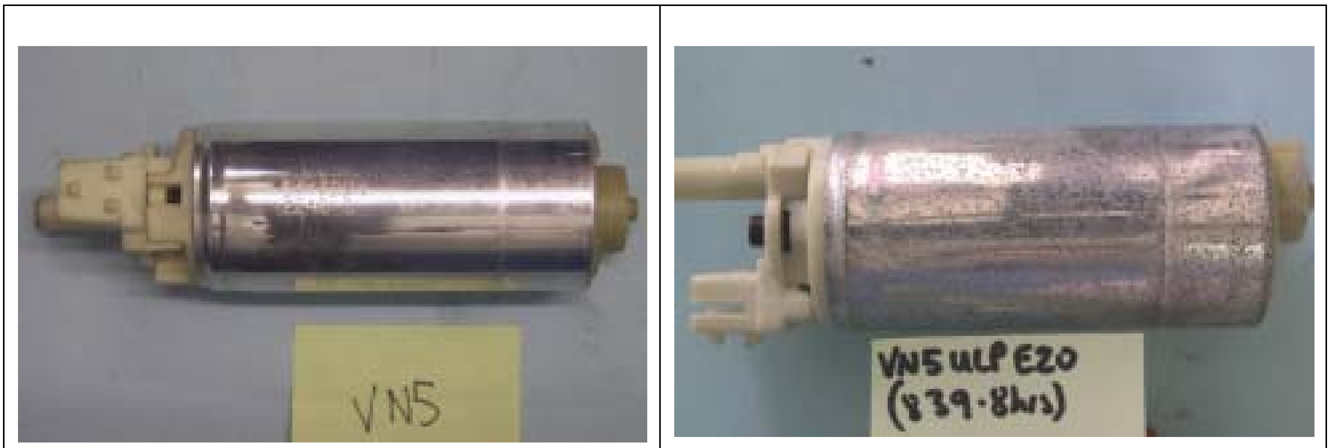
With the immersed samples having reached a significant number of hours, the components were inspected at intermediate test points. These results are presented in the attached reports in Appendix L. Significant results are discussed below.

### 8.4.1 VN Commodore Interim Inspection Results.

Samples for immersion testing were taken from 40 different components. After some 839 test hours the samples were removed from the heated room, allowed to cool in the ante-room to 23$^{o}$C then inspected and measured as outlined above.

In terms of the metallic engine components, corrosion on the external casing of both the in-tank and in-line fuel pumps in the E20 test fluid was evident, the in-tank pump is shown in photographs 1.1 and 1.2 in Figure 8.3. The in-line fuel pump armature pole pieces demonstrate signs of pitting and the armature shaft showed visible rust with light pitting as evidenced in photographs 1.3 and 1.4 in Figure 8.4. Brass and copper components suffered surface tarnishing in the E20 fluid, this can be seen in comparing photographs 1.3 and 1.4 in Figure 8.4 and photograph 5.1 in Figure 8.8. The fuel injector inlet tube shows surface rust as evidenced in photograph 2.1 and 2.2 in Figure 8.5. All photographs referenced above compare initial condition prior to immersion in the E20 test fluid to the 839 hour immersion in the E20 test fluid.

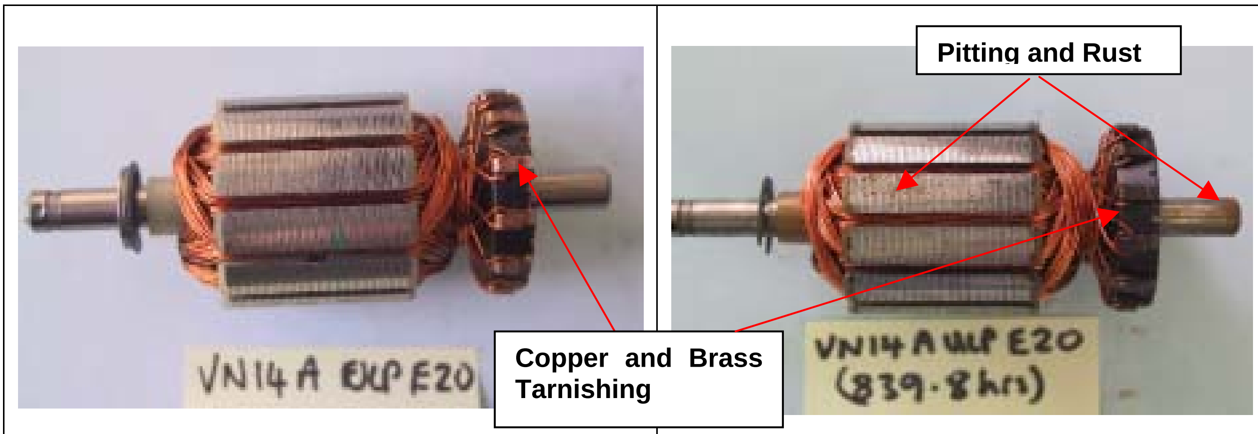
With respect to the fuel system rubber components, parts in general experienced a weight gain in both ULP and the E20 test fluid. However, the weight change was greater in the case of the E20 fluid, by a factor of typically two to three. In general a loss in the hardness of the rubber components was measured for both test fluids, except for the filler vent hose, which increased in hardness. The change in hardness (loss or gain) was in general greater for the components in the E20 fluid than the ULP gasoline. This was accompanied by swelling of the rubber components, such as the fuel return hoses, which were visibly more swollen after immersion in E20 fluid than the parts which were immersed in ULP, see photograph 3.1 in Figure 8.6.



Photograph 1.1. In-tank pump, initial condition

Photograph 1.2. In-tank pump after immersion in E20, corrosion and pitting clearly evident on casing exterior.

**Figure 8.3 In-Tank Fuel Pump**



Photograph 1.3. In-line fuel pump rotor, initial condition.

Photograph 1.4. In-line fuel pump rotor, pitting and corrosion of the rotor armature shaft (evident on RHS of photograph)

**Figure 8.4 Fuel Pump Rotor**

The fuel pressure regulator diaphragm was discoloured to a brown colour in the E20 fluid, whereas it remained bright red for the component in ULP. The metal pressing forming the centre of the diaphragm assembly was rusting around the centre rivet for the component in the E20 fluid. Photograph 4.1 in Figure 8.7 shows the difference in colour along with the rust.

Plastic components, in general suffered minimal weight change in either test fluid.

Photograph 2.1 Fuel injector, initial condition

Photograph 2.2. Fuel injector, showing rusting on metal surface after immersion in E20

**Figure 8.5 Fuel Injector**

Photograph 3.1. Hose, fuel return (end view), showing increased swelling for sample in E20 (RHS).

**Figure 8.6 Fuel Return Hose**

Photograph 4.1. Fuel regulator diaphragm after immersion in ULP (LHS) and E20 (RHS). Showing discolouration changes and rust on component immersed in E20.

**Rust**

**Figure 8.7 Fuel Regulator Diaphragm**

Photograph 5.1. In-line fuel pump terminals after immersion in E20, showing tarnishing of brass terminals and fittings

**Tarnished terminals and fittings.**

**Figure 8.8 In-line Fuel Pump Terminals**

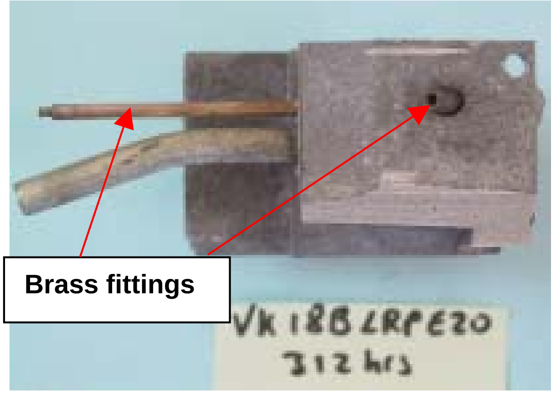
Further details of the components immersion tested can be found in Appendix L-1.

### 8.4.2 VK Commodore Interim Inspection Results.

For these tests, parts were sampled from 26 different test pieces After some 312 test hours the samples were removed from the heated room, allowed to cool then inspected and measured as explained earlier.

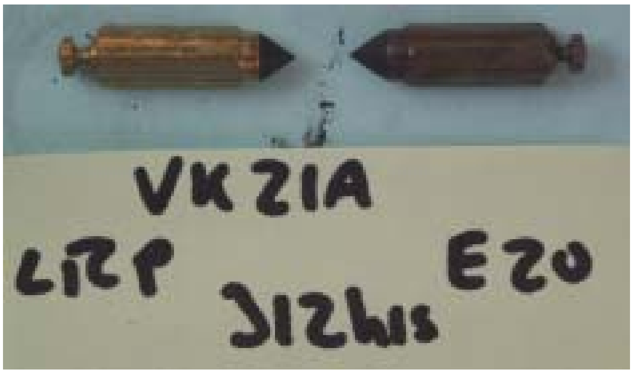
For the metallic fuel system components, corrosion on the carburettor body was evident. The comparison shown in photographs 1.1 and 1.2, in Figure 8.9 is of initial condition to condition after immersion in the E20 test fluid. Brass components were tarnished, having a dark layer on their surfaces as evidenced on the carburettor needle from the needle and seat valve, see photograph 2 in Figure 8.10 where a comparison of immersion in the LRP fluid and the LRP E20 test fluid is provided.

Photograph 1.1. Section from carburettor body, initial condition.



Photograph 1.2. Carburettor body sample, after immersion in E20, showing corrosion of aluminium surface and tarnishing of brass fittings.

**Figure 8.9 Carburettor Body**



Photograph 2. Carburettor float valve needle after immersion in LRP (LHS) and LRP E20 (RHS). Both have tarnished, the E20 component is significantly more tarnished than the LRP component.

**Figure 8.10 Carburettor Needle and Seat Needle**

With respect to the fuel system rubber components, parts in general experienced a weight gain in both LRP and the E20 test fluid. The weight increase was greater for the E20 fluid than the LRP, by a factor of typically three to four.

In general, there was a loss in the hardness of the rubber components for both test fluids. The change in hardness was in general greater for the components in the E20 fluid than the components in the LRP gasoline. For example, the valve stem seals showed a 3% weight gain in the LRP fluid, but a 22% weight change in the E20 fluid.

A carburettor diaphragm was found to distort and curl due to immersion in the E20 test fluid, this behaviour can be seen in photograph 3.2 in Figure 8.11, the metal part of the diaphragm can be seen to have changed colour in the E20 test fluid when comparing photograph 3.1 representing the initial condition, and the image on the right hand side in photograph 3.2.

Photograph 3.1. Carburettor diaphragm, initial condition

Photograph 3.2. Carburettor diaphragms after immersion in LRP (LHS) and E20 (RHS). Rubber sheets have separated for both samples, E20 component has distorted and curled due swelling.

**Figure 8.11 Carburettor Diaphragm**

Plastic components, in general suffered minimal weight change in either test fluid. The exceptions were the carburettor float and positive crankcase ventilation (PCV) valve. The carburettor float gained 5.5% in weight in the E20 test fluid, while gaining only 0.3% in weight in the LRP fluid. This was accompanied by a loss of hardness indicating that the plastic was absorbing the fluid. The PCV valve softened and swelled, which resulted in the metal insert separating from the plastic casing as shown in the comparison photographs 4.1 and 4.2 in Figure 8.12.

Photograph 4.1. PCV valve, initial condition.

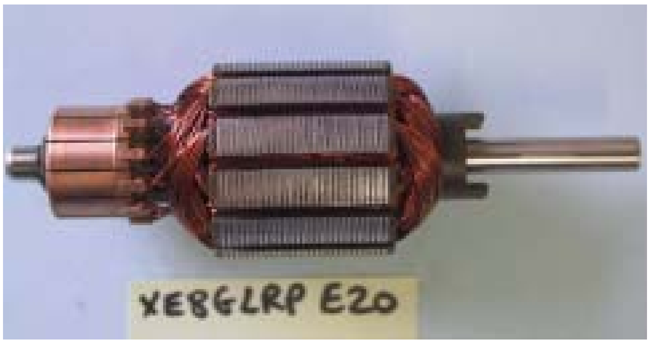
Photograph 4.2. PCV valve after immersion in E20. Metal and plastic components have separated due softening and swelling of the plastic.

**Figure 8.12 PCV Valve Components**

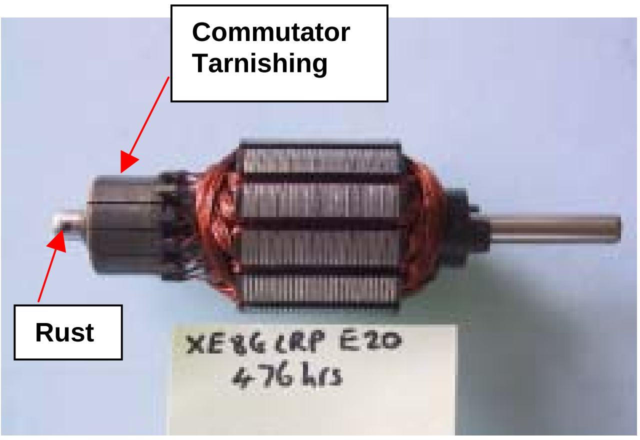
Further details of the components immersion tested can be found in Appendix L-2.

### 8.4.3 XE Falcon Interim Inspection Results.

Parts were sampled from 16 different components for these tests. After some 476 test hours the samples were removed from the heated room, allowed to cool then inspected and measured.



Photograph 1.1. Fuel pump armature and shaft in initial condition.



Photograph 1.2. Fuel pump armature showing tarnishing of commutator after immersion in E20.

**Figure 8.13 Fuel Pump Armature**

In terms of the metallic engine components, ferrous parts with un-plated surfaces showed signs of surface corrosion, while brass and copper components were subject to surface tarnishing. The fuel pump commutator had darkened considerably in the E20 fluid as shown in photographs 1.1 and 1.2 in Figure 8.13, the shaft also showed signs of corrosion, though not easily identified in the photograph.

With respect to the fuel system rubber components, parts in general experienced a weight gain in both LRP and the E20 test fluid. However, the weight change was greater in the case of the E20 fluid.

In general, there was a loss in the Shore hardness of the rubber components for both test fluids. The change in hardness was in general greater for the components in the E20 fluid than the components in the LRP gasoline.

The PCV valve, after immersion in the E20 test fluid, separated into its metal and plastic components, photographs 2.1 and 2.2 in Figure 8.14 show this result. An adhesive or potting mix utilised in the fuel sender unit appears to be dissolving as shown in photograph 3 of Figure 8.15 after immersion in the E20 fluid. Other plastic components such as the fuel tank were little affected by either the LRP or the E20 fluids.

The fuel pressure regulator diaphragm showed more significant colour change in the LRP gasoline then in the E20 test fluid, however further inspection of the diaphragm material revealed swelling an distortion as shown in photograph 4 in Figure 8.15.

Photograph 2.1. PCV valve initial condition.

Photograph 2.2. PCV valve after immersion in E20, showing separation of parts due to swelling of the plastic housing.

**Figure 8.14 PCV Valve Components**


Dissolving Adhesive or Potting Mix

Photograph 3. Fuel sender unit. Close up of adhesive or potting mix being dissolved by E20.

Photograph 4. Fuel pressure regulator diaphragm after immersion in LRP (LHS) and E20 (RHS), showing discolouration in LRP and swelling and distortion in E20.

**Figure 8.15 Fuel Sender Unit and Fuel Pressure Regulator Diaphragm**

### 8.4.4 Discussion and Interim Conclusions from Interim Test Results.

A number of metallic fuel system components have been found to exhibit an incompatibility with the E20 test fluids made with both the gasoline bases, ULP and LRP. Rust was found to occur on un-plated ferrous metal surfaces in electronic fuel pumps, an electronic fuel injector and on the metal parts of a fuel regulator diaphragm. The potential exists for the rust to dislodge and block the filters within the fuel system or through settling on areas where mechanical movement of componentry occurs, cause very much increased wear rates.  The potential increase in wear rate of bearings in electronic fuel pumps and surfaces in electronic fuel injectors may lead to premature component failure with unsatisfactory vehicle operation prior to failure.

The aluminium casings of electronic fuel pumps appear to be particularly vulnerable to pitting corrosion by the E20 test fluid.  The oxide produced again has the potential to gather within sensitive areas of the fuel system causing blockage and potentially increasing moving component wear rates followed by premature component failure.

The aluminium carburettor housing was also particularly vulnerable to pitting corrosion by the E20 test fluid.  With carburettor systems, the material produced by corrosion has the potential to block fuel metering orifices with the potential outcome of significantly degraded driveability.  This may be followed by complete blockage and engine operation failure.

It is for the reasons outlined above that corrosion of fuel system componentry is considered to be an unacceptable impact of the E20 fuel.

It is quite clear that the level of tarnishing of copper and brass components is significantly increased when the component is immersed on the E20 test fluid. The tarnish is effectively oxidation of the surface of the component.  For moving components in contact with other parts, such as the commutator of a fuel pump armature and the brushes, oxidation provides the potential of very much increased wear rates of both components that may result in premature component failure.  Many of these brass and copper components carry an electrical load.  The potential exists for a high contact resistance at electrical connections due to the oxide layer that may result in reduced performance or non-operation of the component.

With the fuel metering jets and valves made from brass, the oxidation has the potential to change the metering performance of these jets as they are manufactured to within small tolerances to ensure correct metering of fuel. Should oxidation occur, the intended nominal fuel metering control has the potential to be lost, resulting in potential degradation or loss of engine function.

In general, rubber components were found to experience a greater change in weight or hardness when immersed in the E20 test fluid than when immersed in neat gasoline.  In general, the increase in weight or loss of hardness of the rubber components tested indicates that these rubber components are more likely to degrade when used with the E20 test fluid then with gasoline.

Of significant concern was the distortion and swelling of the fuel pressure regulator diaphragms of the Electronic Fuel Injected (EFI) fuel systems and the diaphragm of the carburetted fuel system.  The EFI diaphragms are under stress during operation and coupled with the findings of the immersion tests the potential for premature failure exists.  Such failure would render the vehicle inoperable and has the potential to result in fuel leakage.  With the carburettor diaphragm, the potential for loss of internal and external sealing exists which in turn may lead to fuel leakage and vehicle stoppage.  These impacts are considered as unacceptable due to the increased potential for fuel leakage.

Most of the plastic material tested experienced little or no changes in weight or hardness when immersed in the E20 test fluid. The exceptions are the carburettor float and the tested PCV valves. The carburettor floats 5.5% weight increase will change the fuel level in the carburettor float chamber, which in turn will change the fuelling calibration of the engine. This calibration change has the potential to impact on the driveability and general operability of the vehicle including exhaust gas emissions. It should be noted that it might not be possible to successfully adjust the calibration to allow seamless operation on both neat gasoline and the E20 fuel blend. The softening and swelling of the plastic part of the PCV valve has lead to separation of the plastic and metal parts. Should this behaviour be experienced on the vehicle, it would lead to significant engine driveability, operability and exhaust emissions degradation, as it would present as a significant engine air leak with concomitant loss of the fuel and air metering accuracy required for normal engine operation.

The final findings of the materials component compatibility tests are planned to be reported in early May 2003 when all the engine and fuel systems components and materials under test complete the 2000 hour immersion schedule. However, based on the interim findings of the materials/component compatibility testing, there are a number of materials utilised in the vehicles components tested to provide sufficient evidence that the potential impacts on the Australian vehicle fleet are of sufficient magnitude to consider them as unacceptable.

Paint Test Activity.

## 8.5 Overview.

This activity is focussed on conducting testing to assess the impact of the E20 fuel blend on the paint finish in the vicinity of the fuel filler cap. To this end, the ISO 2812-1 International Standard (11) was adopted and followed as closely as possible. This standard sets out the methodology for the determination of the resistance of paints and varnishes to liquids.

The experiment and testing is designed only to highlight any potential incompatibility between the paint finish and the E20 fuel blend. The testing and experimental design is not an attempt to fulfil the requirements of qualifying the applied finish as being compatible with the E20 fuel blend.

## 8.6 Component Test Preparation.

### 8.6.1 Test Fluid.

As proposed in the tender submission, testing occurred with neat gasoline and the E20 fuel blend. Test fluids adopted for the evaluation reported here are:

- Standard unleaded gasoline (WA pump gasoline)
- Standard unleaded gasoline with 20% ethanol by volume

### 8.6.2 Test Sample Selection and Preparation.

Rather than testing the fuel filler cap or a section the car's bodywork, the door to the filler location was used for convenience. Test samples were chosen based on the fact that the new vehicle manufacturers utilised two base materials for the filler door, plastic and sheet metal. The vehicles chosen to provide the filler doors were the Holden Commodore (AENHO01 and ANEHO06) and the Ford Falcon (AENFO02 and AENFO07) for plastic and metal filler doors, respectively. The location and surrounds of the fuel filler doors are shown in Figure 8.16. Both the filler doors types met the dimensional requirements of the standard in terms of area.

The filler doors from the test fleet were used as they have a true factory finish paint coating, unlike parts purchased as spares which are supplied unpainted. One filler door of each material type was exposed to ULP and one to E20.

Ford: Metal fuel filler door, plastic splash surround

Holden: Plastic fuel filler door, metal splash surround

**Figure 8.16 Vehicle Fuel Filler Door Location and Surrounds**

The test Standard outlines several options for the application of the liquid to the sample. Method 3 (spotting method) was selected as it was deemed to be most representative of the likely fuel contact in the field where fuel may splash during re-fill and subsequently evaporate. The methods not chosen were either full immersion or prolonged blotting; neither representative of in-field contact.

### 8.6.3 Fixtures, Test Conditions, and Facility

The testing occurred in the material compatibility testing anteroom area allowing air free access to the test samples. The anteroom temperature was controlled to the specified 23+/-2$^{o}$C, the same as specified for the material compatibility testing.

The test samples were mounted horizontally on fixtures facilitating the application of the recommended droplet sizes and placement as described in the standard, see Figure 8.17. Each test sample was exposed to the respective test fluid every 24 hours during the working week.

|  |  |
|---|---|
| Template used to ensure droplets are placed in the same position and in accordance to the Standards recommendations. | The same template is used with all fixtures. The fixtures are designed to hold the samples in the horizontal orientation. |

**Figure 8.17 Vehicle Fuel Filler Door Test Fixtures**

The application and exposure periods are not specified in the Standard. As a consequence the application frequency adopted was chosen to represent a high fuel tank re-fill frequency while the overall test period is a program timing related choice. Periodically and at the end of the target exposure period the test samples are inspected for deterioration from a visual perspective and also analysed to determine if there was degradation in the paint finish based on a measured change in the paint thickness in the area exposed to the test fluid.

## 8.7 Interim Test Observations

At the time of this report, the samples have only completed two weeks of exposure. As such, only interim observations will be discussed. Further results will be available at the time when the materials/component compatibility testing and report is complete providing more exposure of the paint test sample to the test fluids.

All samples presently show:

- No evidence of paint peeling
- No evidence of blistering
- No evidence of crazing
- No evidence of dulling
- Some evidence of staining (white painted fuel filler door only)

The staining is only evident on the white painted fuel filler door sample. To the naked eye the staining shown is slightly more prominent on the sample exposed to E20 than to the baseline ULP sample. Neither staining is however dark enough to be readily captured using digital photography. The paint finish between the two filler door types is notably different given the difference in base material and paint type (the Ford component has a “metallic” paint finish, on a sheet metal part). These surface finish variations may be reasons in addition to the base colour that have contributed to the staining on one sample type and not the other.

# 9 Summary and Conclusions.

This chapter summarises the resulting analysis of reviewed literature, study, testing within the program of work conducted on the vehicle pool and other components with the respective baseline gasolines and the E20 fuel blend.

The potential greenhouse gas impact is also presented both in terms of Well to Tank and Tank to Wheel.

The interim findings of the material/component compatibility testing is also reported with the final findings and report planned for early May 2003. The final findings of the paint testing activity are also planned for reporting at the same time, with interim results presented here.

## 9.1 Vehicle Performance.

### 9.1.1 Engine Power Evaluation.

The testing comprised testing the vehicle pool under WOT conditions basing the procedure on SAE J1491, measuring acceleration from both standing start and from a stabilised speed of 64km/h. The aim of this evaluation was to determine if operation on E20 effects:

- Full load power output
- Full load catalyst temperature
- Engine air equivalence ratio (lambda) at WOT
- Engine knock at WOT

All test vehicles utilising closed loop control were operated for 200 km on an open road circuit to ensure the engine management system had adapted to the fuel used during testing.

The following Table 9.1 summarises the full load power output findings

| Vehicle New | Standing start | 64 km/h start | Vehicle Old | Standing start | 64 km/h start |
|---|---|---|---|---|---|
| AENHO01* | Increase | Increase | AENHO11* | Decrease | Decrease |
| AENFO02* | Increase | Decrease | AENFO12 | Increase | Decrease |
| AENTO03* | Increase | Decrease | AENMI13 | Increase | Increase |
| AENHY04 | Decrease | Increase | AENTO14* | Decrease | Decrease |
| AENSU05 | Decrease | Increase | | | |
| *Automatic only | Increase | Decrease | *Automatic only | Decrease | Decrease |

**Table 9.1 - Engine Power Evaluation**

Table 9.1 presents the changes in power where a decrease in time required to complete the acceleration tests equates to an increase in engine power and conversely an increase in time equates to a decrease in engine power. It should be noted that as some vehicle have manual transmissions, gear changing times may influence the result, the automatic transmission vehicles present a more consistent pattern where in general power increase may be returned with the new vehicles under standing start conditions while a decrease may be evident under acceleration from the constant speed condition. With the old automatic vehicles, both acceleration conditions demonstrate a lower power.

The exhaust gas temperatures are presented in Table 9.2 as a summary for all the vehicles. The pre and post catalyst temperatures are those immediately up or down stream of the catalysts for the catalysed vehicles while the un-catalysed vehicles only one thermocouple was required and was placed just downstream of the junction between the manifold runners and the exhaust down pipe. Only the standing start data is shown here, refer to the appropriate vehicle appendix for the data from the 64km/h start test.

| **Vehicle Catalysed** | **Pre-catalyst Temperature** | **Post-catalyst Temperature** |
|---|---|---|
| AENHO01 | Increase | Increase |
| AENFO02 | Increase | Increase |
| AENTO03 | No change | No change |
| AENHY04 | No change | No change |
| AENSU05 | Increase | Increase |
| AENMI13 | Increase | No change |
| AENTO14* | No change | No change |

| **Vehicle No Catalyst** | **Exhaust Gas Temperature** |
|---|---|
| AENHO11* | Decrease |
| AENFO12 | Increase |

**Table 9.2 - Exhaust System Temperature Evaluation**

The details of the actual temperature changes are provided in the relevant sections within this report. Of the five new vehicles tested, three show increased exhaust gas temperatures both pre and post on the catalyst indicating an increase in the catalyst temperature with two showing no measured change. For the two old catalysed vehicles, the Mitsubishi shows an increase in pre catalyst temperature with the Toyota showing no change and both presenting with no change in post catalyst temperatures. For the old Holden a decrease in exhaust gas temperature was measured while the Ford showed an increase.

The changes to the exhaust gas air equivalence ratio (lambda) are shown in Table 9.3 for all vehicles for the standing start acceleration test only. Refer to the appropriate vehicle appendix for the 64km/h test data. The data presented is from a wide band oxygen sensor placed in each vehicles exhaust system upstream of the catalyst if fitted or just downstream of the junction between the exhaust manifold runners and the exhaust down pipe.

The new vehicles display differing Lambda responses to the E20 fuel with the Holden, Ford and Hyundai displaying an enleanment response and the Toyota and the Subaru displaying no change, the expected response for closed loop controlled engine management.

All the old vehicles display the expected trends, the Toyota Camry showing no change in Lambda as it is “closed loop” and the other three showing the expected enleanment due to them having no means to correct.

| Vehicle New | Lambda change | Vehicle Old | Lambda change |
|---|---|---|---|
| AENHO01 | Lean | AENHO11 | Lean |
| AENFO02 | Lean | AENFO12 | Lean |
| AENTO03 | No change | AENMI13 | Lean |
| AENHY04 | Lean | AENTO14 | No change |
| AENSU05 | No change | | |

**Table 9.3 – Lambda Variation Evaluation**

## 9.1.2 Tailpipe Emissions Assessment, Regulated and Highway Cycle.

### 9.1.2.1 New Vehicle Regulated Tailpipe Emissions Assessment.

The new vehicles regulated tailpipe emissions assessment is presented both from averaging all the vehicle emissions and also from an understanding of the performance of each of the new vehicles as there are quite different outcomes from each vehicle. Table 9.4 following shows that the average outcome is very much in line with published data (35). It should be noted that the emissions regulations requirements for the vehicles tested by (35) are the same as those the new vehicles tested here must comply with.

| Emission. | Guerrieri (35) | Measured |
|---|---|---|
| **THC (g/km)** | -25% | -30% |
| **CO (g/km)** | -27% | -29% |
| **NOx (g/km)** | +29% | +48% |
| **CO2 (g/km)** | ~0% | -1% |

**Table 9.4 - New Vehicle Average Regulated Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

The individual vehicle performance was found to be quite specific and is shown in Table 9.5.

| New Vehicle | THC (g/km) | CO (g/km) | NOx (g/km) | CO2 (g/km) |
|---|---|---|---|---|
| **AENHO01** | -42% | -2% | -2% | -0.3% |
| **AENFO02** | -34% | -37% | +97% | -1.1% |
| **AENTO03** | -3% | -31% | +83% | -1.4% |
| **AENHY04** | -2% | 1% | +22% | -2.6% |
| **AENSU05** | -22% | -43% | +43% | -0.4% |

**Table 9.5 - New Vehicle Individual Regulated Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

Because of the large differences in magnitude of change in emissions between vehicles when using E20, a simple calculation was performed to estimate the impact on city cycle regulated emissions from new vehicles of E20 compared to gasoline only fuel. This estimate is based on the new car volumes of several different vehicle classes, and estimated the impact of E20 as summarised in Table 9.6.

| Regulated Emission | Fuel Type | | Percentage Change (%) |
|---|---|---|---|
| | Gasoline | E20 | |
| THC (g/km) | 0.088 | 0.063 | -27.9 |
| CO (g/km) | 0.835 | 0.659 | -21.1 |
| NOx (g/km) | 0.121 | 0.161 | 33.5 |

**Table 9.6 – New Vehicle Class and Volume Weighted Emissions Impact Estimate.**

### 9.1.2.2 Old Vehicle Regulated Tailpipe Emissions Assessment.

For the old vehicles the regulated tailpipe emissions have been analysed both from averaging all the vehicle emissions and also individually to gain an understanding of the performance of each vehicle as each utilises quite different control and emissions compliance technology. The averaging process has skewed some of the specific emissions due to the differing technologies employed to meet the then current emissions regulations. Table 9.7 summarises the average outcome, for the open loop vehicles it was found to very much in line with the published data.

| **Emission.** | **Measured** |
|---|---|
| **THC (g/km)** | -4% |
| **CO (g/km)** | -70% |
| **NOx (g/km)** | +9% |
| **CO2 (g/km)** | +2% |

**Table 9.7 - Old Vehicle Average Regulated Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

| **Old Vehicle** | **THC (g/km)** | **CO (g/km)** | **NOx (g/km)** | **CO2 (g/km)** |
|---|---|---|---|---|
| **AENFO11** | -0.3% | -71% | +3% | +7% |
| **AENHO12** | -10% | -76% | +28% | +2% |
| **AENMI13** | +2% | -52% | +9% | +3% |
| **AENTO14** | 0% | -5% | -10% | -1% |

**Table 9.8 - Old Vehicle Individual Regulated Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

The Toyota Camry (AENTO14) was found to be very different in outcome as it is a closed loop vehicle with a TWC, the individual vehicle emissions performance can be found in Table 9.8.

### 9.1.2.3 New Vehicle Highway Tailpipe Emissions Assessment.

A summary of the new vehicles highway tailpipe emissions assessment is given by averaging all the vehicle emissions and also by assessing the individual vehicle performance. Table 9.9 following summarises the average outcome.

| Emission. | Measured |
|---|---|
| **THC (g/km)** | -25% |
| **CO (g/km)** | -48% |
| **NOx (g/km)** | -9% |
| **CO2 (g/km)** | -1% |

**Table 9.9 - New Vehicle Average Highway Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

The individual vehicle performance was found to be quite specific and is shown in Table 9.10.

| New Vehicle | THC (g/km) | CO (g/km) | NOx (g/km) | CO2 (g/km) |
|---|---|---|---|---|
| **AENHO01** | -20% | -79% | -10% | -1.6% |
| **AENFO02** | -31% | -58% | -10% | -1.6% |
| **AENTO03** | -30% | -44% | +67% | -3% |
| **AENHY04** | -18% | -1% | +45% | -1% |
| **AENSU05** | 0% | -1% | +33% | +1.5% |

**Table 9.10 - New Vehicle Individual Highway Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

### 9.1.2.4 Old Vehicle Highway Tailpipe Emissions Assessment.

Table 9.11 summarises the average highway tailpipe emissions performance of the pool of old vehicles.

| Emission. | Measured |
|---|---|
| **THC (g/km)** | -10% |
| **CO (g/km)** | -76% |
| **NOx (g/km)** | +10% |
| **CO2 (g/km)** | +1% |

**Table 9.11 - Old Vehicle Average Highway Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

The individual vehicle performance was found to be quite specific and is summarised in Table 9.23.

| **Old Vehicle** | **THC (g/km)** | **CO (g/km)** | **NOx (g/km)** | **CO2 (g/km)** |
|---|---|---|---|---|
| **AENFO11** | -32% | -75% | +8% | +5% |
| **AENHO12** | +18% | -80% | +12% | +0.8% |
| **AENMI13** | -12% | -46% | -4% | -2% |
| **AENTO14** | +7% | -21% | +56% | +0.4% |

**Table 9.12 - Old Vehicle Individual Highway Tailpipe Emissions Percentage Difference Comparison to Gasoline.**

#### 9.1.2.5 Tailpipe $CO_2$ Emissions Summary.

Although carbon dioxide is not classified as a regulated emission, it is a greenhouse gas contributor, and therefore needs to be included in the analysis of the impacts of E20 on the Australian passenger vehicle fleet. A general trend of reduced $CO_2$ emissions with the use of E20 when compared with gasoline only fuel was found. The trend is consistent across the range of vehicles tested, with only small $CO_2$ reductions summarised in Table 9.13.

| Vehicle Group | Change in CO2 Emissions (%) | |
|---|---|---|
| | City Cycle | Highway Cycle |
| New Vehicle Average | -1.2 | -0.75 |
| Old Vehicle Average | +2.0 | + 1.2 |

**Table 9.13 - Tailpipe $CO_2$ Emissions Summary**

### 9.1.3 Engine Management System and Calibration Summary.

The new and old vehicle engine out exhaust (un-catalysed) and tailpipe (catalysed if catalyst fitted) emissions have been studied and analysed allowing a suitable understanding of each vehicles engine management system and calibration. This enables conclusions to be drawn on the capability of the engine management system in terms of adapting to the E20 fuel blend as well as the impacts the blend has on the open loop vehicles calibration.

#### 9.1.3.1 New Vehicles.

Each of the three phases of the ADR37/01 (city) test cycle have been analysed, phase one cold transient, phase two hot stabilised and phase three hot transient. Varying changes to the engine out emissions characteristics were found when comparing the gasoline and E20 results. In summary, all the vehicles engine management systems were found to adapt to the change in fuel, however the way in which the adaptation parameter was utilised in the various engine operating regimes was specific to each manufacturers engine control strategy. This specific control strategy is effectively the reason for the differences in the emissions performance of each vehicle. Small differences in catalyst conversion efficiencies were found.

#### 9.1.3.2 Old Vehicles.

Within this group of vehicles, the Holden Commodore and the Ford Falcon were tested to ADR 27C comprising two phases the cold transient and the hot steady state. Effectively, both vehicles experienced a lean shift due to the E20 fuel blend though the Ford Falcon exhibited unexpected high exhaust oxygen content while operating on E20. The Mitsubishi Magna also demonstrated a lean shift, however there was unexplained coincident exhaust oxygen content during the idle period. In summary, these three open loop vehicles experienced a lean shift though not necessarily as expected. With the Toyota Camry, it was found that the it showed same emission trends to the new Holden Commodore and Hyundai Accent with the closed loop controller rich biased. One major difference was that this vehicle does not operate the closed loop controller during idle, though some correction has been applied during idle it is in an open loop manner. The Mitsubishi Magna and the Toyota Camry have catalysts fitted those being an oxidation and three way catalyst respectively. Some small changes in conversion efficiency were found.

### 9.1.4 Unregulated Toxic Tailpipe Emissions Summary.

During the regulated tailpipe emissions testing samples where extracted for analysis to determine the tailpipe aldehyde emissions and BTEX emissions. Due to the nature of the analysis two samples where taken, one for analysis by GC (Gas Chromatography) and one for analysis by HPLC (High Performance Liquid Chromatography). Four samples where taken per test, one per phase and one background. From the samples taken the concentrations of the compounds listed in Table 9.14 –Summary of Air Toxics Analysed were determined.

| Compound | | Analysis technique |
|---|---|---|
| Formaldehyde | $CH_2O$ | HPLC |
| Acetaldehyde | $C_2H_4O$ | HPLC |
| Acrolein | $C_3H_4O$ | HPLC |
| Propionaldehyde | $C_3H_6O$ | HPLC |
| 1,3 Butadiene | $C_4H_6$ | GC |
| Benzene | $C_6H_6$ | GC |
| Hexane | $C_6H_{14}$ | GC |
| Toluene | $C_7H_8$ | GC |
| P-Xylene | $C_8H_{10}$ | GC |
| O-Xylene | $C_8H_{10}$ | GC |

**Table 9.14 –Summary of Air Toxics Analysed**

#### 9.1.4.1 New Vehicles.

The level of Aldehydes measured was very low and in many cases below the measurable range of the instruments used for both gasoline and E20. Acrolein was not measurable in any of the vehicle emissions samples. Due to the low levels of Formaldehyde and Propionaldehyde it was not possible to determine a clear trend between gasoline and E20 fuel. Acetaldehyde was found to increase for all vehicles with E20 fuel with the main contribution coming from phase 1 of the drive cycle when the vehicle is warming up.

Tailpipe exhaust toxics are largely a by-product of the combustion or un-combusted gasoline and in general should decrease with increasing ethanol content in gasoline. Overall this was found to be the case though the compounds 1,3 Butadiene and Xylene were found to increase, following table summarises the findings.

| **Compound** | **Percentage Change (%)** |
|---|---|
| 1,3 Butadiene | +11.1% |
| Benzene | -46.0% |
| Hexane | -44.3% |
| Toluene | -28.4% |
| Xylene | +3.8% |

**Table 9.15 - New Vehicle Exhaust Emissions Toxics Percentage Difference between Gasoline and E20.**

#### 9.1.4.2 Old Vehicles.

### 9.1.5 Regulated Evaporative Emissions Summary.

#### 9.1.5.1 New Vehicles.

The evaporative emissions were tested according to ADR 37/01. On average the diurnal component of the total emissions was found to decrease following the published trend. Within the hot soak test, an increase in the evaporative emissions was measured again in line with the published trend. The hot soak test occurs with fuel temperatures higher than for the diurnal test and where the distortion to the distillation curve of the E20 fuel blend in comparison to neat gasoline occurs. It was thought that there might be some discernable differences between vehicles with returnless fuel systems (Toyota Camry and Hyundai Accent) and the conventional fuel systems. With the returnless system there should be less heat returned (no hot return fuel) to the fuel tank thereby reducing the bulk fuel temperature in the fuel tank. However, all the carbon canisters are new and hence have not lost working volume, which may be masking this effect. An unexpected result with the Subaru Impreza WRX occurred where the E20 evaporative emissions result was lower than for gasoline. All evaporative emissions were measured to be well below the regulated limit of 2.0g/test. Table 9.16 summarises the outcome for each vehicle and on the average.

| New Vehicle | Diurnal | Hot Soak | Total |
|---|---|---|---|
| **AENHO01** | +7% | +1% | +4% |
| **AENFO02** | +23% | +88% | +53% |
| **AENTO03** | -59% | +45% | -20% |
| **AENHY04** | -15% | +20% | +65% |
| **AENSU05** | -53% | -46% | -38% |
| **Average** | -25% | +30% | +23% |

**Table 9.16 - Regulated Evaporative Emissions Percentage Difference Between Gasoline and E20 Fuel**

#### 9.1.5.2 Old Vehicles.

The evaporative emissions were tested according to ADR 27C and ADR 37/00 with the legislated target of 6 and 2g/test respectively. The two vehicles tested under ADR27C (Ford Falcon and the Holden Commodore) show a diurnal result for the Ford Falcon going strongly against the expected result of a small improvement in emissions, thought this was also reported elsewhere. During hot soak both vehicles displayed the expected trend, however the Holden Commodore emitted very high emissions on the E20 fuel blend that is in line with the evaporative emissions handling technology utilised in this vehicle. The total outcome for both vehicles was significant increases in evaporative emissions when using the E20 fuel blend. For the Mitsubishi Magna and the Toyota Camry the expected trends are observed, a reduction in diurnal emissions and an increase in hot soak emissions when using the E20 fuel blend. The overall result for the ADR 37/00 vehicles has been however skewed by an unexpected high diurnal emissions result for gasoline for the Toyota Camry. The following Table 9.17 provides the percentage difference compared to gasoline for the two emissions legislations applicable.

| ADR 27C | Diurnal | Hot Soak | Total | ADR 37/00 | Diurnal | Hot Soak | Total |
|---|---|---|---|---|---|---|---|
| **AENFO11** | +331% | +59% | +153% | **AENMI13** | -14% | +57% | +37% |
| **AENHO12** | +7% | +96% | +82% | **AENTO14** | -74% | +26% | -68% |
| **Average** | +156% | +87% | +102% | **Average** | -66% | +53% | -32% |

Table 9.17 - Old Vehicle Evaporative Emissions Comparison Percentage Difference Between Gasoline and E20 Fuel.

### 9.1.6 Unregulated Toxic Evaporative Emissions Summary.

#### 9.1.6.1 New Vehicles.

#### 9.1.6.2 Old Vehicles.

### 9.1.7 Fuel Consumption Assessment Summary.

#### 9.1.7.1 New Vehicles.

The new vehicles were assessed for city and highway fuel consumption according to ADR37/01 and AS2877 respectively for both gasoline and the E20 blend fuel. The Metro-Highway fuel consumption composite has also been calculated, where the Metro is equivalent to the city or ADR37/01 component. The expected increase in fuel consumption was of the order of 7% based on published information. This assumes that the vehicles control systems were able to adapt to the E20 fuel blend, this was found to be the case with all vehicles adapting over the ADR37/01 test cycle. Over the city cycle and the highway cycle it was found that the measured increase in fuel consumption was less on average than the expected 7%. It is expected that subtle differences in how the EMS utilise the adaptation, based on the individual vehicles control system strategies, contributes to the less than expected 7%. The following Table 9.18 provides the differences for each vehicle and overall for both the city and highway and finally the Metro-Highway composite.

| New Vehicle | ADR37/01 City Cycle | AS2877 Highway Cycle | Metro-Highway Composite |
|---|---|---|---|
| **AENHO01** | +6.13% | +4.08% | +4.94% |
| **AENFO02** | +3.89% | +3.71% | +3.79% |
| **AENTO03** | +4.89% | +2.48% | +3.54% |
| **AENHY04** | +3.92% | +7.04% | +5.57% |
| **AENSU05** | +4.84% | +6.97% | +5.98% |
| **Average** | +4.79% | +4.76% | +4.72% |

Table 9.18 - New Vehicle Fuel Consumption Summary Percentage Difference Between Gasoline and E20 Comparison.

#### 9.1.7.2 Old Vehicles.

The old vehicles were assessed for fuel consumption according to ADR27C or ADR37/00 city cycles and AS2877 for the highway cycles for both gasoline and the E20 blend fuel. The Metro-Highway fuel consumption composite has also been calculated, where the Metro is equivalent to the city or ADR27C and ADR37/00 component. An increase in fuel consumption was not expected for the open loop vehicles assuming they were lean calibrated based on published information. The Ford Falcon result on the E20 blend was not as expected, it appears as though there may have been a running quality issue while operating on the E20 fuel, not necessarily related to the E20 fuel blend. The Toyota Camry was expected to follow a similar trend as for the new vehicles as it operated with a closed loop control system. The following Table 9.19 presents a summary of the fuel consumption outcome as a percentage difference between gasoline and the E20 fuel.

| Old Vehicle | ADR37/01 City Cycle | ADR27C City Cycle | AS2877 Highway Cycle | Metro-Highway Composite |
|---|---|---|---|---|
| **AENFO11** | +5.98% | - | +5.19% | +5.53% |
| **AENHO12** | -0.29% | - | +2.05% | +0.96% |
| **AENMI13** | - | +1.05% | +3.18% | +2.26% |
| **AENTO14** | - | +3.57% | +6.21% | +5.00% |
| **Average** | +2.71% | | +4.07% | +3.42% |

**Table 9.19 Old Vehicle Fuel Consumption Summary Percentage Difference Between Gasoline and E20 Comparison.**

### 9.1.8 Vehicle Driveability Summary.

Driveability assessments were focussed on evaluating the engine starting behaviour and driveability characteristics of the vehicle. The assessments made are for ambient, hot and cold temperature weather conditions, the hot and cold conditions simulated in an extreme environmental chamber where the stationary vehicle assessments are made. This includes starting and idle. Driveability assessments occurred on the open road and follow the driving cycle displayed in Figure 0.1. Ratings were given according to the drive ratings Table 5.9, the performance ratings Table 5.10 and the startability and idle ratings Table 5.11 for the various aspects of the testing, a rating of just less than 7.0 indicates the average driver will notice a slight defect with lower numbers indicating a greater defect. Two independent vehicle engineers assess and rate the characteristics for the baseline gasoline and E20 fuel, the average rating is calculated though an assessment is firstly made to ensure the difference between the awarded ratings is not significant. This helps ensure a level of quality in terms of identifying a potential problem with the vehicle early and highlighting the validity of the test. It is the differences between the two average ratings for gasoline and E20 fuel that was used to determine the impact of the E20 fuel. Specific summer test fuel was used for the ambient and hot testing and winter test fuel for the cold testing.

#### 9.1.8.1 New Vehicles.

##### 9.1.8.1.1 Ambient Conditions Summary.

Three assessment areas were evaluated within this evaluation that in general occurred at a temperature of 25$^{o}$ Celcius. Within the startability and Idle quality assessment there were no reported differences identifiable by the average driver.

Within the vehicle performance test designed to assess the acceleration performance facets of normal driving, average driver identifiable impacts were found, these impacts were relatively small and are summarised in Table 9.20.

The warmed-up driveability test assesses the normal driving response of the warmed-up vehicle. For the ambient conditions testing, the vehicles were in general found to operate in a similar manner while operating on E20 fuel to gasoline. The Hyundai Accent during the passing feeling acceleration test was found to degrade along with the delivery of full load torque delivery to the point where the average driver would notice the difference. Table 9.20 provides an overall summary for each vehicle and the three assessment areas.

| Vehicle | | Ambient Driveability | | Hot Driveability | | Cold Driveability | |
|---|---|---|---|---|---|---|---|
| | | Gasoline | E20 | Gasoline | E20 | Gasoline | E20 |
| **Holden Commodore VX II AENHO01** | Average | 7.7 | 7.7 | 7.8 | 7.4 | 7.9 | 7.8 |
| | Maximum | 8.5 | 8 | 8 | 8 | 8 | 8 |
| | Minimum | 6.8 | 7.2 | 7.3 | 6 | 7.3 | 7 |
| **Ford Falcon AU III AENFO02** | Average | 7.4 | 7.3 | 7.6 | 7.2 | 7.8 | 7.4 |
| | Maximum | 8 | 7.9 | 8 | 8 | 8 | 8 |
| | Minimum | 6.1 | 6.8 | 6.8 | 5.8 | 7.3 | 6.3 |
| **Toyota Camry Altise AENTO03** | Average | 7.6 | 7.8 | 7.9 | 7.7 | 7.9 | 7.6 |
| | Maximum | 8.3 | 8 | 8 | 8 | 8 | 7.8 |
| | Minimum | 7 | 7.3 | 7.8 | 7 | 7.5 | 7.3 |
| **Hyundai Accent AENHY04** | Average | 7.8 | 7.5 | 7 | 7.3 | 8 | 7.5 |
| | Maximum | 8 | 8 | 8 | 8 | 8 | 8 |
| | Minimum | 7.5 | 6.6 | 4.7 | 6.5 | 7.9 | 7.2 |
| **Subaru Impreza WRX AENSU05** | Average | 7.8 | 7.8 | 7.6 | 7.4 | 7.7 | 7.4 |
| | Maximum | 8.3 | 8.3 | 8 | 8 | 8 | 8 |
| | Minimum | 7 | 7.3 | 7 | 6 | 6.8 | 4 |

**Table 9.20 - New Vehicle Driveability Summary**

### 9.1.8.1.2 Hot Conditions Summary.

For the hot conditions testing, the starting and re-starting testing for the Ford Falcon identified significantly increased time to start the engine when operating on E20 fuel. Also during the re-start test following an extended idle the same characteristic was identified. These times were of the order of three seconds, the average driver will identify this impact. Further the Holden Commodore startability and idle quality after a 30 minute hot soak were found to degrade to the point when operating on E20 fuel where the average driver would notice.

### 9.1.8.1.3 Cold Conditions Summary

During the cold conditions testing, the Ford Falcon again required three seconds to start and with the Subaru Impreza WRX required more than three seconds to re-start when operated on the E20 fuel, this is identifiable by the average driver. Further the Subaru Impreza WRX stalled after fire on both the re-start tests, the applied rating indicates poor performance with the average driver viewing this as disturbing defects present but still confident of continual operation and would seek corrective action.

#### 9.1.8.2 Old Vehicles.

The same evaluation procedures as for the new vehicles were used for the old vehicles. While these ratings tables criteria are likely to be significantly beyond the capability of the old open loop vehicles, the Ford Falcon (AENFO11), the Holden Commodore (AENHO12) and the Mitsubishi Magna (AENMI13) due to their age (not condition), it is still valid to use the rating system as the objective is to compare the performance on gasoline and E20.

##### 9.1.8.2.1 Ambient Conditions Summary.

For the ambient conditions testing, poor to mediocre startability was identified on the Holden Commodore and Mitsubishi Magna with the driver either seeking or likely to seek corrective action respectively. Idle quality issues on the Ford Falcon and the Holden Commodore were rated as poor and mediocre respectively with the driver of the Ford Falcon seeking corrective action. In terms of the vehicle performance, the Holden Commodore rated mediocre for the WOT launch leaving the driver feeling that it does not perform as well as thought with poor acceleration capability under normal circumstances. Once the vehicle was warmed up, there were a number of driveability areas where the Mitsubishi Magna presented with poor or mediocre rating with the driver seeking or likely to seek corrective action.

##### 9.1.8.2.2 Hot Conditions Summary.

Longer hot conditions starting times and stalling after crank and fire for start and re-start was identified for the Mitsubishi Magna, Holden Commodore and the Ford Falcon. These issues received ratings from 2.5 to 4.8 interpreted as undermining the drivers confidence and not reliable through to the user seeking corrective action. Idle quality of the Holden Commodore and Mitsubishi Magna was rated mediocre for both vehicles. Following the extended idle and startability a hot soak of 20 minutes occurred with open road assessment of the hot driveability following. Significant hesitation under WOT acceleration from standing start for the Holden Commodore rated as poor was identified. The Holden Commodore and Mitsubishi Magna both displayed degradation in the 50 and 70 km/h cruise tests with instability in combustion the average driver would notice.

| Vehicle | | Ambient Driveability | | Hot Driveability | | Cold Driveability | |
|---|---|---|---|---|---|---|---|
| | | Gasoline | E20 | Gasoline | E20 | Gasoline | E20 |
| AENFO11 - | Average | 6.6 | 6.1 | 6.1 | 3.9 | 6.7 | 6.2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1985 Ford Falcon XF (ADR27C) | Maximum | 7.3 | 7 | 7.3 | 4.5 | 7.3 | 7.1 |
| | Minimum | 5.6 | 4.3 | 5 | 3.5 | 5.5 | 5 |
| AENHO12 - 1985 Holden Commodore VK (ADR27C) | Average | 7.1 | 6.6 | 6.9 | 6 | 5.8 | 4.2 |
| | Maximum | 8 | 7.8 | 8 | 7.3 | 7.4 | 6 |
| | Minimum | 6.2 | 4.6 | 4.8 | 4.5 | 1 | 1 |
| AENMI13 - 1986 Mitsubishi Magna TM (ADR37/00) | Average | 7 | 6.7 | 6.5 | 5.9 | 6.5 | 7.1 |
| | Maximum | 7.8 | 7.5 | 7.8 | 7.8 | 7.3 | 7.8 |
| | Minimum | 5.5 | 7.5 | 5 | 2.5 | 5 | 5.5 |
| AENTO14 - 1993 Toyota Camry Ultima (ADR37/00) | Average | 7.6 | 7.5 | 7.9 | 7.3 | 8 | 7.9 |
| | Maximum | 8 | 8 | 8.3 | 8 | 8.3 | 8.3 |
| | Minimum | 6.5 | 6.8 | 7.5 | 3 | 7.5 | 7.4 |

**Table 9.21 - Overall Old Vehicle Driveability Summary**

### 9.1.8.2.3 Cold Conditions Summary.

Cold start evaluations after the vehicle was soaked for at least 8 hours at –10$^o$ Celcius identified significant increases in start times for the Holden Commodore and the Ford Falcon. Using gasoline, the Holden Commodore took 22.5 seconds to start while with E20 this increased to 65 seconds. The Ford Falcon start time increased by 3.7 seconds with a very rough idle rated as 5.0 indicating the driver is likely to seek corrective action. Restart for the Holden Commodore was rated poor due to stalling. In general idle quality for the Holden Commodore was rated from very poor to poor due to stalling and very rough idle, some assessment points on gasoline were rated as mediocre though there was a significant degradation over the gasoline baseline with E20 fuel. Immediately following the startability and idle quality assessment, the warm-up driveability on the open road was evaluated. The WOT performance of the Holden Commodore was rated very poor due to severe hesitation upon throttle demand, undermining driver confidence and as it is not reliable. Further acceleration degradation for the Holden Commodore and Mitsubishi Magna was identified for the interrupted acceleration test, the Mitsubishi Magna stalling and the Holden Commodore found to hesitate upon throttle demand. The Holden Commodore and the Ford Falcon were found to run roughly and display hesitation during the 50 km/h cruise with the Holden Commodore driver likely to seek corrective action. Table 9.21 provides an overall summary for each vehicle and the three assessment areas.

### 9.1.9 Fuelling Adaptation (Enleanment) Assessment Summary.

The fuelling adaptation assessment was a simple test designed to help establish an understanding of a particular vehicles EMS ability to accommodate the differences between gasoline and the E20 fuel. The test is only applicable to new vehicles and the old Toyota Camry (AENTO14) as these vehicles are fitted with closed loop controllers. The aim of the test was to establish the approximate limits of the adaptation, it is not an exact measure. The tests were carried out at two points idle and at an arbitrary speed/load point within the emissions envelope, typically equating to a vehicle speed of 60km/h. Measurement of the fuel injector electrical duration while reducing the fuel pressure until the lambda sensor became inactive was taken as the limit of adaptation. The following Table 9.22 summarises the outcome as a percentage increase in fuel injector pulse width from the initial fuel pressure to the point of inactivity of the lambda sensor.

| **Vehicle Type** | **Vehicle code** | **Percentage increase in injector pulse width** | | | |
|---|---|---|---|---|---|
| | | **Idle (gasoline)** | **Idle (E20)** | **Off idle (gasoline)** | **Off idle (E20)** |
| **Holden Commodore VX** | AENHO01 | 41.0% | 30.5% | 47.7% | 32.7% |
| **Ford Falcon AU** | AENFO02 | 40.1% | 52.2% | 62.4% | 65.4% |
| **Toyota Camry Altise** | AENTO03 | 17.0% | 16.8% | 18.0% | 21.3% |
| **Hyundai Accent** | AENHY04 | 54.9% | 45.1% | 52.3% | 47.6% |
| **Subaru Impreza WRX** | AENSU05 | 25.2% | 25.1% | 38.1% | 41.1% |
| **Toyota Camry Ultima** | AENTO14 | 0.3[§]% | 0.1[§]% | 31% | 14.2% |

§ see Table 5.13

**Table 9.22 - Percentage Increase in Fuel Injector Pulse Width.**

### 9.1.10 Snap Fuelling Change Assessment Summary.

This test was focussed on developing an understanding of the rate at which the vehicle EMS is capable of coping with sudden switches from gasoline to E20 fuel and vice versa. Only the testing and reporting for the switch from gasoline to E20 fuel is reported, the reverse test is scheduled upon completion of the 80,000km mileage accumulation program phase. Vehicle driveability and IM240 emissions testing procedures were adopted for the assessment. In general the driveability outcomes were identical to those revealed in the driveability section of this report. The emissions characteristics were also found to be very similar on an individual vehicle basis as that identified in sections 5.1.2.1 and 5.2.2.1 (for the old Toyota Camry) of this report.

## 9.2 WTW, Lifecycle, Greenhouse Gas Emissions Assessment.

A desktop study and literature review of contemporary scientific and engineering publications related to lifecycle or Well to Wheel greenhouse gas emissions revealed five significant publications that allowed the determination of the Well to Tank component of the lifecycle greenhouse gas emissions. One of these publications written by the CSIRO was specifically utilised to make the lifecycle greenhouse gas emissions conclusion as reported here. The data within this publication was considered to be most relevant as it contained specific Australian related information.

The Global Warming Potentials adopted within this report assume the Second Assessment Report values as defined by the Intergovernmental Panel on Climate Change (IPCC).

Test vehicle tailpipe emissions were directly measured for Carbon Dioxide and Methane. The Nitrous Oxide tailpipe emissions were estimated based on a relationship with the measured tailpipe Oxides of Nitrogen. Evaporative emissions were measured for methane content during the hot soak period of the ADR vehicle emissions testing. From these emission measurements, the 'Tank to Wheel' greenhouse gas emissions were determined.

The 'Well to Wheel' greenhouse gas emissions were calculated from the summation of the 'Well to Tank' data obtained from the literature reviewed and the measurements of 'Tank to Wheel' greenhouse gas emissions from the test vehicles. The 'Well to Wheel' greenhouse gases emitted by vehicles fuelled with gasoline were compared to the same vehicles fuelled with E20, to determine the advantage, if any, of E20 in terms of greenhouse gas emissions.

## 9.3 Materials/Components Compatibility Interim Assessment.

The interim findings show that the E20 test fuel is incompatible with a significant number of the components from the three vehicle fuel systems currently under test. These findings are based on a visual inspection with photographic evidence, weight and hardness results of the components after 312, 476 and 839 hours respectively of immersion time. Those fuel system components, when immersed in the gasoline test fuel and subsequently inspected after the same immersion period, did not show any significant evidence of incompatibility with the gasoline test fuel.

A summary of findings is as follows, and unless stated the components did not show any visible appearance of incompatibility with the gasoline test fluid.
Metallic Components.

- Fuel pump armatures displayed rust and pitting corrosion on the shaft and the armature rotor.
- The fuel injector displayed rust on the fuel inlet tube area.
- A fuel pressure regulator diaphragm showed rust occurring on the rivet and washer components of the diaphragm.
- Fuel pump casings (aluminium) displayed significant pitting corrosion.
- The carburettor body (aluminium) displayed significant pitting corrosion.

Brass and copper metal components.

- Fuel pump armature commutator presented with significant tarnishing.
- Electrical contacts were also highly tarnished presenting the possibility of increased electrical contact resistance due to the oxide layer.
- Effectively, all brass and copper material was significantly tarnished when exposed to the E20 test fluid.

Rubber Components.

- Fuel pressure regulator diaphragms from EFI fuel systems were found to distort and swell.
- A diaphragm from the carburettor fuel system was also found to distort and swell.
- In general, rubber components were found to experience a greater change in weight and hardness when immersed in the E20 test fluid in when compared to the samples immersed in the gasoline fluid.

Plastic Components.

- Generally plastic components experienced little of no change in weight or hardness.
- The carburettor float increased in weight by 5.5% when immersed in the E20 test fluid and only 0.3% in the gasoline fluid.
- The plastic parts of the PCV valves distorted and detached from the metal past of the valve.

## 9.4 Conclusions

Based on the outcome of the testing, literature review and study and analysis undertaken within the program of work designed to uncover and confirm the potential impacts of the E20 fuel blend on the automotive vehicle fleet, the following conclusions can be drawn within each component of the program activity.

### 9.4.1 Vehicle Performance Conclusions.

#### 9.4.1.1 Engine Power New and Old Vehicles Conclusions.

For both the new and old vehicles, the result of the acceleration testing indicates that there is no evidence of a detriment in power caused by the use of E20 fuel. However increases in exhaust gas temperature were measured in five of the nine vehicles tested with three of these showing increases in catalyst temperature. The enleanment was found to occur on six of the nine vehicles tested three of them having closed loop type control systems. In general the increase in exhaust gas temperature was found to follow those vehicles with enleanment. The enleanment and rise in exhaust gas temperature is on concern as the rise in exhaust gas temperature has the potential to impact on engine and aftertreatment durability of those vehicles as it is predominantly the calibration of the wide open throttle fuelling that is used to control the exhaust gas temperature.

#### 9.4.1.2 New Vehicle Regulated Tailpipe Emissions Conclusions.

- When the results are averaged across all new vehicles tested, the tailpipe emissions changes follow trends published in the automotive literature i.e. there is a general trend of reduced HC and CO emissions, and an increase in NOx emissions due to operation on E20 compared with gasoline only fuel.
- The overall average changes in emissions summed across all vehicles are not representative of the change for each individual vehicle in the study. Although the general trend follows for the majority of the vehicles, the magnitude of the change is substantially different. This is largely a function of engine control system, and its ability to compensate accurately for the change in fuel properties.
- A simple prediction of the overall impact on regulated emissions of the new car vehicle fleet has been performed which shows that the HC and CO emissions would be reduced by approximately 28% and 21% respectively, while the NOx emissions would be increased by approximately 33%.
- The average percentage change of all the vehicles from gasoline to E20 compares favourably with other studies of vehicles of similar emissions compliance, however as stated, this average can give a false impression of each of the individual vehicle emissions outcome.

### 9.4.1.3 Old Vehicle Regulated Tailpipe Emissions Conclusions.

- For older vehicles without closed loop control, there was a large reduction in CO emissions for all vehicles when operating on E20 compared with gasoline only fuel. The NOx emissions showed a general increase with E20, while the HC emissions remained relatively unchanged. This compares favourably with other studies on vehicles with similar control systems.
- The older vehicle with closed loop fuelling control (Toyota Camry) showed little change in regulated emissions when operated on E20.
- If the average percentage change of the emissions for all vehicles from gasoline to E20 is calculated, the approximate decrease in emissions of THC will be 4%, CO will be 70% and NOx will increase by approximately 9%. When including the closed loop vehicle in the older vehicle group, these average results do not represent the individual vehicle emissions change when using E20.

### 9.4.1.4 New Vehicle Highway Tailpipe Emissions Conclusions.

- There is a general trend across all vehicles of reduced HC and CO emissions when operating on E20 compared with gasoline only fuel.
- Tailpipe NOx emissions changes are varied depending on the vehicle with no clear trend evident. This was due to some of the vehicles operating lean without closed loop control, and hence had comparatively high NOx emissions with both gasoline and E20 fuels.
- The overall average changes in emissions summed across all vehicles are not representative of the change for each individual vehicle. Differences in control and calibration strategies and characteristics result in different tailpipe emissions changes when using E20 compared to gasoline only fuel.
- The average change across all vehicles in tailpipe emissions shows a reduction in HC, CO and NOx of 25%, 48% and 9% respectively.
- The average $CO_2$ emissions across all vehicles was reduced by approximately 1% for E20 when compared with gasoline only fuel. The reduction in $CO_2$ emissions with E20 was not consistent for all vehicles tested.

### 9.4.1.5 Old Vehicle Highway Tailpipe Emissions Conclusions.

- For older vehicles without closed loop control, there was a large reduction in CO emissions for all vehicles when operating on E20 compared with gasoline only fuel. The HC and NOx emissions did not display any general trend for each vehicles when using E20.
- The older vehicle with closed loop fuelling control (Toyota Camry) showed an increase in NOx emissions with a small reduction in HC emissions and negligible change in HC emissions when using E20 fuel.
- The average emissions across all vehicles show a HC and CO reduction of approximately 10% and 76% respectively, while the NOx emissions increase by approximately 10% when operating on E20 compared with gasoline only fuel. The average differences in emissions do not represent the change for each individual vehicle.

- For the open loop vehicles the difference in tailpipe CO emissions on the highway cycle are similar to the emissions differences on ADR27C and ADR37/00 cycle.

#### 9.4.1.6 Tailpipe $CO_2$ Emissions Conclusions.

The results from the 5 new vehicles of the effect on $CO_2$ emissions from E20 showed the following:

- $CO_2$ emissions were generally reduced over the city cycle, with an average reduction over all vehicles of approximately 1%.
- $CO_2$ emissions were generally reduced over the highway cycle, with an average reduction over all vehicles of approximately 1%.
- The reduction in $CO_2$ emissions for these type of vehicles is consistent with the automotive literature.

The results from the 4 old vehicles of the effect on $CO_2$ emissions from E20 showed the following:

- $CO_2$ emissions showed no general trend over the city cycle when considering individual vehicle results. Large reductions in CO emissions for two of the vehicles, however, resulted in increased $CO_2$ emissions which dominated the overall $CO_2$ emissions change, resulting in an overall increase for all vehicles in $CO_2$ emissions of approximately 2%.
- $CO_2$ emissions again showed no general trend over the highway cycle. Large reductions in CO emissions for two of the vehicles resulted in increased $CO_2$ emissions which dominated the overall $CO_2$ emissions changes, resulting in an overall increase across all vehicles in $CO_2$ emissions of approximately 1%.

#### 9.4.1.7 Engine Management System and Calibration Conclusions.

##### 9.4.1.7.1 New Vehicles.

- All vehicles maintained closed loop control while operating on E20 during the ADR37/01 test procedure.
- Based on the data presented, individual vehicles have very different pre-catalyst emissions outcomes when switched from straight gasoline to E20.
- The differences are a function of how the EMS for the particular vehicle adapts the closed loop controller.
- It appears from the measured data that the adaptation process is specific to the vehicle manufacturers control strategy.
- Little difference in catalyst efficiencies was identified once warmed up, though the Ford Falcon did display a reduction in catalyst conversion efficiency likely due to the lean biased closed loop control strategy.
- Slightly different biasing of the closed loop controller was found to occur when operating on gasoline and the E20 fuel blend.
- Minor differences in the oxidation performance of the catalysts in the cold transient phase of the ADR37/01 test procedure were identified, at the low mileage point of the catalysts this is not thought to be significant.

- Potentially, the engine management/control systems of some new vehicles are not able to maintain the intended control of the engines when operating on the E20 fuel blend.

#### 9.4.1.7.2 Old Vehicles.

- Open loop vehicles have similar pre-catalyst/engine out emissions outcomes when switched from straight gasoline to E20. The predominant difference is the reduction in CO emissions. The changes to the other regulated emissions are different from vehicle to vehicle.
- As expected all the open loop vehicles experience a lean shift when operated on E20. The effect on emissions other than CO appears to be a function of the base calibration (mixture strength) of the engine/vehicle.
- For the Toyota Camry the adaptation of the fuelling has occurred and clearly shows that the oxygen levels in the exhaust for E20 are lower than for gasoline. The nett affect on pre-catalyst emissions is an increase in CO with no change to the other regulated emissions. The exhaust lambda trace for this vehicle shows there has be a relative change in the bias of the closed loop controller between gasoline and E20.
- Overall there is little difference in catalyst efficiency between operating the vehicles on gasoline and E20, though a change in the NOx emission conversion was found with the Mitsubishi Magna oxidation only catalyst and therefore the gasoline conversion is very low to start with.

### 9.4.1.8 New Vehicle Unregulated Toxic Tailpipe Emissions Conclusions.

#### 9.4.1.8.1 Exhaust Aldehydes

- Overall there will be an increase in Aldehydes when the vehicles are operated on E20, though the measured values are very low.
- The increase comes predominantly from an increase in Acetaldehyde.
- The largest impact is in the first phase of the drive cycle, which includes the cold start.
- The trends reported here compare favourably with other studies.

#### 9.4.1.8.2 Exhaust Toxics

- The following overall decreases in exhaust toxics were measured when the vehicles are operated on E20: Benzene 40%, Hexane 40% and Toluene 30%.
- These trends compare favourably with other studies.
- There is a good correlation between exhaust Benzene, Hexane, Toluene and THC on both gasoline and E20, this substantiates the claim that a significant source of toxics is by products of combustion and un-combusted gasoline.
- The largest impact is in the cold transient phase, further confirming that the major source of toxics is by products of combustion and un-combusted gasoline.

#### 9.4.1.9 Old Vehicle Unregulated Toxic Tailpipe Emissions Conclusions.

##### 9.4.1.9.1 Exhaust Aldehydes.

- Overall there was a large increase in Aldehydes from the ADR27C vehicles when operated on E20, of the order of 700%.
- There was also an increase in Aldehydes with the ADR37/00 vehicles, in this case the absolute level is significantly lower than for the ADR27C vehicles, from a percentage perspective the ADR37/00 vehicles are approximately 900% lower than the ADR27C with aldehyde emissions.
- The increase comes predominately from an increase in Acetaldehyde.
- This trend compared favourably with other studies.

##### 9.4.1.9.2 Exhaust Toxics.

- Overall there was a decrease in exhaust toxics when the vehicles are operated on E20 as follows, 1,3 Butadiene 15% Benzene 20%, and Toluene 10%.
- The un-catalysed vehicles emitted the same output of toxics regardless of the phase of the drive cycle i.e. cold or hot.
- These trends compare favourably with other studies.

#### 9.4.1.10 New Vehicle Regulated Evaporative Emissions Conclusions.

- In general the diurnal THC emissions decreased when the vehicles are operated on E20.
- In general the hot soak THC emissions increased when the vehicles are operated on E20.
- Overall the total evaporative emissions increased when vehicles are operated on E20
- This data measured compares favourably with other studies.
- As the SHED (Sealed Housing for Evaporative Determination) test is primarily a “go no-go” test and gives no indication of the impact on the vehicle evaporative emissions system it maybe preferable to conduct running loss tests in the future to improve the understanding of the evaporative emissions impact.

#### 9.4.1.11 Old Vehicle Regulated Evaporative Emissions Conclusions.

- From the measured data, in general for the ADR27C vehicles the diurnal THC emissions increased when the vehicles are operated on E20. This is contradictory to the data for the ADR37/00 and ADR37/01 vehicles, which show a decrease.
- In general the hot soak THC emissions increased for both the ADR27C and ADR37/00 vehicles when operated on E20.
- Carburetted vehicles that do not have the float chambers vented to the carbon canister may potentially show a large increase in hot soak evaporative emissions when operated on E20 fuel.
- Overall for the ADR27C vehicles tested, the evaporative emissions increased when operated on E20.

- Overall for the ADR37/00 vehicles tested, the evaporative emissions decreased when operated on E20, however this result is potentially skewed by the high gasoline diurnal emissions from the Toyota Camry.

#### 9.4.1.12 Air Toxics Evaporative Emissions Conclusions.

##### 9.4.1.12.1 New Vehicles.

- Overall there will be a increase in evaporative air toxics when the new vehicles are operated on E20.
- The increase in air toxics concurs with the increase in THC measured during the evaporative test.

##### 9.4.1.12.2 Old Vehicles.

- Overall there will be a increase in evaporative air toxics when the old vehicles are operated on E20,
- The increase in air toxics concurs with the increase in THC measured during the evaporative test

#### 9.4.1.13 New Vehicle Fuel Consumption Conclusions.

Clear fuel consumption increases when operating with the E20 fuel have been measured for the new vehicles, however the increases are only in some cases up to the theoretical 7% mark based on the decrease in energy content of the fuel when adding 20% by volume ethanol.

- In general there is an increase in fuel consumption when the vehicles tested are operated on E20 ranging from 2.5% to 7% depending on the cycle and the vehicle.
- The level of increase on average was less than expected. It is thought the differences might be due to subtleties in the adaptation strategies of the various vehicles control systems.
- Increases in fuel consumption of 5% or more are considered to be recognisable to the average driver.

#### 9.4.1.14 Old Vehicle Fuel Consumption Conclusions.

Excluding the Ford Falcon which may have operated with an unknown compromise not necessarily due to the E20 fuel:

- In general there was a minor increase in fuel consumption when the open loop fuelled vehicles were operated on E20.
- The closed loop fuelled vehicle behaved similarly to the new vehicles tested with an increase in fuel consumption when operated on E20 ranging from 3.5% to just over 6% depending on whether operated over the city or highway cycle.

#### 9.4.1.15 Vehicle Driveability Conclusions.

##### 9.4.1.15.1 New Vehicles.

- Under ambient conditions some vehicles potentially may experience a noticeable degraded WOT acceleration performance.

- Under hot conditions, some vehicles potentially may experience increased starting times of up to three seconds while idle stability may be degraded such that it will be noticed by the average driver.
- Under cold conditions some vehicles potentially may experience longer starting times of up to three seconds and engine stalls once the engine fires, the driver will view this as s disturbing defect but still retain confidence of continual operation and would seek corrective action.
- These impacts are related to the changes made to the distillation curve of the gasoline by addition of 20% ethanol along with enleanment and the greater heating required to vaporise ethanol and are confirmed by the literature review completed earlier (4).

#### 9.4.1.15.2 Old Vehicles.

- Under ambient conditions, potentially significant startability problems with old open loop carburetted vehicles such as long starting times with stall after firing may occur. Idle quality may potentially degrade on open loop vehicles to the point where stability and roughness are experienced. Issues such as hesitation to throttle demand and mediocre WOT launchability performance may also occur which are more significant when the engine is cold. Even when warmed-up, some cars may suffer throttle response problems along with a number of other degraded driveability issues. For some of these impacts, the average driver will believe disturbing defects are present but still have confidence of continual operation will however seek corrective action
- For hot conditions, startability of some older vehicles may display stalling and rough running to such a degree that the driver will believe the vehicle will fail to stay running and will not operate consistently. Other vehicles startability may degrade to the point where the driver believes disturbing effects are present but is still confident of continual operation and seek corrective action. Idle quality may also degrade to similar levels with unstable and rough running indicating the driver would seek corrective action. Significant hesitation to WOT demand may be experienced along with hesitation at cruise speeds of 50 to 70 km/h. Some vehicles may experience hesitation to the point of the driver seeking corrective action.
- Under cold conditions starting may become degraded to the point of stalling and rough running such that the driver seek corrective action due to the disturbing defects present. Idle quality may also degrade to the level of stalling and rough operation such that drivers confidence is undermined as it is believed the vehicle is not reliable. Further during warm-up after a cold condition start, severe hesitation to WOT throttle demand and other acceleration functions may occur such as to undermine the drivers confidence such that it is believed the vehicle is unreliable. Hesitation at cruise speed of 50 km/h was also noted that may cause the average driver to seek corrective action.
- These impacts are related to the changes made to the distillation curve of the gasoline by addition of 20% ethanol along with enleanment and the greater heating required to vaporise ethanol and are confirmed by the literature review completed earlier (4).

#### 9.4.1.16 Fuelling Adaptation (Enleanment) Conclusions.

From the simple test conducted there appears to be an adequate range of adaptation for the closed loop vehicles tested when operated on E20.

#### 9.4.1.17 Snap Fuel Change Conclusions.

For the snap fuel test of gasoline to the E20 fuel the following conclusions can be drawn:

- The closed loop controlled vehicles appear to quickly adapt to the snap fuel change demonstrating very similar driveability characteristics when operating on both gasoline and E20 fuel.
- Exhaust emissions trends are similar to those found in the city cycle ADR37/01 and ADR37/00 test procedures.

### 9.4.2 WTW, Lifecycle Greenhouse Gas Emissions Conclusions.

Data from the CSIRO report and measurements of Tank to Wheel greenhouse gas were used to draw conclusions regarding the potential for E20 to produce lower 'Well to Wheel' greenhouse gas emissions. The specifics of the 'Well to Wheel' analysis data are summarised as follows:

- E20, consisting of ethanol produced from wood waste, will produce lower quantities of greenhouse gas per unit of fuel, when compared to gasoline, during the 'Well to Tank' period.
- It can be concluded that E20, with the exception of E20 consisting of ethanol produced from wood waste, will produce higher quantities of greenhouse gas per unit of fuel, when compared to gasoline, during the 'Well to Tank' period. This same conclusion can be drawn from the GMC data.
- Future measurement of tailpipe greenhouse gas emissions should utilise the direct measurement of N2O thereby improving the accuracy and understanding of the behaviour of N2O formation from the vehicle fleet.
- Neither E20 nor gasoline emits CH4 gas as a result of evaporative losses from the vehicle.
- E20 consisting of ethanol produced from ethylene emits with statistical significance greater 'Well to Wheel' greenhouse gas emissions than gasoline for old and new vehicles, and the Australian vehicle fleet.
- E20, consisting of ethanol produced by any method other than from ethylene, emits with statistical significance less 'Well to Wheel' greenhouse gas emissions than gasoline for new vehicles, and when the entire Australian vehicle fleet is considered.
- E20, with the exclusion of ethanol produced from ethylene, from molasses with an economic allocation and from premium wheat, emits with statistical significance less 'Well to Wheel' greenhouse gas emissions than gasoline for the old vehicles.
- E20, consisting of ethanol produced from molasses with an economic allocation and from premium wheat, can be considered to emit statistically similar 'Well to Wheel' greenhouse gas emissions when compared to gasoline for old vehicles.
- E20 containing ethanol produced by wood-waste provides with statistical significance the greatest GHG advantage over gasoline, approximately 11% on average when considering the overall fleet and both city and highway driving.

The following tables (Table 9.23 and Table 9.24) provide a summary of the potential outcomes for both driving cycles, for new and old and the vehicles combined. Compared to the baseline gasoline, the various ethanol sources and production process are provided in order of decreasing benefit in terms of reduction of greenhouse gases.

| Comparison of Transport Fuels CSIRO base Well To Tank Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **ADR WTW Emissions City Cycle** | **Gasoline** | **E20** | | | | | | |
| | Reference (PULP) | Azeotropic (wood waste) | Azeotropic (wheat) fired with wheat straw | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (wheat) | Azeotropic (molasses - Sarina - Economic Allocation) | Azeotropic (ethylene) |
| New Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |
| Old Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Same*** | ***Same*** | ***Worse*** |
| **Overall – E20 to Petrol Assessment** | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |

## Table 9.23 - City Cycle Well to Wheel Greenhouse Gas Outcome

| Comparison of Transport Fuels CSIRO base Well To Tank Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **AS2877 WTW Emissions Highway Cycle** | **Gasoline** | **E20** | | | | | | |
| | Reference (PULP) | Azeotropic (wood waste) | Azeotropic (wheat) fired with wheat straw | Anhydrous (wheat starch waste - Bomaderry) | Azeotropic (molasses - Sarina expanded system boundary) | Azeotropic (wheat) | Azeotropic (molasses - Sarina - Economic Allocation) | Azeotropic (ethylene) |
| New Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |
| Old Vehicle - E20 to Petrol Assessment | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Same*** | ***Same*** | ***Worse*** |
| **Overall – E20 to Petrol Assessment** | | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Better*** | ***Worse*** |

## Table 9.24 - Highway Cycle Well to Wheel Greenhouse Gas Outcome.

### 9.4.3 Materials/Component Compatibility Interim Conclusions.

The conclusions presented here are from interim findings of the materials/component compatibility testing schedule. A final report on the assessment of the testing when all components complete the 2000 hour immersion is planned for early May 2003.

The corrosion of metallic fuel system components by the E20 test fluid reported herein is considered as unacceptable as the potential exists for the oxide to dislodge and deposit in fuel filters and fuel metering devices causing blockage. Further the dislodged oxide has the potential to settle in areas where mechanical movement of components occurs, such as bearings in fuel pumps and fuel injectors potentially accelerating the wear of these components.

The potential impact on the vehicle fleet from corrosion of the metallic fuel system components may be premature component failure, degraded driveability and operability followed by engine operation failure, the details of which are described within the material/component compatibility section of this report.

Nearly all brass and copper components displayed a significantly increased tarnishing when in contact with the E20 test fluid. This corrosion is considered as a concern as it presents the potential for changing the fuel metering performance of fuel metering jets, may cause premature component failure of rubbing components such as the fuel pump commutator and may cause changes in the electrical performance of components due to changes in the contact resistance of electrical connections within fuel submerged pumps for example.

In general, rubber components were found to experience a greater change in weight and hardness when immersed in the E20 test fluid then in neat gasoline. Of significant concern was the distortion and swelling of the fuel pressure regulator diaphragms from the EFI fuel systems tested. These components are under stress in operation and coupled with the findings of the immersion tests the potential for premature failure exists. Such failure may render the vehicle inoperable and has the potential to result in fuel leakage. A carburettor diaphragm displayed distortion and swelling, potential premature failure for this diaphragm as well with the potential for fuel leakage exists for this component as well. These impacts are considered as unacceptable due to the increased potential for fuel leakage.

Most of the plastic materials tested experienced little or no changes when immersed in the E20 test fluid. However the carburettor float tested increased in weight by 5.5% presenting the potential for loss of fuel metering performance of the carburettor with potential resultant driveability and operability impacts. A further E20 effect was found on the two PCV valves tested, the plastic part of the valve was found to completely separate from the metal part of the valve. This is a concern as the potential exists for degraded driveability and operability due to a significant engine air leak should the separation be experienced on the vehicle.  This would potentially result in the loss of the fuel and air metering accuracy required for normal engine operation.

The final findings of the materials component compatibility tests are planned to be reported in early May 2003 when all the engine and fuel systems components and materials under test complete the 2000 hour immersion schedule.  However, based on the interim findings of the materials/component compatibility testing, there are a number of materials utilised in the vehicles components tested to provide sufficient evidence that the potential impacts on the Australian vehicle fleet are of sufficient magnitude to consider them as unacceptable.

### 9.4.4 Paint Testing Interim Conclusions.

The findings presented here represent a time limited assessment of the potential for the E20 fuel blend to degrade the paint work on new vehicles in the vicinity of the fuel filler door. Fuel filler doors from the Holden Commodore and the Ford Falcon have been subjected to both gasoline and E20 test fluid. This assessment represents 2 weeks of application of the test fluids to the test samples where all samples presently show:

- No evidence of paint peeling
- No evidence of blistering
- No evidence of crazing
- No evidence of dulling
- Some evidence of staining (white painted fuel filler door only)

The staining is only evident on the white painted fuel filler door sample. To the naked eye the staining shown is slightly more prominent on the sample exposed to E20 than to the baseline ULP sample. Neither staining is however dark enough to be readily captured using digital photography.

Testing is to continue for the remaining period of materials/components compatibility testing program and the final report on this testing is planned for early May 2003.

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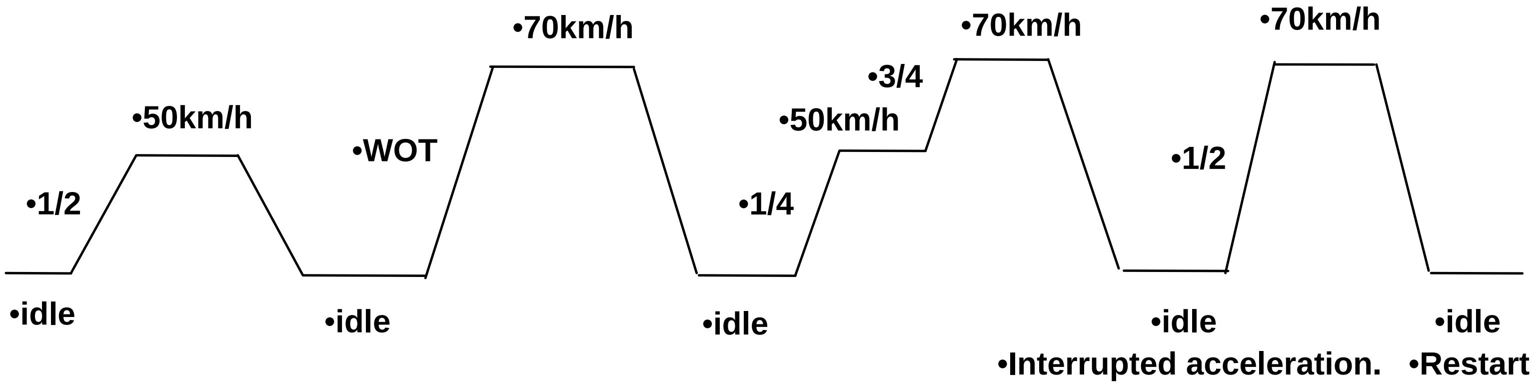
## Acronyms

| | |
|---|---|
| ADR | Australian Design Rule |
| AFR | Air Fuel Ratio |
| A/F ratio | Air/Fuel Ratio |
| CO | Carbon Monoxide |
| E20 | Gasoline blended with 20 % Ethanol |
| EA | Environment Australia |
| EMS | Engine Management System |
| FMEA | Failure Mode Effect Analysis |
| THC | Total Hydrocarbons (Hydrocarbons plus Methane, CH4) |
| MACD | Mileage Accumulation Chassis Dynamometer |
| M-H | Metro (city)-Highway composite number |
| MSDS | Material Safety Data Sheet |
| NOx | Oxides of Nitrogen. |
| SAE | Society of Automotive Engineers. |
| SHED | Sealed Housing for Evaporative Determination. |
| THC | Total Hydrocarbons. |
| TWC | Three Way Catalyst. |
| UEGO | Universal Exhaust Gas Oxygen analyser |
| ULP | Unleaded Petrol. |
| WOT | Wide Open Throttle. |



- 10 second idle check
- ½ throttle to 50km/h (Launch, acceleration check)
- 50km/h cruise (stability check)
- 10 second idle check

- Full throttle to 70km/h (Launch, acceleration check)
- 70km/h cruise (stability check)
- 10 second idle check

- 1/4 throttle to 50km/h (Launch, Tip-in/out, acceleration check)
- 50km/h cruise (stability check)
- ¾ throttle to 70km/h (Tip-in/out, Acceleration check)
- 70km/h cruise (stability check)
- 10 second idle check
- Sudden brake as soon as a vehicle moves (Engine stall, idle stability check)

- Full throttle to 70km/h (Launch, acceleration check)
- 70km/h cruise (stability check)
- 20 seconds idle check
- Steering lock to lock
- Idle in P/N
- Ignition off
- Restart within 5 seconds

**Figure 0.1 - Hot and Cold Driveability Driving Cycle**