



Camden Council Biodiesel Trial

Emissions Analysis:

Comparing Emissions Testing Results

Camden Council



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1 INTRODUCTION

The substitution of traditional diesel with biodiesel in motor vehicles has the potential to reduce pollutant emissions to air and thereby improve air quality and human health. To this end, Camden Council implemented a trial¹ that assessed the viability of using biodiesel as the fuel for the Council's waste collection vehicle fleet.

The aim of the trial was to quantify the effect on pollutant emissions and engine performance for the Council's waste collection fleet by substituting ultra low sulphur diesel with 100% biodiesel (B100).

Pacific Air & Environment was engaged by Camden Council to manage the trial while the Roads and Traffic Authority (RTA) provided emissions testing services². A detailed description of the trial is provided in RTA's report, *'Camden Council Biodiesel Trial – Third and Final Progress Report, June 2004 (RTA, 2004)*.

The objective of this report is to review and interpret the testing results and compare where possible, with the results of other studies quantifying emissions of biodiesel.

2 LITERATURE REVIEW

To aid in developing the scope of the trial, it is important to identify the common environmental issues associated with fossil fuel combustion, so that the effect of biodiesel substitution can be best measured. The three significant issues associated with motor vehicles are photochemical smog formation, air toxic releases and greenhouse gases, and these are discussed below (Sections 2.1, 2.2 and 2.3 respectively). Also, to provide some indication of expectations of the results from the biodiesel trial, a review of literature on emissions from biodiesel fuelled vehicles is performed in Section 2.4.

2.1 Photochemical Smog

Fuel combustion and other industrial activities release into the atmosphere a large number of pollutants which can be harmful to public health or vegetation. This air pollution is commonly called "smog" (a cross between smoke and fog) because it is associated with reduced visibility. The low visibility is due to scattering of solar radiation by high concentrations of aerosols (very small particles). The health hazards of smog are caused in part by the aerosol particles but also by toxic gases including ozone (O₃), carbon monoxide (CO), sulphur dioxide (SO₂) and carcinogens present in the polluted air together with the aerosols (Jacob, 1999).

¹ The trial was funded by the NSW Department of Environment and Conservation (NSW DEC).

² Diesel Test Australia (DTA) were contracted to provide testing services to the RTA for this project. RTA contracted the services of CSIRO to undertake the sampling and analysis of the air toxics component of the program and Intertek to undertake fuel analysis.



Ozone in smog is formed by a complex reaction between oxides of nitrogen (NO_x) and various volatile organic compounds (including polycyclic aromatic hydrocarbons) in the presence of UV radiation. Generally, the level of smog formation depends on the fractions of each type of pollutant together with the total level of pollutant in the atmosphere (Jacob, 1999).

Motor vehicles running on fossil fuels release both NO_x and reactive hydrocarbons. Motor vehicles contribute approximately 70% of emissions of NO_x and about 52% of volatile organic compounds (VOC) emissions in the greater metropolitan region of Sydney (NSWEPA, 2000).

2.2 Air Toxics

Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects, birth defects or adverse environmental effects. Motor vehicles running on fossil fuels release a variety of air toxics such as benzene, toluene and xylene (USEPA, 2004a).

2.3 Greenhouse Gases

Motor vehicles release significant amounts of carbon dioxide (CO_2), the most common greenhouse gas. Anthropogenic greenhouse gases alter the earth's radiation balance so that more long-wave radiation is being absorbed in the lower atmosphere and some of this is being re-emitted back to the earth's surface – known as the 'enhanced greenhouse effect' (NSWEPA, 2000). In Australia 12.7% of CO_2 equivalent³ emissions are due to road transport emissions (AGO 2002). It is important to note that this study only looks at the tailpipe emissions of CO_2 . It does not assess the net CO_2 emissions due to the entire lifecycle of the fuel. The reader should refer to other studies (e.g. Beer et. al., 2000) to understand the net greenhouse benefits of biodiesel as a renewable fuel.

2.4 Emissions from Biodiesel-Fuelled Vehicles

Most of the relevant studies relating to the use of biodiesel have been conducted in the US. This report draws heavily on the results of *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions* compiled by the USEPA (USEPA, 2002) which reviewed 80 separate studies relating to emissions from biodiesel powered vehicles, many of which were relevant to the Camden trial. Other studies were also reviewed to fill gaps in the data and these are referenced where relevant.

Biodiesel engines have a different emission profile to those powered by fossil fuels. In general, the literature indicates that emissions of particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO) should decrease and emissions of oxides of nitrogen (NO_x) should increase as a result of substitution with biodiesel. Tailpipe emissions of carbon dioxide CO_2 should also increase, although over the lifecycle of the fuel (assuming the biodiesel is produced from a renewable resource) emissions of CO_2 should decrease significantly. Figure 1 shows the expected changes in emissions when substituting diesel with biodiesel in motor vehicles.

³ A term that takes into account the different potentials that different gases have to contribute to the enhanced greenhouse effect.

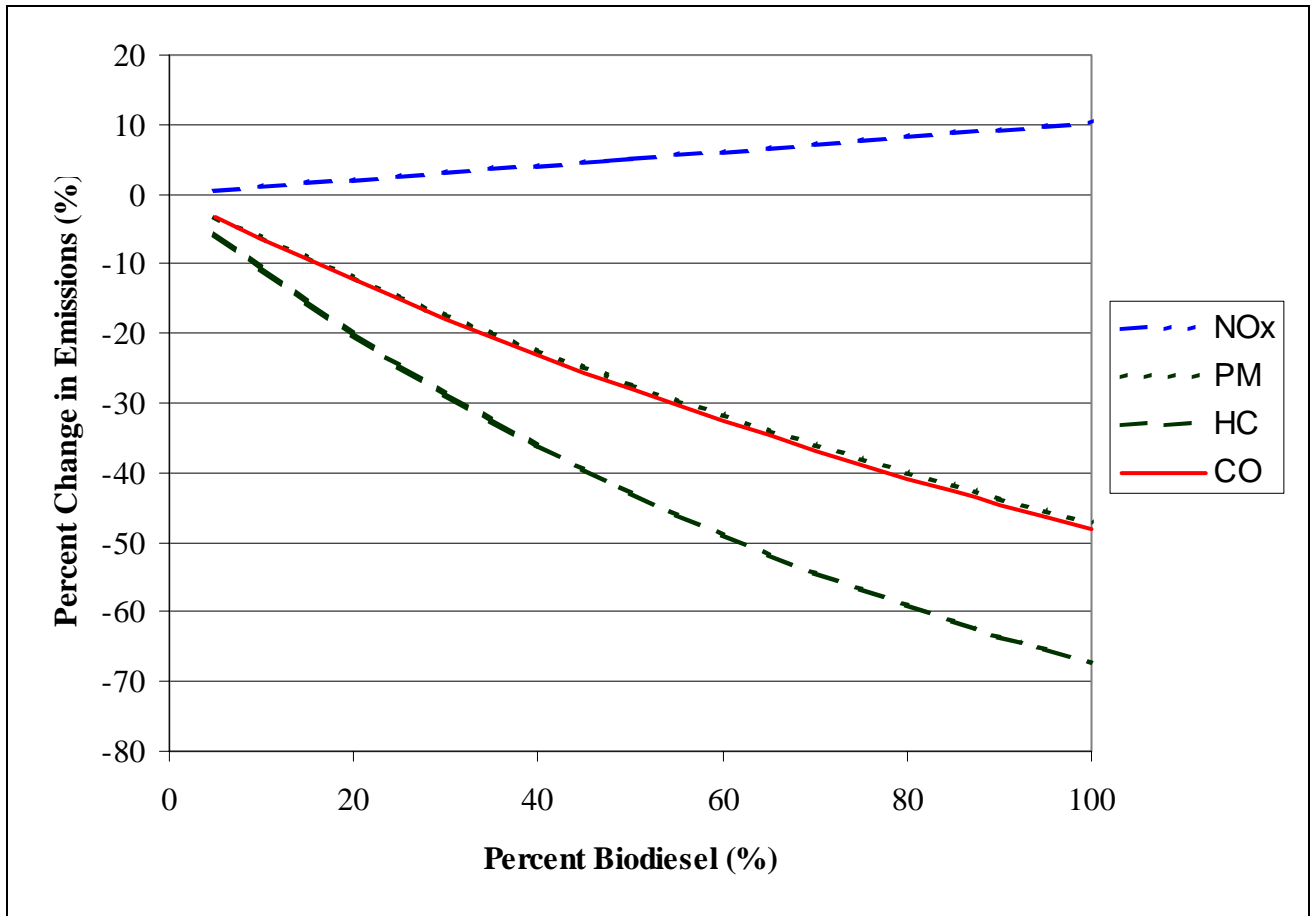


Figure 1: Average Emissions Performance of Biodiesel for Heavy Duty Vehicles (compared to diesel), at a 5% confidence level (USEPA, 2002)

The literature also indicates that emissions of air toxics, on aggregate, are expected to decrease as a result of substitution with biodiesel. Individual air toxics are more difficult to consider as data are limited. However, some analysis is possible and is summarised in Table 1. Compounds are categorised as Tier 1 (can be quantified with reasonable confidence), Tier 2 (should be estimated qualitatively) or Tier 3 (conclusions should not be drawn from these estimates).

Table 1: Air Toxic Emission Trends Observed for Biodiesel (USEPA, 2002)

Tier	Description	Toxics (decrease or increase with B100) ^a
1	Includes those toxic compounds for which the analyses appear to be largely consistent with one another. The effect of biodiesel on toxics can be quantified with reasonable confidence.	Acetaldehyde (14% decrease) Ethylbenzene (61% decrease) Formaldehyde (15% decrease) Naphthalene (27% decrease) Xylene (40% decrease)
2	Includes those toxic compounds for which the analyses may not be entirely consistent with one another, or not statistically significant. However, the effect of biodiesel	Acrolein (decrease) n-Hexane (decrease) Styrene (increase)



	on toxics can still be estimated qualitatively in terms of directional effects.	
3	Includes those toxic compounds for which the analyses are significantly in conflict with one another. No clear conclusions can be drawn.	Benzene (decrease) 1,3 butadiene (decrease) Toluene (increase)

a Expected increases based on the literature are only quantified for Tier 1 substances, as the other categories cannot be quantified, based on the literature, with any confidence.

Biodiesel also reduces polycyclic aromatic hydrocarbons (PAH) when compared to petroleum diesel exhaust. For example, targeted PAH compounds from a 1997 Cummins N14 diesel truck engine (370 HP at 1800 rpm) were reduced by 75% to 85% with the combustion of B100 in studies conducted by Sharp (1988).

Emissions tend to vary depending on the type of biodiesel (e.g., soybean, rapeseed or animal fats) and the type of diesel with which the biodiesel is blended.

It is also important to consider the test cycle that is used to obtain results. Standard test cycles are used to simulate typical driving conditions while providing a useful basis for comparison. The literature presented here is based mostly on the US Urban Driving Dynamometer Schedule (UDDS), which operates an engine at several different speeds and loads to simulate urban driving conditions (USEPA, 2004b). Test results were only included if they were representative of this driving schedule or if emissions for a particular pollutant were independent of driving cycle.

3 METHODOLOGY

3.1 Test Program

The information presented in this section is taken mostly from *Camden Council Biodiesel Trial – Third and Final Progress Report, June 2004* (RTA, 2004).

Two trucks were used in the test program. They were each being operated on two garbage collection routes. Two drivers were assigned to the program, which is summarised in Table 2.

Table 2: Program summary

	First 150 hrs operation		Second 150 hrs operation	Third 150 hrs operation	Fourth 150 hrs operation	
Test Phase		1		2		:
Truck 1						
Driver	1		1	2	2	
Fuel	Biodiesel		Biodiesel	Biodiesel	Biodiesel	
Route	1		1	2	2	
Truck 2						
Driver	2		2	1	1	
Fuel	Diesel		Diesel	Diesel	Diesel	
Route	2		2	1	1	
	Emissions Testing for Phase 2 occurred in the period from 300 to 450 hours of operation. For Phase 3 each vehicle was tested on both fuels.					



Table 3 lists the parameters tested during the trial. A sample, intended to be representative, of the tailpipe emissions of pollutants commonly associated with smog formation, air toxics and the enhanced greenhouse effect (see Section 2) was selected together with some indicators of engine performance. The impact of this change in fuel type on noise, odour emissions, engine and fuel system wear or engine life and operability is outside the scope of this phase of the project but may be considered at a later date.

Table 3: Parameters Tested in the Camden Trial

Smog Formation	Air Toxics	Greenhouse Gases	Engine Performance
Particulate matter (PM) Oxides of nitrogen (NO _x) Total hydrocarbons (HC) Benzene Toluene Xylenes 1,3-Butadiene Selected ^a individual and total polycyclic aromatic hydrocarbons (PAHs)	Acetaldehyde Acrolein Benzene 1,3-Butadiene Formaldehyde Propionaldehyde Naphthalene Toluene Xylenes	Carbon dioxide (CO ₂)	Fuel consumption Maximum power

^a The eighteen US EPA listed priority compounds plus 2-methylnaphthalene.

3.2 Test Methods

Two test methods were used for this project. The DT80 (simplified typical driving cycle – see Appendix A) test was used for opacity, emissions of particulate matter (PM), oxides of nitrogen (NO_x), hydrocarbons (HC), carbon dioxide (CO₂), fuel consumption (FC) and maximum power output. The D550 (simulated steady state at 5% gradient and 50 km/h – see Appendix B) test was used for polycyclic aromatic hydrocarbons (PAHs) and C1-C3 aldehydes plus the parameters tested using the other test. Raw test results are recorded in Appendix C and Appendix D.

Fuel consumption, based on the carbon balance method, was calculated from the emissions of total hydrocarbon and carbon dioxide.

Maximum power developed at the rear wheels on the dynamometer at 80 kph was measured and recorded at the end of each test.

A number of other parameters were also measured and recorded during testing for use in determining emissions. They are not reported but included ambient temperature, relative humidity, barometric pressure, test duration and diluted exhaust sample temperature.

3.3 Test Vehicles

The two test vehicles used for this trial were International ACCO 2350G waste collection vehicles powered by Cummins ISC 250 HP engines and fitted with Alison MD 3560 PR 5 speed automatic transmissions. Both waste collection vehicles were fitted with an Engelhard CCX Oxidising Catalyst (for diesel engines).

Vehicles fitted with oxidising catalysts demonstrate reduced emissions of CO, HC, and PM under normal diesel operating conditions (Nett Technologies, 2004). Conversely, emissions of CO₂ and



NO₂ (nitrogen dioxide) can increase due to the use of an oxidising catalyst (Nett Technologies, 2004; NTSEL, 2004).

Hence, tailpipe emissions of HC and PM produced by both the B100 fuelled (test) vehicle and the diesel fuelled (control) vehicle in this trial are expected to be less than that of typical waste collection vehicles not fitted with an oxidising catalyst running on diesel or B100 fuel. The reported emission differences in this trial are relative to diesel waste collection vehicles fitted with an oxidising catalyst (i.e. the reported reductions in emission results are over and above the reductions in emissions due to the oxidising catalyst). Emissions of NO_x reported in this trial are not affected by the oxidising catalyst due to the fact that emissions of NO_x are reported on an "as NO₂ basis". This implies that all nitric oxide (NO) is oxidised to NO₂ before measurement is taken, eliminating the mass effect of the oxidising catalyst.

3.4 Test Fuels

The test fuels used were:

- ❑ Automotive Ultra Low Sulphur (50 ppm) Diesel meeting the Australian standard for automotive diesel set under the Fuel Quality Standards Act 2000; and
- ❑ B100 biodiesel. The B100 biodiesel did not meet the Australian standard for biodiesel set under the Fuel Quality Standards Act. The fuel parameters for each batch of B100 biodiesel used in the trial are shown in Table 4. The parameters which did not meet the Australian Standard are shaded grey in Table 4.



Table 4: Fuel Parameters of B100 Biodiesel Used in the Trial^a

Parameter	Unit	Batch 1	Batch 2	Batch 3	Australian standard
Density @ 15°C	kg/m ³	881.1	881.3	886.9	860 - 890
Sulphur	ppm	19	40	50.3	50
Cold Filter Plugging Point	°C	1	6	9	
Flash Point	°C	150	105	67	120 (min)
Viscosity @ 40°C	mm ² /s	4.660	4.725	6.254	3.5 - 5.0
Sulfated Ash	% (mass)	< 0.005	< 0.010	0.005	0.020 (max)
Carbon Residue	% (mass)	0.02	0.05	0.13	0.050 (max)
Water & Sediment	% (vol)	< 0.005	< 0.010	0.15	0.050 (max)
Copper Corrosion		1A	1A	1A	3 (max)
Total Contamination	mg/kg	0.88	11.1	124.2	24 (max)
Acid Value	mg KOH/g	0.27	0.08	0.95	0.80 (max)
Cetane Number		55.0	59.5	52.7	51.0 (min)
Distillation T90	°C	353	355	420	360 (max)
Ester Content	% (mass)	93.2	92.8	80.0	96.5 (min)
Total Glycerol	% (mass)	0.20	0.28	0.70	0.25 (max)
Free Glycerol	% (mass)	0.014	0.006	< 0.001	0.02 (max)
Phosphorus	ppm	4	3	1	10 (max)
Oxidation Stability		1	1	0.4	6 hours @ 100°C (min)
Ca, Mg	ppm	1.3	< 2	< 1	≤ 5 (max)
Na, K	ppm	3	< 4	< 1	≤ 5 (max)
Alcohol Content	% (m/m)	< 0.02	0.23	0.44	< 0.20

^a Shaded parameters indicate that the batch did not meet the Australian standard specifications

As can be seen from Table 4, the first two samples were close to meeting the Australian standard for all biodiesel fuel parameters. However, the last sample was off Australian standard specifications for almost all parameters. More detail on the B100 fuel parameters is provided in Appendix D.

Prior to the commencement of emissions testing both trucks had sufficient operation to ensure that the fuel tank contained only the test fuel and that any traces of the previous fuel used had been flushed out.



4 RESULTS

This section compares the results of the Camden trial with the relevant literature and is divided into five sections, namely common air pollutants (typical air pollutants including PM, NO_x, HC and CO₂), VOCs (benzene, toluene, xylene and 1,3 butadiene), selected aldehydes (formaldehyde, acetaldehyde and propionaldehyde), PAHs and vehicle performance (power loss and fuel consumption). Opacity (a measure of the opaqueness of the exhaust gas) is highly dependent on contextual factors such as vehicle maintenance and fuel type and although opacity studies are available in the literature, they were not considered relevant in this case and were therefore not used for comparison. It is important to note that all emission results presented in this report are tailpipe exhaust emissions and are not emissions from the lifecycle of biodiesel or diesel usage.

4.1 Common Air Pollutants

The change in emissions from the Camden trial is compared with the literature in Figure 2 (percentage terms). All literature data are from USEPA (2002). The results are summarised as follows:

- ❑ Emissions of particulate matter in the trial were reduced in all cases with the literature predicting a smaller reduction. Opacity was reduced by an average of 79%.
- ❑ Emissions of NO_x in the trial were increased in all cases with a small increase of 1.4% in Phase 1 and increases of 11.7% and 7.9% for Phase 2 and Phase 3. However, an analysis of variance on emissions of NO_x measured during the trial showed that there was no statistical difference in emissions of NO_x between petroleum diesel and B100 to a 95% confidence level. The literature generally predicts an increase of NO_x emissions of approximately 10%.
- ❑ The literature correlates well in terms of the HC emission results.
- ❑ Results from the Camden Trial predict a decrease in CO₂ emissions and the literature predicts no significant change although in percentage terms (Figure 2), the difference is not large and likely to be within the uncertainty of the literature.

The steady state D550 test results for criteria pollutants agreed broadly with the other tests and were not considered further.

Given the uncertainty typically associated with literature emissions estimation data, criteria pollutant emissions from the Camden trial agree quite well with the literature. Based on the results, the off specification fuel parameters (based on the Australian standard for biodiesel) appears to have little effect on the expected emissions.

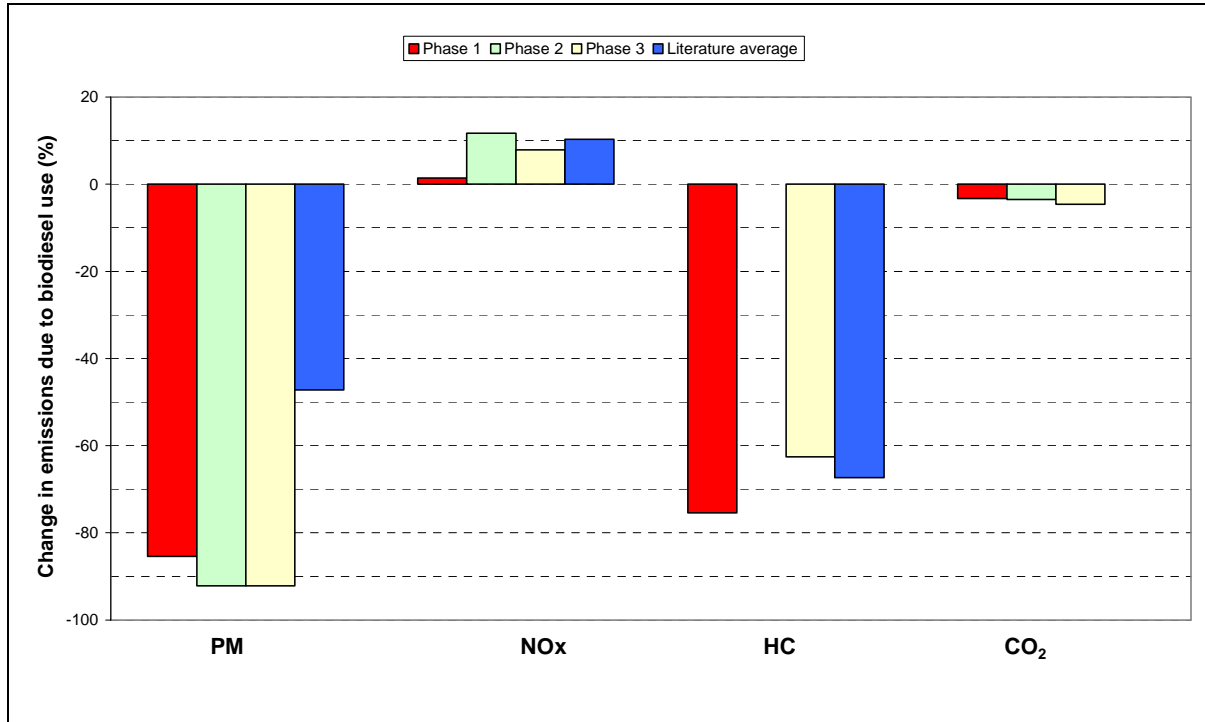


Figure 2: Comparison of emissions of criteria pollutants in percentage terms

- Notes:
- Literature data are taken from USEPA (2002) for heavy-duty highway vehicles.
 - CO₂ emissions are not over the life-cycle of the product and are compared in terms of tailpipe exhaust only.
 - CO₂ emissions are taken from data for 100% plant biodiesel.
 - Total HC emissions were not measured during phase 2

4.2 Volatile Organic Compounds

Available literature data for benzene and toluene are associated with a poor correlation with biodiesel fraction and are hence associated with high uncertainty (USEPA, 2002). This most likely explains the difference in the trial results and literature for these two pollutants (see Figure 3). Emissions of xylenes and 1,3-butadiene agree closely with the literature. The trial suggests that VOCs are likely to be reduced through the use of biodiesel.

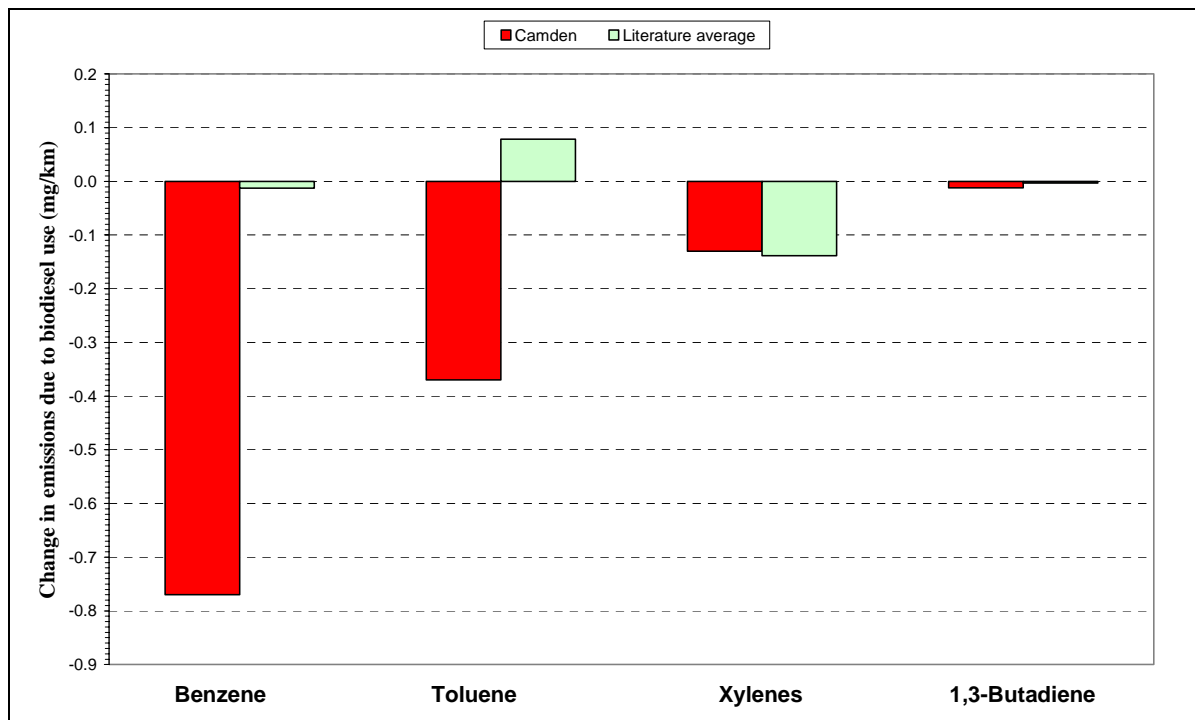


Figure 3: Comparison of emissions of VOCs

Notes: Literature data were estimated by taking the predicted % change in emissions (USEPA, 2002) for heavy-duty highway engines and multiplying by the average emissions in the trial. Percentage changes in emissions were not considered relevant at such low emission rates.

4.3 Aldehydes

Most aldehydes were detected at low levels (see Figure 4). The literature predicts small decreases in formaldehyde and acetaldehyde emissions, insignificant changes in acrolein and a small increase in propionaldehyde emissions. The Camden trial indicates similar results although the magnitudes of the changes differ (especially for formaldehyde and acetaldehyde), which is acceptable given the low levels at which these pollutants were detected. Pollutants for which no emissions were recorded were not listed in Figure 4 since the methodology used in this report would also predict zero emission rates in this case.

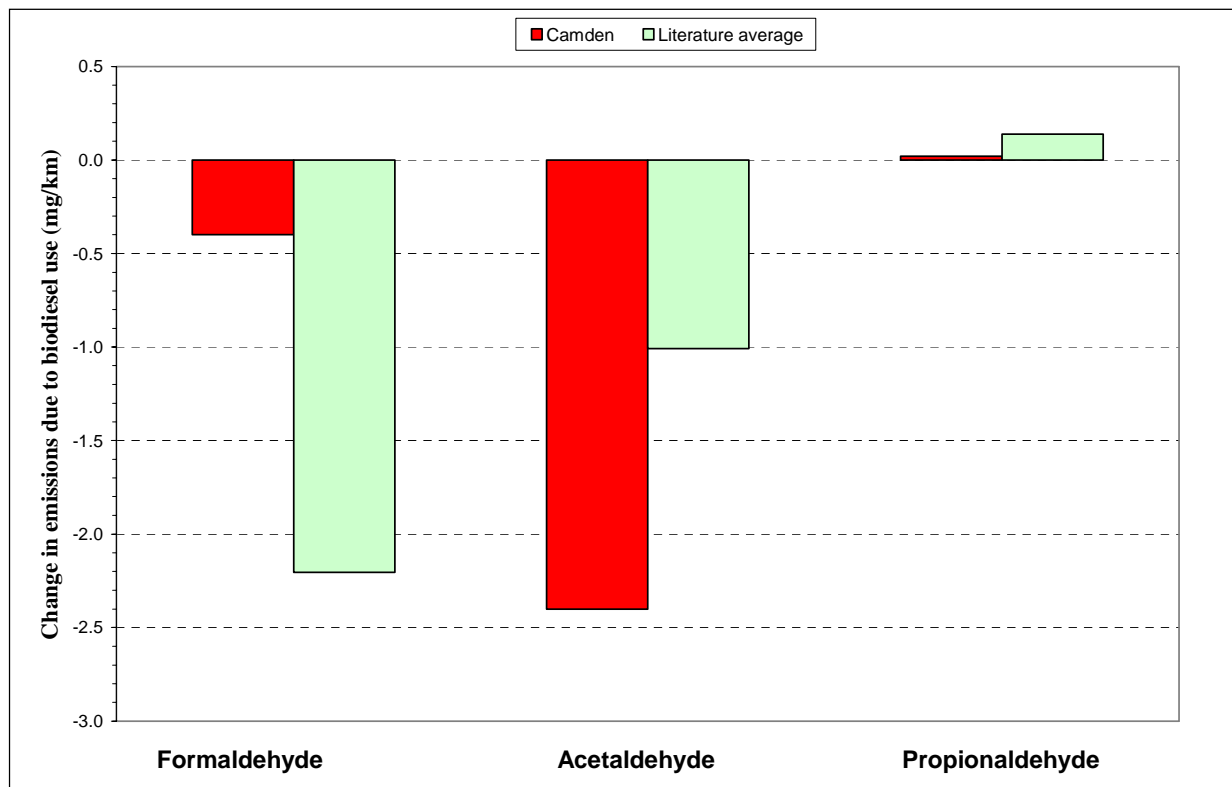


Figure 4: Emission comparison of selected aldehydes

Notes: Literature data taken from USEPA (2002) for all pollutants except propionaldehyde (Graboski et. al., 2003).

Literature data were estimated by taking the predicted % change in emissions from the literature for engines similar to those used in the Camden trial and multiplying by the average emissions measured in the trial. Percentage changes in emissions were not considered relevant at such low emission rates.

4.4 Polycyclic Aromatic Hydrocarbons

Literature data for PAHs were taken from a variety of sources and are considered more uncertain than the data for other pollutants. However, the literature corresponds well to the trial results when considering that many of the pollutants were measured close to their detection limit (see Figure 5) of the test method. Pollutants for which no emissions were recorded were not listed in Figure 5 since the methodology used in this report would also predict zero emission rates in this case.

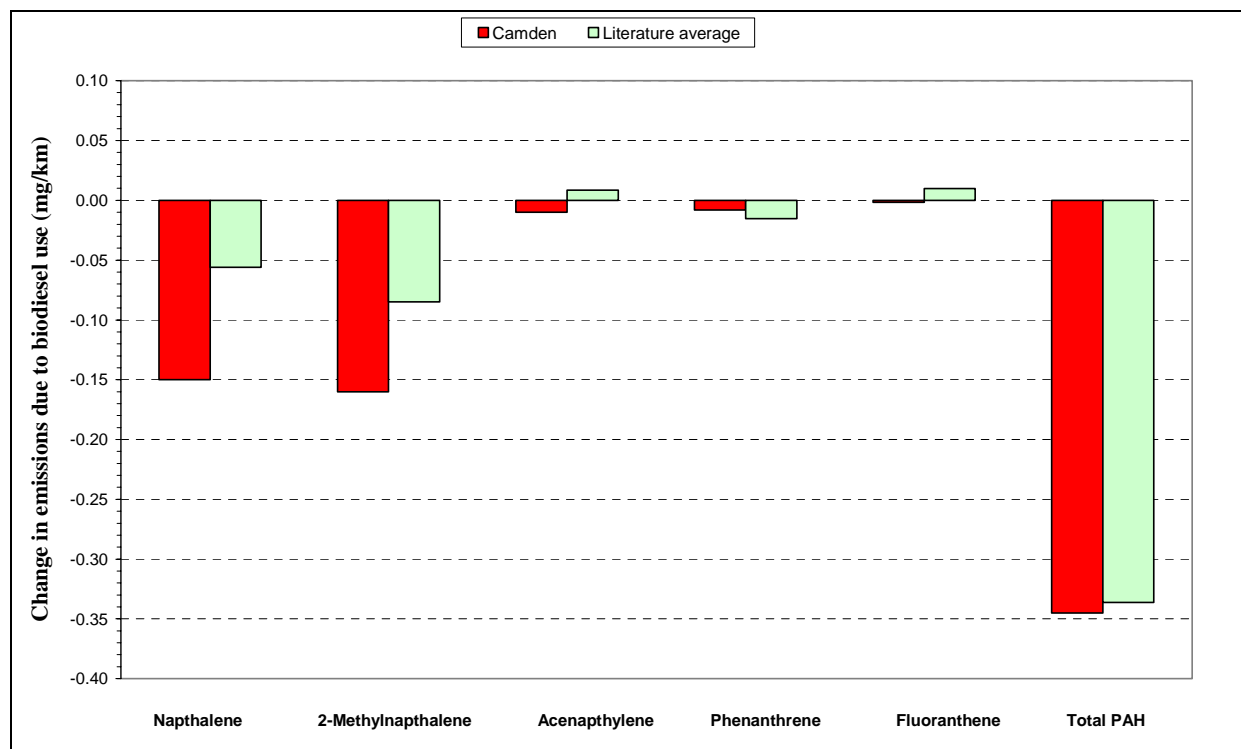


Figure 5: Emission comparison of PAHs

Notes: Literature data taken from (Durbin et.al., 1999) for all pollutants except total PAHs (Pan et. al., 2000) and naphthalene (USEPA, 2002).

Literature data (except acrolein) were estimated by taking the predicted % change in emissions (USEPA, 2002) for heavy-duty highway engines and multiplying by the average emissions in the trial. Percentage changes in emissions were not considered relevant at such low emission rates.

Literature acrolein emissions were estimated using literature data for the fraction of acrolein typically found in biodiesel exhaust emissions (USEPA, 2002) of hydrocarbons multiplied by the change in hydrocarbon emissions for the Camden trial.

4.5 Vehicle Performance

Fuel consumption is generally expected to increase with the use of biodiesel with USEPA (2002) predicting an increase of between 4.6% and 10.6% in fuel consumption. The Camden trial indicates that no significant difference in fuel consumption is observed with the use of B100 fuel. Assuming constant engine performance fuel consumption is dependent on the energy content of the fuel. Without energy content data of the fuels used in the trial, the discrepancy between trial and literature data is difficult to assess further.

Power losses of 5-7% are predicted in the literature (EMA, 2003). The Camden trial found larger decreases (average of 16.8%) in performance due to the use of biodiesel. It is possible that the off-specification B100 fuel may have contributed to increased power loss from the trucks used in the trial.



5 SUMMARY OF RESULTS

The results of this assessment are summarised in Table 5.

Table 5: Difference Between End of Pipe Emissions (Biodiesel Vs Diesel)

PARAMETER	RESULTS FROM THE CAMDEN TRIAL	RESULTS FROM SIMILAR STUDIES
Particulate matter	91% decrease	47% decrease
Oxides of nitrogen	No significant difference ¹	10% increase
Hydrocarbons	68% decrease	67% decrease
Carbon dioxide	3.8% decrease	2.9% increase
Benzene	0.77 mg/km decrease	0.013 mg/km decrease
Toluene	0.37 mg/km decrease	0.078 mg/km increase
Xylenes	0.13 mg/km decrease	0.14 mg/km decrease
1,3 Butadiene	0.012 mg/km decrease	0.0030 mg/km decrease
Formaldehyde	0.40 mg/km decrease	2.2 mg/km decrease
Acetaldehyde	2.4 mg/km decrease	1.0 mg/km decrease
Propionaldehyde	0.020 mg/km increase	0.14 mg/km increase
Napthalene	0.15 mg/km decrease	0.056 mg/km decrease
2-Methylnapthalene	0.16 mg/km decrease	0.085 mg/km decrease
Acenaphthylene	0.010 mg/km decrease	0.0084 mg/km increase
Phenanthrene	0.0080 mg/km decrease	0.015 mg/km decrease
Fluoranthene	0.0015 mg/km decrease	0.0098 mg/km increase
Total PAH	0.34 mg/km decrease	0.34 mg/km decrease
Fuel consumption	No significant difference ¹	4.6% to 11% increase
Power output	17% decrease	5% to 7% decrease

¹ An analysis of variance test to a 95% confidence level showed that there is statistically no significant difference between B100 and petroleum diesel.



6 DISCUSSION

The Camden trial indicates that the use of biodiesel is likely to lead to:

- ❑ Reductions in emissions of PM, HC, CO₂, VOCs, PAHs and most aldehydes;
- ❑ A decrease in maximum power output; and
- ❑ No significant difference in emissions of NO_x and fuel consumption.

In terms of the direction of change, the trial results broadly agreed with literature. The important exceptions were CO₂ and NO_x emissions and fuel consumption. With regard to CO₂ emissions, the literature indicates that no significant change should occur and the trial observed a decrease in emissions. However, the trial results for CO₂ are consistent with those for maximum power output, as a decrease in engine performance is generally associated with a decrease in CO₂ emissions. Literature indicates that NO_x emissions and fuel consumption are expected to increase slightly. The trial results for NO_x and fuel consumption showed that no statistically significant difference was observed between petroleum diesel and B100.

When referring to a conglomerate of industry-wide test results presented in the literature, it is important to note that the uncertainty in these results can be relatively large. Care was taken to ensure that the best available data were used for the comparison, although in some cases, the relevant site-specific data were unavailable. Due to differences in factors such as testing methods, driving schedules, engine types, engine maintenance and fuel types, care should be taken when using industry-wide emission factors to compare with performance of individual vehicles as they may not represent site-specific conditions and uncertainties of 100% or more are possible.

When considered in this light, the results of the Camden trial are considered reliable as results are well within typical margins of error for industry-wide data.

Mass emission reductions for PM equates to a 90% average reduction, so if the fleet were 10 trucks, changing to biodiesel would be equivalent to taking 9 trucks off the road, even more if older, less-well maintained trucks than those used in the trial were replaced. Furthermore, petroleum diesel particulate is a toxic air contaminant that is carcinogenic and the diesel vehicle fleet is the major transport source of particles, contributing up to 80% of vehicle produced particles in major cities (NEPC, 1998).

Similarly for HC, if the fleet were 10 trucks, a change to B100 would be equivalent to removing 7 trucks. Research also documents that the ozone forming potential of the hydrocarbon emissions of pure biodiesel is nearly 50% less than that of petroleum fuel (NBB, 2004).

The RTA report showed that there was no significant difference between diesel and B100 for NO_x emissions and fuel consumption. It is noted that data from literature indicates that emissions of NO_x and fuel consumption are expected to increase with the use of B100 fuel. It should be noted that the vehicles used in this study were tuned to run on petroleum diesel. It is reported that NO_x emissions can be reduced with the use of mechanical remediation techniques (e.g. timing changes) (pers comm. Korbitz, W, 2002). Furthermore, it is reported that the use of biodiesel additives that enhance the cetane number or antioxidant additives to biodiesel may also reduce NO_x emissions (McCormick et. al., 2003).



The results of this study indicate that CO₂ emissions from the tailpipe will be decreased with the use of biodiesel to an extent of 3.8%. However, it must be noted that this study does not assess the difference in CO₂ emissions over the entire lifecycle and is only an analysis of tailpipe emissions. Other studies indicate entire lifecycle emissions from the use of B100 can show a significant net decrease of greenhouse gases (e.g. CO₂) of approximately 50 to 60% when compared to petroleum diesel (Beer et. al., 2000).

The increased power loss observed in the trial (16.8% reduction) when compared to literature (between 5 and 7% reduction) could be related to the low ester content of the biodiesel used in the trial. A higher conversion of feedstock oils to ester gives better engine performance (Environment Australia, 2003). Unreacted feedstock oils, that include mono, di and triglycerides (bound glycerol), have a high viscosity (Environment Australia, 2003). Increased viscosity is associated with carbon deposits on fuel injector tips and reduced spray effect of fuel injection (Environment Australia, 2003). These effects could result in increased power loss. Interestingly, the variation in fuel parameters did not appear to effect emissions significantly as emission results are broadly similar from operation on each biodiesel fuel batch.

The trial demonstrates significant reduction in emissions for many of the key pollutants related to urban air quality. At the local level, predicting final impacts on air quality and human health from the adoption of biodiesel is very difficult without detailed air dispersion and photochemical modelling based on site-specific weather data and time-varying emission profiles using a model such as TAPM (The Air Pollution Model) or CTM (Chemical Transport Model). Further investigations are required to assess whether emissions of NO_x from biodiesel usage can be improved in comparison with petroleum diesel due to mechanical remediation techniques and with the use of biodiesel fuel additives. However, given that the emissions of most criteria pollutants, air toxics and greenhouse gases are likely to be reduced (i.e., the load to the environment is decreased) environmental impacts from the waste collection trucks are likely to be improved. The magnitude of these impacts on the region cannot be estimated without more detailed study.

This study considered the use of 100% biodiesel only (B100). It is also possible to blend biodiesel with standard diesel. Effects on emissions are close to linear (see Figure 1 in Section 2.4 for literature correlations for NO_x, PM, HC and CO). For example, a 60% biodiesel blend would achieve close to 60% of the reductions of HC emissions associated with the use of B100. Camden Council is considering further investigations into the use of biodiesel blends (at blends higher than B20 i.e. 20% biodiesel and 80% petroleum diesel) which will provide more certainty as to the emission benefits from the use of biodiesel blends in the waste collection fleet.



7 CONCLUSIONS

The Camden trial indicates that the use of biodiesel is likely to lead to reductions in PM, HC, CO₂, VOCs, PAHs, most aldehydes and maximum power output. There was no significant difference between diesel and B100 biodiesel for NO_x emissions and fuel consumption. The relevant literature on biodiesel emissions generally supports these findings although the literature emissions for benzene, toluene and many of the PAHs are associated with relatively high uncertainty. The results should provide a useful basis for decision making regarding the adoption of biodiesel for use in waste collection vehicles, and air quality in the region is likely to be improved with the widespread adoption of the fuel.

Further investigation is required to:

- ❑ Determine the magnitude of the air quality impact from replacing petroleum diesel with biodiesel with detailed photochemical and air dispersion modelling based on site-specific weather data and time-varying emissions profiles.
- ❑ Determine whether NO_x emissions from biodiesel combustion can be improved with mechanical remediation techniques to the engine and with the use of biodiesel additives.
- ❑ Determine whether the power output observed in the trial can be improved with the use of B100 fuel that meets the Australian Standard under the Fuel Quality Standards Act.
- ❑ Determine with greater certainty the emission benefits using biodiesel blends in the waste collection fleet.



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APPENDIX A: DT80 Test

A1 Test Procedure

Before each test record vehicle details and conduct a pre-test safety inspection.

- Secure vehicle on dynamometer. Vehicles should be tested using the fuel present in the vehicle tank when it is submitted for testing.
- Set dynamometer to simulate the correct load and inertia for the vehicle under test.
- Start sampling
- Idle for 60 seconds
- Accelerate rapidly to 80 km/hr under simulated inertia using wide open throttle

Decelerate by removing all pressure from the accelerator pedal and gently applying brakes to standstill

- Idle for 10 seconds
- Accelerate rapidly to 80 km/hr under simulated inertia using wide open throttle
- Decelerate by removing all pressure from the accelerator pedal and gently applying brakes to standstill
- Idle for 10 seconds
- Accelerate rapidly to 80 km/hr under simulated inertia using wide open throttle
- Maintain speed at 80 km/hr for 60 seconds – stop sampling. Bring vehicle to rest.

A2 Test Equipment

The test system has been designed to enable transportation to any site and to allow quick deployment. The system consists of the following:

- Chassis dynamometer
- Sample handling system
- Emissions instrumentation
- Data acquisition/reporting system

The dynamometer has:

- Twin rollers for easy wheel positioning and security
- Idler rollers for bogie axle vehicles
- 14 tonne axle load capacity
- Modular assembly and quick disconnect/tie down system
- A drivers aid with test instructions and dynamometer output display
- Inertia simulation on acceleration
- Real-time data acquisition and printout

With the exception of the sample used for opacity measurement the vehicle exhaust is diluted and the emissions analysers draw samples from the dilution tunnel.

The particulate matter sample is kept below 125°F (51.7°C) in accordance with U.S. EPA CFR specifications and is measured using a laser light photometer calibrated for the particle size range found in diesel exhausts.



NO_x is calculated from the measurement of NO and corrected for atmospheric conditions at the test site and time of sampling in accordance with U.S. EPA light-duty in-service testing protocols. As NO is the actual pollutant measured on which NO_x is calculated there is no deterioration of the sample due to the NO₂ dissolving in water condensation.

Atmospheric conditions (air temperature, pressure and relative humidity) are measured and recorded during each test to enable the results to be corrected to standard temperature and pressures.

Smoke is measured using a partial flow opacimeter sampling raw exhaust. Percentage opacity is measured continuously and average and maximum opacities are calculated from this data.

The data acquisition system is designed to enable results to be calculated on site at the completion of a test.

A3 Data Collected

A3.1 Pre-Test Data

Table A1 details the data to be collected on each vehicle before testing is commenced. Apart from any adjustments to enable safe operation of the vehicle during the test, the person undertaking the pre-test inspection shall not undertake any work to alter the "as delivered" condition of the vehicle, as this would defeat the objective of assessing real world emissions.

Table A1 – Pre-Test Data – Item To Be Provided

Vehicle Details	
Registration Number	
Vehicle Make	
Vehicle Model	
Odometer readingkm
Compliance Date	
Tare Mass & GVM	
Test Mass	
Fuel type	

A3.2 Test Data

Table A2 details the data to be collected from each vehicle undergoing the vehicle testing.

Table A2 – Test Data To Be Provided

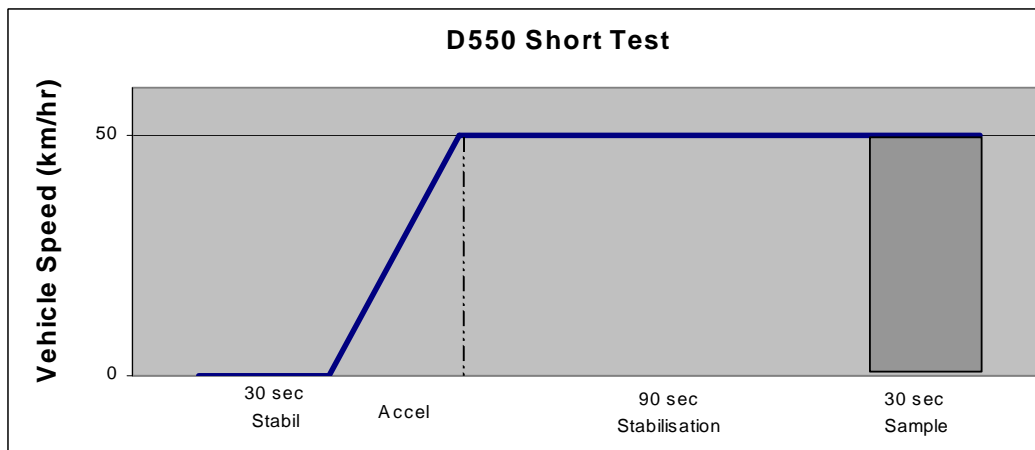
Time vehicle arrives	Hr: min
Time test commences	Hr: min
Test duration	Seconds
Distance travelled during test	Km
NO _x emissions	g/km & g/km/tonne
Particulate mass emissions	g/km & g/km/tonne
Smoke emissions	Average & maximum (% opacity)
Time vehicle departs	Hr: min
Second by second data for the above pollutants matched to the respective speed trace	
Comments on any operational issues	



APPENDIX B: D550 Test

The D550 test is detailed in Anyon P, 1995, *Diesel Inspection and Maintenance. The D550 Short Test*. A copy of this paper can be found on the Environment Protection and Heritage Council's web site under the Diesel Vehicle Emissions Preparatory Projects, Project 2: In-Service Emissions Performance, Phase 1 – Drive Cycles, Attachment 3 (www.ephc.gov.au/nepms/diesel/diesel_prepare.html).

This Steady-state test is carried out at a dynamometer load equivalent to a fully laden vehicle driving up a 5% gradient at 50 km/h. This represents a near full-load condition for most vehicles. As it is a constant load, constant-speed test, it requires only a simple power dynamometer. The test is designed so that there is no need to establish maximum power or torque outputs.





Appendix C: Test Results (Excluding Air Toxics)

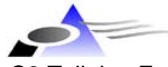
C1 Tailpipe Emissions – Phase 1

Fleet No	Vehicle Make	Vehicle Model	Odometer (km)	Compliance Date	Test Mass (kg)	Fuel Type	Test Number	Date	Average Opacity (%)	Maximum Opacity (%)	NOx (g/km.t)	PM (mg/km.t)	HC (mg/km/t)	CO ₂ (g/km)	Fuel (L/100km)	Max Power (kW)
QZM 171	Mitsubishi	FM	89,411	Feb-94	9750	Diesel	8141-1	13-10-03	2.65	10.12	0.75	18.01				
UUh 922	Isuzu	FVZ1400A	123,528	Oct-97	15880	Diesel	8143-1	13-10-03	7.47	46.15	0.80	25.81				
QZV 057	Mitsubishi	FK600	72,771	Mar-97	7135	Diesel	8145-1	14-10-03	7.80	27.13	0.31	32.87				
WXD 934	Isuzu	FVR900A	30,945	Jun-00	11490	Diesel	8147-1	14-10-03	2.25	17.39	0.30	15.11				
WXC 754	Isuzu	FSR700A	71,857	Mar-00	8795	Diesel	8149-1	14-10-03	8.87	35.07	0.50	44.68				
YTT 271	Isuzu	N3 NP	1,754	Apr-03	5580	Diesel	8151-1	14-10-03	2.81	31.08	0.38	6.86				
QUC 503	International	ACCO 2350G	125,728	Dec-96	18170	Diesel	8153-1	14-10-03	1.12	8.13	0.58	8.92				
QUC 504	International	ACCO 2350G	105,160	Dec-96	18170	Diesel	8155-1	14-10-03	0.84	4.44	0.81	6.31				
XXG 984	International	ACCO 2350G	30,349	Mar-02	17930	Diesel	8158-1	14-10-03	0.94	9.46	0.48	2.94				
UXM 333	Mitsubishi	Canter	34,959	Jan-98	3568	Diesel	8160-1	14-10-03	13.29	56.44	0.56	69.43				
QXZ 834	Mitsubishi	Canter	77,348	Mar-97	4770	Diesel	8162-1	15-10-03	10.01	35.09	0.41	27.62				
YAF 577	International	ACCO 2350G	27,997	Mar-02	14050	Diesel	8166-1	15-10-03	1.06	7.92	0.47	3.77				
VMU 428	International	ACCO 2350G	130,067	Aug-98	12800	Diesel	8168-1	15-10-03	1.32	5.58	0.61	10.43				
YPF 701	International	ACCO 2350G	8,680	Jul-02	17840	Diesel	8170-1	15-10-03	1.34	8.89	0.32	2.22				
XXG 983	International	ACCO 2350G	25,364	Mar-02	18010	B100 Biodiesel	8178-1	16-10-03	0.01	1.18	0.47	0.30	1.69	1521.3	60.53	106
XXG 983	International	ACCO 2350G	25,364	Mar-02	18010	B100 Biodiesel	8179-1	16-10-03	0.13	8.01	0.48	0.31	1.90	1530.7	60.90	106
XYG 403	International	ACCO 2350G	26,140	Mar-02	18010	Diesel	8184-1	16-10-03	0.49	4.03	0.48	1.72	4.62	1629.1	60.63	121
XYG 403	International	ACCO 2350G	26,140	Mar-02	18010	Diesel	8185-1	16-10-03	0.52	3.89	0.51	1.48	4.44	1619.3	60.26	121



C2 Tailpipe Emissions – Phase 2

Fleet No	Vehicle Make	Vehicle Model	Compliance Date	Test Mass (kg)	Fuel Type	Test Number	Date	Average Opacity (%)	Maximum Opacity (%)	NOx (g/km.t)	PM (mg/km.t)	CO₂ (g/km)	Fuel (l/100km)	Max Power (kW)
XXG 983	International	ACCO 2350G	Mar-02	18010	B100 Biodiesel	8440-1	4-2-04	0.12	1.60	0.41	0.32	1467.5	58.39	112.8
XXG 983	International	ACCO 2350G	Mar-02	18010	B100 Biodiesel	8441-1	4-2-04	0.12	0.85	0.41	0.30	1484.0	59.04	112.8
XYG 403	International	ACCO 2350G	Mar-02	18010	Diesel	8454-1	5-2-04	0.69	9.62	0.41	2.97	1619.5	60.26	128.9
XYG 403	International	ACCO 2350G	Mar-02	18010	Diesel	8455-1	5-2-04	0.73	9.62	0.37	3.24	1527.2	56.83	128.9



C3 Tailpipe Emissions – Phase 3

Fleet No	Vehicle Make	Vehicle Model	Compliance Date	Test Mass (kg)	Fuel Type	Test Number	Date	Average Opacity (%)	Maximum Opacity (%)	NOx (g/km.t)	PM (mg/km.t)	HC (mg/km/t)	CO ₂ (g/km)	Fuel (l/100km)	Max Power (kW)
XYG 403	International	ACCO 2350G	Mar-02	18010	Diesel	8884-1	6-4-04	0.25	6.36	0.44	3.18	7.68	1634.3	60.83	125
XYG 403	International	ACCO 2350G	Mar-02	18010	Diesel	8886-1	6-4-04	1.06	6.05	0.41	1.83	6.04	1653.9	61.55	125
XYG 403	International	ACCO 2350G	Mar-02	18010	B100 Biodiesel	8889-1	6-4-04	0.02	1.60	0.46	0.34	4.35	1566.1	62.32	108
XYG 403	International	ACCO 2350G	Mar-02	18010	B100 Biodiesel	8891-1	6-4-04	0.85	8.10	0.47	0.37	4.15	1572.2	62.56	108
XXG 983	International	ACCO 2350G	Mar-02	18010	B100 Biodiesel	8907-1	14-4-04	0.04	0.66	0.43	0.24	4.11	1514.5	60.27	116
XXG 983	International	ACCO 2350G	Mar-02	18010	B100 Biodiesel	8908-1	14-4-04	0.34	2.91	0.44	0.22	4.16	1534.5	61.06	116
XXG 983	International	ACCO 2350G	Mar-02	18010	Diesel	8911-1	14-4-04	0.75	7.62	0.41	2.80	10.37	1578.7	58.77	133
XXG 983	International	ACCO 2350G	Mar-02	18010	Diesel	8912-1	14-4-04	0.94	11.12	0.41	3.75	12.00	1611.6	59.99	133



Appendix D: Test Results (Air Toxics)



INVESTIGATION REPORT ET/ IR 656

**BIODIESEL:
EVALUATION OF TOXIC COMPOUNDS IN
EXHAUST EMISSIONS**

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Prepared for Diesel Test Australia Pty Ltd

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1 INTRODUCTION

Biodiesel is a renewable fuel that can be produced from vegetable oils, animal fats and exhausted cooking oil. It can be used in its neat form, or as a blend with conventional diesel fuel. Biodiesel has emission advantages for use in diesel engines because it can provide improvements to a number of fuel properties, most importantly cetane and oxygen content.

In order to discuss the role of biodiesel in reducing air toxics emissions from diesel engines, CSIRO Energy Technology was commissioned by Diesel Test Australia Pty Ltd (DTA) to measure and assess these emissions from truck engines using biodiesel and standard diesel. This work was done as a subset to an emissions testing program commissioned by the RTA, and the emissions were sampled while operating the vehicles on DTA's mobile chassis dynamometer test facility. The test vehicles were garbage collection trucks used by Camden Council, which are routinely run on biodiesel and diesel fuels. The tests were performed at Camden Council Depot, Narellan, on the 16th October, 2003.

This report presents the results of this testing, where a range of air toxic compounds were measured from a vehicle fuelled with 100% biodiesel (B100) and a second vehicle fuelled with standard refinery diesel. The study is obviously limited but provides preliminary and indicative information as to the likely effects of biodiesel on air toxics emissions.

Three classes of air toxics were measured, namely the volatile organic compounds (VOCs), carbonyl compounds and polycyclic aromatic hydrocarbon compounds (PAHs). Within each class, compounds specific to diesel exhaust were selected based on their classification as hazardous air pollutants (HAPs) under the USEPA Clean Air Act, Title III, and as priority air toxics under Environment Australia's Living Cities - Air Toxics Program (2001). They included those targeted for future regulation under the NEPC Australian Air Toxics NEPM (2003). The compounds selected are listed in Table 1. The NEPM target compounds are marked with an asterisk.

Table 1. Priority Air Toxic Compounds Selected for Assessment

Volatile Organic Compounds (VOCs)

- Benzene *
- Toluene *
- Total Xylenes *
- 1,3-Butadiene

Carbonyls

- Formaldehyde *
- Acetaldehyde
- Acrolein
- Propionaldehyde
- Acetone

Polycyclic Aromatic Hydrocarbons (PAHs)

- Naphthalene
- 2-Methylnaphthalene
- Acenaphthylene
- Acenaphthene
- Fluorene
- Phenanthrene
- Anthracene
- Fluoranthene
- Pyrene
- Benz[*a*]anthracene
- Chrysene
- Benzo[*b*]fluoranthene
- Benzo[*k*]fluoranthene
- Benzo[*e*]pyrene
- Benzo[*a*]pyrene *
- Perylene
- Indeno[1,2,3-*cd*]pyrene
- Dibenzo[*a,h*]anthracene
- Benzo[*g,h,i*]perylene

Notes:

- Compounds marked with an asterisk are those targeted for regulation under the Air Toxics NEPM.
 - Acetone is measured to exhibit chromatographic resolution from acrolein. It is not reported as an air toxic.
 - Eighteen of the nineteen USEPA priority PAHs were measured, with the exception of the high molecular weight compound coronene (due to its analytical difficulty), and the addition of 2-methylnaphthalene (due to its relatively high toxicity and high abundance in diesel exhaust).
-

2 EXPERIMENTAL

Two NC class (12.5 - 25 tonne) trucks were driven on a chassis dynamometer test facility operated by DTA Pty Ltd, under DT80 and D550 test procedures for diesel vehicles. Truck 1 (Registration Number XXG 983, compliance 2002) was fuelled with 100% biodiesel (B100) and Truck 2 (Registration Number XYG 403, compliance 2002) was fuelled with normal refinery diesel. Emission samples were collected over the period of the test and subsequently analysed for the compounds listed in Table 1 at the CSIRO Air Toxics Assessment Laboratory. The test parameters used were applied to the concentrations found to calculate an emission rate in milligrams per kilometre (mg/km) for each test. The trucks were subjected to two identical DT80 tests, as a check on repeatability, and one D550 test.

2.1 Exhaust Sampling Procedure

Internationally recognised standard procedures for the determination of gas phase organic compounds were followed preferencing, where possible, those specific to a vehicle exhaust matrix. The specific methods used are discussed in the analytical section 2.2.

The exhaust sample was taken from the primary dilution tunnel and directed into a $\frac{3}{4}$ inch stainless steel manifold via a $\frac{1}{4}$ inch Teflon line. The manifold separated the exhaust into three sampling streams using canister, DNPH-cartridge and sorbent-backed filter systems for collection of the VOCs, carbonyl compounds and PAHs respectively, as shown in Figure 1. Optimally the gas at the collection point is at a temperature less than 50°C, is diluted sufficiently to keep it above its dewpoint whilst maintaining an analyte concentration which allows collection of quantifiable amounts. Every effort was made to sample under these conditions. The exhaust was collected at a constant flow rate, applicable to the particular sampling system, for a time period corresponding to the duration of each test. The specific collection systems used for each of the three classes of compounds measured is described.

2.1.1 VOCs

Samples of diluted exhaust were collected in SUMMA[®] electro-polished, passivated stainless steel canisters (Scientific Instrumentation Specialists, USA) for analyses of 1,3-butadiene, benzene, toluene and the xylene isomers. Prior to use, the canisters were cleaned using an Entech[®] canister cleaning system which repeatedly fills and evacuates the heated canisters. This procedure follows CARB MDL 020 "Procedure for Cleaning SUMMA Polished Canisters", and gives very low background concentrations of hydrocarbons, suitable for trace analysis of VOCs.

During sampling, diluted exhaust was withdrawn from the manifold under the vacuum held in the canister through a restrictor which had been calibrated to bring the canister to just below atmospheric pressure by the completion of the test. A 47 mm glass fibre filter prevented particulate matter from entering the system (Figure 1). On receipt at the laboratory the canisters were pressurised with purified nitrogen to maintain the integrity of the sample.

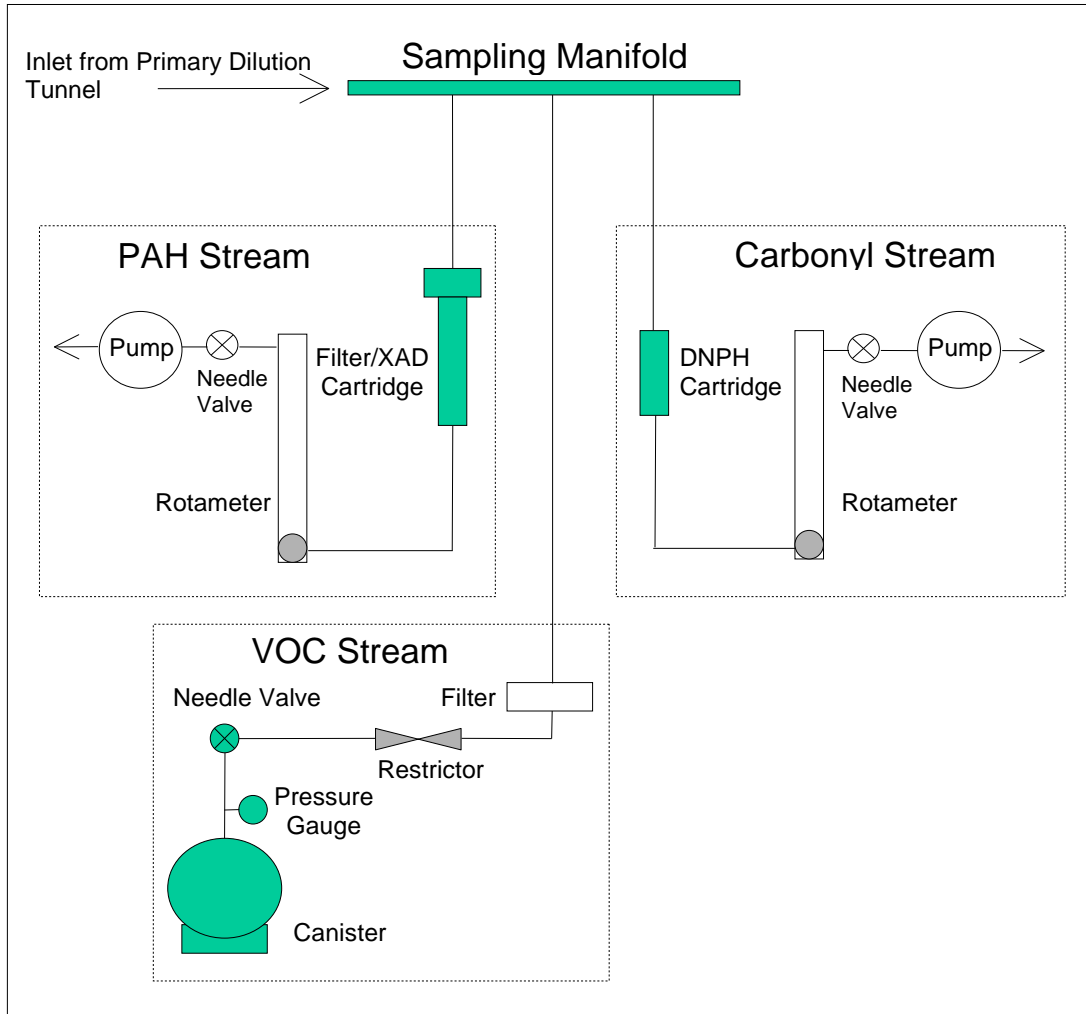


Figure 1. Schematic Layout of the Toxics Sampling System

2.1.2 Carbonyl Compounds

Carbonyl compounds were sampled using Supelco Inc. LpDNPH-S10L sample cartridges. These cartridges contain 2,4-dinitrophenylhydrazine (DNPH) supported on a silica substrate. The DNPH reacts *in-situ* with the carbonyl compounds in the gas phase to yield derivative compounds, which are more stable than their reactive counterparts. Diluted exhaust was drawn through the cartridges at a rate of 1.5 L/min using a small pump and the flow controlled and monitored using a rotameter upstream of the pump. The exposed cartridges were capped, protected from light and heat then refrigerated at the laboratory until analysis.

2.1.3 PAHs

The diluted exhaust was sampled from the manifold through a resin-backed filter cartridge. The cartridge is packed with a bed of XAD-2 resin (Supelco Inc.) to capture vapour phase PAH components and a glass fibre (GFA) filter precedes the resin to collect particulate phase components. A pump and rotameter system was used to draw the sample through the cartridge at a constant flow rate of 10 L/min. Samples were protected from light and heat and refrigerated at the laboratory until analysis.

2.2 Analytical Methods

Internationally recognised standard procedures for the determination of gas phase organic compounds were followed preferencing, where possible, those specific to a vehicle exhaust matrix. Methods were sourced mainly from the California EPA Air Resources Board (CARB) and US EPA agencies.

2.2.1 VOCs

The method used for sampling and analysis of VOCs was based on CARB method MDL 102/103 "Procedure for the Determination of C₂ to C₁₂ hydrocarbons in Automotive Exhaust Samples by Gas Chromatography", which was modified and validated in-house to the specific requirements of the determination.

The analysis was performed using a Perkin Elmer ATD400 thermal desorption system linked to a HP 5890 Series II GC with flame ionisation detection (TD/GC-FID). The ATD is equipped with an air sampling accessory, which allows direct injection of controlled volumes of gas from SUMMA[®] canisters. An amount of gas is cyro-trapped on a bed of adsorbent material and the analytes are thermally desorbed and transferred to the GC column. The low molecular weight species (C₂ - C₅) are separated on an Al₂O₃/KCl PLOT column for detection by FID. At a pre-determined time the higher boiling species are redirected away from the PLOT column and are detected by a second FID after separation on a methyl silicone column. This dual column, dual FID system enables efficient separation and detection of hydrocarbon mixtures containing components of low to mid-volatility.

The system was calibrated using a hexane standard gas and a gas mixture containing the compounds of interest. The VOC compounds were identified by comparing their retention times to those of the standard compounds and quantified based on their area response compared to a hexane external standard calibration. This single component calibration utilises the linear response of an FID detector to carbon for quantitation of

hydrocarbon compounds. A correction for the aromatics benzene and toluene was made based on known response factors for these compounds compared to hexane.

Unlike the aromatic VOC species, 1,3-butadiene is unstable in vehicle exhaust due to its reaction with NO_x. To compensate for this, a correction can be made to the analytical result based on the method developed by Ye *et al.* (1997). In this method, the rate of decay of 1,3-butadiene is taken to follow first order kinetics according to an integrated rate expression. However in these determinations we have found the rate established by this method to significantly overestimate the calculated initial butadiene concentration, based on our knowledge of the expected concentration using VOC and total hydrocarbon data. This is most likely due to the high concentration of NO_x encountered in the sample and importantly, compared to the samples tested by Ye *et al.* from gasoline vehicles, a higher proportion of the NO_x is present as NO₂ in diesel exhaust. A check made on the stability of the compound found no change in its concentration after 5 days, and hence the uncorrected value will be reported.

Under the sampling and analysis conditions used, the method delivered sensitivity to hydrocarbon compounds of 0.1 ppbv (as concentration in the sample collected), equivalent to an emission of approximately 0.01 mg/km, based on DT80 test parameters.

2.2.2 Carbonyls

The method used for sampling and analysis of carbonyl compounds was based on CARB MDL 104 for the "Determination of Aldehyde and Ketone Compounds in Automotive Source Samples by High Performance Liquid Chromatography". The method was optimised and validated in-house to the requirements of the determination.

The carbonyl-DNPH derivatives were eluted from the sample cartridges in acetonitrile and analysed by HPLC (GBC Model LC1150) using reverse phase and gradient elution from a Supelcosil LC-18 column. The mobile phase solvent regime was optimised for the separation of closely eluting compounds, such as acetone and acrolein, and for separation of exhaust gas interferences, such as NO₂. The derivatives were detected at 360 nm using a Jasco Uvidec-100 variable wavelength ultraviolet detector.

The carbonyl derivatives in the samples were identified by comparing their retention times to those in a standard mixture and quantified using peak areas entered into a linear regression equation obtained from a multi-point calibration. Analysis of a field blank was performed to check for cartridge background and/or environmental contamination and the concentrations found in the samples corrected for any analyte background obtained.

Under the sampling and analysis conditions used the method delivered sensitivity to carbonyl compounds of 50 ng (as mass collected), equivalent to an emission of approximately 0.1 mg/km, based on DT80 test parameters.

2.2.3 PAHs

The PAH sampling method was based on US EPA 8270 "Determination of Organic Compounds by Gas Chromatography and Mass Spectrometry" and incorporated SAE technical paper "Sampling and Analysis of Vapour Phase and Particulate Bound PAH from Vehicle Exhausts" (Collier *et al.*, 1998). The cartridge samples for PAH analysis

were dispatched to the Australian Government Analytical Laboratories (AGAL) for extraction and analysis. Analytical methods used by this laboratory were based on CARB MDL 429 for the extraction and purification procedures and USEPA Method 8270 for PAH determination using gas chromatography and mass spectrometry (GC/MS).

The analysis involved solvent extraction of the GFA filter and XAD-2 resin with DCM/ethanol and their concentration using soxhlet and Kuderna-Danish techniques, respectively. The extracts were purified, by chemical treatment and column chromatography, to remove aliphatic hydrocarbon background and prepared for analysis by the addition of deuterated PAH standard compounds. Surrogate standards were added to the samples prior to extraction to determine analyte recovery. Analysis was performed on a Hewlett Packard 5972 GC/MS spectrometer in the selected ion monitoring (SIM) mode, using a DB5ms capillary column (30m x 0.25mm x 0.25 µm). Analytes were identified by comparing their retention time to that of a standard mixture and quantified using an internal standard technique.

Under the sampling and analysis conditions used the method delivered sensitivity to PAH compounds of 20 ng (as mass collected), equivalent to an emission of approximately 0.01 mg/km, based on DT80 test parameters.

3 RESULTS

The results of emissions of VOCs, carbonyls and PAHs from the two test trucks, one fuelled with 100% biodiesel (B100) and the other normal refinery diesel, are discussed and summarised in Table 2 and Figures 2 to 5. Table 2 reports the emission rate data for the DT80 tests, Figures 2 to 4 compare the two fuels in their emissions of VOCs, C₁ - C₃ aldehydes (excluding the non-priority compound acetone) and PAHs, respectively, and Figure 5 expresses the results as the percentage change in emissions using biodiesel compared to diesel fuel.

The emission rates of the exhaust gas components are expressed in units of milligrams per kilometre (mg/km) after applying the test parameters to the concentrations found in the sample collected. The lower limit to which the method can accurately determine the analyte (the MQL, method quantitation limit) is reported under the parameters of each test.

The average result for the duplicate DT80 tests is also reported. The repeatability (of the combined test procedure, sampling and analysis) averaged 20%, as relative percent difference.

The duration of the D550 test (B100; 50 seconds, diesel; 37 seconds) was considered too short to ensure that a representative sample was collected. The results from the analysis confirmed this, with little correlation in the data. Hence the D550 result is not reported.

In drawing conclusions as to the changes in emissions between biodiesel and standard diesel the fact that different vehicles were used must be taken into account, due to the differences in each vehicles reference emission. Hence the reported values for the percentage change are an indication only and this change must be significant in order to make a reliable prediction as to the positive or negative effect of biodiesel on emission rates.

Table 2. DT80 Emission Rates of Priority Air Toxics for Biodiesel and Diesel Fuels

DT80	Emission Rate, mg/km					
	<i>B100 - 100% Biodiesel Fuel</i>			<i>Diesel Fuel</i>		
	DT80 Test 1	DT80 Test 2	DT80 Average	DT80 Test 1	DT80 Test 2	DT80 Average
VOCs						
Benzene	0.86	0.81	0.83	1.66	1.54	1.60
Toluene	0.24	0.19	0.22	0.47	0.70	0.59
Xylenes	0.22	0.22	0.22	0.31	0.39	0.35
1,3-Butadiene	0.013	0.011	0.012	0.024	0.023	0.024
MQL (Method Quantitation Limit)	0.007	0.007	0.007	0.007	0.007	0.007
Carbonyls						
Formaldehyde	14.6	13.7	14.2	14.6	14.6	14.6
Acetaldehyde	4.1	5.1	4.6	6.3	7.6	7.0
Acrolein	0.24	< MQL	0.18	< MQL	< MQL	< MQL
Propionaldehyde	0.45	0.70	0.57	0.37	0.72	0.55
Acetone	0.38	0.07	0.23	1.7	2.4	2.1
MQL (Method Quantitation Limit)	0.12	0.12	0.12	0.13	0.14	0.135
PAH Compounds						
Naphthalene	0.051	0.071	0.06	0.19	0.24	0.21
2-Methylnaphthalene	0.011	0.013	0.01	0.15	0.20	0.17
Acenaphthylene	0.011	< MQL	0.010	0.018	0.021	0.020
Acenaphthene	< MQL	< MQL	< MQL	< MQL	< MQL	< MQL
Fluorene	< MQL	< MQL	< MQL	0.014	< MQL	0.011
Phenanthrene	0.021	0.022	0.022	0.021	0.039	0.030
Anthracene	< MQL	< MQL	< MQL	< MQL	< MQL	< MQL
Fluoranthene	0.007	< MQL	0.0075	0.009	0.009	0.009
Pyrene						
Benzo[a]anthracene						
Chrysene						
Benzo[b]fluoranthene						
Benzo[k]fluoranthene						
Benzo[e]pyrene	All compounds < MQL			All compounds < MQL		
Benzo[a]pyrene						
Perylene						
Indeno[1,2,3,-c,d]pyrene						
Dibenz[a,h]anthracene						
Benzo[g,h,i]perylene						
Total PAH	0.10	0.11	0.105	0.39	0.51	0.45
MQL (Method Quantitation Limit)	0.007	0.008	0.0075	0.007	0.008	0.0075

Note: where a < MQL result is returned the average is calculated using the value of the MQL.

3.1 VOC Emissions

Biodiesel fuel produced a significant reduction in the emission rates of VOC compounds, as can be seen in Figures 2 and 5.

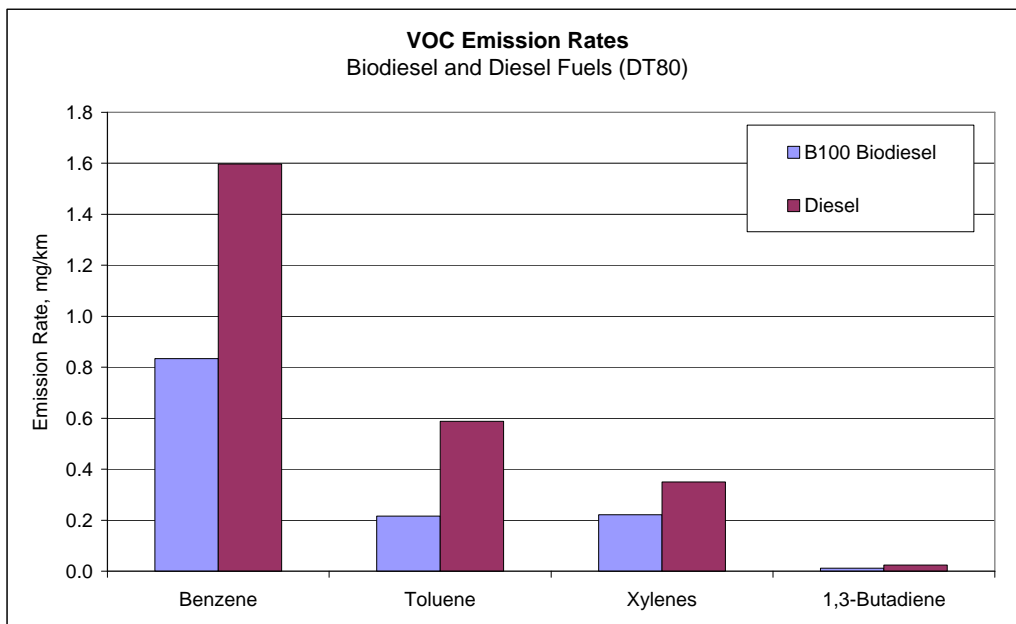


Figure 2. Comparison of VOC Emission Rates (mg/km) for Biodiesel and Diesel Fuels - DT80

Benzene returned a 48% reduction, toluene decreased most significantly with a 63% reduction in emissions, xylenes decreased by 37% and 1,3-butadiene by 50%, although the error associated with trace concentration must be taken into account for this compound. The reduction in the emissions of the combined priority aromatics (as total BTX) was 50%, from 2.54 to 1.27 mg/km. These results are somewhat different to a US EPA study (2002) which found a statistically significant decrease in xylenes but found benzene, toluene and 1,3-butadiene to be unaffected.

Absolute values for emission rate for diesel vehicles were in broad agreement with a range of overseas studies (Neumann *et al.*, 1993, Rijkeboer *et al.*, 1993, and as summarised in Day *et al.*, 2000), and up to 5 times lower than those obtained in the diesel NEPM study (Day *et al.*, 2000), using the minor roads segment of the CUEDC drive cycle. The NEPM study was performed on older vehicles (around 1996 for the NC class), and although not absolutely comparable, this perhaps indicates the improvement in vehicle emissions with improved fuel standards and vehicle technology.

Of interest was the observation that styrene, a compound which was not part of the target list, was found to increase significantly in the biodiesel exhaust. Styrene is a Category 2 carcinogen and is listed as a priority air toxic by NEPC, although it has not been targeted for regulation under the proposed NEPM. The emission of styrene was 0.13 mg/km for biodiesel compared with 0.06 mg/km for diesel, a 116% increase compared with diesel fuel.

3.2 Aldehyde Emissions

The effect of biodiesel on the emissions of C₁ - C₃ aldehydes was largely inconclusive. The slight reduction in formaldehyde is within the error of the test as was the slight increase in propionaldehyde. Acrolein was below the detection limit in most of the samples, although one sample (unreported) showed slight acrolein activity. The exception was acetaldehyde which found a 30% reduction under biodiesel. A conclusion that a decrease was found, rather than the actual extent of the decrease, can be drawn for this compound. It was observed, in the diesel NEPM, that aldehyde production is quite sensitive to slight changes in engine operating conditions and, taking into account that different vehicles were used for the two fuels, it is difficult to draw any accurate conclusions on the effect of biodiesel on aldehyde emissions, from this study.

The aldehyde emission values were broadly similar to that found in the diesel NEPM testing and compare well with results from overseas studies performed under broadly similar standards (as referenced in VOC section).

The biodiesel samples also showed a number of unknowns in the HPLC chromatogram, which were not seen in a diesel sample. They eluted in the polar region of the chromatogram and are assumed to be oxygenated carbonyl compounds, resulting from the highly oxygenated nature of the fuel.

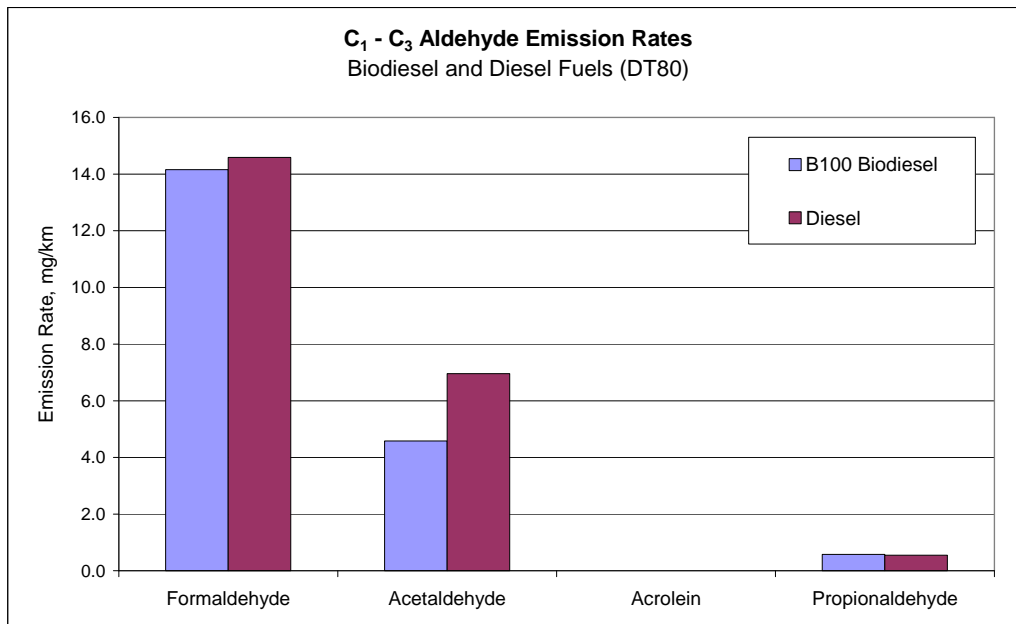


Figure 3. Comparison of C₁ - C₃ Aldehyde Emission Rates (mg/km) for Biodiesel and Diesel Fuels - DT80

3.3 PAH Emissions

PAH emissions from diesel vehicles are normally found in both the vapour and particulate phases. As can be seen in Figure 4, the compounds detected in this study are mainly vapour phase components with fluoranthene considered to partition between the gas and particulate phases. As the particle bound components are generally at relatively lower concentration from a diesel combustion source, it is surmised that they were actually present but at masses below the detection limit of the method used (equivalent to 0.008 mg/km). Higher sample collection volumes are required using either higher flow rates (the present method does not allow for substantial increases, however) or longer sample times. A higher sensitivity analysis is also an option.

Of the components measured, most were close to the analytical detection limits, as can be seen in Table 1., and hence the data is subject to relatively large error. For this reason the observations described below should be treated with caution and are certainly not promoted as conclusive.

A significant reduction in emissions of vapour phase components was indicated in the vehicle operated with biodiesel fuel, as presented in Figure 5. A 75% reduction in total vapour phase PAH, from 0.45 to 0.1 mg/km, was found. However, this may not follow for the particulate bound components, as examination of the individual PAH data suggests that there may be a correlation with the volatility of the PAH and its reduction. The most volatile PAHs (naphthalene and 2-methylnaphthalene) found an 80% (average) decrease, which stepped down with each compound through to fluoranthene with a 20% decrease in the emission. Hence, the particulate phase PAH (including the most toxic compound, benzo[*a*]pyrene) may not show any significant reduction under biodiesel. However, without particulate bound PAH information these observations are not conclusive.

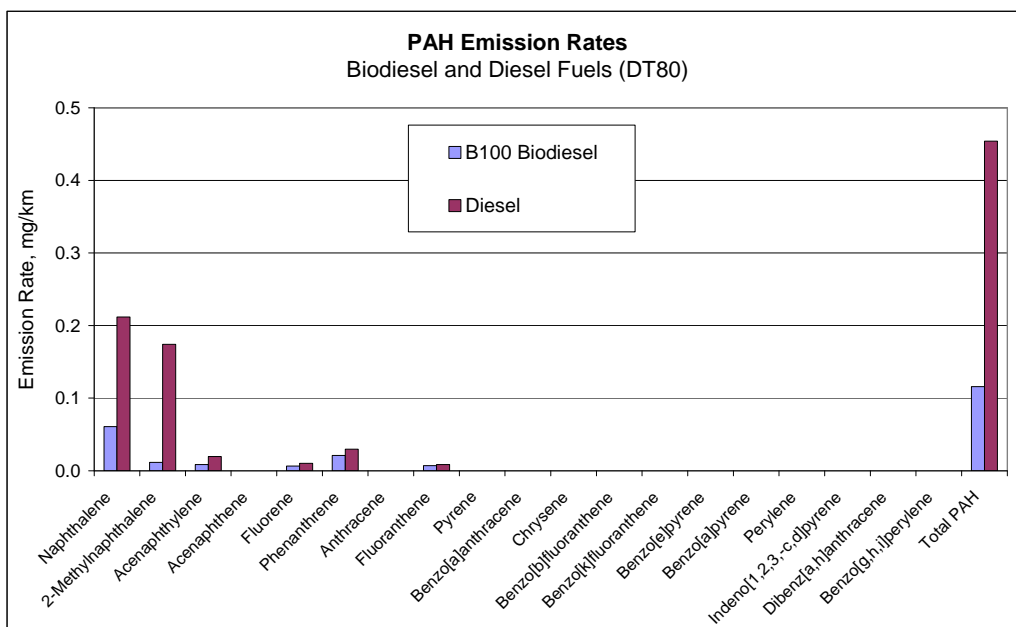


Figure 4. Comparison of PAH Emission Rates (mg/km) for Biodiesel and Diesel Fuels - DT80

In absolute terms the generation of PAH from these vehicles is quite low with total PAH concentrations, of the compounds detected, around 0.45 mg/km for diesel and 0.1 mg/km for the biodiesel. Accounting for possible particle bound PAHs (at less than 0.008 mg/km (MQL) for each compound), would not increase the emission considerably. A significant proportion of the total PAH is made up of the most volatile PAHs, with naphthalene plus 2-methylnaphthalene contributing 63 and 85% to the total compounds measured, for biodiesel and diesel respectively. Naphthalene is included (by convention) in the priority PAHs but has very low relative toxicity. For similar, but older vehicles, run under the minor and arterial roads segments of CUEDC drive cycle, emissions around 5 mg/km of total PAH were found (including particulate bound compounds). As seen with the VOC emissions, the effect of improved emission technologies and the associated overall decrease in particulate mass emitted may account for this difference. The diesel emission rates are of the same order as overseas studies (as referenced in the VOCs section), however a direct comparison is difficult based on the parameters of the test and also that many of these studies concentrate mainly on the particle bound PAH concentrations.

Figure 5 presents the emissions change using biodiesel compared with the reference diesel, the results of which are discussed in the previous sections.

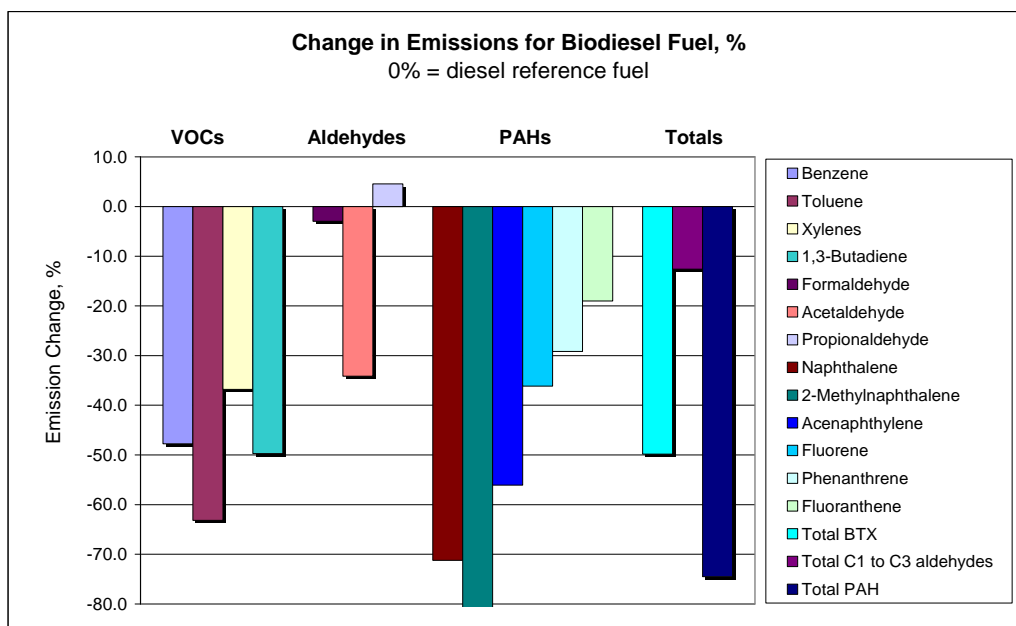


Figure 5. Percentage Change in the Emissions for Individual Compounds Measured, and for Total BTX, C₁ - C₃ Aldehydes and PAH.

4 CONCLUSIONS

Testing designed to provide a preliminary evaluation of the exhaust emissions of a range of air toxic compounds from vehicles fuelled with 100% biodiesel and normal refinery diesel have been reported. Within the limitations of the testing, the results show:

- Emission rates of the priority VOCs (benzene, toluene, xylenes and 1,3-butadiene) were significantly reduced in the vehicle operated using the biodiesel fuel compared to the vehicle run using diesel fuel. Benzene and toluene found the largest reduction and the decrease in total priority aromatics (BTX) was around 50%. A tentative conclusion of a reduction in 1,3-butadiene is made.
- C₁ - C₃ aldehyde compounds were generally unaffected under biodiesel except possibly acetaldehyde which showed some decrease in emissions. Due to the sensitivity of aldehydes to engine operating conditions a more extensive study would be required to confirm this observation.
- PAH compounds were seen to decrease quite considerably in the components associated with the vapour phase. A total reduction of 75% was found for these compounds. Evaluation of the data indicates that the effect of biodiesel is less significant as molecular weight increases. Higher molecular weight species, normally found on the particulate phase, were expected but were not detected, under the testing parameters used.
- It should be borne in mind that, for both fuels, the PAH levels were generally close to detection limits and the associated increase in relative error requires that these observations be treated as indicative only. More sensitive measurement, which also allows assessment of the particulate phase (where the more toxic PAH compounds are found), is therefore required before any firm conclusions can be drawn on the effect of biodiesel on overall PAH emissions.
- Of interest is the observation that styrene (a hydrocarbon VOC) was found to increase significantly (116%) in the biodiesel emission. Styrene is a category 2 carcinogen and priority air toxic, and its inclusion in the assessment of biodiesel emissions could be considered.

5 REFERENCES

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- Collier, A.R., Jemma, C.A., Wedekind, B. "Sampling and Analysis of Vapour Phase and Particulate-Bound PAH from Vehicle Exhaust", SAE Technical Paper 982727.
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- US EPA (2002) "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions - Draft Technical Report", EPA420-P-02-001.
- US EPA "Test methods for Evaluating Solid Waste ", SW846.
- Ye, Y., Galbally, I. E. and Weeks, I. A. (1997) Emissions of 1,3-butadiene from petrol-driven motor vehicles. *Atmospheric Environment* **31**, 1157-1165.



Appendix E: Fuel Certificates Of Analysis

E1 Automotive Ultra Low Sulphur Diesel – Phase 1

Intertek Caleb Brett

CLYDE LABORATORY – TEST REPORT

 Intertek Caleb Brett
 ABN 56001722854

 Clyde Laboratory
 Durham Street Rosehill
 New South Wales 2142

 Telephone (02) 9897-8509
 Facsimile (02) 9897-8069

SAMPLE **DIESEL Sample 2** **SAMPLE No:** **M 629A-03**
 Camden XYG 403
 16/10/2003

REFERENCE **Diesel Test Australia** **DATE** **24/10/2003**

SAMPLE ORIGIN:

1 sample arrived from Camden Council (Registration XYG 403)

RESULTS:

Test	Method	Units	Results
Density @ 15 deg C	D4052	kg/m3	855.6
Sulphur	D5453	ppm	30
Colour	D1500	---	1.0
Flash Point	D93	degC	89
Filterability	IP387		1.02
Cetane Index	D4737		50.2
Viscosity @ 40C	D445	mm2/s	3.40
Ash	D482	%mass	<0.01
Carbon Residue	D4530	%mass	0.06
Water and Sediment	D2709	%vol	<0.01
Copper Corrosion	D130		1A
Oxidation Stability	D2274	mg/L	4.3
Lubricity	IP450	microns	399
Conductivity	D2624	pS/m	560
Aromatic Hydrocarbon			
Mono aromatic	IP391	%mass	19.1
Di aromatic	IP391	%mass	10.2
Tri+ aromatic	IP391	%mass	3.4
Poly aromatic	IP391	%mass	13.6
Total Aromatic	IP391	%mass	32.7
Distillation			
10% rec	D86	degC	252.9
50% rec	D86	degC	279.4
90% rec	D86	degC	325.1
95% rec	D86	degC	336.8

COMMENTS:

Laboratory Officer: G. Agosti

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 Results were obtained on the sample as received.


Intertek Caleb Brett
CLYDE LABORATORY -- TEST REPORT

 Intertek Caleb Brett
 ABN 56001722854

 Clyde Laboratory
 Durham Street Rosehill
 New South Wales 2142

 Telephone (02) 9897-8509
 Facsimile (02) 9897-8069

SAMPLE **BIODIESEL** **SAMPLE No:** **M 630A-03**
REFERENCE **Diesel Test Australia** **DATE** **23/12/2003**
 Darren Pattison

SAMPLE ORIGIN:

Sample # 1, B100 Bio Diesel, 16/10/2003 Camden XXG983

RESULTS:

Test	Method	Units	Results	Spec.
Density @ 15 deg C	D1298	kg/m3	881.1	860 - 890
Sulphur	D5453	ppm	19	50
CFPP	D2500	degC	+1	
Flash Point	D93	degC	150	120 min
Viscosity @ 40C	D445	mm2/s	4.660	3.5-5.0
Sulfated Ash	D874	%mass	< 0.005	0.02 max
Carbon Residue	D4530	%mass	0.02	0.05 max
Water and Sediment	D2709	%vol	< 0.005	0.05 max
Copper Corrosion	D130		1A	3 max
Particulates	D5452	Mg/L	1	24 max
Acid Value	D664	mgKOH	0.27	0.80 max
Cetane Number	D613		55.0 @	51.0 min
90% rec (vacuum dist)	D1160@	degC	353 @	360 max
Ester Content	PrEN 14103	% mass	** 93.2 #	96.5 min
Total Glycerol	D6584@	% mass	0.20 @	0.25 max
Free Glycerol	D6584@	%mass	0.014 @	0.02 max
Phosphorus	D4951@	ppm	4 #	10 max
Oxidation Stability	PrEN 14112		1.0 &	6 hours @ 110°C max
Ca, Mg	PrEN14108 & 14109	ppm	1.3 #	<&=5 max
Na, K	PrEn 14538	PPM	3 &	<&=5 max
Alcohol Content	PrEn 14110	% m/m	< 0.02 #	< 0.20

COMMENTS: This report relates specifically to the sample as received.

Results on these tests from ITS Probe
@ The results on these tests from ITS Caleb Brett Singapore
& Results on these tests from ITS Sunbury
**** sample off grade for these tests**

Laboratory Manager: Andrew Hoy

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 Results were obtained on the sample as received.



E3 Automotive Ultra Low Sulphur Diesel – Phase 2

Intertek Caleb Brett

CLYDE LABORATORY -- TEST REPORT

Intertek Caleb Brett
ABN 56001722854

Clyde Laboratory
Durham Street Rosehill
New South Wales 2142

Telephone (02) 9897-8509
Facsimile (02) 9897-8069

SAMPLE **DIESEL** **SAMPLE No:** **M 063-04**

REFERENCE **Diesel Test Australia** **DATE** **18/02/2004**
Darren Pattison
Purchase Order #272

SAMPLE ORIGIN:

Sample #2 – 05/02/2004, Camden City Council, Straight Diesel

RESULTS:

Test	Method	Units	Results	Diesel 500 specification
Density @ 15 deg C	D1298	kg/m3	841.6	820.0 to 860.0
Sulphur	D5453	ppm	60	500 max
Flash Point	D93	degC	79	61.5 min
Viscosity @ 40C	D445	mm2/s	3.202	2.0 to 4.5
Ash	D482	%mass	<0.005	0.01 % max
Carbon Residue	D4530	%mass	<0.01	0.20% max
Water and Sediment	D2709	%vol	<0.010	0.05% max
Copper Corrosion	D130		1a	1 max
Colour	D1500		1.5	2.0 max
95% rec (distillation)	D86	degC	349.5	371 max
Filterability	IP387		1.02	2.0 max
Electrical Conductivity	D2624	pS/m	520	50 min
Lubricity	IP450	microns	204	460 max
Cetane Index	D4737		55.6	46 min
Oxidation Stability	D2274	mg/L	1.1	25 max
Mono Aromatics	IP391	%mass	19.4	
Di Aromatics	IP391	%mass	6.5	
Tri Aromatics	IP391	%mass	2.4	
Poly Aromatics	IP391	%mass	8.9	

COMMENTS: This report relates specifically to the sample as received.
**** sample off grade for these tests**

Laboratory Supervisor: Leanne Johnston

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Results were obtained on the sample as received.



E4 Biodiesel (B100) – Phase 2

Intertek Caleb Brett

CLYDE LABORATORY -- TEST REPORT

Intertek Caleb Brett
ABN 56001722854

Clyde Laboratory
Durham Street Rosehill
New South Wales 2142

Telephone (02) 9897-8509
Facsimile (02) 9897-8069

SAMPLE **BIODIESEL** **SAMPLE No:** **M 064-04**

REFERENCE **Diesel Test Australia** **DATE** **15/03/2004**
Darren Pattison
Purchase Order 272

SAMPLE ORIGIN:

Sample # 1, B100 Bio Diesel, 04/02/2004, from Camden City Council

RESULTS:

Test	Method	Units	Results	Spec.
Density @ 15 deg C	D1298	kg/m3	881.3	860 - 890
Sulphur	D5453	ppm	40	50
CFPP	IP309	degC	+6	
Flash Point	D93	degC	105 **	120 min
Viscosity @ 40C	D445	mm2/s	4.725	3.5-5.0
Sulfated Ash	D874	%mass	<0.010	0.02 max
Carbon Residue	D4530	%mass	0.05 ++	0.05 max
Water and Sediment	D2709	%vol	<0.010	0.05 max
Copper Corrosion	D130		1a	3 max
Particulates	D5452	Mg/L	12.6	24 max
Acid Value	D664	mgKOH/	0.08	0.80 max
Cetane Number	D613		59.5@	51.0 min
90% rec (vacuum dist)	D1160@	degC	355@	360 max
Ester Content	PrEN 14103	% mass	92.8# **	96.5 min
Total Glycerol	D6584@	% mass	0.280@ **	0.25 max
Free Glycerol	D6584@	%mass	0.006@	0.02 max
Phosphorus	D4951@	ppm	3#	10 max
Oxidation Stability	PrEN 14112		1&	6 hours @ 110°C max
Ca, Mg	PrEN14108 & 14109	ppm	<2#	<&=5 max
Na, K	PrEn 14538	PPM	<4&	<&=5 max
Alcohol Content	PrEn 14110	% m/m	0.23# **	< 0.20

COMMENTS: **This report relates specifically to the sample as received.**

Results on these tests from ITS Probe

@ The results on these tests from ITS Caleb Brett Singapore

& Results on these tests from ITS Sunbury

**** sample off grade for these tests**

++ sample just on the limit for this test

Laboratory Supervisor: Leanne Johnston

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Results were obtained on the sample as received.



E5 Automotive Ultra Low Sulphur Diesel – Phase 3

Intertek Caleb Brett

CLYDE LABORATORY -- TEST REPORT

Intertek Caleb Brett
ABN 56001722854

Clyde Laboratory
Durham Street Rosehill
New South Wales 2142

Telephone (02) 9897-8509
Facsimile (02) 9897-8069

SAMPLE **DIESEL** **SAMPLE No:** **M 168-04**

REFERENCE **Diesel Test Australia** **DATE** **15/04/2004**
Julian Anderson
PO # 285

SAMPLE ORIGIN:

A sample arrived on 08/04/2004 from Diesel Test Australia.
The sample was diesel from a Camden Truck

RESULTS:

Test	Method	Units	Results	Diesel 50 specification
Density @ 15 deg C	D1298	kg/m3	850.7	820.0 to 860.0
Sulphur	D5453	ppm	34	50 max
Flash Point	D93	degC	80	61.5 min
Viscosity @ 40C	D445	mm2/s	3.735	2.0 to 4.5
Ash	D482	%mass	<0.005	0.01 % max
Carbon Residue	D4530	%mass	0.02	0.20% max
Water and Sediment	D2709	%vol	# < 0.005	0.05% max
Copper Corrosion	D130		1A	1 max
Colour	D1500		<0.5	2.0 max
95% rec (distillation)	D86	degC	341.7	371 max
Filterability	IP387		1.03	2.0 max
Electrical Conductivity	D2624	pS/m	420	50 min
Lubricity	IP450	microns	410	460 max
Cetane Index	D4737		53.6	46 min
Oxidation Stability	D2274	mg/L	3.7	25 max
Mono Aromatics	IP391	%mass	20.8	
Di Aromatics	IP391	%mass	4.2	
Tri Aromatics	IP391	%mass	0.8	
Poly Aromatics	IP391	%mass	5.0	

COMMENTS: **This report relates specifically to the sample as received.**

results from ITS Botany

**** sample off grade for these tests**

Laboratory Supervisor: Leanne Johnston

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Results were obtained on the sample as received.


Intertek Caleb Brett
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SAMPLE **BIODIESEL** **SAMPLE No:** **M 173-04**
REFERENCE **Diesel Test Australia** **DATE** **10/05/2004**
Julian Anderson
PO # 287

SAMPLE ORIGIN: A sample of Biodiesel arrived in the lab on 16/04/2004, sampled from a truck on 14/04/2004

RESULTS:

Test	Method	Units	Results	Spec.
Density @ 15 deg C	D1298	kg/m3	886.9	860 - 890
Sulphur	D5453	ppm	50.3 **	50 max
CFPP	D2500	degC	9	
Flash Point	D93	degC	67 **	120 min
Viscosity @ 40C	D445	mm2/s	6.254 **	3.5-5.0
Sulfated Ash	D874	%mass	<0.005	0.020 max
Carbon Residue	D4530	%mass	0.13 **	0.050 max
Water and Sediment	D2709	%vol	#0.15**	0.050 max
Copper Corrosion	D130		1A	3 max
Particulates	D5452	Mg/L	140 **	24 max
Acid Value	D664	mgKOH/g	0.95 **	0.80 max
Cetane Number	D613		@52.7	51.0 min
90% rec (vacuum dist)	D1160	degC	@420**	360 max
Ester Content	PrEN 14103	% mass	& 80.0**	96.5 min
Total Glycerol	D6584	% mass	@0.70**	0.25 max
Free Glycerol	D6584	%mass	@<0.001	0.02 max
Phosphorus	D4951	ppm	& 1	10 max
Oxidation Stability	PrEN 14112		\$ 0.4 **	6 hours @ 110°C min
Na, K	PrEN14108 14109	ppm	\$ < 1	<&=5 max
Ca, Mg	PrEn 14538	PPM	& < 1	<&=5 max
Alcohol Content	PrEn 14110	% m/m	& 0.44 **	< 0.20

COMMENTS: **This report relates specifically to the sample as received.**

@ The results on these tests from ITS Caleb Brett Singapore

& The results on these tests from ITS PROBE

\$ The results on these tests from ITS Sunbury

The results for this test from ITS Botany

**** sample off grade for these tests**

Laboratory Supervisor: Leanne Johnston

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 Results were obtained on the sample as received.



E7 Automotive Ultra Low Sulphur Diesel – Phase 3 – Bowser Sample

Intertek Caleb Brett

CLYDE LABORATORY -- TEST REPORT

Intertek Caleb Brett
ABN 56001722854

Clyde Laboratory
Durham Street Rosehill
New South Wales 2142

Telephone (02) 9897-8509
Facsimile (02) 9897-8069

SAMPLE **DIESEL** **SAMPLE No:** **M172-04**

REFERENCE **Diesel Test Australia** **DATE** **19/04/2004**
Julian Anderson
PO # 287

SAMPLE ORIGIN:

A sample of diesel arrived in the lab on 16/04/2004, sampled from a drum on 14/04/2004

RESULTS:

Test	Method	Units	Results	Diesel 50 specification
Density @ 15 deg C	D1298	kg/m3	850.7	820.0 to 860.0
Sulphur	D5453	ppm	28	50 max
Flash Point	D93	degC	82	61.5 min
Viscosity @ 40C	D445	mm2/s	3.716	2.0 to 4.5
Ash	D482	%mass	<0.005	0.01 % max
Carbon Residue	D4530	%mass	0.01	0.20% max
Water and Sediment	D2709	%vol	#< 0.005	0.05% max
Copper Corrosion	D130		1A	1 max
Colour	D1500		<0.5	2.0 max
95% rec (distillation)	D86	degC	339.8	371 max
Filterability	IP387		1.02	2.0 max
Electrical Conductivity	D2624	pS/m	100	50 min
Lubricity	IP450	microns	387	460 max
Cetane Index	D4737		53.4	46 min
Oxidation Stability	D2274	mg/L	17.6	25 max
Mono Aromatics	IP391	%mass	21.7	
Di Aromatics	IP391	%mass	4.7	
Tri Aromatics	IP391	%mass	0.9	
Poly Aromatics	IP391	%mass	5.6	

COMMENTS: **This report relates specifically to the sample as received.**

Result for this test from ITS Botany

**** sample off grade for these tests**

Laboratory Supervisor: Leanne Johnston

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Results were obtained on the sample as received.


Intertek Caleb Brett
CLYDE LABORATORY -- TEST REPORT

 Intertek Caleb Brett
 ABN 56001722854

 Clyde Laboratory
 Durham Street Rosehill
 New South Wales 2142

 Telephone (02) 9897-8509
 Facsimile (02) 9897-8069

SAMPLE **BIODIESEL** **SAMPLE No:** **M 169-04**
REFERENCE **Diesel Test Australia** **DATE** **10/05/2004**
 Julian Anderson
 PO # 285

SAMPLE ORIGIN: Sample received on 08/04/2004
 Sample is Ex Camden B100 Drum

RESULTS:

Test	Method	Units	Results	Spec.
Density @ 15 deg C	D1298	kg/m3	886.1	860 - 890
Sulphur	D5453	ppm	44	50 max
CFPP	D2500	degC	> 24	
Flash Point	D93	degC	78**	120 min
Viscosity @ 40C	D445	mm2/s	6.120**	3.5-5.0
Sulfated Ash	D874	%mass	< 0.010	0.020 max
Carbon Residue	D4530	%mass	0.10**	0.050 max
Water and Sediment	D2709	%vol	#0.400**	0.050 max
Copper Corrosion	D130		1A	3 max
Particulates	D5452	Mg/L	737.2**	24 max
Acid Value	D664	mgKOH/	1.256**	0.80 max
Cetane Number	D613		@54.2	51.0 min
90% rec (vacuum dist)	D1160	degC	@431**	360 max
Ester Content	PrEN 14103	% mass	& 81.0 **	96.5 min
Total Glycerol	D6584	% mass	@0.72**	0.25 max
Free Glycerol	D6584	%mass	@< 0.001	0.02 max
Phosphorus	D4951	ppm	& < 1	10 max
Oxidation Stability	PrEN 14112		\$ 0.8 **	6 hours @ 110°C min
Na,K	PrEN14108 14109	ppm	\$ < 1	<&=5 max
Ca,Mg	PrEn 14538	PPM	& < 1	<&=5 max
Alcohol Content	PrEn 14110	% m/m	& 0.44 **	< 0.20

COMMENTS: This report relates specifically to the sample as received.

@ The results on these tests from ITS Caleb Brett Singapore

& The results on these tests from ITS Probe

The results on these tests from ITS Botany

\$ The results on these tests from ITS Sunbury UK

****** sample off grade for these tests

Laboratory Manager: Andrew Hoy

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Results were obtained on the sample as received. 7