Investigations into Reducing Emissions from Heavy Duty Diesel Vehicles in Auckland – a Summary Report

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Investigations into Reducing Emissions from Heavy Duty Diesel Vehicles in Auckland – a Summary Report

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Executive Summary

Motor vehicles are a significant contributor to air pollution in the Auckland region. The adverse effects of vehicle emissions are considerable, with the annual health costs estimated at $466 million (Kuschel *et al.,* 2012). Nearly 130 Aucklanders die prematurely every year due to pollution emitted from motor vehicles and 215,000 days are lost due to illness or poor health.

Diesel vehicles in Auckland are estimated to be responsible for 81 per cent of all vehicle-related air pollution health costs, despite making up only 23 per cent of the fleet based on mileage (Wickham *et al.,* 2014). Approximately one third of this contribution comes from heavy duty trucks and buses. Therefore, initiatives designed to target diesel vehicles, in particular, are likely to yield the best improvement in Auckland's air quality and minimise the associated health burden.

In 2003, the former Auckland Regional Council commenced a work programme investigating emissions reductions options for heavy duty diesel vehicles. The pilot trials started with buses due to the established relationship between the Auckland Regional Council and the bus operators. In addition, buses generally travel in high density corridors which means disproportionately more people are exposed to their emissions. The intention was to trial emissions reductions options on the Auckland bus fleet and then apply the findings to other fleets, such as truck operators, later.

Effective management of vehicle emissions typically focusses on four main areas: clean fuels, appropriate maintenance, clean vehicle technology and traffic/demand management (Walsh, 2003). The initiatives investigated in the work programme covered the first three areas and included:

- Evaluation of the **environmental performance of different bus fleet options** (including cost-benefit analyses).
- Undertaking **emissions testing** to highlight "gross emitting" buses for targeted maintenance.
- Participating in a joint **biodiesel trial** of buses with other stakeholders to identify potential air quality benefits.
- Trialling retrofitting of **diesel oxidation catalysts** as a cost-effective means to reduce emissions from older buses.
- Monitoring **on-road emissions of heavy duty vehicles** using remote sensing to understand the "real life emissions" of buses and trucks.
- Undertaking preliminary investigations of **truck fleet emissions.**

Key outcomes and findings

The key outcomes and findings from the work included:

- A **Bus Emissions Prediction Model (BEPM)** was developed, which compares the total emissions, reductions, costs and environmental ratings of various scenarios to compare the environmental (air quality) performance of different fleets.
- From the **cost-benefit analyses**, the most effective emissions reductions strategies in 2004 were implementing an inspection, maintenance and repair programme on the highest emitting 20 per cent of buses and retrofitting diesel oxidation catalysts (DOCs) to the older buses. However, projecting out to 2011, the options became more expensive as the base buses in the fleet improved by natural turnover.
- Two **simple or short emissions tests** – snap peak and stall average - were trialled. Smoke measurements from the short tests, particularly the stall average tests, correlated well with particulate matter (PM), carbon monoxide (CO) and hydrocarbon (HC) emissions but were not able to provide information on nitrogen oxides (NO_X) emissions rates.
- The disproportionate impact of **gross emitting vehicles** was conclusively shown in all emissions testing undertaken. The contribution of the worst 10 per cent of all heavy vehicles is responsible for at least 30 per cent of the total emissions from that sector of the fleet.
- Significant emission reductions were found with tallow methyl ester (TME) **biodiesel blends** for buses versus straight automotive diesel fuel at 50ppm sulphur in both detailed dynamometer and field testing.
- Significant emission reductions were found for buses that had been **retrofitted with DOCs** versus those without DOCs in all testing. Retrofitting of exhaust after-treatment devices was subsequently recognised by the NZ Transport Agency in the urban bus requirements.
- From the **on-road monitoring**, vehicle age, odometer reading and gross vehicle mass (GVM) all increased HC and uvSmoke emissions but NO emissions were largely unaffected. Although CO and HC emissions were not significantly different for New Zealand new and Japanese used trucks for the same year of manufacture, NO emissions were higher.
- Buses, on average, emitted significantly more NO than trucks for the same year of manufacture. However, trucks emitted significantly more uvSmoke.

For buses, all pollutants (except uvSmoke) generally trended downward with improving emission standard but not to the extent expected.

- Preliminary work was begun on engaging with Auckland truck operators and on scoping a **Truck Emissions Prediction Model** (TEPM) that could be used to reduce emissions from their fleets.

Key recommendations

Given the time that has elapsed since the pilot bus work began in 2003, most of the initiatives would benefit from being updated with more recent information on technological and policy developments.

- BEPM is based on 2006 data but could be relatively easily be updated to incorporate the newer emission technologies missing in the current version, revise the costs presented for the various emission reduction strategies and re-assess the environmental ratings to reflect the increased concerns about NO_2 health effects. A **revised BEPM** would enable robust assessment of the impacts of any proposed major transport corridor projects, involving buses. It would also allow evaluation of future population exposure as housing developments intensify along key corridors.
- Further investigation of the **impact of gross emitting vehicles** is warranted. If these vehicles could be identified and repaired, significant air quality benefits could be realised.
- A **stall average** simple test could be considered for in service compliance emissions testing for heavy vehicles with automatic transmissions.
- Either the stall average or the snap peak tests could be used by fleet operators to set **trigger points for targeted maintenance.**
- The significant emission reductions were found with both **biodiesel blends** and **retrofitting diesel oxidation catalysts** for buses using diesel fuel at 50ppm sulphur. Emissions reductions are probably still appreciable at current levels of 10ppm sulphur but warrant further investigation to incorporate the impact of improved fuel quality and emission control technology improvements that have occurred in recent years.
- **On-road monitoring using remote sensing** could be considered to identify gross-emitting heavy vehicles in service (on road). However, the capture rates (given the variable positions of heavy vehicle exhausts) may not make this as economic as adopting a simple test.

- Regardless, the datasets collected to date would be useful for confirming trends in heavy duty diesel vehicle emissions, and warrant further analysis, especially the actual impact of the improved emission standards legislation since 2003.
- There is potential for Auckland Council to partner with the Energy Efficiency and Conservation Authority (EECA) on their Heavy Vehicle Fuel Efficiency programme and approach Auckland trucking fleets to evaluate co-benefits in ambient air quality in addition to the greenhouse gas emissions reductions and fuel savings.
- A **TEPM** developed along similar lines as BEPM would be an invaluable tool, given the greater number of these vehicles in the Auckland region and the greater potential for emissions improvements.

Conclusion

In conclusion, the initiatives discussed in this report are likely to remain valid for the foreseeable future to better manage Auckland's air quality in the face of projected trends in population growth, public transport and freight.

A suite of robust tools for improving the management of heavy duty diesel vehicle emissions would support many of the policies outlined in the Proposed Auckland Unitary Plan and assist Auckland to become the world's most liveable city.

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1 Introduction

Motor vehicles are a significant contributor to air pollution in the Auckland region, with diesel vehicles contributing to almost 81 per cent of vehicle related air pollution. It is estimated that approximately one third of this contribution comes from heavy duty trucks and buses. Therefore initiatives designed to target diesel vehicles, in particular, are likely to yield the best improvement in Auckland's air quality and minimise the associated health burden.

In 2003, the former Auckland Regional Council commenced a work programme investigating emissions reductions options for heavy duty diesel vehicles. Although much time has elapsed since the programme first commenced with the pilot bus work in 2003, many of the findings from the work are still relevant to managing heavy duty diesel vehicle emissions in Auckland to support the proposed policies outlined in the Proposed Unitary Plan and achieve the vision of the Auckland Plan to make Auckland the world's most liveable city.

This report reviews the initiatives investigated from 2003 to 2010, and summarises the key outcomes (eg, actions) and key findings (eg, results). A list of the main outputs is provided at the end of each chapter.

1.1 Current state and impact of heavy duty vehicle emissions in Auckland

1.1.1 State

Auckland's air quality has generally improved since 2006 but still exceeds air quality standards and guidelines on occasion in the urban area (Auckland Council, 2013a). Although emissions from wood burning to heat homes dominate in winter, motor vehicles are a significant contributor to air pollution in the Auckland region year round, being responsible for a quarter of the particulate matter less than 10 micrometres (PM_{10}) and less than 2.5 micrometres ($PM_{2.5}$), and about half of the nitrogen oxides (NO_X) emitted each year (Xie *et al.,* 2011).

Delving further into the vehicle contribution, diesel vehicles are disproportionate emitters. Diesel vehicles in Auckland are estimated to be responsible for 81 per cent of all vehicle-related air pollution, despite making up only 23 per cent of the fleet based on mileage (Wickham *et al.,* 2014). Approximately one third of this contribution comes from heavy duty (those weighing more than 3.5 tonnes) trucks and buses.

Particulate matter emissions from vehicles come from both exhaust and non-exhaust (such as re-suspended road dust, brake and tyre wear) sources. While exhaust emissions from vehicles have reduced substantially with reduction policies, advances in fuel efficiency and improved control technologies, non-exhaust emissions have not reduced to the same extent and remain a significant contributor to airborne particulate matter. Quantifying non-exhaust discharges is more complicated as emissions are related to vehicle movements, road conditions and weather. Studies have been carried out to improve estimates of the non-exhaust emissions in Auckland, based on the source apportionment datasets. The results suggest that the contribution of all vehicle related particulate emissions (exhaust and non-exhaust) could be up to 15 per cent higher than previously reported (Xie and Davy, 2014).

1.1.2 Impact

The adverse effects of vehicle emissions in Auckland are considerable. Each year nearly 130 Aucklanders die prematurely and 215,000 days are lost due to illness or poor health due to vehicle-related pollution alone, with an associated annual health cost of $466 million (Kuschel *et al.,* 2012).

Groups with the highest exposure include people who live near busy roads or road canyons with heavy traffic, road users (commuters etc.) and people whose jobs require them to spend a long time on the roads (bus drivers etc.). Asthmatics are particularly sensitive to poor air quality and New Zealand has one of the highest rates in the world, with a prevalence of one child in four and one adult in six (Asthma Foundation, 2014).

Diesel exhaust, specifically, was identified by the World Health Organisation as *probably carcinogenic* to humans as early as 1988. This classification was upgraded in 2012 to *carcinogenic* to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk of lung cancer and a potential increased risk of bladder cancer (IARC, 2012).

1.2 Trends in the national vehicle fleet and its emissions

Since 2000, all sectors of the national fleet have experienced growth but to differing degrees. Whilst the heavy truck fleet has grown at the *same* rate as the light fleet, the heavy bus fleet has grown *significantly faster*, both in terms of numbers and in terms of travel as shown in Figures 1-1 and 1-2 respectively (MoT, 2013).

In 2012, the heavy bus fleet included 66 per cent more vehicles and was travelling 48 per cent further than the heavy bus fleet in 2000. The heavy truck and light fleets also grew but only by 25 per cent in numbers and 10 per cent in travel.

Interestingly for all sectors, the national fleet *numbers* have grown at a greater rate than the *kilometres travelled* indicating that the average mileage per vehicle is dropping for all types of vehicles. There are currently more than 3.27 million registered motor vehicles in New Zealand.

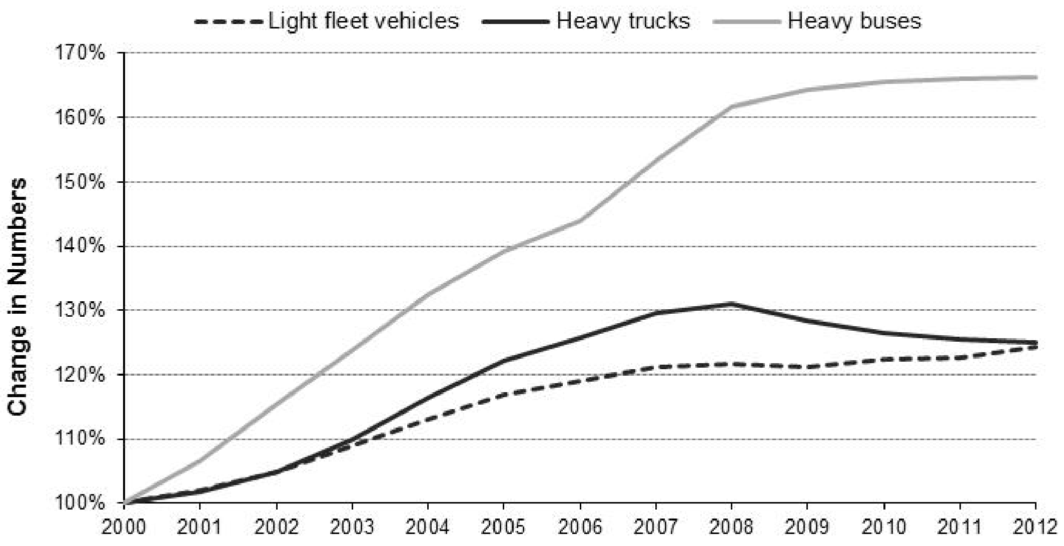

Figure 1-1 Change in national vehicle numbers relative to January 2000 (MoT, 2013)

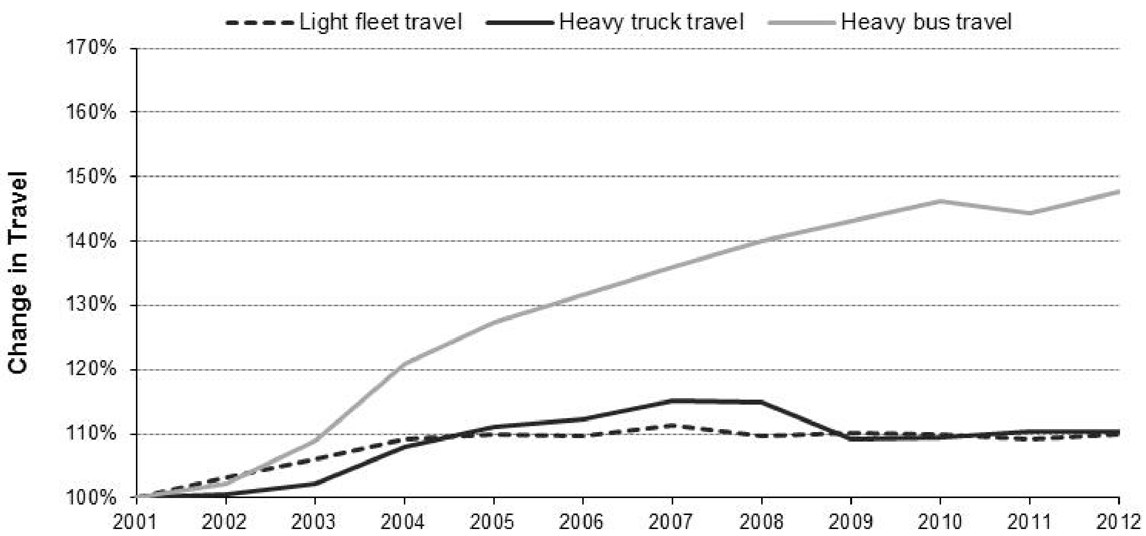

Figure 1-2 Change in national vehicle travel relative to January 2001 (MoT, 2013)

Over the same period, the average ages of the national light and truck fleets increased. However, the average age of the bus fleet dropped slightly and is now younger than the average age of the truck fleet, as seen in Figure 1-3 (MoT, 2013).

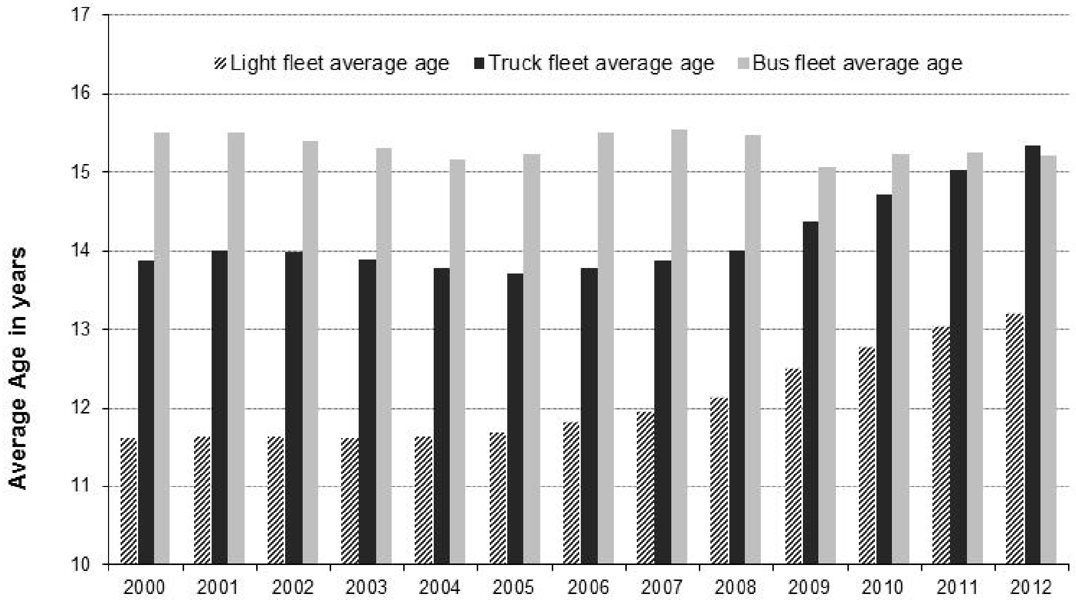

Figure 1-3 Change in national fleet average ages since 2000 (MoT, 2013)

Looking at the trends in the Auckland region between 2001 and 2012 (MoT, 2014):

- Bus numbers in the Auckland region increased by 46 per cent versus 66 per cent nationally.
- Truck numbers in the Auckland region increased by 29 per cent versus 25 per cent nationally.
- Light vehicle numbers in the Auckland region increased by 27 per cent versus 25 per cent nationally.
- Total vehicle kilometres travelled in the Auckland region increased by 22 per cent versus 19 per cent nationally.

The trends are broadly similar to those nationally, but with much less growth in bus numbers and slightly more growth in total travel and numbers of trucks and light vehicles.

1.3 Key milestones in managing heavy duty vehicle emissions

In order to effectively reduce vehicle pollution, four key management areas need to be targeted, progressively and incrementally, as shown in Figure 1-4. Initiatives around appropriate maintenance, clean fuels and clean vehicle technology assist in reducing individual vehicle emissions whereas traffic and demand management initiatives (such as integrated transportation and land use planning) influence the use of vehicles.

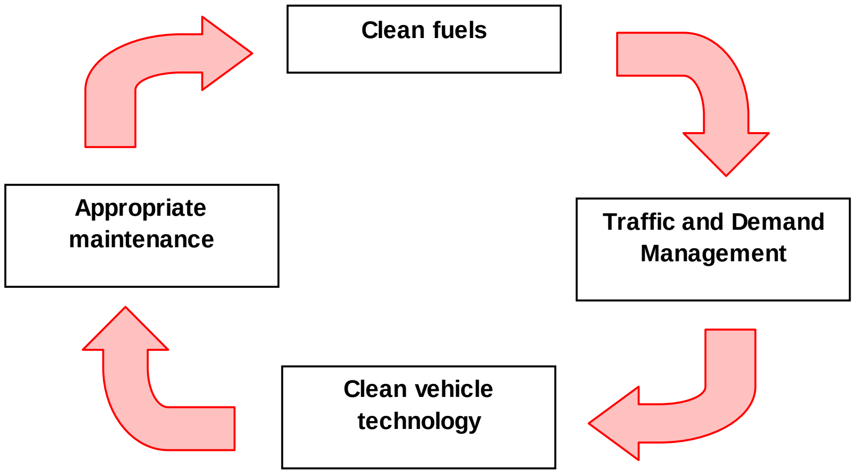

Figure 1-4 Elements of an effective vehicle emissions management strategy (Walsh, 2003)

From a position of being well behind the rest of the developed world in terms of fuels and emissions standards in the mid-1990s, New Zealand has gradually built up momentum to the point where the gap between us and the rest of the world now has shrunk considerably. Major progress has been made in clean fuels and technology, with some progress occurring in maintenance and demand management.

In Auckland there has also been a renewed focus and increased expenditure on sustainable transport infrastructure, including, for example, improvements to the public transport network and increased provision of cycle infrastructure.

The regulatory measures have been implemented by central government with support from former Auckland Regional Council and more recently the Auckland Council, whereas other activities have mostly been led by Council in partnership with central government.

Clean Fuel

The quality of vehicle fuel impacts vehicle emissions in a number of ways.

Improving fuel quality improves emissions from *existing* vehicles in the fleet. For example, reducing benzene levels in petrol lowers benzene exhaust emissions and reducing sulphur levels in diesel lowers particulate and sulphur dioxide emissions.

However, more importantly, improving fuel quality is critical to the adoption cleaner vehicle technologies in *new* vehicles entering the fleet. For example, removing lead from petrol enables the widespread adoption of catalytic converters which are able to reduce a suite of air pollutants in the exhaust (New Zealand banned lead in petrol in 1996). For diesel vehicles, low or zero sulphur levels means vehicles can be fitted with filters that remove particulate and/or catalysts which treat NO_X emissions.

The key clean fuel milestones that have reduced (or are scheduled to reduce) emissions from heavy diesel vehicles in New Zealand are as follows:

2002	Reducing sulphur in diesel from 3000ppm to 1000ppm in Auckland
2004	Reducing sulphur in diesel to 500ppm allowing Euro III diesel vehicle technology
2006	Reducing sulphur in diesel to 50ppm allowing Euro IV diesel vehicle technology
2009	Reducing sulphur in diesel to 10ppm allowing Euro V diesel vehicle technology

Clean Vehicle Technology

Vehicle technology has improved significantly since the 1970s when catalytic converters were first introduced to petrol-fuelled vehicles to comply with the U.S. Environmental Protection Agency's stricter regulation of exhaust emissions. Exhaust treatment options, such as particulate filters, are now available for diesel vehicles. In addition, cleaner burning diesel and petrol engines have been developed which utilise fuel injection and engine management systems.

Exhaust emissions are regulated in most countries worldwide, with the most common system used being the “Euro” standards developed in Europe. In the Euro standard system, Arabic numerals indicate standards for light duty vehicles (eg, Euro 4 applies to light diesels) and Roman numerals are used for heavy duty vehicles (eg, Euro IV). The Euro standards have progressively tightened over the years. Illustrating this, Euro 1 first came into force in 1992 and required all new light diesel passenger vehicles to meet a particulate limit of 0.14 grams per kilometre (g/km). By 2009, the standard was now Euro 5 and new light diesel passenger vehicles now had to meet a particulate limit of only 0.005 g/km (representing a 96 per cent decrease in particulate emissions).

The key clean technology milestones that have reduced (or are scheduled to reduce) emissions from heavy diesel vehicles in New Zealand are as follows:

2005	Requiring new heavy duty diesel imports to meet Euro III emissions standards (new models only) *and* Requiring all used heavy duty diesel imports to have been built to an approved emissions standard at the time of manufacture
2006	Requiring all new heavy duty diesel imports to meet Euro III emissions standards
2008	Requiring new heavy duty diesel imports to meet Euro IV emissions standards (new models only) *and* Requiring all used heavy imports to meet Euro III emissions standards

2009	Requiring all new and all used heavy duty diesel imports to meet Euro IV emissions standards
2011	Requiring new heavy duty diesel imports to meet Euro V emissions standards (new models only)
2012	Requiring all new heavy duty diesel imports to meet Euro V emissions standards *and* Requiring all urban bus fleets to have a fleet average age of no more than 12.5 years, with no individual vehicle older than 20 years
2015	Requiring any vehicles purchased before 2000 in urban bus fleets to meet Euro II emissions standards or be fitted with particulate filters
2017	Requiring all urban bus fleets to have a fleet average age of no more than 10.0 years, with no individual vehicle older than 20 years

Appropriate Vehicle Maintenance

Vehicle maintenance has a significant impact on vehicle emissions. In a review of monitoring undertaken around the world, Zhang *et al.* (1995) found that:

> *"The absolute **emissions differences between well- and badly-maintained vehicles of any age are considerably larger** than observable effects of emission control technology and vehicle age."*

On-road vehicle exhaust measurements show vehicle emissions follow a highly skewed distribution. The majority of vehicles record very low emissions but the majority of emissions come from the highest emitting 10 per cent of vehicles –commonly referred to as "gross emitters". Most of the high emitters are the result of a combination of malfunctioning vehicles, improper or inadequate maintenance, damage and owner/mechanic tampering.

The key vehicle maintenance milestones that have reduced (or are scheduled to reduce) emissions from heavy diesel vehicles in New Zealand are as follows:

2001	Introducing the 10 second rule for excessive smoke targeting on-road "gross-emitting" smoky vehicles (mainly diesels)
2006	Introducing the 5 second visible smoke check as part of the certificate of fitness targeting in-service "gross-emitting" smoky vehicles (mainly diesels)

Note: There are two initiatives missing from the above lists which Auckland Council has been promoting to further improve heavy duty vehicle emissions as follows:

- Setting a date for used heavy duty diesel imports to meet Euro V or equivalent emissions standards *and*
- Requiring a quantitative emissions test for heavy duty diesel vehicles as part of the certificate of fitness inspection

Central government is due to investigate both of these in 2014 as part of the Safer Journeys and other work programmes (NRSC, 2013)

1.4 Trends in Auckland’s growth

Auckland is now home to more than a third of New Zealand’s total population, with just over 1.4 million people living in the Auckland region (StatsNZ, 2013). More than half of the population growth in New Zealand between 2006 and 2013 occurred in Auckland, which continues to grow at a faster rate than the rest of the country.

Looking to the future, the current high-growth model for Auckland projects a population of 2.5 million in 2041 (Auckland Council, 2012). In order to accommodate this growth, there will be more intensification, particularly around transport corridors, with an additional 400,000 dwellings needed to be built in the region. This will potentially bring more people into contact with motor vehicle emissions. Children and the elderly are particularly susceptible to the effects of air pollution. More than one third of all children and more than a quarter of the elderly (65 years and over) live in Auckland and both of these proportions are projected to increase over time.

Compounding the problem, heavy duty transport is also projected to increase significantly in future. In 2041, heavy commercial vehicle trips and bus service kilometres travelled are predicted to increase by 76 per cent and 97 per cent respectively in the morning peak over 2011 levels (Auckland Transport, 2013). This compares with an increase for private vehicle trips of 47 per cent for the same period. This means the impact of heavy vehicles on emissions is likely to be even greater.

1.5 Auckland Council policy

Auckland Council recognises the issue of increasing population exposure to vehicle emissions, and have set a directive in The Auckland Plan to reduce emissions by 50 per cent by 2016 based on 2006 levels) to meet national and international ambient air quality standards and guidelines (Auckland Council, 2012). Meanwhile, the Regional Policy Statement (RPS) in the Proposed Auckland Unitary Plan (Auckland Council, 2013b) sets air quality objectives, most notably:

1. *Air discharges and the use and development of land are managed to improve air quality, enhance amenity values and reduce reverse sensitivity in Auckland’s urban areas and to maintain air quality at existing levels in rural and coastal marine areas.*
   …
4. *Adverse effects of air discharges on human health, property and the environment are avoided, remedied or mitigated including those from:*
   …
   e. motor vehicles

The proposed RPS has policies to "*manage discharges to air and the use and development of land*" as well as to specifically "*reduce the impacts of air contaminant discharges from motor vehicles on human health and the environment*". The methods that the RPS proposes to give effect to these policies (specifically as they relate to managing the effects of heavy duty vehicle emissions) include:

Regulatory

Unitary Plan:

- *Auckland-wide objectives, policies and rules for air quality*
- *Overlay objectives, policies and rules for industry transition, sensitive activity restriction and transport corridor separation*

Non regulatory

Advocacy and education:

- *Raising awareness of air quality issues*

Monitoring and information gathering

The work summarised in this report will help in developing options to achieve the proposed policies outlined in the Proposed Unitary Plan and highlights some of the non-regulatory methods that have been tried to date to address heavy duty diesel emissions in Auckland.

1.6 History of the overall work programme

In July 2003, the Auckland Regional Council (ARC) commenced a programme of work investigating emissions reductions options for heavy duty diesel vehicles, starting with pilot work on buses.

At that time, diesel vehicles in Auckland were estimated to be responsible for 91 per cent of all vehicle-related air pollution health costs, despite making up only 17 per cent of the fleet based on mileage. Approximately half of this contribution was estimated to come from heavy duty trucks and buses. Therefore, initiatives designed to target diesel vehicles in particular were likely to yield the best improvement for Auckland's air quality and minimise the associated health burden.

Although estimated to be responsible for only three per cent of the vehicle health costs, buses were seen as ideal leaders for showcasing and promoting sustainable transport initiatives. The ARC and bus operators already had an established relationship, which made it easier to trial a range of options on the public transport fleet and then apply the results to other fleets, such as truck operators and courier companies, at a later date.

Buses generally travel in high density corridors which mean disproportionately more people are exposed to their emissions.

The programme was launched externally at a special Bus Emissions Reduction Workshop for bus operators and key stakeholders in May 2004 (ARC, 2004). Initial work focussed on:

- Developing a Bus Emissions Prediction Model to evaluate the environmental performance of different fleet options
- Undertaking emissions testing to highlight "gross emitting" buses for targeted maintenance
- Participating in a joint biodiesel trial with other stakeholders to identify potential air quality benefits
- Trialling retrofitting of diesel oxidation catalysts as a cost-effective means to reduce emissions from older buses

During the course of the work programme, which essentially ended in late 2009, additional work was also undertaken on remote sensing of heavy duty diesel vehicle emissions (both buses and trucks) and on scoping the application of the findings to trucks via preliminary development of a truck emissions prediction model.

1.7 Purpose and structure of the report

This report overviews the key initiatives investigated between 2003 and 2010 by the Auckland Regional Council and others to reduce emissions from heavy duty diesel vehicles in Auckland. Each initiative is outlined in terms of:

- Its objective
- The organisations involved in funding, supporting or undertaking the work
- A brief description of work undertaken
- A summary of key outcomes and findings
- A list of key outputs, such as reports, datasets and models

This report is structured as follows

- **Chapter 2** discusses the development of the Bus Emissions Prediction Model which enables comparison of the environmental performance of different fleets and/or emissions reduction options plus the associated cost-benefit analyses

- **Chapter 3** summarises the results of the bus emissions testing work undertaken to establish whether a simple test could be developed to identify gross-emitting buses for remedial maintenance
- **Chapter 4** presents the key findings of trials which investigated likely emissions improvements for different biodiesel blends versus mineral diesel
- **Chapter 5** describes the programme undertaken to retrofit diesel oxidation catalysts to older buses in the fleet to reduce their emissions
- **Chapter 6** shows the results of a specific remote sensing campaign conducted for buses and trucks at bus depots and the port but also lists heavy duty emissions datasets available from light duty on-road remote sensing campaigns
- **Chapter 7** reviews the scoping completed for the development of a Truck Emissions Prediction Model, including a preliminary survey of truck operators
- **Chapter 8** summarises the overall outcomes and findings and presents recommendations for the future
- **Chapter 9** lists all of the background and original technical reports which have been summarised and synthesised to produce this report

Much time has elapsed since the programme first commenced in 2003. However, the key findings remain relevant for better managing Auckland’s air quality in the face of projected trends in population growth, public transport and freight to achieve the world’s most liveable city.

Note about the use of opacity as a measurement of emissions

The opacity of a diesel vehicle’s exhaust is considered an indicator of its level of maintenance and is used for this purpose in legislation in many jurisdictions that have in-service emissions testing. Opacity may therefore be considered as a measure of the relative level of emissions of diesel vehicles, especially when it is used to compare the performance of vehicles built to the same standards. However, it is important to note that opacity is not suitable as a proxy for the measurement of particulate mass. In this report it has been used as a qualitative rather than a quantitative indicator of the relative levels of pollution from vehicles.

2 Evaluating Bus Fleet Emissions Performance

This chapter discusses the development of the Bus Emissions Prediction Model enabling comparison of the environmental performance of different fleets and/or emissions reduction options plus the associated cost-benefit analyses.

The work in this chapter applies to vehicle emissions management areas of clean fuels, appropriate maintenance, and clean technology.

2.1 Objective

- Develop a bus emissions prediction model to evaluate the environmental performance of different Auckland bus fleet options

2.2 Organisations involved

The development of the Bus Emissions Prediction Model was:

- undertaken by Auckland UniServices Energy and Fuels Research Unit (EFRU)
- funded by Auckland Regional Council (ARC) with support for the biodiesel option provided by Energy Efficiency and Conservation Authority (EECA)
- with assistance provided by Stagecoach New Zealand Ltd.

2.3 Brief description of the work undertaken

Work began in 2003 on the development of a Bus Emissions Prediction Model (BEPM) to evaluate the emissions of existing Auckland bus fleets and predict emission reductions for various mitigation scenarios. The scenarios were selected from reduction options in use overseas at the time the project commenced, for which suitable and robust data existed.

The project was completed in two stages:

1. Developing fleet average emission factors which could then be predicted for various scenarios
2. Incorporating the capital and operating cost implications of each scenario

An initial version was released in 2004 then updated in 2005 to include the additional fuel option of biodiesel and biodiesel/conventional diesel blended fuels.

2.3.1 Development of the fleet average emission factors

The structure of the model is shown in Figure 2-1. The model generates speed dependent emission factors for carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), non-methane hydrocarbons (NMHC – only for gaseous-fuelled buses), oxides of nitrogen (NO_X), and total particulate matter (PM – approximately equivalent to PM_{10}), for each technology class, for the baseline emissions/bus technology classes. These categories are listed in Table 2-1.

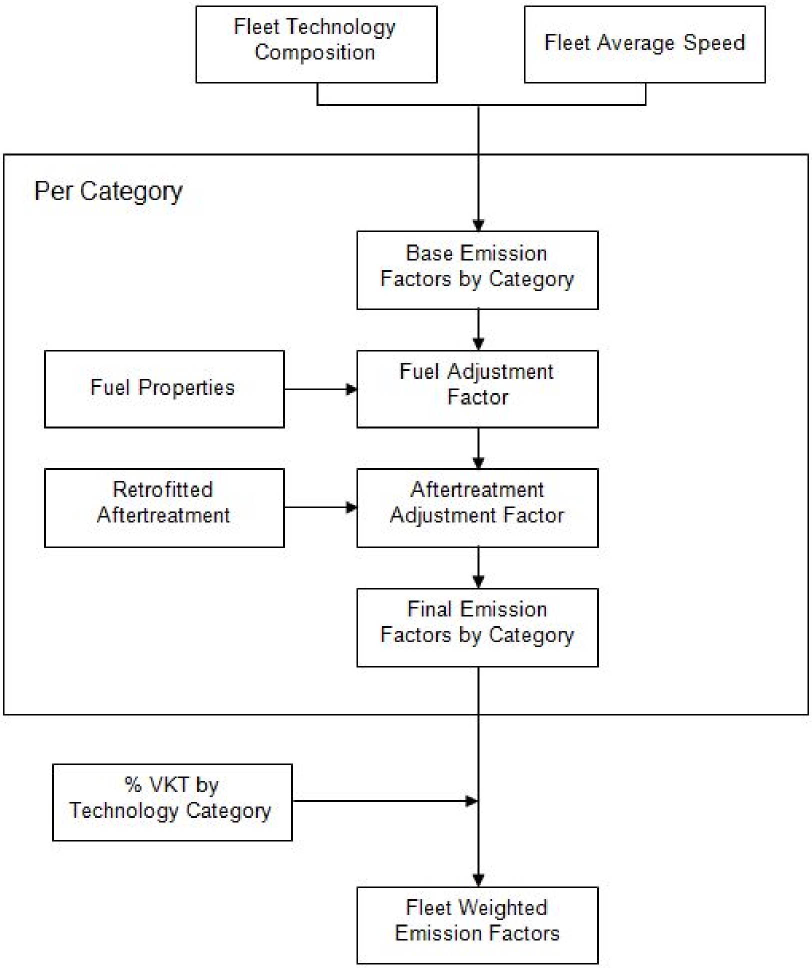

Figure 2-1 Schematic of the Bus Emissions Prediction Model (BEPM) structure (EFRU, 2003a)

The categories for diesel buses are based on the emission certification regulations in the year of manufacture in the country of origin. For alternative fuel and hybrid buses the categories are based on the technology specification of the buses.

Table 2-1 Base bus technology categories used in BEPM (EFRU, 2003a)

1.0 Diesel

1.1 European	Title	Model years	1.2 Japanese	Title	Model years
(i)	Pre-Euro	< '88	(i)	Pre '94	< '94
(ii)	Euro 0	88-91	(ii)	J94	94-97
(iii)	Euro I	92-95	(iii)	J98	98-02
(iv)	Euro II	96-99	(iv)	J03	03-05
(v)	Euro III	00-04	(v)	J05	> 05
(vi)	Euro IV	05-07			
(vii)	Euro V	08			

1.3 US Federal	Title	Model years
(i)	US '88	88-89
(ii)	US ' 90	90
(iii)	US '91	91-92
(iv)	US '93	93
(v)	US '94	94-95
(vi)	US '96 (data for no cat)	96-97
(vii)	US '98 (generally have oxidation cats)	98-03
(viii)	LEV	98-03
(ix)	ILEV	98-03
(x)	ULEV	98-03
(xi)	ZEV	98-
(xii)	US '04 (assume will have oxidation cat + EGR)	04-06
(xiii)	US '07 (assume catalytic PM trap + NOx cat)	>07

2.0 Alternative Fuel

2.1 CNG/LPG	
(i)	Open loop carb/mixer - no cat (early US, NZ)
(ii)	Open loop carb/mixer - oxidation cat (early US, NZ)
(iii)	Closed loop lean burn - no cat (US)
(iv)	Closed loop lean burn - oxidation cat (current US)
(v)	Closed loop stoichiometric - three way cat (European)

3.0 Hybrid-Electric (HEV)

3.1 Diesel HEV	
(i)	Reciprocating internal combustion engine: Diesel (US)
(ii)	Diesel turbine (NZ)

3.2 Gas HEV	
(i)	Reciprocating internal combustion engine: Gas
(ii)	Gas turbine (NZ)

Note: The **base emission factors** were obtained from published international literature and where necessary adjusted to account for variation in the fuel consumption between that reported by the bus operators and that reported in the literature.

These base emission factors are modified by a number of factors. Firstly for diesel buses, a **fuel effect correction** is applied to cater for fuels significantly different to the fuel upon which the base emission factor is based.

Secondly, an **after-treatment factor** is applied where applicable to estimate emission reductions of retrofit technology such as diesel oxidation catalysts (DOC), diesel particulate filters (DPF) including the current production technology of continuously regenerating traps (CRT). These after-treatment options are only able to be selected for older technology buses that were <u>not</u> originally manufactured with these devices; the base emission factors for newer bus categories where these devices were incorporated into manufacture already reflect improved emissions performance.

Finally, the individual adjusted emission factors for each technology category are combined according to the relative vehicle kilometres travelled by each category to produce a set of **fleet weighted emission factors**, in grams per kilometre.

The model includes:

1. Emission factors for key regulated emission species (eg, PM, NOx, plus CO_2) and fuel consumption broken down by emission standard, fuel type and country of origin.
2. Speed dependency of these emission factors.
3. Impact of fuel properties on base engine out emissions.
4. Impact of various after-treatment devices, as a function of bus emission category (raw engine out emissions) and fuel specifications.
5. Aggregation of fleet emission factors to provide fleet averaged emission rates. This can then be used with an estimate of bus fleet vehicle kilometres travelled (VKT) to provide region wide total emissions to the airshed.
6. Provision of a comparative environmental rating of specified fleet based on the fleet weighted emission factors.
7. Cost estimates of various emission reduction scenarios.

The **environmental rating factor** is calculated on a scale of zero to 30, with a higher value of this factor indicating a better performing bus. A fleet can also be allocated an overall rating factor based on the buses in the fleet and the VKT of each type.

The actual fleet average emission for each pollutant is initially pro-rated against a scale where the highest emission factor across the categories, typically for the oldest technology bus, is rated the worst (0) and a zero emission factor, typically only achievable for an electric vehicle, is rated the best (10). These overall scores divided by 10 are then multiplied by the weightings within each criterion and combined to yield an overall environmental rating factor according to Table 2-2.

Table 2-2 Relative weighting of emissions species and fuel consumption used in the calculation of the environmental rating factor (EFRU, 2002)

Rating Points	**Criterion**	**Weighting Within the Criterion**						
		CO	**NOx**	**NMHC**	**PM**	**CH_4**	**CO_2**	**FC**
2	Fuel Consumption	-	-	-	-	-	-	2
3	Global Warming Potential	9/43	21/43	33/43	-	63/43	3/43	-
25	Health Effects	6	6	2	11	-	-	-

Note: Total hydrocarbons (THC) is the sum of non-methane hydrocarbons (NMHC) and methane (CH_4)

The health effects are given the majority of the rating points due to concern about the population exposed to urban bus emissions. Within health effects, PM is weighted the strongest because of its impacts relative to other species.

The final version of BEPM was released on May 2005 as a Microsoft Excel™ spreadsheet model. It includes biodiesel fuel options and is populated with a base fleet of 200 buses representing the technology and age distributions typical of an Auckland operator in 2006 (EFRU, 2005a).

The model was released with a users' guide containing a full set of instructions on how to use BEPM to predict emissions for the scenario/s of interest (EFRU, 2005b).

Full technical details on the development of BEPM and the subsequent incorporation of biodiesel scenarios are described in EFRU (2003a) and Boielle (2005), respectively. The development of the environmental rating factor is discussed in EFRU (2002).

Note: At the time BEPM was developed sulphur levels in diesel were 500ppm. With levels now at 10ppm, many of the "low hanging fruit" options identified have already been taken up or no longer apply.

2.3.2 Analysis of cost-benefits of various bus emission reduction strategies

Incorporation of costs into BEPM

The development of BEPM involved the investigation of costs associated with the following emissions reduction strategies:

- Replacing older buses with new diesel, hybrid electric, and gaseous fuelled options
- Adopting low sulphur diesel (500ppm max) and ultra-low sulphur diesel (ULSD - 50ppm max)
- Retrofitting of diesel oxidation catalysts (DOC) and PM traps (continuously regenerating traps – CRT). For CRTs, the cost included the necessity of ULSD
- Implementing an emissions inspection and maintenance (EI&M) programme targeting repair of the worst 20 per cent of buses
- Use of water blend fuel emulsions (WBF)

The costs for each scenario were estimated from a range of sources, such as:

- Stagecoach New Zealand Ltd (for new bus costs)
- Ministry of Economic Development (for improved fuels)
- Catalyst suppliers (for retrofitting after-treatment devices)
- Various Australian government agencies (for targeted maintenance)
- Lubrizol Corporation (for water emulsion costs)

and then incorporated into the initial release of BEPM (EFRU, 2003b). The costs associated with biodiesel were added later to the final version of BEPM as part of the work undertaken by Boielle (2005) for EECA.

All costs were separated into capital and operating costs as at 2004. Capital costs were defrayed over the useful life of the equipment (8 years for CRTs/DOCs and 20 years for new buses) at a user-entered interest rate. Operating costs differences generally comprised fuel costs (both unit fuel price and fuel consumption components) and repairs and maintenance costs.

Analysis of specific cost-benefits for a typical Auckland bus fleet

After BEPM was finalised, a specific analysis was undertaken to assess the emission reductions and relative cost effectiveness of a range of strategies and measures for a bus fleet representative of Auckland.

The **baseline fleet composition** was taken to be that of an October 2004 fleet of 200 buses travelling a total of approximately 9 million kilometres per annum. Business as usual (BAU) fleet compositions were estimated for May 2006 and May 2011, assuming that buses were replaced at the end of a 20 year life span. The vehicle kilometres travelled (VKT) by bus emissions technology were estimated, assuming that the older buses were generally only used to meet peak demand so the newer, and lower emitting, buses accrued higher annual VKT. The total annual VKT was assumed largely unchanged over the scenario period. The BAU fleet compositions and annual VKT in '000s of kilometres are shown in Table 2-3.

Table 2-3 Business as usual (BAU) fleet composition by emissions technology (EFRU, 2005c)

Bus Technology	Oct 2004		May 2006 BAU		May 2011 BAU	
	# buses	VKT ('000s)	# buses	VKT ('000s)	# buses	VKT ('000s)
Pre-Euro	70	35	51	30	13	30
Euro 0	10	35	10	35	9	30
Euro I	35	55	32	50	32	45
Euro II	10	55	10	50	10	54
Euro III	30	55	57	56	65	54
Euro IV					19	54
Euro V					12	54
Pre-J94	5	40				
J94	40	47	40	47	40	30
TOTALS	**200**	**9005**	**200**	**9052**	**200**	**9024**

Emissions reduction options were then modelled for each of the three fleets – 2004, 2006 and 2011. The options modelled are listed in Table 2-4, assuming the following:

- A fleet average speed of 20 km/h
- The diesel fuel was assumed to have 500ppm sulphur content in 2004, 50ppm in 2006 and 30ppm in 2011
- All costs were taken in 2004 dollar terms

The total annual mass of emissions of carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NO_X) and particulate matter (PM) were then calculated for each of the three fleet years with the BAU and emission reduction options. Based on the emissions and cost modelling, recommendations were made on the most viable and cost effective emission reduction strategies and discussed in EFRU (2005c).

Table 2-4 List of options modelled for each fleet year (EFRU, 2005c)

Base Fleet 2004 (500ppm sulphur fuel)	**Base Fleet 2006 (50ppm sulphur fuel)**	**Base Fleet 2011 (30ppm sulphur fuel)**
EI&M repair worst 20%		
DOC on pre-Euro and pre-J94 only	DOC on pre-Euro and pre-J94 only	DOC on pre-Euro and pre-J94 only
DOC on all buses	DOC on all buses	DOC on all buses
50ppm sulphur fuel		
50ppm and DOC on all buses		
50ppm and DOC on pre-Euro and pre-J94 rest CRT	DOC on pre-Euro and pre-J94 rest CRT	DOC on pre-Euro and pre-J94 rest CRT
WBF based on 5 cents per litre increase in cost	WBF based on 5 cents per litre increase in cost	WBF based on 5 cents per litre increase in cost
WBF and DOC on all buses	WBF and DOC on all buses	WBF and DOC on all buses
WBF and 50ppm fuel and DOC on all buses		
WBF and 50ppm fuel and DOC on pre-Euro and pre-J94 rest CRT	WBF and DOC on pre-Euro and pre-J94 rest CRT	WBF and DOC on pre-Euro and pre-J94 rest CRT
10 new buses replacing 10 pre-Euro	10 new buses replacing 10 pre-Euro	10 new buses replacing 10 pre-Euro

2.4 Key outcomes and findings

2.4.1 Applications of BEPM

From 2004, BEPM was used in a number of applications to compare the environmental performance of bus fleets both in Auckland and nationally. Some examples include:

- In 2004, BEPM was used in the evaluation of tenders called by the Auckland Regional Transport Agency (ARTA) for the **North Shore commercial bus services** contract. Four operators provided details of their proposed fleets which were fed into BEPM to evaluate the environmental performance of each. The proposed fleets scored environmental ratings between 14.6 to 25.5 (where zero is poor and 30 is excellent) which were added to the other tender assessment criteria.
- Later that year, BEPM was used for the **Auckland Schools commercial bus services** contract, also managed by ARTA. For the eight fleets offering their services, the environmental ratings ranged from 5.2 to 22.7 reflecting the less the strict requirements that are typically in place for school bus services.

- In 2006, BEPM was run for Waikato Regional Council to evaluate the impact of switching to natural gas, retrofitting DOCs only, and extending the retrofits to both DOCs and CRTs for the **Hamilton city bus fleet**.
- Following concern about the quality of **school bus services across New Zealand**, the Ministry of Education commissioned a review of their contracted fleets in 2008. Typically the oldest buses are used on these services yet they transport one of the population groups most sensitive to the effects of air pollution – children. The Ministry asked operators to provide fleet information so an evaluation could be done using BEPM. However, the completeness of the responses varied hugely making it difficult to undertake a robust analysis. At the start of the project, it was hoped that a minimum standard could be developed somewhat similar to that which was being developed for urban buses (NZTA, 2008) but this proved impossible. Ultimately, the Ministry felt that the NZTA urban bus requirements would result in an improvement in the quality of the school bus fleets as buses which did not meet the new urban bus requirements would then be available to be put into service as school buses.

2.4.2 Analysis of cost and benefits

Business as usual (BAU) emissions 2004 to 2011

For the BAU fleet turnover, PM reductions of 27 per cent and 57 per cent were estimated for the 2006 and 2011 bus fleets respectively compared to the 2004 fleet, as shown in Figure 2-2.

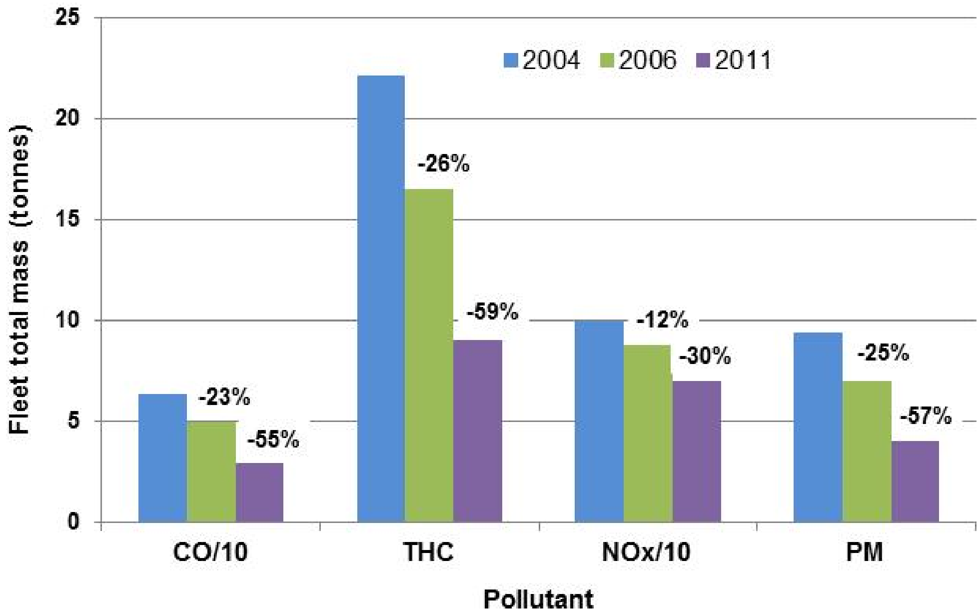

Figure 2-2 Annual emissions and percentage change of the BAU scenarios versus the baseline (2004) fleet (EFRU, 2005c)

Scenario emissions 2004 to 2011

The costs per tonne and the total PM reductions relative to the baseline (or BAU fleets) for the respective years modelled are shown in Tables 2-5 to 2-7.

Reductions in other pollutant species also occurred for some options but these were not monetised as the focus of this work was on PM reduction. The tables also present the environmental ratings for each fleet scenario.

Table 2-5 2004 scenarios - total PM emissions, reductions, costs and environmental ratings (EFRU, 2005c)

2004 Scenarios	**Total Fleet PM (T/yr)**	**PM Reduction (T/yr)**	**Cost[1] per T/yr ($)**	**Env. Rating Factor**
Base Fleet 2004 @ 500ppm sulphur diesel	**9.4**			**16.1**
EI&M repair worst 20%	8.4	1.0	$60,000	17.2
DOC on pre-Euro and pre-J94 only	7.4	1.9	$39,000	18.6
DOC on all buses	6.3	3.1	$64,000	19.9
50ppm sulphur fuel[2]	9.0	0.4	$195,000	16.3
50ppm and DOC on all buses	6.0	3.3	$80,000	20.1
50ppm and DOC on pre-Euro and pre-J94 and rest CRT	3.8	5.5	$120,000	21.8
WBF (assume 5c per litre additional cost)	4.2	5.1	$60,000	18.9
WBF and DOC on all buses	2.8	6.5	$77,000	21.7
WBF and 50ppm and DOC on all buses	2.7	6.7	$87,000	21.8
WBF and 50ppm and DOC on pre-Euro and pre-J94 and rest CRT	1.7	7.6	$128,000	22.8
10 new buses replacing 10 pre-Euro	8.7	0.7	$267,000	17.0

Note in the above table:

1. The cost per tonne per year is assumed over the *life* of the option. For example, the maintenance (E&IM) cost is per year for 1 year. In the case of DOCs/CRTs, the costs shown are the annual costs each year for 8 years. For new buses, these are annual costs every year for 20 years.
2. For this option, the costs shown are for the early introduction of this lower sulphur fuel only which by itself is relatively expensive ($195,000 per tonne per year). For the next option, the costs are much lower as the cost effectiveness of DOCs for PM reductions is much improved (at $39,000 per tonne per year for pre-Euro and pre-J4 vehicles) and so brings the 50ppm with DOC combination costs down.

Table 2-6 2006 scenarios - total PM emissions, reductions, costs and environmental ratings (EFRU, 2005c)

2006 Scenarios	**Total Fleet PM (T/yr)**	**PM Reduction (T/yr)**	**Cost per T/yr ($)**	**Env. Rating factor**
Base Fleet 2006 @ 50ppm sulphur diesel	**7.0**			**19.0**
DOC on pre-Euro and pre-J94 only	5.9	1.1	$45,000	20.4
DOC on all buses	4.7	2.3	$85,000	21.8
DOC on pre-Euro and pre-J94 rest CRT	2.4	4.6	$144,000	23.7
WBF (assume 5c per litre additional cost)	3.2	3.9	$80,000	20.9
WBF and DOC on all buses	2.1	4.9	$103,000	23.0
WBF and DOC on pre-Euro and pre-J94 rest CRT	1.1	5.9	$164,000	24.1
10 new buses replacing 10 pre-Euro	6.4	0.6	$328,000	19.7

Note in the above table: The cost per tonne per year is assumed over the *life* of the option. For example, in the case of DOCs/CRTs, the costs shown are the annual costs each year for 8 years. For new buses, these are annual costs every year for 20 years.

Table 2-7 2011 scenarios - total PM emissions, reductions, costs and environmental ratings (EFRU, 2005c)

2011 Scenarios	**Total Fleet PM (T/yr)**	**PM Reduction (T/yr)**	**Cost per T/yr ($)**	**Env. Rating factor**
Base Fleet 2011 @ 30ppm sulphur diesel	**4.0**			**22.7**
DOC on all buses	2.9	1.2	$133,000	24.2
DOC on pre-Euro and pre-J94 rest CRT	1.0	3.1	$209,000	25.7
WBF (assume 5c per litre additional cost)	1.8	2.2	$136,000	23.5
WBF and DOC on all buses	1.3	2.8	$167,000	24.6
WBF and DOC on pre-Euro and pre-J94 and rest CRT	0.3	3.7	$267,000	25.5
10 new buses replacing 10 pre-Euro	3.4	0.6	$322,000	23.6

Note in the above table: The cost per tonne per year is assumed over the *life* of the option. For example, in the case of DOCs/CRTs, the costs shown are the annual costs each year for 8 years. For new buses, these are annual costs every year for 20 years.

From the scenario modelling, the most cost effective strategies were found to be:

- Implementing **emissions inspection and maintenance**, combined with repair of the highest emitting 20 per cent of the buses, costing $60,000 per tonne of PM reduced.
- Fitting **diesel oxidation catalysts** to all buses at an average cost of $63,000 per tonne, ranging from $38,000 for pre-Euro buses to $93,000 for Euro 0 buses.
- Using **water blend fuel** at the estimated cost of 5c per litre above standard diesel fuel.

Projecting out to 2011 indicated that most options would become more expensive per tonne of PM reduced because the base buses in the (BAU) fleet would be emitting much lower total PM than those in 2004.

2.5 Key outputs

The key outputs from the development of the bus emissions prediction model include:

- The Bus Emissions Predictions Model (BEPM), Biodiesel-200 Buses Version
  EFRU (2005a)
- Instructions for Using BEPM, Biodiesel-200 Buses Version
  EFRU (2005b)
- Report on Benefits and Costs of Emissions Reduction Strategies for a Bus Fleet
  EFRU (2005c)
- Report on Recommendations for Environmental Rating Factors for Bus Tenders
  EFRU (2002)
- Report on the Development of the Bus Emissions Prediction Model
  (EFRU, 2003a)
- Report on the Analysis of Costs and Benefits of Bus Emission Reduction Strategies
  (EFRU, 2003b)
- Report on the Incorporation of Biodiesel Scenarios into BEPM
  (Boielle, 2005)

3 Bus Emissions Testing

This chapter summarises the results of the bus emissions testing work undertaken to establish whether a simple test could be developed to identify gross-emitting buses for remedial maintenance.

The work in this chapter applies to vehicle emissions management area of appropriate maintenance, in particular.

3.1 Objective

- Develop a method to identify buses that are high emitters so that remedial maintenance can be undertaken to reduce their emissions

3.2 Organisations involved

The emissions testing was:

- undertaken by Auckland UniServices Energy and Fuels Research Unit (EFRU)
- funded by Auckland Regional Council (ARC)
- with support from the major Auckland bus fleet operators.

3.3 Brief description of the work undertaken

The emissions testing programme began with a pilot study in 2003 to trial logistical and procedural techniques in advance of a full scale smoke test programme being undertaken on the entire Stagecoach bus fleet in 2004. Testing was extended in 2005 to the other major bus operators fleets in the Auckland region – Birkenhead Buses, Howick and Eastern, Ritchies and Bayes to create a 2003 to 2005 dataset. The final stage of field testing was completed in 2007.

Initial in-field testing (at the various bus depots) utilised a snap acceleration test but later also used a variant called a stall test. The field results were complemented by detailed testing in 2006 on two buses, consisting of detailed emissions measurement with the vehicles operating on a chassis dynamometer.

The **free acceleration or snap test** is an internationally recognized and commonly used short test for diesel vehicles documented by the Society of Automotive Engineers. The snap test requires that a vehicle's engine temperature be in its normal operating range. The vehicle's transmission is placed in neutral and a check is performed to ensure that the engine's governor is operational. Once these conditions are satisfied the accelerator pedal is depressed fully and rapidly, thereby accelerating the engine to its governed speed. Once reached, the governed speed is maintained for approximately one second before the pedal is released and the engine returns to idle, this event is known as a "snap" and this is initially repeated three times to clear soot from the vehicle's exhaust system in a process known as the "clear outs" prior to the collection of opacity data. Following the clear outs, a smoke meter sensor is placed over the end of the vehicle's exhaust pipe. A number of snap tests are then performed, separated by a five second pause. The peak smoke density (K in m^{-1}) of each snap is recorded and this continues until a minimum of three consistent snap results are achieved that do not show a continuing trend of increasing or decreasing smoke density. Typically five or more snaps may be performed on any given bus. The final result is averaged from the final three or more snap results depending on consistency of the data.

Smoke density (K) is a fundamental means of quantifying the ability of a smoke plume or smoke-containing gas sample to obscure light. By convention, smoke density is expressed on a per meter basis (m^{-1}). The smoke density is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles, and the light absorption and scattering properties of the particles. In the absence of blue or white smoke, the size distribution and the light absorption/scattering properties are similar for all diesel exhaust gas samples, and the smoke density is primarily a function of the smoke particle density and considered as only a proxy for fine particulate concentrations.

The **stall test** is a variant of the snap test and performed in the same way except that instead of operating the vehicle in neutral, the transmission is placed in drive and the brake used to prevent the vehicle from moving. Thus when clear outs and stall tests are performed, instead of the engine achieving governed speed it will reach a steady "stall speed", the speed at which the load applied through the automatic transmission's torque converter matches the engine's power output. Stall tests take longer than snap tests to perform as the engine accelerates slower due to the increased load. Once the stall speed is reached, it is maintained for approximately ten seconds before releasing the pedal. Data collection is the same as for a snap test. A stall test represents the engine operating at full load, slightly below its peak torque value. As with the snap test, a smoke meter sensor is used to measure opacity data.

By comparison, **detailed dynamometer testing** involves the use of a chassis dynamometer and a full dilution flow constant volume sampler (CVS) system with full recording of gaseous and particulate phase exhaust emissions. The dynamometer is programmed to follow a test drive cycle which simulates "real" driving by undergoing a series of controlled accelerations, decelerations, steady state and stop-start elements. Simultaneously, the exhaust gases and particulate emissions are captured to enable average emissions of a range of pollutants to be measured in grams per kilometre (g/km). These test results can then be compared with the pollutant limits set for the various emission standards, eg, Euro II.

Over the duration of the testing programme (2003 to 2007), the **regulated maximum sulphur level in diesel fuel** reduced from 500ppm to 50ppm. The introduction of ultra-low (50ppm) sulphur diesel started around September 2005 as new 50ppm sulphur fuel was produced at the refinery and mixed with the existing 500ppm sulphur in storage tanks such that the sulphur levels in diesel available at the pump decreased over time reaching 50ppm prior to the mandated January 2006 changeover. All field data between 2003 and 2005 were collected prior to August 2005 when the 500ppm sulphur diesel was still in use; no field data were collected over the September 2005 to January 2006 period when sulphur levels were declining. This period was instead utilized to investigate the correlation between the short tests and actual vehicle emissions in the detailed testing using a specially procured batch of ultra-low sulphur diesel. For the 2007 field tests, all diesel fuel was at the 50ppm sulphur levels.

Note: Some of the testing undertaken for the purpose of identifying high emitters (described in this chapter) was conducted conjointly with other testing commissioned to investigate the performance of various biodiesel blends (discussed in detail in Chapter 4) and to evaluate potential emissions reductions from retrofitting diesel oxidation catalysts (covered in Chapter 5). Consequently, some of the key outputs and references overlap.

3.3.1 Smoke testing on Stagecoach fleet 2003 to 2004

Testing of the Stagecoach bus fleet began with a two day pilot programme in 2003. A total of 50 buses were tested using equipment setup in the bus parking area. The testing was scheduled to coordinate with the return of buses to the depot after the morning peak period (starting around 9:00am to 9:15am) to provide an ample flow of buses into the depot and to ensure that all buses were at normal operating temperature when tested.

The procedure adopted for the pilot testing was to:

- Check operating temperature, and perform governor check
- Perform three preliminary “clear out” snap accelerations prior to measurement
- Measure three snap accelerations, repeating if necessary to obtain three measurements with a maximum range of 5 per cent opacity. A maximum of three sets of measurements were performed in an attempt to achieve this validity criteria.

The pilot testing measured smoke densities for buses built to the following emission standards: Pre-Euro, Euro I, Euro III and J94. The preliminary results suggested that, over the entire fleet, a test rate of eight to ten buses per hour was achievable.

Following the pilot, testing was undertaken at the Stagecoach city depot – this time on 127 individual buses – using the same snap acceleration test as described. Many of the buses were repeat tested to estimate an average variation of the test procedure. Repeat testing involved both sequenced repeat tests where one bus is subject to several tests each directly after the other and separate date testing where a bus was repeat tested on different dates and under different atmospheric conditions.

The city depot testing measured smoke densities for buses built to the following emission standards: Pre-Euro, Euro I, Euro II, Euro III and J94.

The pilot bus testing was reported in April 2004 (EFRU, 2004a) and followed up with the Stagecoach city depot testing report in August 2004 (EFRU, 2004b).

3.3.2 Field trials for the entire Auckland bus fleet 2005 and 2007

In 2005, the emission testing was expanded to cover the entire Auckland bus fleet. By the end of 2005, 544 buses had been tested in the field, with an additional 134 repeat snap tests and 16 stall tests, a variant of the snap test, making 694 in-field tests in total. Table 3-1 shows the number of buses sampled. The 544 buses tested represented 53 per cent of the Auckland fleet based on 2005 bus numbers, a sufficient sample size for predicting the likely snap test results distribution of the entire fleet.

Table 3-1 In field short testing completed by end 2005 by bus company (EFRU, 2007)

	Stagecoach	**Birkenhead**	**Howick and Eastern**	**Ritchies**	**Bayes**	**Total**
Buses snap tested	414	26	73	20	11	**544**
Buses repeat tested	134	0	0	0	0	**134**
Buses stall tested	16	0	0	0	0	**16**
Total Tests	**564**	**26**	**73**	**20**	**11**	**694**

The snap testing was undertaken in accordance with the snap testing to date as outlined in section 3.3.1.

The stall test was performed in the same way except that instead of operating the vehicle in neutral the transmission was placed in drive and the brake used to prevent the vehicle from moving. Data were collected in the same way as in the snap test.

Note: The stall test can only be applied to automatic transmission vehicles.

Buses were categorized by the relevant emissions standard applicable to the time and country of manufacture in the analysis of the fleet data. The categories used were those available in the bus emissions prediction model (BEPM) and included pre-Euro, Euro 0, Euro I, Euro II, Euro III, pre-J94 and J94. Table 3-2 summarises the number of buses tested in each category.

Table 3-2 In field short testing completed by end 2005 by emissions technology (EFRU, 2007)

Emissions Technology	Buses Snap Tested	No of Repeat Snap Tests	Total Snap Tests	Buses Stall Tested	Total Tests
Pre-Euro	130	40	170	5	**175**
Euro 0	26	0	26	1	**27**
Euro I	82	20	102	7	**109**
Euro II	37	7	44	2	**46**
Euro III	124	43	167	0	**167**
Pre-J94	41	0	41	0	**41**
J94	104	24	128	1	**129**
Total	**544**	**134**	**678**	**16**	**694**

Additional testing was performed in 2007 on a further 98 buses from the Auckland fleet, again subjecting the buses to both snap and stall tests (as shown in Table 3-3).

Table 3-3 Break down of buses tested in 2007. The biodiesel and catalyst buses are included in the number of buses tested (EFRU, 2010b).

Emissions Technology	Buses Tested	No of Repeat Tests	Biodiesel Buses	Catalyst Buses	Total Tests
Pre-Euro	28	0	0	2	28
Euro 0	0	0	0	0	0
Euro I	11	0	0	0	11
Euro II	5	0	0	0	5
Euro III	27	2	0	0	29
Pre-J94	0	0	0	0	0
J94	27	10	3	1	37
Total	**98**	**12**	**3**	**3**	**110**

The testing included three buses fuelled by biodiesel and three equipped with diesel oxidation catalysts; the results from these buses are discussed further in Chapters 4 and 5. The 2007 testing also provided a useful comparison to the earlier testing, giving an indication of how the fleet emissions had evolved over the 2-4 years between tests.

Note: At the start of the field emissions testing, the intention was to test **all** vehicles in the Auckland bus fleet. However, several difficulties arose during the programme that prevented a full census of all vehicles being undertaken. Firstly, the buses were in service and therefore only returned to the depot at the end of their schedules which made them difficult to capture. Also as time went on, the probability of testing an “un-tested” bus reduced as they were a smaller proportion of all buses returning. Finally, some of “un-tested” buses were replaced before the testing could be carried out.

The 2003 to 2005 in field bus emission testing was reported in January 2007 (EFRU, 2007), with the 2007 testing released as an update report in March 2010 (EFRU, 2010b).

3.3.3 Detailed testing in 2006

During the period from October 2005 to June 2006, an extensive research project into the emissions behaviour of two buses was carried out utilising a heavy duty vehicle emissions testing facility established by the EFRU at the premises of Gough, Gough and Hamer in Wiri, Auckland. The project investigated the performance of two buses operating on a selection of controlled fuels with and without diesel oxidation catalysts (DOCs). Bus A was a J94 emissions technology Nissan Scorpion SLF180 and Bus B was a Pre-Euro standard MAN SL202. There were some subtle differences in engine design between these two buses but they were both non-turbocharged with mechanically controlled direct fuel injection and so similar in the fundamental elements of their design.

The research facility was set up principally for testing biodiesel blends and the impact of retrofitting diesel oxidation catalysts. It consisted of a twin roller chassis dynamometer and a full dilution flow constant volume sampler (CVS) system with modal recording of gaseous and particulate phase exhaust emissions along with a total particulate matter measuring system on gravimetric filters. The test results may not be comparable to those of other procedures, eg, USEPA IM240.

The project evaluated emissions from the two buses with ultra-low sulphur diesel, known as the “50ppm” fuel, and biodiesel blends of 20 per cent (B20) and 40 per cent (B40) tallow methyl ester (TME) in 50ppm fuel with and without the addition of a diesel oxidation catalyst (DOC) fitted to the vehicles exhaust. Emissions of carbon monoxide (CO), un-burnt hydrocarbons (HC), oxides of nitrogen (NO_X) and particulate matter (PM) were measured at several steady state engine speeds and power outputs along with short transient tests. Included in this study were the two short tests used in field testing. The snap and stall tests were conducted both with all the emissions equipment operational and with only the smoke meter as would be the case in field testing. The configurations evaluated during the detailed testing are shown in Table 3-4.

Table 3-4 Configurations evaluated during detailed emissions testing (EFRU, 2007)

Bus\Fuel	50ppm	B20	B40	50ppm+DOC	B40+DOC
Bus A	Yes	Yes	Yes	Yes	Yes
Bus B	Yes	Yes	Yes	Yes	No

The addition of the short tests to this larger body of work allowed a direct comparison of the actual emissions character of the buses with a result from a short test. The results of the biodiesel trials and the diesel oxidation catalyst retrofitting are discussed in detail in Chapters 4 and 5 of this summary report.

The detailed testing was also reported in the update report in March 2010 (EFRU, 2010b).

3.4 Key outcomes and findings

3.4.1 Snap testing

Setting trigger points for targeted maintenance

When the snap test results were ranked lowest to highest, the worst 10 per cent of buses in each emissions technology showed rapid rises in smoke density suggesting abnormally high states of emissions (as seen in Figure 3-1).

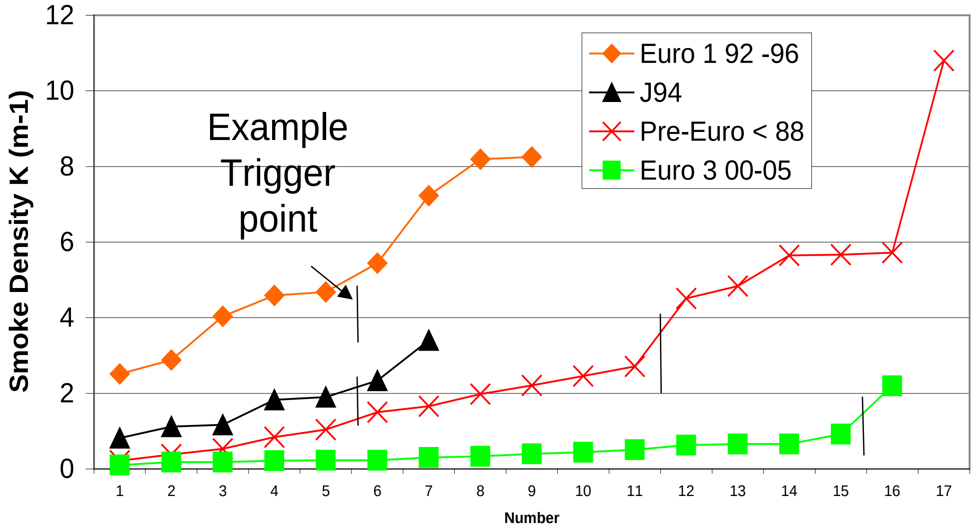

Figure 3-1 Example trigger points from the pilot smoke testing in 2003 (EFRU, 2004a)

From these results, “trigger points” could be set to identify individual buses that were operating outside the normal behaviour. These buses could then be targeted for extra maintenance to reduce emissions.

Figure 3-2 presents the snap test smoke density results for buses of each emissions technology ranked from the lowest to highest values. The results have been normalised to 100 per cent to show the relative distributions for each category. In all cases the results show a sharp increase around the 90th percentile.

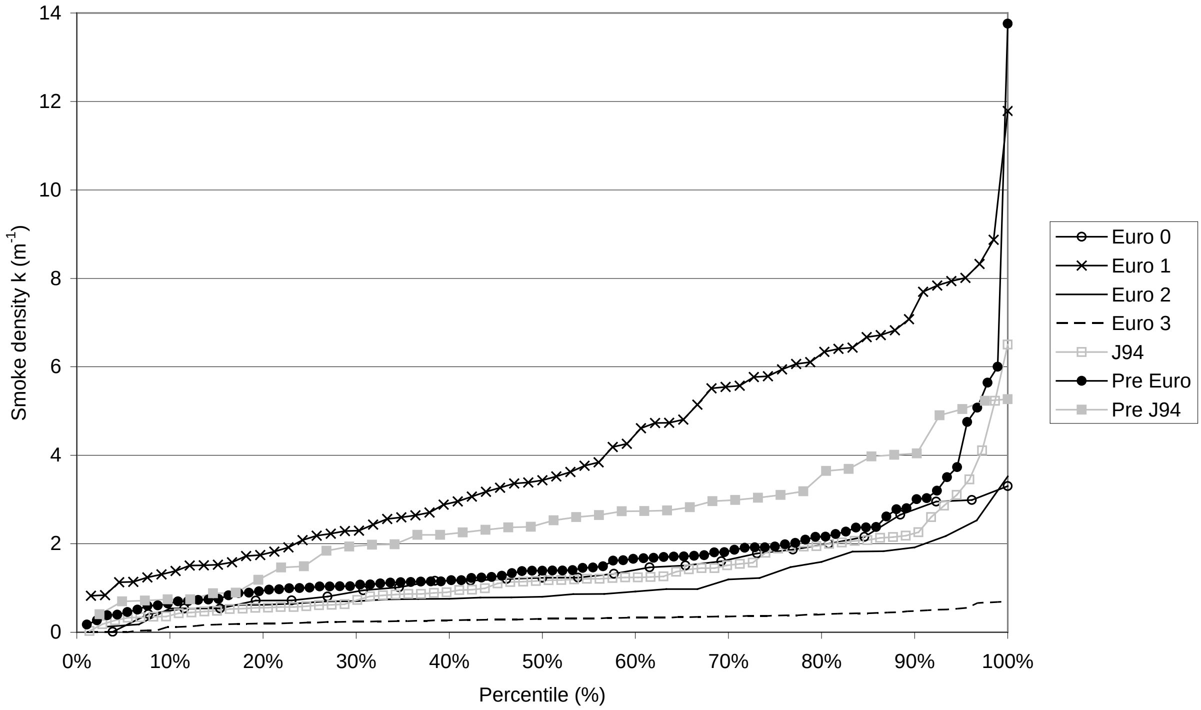

Figure 3-2 Ranked smoke density values from the snap test for the 2005 dataset (EFRU, 2007)

Ideally every bus within an emissions technology should be able to, with proper maintenance, perform (in terms of opacity) at a level approaching that of the lowest emitting vehicles in its class. For example, all the Euro 0 buses tested were of same model (MAN 22.240) and therefore, presumably, were all capable of approximately the same emissions result. However, the Euro 0 results ranged from 0.01m^{-1} to 3.30m^{-1} - (ie, the highest emissions were 330 times greater than the lowest). Therefore repairing high emitters should result in considerable emission reductions, given that all the buses in each class travel approximately the same distance each year in service.

Setting a universal emissions threshold for all buses

While useful *within* an emission technology to identify gross emitters, the snap test results were less conclusive *across* technologies. As seen in Figure 3-2, the highest emitting buses were not the oldest as might have been expected. The Euro I buses registered significantly higher emissions *under this test protocol* than the older pre-Euro buses. This may have been because the Euro I buses were turbocharged while the pre-Euro were not, and the injection pump turbo boost compensation system may not have been able to respond quickly enough under this very transient test. However, this did not necessarily mean that the Euro I buses would emit more smoke under normal operation.

This disparity between the Euro I and other data meant it was not possible to set an absolute smoke density threshold based on the snap test that could be applied universally to guarantee an acceptable emission performance.

Repeatability of the snap test results

During field testing, 134 snap tests were conducted on buses that had been previously snap tested. 117 of these tests were conducted at least one day after the original test with the largest time span between tests of 477 days. Figure 3-3 shows the original and repeat snap test results grouped by the number of days between the tests.

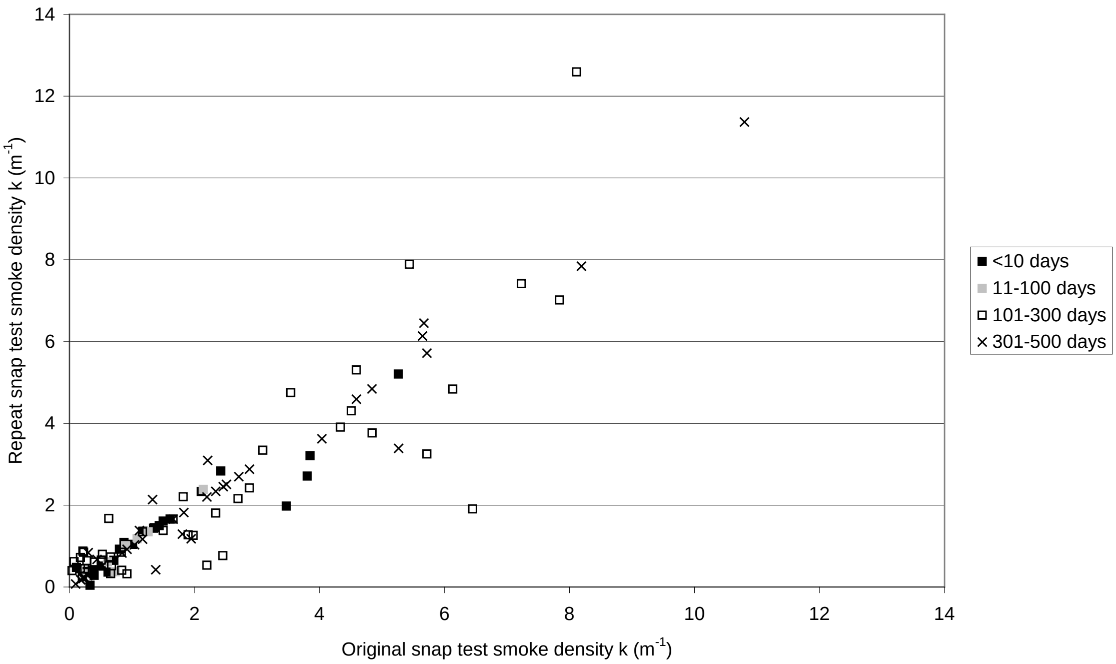

Figure 3-3 Repeat snap test smoke density compared to original snap test smoke density grouped by days between the tests for 2003 to 2005 (EFRU, 2007)

The median value for change in smoke density between the original and repeat snap test was 0 per cent suggesting buses were equally likely to improve their score as display an increased smoke density. No records were available to determine which buses had been serviced during the interval between tests. Servicing could have impacted these results but based on the available data there was no apparent time dependence associated with the difference between the original and the repeat snap test result.

Another repeatability exercise was undertaken by investigating the evolution in fleet emissions. Figure 3-4 shows the smoke density data for each emissions technology giving maximum, upper quartile, median, lower quartile and minimum values using the 2007 results. Figure 3-5 shows the same data for the 2003 to 2005 results.

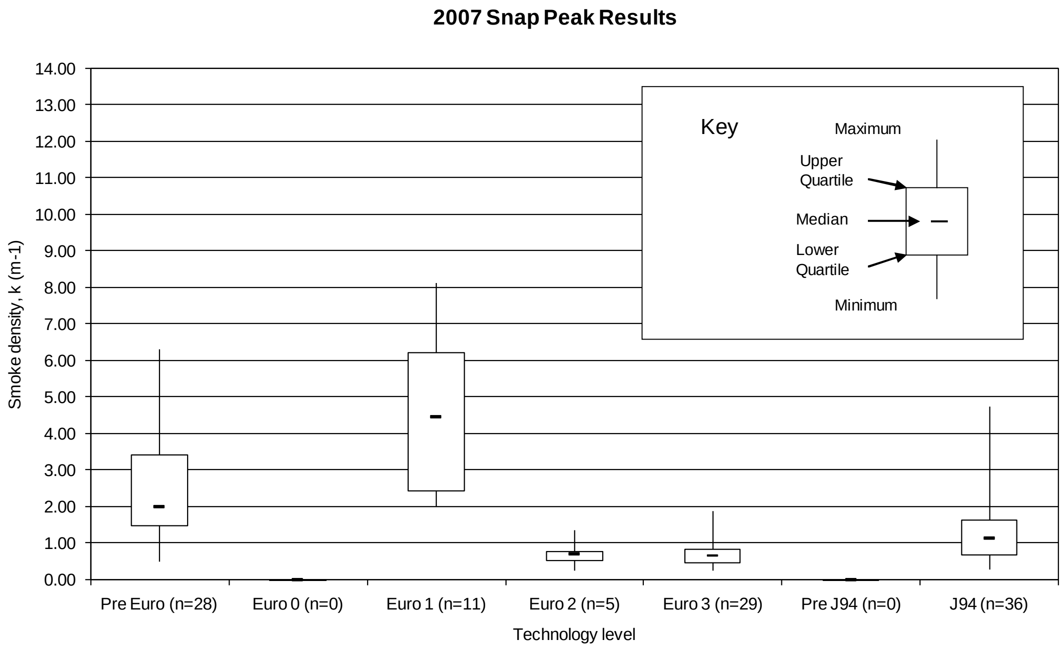

Figure 3-4 Box and whisker plots of the snap test results by emissions technology for 2007 (EFRU, 2010b)

Comparing Figure 3-4 with Figure 3-5, all the emissions technologies tested show similar trends between the two periods of testing, giving confidence to the repeatability between them. This is allowing for the smaller sample size in 2007 versus 2003-2005 and the reduction in diesel fuel sulphur content which occurred in 2006.

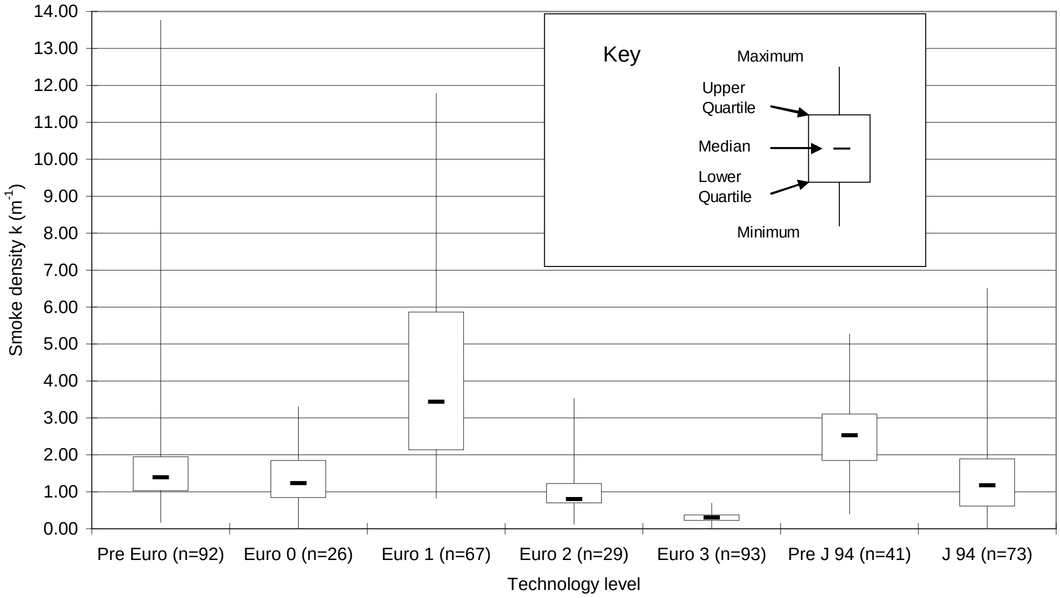

Figure 3-5 Box and whisker plots of the snap test results by emissions technology for 2003 to 2005 (EFRU, 2007)

3.4.2 Stall testing

Sixteen vehicles from the 2003 to 2005 in-field testing were subjected to stall tests in addition to snap tests, with an additional two vehicles undergoing stall tests as part of the detailed testing programme. Figure 3-6 shows a comparison between snap test and stall test results for the sixteen vehicles tested in 2003 to 2005 field work.

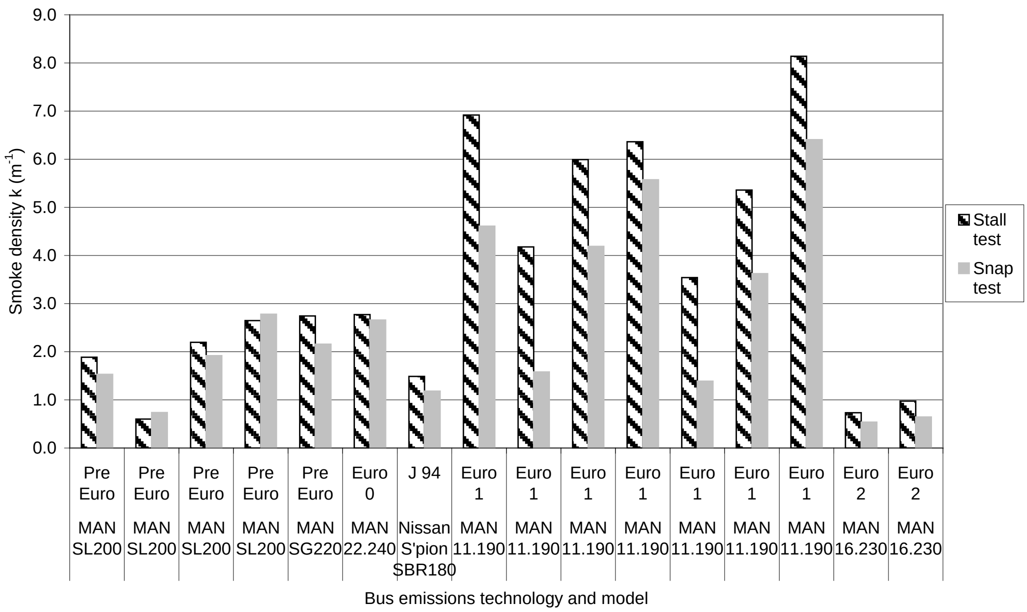

Figure 3-6 Comparison of snap and stall test peak smoke density results on 16 different buses from field testing in 2003 to 2005 (EFRU, 2007)

Stall tests registered a higher peak smoke density than the snap test for 88 per cent of the buses and the average peak recorded with the stall test was 36 per cent higher than the snap test result. It was noted earlier that Euro I buses displayed a high snap test result; the same was true for the *peak* smoke densities recorded using the stall test. However, because of the extended time in the stall test, smoke densities can be measured during the *steady speed* or "stalled" state which should be more representative of dynamometer testing. The alternative stall average test was investigated in the detailed testing discussed next.

Smoke density from a stall test is a good indicator of a loaded vehicle's PM emission rate. Figure 3-7 shows each bus's snap result versus its stall result, with the buses grouped by emissions technology. Lines have been drawn to separate the upper 10 per cent of results from each test, giving an example of the effects of choosing this as a failure criterion.

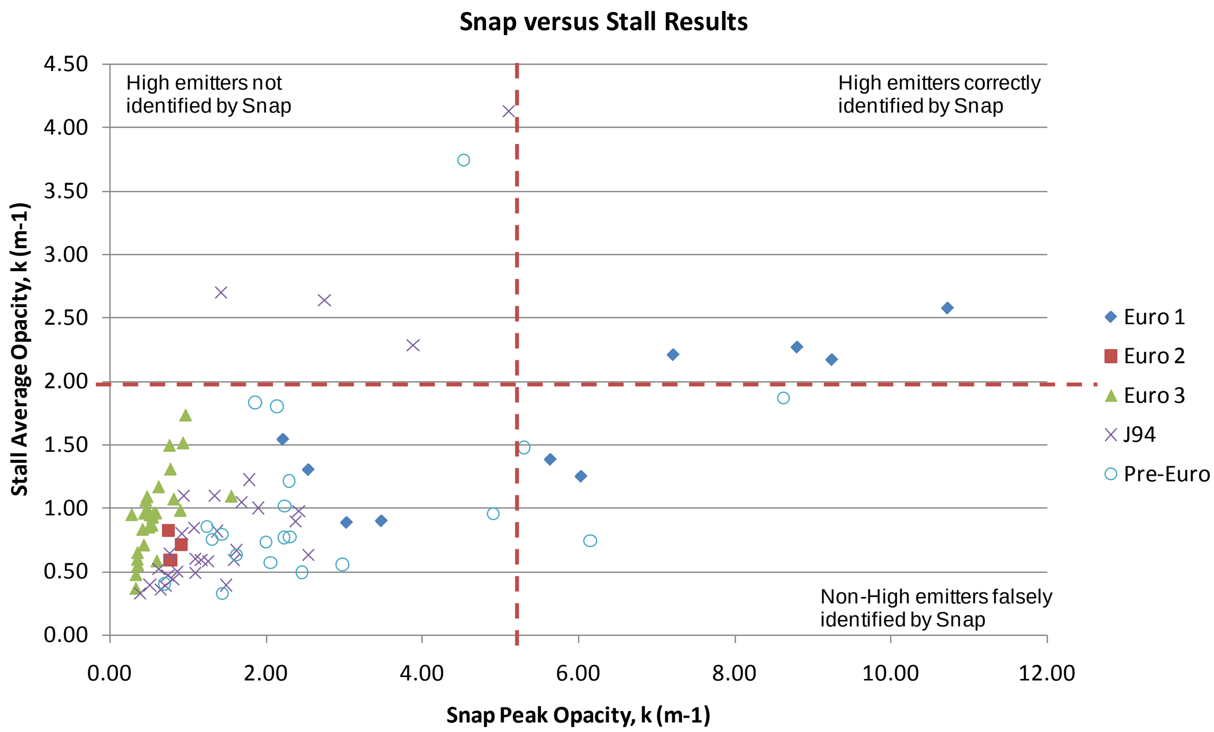

Figure 3-7 Snap results versus stall results for all buses (EFRU, 2010b)

There are several interesting points to take from this plot:

- Of the nine buses that would fail based on the results from each test, only four were identified by both tests as being high emitters

- If the stall test is a better indicator of true PM emission rate during on-road use, then the snap test fails less than half of the true high-emitters, and more than half of those failed by the snap test should not be considered high-emitters.

3.4.3 Detailed testing

Two buses were tested extensively using a chassis dynamometer and laboratory grade emissions measurement equipment, using 50ppm sulphur diesel.

Strong positive correlations were found for PM, CO and HC emissions with the short test smoke density results – both for the snap and the stall tests. However, the stall test produced better correlations with actual emissions than the snap test as shown in Figure 3-7, with its results more consistent and repeatable.

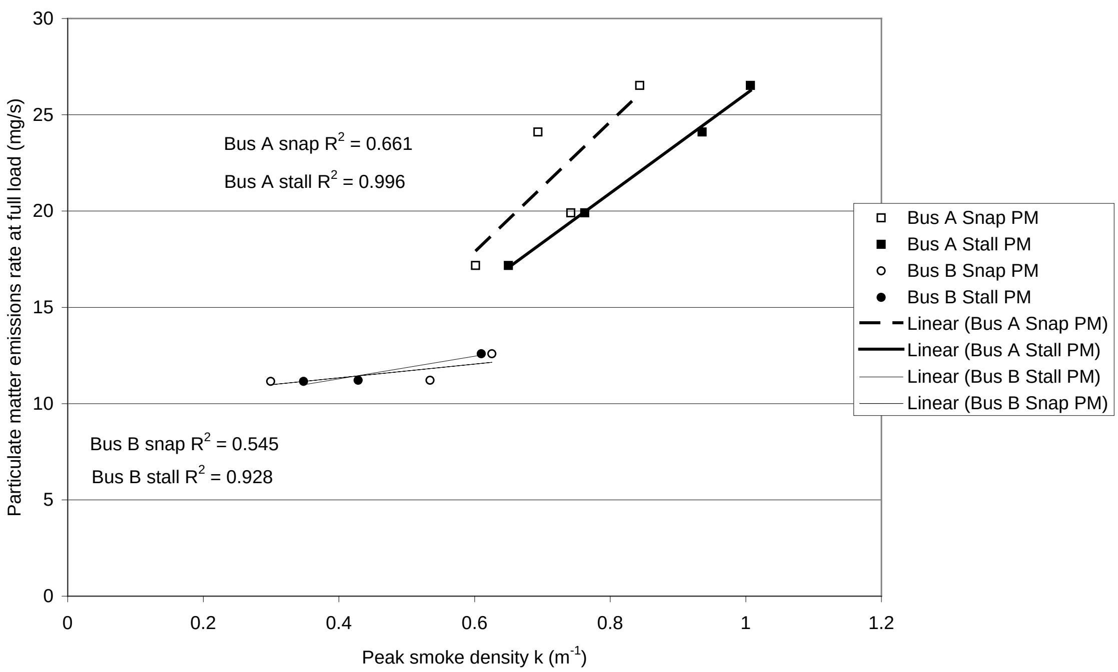

Figure 3-8 Particulate matter emissions rates versus smoke density results from short tests for each of the test conditions for each of the buses tested in the detailed testing programme (EFRU, 2007)

Four gaseous emissions species were also analysed and compared with the smoke density results from the short tests. These were CO, CO_2, HC and NO_X. No correlation was apparent for CO_2 or NO_X with either of the short tests at any test condition. However, CO and HC emissions showed positive correlations similar to those seen for particulate matter emissions with smoke density results as shown in Figure 3-8.

Overall, the detailed testing found that the short test results, both snap tests but particularly stall tests, correlated well with PM, CO and HC emissions. This means that fleet testing using the short test methods can provide some detail regarding the state of the fleet's PM, CO and HC emissions characteristics. The short test methods investigated were not able to provide information on NOx emissions rates.

If the stall average test were to be considered for some form of in service compliance emissions test, it would:

1. need to be calibrated for different emission technologies and weight classes if it were to be used as an absolute limit
2. only be able to be applied to heavy vehicles with automatic transmissions in its current form (so would largely be suitable for buses only and not trucks)

However, either the stall average or the snap peak tests could be used by fleet operators to set trigger points for targeted maintenance to address gross emitters.

3.5 Key outputs

The key outputs from the bus emissions testing include:

- Report on the Bus Field Trials
  (EFRU, 2007)
- Update on the Bus Field Trials
  (EFRU, 2010b)
- Presentation on Detection of High Emitting Diesel Vehicles
  (Elder, 2007)
- Report on the Pilot Emissions Testing at Stagecoach
  (EFRU, 2004a)
- Report on the Extended Emissions Testing at Stagecoach
  (EFRU, 2004b)

4 Biodiesel Blends in Buses

This chapter presents the key findings of trials which investigated likely emissions improvements for different biodiesel blends versus automotive diesel fuel.

The work in this chapter applies to vehicle emissions management area of clean fuels, in particular.

4.1 Objectives

- Investigate the impact of biodiesel (tallow methyl ester) blends on exhaust emissions, power and fuel consumption of buses
- Gain a better understanding of the benefits of New Zealand grade biodiesel on heavy diesel vehicles

4.2 Organisations involved

The biodiesel trials were:

- undertaken by Auckland UniServices Energy and Fuels Research Unit (EFRU)
- funded by Auckland Regional Council (ARC) and BP Oil New Zealand Ltd (BP)
- with support from Biodiesel Oil NZ, Energy Efficiency and Conservation Authority (EECA), Gough, Gough and Hamer (GGH) and Stagecoach New Zealand.

4.3 Brief description of the work undertaken

The term **biodiesel** refers to a group of renewable fuels designed for operation in diesel engines, derived from biological feed stocks (such as animal and plant materials) as opposed to fossil fuels (such as coal and petroleum). This work involved trialling tallow methyl ester (TME) biodiesel, which is made from a rendered form of beef or mutton fat. TME is a liquid fuel that can be blended with or wholly substituted for conventional petroleum-based automotive diesel. At the time, the use of animal tallow made TME differed to most biodiesel investigated overseas which were primarily derived from plant oils. Consequently the scarcity of data on the exhaust emissions of TME blends prompted a call for New Zealand based research into this fuel.

Various TME blends were trialled in two programmes as follows:

- Detailed testing of two buses in 2006 at a heavy duty chassis dynamometer facility, measuring various air contaminants
- Field testing of three buses in 2007 at Stagecoach depots across Auckland, measuring smoke density (opacity)

Note: Some of the testing undertaken for the purpose of investigating the performance of various biodiesel blends (described in this chapter) was conducted conjointly with other testing commissioned to identify high emitters (discussed in Chapter 3) and to evaluate potential emissions reductions from retrofitting diesel oxidation catalysts (covered in Chapter 5). Consequently, some of the key outputs and references overlap.

4.3.1 Detailed testing at a heavy duty dynamometer facility

A heavy duty vehicle emissions testing facility was established by the EFRU in early 2005 at the premises of Gough, Gough and Hamer (a company specialising in the sale, maintenance and repair of heavy duty vehicles and machinery) in Wiri, Auckland.

The equipment consisted of a twin roller chassis dynamometer and a full dilution flow constant volume sampler (CVS) system with modal recording of gaseous and particulate phase exhaust emissions along with a total particulate matter measuring system on gravimetric filters (as shown in Figure 4-1).

Two buses were selected for testing. As the biodiesel testing was also synchronised with an investigation into the impacts of retrofitting diesel oxidation catalysts (DOC), the selection criteria included the likely return of fitting the buses with a DOC taking into account the likely reductions in exhaust emissions, annual vehicle mileage and the expected service life remaining. Bus A was a Nissan Scorpion SLF180, manufactured in Japan in 1997 and expected to meet the J94 emissions regulations in place at the time of production. Bus B was a MAN SL202, manufactured in Europe in 1988 and expected to meet the Pre-Euro emissions regulations in place at the time of production. Neither Bus A or Bus B had any exhaust gas after-treatment devices fitted.

Three fuels were used during the testing:

- A 50ppm sulphur reference automotive diesel fuel (ADF) – referred to as “50ppm”
- A 20 per cent TME and 50ppm sulphur ADF blend – referred to as “B20”
- A 40 per cent TME and 50ppm sulphur ADF blend – referred to as “B40”

If a DOC was used then the fuel name was followed by DOC, eg, “50ppm DOC”.

Figure 4-1 Detailed heavy duty vehicle emissions testing setup (Blackett *et al.*, 2006)

Table 4-1 shows the sequence of fuel and DOC tests during the experiments.

Table 4-1 Fuel and diesel oxidation catalyst test sequence (Boielle, 2006)

Fuel Tests	
Bus A	50ppm
Bus A	B40
Bus A	B20
Bus A	50ppm post
Bus B	50ppm
Bus B	B40
Bus B	B20
Bus B	50ppm post

DOC Tests	
Bus A	50ppm DOC
Bus A	B40 DOC
Bus B	50ppm DOC
Bus A	50ppm DOC

The vehicles were tested at a range of steady state speed and load conditions along with a power test and simple transient test similar to the DT80 drive cycle used for heavy vehicles emissions testing in Australia (Anyon *et al.*, 2000). Measurements were taken of carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_X) and particulate matter (PM) in addition to fuel consumption and power output.

Based on the linearity in the actual measurements, the results were extrapolated back to provide estimates for a 5 per cent (B5) blend. This was because at the time of testing central government was considering the widespread introduction of a B5 blend in order to achieve proposed biofuel sales obligation targets.

The detailed biodiesel testing was reported in December 2006 (Boielle, 2006).

4.3.2 Field testing at bus depots

Testing was undertaken in early 2007 at Stagecoach's Swanson depot. Three buses were fuelled with B20 and tested relative to a "datum" bus fuelled by ADF with 50ppm sulphur. A portable opacity meter was used to measure smoke density (K in m^{-1}) as a proxy for particulate matter.

The buses underwent both a snap acceleration test as well as a stall test.

The field biodiesel testing was reported initially to BP in July 2008 (EFRU, 2008) and then fully in March 2010 (EFRU, 2010a).

4.4 Key outcomes and findings

4.4.1 Detailed testing at a heavy duty dynamometer facility

Emissions reductions for CO, HC, NO_X and PM were found for the TME biodiesel blends when compared with 50ppm sulphur ADF, as presented in Table 4-2. However, fuel consumption on average slightly increased for the biodiesel blends.

Table 4-2 Average percentage change in emissions and performance of buses operating on TME biodiesel blends relative to 50ppm automotive diesel fuel (Boielle, 2006)

Change Relative to ADF	B5 (extrapolated)	B20	B40
CO	-2.7%	-10.7%	-21.4%
HC	-2.2%	-8.9%	-17.8%
NO_x	-0.5%	-2.0%	-4.0%
PM	-2.1%	-8.6%	-17.2%
Fuel Consumption	+0.2%	+1.0%	+1.9%

The results shown in Table 4-2 relate to *average* emissions reductions across the range of conditions and buses tested. Looking at the results in more detail, the testing found that:

- The two buses tested responded differently to TME biodiesel blends in terms of emissions and performance behaviour in the majority of tests.
- The observed changes in emissions and performance behaviour of the buses did not always correlate linearly with an increase in TME biodiesel blend strength.
- The power and fuel consumption penalties recorded for the TME biodiesel blends were within the level of measurement uncertainty and therefore would warrant further investigation before definitive predictions could be made.
- The reduction in CO, HC, and PM emissions recorded for the TME biodiesel blends depended on the vehicle load and speed conditions but generally agreed with international findings for biodiesel. However, the reduction in NO_X emissions recorded for the TME biodiesel blends was counter to the USEPA who found NO_X emissions increased with generic biodiesel (USEPA, 2002).

4.4.2 Field testing at bus depots

Table 4-3 compares the stall and snap test smoke density results for the buses operating on B20 versus ADF. In order to test whether any differences between the results were statistically significant, 95 per cent confidence intervals for the means were calculated using Student's t-distribution.

Table 4-3 Stall and snap test smoke density results for buses fuelled by B20 versus ADF (EFRU, 2010a)

Smoke Density K (m^{-1})	ADF Stall Average	ADF Snap Peak	B20 Stall Average	B20 Snap Peak
Mean	0.73	1.43	0.50	1.01
Standard Deviation	0.28	0.66	0.09	0.38
Maximum	1.22	2.74	0.66	1.62
Median	0.64	1.36	0.49	0.86
Minimum	0.32	0.39	0.38	0.62

Figure 4-2 illustrates the confidence intervals for each test and fuel type. The bar in the middle of each line represents the sample mean, and the vertical line represents the interval within which there is a 95 per cent probability that the true population mean lies.

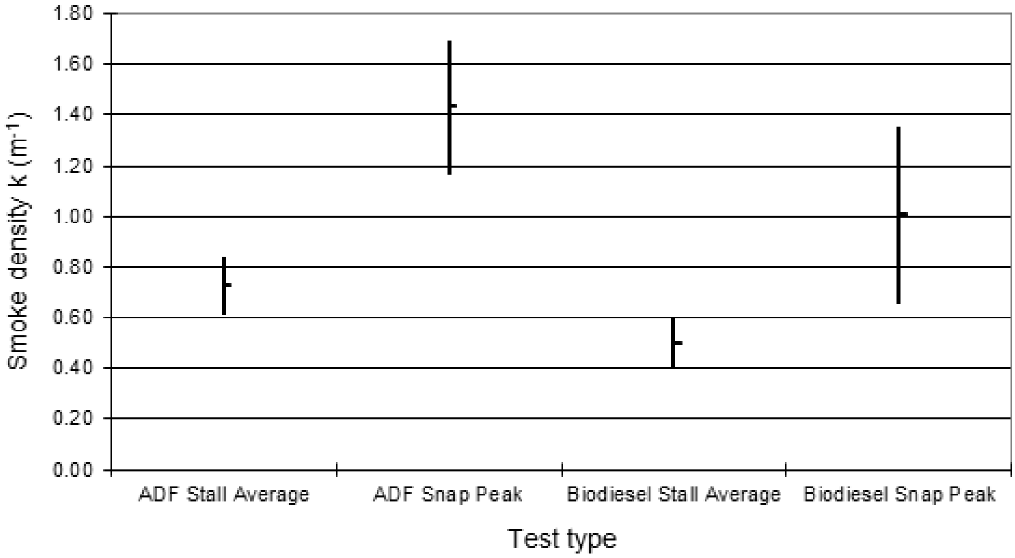

Figure 4-2 Comparison of the 95 per cent confidence intervals for the snap peak and stall average smoke densities for buses tested with B20 and ADF (EFRU, 2010a)

The stall average tests showed a statistically significant reduction in smoke density from the B20 buses compared to those operating on ADF. The value of this reduction was between 3 per cent and 50 per cent at the 95 per cent confidence level. This agreed with the detailed testing performed by the EFRU which has showed both that stall test results closely match PM emission rates at full load, and that running a diesel engine on biodiesel resulted in reductions in PM emission rate at high torque values. The results of the stall average suggest there was a genuine reduction in PM emissions in the buses fuelled by B20 compared to those running on ADF.

The snap peak tests did not show a statistically significant difference in smoke density.

4.5 Key outputs

The key outputs from the biodiesel trials include:

- Report on the Detailed Emissions Testing of Buses using TME and DOCs (Boielle, 2006)
- Presentation on Biodiesel Developments in Auckland: Bus Emissions Testing (Blackett *et al.*, 2006)
- Report on Smoke Density Levels for Buses using TME (EFRU, 2008)
- Report on the Field Testing of Buses using TME and DOCs (EFRU, 2010a)

5 Bus Retrofitting Trials

This chapter describes the programme undertaken to retrofit diesel oxidation catalysts to older buses in the fleet to reduce their emissions.

The work in this chapter applies to vehicle emissions management area of clean technology, in particular.

5.1 Objective

- Trial retrofitting of diesel oxidation catalysts as a cost-effective means of reducing emissions from older buses

5.2 Organisations involved

The retrofitting of diesel oxidation catalysts was:

- undertaken by Auckland UniServices Energy and Fuels Research Unit (EFRU)
- funded by Auckland Regional Council (ARC)
- with support from Auckland Regional Transport Authority (ARTA) and the major Auckland bus fleet operators, who each offered up at least one older bus suitable for being retrofitted.

5.3 Brief description of the work undertaken

Recognising that urban buses often have a service life of 20 years or more, one of the most cost-effective ways to reduce diesel emissions is retrofitting exhaust after-treatment devices. Although purchasing newer, lower emitting vehicles is important, replacing an entire diesel fleet is an expensive proposition that needs to be phased in over time.

Retrofits can reduce emissions of particulate matter (PM) and other contaminants significantly, depending on the technology of the bus, the fuel quality (diesel sulphur levels are critical) and the type of retrofit device (see Table 5-1).

Table 5-1 Typical emissions reductions of diesel retrofit devices (USEPA, 2014)

Technology	Typical Emission Reductions (per cent)		
	PM	HC	CO
Diesel Oxidation Catalyst (DOC)	20-40	40-70	40-60
Diesel Particulate Filter (DPF)	85-95	85-95	50-90
Partial Diesel Particulate Filter (pDPF)	up to 60	40-75	10-60

Diesel oxidation catalysts (DOCs) are typically packaged with the engine muffler and are widely used as a retrofit technology because they require little or no maintenance. Engine manufacturers have used DOCs in a variety of applications for many years. DOCs consist of a flow-through honeycomb structure that is coated with a precious metal catalyst and surrounded by a stainless steel housing. As hot diesel exhaust flows through the honeycomb (or substrate), the precious metal coating causes a catalytic reaction that breaks down the pollutants. These devices can be formulated to operate with fuel sulphur levels of 500ppm or less, but they are most effective at lower fuel sulphur levels (15ppm or less). DOCs can be coupled with closed crankcase ventilation, selective catalytic reduction or lean NO_X catalyst technologies for additional emission reductions.

Diesel particulate filters (DPFs) typically use a porous ceramic or cordierite substrate or metallic filter to physically trap particulate matter (PM) and remove it from the exhaust stream. The technology is typically combined with oxidation catalyst technology to achieve significant reductions in HC and CO emissions. DPFs can be installed on existing vehicles but must be used in conjunction with diesel which has a sulphur content of near zero (15ppm or less). DPFs may require special mounting or brackets as they are typically heavier than a conventional muffler or DOC. In addition, an electronic back pressure monitoring and driver notification system must be used with a DPF.

DPFs use either passive or active regeneration systems to oxidize the PM accumulated in the DPF. Passive filters require operating temperatures high enough to initiate combustion of collected soot. Active regeneration uses other heat sources, such as fuel burning or electric heaters, to raise a DPF temperature sufficiently to combust accumulated PM. In addition, filters require periodic maintenance to clean out non-combustible materials, such as ash. One common form of passive DPF is the continuous regenerating technology (CRT) particulate trap.

Knowing the age and type of each engine in the fleet as well as the drive cycles of the vehicles is an important part of any retrofit project. Exhaust gas temperature data logging must be performed to determine if the exhaust temperature profile meets DPF-specific requirements. DPFs can be coupled with closed crankcase ventilation, selective catalytic reduction or lean NO_X catalyst technologies for additional emission reductions.

Partial diesel particulate filters (pDPFs), or flow-through filters, provide moderate (30 to 50 percent) reduction of PM from diesel exhaust. Partial filters use catalysed metal wire mesh structures or metal foil-based substrates with sintered metal sheets to reduce diesel PM. As with DPFs, pDPFs are typically combined with oxidation catalyst technology to achieve reductions in HC and CO emissions.

Partial filters trap PM with lower efficiencies than DPFs. However, because they trap particles, partial filters are always subject to minimum temperature requirements necessary for periodic regeneration (ie, combustion of collected PM). Partial filters should incorporate electronic back pressure monitoring equipment to signal vehicle and equipment operators when the devices need to be cleaned.

The cost benefit analysis undertaken for BEPM (discussed in Chapter 2) found DOCs to be one of the most cost-effective means to reduce PM emissions for older fleets, with the costs averaging $63,000 per tonne of PM reduction versus costs of new buses at $328,000 per tonne.

In this project, each of the major Auckland bus fleet operators was approached to offer up at least one of the older buses in their fleets suitable for being retrofitted. In total 13 DOCs were retrofitted mid to late 2006 to determine the potential benefits for buses typical of NZ fleets as shown in Table 5-2.

Coincident with the biodiesel testing discussed in Chapter 4, the impact of the DOC retrofit on emissions was trialled in two programmes as follows:

- Detailed testing of two buses in 2006 at a heavy duty chassis dynamometer facility, measuring various air contaminants
- Field testing of three buses in 2007 at Stagecoach depots across Auckland, measuring smoke density (opacity)

Note: Some of the testing undertaken for the purpose of evaluating potential emissions reductions from retrofitting diesel oxidation catalysts (described in this chapter) was conducted conjointly with other testing commissioned to identify high emitters (discussed in Chapter 3) and to investigate the performance of various biodiesel blends (covered in Chapter 5). Consequently, some of the key outputs and references overlap.

Table 5-2 Buses fitted with diesel oxidation catalysts (DOCs) for testing (EFRU, 2010a)

Company	Make/Model	Fleet No	Reg No	Year of Reg	Emissions Technology
Bayes Coachlines	Volvo B10M (Bendy)	98	TBA	2006	Euro I
Birkenhead Transport	Isuzu LT	6	PR 6379	1991	Pre-J94
	Isuzu LT	25	PR 6367	1991	Pre-J94
Howick and Eastern	HINO RG	32	SN6276	1994	Pre-J94
	HINO RG	35	SN6277	1994	Pre-J94
Ritchies Coachlines	Volvo B7LE	640	AQB611	2002	Euro II
	Volvo B7LE	645	n/a	2002	Euro II
Stagecoach Swanson	MAN SL202	1733	NS3202	1988	Pre-Euro
	MAN SL202	1741	NY9890	1988	Pre-Euro
	MAN SL202	1747	OD3724	1989	Pre-Euro
	Nissan Scorpion SLF180	1841	WB2445	1997	J94
	Nissan Scorpion SLF180	1864	CHQ73	1997	J94
	Nissan Scorpion SLF180	1877	WO2146	1997	J94

5.3.1 Detailed testing at a heavy duty dynamometer facility

The detailed testing for the impact of the DOC retrofitting was conducted simultaneously with the detailed biodiesel testing discussed in Chapter 4 at the heavy duty vehicle emissions testing facility established by the EFRU in early 2005 at the premises of Gough, Gough and Hamer in Wiri, Auckland.

The equipment consisted of a twin roller chassis dynamometer and a full dilution flow constant volume sampler (CVS) system with modal recording of gaseous and particulate phase exhaust emissions along with a total particulate matter measuring system on gravimetric filters.

Two buses were selected for testing. The selection criteria included the likely return of fitting the buses with a DOC taking into account the likely reductions in exhaust emissions, annual vehicle mileage and the expected service life remaining. Bus A was a Nissan Scorpion SLF180, manufactured in Japan in 1997 and expected to meet the J94 emissions regulations in place at the time of production. Bus B was a MAN SL202, manufactured in Europe in 1988 and expected to meet the Pre-Euro emissions regulations in place at the time of production. Neither Bus A or Bus B had any exhaust gas after-treatment devices fitted.

Two fuels were used during the DOC testing:

- A 50ppm sulphur reference automotive diesel fuel (ADF) – referred to as “50ppm”
- A 40 per cent TME and 50ppm sulphur ADF blend – referred to as “B40”

If a DOC was used then the fuel name was followed by DOC, eg, “50ppm DOC”.

The vehicles were tested at a range of steady state speed and load conditions along with a power test and simple transient test similar to the DT80 drive cycle used for heavy vehicles emissions testing in Australia (Anyon *et al.*, 2000). Measurements were taken of carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_X) and particulate matter (PM) in addition to fuel consumption and power output.

Table 5-3 shows the sequence of DOC and fuel tests during the experiments.

Table 5-3 Fuel and diesel oxidation catalyst test sequence (Boielle, 2006)

Fuel Tests	
Bus A	50ppm
Bus A	B40
Bus A	50ppm post B40
Bus B	50ppm
Bus B	B40
Bus B	50ppm post B40

DOC Tests	
Bus A	50ppm
Bus A	B40
Bus B	50ppm
Bus A	50ppm

The detailed DOC testing was reported in December 2006 (Boielle, 2006).

5.3.2 Field testing at bus depots

Testing was undertaken in early 2007 at Stagecoach’s Swanson depot. One J94 and two pre-Euro buses were tested relative to similar emissions technology buses not fitted with DOCs. A portable opacity meter was used to measure smoke density (K in m^{-1}) as a proxy for particulate matter. Most of the testing was conducted using 50ppm sulphur diesel but some testing was also undertaken using a 20 per cent biodiesel (B20) blend. B20 rather than B40 was used as the supply of biodiesel was limited and B20 is also a more stable blend to use in the field testing.

The buses underwent both a snap acceleration test as well as a stall test.

The field DOC testing was reported in March 2010 (EFRU, 2010a).

5.4 Key outcomes and findings

5.4.1 Detailed testing at a heavy duty dynamometer facility

Significant emissions reductions for CO, HC, and PM were found for the buses fitted with DOCs when compared with those without, as presented in Table 5-4.

Table 5-4 Average percentage change in emissions and performance of buses operating with DOCs relative to buses operating on 50ppm fuel without a DOC fitted (Boielle, 2006)

Change Relative to 50ppm	50ppm DOC	B40 DOC†
CO	-58.8%	-67.5%
HC	-70.4%	-70.9%
NO_x	+1.8%	-7.7%
PM	-33.0%	-41.4%
Fuel Consumption	+0.2%	-1.5%

† Results for B40 DOC are from Bus A only

The impact on NOx emissions was inconclusive. However, this finding was not surprising given that DOCs work by the principle of *oxidation* and NO_X removal usually relies on a *reduction* processes.

5.4.2 Field testing at bus depots

The snap peak and stall average results for buses with and without a DOC are presented in Figure 5-1. In order to test whether any differences between the results were statistically significant, 95 per cent confidence intervals for the means were calculated using Student's t-distribution. The bar in the middle of each line represents the sample mean, and the vertical line represents the interval within which there is a 95 per cent probability that the true population mean lies.

While the sample size of catalyst-equipped vehicles was small within the Pre-Euro buses, they did appear to represent average to low-emitting vehicles. However, the small sample size resulted in very wide confidence intervals for the true means of the smoke densities recorded for the DOC equipped buses. This prevented any statistically significant difference being established for either the snap peak or stall average tests.

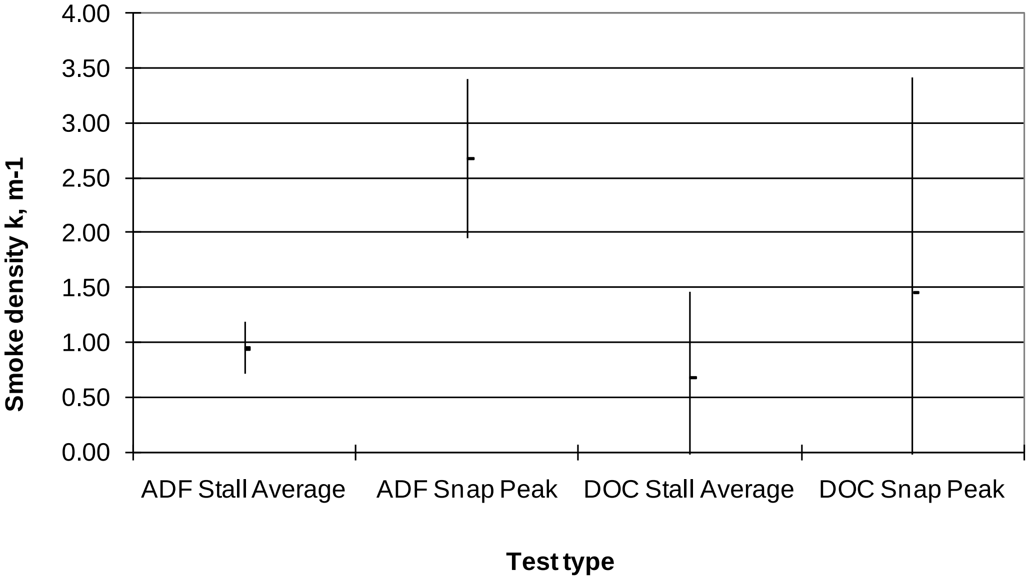

Figure 5-1 Comparison of the 95 per cent confidence intervals for the snap peak and stall average smoke densities for buses tested with and without DOCs fitted (EFRU, 2010a)

5.5 Key outputs

The key outputs from the bus catalyst retrofitting include:

- Report on the Detailed Emissions Testing of Buses using TME and DOCs (Boielle *et al.*, 2006)
- Report on the Field Testing of Buses using TME and DOCs (EFRU, 2010)

6 On-Road Emissions Monitoring

This chapter discusses the results of a specific on-road monitoring campaign conducted for buses and trucks at bus depots and the port using remote sensing. It also lists other heavy duty emissions datasets that were collected during on-road remote sensing campaigns targeting light duty vehicles.

The work in this chapter applies to vehicle emissions management areas of clean technology and appropriate maintenance, in particular.

6.1 Objectives

- Characterise the features of Auckland's diesel vehicle fleet
- Investigate the factors that most strongly influence diesel vehicle emissions
- Compare emissions from New Zealand new and Japanese used imported light and heavy duty diesel vehicles
- Determine the effect of emission standard on "real world" bus emissions
- Assess the effect of "gross emitting" diesel vehicles
- Create a database of "real world" emissions from heavy and light duty diesel vehicles to enable measurements to be compared with results from other remote sensing and emissions testing programmes.

6.2 Organisations involved

The specific heavy duty emissions measurement work was:

- undertaken by National Institute of Water and Atmospheric Research (NIWA) and Emission Impossible Ltd
- funded by Auckland Regional Council (ARC)
- with support provided by various Auckland local councils and bus fleet operators, Ports of Auckland, Ministry of Transport and Land Transport New Zealand.

The various light duty on-road remote sensing campaigns (four to date) were:

- undertaken by NIWA and Emission Impossible Ltd
- funded by ARC, Auckland Council, NIWA and the NZ Transport Agency
- with support provided by various Auckland local councils and schools, Land Transport Safety Authority, Ministry of Transport, Motor Trade Association, NZ Police, NZ Transport Agency and Transit NZ.

6.3 Brief description of the work undertaken

Various on-road emissions monitoring campaigns using remote sensing have been commissioned by Auckland Regional Council since 2003 to establish "real world" emissions from the Auckland vehicle fleet. Full details on the method and equipment used are available in the reports listed in section 6.5 but are summarised below.

Remote sensing of vehicle emissions involves deploying a source of infrared and ultraviolet light at the side of a roadway and passing the beams of light through the exhaust plumes of the vehicles as they pass the device. The light beams are absorbed and scattered by different air pollutants at different wavelengths. Therefore the concentration of pollutants can be calculated from differences in the spectra of the light emitted and the light received.

In addition to the emissions equipment, remote sensing typically involves a video camera to record images of the license plates of the vehicles passing. This enables the emissions data to be matched afterwards to vehicle characteristics (eg, make, model, year of manufacture, country of first registration etc.) via the Motor Vehicle Register maintained by the NZ Transport Agency.

On occasion, a 'smart sign' was also deployed which provides instantaneous feedback to the drivers of vehicles who have just passed through the monitoring site. The smart sign flashes a message indicating the general state of a vehicle's emissions as 'good', 'fair' or 'poor' based on pre-determined cut-off points and can be particularly useful for public education campaigns.

Note: This type of emissions monitoring poses a number of challenges in that the remote sensing device (RSD) needs to be installed on single lane motorways, on ramps or arterial roads in order to distinguish emissions from individual vehicles. In addition, the RSD is typically set up to measure emissions just above road level so emissions for vehicles that discharge vertically (eg, some heavy duty trucks) cannot be measured.

6.3.1 Specific light and heavy duty diesel vehicles remote sensing campaign

Given the disproportionate contribution of diesel vehicles to air pollution health effects in the region, a specific remote sensing programme of measurements was undertaken in late 2004 and augmented with results from one of the light duty campaigns in mid-2005.

Vehicles were sampled at the Ports of Auckland (trucks), five Auckland bus depots (buses), and 20 roadside sites (heavy and light duty vehicles), yielding valid results for 1,235 heavy duty diesel (HDD) and 6,484 light duty diesel (LDD) vehicles in total.

Emissions were recorded for four pollutants:

- carbon monoxide (CO)
- hydrocarbons (HC)
- nitric oxide (NO) and
- uvSmoke (as a proxy for particulates)

together with information on each vehicle's characteristics.

Note: uvSmoke or Smoke Factor (SF) is a term introduced by the manufacturer of the equipment (ESPH) to describe its remote sensing measurement of smoke. It represents a ratio of exhaust opacity to the amount of fuel burned at the time of measurement. SF is measured in the UV using frequencies providing the greatest sensitivity to the particulate mass fraction. The amount of fuel burned element of the ratio is formulated by summing measurements of the carbon-based gases of the exhaust. For black diesel smoke, a SF of 1 indicates 1 per cent of fuel by mass is emitted as PM (ESPH, 2010).

Targeted bus emissions monitoring was carried out in November 2004 at five depots across the Auckland region. These measurements were combined with bus emissions data captured at 20 roadside sites in late 2004 and mid-2005 to yield 283 emissions measurements from 247 individual buses.

Figure 6-1 shows the remote sensing system in operation at a bus depot sampling site. The monitoring equipment was set up with a 100 metre long coned lane leading to the equipment and the buses were driven by company drivers. The drivers were instructed to accelerate slowly in the lane and to ensure that they were travelling at approximately 30 km/hr and still accelerating as they passed through the monitoring site. Buses were typically driven through the monitoring site multiple times to ensure that a valid reading was obtained and to provide an indicator of repeatability.

Targeted truck emissions monitoring was carried out in December 2004 at the Ports of Auckland trucking terminal. These measurements were combined with truck emissions data captured at the roadside sites in late 2004 and mid-2005 to yield 1,159 valid emissions measurements from 988 individual trucks.

Figure 6-1 Monitoring emissions from buses at a depot in Auckland (Bluett *et al.*, 2010b)

Figure 6.2 shows the remote sensing system in operation at the Ports of Auckland sampling site. The monitoring equipment was set up with a 100 metre long coned lane leading to the equipment and the trucks were driven by contracted drivers. The drivers were instructed to accelerate slowly in the lane and to ensure that they were travelling at approximately 30 km/hr and still accelerating as they passed through the monitoring site.

Figure 6-2 Monitoring emissions from trucks at the Ports of Auckland (Bluett *et al.*, 2010b)

Following the monitoring, the combined datasets were analysed for a range of vehicle parameters, such as vehicle type, year of manufacture, mileage, vehicle weight and country of first registration to establish which of these had the greatest influence on emissions. The analyses were undertaken for the LDD and HDD fleets overall, with the HDD fleet broken down further into trucks and buses (where sufficient data existed for the statistical analyses). Separate assessments of the influence of emission standard on bus emissions and the effect of diesel gross emitters were also performed.

The specific light and heavy duty diesel emissions work was reported in October 2010 (Bluett *et. al.*, 2010b)

6.3.2 Other heavy duty diesel vehicle data from remote sensing campaigns

Heavy duty diesel emissions were also recorded in other on-road remote sensing campaigns undertaken in 2003, 2009 and 2011. As these other campaigns focussed on measuring light duty emissions, the heavy duty vehicle datasets were stored but not analysed or reported. Data are available for both trucks and buses as shown in Table 6-1.

Table 6-1 Number of heavy duty diesel vehicle measurements from all remote sensing campaigns (Bluett, 2014, *pers. comm.*)

Campaign	2003	2005	2009	2011
Buses	54	335	72	70
Trucks	789	1,379	401	338

Note:

1. The table shows the number of emission *measurements* available for diesel (only) vehicles with a gross vehicle mass greater than 3500 kg, where the vehicle specific power (a measure of steady state driving) is between 0 and 40 for the 2005-2011 campaigns or “null” (no measurements) for 2003 when VSP was not able to be measured. Some vehicles were measured more than once so the number of individual *vehicles* will be less.
2. The values shown for 2005 include the specific 2004 remote sensing campaign discussed in section 6.3.1.

The results from these other remote sensing campaigns were reported in Fisher *et. al.* (2003), Bluett *et. al.* (2010a), Bluett *et. al.* (2011) and Kuschel *et al.* (2013).

All datasets from the Auckland remote sensing campaigns have been consolidated into a Microsoft Access^{TM} database, which has real-world emissions records for approximately 146,000 vehicles (described in Bluett *et. al*, 2013).

The database is structured around two principal tables:

- The *Emissions* table contains all (valid and non-valid) road-side records obtained from the RSD equipment, including those from the HDD campaign (210,384 records). Key fields in this table include site name, date and time of measurements, pollutant concentrations, and licence plate.
- The *Vehicles* table holds all available information obtained from the Motor Vehicle Register for each licence plate associated with a valid emission measurement (146,550 records). Key fields in this table include licence plate, make/model, year of manufacture, and fuel type.

The database can be interrogated using standard Microsoft Access queries, or by statistical software packages such as R or Matlab. Extracting subsets of data relevant to a particular study is generally straightforward, but care is necessary when linking the Vehicles and Emissions tables via the vehicle licence plate field. Individual vehicles are frequently encountered more than once (eg, by passing through one or more sites several times during the same day) and can easily generate spurious duplicate records if queries are incorrectly formulated.

Note: The ownership of the data within the on-road vehicle emission database rests with the organisations which funded each of the specific monitoring campaigns - 2003 (ARC and NIWA), 2005 (ARC), 2009 (NZTA, ARC and NIWA) and 2011 (Auckland Council). The database was developed and is hosted by NIWA.

6.4 Key outcomes and findings

6.4.1 Specific light and heavy duty diesel vehicles remote sensing campaign

The most significant findings from the specific light and heavy duty diesel vehicle campaign were as follows.

Country of first registration

Approximately 56 per cent of the HDDs were New Zealand new vehicles, with the remaining 44 per cent being imported used from Japan. However these proportions varied significantly depending on whether the HDDs were trucks or buses, with 39 per cent of the trucks and 89 per cent of the buses being New Zealand new. For all types of diesel vehicles, the Japanese used imports were between four and seven years older than the New Zealand new ones on average.

Figure 6-3 presents the truck emissions by country of first registration for different years of manufacture.

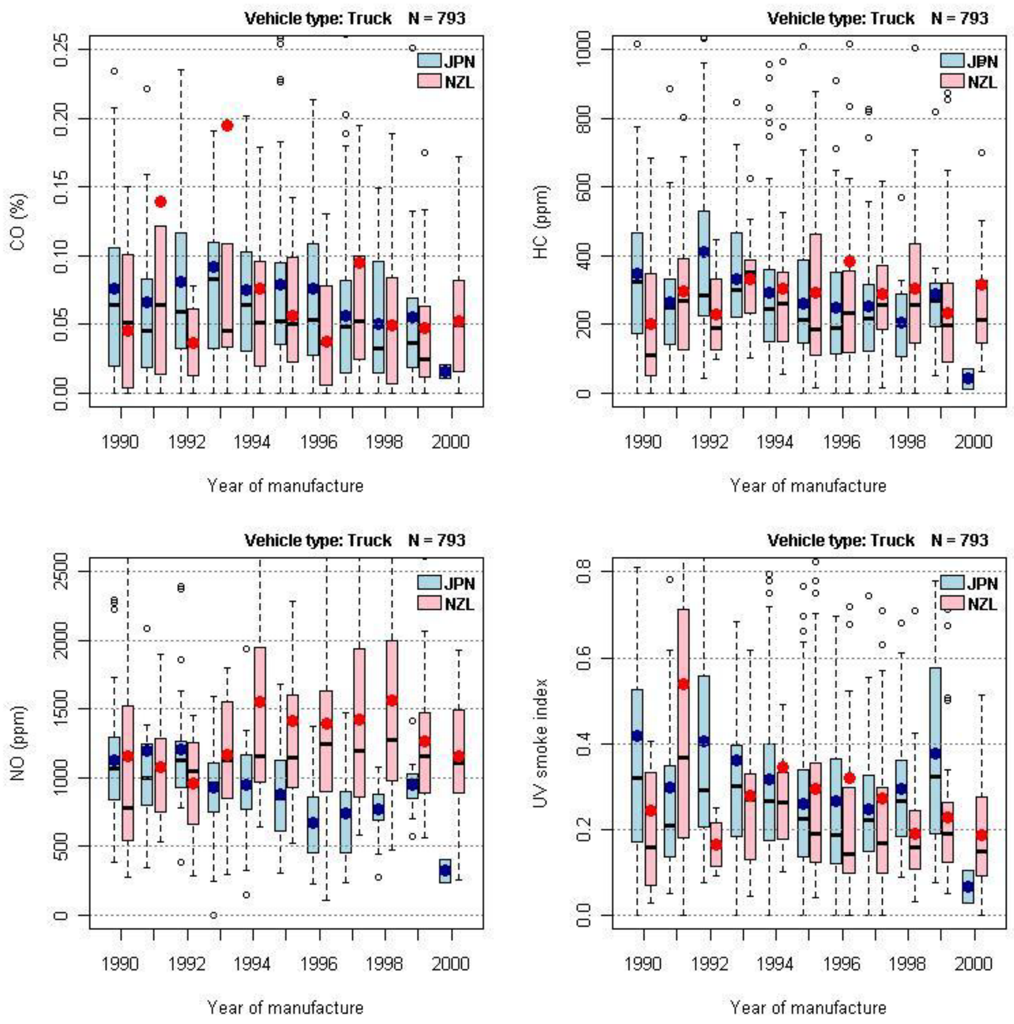

Figure 6-3 HDD truck emissions by country of first registration and year of manufacture, where JPN=Japan used, NZL=New Zealand new (Bluett *et al.*, 2010b).

Note: In Figures 6-3 and 6-4, the "box" represents the 25th and 75th percentiles, the "whisker" the 5th and 95th percentiles, the "line" the median, the "solid dot" the mean and the "open dots" are outliers.

Figure 6-3 shows:

- CO and HC emissions were not significantly different for New Zealand new and Japanese used HDD trucks for the same year of manufacture.
- NO emissions were higher for New Zealand new than Japanese used HDD trucks for the same year of manufacture. This is consistent with Japanese domestic emissions standards which have been more stringent on NO_X emissions than the equivalent Euro standards until relatively recently.
- uvSmoke emissions were generally similar for New Zealand new and Japanese used HDD trucks for the same year of manufacture.

- There was no or very little change in emissions of CO or HC from New Zealand new and Japanese used HDD trucks with year of manufacture. However, these are minor pollutants for diesel vehicles relative to PM and NO_X.
- A general decrease in emissions of NO from Japanese used HDD trucks was found with year of manufacture, but no change for New Zealand new HDD trucks. Again this is consistent with Japan requiring increasingly lower NO_X emissions.
- Some reduction in uvSmoke emissions was seen with later years of manufacture for New Zealand new and Japanese used HDD trucks.

Age and odometer reading

For HDDs, older vehicles and those with higher odometer readings tended to emit more CO, HC and uvSmoke but NO emissions were largely unaffected.

Buses versus trucks

Buses, on average, emitted significantly more NO than trucks, as seen in Table 6-2. However, trucks, on average, emitted significantly more uvSmoke than buses. There was no statistically significant difference between the average emissions of CO or HC from trucks or buses from 1995 onwards.

Table 6-2 Mean emissions for HDD trucks versus HDD buses manufactured in 1985, 1995 and 2005 (Bluett *et al.*, 2010b)

Year of Manufacture	1985		1995		2005	
	Trucks	**Buses**	**Trucks**	**Buses**	**Trucks**	**Buses**
CO (%)	0.081	0.273	0.073	0.081	0.040	0.043
HC (ppm)	261	986	269	308	124	54
NO (ppm)	837	1704	1020	1218	834	1208
uvSmoke	0.262	0.114	0.269	0.247	0.110	0.065

Bus emissions standards

A comparison of bus emissions by emission control technology showed that the measured emissions of all pollutants (except uvSmoke) generally trended downward with improving emission standard (see Figure 6-4). However, the relative improvement in the measured emissions was not as great as the relative improvement expected based on the limits set for the emissions standard.

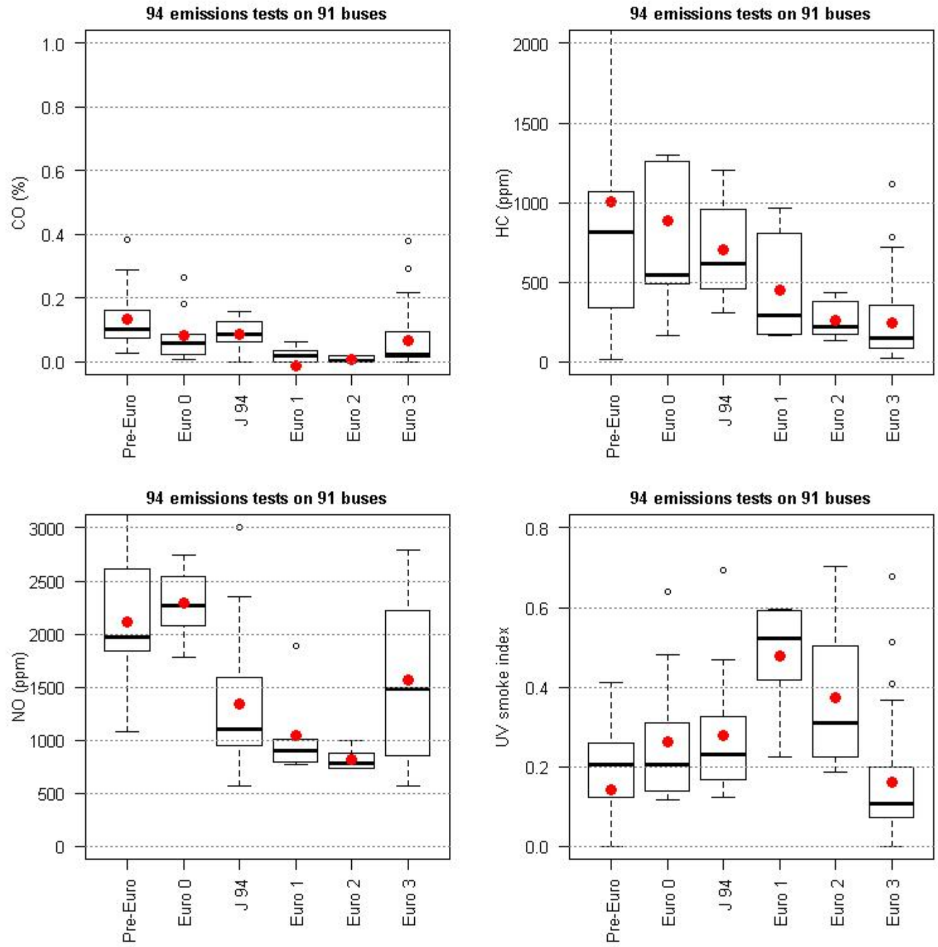

Figure 6-4 HDD bus emissions by emissions standard (Bluett *et al.*, 2010b)

Gross vehicle mass

HDD emissions of HC and uvSmoke increased with gross vehicle mass (GVM) but this trend was not seen for CO or NO emissions.

Gross emitters

The highest 10 per cent (gross emitting) diesel vehicles in all categories – HDD, truck and bus - were found to disproportionately influence the fleet performance. For HDDs, gross emitters contributed 43 per cent, 35 per cent, 22 per cent and 33 per cent of the total CO, HC, NO and uvSmoke emissions respectively.

6.4.2 Other heavy duty diesel vehicle data from remote sensing campaigns

The datasets listed in Table 6-2 are yet to be analysed but would be a valuable resource to re-analyse or re-confirm the results seen in the specific light and heavy duty diesel vehicle campaign undertaken in 2004/2005.

The smaller numbers of readings in the 2003, 2009 and 2011 campaigns relative to 2005 may limit the statistical power of the analyses making it hard to draw definitive conclusions from the analyses but investigation is warranted, nonetheless.

6.5 Key outputs

The key outputs from the heavy duty diesel remote sensing work include:

- Report on Light and Heavy Duty Diesel Vehicle Emissions Measurements (Bluett *et al.*, 2010b)
- Database of All On-Road Vehicle Emissions Data (database available from NIWA, reported in Bluett *et al.*, 2013)

7 Truck Fleet Investigations

This chapter reviews the scoping completed for the development of a Truck Emissions Prediction Model, including a preliminary survey of truck operators.

The work in this chapter applies to vehicle emissions management areas of clean fuels, appropriate maintenance, and clean technology.

7.1 Objectives

- Investigate willingness of truck operators to reduce their fleet emissions via a survey
- Start scoping development of a Truck Emissions Prediction Model (TEPM) to be used to evaluate truck fleet emissions performance

7.2 Organisations involved

The emissions survey of Auckland trucking companies was:

- undertaken by Clean Air Auckland (CAA) volunteers
- with support provided by Auckland Regional Council (ARC), the Sustainable Business Network (SBN) and participating truck fleet operators.

The preliminary scoping of TEPM was:

- undertaken by Auckland UniServices Energy and Fuels Research Unit (EFRU)
- funded by ARC
- with support from a number of Auckland truck operators who provided useful information about their fleets.

7.3 Brief description of the work undertaken

7.3.1 Truck emissions survey

In October 2004, the Clean Air Auckland (CAA) lobby group launched a campaign to encourage truck fleet operators to reduce their emissions. Surveys were sent out to 200 Auckland trucking companies to investigate the types of vehicle maintenance practices in place, and survey participants were offered free information on how to clean up their fleets. Of the surveys that were successfully delivered, 32 companies responded (equal to a response rate of 19 per cent).

The survey comprised the questions shown in Table 7-1. Responses were collated at the end of the 2004, analysed then reported in July 2005 (SBN, 2005).

Table 7-1 Clean Air Auckland truck emissions survey questions (SBN, 2005)

1.	Is your company concerned about vehicle emissions? If “YES”, please advise us as to that company’s vehicle maintenance policy, or provide contact information.	YES/NO
2.	Do you subcontract vehicles with another company?	YES/NO
3.	Do you have regular maintenance schedules for your vehicles? If “YES”, how often are vehicles tuned? ____	YES/NO
4.	Do you check the emissions of your fleet on a regular basis? If “YES”, how is this done? ____	YES/NO
5.	Are you aware of that free emissions testing is available as part of WoF/CoF at the Waitakere City Council Testing Station in Henderson?	YES/NO
6.	Are you aware that compulsory exhaust emissions testing is due to come in as part of WoF/CoF in mid to late 2006?	YES/NO
7.	Do you monitor and track your fuel economy for individual vehicles?	YES/NO
8.	Does your company have a specific environmental or sustainability policy related to the operation of your fleet? If “YES”, would it be possible to obtain a copy?	YES/NO
9.	Are you aware of environmental/sustainability initiatives, such as Greenfleet (via SBN) or Fleetcheck (via EECA)? Would you like free information on how to clean up your fleet and lower operation costs? If “YES”, how may we reach you? ____	YES/NO YES/NO

7.3.2 Truck Emissions Prediction Model scoping work

Following the success of the Bus Emissions Prediction Model (BEPM), the ARC commissioned EFRU in early 2007 to commence work on a Truck Emissions Prediction

Model (TEPM). The original plan was to undertake a feasibility study (Stage 1) and then develop a beta emissions prediction model for preliminary evaluation (Stage 2). However, the project timetable was delayed due to funds needing to be diverted to the development of the Vehicle Emission Prediction Model (VEPM), which was completed in 2009.

Stage 1 - reviewing international truck emissions models then recommending a development plan for TEPM - was completed and written up in 2010 (EFRU, 2010).

Stage 2 – developing the model itself - was deferred and has remained on hold since then due to other more pressing council priorities.

7.4 Key outcomes and findings

7.4.1 Truck emissions survey

Despite all trucking companies being concerned about vehicle emissions in 2004, only 39 per cent of respondents were checking their fleet emissions on a regular basis and only 16 per cent had specific environmental or sustainability policies in place. It was difficult to establish whether concern about vehicle emissions was borne from the associated environmental and health issues or prompted by the possibility of compulsory emissions testing in 2006 as nearly 60 per cent of respondents confirmed that they were aware of the proposed emissions testing.

Most companies (84 per cent) monitored and tracked fuel economy for individual fleet vehicles but most likely in order to minimise fuel and long-term maintenance costs rather than to reduce their emissions.

Despite only 22 per cent of companies being aware of environmental/sustainable fleet management initiatives such as GreenFleet and Fleetcheck, 82 per cent of survey participants indicated that they would like free information on how to clean up their vehicle fleets and lower operating costs.

7.4.2 Truck Emissions Prediction Model scoping work

One of the primary purposes of TEPM would be for characterising the emissions performance of small fleets of trucks, in much the same way as BEPM models bus fleets. That is to say, to be able to compare emissions reductions strategies, such as purchasing new vehicles versus installing diesel oxidation catalysts, on a fleet by fleet basis. Overall the framework and methodology applied in BEPM would be appropriate for TEPM.

The classes of heavy vehicles included in VEPM would be a good starting point for covering most of the trucks operating within the fleet. These classes could then be refined based on survey work undertaken with the major operators. However, it is worth noting that fleet managers have been reluctant to provide information in the past because they are often too busy to fill in the survey forms. Therefore any surveys would have to be carefully designed to ensure good response rates.

Modelled emissions factors developed for European, American and Japanese vehicles should be compared to determine whether to use one modelling regime and develop equivalencies as applied in VEPM or to use the emissions algorithms for countries of origin. This is an area that would require additional analysis before making a final decision.

The likely vehicle classes for European and Japanese heavy duty vehicles are presented in Table 7-2. However, J09 would need to be added to the Japanese emissions standards as it is now in force.

Table 7-2 Vehicle classes for European and Japanese heavy duty commercial vehicles (EFRU, 2010c)

Heavy Duty Vehicles Euro		
Pre-Euro	3.5 - 7.5 t	< '92
	7.5 - 16 t	
	16 - 32 t	
	> 32 t	
Euro I	3.5 - 7.5 t	92 - 95
	7.5 - 16 t	
	16 - 32 t	
	> 32 t	
Euro II	3.5 - 7.5 t	96 - 00
	7.5 - 16 t	
	16 - 32 t	
	> 32 t	
Euro III	3.5 - 7.5 t	01 - 05
	7.5 - 16 t	
	16 - 32 t	
	> 32 t	
Euro IV	3.5 - 7.5 t	06 - 08
	7.5 - 16 t	
	16 - 32 t	
	> 32 t	
Euro V	3.5 - 7.5 t	> 08'
	7.5 - 16 t	
	16 - 32 t	
	> 32 t	

3.0 Heavy Duty Vehicles		**Japan**
Pre 1974	<5 t GVW	**50 - 73**
Pre 1974	5-12 t GVW	**50 - 73**
Pre 1974	> 12 t GVW	**50 - 73**
	>30	**50 - 73**
J74, J77, J7	<5 t GVW	**74 - 87**
J74, J77, J7	5-12 t GVW	**74 - 87**
J74, J77, J7	> 12 t GVW	**74 - 87**
	>30	**74 - 87**
J88	<5 t GVW	**88 - 93**
J88	5-12 t GVW	**88 - 93**
J88	> 12 t GVW	**88 - 93**
	>30	**88 - 93**
J94, J97	<5 t GVW	**94 - 97**
J94, J97	5-12 t GVW	**94 - 97**
J94, J97	> 12 t GVW	**94 - 97**
	>30	**94 - 97**
J97	<5 t GVW	**98 - 02**
J97	5-12 t GVW	**98 - 02**
J97	> 12 t GVW	**98 - 02**
	>30	**98 - 02**
J03	<5 t GVW	**03 - 04**
J03	5-12 t GVW	**03 - 04**
J03	> 12 t GVW	**03 - 04**
	>30	**03 - 04**
J05	<5 t GVW	**> 05'**
J05	5-12 t GVW	**> 05'**
J05	> 12 t GVW	**> 05'**
	>30	**> 05'**

Table 7-3 lists the likely weight and emissions classes for US heavy duty vehicles. Each weight class may need to be considered for each US emissions class.

Table 7-3 Weight and emissions classes for US heavy duty commercial vehicles (EFRU, 2010c)

Designation	Description	Gross Vehicle Weight (lbs)
HDGV (class 2B)	Light heavy-duty gasoline trucks	8,501-10,000
HDGV (class 3)	Light heavy-duty gasoline trucks	10,001-14,000
HDGV (class 4)	Light heavy-duty gasoline trucks	14,001-16,000
HDGV (class 5)	Light heavy-duty gasoline trucks	16,001-19,500
HDGV (class 6)	Medium heavy-duty gasoline trucks	19,501-26,000
HDGV (class 7)	Medium heavy-duty gasoline trucks	26,001-33,000
HDGV (class 8a)	Heavy heavy-duty gasoline trucks	33,001-60,000
HDGV (class 8b)	Heavy heavy-duty gasoline trucks	>60,000
HDDV (class 2B)	Light heavy-duty diesel trucks	8,501-10,000
HDDV (class 3)	Light heavy-duty diesel trucks	10,001-14,000
HDDV (classes 4)	Light heavy-duty diesel trucks	14,001-16,000
HDDV (class 5)	Light heavy-duty diesel trucks	16,001-19,500
HDDV (class 6)	Medium heavy-duty diesel trucks	19,501-26,000
HDDV (class 7)	Medium heavy-duty diesel trucks	26,001-33,000
HDDV (class 8A)	Heavy heavy-duty diesel trucks	33,001-60,000
HDDV (class 8B)	Heavy heavy-duty diesel	>60,000
HDGB	Heavy-duty gasoline buses (all types)	all
HDDB (school)	Heavy-duty diesel school buses	all
HDDB (transit & urban)	Heavy-duty diesel transit & urban buses	all

Heavy Duty Vehicles		US Federal
	US '88	88-89
	US ' 90	'90
	US '91	91-92
	US '93	'93
	US '94	94-95
	US '96	96-97
	US '98 (gen have (	98-04
	LEV	98-04
	ILEV	98-04
	ULEV	98-04
	ZEV	98-04
	US '04 (assume w	04-06
	US '07 (assume c	07

7.5 Key outputs

The key outputs from the truck emissions investigations include:

- Report on Results of the Clean Air Auckland Truck Emission Survey (SBN, 2005)
- Spreadsheet of the Clean Air Auckland Truck Emission Survey (available separately)
- Report on Truck Emissions Prediction Model (EFRU, 2010c)

8 Outcomes, Findings and Recommendations

Based on current trends, heavy duty diesel vehicles are likely to remain significant contributors to poor air quality in the Auckland region for the foreseeable future.

This chapter summarises the key outcomes and findings of the programme undertaken between 2003 and 2010 as well as recommendations going forward.

The uptake of the programme overall is discussed first before discussing the specific initiatives.

8.1 Overall programme

The most important outcome of the overall programme was uptake by stakeholders and the eventual incorporation of key findings into urban bus standards and requirements.

As findings came to light, the ARC was in contact with the bus operators and Auckland Regional Transport Authority (ARTA) to encourage uptake. In the 2005 Auckland Regional Land Transport Strategy, this uptake was highlighted in the following policy:

> *1.8.2 Accelerate environmental performance improvements that reduce air emissions from heavy-duty diesel vehicles in the region, such as the public bus and commercial trucking fleets. (ARC, ARTA)*

Up to April 2006, the liaison between ARC and ARTA centred largely on using the Bus Emission Prediction Model to evaluate the relative environmental performance of different bids being submitted for route tenders on an ad hoc basis. In May 2006, however, the ARC made a submission on the draft Passenger Network Plan recommending that ARTA set a rolling schedule of minimum emissions standards for contracts in their Vehicle Quality Standards manuals.

In late 2006, ARC staff were approached by ARTA to go one step further and recommend a schedule including not only minimum fleet-average emissions standards to be achieved from now out to the future but also requirements to retrofit older buses, recognising that these are a legacy of much higher emitting technology. The ARC drafted a schedule reflecting a slight lag from the emissions standards schedule for new and existing vehicles entering New Zealand, factoring in experience from the catalyst retrofitting trial (discussed later in Chapters 4 and 5) to recommend buses for retrofitting.

This schedule was incorporated into the vehicle quality standards manuals (ARTA, 2007a and ARTA, 2007b) which applied to tenders in 2010 as follows:

> *For new buses: The vehicle exhaust emissions will, as a minimum, and regardless of fuel used, meet the Euro IV, US 2004, Japan 05 or equivalent emission standard.*

For existing buses: The vehicle exhaust emissions will, as a minimum, and regardless of fuel used, meet or exceed the Euro III, US 98D, Japan 02/04 or equivalent emission standard. The Euro III or equivalent emission standard may be met through engine refit or retrofitting equipment to reduce emissions as approved by ARTA, subject to satisfactory emissions testing.

For both new and existing buses: The vehicle will create a minimum amount of visible smoke. Where a vehicle is observed by ARTA to be producing excessive amounts of smoke, the Operator will either:

(a) produce evidence of rectification (or confirm that the vehicle has been withdrawn from service for rectification) to ARTA's satisfaction within 14 days of receiving notification from ARTA; or

(b) submit the vehicle to a Certificate of Fitness inspection within 14 days of receiving notification from ARTA.

Following on from this work, the NZ Transport Agency (NZTA) developed a set of vehicle requirements to be applied nationally to urban bus fleets (NZTA, 2008). The document was intended for use by regional authorities in their procurement of urban bus services. The minimum standards initially came into force on 1 January 2010 but were updated in 2011 to clarify issues regarding their implementation (NZTA, 2011). The current standards require:

For new buses: All buses must meet the current Vehicle Exhaust Emissions Rule (which from 1 January 2014 is now Euro V, US 2007, Japan 09 or equivalent emission standard for new models.)

For existing buses: By 1 July 2015, all diesel buses purchased before 2000 that do not meet Euro II or equivalent shall fit particulate filters where it is feasible to do so.

8.2 Evaluating bus fleet emissions performance

Key outcomes

A Bus Emissions Prediction Model (BEPM) was developed. It is a tool that can be used to objectively assess the impact of bus emissions reduction options on Auckland's air quality.

BEPM compares the total emissions, reductions, costs and environmental ratings of various scenarios to identify the most cost effective reduction strategies for a particular base fleet. It can also be used to compare the environmental (air quality) performance of different fleets.

BEPM has been used by a number of external agencies. Auckland Regional Transport Agency and Otago Regional Council have used it in evaluations of commercial bus contracts. The Ministry of Education has also used it to review school bus tenders.

Key findings

The cost-benefit analyses were able to clearly identify the most cost-effective reduction strategies for typical Auckland bus fleets between 2004 and 2011.

In 2004, the most effective strategies were implementing an inspection, maintenance and repair programme on the highest emitting 20 per cent of buses and retrofitting diesel oxidation catalysts (DOCs) to the older buses. Projecting out to 2011, the options typically became more expensive as the base buses in the fleet improved by natural turnover.

Now in 2014, with the urban bus requirements in place, options targeting the older buses may be limited by the number of older suitable vehicles left in the fleet. However, there may still be some benefits from inspection and maintenance.

Recommendations

The key limitation of the current version is that it is based on 2006 data. It would be useful to check and update the underpinning assumptions. Nonetheless, the methodology and model framework still hold. BEPM could be relatively easily be updated to incorporate the newer emission technologies missing in the current version, revise the costs presented for the various emission reduction strategies and re-assess the environmental ratings to reflect the increased concerns about NO_2 health effects.

Although BEPM was only targeting a small portion of the fleet, exposure to bus emissions is a significant issue on major transport routes. A revised BEPM would enable robust assessment of the impacts of any proposed major transport corridor projects, involving buses. It would also allow evaluation of future population exposure as housing developments intensify along key corridors.

8.3 Bus emissions testing

Key outcomes

A significant proportion of the Auckland bus fleet (at the time) was tested between 2003 and 2007.

Simple and detailed emissions tests were conducted on a range of vehicles representing the full cross-section of the Auckland bus fleet – from pre-Euro to Euro III vehicles – across all major operators.

Key findings

In terms of simple or short emissions tests, the stall average test was found to be to be more representative of on-road emissions than the snap peak test.

The detailed testing found that the smoke opacity results from the short tests, particularly the stall average tests, correlated well with particulate matter (PM), carbon monoxide (CO) and hydrocarbon (HC) emissions. This means that fleet testing using the short test methods could provide some detail regarding the state of the fleet's PM, CO and HC emissions characteristics. The short test methods investigated were not able to provide information on nitrogen oxides (NO_X) emissions rates.

The disproportionate impact of gross emitting vehicles was conclusively shown in all emissions testing undertaken to date whether it be in-field snap and stall testing, detailed chassis dynamometer testing or remote sensing. The contribution of the worst 10 per cent of all heavy vehicles is responsible for at least 30 per cent of the total emissions from that sector of the fleet.

If these vehicles could be identified and repaired, significant emissions reductions could be made. In the case of fleet operators, even greater emissions improvements would be possible by comparing the emissions performance of vehicles of the same emissions technology and model then targeting the worst emitters for maintenance and repair.

Recommendations

A stall average test could be considered for in service compliance emissions testing - either in response to the Ministry of Transport's planned investigation of options in 2014 or for adoption by Auckland Transport or the NZ Transport Agency as part of future improvements in urban bus requirements. However, it would:

1. need to be calibrated for different emission technologies and weight classes if it were to be used as an absolute limit
2. only be able to be applied to heavy vehicles with automatic transmissions in its current form (so would largely be suitable for buses only and not trucks)

The stall average or the snap peak tests could be used by fleet operators to set trigger points for targeted maintenance to address gross emitters.

8.4 Biodiesel blends in buses

Key outcomes

Two blends of tallow methyl ester (TME) biodiesel in automotive diesel fuel (ADF) were trialled at a detailed dynamometer facility and in the field at bus depots. Emissions and fuel consumption were measured versus straight ADF.

Key findings

Significant emission reductions were found with TME biodiesel blends for buses versus straight ADF at 50ppm sulphur in both detailed dynamometer and field testing.

On average, emissions of PM, CO and HC reduced by up to 21 per cent for B40 (40 per cent biodiesel) blends versus ADF in the detailed testing. More modest reductions (up to 4 per cent) were found for NO_X emissions.

The stall average field tests showed a statistically significant reduction in smoke density for B20 buses compared to those operating on 50ppm sulphur ADF.

Recommendations

Following completion of these tests in 2007, diesel fuel quality improved further and sulphur levels are now at “zero” (10ppm maximum) levels. The emissions reductions of up to 70 per cent (when combined with a diesel oxidation catalyst) reported in 2007 would likely be lower now in 2014. However, the reductions may still be appreciable and therefore warrant reviewing.

8.5 Bus retrofitting trials

Key outcomes

In this project, each of the major Auckland bus fleet operators was approached to offer up at least one of the older buses in their fleets suitable for being retrofitted with diesel oxidation catalysts (DOCs). In total 13 DOCs were retrofitted mid to late 2006 to determine the potential benefits for buses typical of NZ.

In 2008, the NZ Transport Agency recognised exhaust after-treatment retrofits as an option to achieve minimum performance standards in their urban bus requirements. The minimum standards were updated in 2011 but still allow for the retrofitting of particulate filters (NZTA, 2011). The current standards require:

> *For existing buses: By 1 July 2015, all diesel buses purchased before 2000 that do not meet Euro II or equivalent shall fit particulate filters where it is feasible to do so.*

Key findings

Significant emission reductions were found for buses that had been retrofitted with DOCs versus those without DOCs in both detailed dynamometer and field testing.

On average, emissions of PM, CO and HC reduced by between 33 and 70 per cent for DOC fitted buses versus non-DOC fitted buses of the same technology type operating on 50ppm sulphur diesel. NO_X emissions increased slightly (up to 2 per cent).

No statistically significant difference in smoke density was found in either the stall average or snap acceleration fields test when comparing DOC fitted versus non-DOC fitted buses.

However, this may have been due to the very small sample sizes (only three catalyst-equipped buses were tested in the field).

Recommendations

As mentioned in the biodiesel recommendations, diesel fuel quality has improved further since 2007 and sulphur levels are now at “zero” (10ppm maximum) levels. The emissions reductions of up to 70 per cent reported in 2007 would likely be lower now in 2014. However, they may still be appreciable and therefore warrant reviewing.

In addition, emissions control technology in buses has advanced considerably and increasingly the focus is turning to addressing NO_X emissions. There are likely to be fewer candidate buses remaining in the Auckland bus fleets suitable for DOC retrofitting so there would be value in widening the investigation to diesel particulate filters (DPFs) or even DPFs combined with selective catalytic reduction (SCR) for NO_X control.

8.6 On-road emissions monitoring

Key outcomes

Heavy duty diesel vehicles were sampled using as part of a special remote sensing campaign at the Ports of Auckland (trucks), five Auckland bus depots (buses) and various roadside sites (both) in 2004. Valid results for 1,235 heavy duty vehicles in total were analysed to investigate factors affecting on-road diesel emissions.

A further 2,200 additional heavy vehicle measurements were collected as part of other remote sensing campaigns (focussing on light duty vehicles) between 2003 and 2011 but these are yet to be analysed.

Key findings

Older heavy duty vehicles and those with higher odometer readings tended to emit more CO, HC and uvSmoke but NO emissions were largely unaffected.

Emissions of HC and uvSmoke increased with gross vehicle mass (GVM) but this trend was not seen for CO or NO emissions.

Although CO and HC emissions were not significantly different for New Zealand new and Japanese used trucks for the same year of manufacture, NO emissions were higher. This is consistent with Japanese domestic emissions standards which have been more stringent on NOX emissions than the equivalent Euro standards until relatively recently.

Buses, on average, emitted significantly more NO than trucks for the same year of manufacture. However, trucks, on average, emitted significantly more uvSmoke than buses. There was no statistically significant difference between the average emissions of CO or HC from trucks or buses from 1995 onwards.

For buses, measured emissions of all pollutants (except uvSmoke) generally trended downward with improving emission standard but the relative improvement in the measured emissions was not as great as would be expected based on the limits set for the emissions standard.

The highest 10 per cent (gross emitting) of heavy diesel vehicles in all categories (bus or truck) were found to disproportionately influence the fleet performance. Gross emitters contributed 43 per cent, 35 per cent, 22 per cent and 33 per cent of the total CO, HC, NO and uvSmoke emissions respectively

Recommendations

Remote sensing could be considered to identify gross-emitting heavy vehicles in service (on road). However, the capture rates (given the variable positions of heavy vehicle exhausts) may not make this as economic as adopting a simple test.

Regardless, the datasets collected to date would be useful for confirming trends in heavy duty diesel vehicle emissions, and warrant further analysis, especially the actual impact of the improved emission standards legislation since 2003.

8.7 Truck fleet investigations

Key outcomes

A preliminary survey was sent out in 2004 to commence engagement with Auckland trucking companies.

The potential framework for developing a Truck Emissions Prediction Model (TEPM) was scoped out for consideration, with vehicle, emissions, and weight classes already identified for the trucks likely to feature in the Auckland fleet.

Key findings

The initial survey identified that, even as early as 2004, trucking companies were concerned about vehicle emissions and were interested in how to clean up their vehicle fleets and lower operating costs.

TEPM scoping was completed but the model development itself was put on hold.

Recommendations

The truck emissions investigations to date provide a good platform for future development.

Since 2004, the price of diesel fuel has increased significantly and there has been increased publicity about air quality effects of diesel vehicle emissions (IARC, 2012). The Energy Efficiency and Conservation Authority (EECA) now runs a Heavy Vehicle Fuel Efficiency programme which aims to improve the fuel efficiency of heavy vehicle fleets through expert advice and funding assistance. Most heavy vehicle fleets can cut fuel costs by at least 10 per cent through maintenance, driver training, improved fleet management and vehicle selection.

There is potential for Auckland Council to partner with EECA and approach Auckland trucking fleets to evaluate co-benefits in ambient air quality in addition to the greenhouse gas emissions reductions and fuel savings.

A TEPM modelled along similar lines as BEPM would be an invaluable tool, given the greater number of these vehicles in the Auckland region and the greater potential for emissions improvements. TEPM would need to pay particular attention to addressing loading and gradient.

8.8 Conclusion

In conclusion, the initiatives discussed in this report are likely to remain valid for the foreseeable future to better manage Auckland’s air quality in the face of projected trends in population growth, public transport and freight.

Although much time has elapsed since the pilot bus work began in 2003, many of the initiatives investigated are still relevant to managing heavy duty diesel vehicle emissions in Auckland but would benefit from being updated with more recent information on technological and policy developments.

A suite of robust tools for improving the management of heavy duty diesel vehicle emissions would support many of the policies outlined in the Proposed Unitary Plan and assist Auckland to become the world’s most liveable city.

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