Environment Australia
Department of the Environment and Heritage

# Technical Report No. 1:

# Toxic Emissions from Diesel Vehicles in Australia

A consultancy funded by Environment Australia.
Prepared by Parsons Australia Pty Ltd

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We make special mention of the staff at CSIRO Division of Energy and Technology who collected toxic and metal samples on site and those who then processed the samples to generate results behind the scenes at the CSIRO laboratories.

The Study has proved to be a great success, providing for the first time toxic data on the diesel fleet and information as to the relative emissions performance of vehicles operating on a range of future low sulfur fuels.

# EXECUTIVE SUMMARY

## Project Aims

This Project consisted of two parts.

Part A involved the measurement and reporting of the toxic emissions from 12 diesel vehicles when driven over the Composite Urban Emissions Drive Cycle (CUEDC) using a commercial grade diesel fuel. These vehicles were selected from the 80 vehicles used in Project 2.2 of the Diesel NEPM.

Part B involved the further testing of two of the vehicles used in Part A over the CUEDC using six different diesel fuel blends. These fuels represent different stages of the control of fuel specifications. Toxic (VOC, PAHs, aldehydes) and metal emissions were measured as well as particulate and gaseous emissions.

### What does the project deliver?

This report provides a comprehensive set of results of emission testing carried out on a sample of current technology diesel vehicles using the CUEDC.

Toxic emissions are reported from the testing of 12 vehicles using commercial diesel fuel. On two of these vehicles additional measurements are reported for toxic, PAHs, aldehyde and metal emissions as well as gaseous and particulate emissions on six different diesel fuels.

The six diesel fuel blends used in this project represent a range of existing, proposed or possible future fuel specifications from around the world. Sulfur content of the test fuels vary from 24 to 1700ppm, polycyclic aromatic content ranges from 0.5 to 9.9%, cetane index ranges from 44 to 58.7, total aromatics range from 7.7 to 33%, distillation T90 ranges from 309.7 to 333.8$^0$C. Each of these properties can affect the emissions from a vehicle.

## Introduction

This report provides the results of a test project undertaken by Parsons Australia Pty Ltd, with the participation and assistance of the CSIRO Energy Technology Section, under contract to Environment Australia.

This project is an adjunct to a DNEPM Project 2.2, which measured the gaseous, particulate and visible smoke emissions from 80 diesel vehicles using commercial fuel using the CUEDCs.

A single report is provided combining the results of both Parts A and B of this project. However, a separate supplementary report is provided detailing the work carried out relating to Part B - metals. This supplemental report is provided under Section 8 of this report. A further comprehensive CSIRO report is available giving complete results and discussion of their measurements of air toxics.

### Project Scope

The scope of this Project, as defined in the project proposal, for **Part A** is:

*To obtain a mass based emission result for a range of air toxics emitted from a set of 12 in-service diesel vehicles using the CUEDC.*

and for **Part B** is:

*To obtain an indication of the likely reductions in emissions of toxics, particulates, gaseous and metal emissions from current model diesel vehicles when operated on a range of diesel fuels with varying levels of sulfur content.*

The fuels used for this study were:

- Current Australian commercial fuel
- Euro 2 fuel
- Euro 3 fuel
- Euro 4 fuel
- World-Wide Spec Fuel (category 3)
- Typical current CARB commercial fuel

In particular the likely reduction in particulate emissions from reducing the sulfur content of diesel fuel is to be examined.

## Diesel Vehicle Emissions

### Test Procedures

Vehicle emissions were measured when operated on a chassis dynamometer, under laboratory conditions, using the appropriate “Composite Urban Emissions Drive Cycle” (CUEDC).

The CUEDC comprises four segments each of which represent different urban traffic conditions (congested, residential/minor roads, arterial roads and highway/freeway). A series of CUEDCs have been developed representing the various ADR vehicle categories. The particular drive cycle pertaining to the test vehicle category was used for each emission test.

The project was divided into two parts. Part A involved the measuring of the toxic emissions from 12 vehicles using commercial diesel fuel. Part B required additional testing of two the vehicles used in Part A, using five additional diesel fuel blends, and measuring toxic, gaseous and particulate emissions.

In Part B nine tests were performed on Vehicle 1, with repeat tests carried out using Euro 2, Euro 3 and CARB fuel, Eight tests were performed on Vehicle 2, with repeat tests carried out using Euro 4 and World-Wide fuel.

The test fuels used were representative of:

- Current commercial fuel
- Euro 2
- Euro 3
- Euro 4

- World –Wide Spec (category 3)
- CARB

The test fuels were chosen to represent progressive levels of stringency for the control of fuel properties considered important to control emissions from diesel vehicles. The specification of the current commercial fuel was the least stringent and the World-Wide fuel has the tightest specification.

The following emissions were reported for these tests:

For both **Parts A and B**:

- VOCs (monoaromatics and 1.3-butadiene)
- Aldehydes

And for **Part B**:

- $CO_2$
- CO
- $NO_x$
- HC
- Particulate mass by filter paper
- Particulate mass using laser light scattering photometry (LLSP)
- Particulate mass using Tapered Element Oscillating Microbalance (TEOM) instrument
- Average and Maximum Smoke Opacity
- PM1.0, PM2.5 and PM10 mass by APS
- Fuel Consumption
- Metals – refer section 8 for supplementary report

### Emissions

Whilst there has been a great deal of data collected in this test program it is difficult to determine the benefit that can be attributed to individual fuel properties or fuels.

### Air Toxics

Emissions of selected toxic species in diesel exhaust, conducted under Parts A and B of the Supplementary Toxic Study of the Diesel NEPM Preparatory Project 2.2 are reported.

Sampling and analytical methods were developed and used to measure volatile organics (VOCs, in this case monoaromatics and 1.3-butadiene), aldehydes and polycyclic aromatic hydrocarbons (PAHs) toxics in diesel exhaust emissions. Part A involved selecting 12 of the 80 vehicles tested for the NEPM project and measuring the emissions of the target species. Emissions are reported as g/km for each of the four road flow modes of a specially developed urban drive cycle (CUEDC). Vehicles were chosen such that two from each of the six vehicle classes were represented.

In Part B, two vehicles selected from the previous 12, were driven through the CUEDC with a range of diesel fuel formulations. The fuels ranged in sulfur content from 24-1700 ppm, and in total aromatics from 7.7-33 mass%. Emission rates (g/km) were determined for the same species.

## Conclusions

### Toxics – Part A and Part B

The results show that emission rates of the toxic species are consistent with those previously determined in US and European studies.

- Benzene is usually the most abundant monoaromatic species
- Aldehyde emission rates usually exceed VOC emission rates
- PAH emission rates are significantly less than VOC and aldehyde emission rates

The results obtained for VOCs and aldehydes show that lower sulfur and aromatic content of diesel fuel do not have a significant effect on emissions of these species. This suggests that the combustion process controls the formation of these species in diesel exhaust. Total emissions of PAHs, by contrast decrease as fuel aromatic content decreases.

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This result is, perhaps, not unexpected. The monoaromatics and aldehydes are not diesel fuel components, but are formed in the combustion process from fuel fragments produced in the initial oxidative pyrolysis of the fuel. These fuel fragments are hydrocarbon radical species that are largely derived from the major constituents of the fuel (straight chain aliphatic hydrocarbons and related species). Hence, their formation is largely determined by combustion conditions such as local stoichiometry and temperatures. The PAHs, on the other hand, are, in some cases, fuel components and their formation is closely related to carbonaceous particulate formation.

In the case of PAHs, there appears to be some effects of fuel quality on emissions. The results indicate that lower aromatic content fuels result in lower PAH emissions.

### Gaseous and Particulate Emissions - Part B

Gaseous and particulate emissions from diesel vehicles were found to be reduced with the use of new fuel formulations.

Whilst a relationship between particulate emissions and fuel sulfur content was demonstrated, because of the variations in important fuel specifications it is not possible to attribute all of the benefits only to the sulfur content reduction.

While it is not statistically sound to base a comparison of the fuels on the results of one set of tests, as an example, the following tables compare the performance of one of the vehicles when using Euro 4 and CARB fuel with the results recorded using the baseline fuel. The complete tabulation of these results is shown in Table 4.4.

*Percentage comparison of gaseous emission results using Euro 4 and CARB fuel compared to Baseline (standard) fuel. Vehicle 2 (Rigid Truck)*

| Fuel | $CO_2$ g/km | FC l/100km | CO g/km | $NO_x$ g/km | HC g/km | Sulfur content mg/kg |
|---|---|---|---|---|---|---|
| **Base Fuel emission results** | 782.4 | 32.9 | 3.45 | 10.6 | 1.01 | 1700 |

| % of Base result | Euro4 | 92% | 93% | 91% | 81% | 72% | 2.29% |
|---|---|---|---|---|---|---|---|
|  | CARB | 99% | 96% | 76% | 81% | 83% | 16% |

**Carbon Dioxide emissions and Fuel Consumption.**

Both $CO_2$ emissions and fuel consumption were reduced, by about the same percentage, when using Euro 4 and CARB fuel. It would be expected that there would be a close relationship between these results.

These emissions are not affected by fuel sulfur content but can be affected by fuel density and viscosity.

**Carbon Monoxide emissions**

CO emissions may be affected by density or cetane number but the variation in the percentage reductions recorded for the EURO 4 and CARB fuel cannot be explained.

**$NO_X$ emissions**

Similar reductions were recorded with each of the fuels. These reductions could be attributable to an increase in the Cetane number, reduced density and a decrease in T95 distillation temperature.

**HC emissions**

Significant reductions in HC emissions were recorded. The reasons for these reductions are not clearly established by this test program.

*Percentage comparison of particulate emission results using Euro 4 and CARB fuel compared to Baseline (standard) fuel. Vehicle 2 (Rigid Truck)*

| Fuel |  | LLSP Mass mg/km | TEOM Mass Mg/km | Filter Mass mg/km | Ave Opacity % | Max Opacity % | Mass PM1.0 % | Mass PM2.5 % | Mass PM10 % |
|---|---|---|---|---|---|---|---|---|---|
| **Base Fuel – particulates results** |  | 182.8 | 265.2 | 447.3 | 1.08 | 12.8 | 423.8 | 424.4 | 438.7 |
| **% of Base result** | **Euro4** | 76% | 76% | 64% | 206% | 175% | 62% | 62% | 63% |
|  | **CARB** | 70% | 75% | 67% | 165% | 152% | 63% | 63% | 66% |

Significant reductions were recorded for particulate emissions. These reductions can be due to reduced fuel density, reduced polyaromatic content of the fuel and sulfur content. It is not possible to determine why there was a greater reduction of PM1.0, PM2.5 and PM10 emissions for the use of CARB fuel in comparison to the EURO 4 fuel since the sulfur content of the CARB fuel was greater than that of the EURO 4 fuel and their polyaromatic content was the same.

Further testing would be required to establish the reason for these results.

The major benefits for reduced sulfur content of diesel fuel is that exhaust gas after-treatment devices can be fitted. The durability and long term efficiency of these devices is affected by the sulfur content of diesel fuel.

The increase in maximum and average opacity recorded cannot be explained and the results of the other vehicle tested showed reductions in both the maximum and average opacity (ref Table 4.3).

## Recommendations

This project has provided some valuable information on gaseous, toxic and particulate emissions from current model vehicles and an indication of the potential benefit from using new diesel fuel formulations.

However further testing would be required if information was needed to enable projections of the total toxic, aldehyde and PAH emissions from the whole in-service fleet.

In addition to obtain a more precise estimate of the benefit of introducing new diesel fuels, a larger sample of vehicles would need to be tested.

It is recommended that:

- A larger sample of vehicles is measured to collect more precise data on the toxic, aldehyde and PAH emissions from the diesel fleet using commercially available fuel and an advanced specification fuel such as either World-Wide spec fuel or Euro 4 fuel.

- To determine a more precise estimate of the potential benefits of introducing new diesel fuels, testing is carried out on a greater sample of vehicles but using two fuels – commercially available fuel (as a baseline fuel) and an advanced specification fuel such as either World-Wide category 3 spec fuel or Euro 4 fuel.

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## APPENDICES

# 1 INTRODUCTION

This Report outlines the facilities, equipment, vehicles and test results obtained during the Diesel NEPM Project 2-2 Supplementary Toxic Emission and Fuel Study. The Study was conducted in two distinct and very different parts:

- **Part A** - development of a toxic emission profile for the diesel fleet using commercial fuel,
- **Part B** - the comparison of emissions (gaseous, particulate, metals and toxics) between a range of diesel fuels.

The study was considered a supplementary study as it utilised the vehicles and testing protocols used in the Project 2-2 of the DNEPM. Project 2-2 required 80 vehicles to be tested across real world drive cycles to develop an emission (gaseous and particulate emissions) profile of the diesel fleet. For details refer to the Parsons Australia report dated May 2000 (commissioned by NEPC and available at www.nepc.gov.au).

While all testing was carried out at the Parsons Australia Heavy-Duty Testing Facility, the CSIRO Division of Energy and Technology was contracted to undertake the specific toxic/metal sampling and analysis work

The results and the analysis of the test data from the CSIRO report have been included in this report as has a supplementary report specifically on the emission of metals. All other activities pertaining to vehicle sourcing, test fuel, test protocols, sampling of gaseous and particulate emissions and those results are discussed in this report.

## 1.1 Objectives

The objectives for each part of this Supplementary Study are listed below:

**Part A – Toxic emissions profile of the diesel fleet**

> *To obtain a mass based result for a range of air toxics emitted from a base set of 12 vehicles during the drive cycle testing phase of the DNEPM Project 2-2.*

**Part B – Evaluation of emissions from the use of low sulfur/future fuels**

> *To obtain an indication of the likely reduction in emissions of toxics metals, particulates and gaseous emissions from diesel vehicles when operated on low sulfur fuels.*

The evaluation of Part B was separated into three additional sub-parts based on the specific pollutants being measured:

1: Measurement of toxic, PAHs and aldehyde emissions
2: Measurement of gaseous and particulate emissions
3: Measurement of metals

## 1.2 Context for the work

The diesel NEPM preparatory work, which this Study supplements, is underpinned by strong commitment of Commonwealth, State and Territory Governments to reduce the environmental impacts of motor vehicles. It complements other activities and projects undertaken or sponsored by Commonwealth Agencies, with support and assistance from NEPC, the National Road Transport Commission (NRTC) and their joint Motor Vehicle Environment Committee (MVEC). The following commitments, activities and projects are of particular relevance to diesel vehicles –

- The Commonwealth Government's *Environmental Strategy for the Motor Vehicle Industry,* first announced by the Prime Minister in 1997, which among other things sought the 'progressive tightening of noxious emission standards with a view to harmonisation with International Standards by 2006'.
- The Prime Minister's commitments under the *Measures for a Better Environment* elements of the *Tax Package Agreement* of May 1999. This sought (among other things) a mandated maximum sulfur level of 50 ppm in all diesel fuel by 1 January 2006, and for incentives to be provided during 2003/4/5 to accelerate introduction of this ultra-low sulfur (ULS) diesel into the market. The Agreement also sought early introduction of Euro vehicle emission standards. New tax legislation incorporating this Agreement was passed by the Parliament in June 1999.
- MVEC's *Review of Motor Vehicle Emission Standards* published in January 1999, and *Revised Emission Standards Package* of June 1999, which recommended the introduction of Euro 2 or 3 diesel vehicle emission standards in 2002/3, and Euro 4 diesel vehicle emission standards in 2006/7.
- The *Review of Fuel Quality Requirements for Australian Transport* (final report published March 2000) carried out by Coffey Geosciences Pty Ltd under contract to Environment Australia.

## 1.3 The need for control of toxics

The emissions from vehicles fuelled with diesel fuel are a complex mixture of inorganic and organic compounds that can be present in gaseous, liquid and solid phases. As with other fossil fuel combustion sources, the primary gaseous components are nitrogen ($N_2$), oxygen ($O_2$), carbon dioxide ($CO_2$), and water vapour ($H_2O$). However, combustion of diesel fuels in vehicles also results in the formation of a very large variety of trace compounds, and gives rise to some significant concerns about potential effects on human health. For example, a number of the exhaust components, such as arsenic, benzene and nickel, are known to cause cancer in humans. In excess of 40 components of exhaust have been listed as Toxic Air Contaminants (TACs) by the Californian Air Resources Board (CARB), and as hazardous air pollutants (HAPs) by the US EPA (CARB, 1998). Table 1.1 lists the compounds identified by CARB. CARB has also begun a process to reduce health risks posed by toxic air contaminant emissions from diesel-fuelled engines.

A large amount of work has been directed to diesel emissions of fine particulates and the soluble organic fraction of the particulates (polycyclic organic compounds (PACs) and other species of low volatility). However, in spite of the documented emission of gaseous TACs and/or HAPs in diesel exhaust, much of this work is qualitative in nature. It is difficult to obtain quantitative information on emissions of toxic compounds as a function of fuel burnt or distance travelled. According to a recent analysis (HEI, 1995) by the Health Effects Institute "the composition of diesel exhaust varies considerably depending on engine type and operating conditions, fuel, lubricating oil, and whether an emissions control system is present." Diesel engine emissions are also likely to have changed significantly over the past 30 years because of improvements in engine technology, emission controls, and fuel formulation.

In their review of the potential health effects of diesel emissions (CARB, 1998) CARB note that "the total emissions of toxic diesel exhaust species have not been estimated because inadequate analytical methods...prevent the detection and quantification of the many individual toxic and potentially toxic species and their atmospheric contribution". In fact CARB and others have initiated research to improve and refine the estimates of exposure to the gas-phase portion of the exhaust.

*Table 1.1. Substances in Diesel Exhaust Listed by the CARB as Toxic Air Contaminants*

acetaldehyde
acrolein
aniline
antimony compounds
arsenic
benzene
beryllium compounds
biphenyl
bis[2-ethylhexyl]phthalate
1,3-butadiene
cadmium
chlorine
chlorobenzene and their derivatives
chromium compounds
cobalt compounds
cresol isomers
cyanide compounds
dioxins and dibenzofurans
dibutylphthalate
ethylbenzene
formaldehyde

hexane
inorganic lead
manganese compounds
mercury compounds
methanol
methyl ethyl ketone
naphthalene
nickel
4-nitrobiphenyl
phenol
phosphorus
POM, including PAHs

propionaldehyde
selenium compounds
styrene
toluene
xylene isomers and mixtures
o-xylenes
m-xylenes
p-xylenes

# 2 BACKGROUND

Diesel vehicles are a major source of air pollutants that are now widely acknowledged to have a direct impact both on human health and on overall emissions of greenhouse gases.

In Australia, diesel vehicles are an increasingly significant source of criteria air pollutants (i.e. those included in the National Environment Protection Measure (NEPM) on Ambient Air Quality, issued by the National Environment Protection Council (NEPC) in 1997. These include:

- ozone ($O_3$), nitrogen dioxide ($NO_2$), and suspended particulate matter ($PM_{10}$), and
- to a lesser extent, carbon monoxide (CO) and sulfur dioxide ($SO_2$).

Diesel vehicles are also of increasing concern as a source of non-criteria air pollutants (those not included in the NEPM) –

- fine, and ultra-fine particulate matter ($PM_{2.5}$ and $PM_{1.0}$),
- reactive organic compounds (ROCs), and
- a range of toxic compounds.

Diesel vehicles also emit a significant and growing proportion of Australia's total greenhouse gases (mainly carbon dioxide ($CO_2$)). These emissions would be subject to control world wide through the Kyoto Protocol to the UN Framework Convention on Climate Change, signed by Australia in 1998 (Commonwealth of Australia 1998). When ratified, the Protocol would impose legally binding limits for greenhouse gases on a nation by nation basis.

The absolute contribution of diesel vehicles to total pollutant and greenhouse emissions has been growing due to their increasing numbers in the fleet and distances travelled. Their relative emission contribution to pollutant emissions has also been growing because (until quite recently) diesel emissions have been largely unregulated, unlike pollutant emissions from petrol vehicles and industrial sources, where control programs have led to progressive reductions.

The diesel emissions of concern are –

- **Air toxics**. These include aromatic compounds (such as benzene, toluene, 1-3 butadiene, PAH), various aldehydes, alkanes, alkenes, and ketones. They also include a number of metals and their inorganic and/or organic compounds. These and other contaminants are listed as *Hazardous Air Pollutants* by the US EPA, and as *Toxic Air Contaminants* by the State of California. Some of these contaminants are emitted as gas or as particles. Others are emitted as liquids, which may be adsorbed by particulate matter. Mostly, these air toxics are emitted in very low concentrations, but contribute significantly to the toxicity of ambient air. In 1999, the California Air Resources Board identified diesel exhaust as a Toxic Air Contaminant.
- **Particulate matter**, which adds directly to atmospheric fine particle loading ($PM_{10}$). According to the California Air Resources Board (CARB 1998) 98% of diesel particles are less than 10 µm diameter, 94% less than 2.5 µm diameter, and 92% less than 1 µm diameter. The large fractions of diesel particulate in the fine and ultra-fine ranges are of particular (and growing) concern to health professionals. Particulate matter generally in the range of ½ to 2 µm, causes the light absorption and scattering associated with visible smoke and atmospheric haze.

- **Oxides of nitrogen (NOx)** which react in the atmosphere with ROCs to form a number of secondary air pollutants. These include Ozone ($O_3$ - a principle constituent of photochemical air pollution, or smog), $NO_2$, and nitrate aerosols (which add to atmospheric particle loading).
- **ROCs**, comprising mainly hydrocarbons (HC) but including many other reactive species contributing to formation of photochemical air pollutants (including O3) and organic aerosols (which add to atmospheric particle loading).
- **Sulfur compounds** (originating as sulfur in diesel fuel), which add to atmospheric SO2, and form sulfate aerosols in the atmosphere contributing to atmospheric particle loading.
- **CO**, which adds directly to atmospheric CO pollution.
- **$CO_2$**, and much smaller amounts of $N_2O$ and methane ($CH_4$), which contribute directly to total greenhouse gases.

## 2.1 Regulatory environment

Growing concern in many of the major world population centres over the last twenty years and more over health and visibility problems attributable to emissions from motor vehicles has led to progressively tightening emission standards for all new motor vehicles.

Initially regulatory action was directed primarily at reducing emissions from petrol engined passenger and light commercial vehicles. However, as the emission standards for these classes of vehicles were progressively tightened, it became apparent that more stringent action needed to be taken to reduce the emissions of all diesel vehicles.

Research into means to reduce the emissions from diesel vehicles has established that modification to the specification of commercial diesel fuel is necessary to implement and optimise the emission reductions possible from diesel engines. More stringent diesel fuel standards have been progressively introduced to assist primarily in reducing the emissions of $NO_x$, Particulates, $CO_2$ and fuel consumption.

The following list details the anticipated benefits of changing specific fuel properties.

Increasing the Cetane Number (or Index) of diesel fuel has been shown to decrease $NO_x$ emissions. In addition HC emissions may reduce and fuel consumption decrease. CO emissions may be reduced in some cases.

Control of both the minimum and maximum values of fuel density is required to optimise the effect of mechanical fuel injection timing on emissions, fuel consumption and engine performance.

Reducing fuel density has been shown to reduce particulate emissions from all diesel vehicles and $NO_x$ emissions from heavy diesel vehicles. However reducing fuel density may reduce engine power and decrease fuel economy but $CO_2$ emissions may decrease marginally.

It is well established that reducing the sulfur content of diesel fuel can result in the reduction of particulate emissions.

In addition, to comply with advanced emission control standards it may be necessary to fit "De-$NO_x$" exhaust catalyst systems. The effectiveness and durability of these catalyst systems are improved by reducing the sulfur content of the fuel.

As the aromatic content of diesel fuel is reduced the maximum combustion flame temperature and $NO_x$ emissions are reduced. Reducing the Polyaromatic content of diesel has been found to reduce particulate and PAH emissions.

Modification to the distillation curve of diesel fuel to reduce the upper boiling temperature range, T90, T95 and final boiling point, has been shown to reduce emissions of soot, smoke and particulates.

It can be seen from the table of diesel fuel specifications of the fuels used in this test program (Table 4.3) that progressive changes to the specifications for diesel fuel have accompanied the introduction of more stringent European emission standards.

The World-Wide Spec fuel has been proposed by industry representatives from Europe, Japan and USA for introduction as a future world-wide diesel fuel specification. The proposal to standardise fuel properties would form part of a package aimed at having common vehicle emission standards around the world.

Table 4.3 shows that the cetane number, density, T90 & T95, sulfur and aromatics are progressively reduced as the more stringent fuel standards (Euro 2, Euro 3, Euro 4 and World-Wide Spec) are introduced.

The aim of these modifications to fuel properties is to assist primarily in reducing emissions of $NO_x$ and particulates (including smoke). Reductions of HC, $CO_2$, CO and fuel consumption may also be achieved.

Due to the limited testing included in this program, it is unlikely that the full potential benefits of the various fuels and their individual properties can be established with statistical certainty. Some benefits may be more apparent when heavy vehicles are tested and other benefits may be more apparent with light vehicles. It is even possible that while some changes can improve performance in light vehicles they could make performance worse in heavy vehicles and vice-versa.

### 2.1.1 The need for standardisation

When new Australian Standards are being considered it is now necessary to, not only justify the need for a new standard but also to justify any proposal to depart from accepted common overseas standards. A decision to introduce unique Australian standards may need to be justified to the World Trade Organisation.

With consideration being given to introducing more stringent emission standards for all diesel vehicles the requirement for new fuel standards must be considered in parallel.

It is now considered inevitable that any new vehicle emission will be aligned with European standards and to obtain the benefits available from adopting these standards European diesel fuel standards will probably also need to be introduced.

Vehicle exhaust standards apply to emissions of NOx, HC, CO, total particulate, and smoke opacity. Future European, US and Japanese standards are tending to converge in response to growing globalisation of the automotive industry.

In Europe, new standards are being introduced in five progressively more stringent steps, Euro1 from 1992, Euro2 from 1995, Euro3 from 2000, Euro4 from 2005 and Euro5 from 2008. The technical requirements of these standards are being progressively adopted as United Nations ECE standards, which are the bases for standards set in many non-European nations.

More stringent fuel specifications are required for compliance with most stages of emission control stringency.

In Australia prior to 1995, diesel-vehicle engines were only required to be certified to Australian Design Rule (ADR) 30, which set limits for smoke opacity. All diesel engines (and most diesel vehicles) marketed in Australia are imported. At this time, there is little published information to indicate the gaseous and particulate emission standards these vehicles/engines were actually designed to meet.

ADR 70, phased in between 1995 and 1997, set emission limits for NOx, HC, CO, particulate and smoke opacity by reference to European, USA and Japanese standards current in 1994.

Recently, the Australian Government adopted new ADRs 30.01(smoke), 79.01 and 79.02 (emissions from light vehicles), 80.01 and 80.02 (emissions from heavy vehicles). For diesel vehicles, these new ADRs adopt the technical requirements of Euro2/3 for implementation in 2002/3, and the technical requirements of Euro4 for implementation in 2006/7. (For heavy vehicles, US 1998 is specified as alternate to Euro2/3, and US 2004 is specified as alternate to Euro4.)

It is anticipated that these new ADRs will be introduced as Trans Tasman Vehicle Standards, and will substantially reduce new vehicle emission levels. The US 1998 and Euro3 standards adopt new requirements for emissions durability and for on-board diagnostics, which are expected to significantly improve in-service compliance.

## 2.2 The need for 'real world' emissions data

Design certification testing for heavy-duty diesel vehicles/engines supplied in Australia, has in all cases been carried out overseas. These emissions type-certification tests have been based upon engine bench test procedures, which are difficult to relate to actual vehicle performance under 'real world' driving conditions. Currently, there are no applicable standard procedures for emissions testing of completed diesel vehicles (as opposed to engines) anywhere in the world.

Estimates of diesel vehicle emissions have hitherto been based upon overseas derived 'emission factors', developed mainly from desk analyses of emission results from type-certification engine bench tests. For the Australian fleet, emissions estimates for inventory purposes have been derived mainly from US EPA 'emission factors'. While these may be representative of vehicles in the US, they have doubtful application for vehicles in Australia. As a result, local inventories of diesel vehicle emissions are at best crude, providing doubtful guidance for emission control policy.

Over the last several years a number of researchers, particularly in North America and Europe, have studied in-service vehicle emissions performance, reflecting growing concern for the health and environmental impacts of diesel vehicle emissions. However, there remains almost a complete lack of representative data that can be extrapolated to the Australian context, and that would provide reliable information on the performance of the Australian heavy-duty diesel fleet.

This Project, in combination with others comprising the preparatory work for the diesel NEPM, aims to provide additional information on the emissions performance of Australian diesel vehicles. Toxic emissions from diesel vehicles are studied and the effects of varying diesel fuel specifications on toxic, gaseous and particulate emissions have been reported.

This study will assist Governments in developing credible inventories of fleet emission performance, including toxic and particulate emissions. The likely benefits from introducing more stringent diesel fuel standards will also be presented for consideration.

# 3 PROJECT OUTLINE

## 3.1 Scope

The objectives for the project were set out in the Project Specification. These objectives, together with the scope of activities carried out to achieve them, are shown below.

### Part A – Toxic emission profile of the diesel vehicle fleet

*Objective:* ***To obtain a mass based result for a range of air toxics emitted from a base set of 12 vehicles during the drive cycle testing phase of the DNEPM Project 2-2.***

Twelve vehicles, two from each ADR category were identified as candidates for the measurement of toxic emissions from the 80 vehicles selected under Project 2-2. These vehicles were referred as the base case and were tested using the same batch of commercial fuel (0.17% sulfur) as used in Project 2-2.

For each vehicle, separate measurements of each nominated emission and fuel consumption were made over each of the four road-flow conditions of the CUEDC, and for the overall CUEDC. However for the 12 vehicles selected for this Study the following toxic emission were also measured:

- The 16 USEPA priority polycyclic aromatic hydrocarbons (PAH's);
- Four volatile organic compounds (VOCs); and
- Two of the prominent aldehydes – formaldehyde and acetaldehyde

The standard measurements performed during Project 2-2 were –

- Oxides of nitrogen (NOx),
- Particles (mass and size),
- Carbon monoxide (CO),
- Carbon dioxide (CO2),
- Total hydrocarbons (THC),
- Visible smoke (opacity),
- Fuel consumption.

The results of these measurements have not been reported in this part of the report.

The CUEDCs (one for each ADR category) were used for all emission testing and each vehicle subjected to an inertia load equal to its tare mass plus half its cargo capacity, i.e. ½ (tare mass + gross vehicle mass {GVM}).

**Part B – Evaluation of emissions from the use of low sulfur/future diesel fuels**

*Objective:* ***To obtain an indication of the likely reduction in emissions of toxics, metals, particulates and gaseous emissions from current technology diesel vehicles when operated on a range of fuels of different specifications, including low sulfur content.***

Only two vehicles were used for this part of the study. A Toyota (Light Commercial <3.5t GVM) and an Isuzu (Rigid Truck 3.5-12t GVM). These particular vehicles represent the most common in their categories used in the urban environment. Six different fuels, varying in sulfur content, and other properties, were evaluated on each vehicle.

The same CUEDC test procedures were used as in Part A.

## 3.2 Test fuel

The group of 12 vehicles tested under Part A were fuelled with a single batch of commercially available diesel fuel (0.17% sulfur).

The six fuels used in Part B of the Study contained varying amounts of sulfur (and other properties) as required by overseas regulations and were sourced from specific refineries as outlined below.

**Commercial diesel fuel:** two of the forty 200-litre drums of commercial diesel fuel batched by Shell in Melbourne for use in Project 2-2 were used as the baseline fuel.

**Euro 2 fuel:** was produced and drummed by BP at its Kwinana refinery in Western Australia and transported to the test facility.

**Euro 3, 4 and World-Wide Fuel Charter (category 3) fuels:** were drummed into 25 litre containers by BP in the United Kingdom and air-freighted to the test facility. A total of 125 litres of each fuel type was sourced from the UK.

**CARB fuel**: was drummed into three 200 litre containers at the Mobil refinery in Los Angeles, California, USA.

Table 3.1 lists the tests performed (**X**) on each vehicle for each of the fuels. Note: vehicles indicated (**XX**) had two tests performed.

*Table 3.1: Fuels tested on each vehicle*

| **Test Fuel** | **Toyota** | **Isuzu** |
|---|---|---|
| Commercial Project 2-2 | **X** | **X** |
| Euro 2# | **XX** | **X** |
| Euro 3* | **X X** | **X** |
| Euro 4* | **X** | **X X** |
| World Wide Fuel Charter* | **X** | **X X** |
| CARB+ | **XX** | **XX** |

Test fuels 'as supplied' by # BP Kwinana WA; * BP London UK; and + Mobil California USA.

Environment Australia arranged the supply of all fuel, excluding the commercial Project 2-2 fuel and the CARB fuel.

*Table 3.2 Fuel characteristics*

| | Cetane No | Cetane Index | Density @15ºC (kg/l) | T10% (ºC) | T50% (ºC) | 90% (ºC) | T95% (ºC) | Sulfur Content (mg/kg) | Mono Aromatic (%) | Poly Aromatic (%) | Total Aromatic (%) | Calorific Value (MJ/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Fuel | | 45.5 | 0.862 | 243 | 278 | 326 | | 1700 | | | 33 | |
| Euro 2 | | 56 | 0.830 | 210 | 274.8 | 333.8 | | 480 | | | | |
| Euro 3 | 53.5 | 51.6 | 0.832 | 225 | 268 | 310 | 336 | 210 | 14.1 | 9.9 | 24 | 42.99 |
| Euro 4 | 58.3 | 57.7 | 0.829 | 231 | 278 | 327 | 340 | 39 | 9.8 | 1.8 | 11.6 | 42.97 |
| Worldwide | 55.7 | 58.7 | 0.823 | 224.6 | 267.5 | 309.7 | 321 | 24* | 7.2 | 0.5 | 7.7 | 43.03 |
| CARB | 49.8 | 44 | | | | | | 264 | 19.5 | 1.8 | 21.3 | |

## 3.3 Outline of facilities and equipment

A description of the Parsons Australia Vehicle Test Facility, and the equipment and instrumentation used to carry out this study, follows.

The operational centrepiece of the facility is the heavy-duty vehicle test cell and instrument laboratory, which were equipped and commissioned during July and August 1999, specifically to carry out preparatory work for the NEPC Diesel NEPM. They provide capability to conduct a full range of tests and analyses of heavy-duty diesel vehicle exhaust emissions.

A schematic plan view of the test cell and laboratory is shown in figure 3.1 below. A picture taken from within the test cell is shown in figure 3.2.

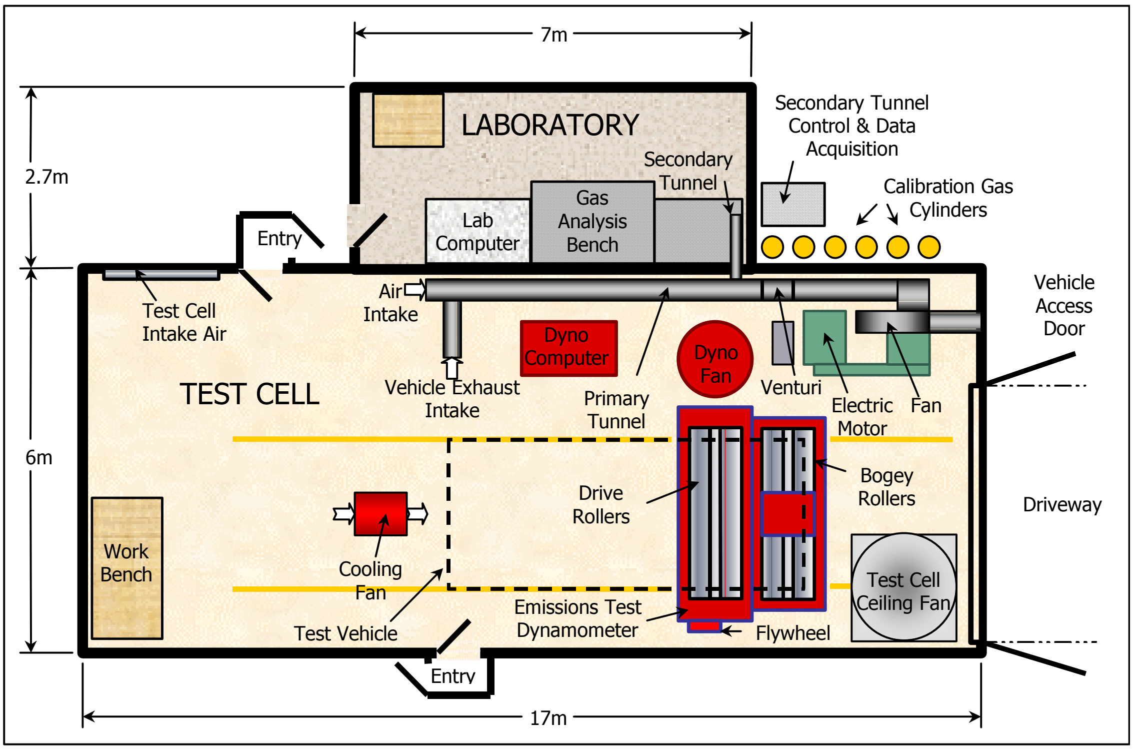


*Figure 3.1: Schematic plan view of test cell and laboratory.*

### 3.3.1 Dynamometer

The custom-built Dyno Dynamics heavy-duty chassis dynamometer is shown in Figure 3.2. This dynamometer incorporates sophisticated control software and electronics that support complex, transient drive cycle testing of vehicles, with inertia simulation for vehicles to 45 tonnes GVM and beyond. It uses large diameter rollers to reduce the potential for tyres to overheat, a 'drivers aid' to display the appropriate drive cycle trace and a single flywheel to provide a base inertia of 1360kg (this falls within the IM240 equipment specification). Acceleration inertia above 1360kg is simulated electrically via the eddy current brake and controlled by the drive cycle software.

The custom-developed open-access dynamometer software allows any drive cycle to be quickly loaded as a time-speed Excel spreadsheet file into the control computer.

The chassis dynamometer was capable of testing the full range of vehicles listed in the project brief. Four wheel drive vehicles were tested by disengaging the front wheel hubs and allowing only the rear wheels to drive. Bogie-axle vehicles were tested by locating the rear wheels on the dynamometer idler rollers, and engaging the power divider so that only the front wheel set drove the rollers. Permanent all-wheel drive vehicles were not tested.

*Figure 3.2: Dyno Dynamics Chassis Dynamometer inside the test cell looking rearward towards the vehicle entry doors*

### 3.3.2 Sampling and Analytical Systems

The overall sampling system and layout of the instruments, as used in this project, is shown schematically in Figure 3.3. Essentially, the system comprised the following main components:

- the primary and secondary exhaust dilution system
- the gas analysis system
- the particle analysis system
- the toxic analysis system
- the data acquisition system.

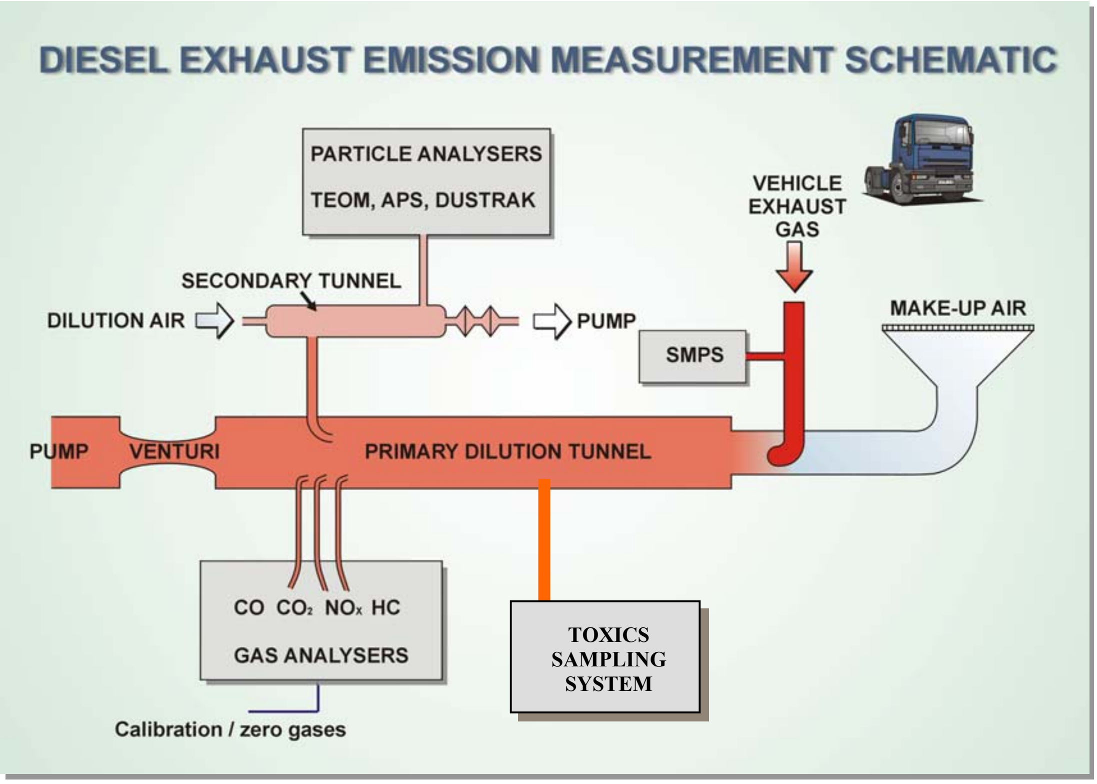


*Figure 3.3: General Layout of Sampling and Analytical Systems.*

### *3.3.2.1 Primary and Secondary Exhaust Dilution System*

The full flow, two-stage exhaust dilution system was designed and constructed to Parsons' specifications by the staff of the Energy and Fuels Research Unit at the University of Auckland (UA), with input and guidance from staff of the exhaust emissions laboratory at West Virginia University in the United States.

The system utilises the *constant volume flow* (CVS) concept with *electronic flow compensation* (EFC), and was designed –

- To meet the requirements of the US Code of Federal Regulations (CFR), Title 40, Subpart B, §86.110-94, applicable to (*inter alia*) 'light duty diesel vehicles' and 'light duty diesel trucks'.
- To enable these technical requirements to be met while testing heavy-duty diesel vehicles, for which the CFR has no chassis dynamometer test requirements.

The toxic, CO, $CO_2$, $NO_x$, and hydrocarbon analysers sampled the diluted exhaust stream from the primary tunnel. All of the particle analysers except the scanning mobility particle sizer (SMPS) sampled from the secondary tunnel.

### *3.3.2.2 Gas Analysis System*

The diluted exhaust gas in the primary tunnel was analysed with a range of on-line, continuous analysers for $CO_2$, CO, $NO_x$ and total hydrocarbons. The analogue output from each instrument was continuously logged by the data acquisition system. The various instruments and their manner of use was generally in conformance with US CFR Title 40, Subpart B, §86.111-90/91.

### 3.3.3 Particle Analysis System

A series of on-line particle analyses instruments were used to provide continuous measurement of the total mass and size distribution of particles within the exhaust.
These included –

- A TSI Inc laser light-scattering photometer (LLSP), specially calibrated for diesel exhaust particulate size distributions, was used for on-line measurement of particle mass during all vehicle tests. The LLSP was set up to measure particles up to 10 microns (PM10).
- A Rupprecht & Patashnick Co Inc Model 1105 Diesel TEOM instrument was run routinely during drive cycle testing for each vehicle. The TEOM was run with no cut-off sampler so that it measured all particles in the sample gas stream (TSP).
- A TSI Model 3310 Aerodynamic Particle Sizer (APS) was used for continuous measurement of particle size distribution during all drive cycle testing. The APS measures particles in the size range of ~0.5 to 50 µm.

Consistent with standard certification testing procedures for particulates, primary and backup filters collected total suspended particulate (TSP) samples from the secondary tunnel. Computerised mass flow controllers were used to measure and regulate sample and dilution-air flow through the filters. Standard gravimetric methods were used for weighing the primary and backup filters. All particle instruments (apart from the SMPS) were connected to the secondary tunnel through isokinetic sampling nozzles for each instrument. The secondary tunnel sampling arrangement is shown in figure 3.4.

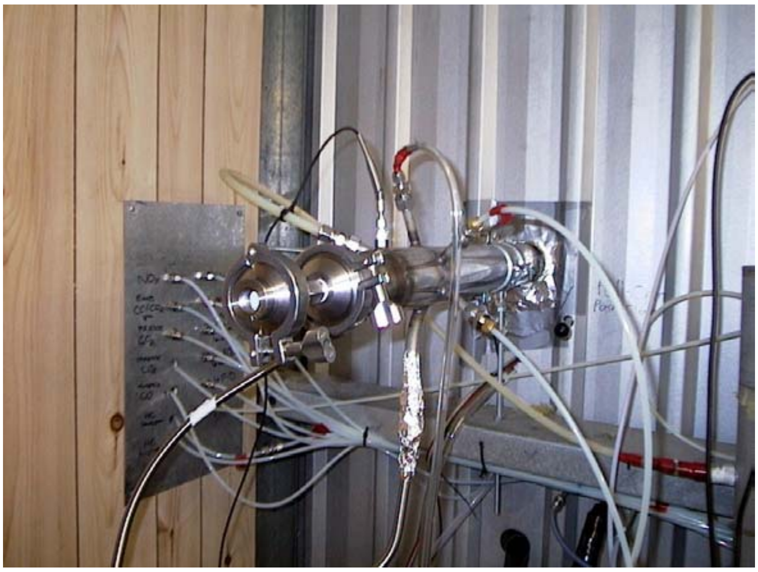


*Figure 3.4: Secondary Tunnel Particle Sampling Arrangement*

In addition, a scanning mobility particle sizer (SMPS) measured particle size distribution within the range 0.04 to 0.5 µm, of 'grab-samples' taken from the raw exhaust inlet during the D550 short test.
A smoke opacimeter was connected into the exhaust sampling system, upstream of the dilution air inlet to the primary tunnel.

### 3.3.4 Toxic Sampling System

Toxic emissions of polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and aldehydes were sampled from the 12 vehicles in Part A and the two vehicle in Part B. In all cases, each mode of the CUEDC was sampled continuously from the time when the secondary tunnel was opened until it was closed at the end of the mode.

Sampling for toxics was through a ¾ inch stainless steel manifold connected to the primary dilution tunnel via a ¼ inch Teflon line. A separate sampling stream was provided for PAHs, VOCs and aldehydes as shown in Figure 3.5 below.

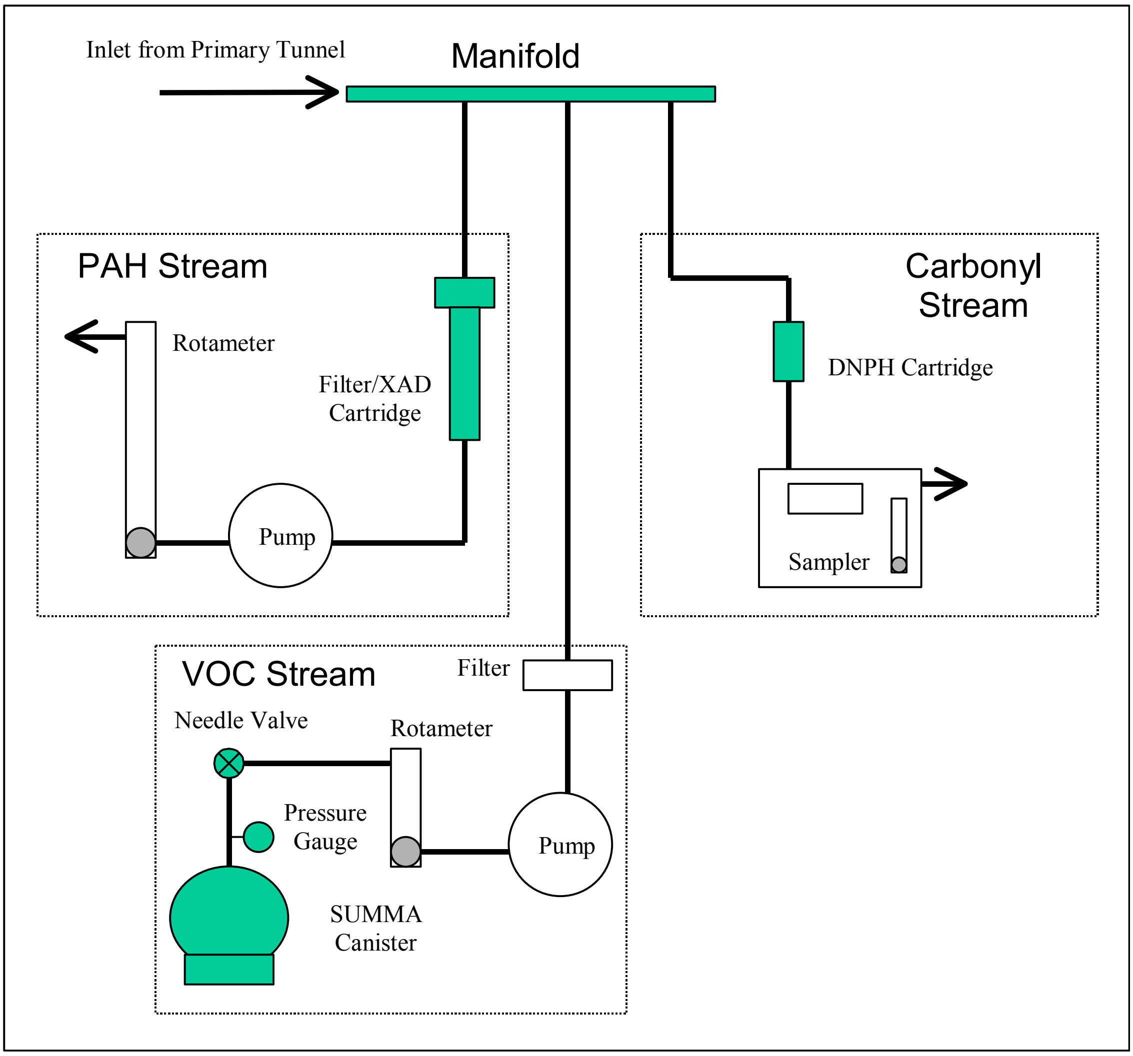


*Figure 3.5 Toxic sample handling schematic*

For PAHs, diluted exhaust was sampled from the manifold with a small diaphragm pump at about 6-8 L/min and passed through a glass sample holder 20 mm in diameter and 75 mm long (supplied by Supelco Inc) containing about 8 g of XAD-2 resin (also supplied by Supelco Inc). This gave a resin bed length of between 50 and 60 mm. A 27mm diameter glass fibre (GFA) filter was placed in front of the resin bed to collect particulates. A rotameter installed downstream of the pump measured the sample flowrate so that the total volume of gas collected could be determined. Samples were protected from light and refrigerated until required for analysis.

For VOCs, samples of diluted exhaust were collected in one-litre electro-polished, passivated stainless steel SUMMA canisters (Scientific Instrumentation Specialists (SIS), USA) for analyses of 1,3-butadiene, benzene, toluene and the xylene isomers. Prior to use the canisters were cleaned using an ENTECH canister cleaning system which evacuates the heated canisters with a dual pumping system (roughing pump and molecular drag pump). During the cleaning process the canisters are first evacuated to remove previous sample material, and then filled with clean nitrogen (from the boil off from a liquid nitrogen tank) to 35 kPa pressure and re-evacuated. The latter procedure is repeated 3 times, and the canister is then left for 30 minutes being pumped on by the molecular drag pump. This procedure gives very low background concentrations of hydrocarbons.

During sampling, diluted exhaust was withdrawn from the manifold and pumped into the canister with a small Teflon diaphragm pump (Scientific Instrumentation Specialists, model N05-SV1). A 47mm glass fibre filter prevented particulate matter from entering the system. The flow rate of gas into the canister was adjusted with a rotameter and needle valve so that the final pressure in the canister was between 35 and 70 kPa. The samples were then transported from the vehicle test facility to the CSIRO laboratories and analysed on the day of collection to minimise decay of the hydrocarbon species.

Carbonyl compounds (aldehydes) were sampled using Supelco Inc LpDNPHS10L sample cartridges. These cartridges contained 2,4-dinitrophenylhydazine (DNPH) supported on a silica substrate. The DNPH reacted *in-situ* with carbonyls to yield derivative compounds that were later extracted and analysed for formaldehyde and acetaldehyde by an HPLC technique. Diluted exhaust was drawn through the cartridges at a rate of about 1 L/min for the duration of the sampling period. Initially, a personal sampler, which was a self-contained pump and flow control device, was used for this purpose, however, it was prone to cut out during a test. It was therefore replaced by a separate pump and needle valve capable of maintaining a constant flow rate during each test. The exposed cartridges were capped and stored in light-proof sachets then refrigerated until required for analysis.

#### *3.3.4.1 Analytical Methods*

Samples were analysed by a range of chromatographic techniques which are described in detail below.

*a) Volatile Organic Compounds (VOCs).*

The analytical method for VOCs was developed in-house and is based on a Perkin Elmer Corporation technique for analysis of ozone precursor VOCs using thermal desorption and gas chromatography (TD/GC). The method is applicable to the determination of the target VOCs, required for the diesel NEPM project, namely:

- Benzene

- Toluene
- Total xylenes
- 1,3-butadiene.

The method utilises a Perkin Elmer ATD400 thermal desorption system linked to a HP 5890 Series II GC. The ATD is equipped with an air sampling accessory, which allows direct injection of controlled volumes of gas from SUMMA® canisters. An amount of the exhaust or calibrant gas is drawn through a bed of adsorbent material designed to trap and concentrate the VOC compounds of interest. The trap is rapidly heated and the sample is transferred to the GC. The low molecular weight species ($C_2$ - $C_5$) are separated on an $Al_2O_3/KCl$ PLOT column for detection by a flame ionisation detector (FID). At a predetermined time the higher boiling species are redirected away from the PLOT column and are detected by a second FID after separation on a methyl silicone column. This dual column, dual FID system enables efficient separation and detection of hydrocarbon mixtures containing components of low to mid-volatility.

The system was calibrated using an ozone precursor standard gas mixture, and 1,3-butadiene and propane standard gases. The VOC compounds of interest were identified by comparing their retention times to the standard compounds and quantified based on their area response entered into a linear regression equation obtained from the calibration curve.

Under the conditions used in the analysis the following quality assurance data were obtained:

- Method quantitation limit: 0.2 ppbV for $C_2 - C_5$ compounds (PLOT column), 0.1 ppbV for $C_6 - C_{12}$ compounds (methyl silicone column).
- Precision: ±10% RSD, measured at 1.0 ppbV over five replicate injections of standard gas mixture.
- Accuracy: 93 - 107 %, measured at 1.0 ppbV using a standard gas mixture.

Unlike the other VOC species reported, 1,3-butadiene is unstable in vehicle exhaust due to its reaction with $NO_x$. To compensate for this, a correction based on the method developed by Ye et al, 1997, was applied to the analytical results. In this method, the rate of decay of 1,3-butadiene is taken to follow first order kinetics according to the integrated rate expression:

$$(1) \qquad \ln C = -kt + \ln C_0$$

Where $C$ is the measured concentration of 1,3-butadiene, $k$ is the 1st order rate constant, $t$ is the elapsed time between sampling and analysis and $C_0$ is the concentration of 1,3-butadiene at the time of sampling. The rate constant was found by Ye et al to be a linear function of the $NO_x$ concentration as shown in Equation 2.

$$(2) \qquad k = 0.0012 \pm 0.0004[NO_x]$$

The average $NO_x$ concentration in each segment was calculated from the data provided by the on-line $NO_x$ analyser used for the exhaust gas analysis. Substituting the appropriate values into Equations 1 and 2 and solving for $C_0$ yielded the actual concentration of 1,3-butadiene in the exhaust. This value was used for calculating the emission rates shown in the Results section of this report.

### *(b) Polycyclic Aromatic Hydrocarbons*

The analytical method used for the extraction and determination of PAH was developed in-house and is based on US EPA Method TO13 for determination of benzo(*a*)pyrene and other polycyclic aromatic hydrocarbons in ambient air using gas chromatography and mass spectrometry (GC/MS).

The method is applicable to the determination of the sixteen US EPA priority PAHs, targeted in this project, namely:

- Naphthalene
- Acenaphthylene
- Acenaphthene
- Fluorene
- Phenanthrene
- Anthracene
- Fluoranthene
- Pyrene
- Benz(*a*)anthracene
- Chrysene
- Benzo(*b*)fluoranthene
- Benzo(*k*)fluoranthene
- Benzo(*a*)pyrene
- Indeno(1,2,3-*cd*)pyrene
- Dibenz(*a,h*)anthracene
- Benzo(*g,h,i*)perylene

PAHs collected on the GFA filter and XAD-2 resin were extracted in a soxhlet apparatus with dichloromethane. Prior to extraction, each sample was spiked with a standard mixture of five deuterated PAH compounds to determine the extraction efficiency and accuracy of the method. The extracted mixture was concentrated using the Kuderna-Danish concentration technique.

The extract was introduced to a HP 5890 Series II GC using splitless injection onto a phenyl methyl silicone column. Detection, using a HP 5971A quadrupole mass spectrometer, was in the selected ion monitoring (SIM) mode.

Calibrant solutions were prepared from a commercially available sixteen component PAH mixture. The PAH compounds present in the samples were identified and quantified by comparing their retention times and ion peak areas to the standard.

Under the conditions used in the analysis the following quality assurance data were obtained:

- Method quantitation limit: 0.005 μg/PAH component.
- Precision: ±10% RSD, measured at 1.0 μg/mL over five replicate injections of standard solution.
- Accuracy: 70 - 80 % for volatile PAHs, 90 - 100 % for semivolatile and nonvolatile PAHs, measured at 1.0 μg/mL from the recoveries of surrogate spikes.

The PAHs values shown in the Results section below were corrected for recovery efficiencies determined from the analyses of the surrogate spikes.

### *(c) Aldehydes*

The analytical method for aldehydes was developed in-house and is based on the US EPA Method T011 for the determination of formaldehyde in ambient air, and the California EPA Air Resources Board Method 1004 for the determination of aldehyde and ketone compounds in automotive source samples, using high performance liquid chromatography (HPLC).

The method is applicable to the determination of the target carbonyls, as required for the diesel NEPM project, namely:

- Formaldehyde
- Acetaldehyde

The carbonyl-DNPH derivatives were eluted from the sample cartridges in acetonitrile and analysed by HPLC (GBC Model LC1150) using reverse phase and gradient elution from a Supelcosil LC-18 column. The derivatives were monitored at 360 nm using a Jasco Uvidec-100 variable wavelength ultraviolet detector.

Analysis of a field blank was performed with each vehicle tested to check for cartridge background and/or environmental contamination and the sample results were corrected for any analyte background obtained.

Calibrant solutions were prepared from a commercially available standard mixture of the carbonyl-DNPH derivatives. The carbonyl derivatives in the samples were identified by comparing their retention times to the standard compounds and quantified using peak areas entered into a linear regression equation obtained from the calibration curve.

Under the conditions used in the analysis the following quality assurance data were obtained:

- Method quantitation limit: 0.05 µg/aldehyde component.
- Precision: ±5% RSD, measured at 0.1 µg/mL over five replicate injections of standard solution.
- Accuracy: 95 - 105 %, measured at 0.1 µg/mL using the standard solution.

### 3.3.5 Data Acquisition System

The following data outputs were all continuously logged on a second-by-second basis:

- all instruments (except for the APS, Toxics and LLSP).
- dynamometer speed, tractive effort, drive cycle tracking errors.
- secondary dilution tunnel controller (temperatures, mass flows).
- the transducers for atmospheric pressure, temperature and relative humidity inside the dynamometer cell, and temperatures of the heated gas sample lines and NOx analyser.

Custom designed software was used to control the logging hardware, display the data in real time and record data to disc. Over 40 data channels were logged at one-second intervals over the entire test sequence.

At the completion of testing, data from all of the instruments were transferred to an automated spreadsheet program for processing and plotting.

As the APS, LLSP and TEOM do not generate real-time outputs, they each required dedicated control and data management software, the output of which was appended to the main data file for each vehicle.

## 3.4 Test vehicles

### 3.4.1 Part A

As previously mentioned twelve of the 80 vehicles tested in Project 2.2 were sampled for air toxics emissions and were selected so that two from each of the six vehicle categories were tested. The vehicle categories were defined as:

- MC off-road passenger vehicle
- NA light commercial < 3.5 t gross vehicle mass (GVM)
- NB medium commercial 3.5 – 12.5 t GVM
- NC rigid truck 12.5 – 25 t GVM
- NC-H articulated truck > 25 t GVM
- ME bus > 5 t GVM

Details of each test vehicle are shown in Table 3.3.

*Table 3.3: Details of the vehicles sampled for toxic emissions*

| **Make** | **Model** | **Year** | **Weight (kg)** | | **Class** |
|---|---|---|---|---|---|
| | | | **Tare** | **GVM** | |
| Nissan | Navara | 95 | 1800 | 2740 | MC |
| Toyota | LX Turbo | 86 | 2050 | 2730 | MC |
| Toyota | Hilux | 93 | 1480 | 2580 | NA |
| Ford | Econovan | 95 | 1520 | 2750 | NA |
| Mitsubishi | Canter | 90 | 2720 | 4495 | NB |
| Toyota | Dyna | 90 | 4130 | 7000 | NB |
| Isuzu | 900SUR | 95 | 7640 | 16000 | NC |
| Mitsubishi | Superframe | 96 | 10580 | 25400 | NC |
| Iveco | INT 9200 | 98 | 14100 | 38000 | NC-H |
| Hino | Ranger 50 | 98 | 14120 | 38000 | NC-H |
| Volvo | B10 | 98 | 11570 | 16330 | ME |
| Scania | L113CRL | 96 | 11040 | 16100 | ME |

*(Note: GVM = Gross Vehicle Mass; GCM = Gross Combination Mass)*

Vehicles were randomly selected from those vehicles sourced during Project 2.2. The above 12 vehicles (forming part thereof of the 80 sample) were sourced from transport operators, bus companies, used truck yards, hire companies and tradesmen.

### 3.4.2 Part B

A Toyota (Light Commercial <3.5t GVM) and an Isuzu (Rigid Truck 3.5-12t GVM) were used to evaluate the effect on emissions from the various fuels. These particular vehicles represent the most common in the light commercial (NA) and rigid truck (NC) ADR categories in the urban environment.

The two vehicles listed below also formed part of the Project 2.2 fleet of vehicles. They were specifically selected on the basis of make, model and age to represent commonly used in-service vehicles.

| Make | Model | Year | Weight (kg) | | Class |
|---|---|---|---|---|---|
| | | | Tare | GVM | |
| Toyota | Hilux | 93 | 1480 | 2580 | NA |
| Isuzu | 900SUR | 95 | 7640 | 16000 | NC |

### 3.4.3 Suitability for testing

Following delivery to the Test Facility, each vehicle underwent a pre-test inspection. Vehicle and engine specifications were recorded and assessments were made of the vehicle's safety and suitability for test.

## 3.5 Emissions testing

### 3.5.1 Preparations for test

Prior to testing, each test vehicle was parked in the dedicated refueling area where its fuel tank(s) was emptied and refilled with sufficient test fuel to complete the testing sequence. The vehicle was then driven to the dynamometer in readiness for testing.

On completion of testing, the 'waste fuel' was used to top up the tank prior to returning the vehicle to its owner.

#### *3.5.1.1 Instrument room preparation*

Daily maintenance, service, calibration and quality control checks were carried out on the sampling and analytical equipment at the start of each test day. All calibrations were logged on the central data acquisition computer.

#### *3.5.1.2 Test facility preparation*

Each vehicle was driven onto the dynamometer, properly secured, and the exhaust sampling system connected.

Vehicle details (registration number, make, category and test weight) were entered into the dynamometer control computer for identification and calculation of the inertia loading applicable for the vehicle. The information was then saved to a dedicated file from which the CUEDC and short test cycles were referenced to set the correct speed and loads during testing. Selection of dynamometer configuration, single or dual axle (1,2,3 or 4 rollers in use) was also made to adjust for parasitic losses.

All safety items, connections and data inputs and dynamometer settings were independently verified.

The vehicle was then driven to warm the engine to normal operating temperatures and pressures. During this period the exhaust concentrations were measured and venturi size(s) selected to provide optimum dilution to meet the calibration ranges of the instruments. The primary dilution tunnel mass flow controller was set for the venturi size selected. Background checks of the dilution air were carried out to establish the baseline for gaseous emissions measurement.

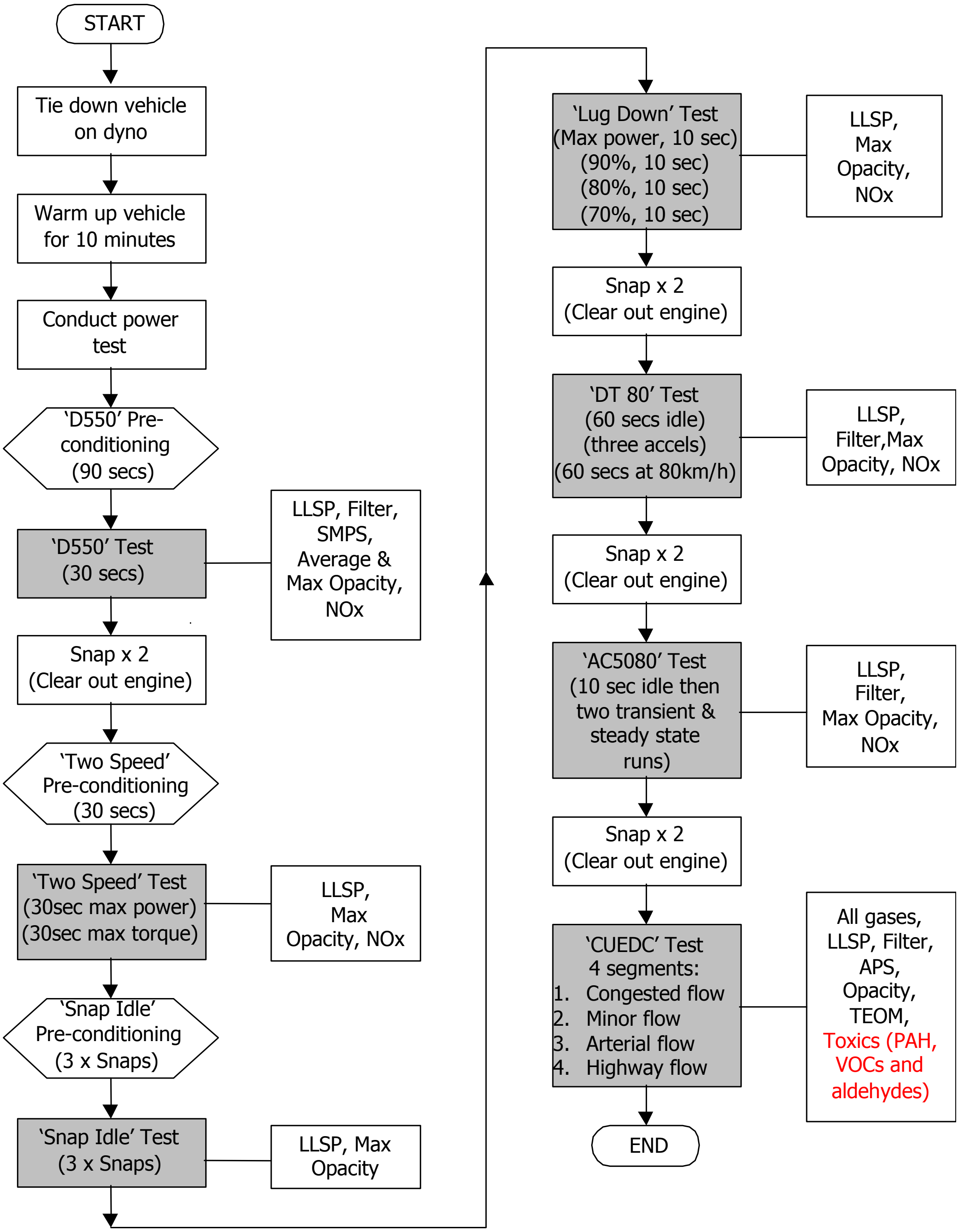


*Figure 3.6: PART A Test Sequence*

### 3.5.2 Sequence of tests

A consistent sequence of tests was applied to each of the vehicles reported on in this document. The test sequence for Part A and B was different as Part A generally compared emissions from various vehicles while part B compared the emission performance of two vehicles using a variety of fuels. Thus the following sections outlines the test sequence for each Part:

#### *3.5.2.1 Part A*

Part A involved the additional sampling of toxic emissions during the CUEDC drive cycle only. Toxic samples were not collected during the short tests evaluated also during Project 2-2. Thus the following test sequence is the same as used in Project 2-2 but with the addition of toxic sampling during the CUEDC – highlighted in red on the schematic diagram in figure 3.6 (previous page). In summary the sequence involved the following three test regimes:

(a) Measurements of power and tractive effort,

(b) Emission performance across six short tests (only *relevant to Project 2-2*),

(c) Emissions performance on the complex "real-world" CUEDC test cycle.

##### *3.5.2.1.1 Short tests.*

Test vehicles were run at idle while final test preparations were completed. A power and tractive effort test was carried out to establish each vehicle’s rated and intermediate speeds for use during the two-speed and lug-down short tests.

The first of the seven short tests was selected from the dynamometer control software menu, and the vehicle was driven sequentially through each test following the trace displayed on the driver’s aid. As these tests were not part of the Toxic Study (Part A or B) but conducted specifically under Project 2-2 they are not discussed in this report. However, for further information refer to the DNEPM Project 2-2 Parsons Australia Report.

##### *3.5.2.1.2 Composite Urban Emissions Drive Cycle (CUEDC)*

To provide a method of testing vehicles that closely replicates actual on-road driving conditions, NEPC commissioned a study in 1998 (DNEPM Project 2.1) to instrument a range of vehicles and record their actual speed/acceleration profiles in congested, minor roads, arterial and highway driving conditions.

The recorded data was then statistically analysed and synthesised into drive cycle segments that most accurately reflected the speed-time patterns for each of these four driving conditions, and subsequently combined into a Composite Urban Emissions Drive Cycle (CUEDC).

Because vehicles of different types have varying driving patterns, a different CUEDC was developed for each of the six major vehicle categories (see Section 3.4.1) used for certification in Australia. The CUEDC drive cycle for each category is shown graphically in figures 3.7 to 3.12.

The twelve vehicles tested under Part A spanned these six drive cycles, two vehicles were tested on each of the six cycles.

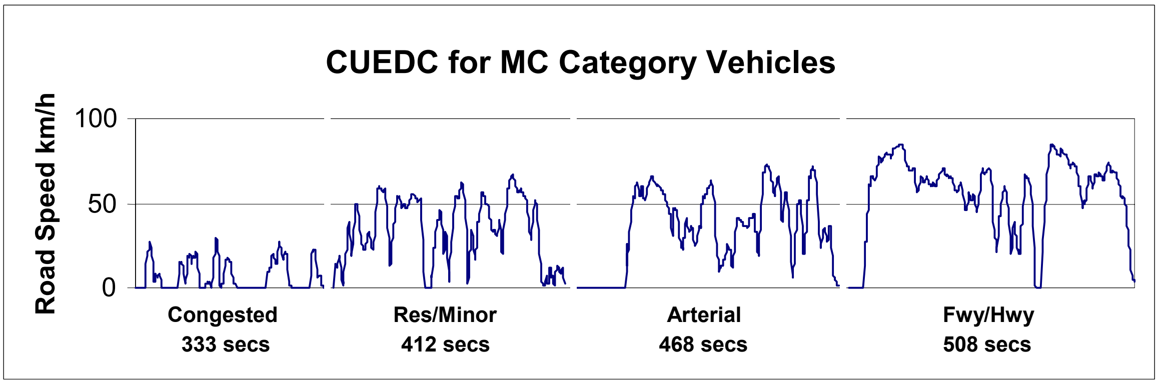


*Figure 3.7: CUEDC for MC Category vehicles*

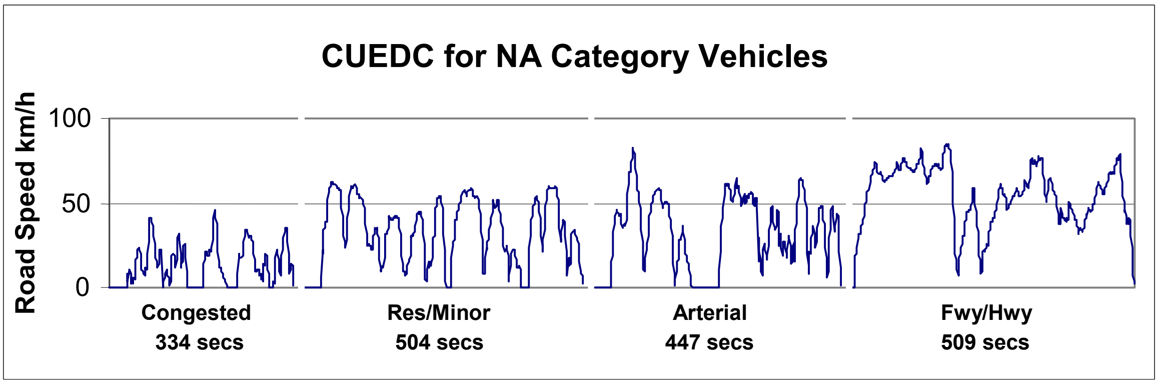


*Figure 3.8: CUEDC for NA Category vehicles*

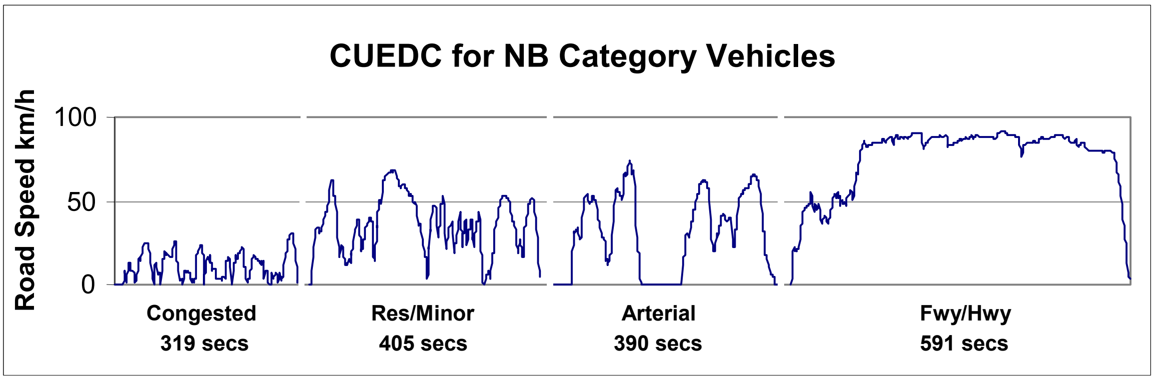


*Figure 3.9: CUEDC for NB Category vehicles*

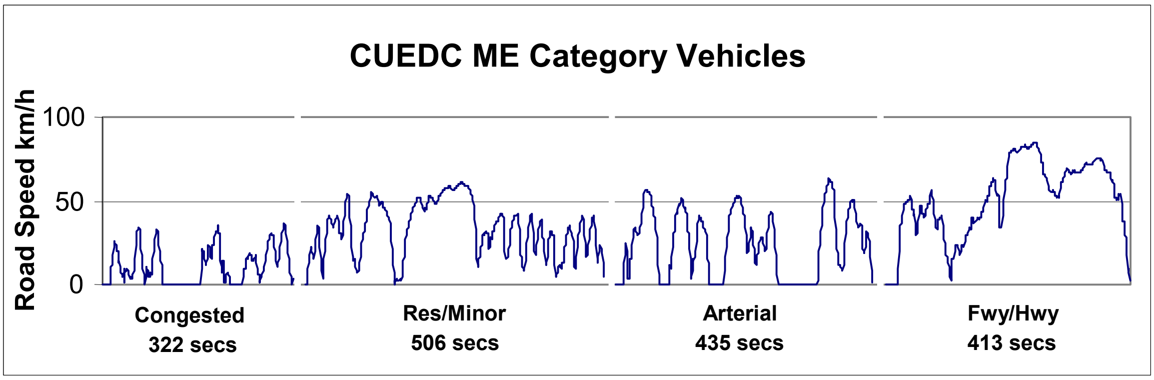


*Figure 3.10: CUEDC for ME Category vehicles*

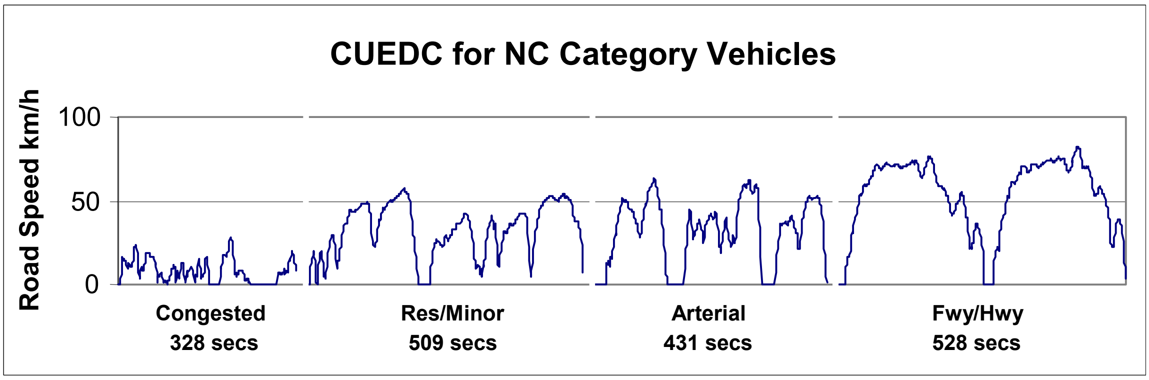


*Figure 3.11: CUEDC for NC Category vehicles*

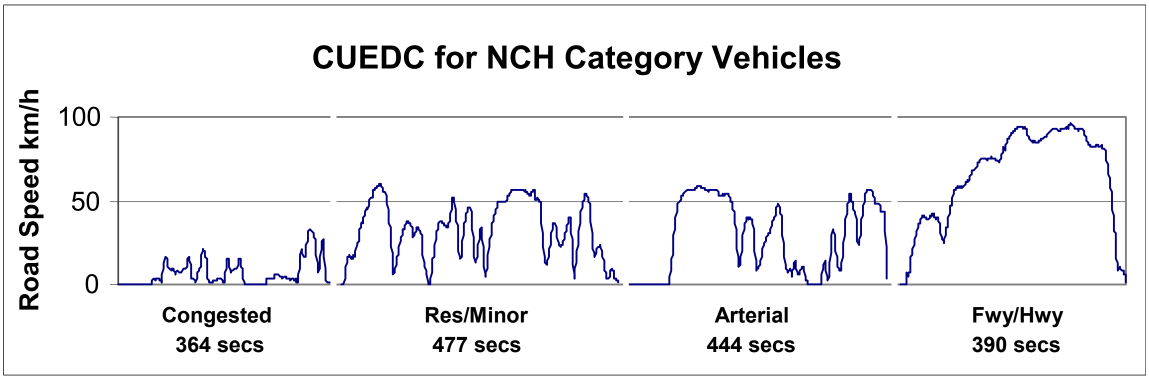


*Figure 3.12: CUEDC for NCH Category vehicles*

Just prior to the start of each CUEDC drive cycle test, the vehicle was accelerated twice under full throttle to clean any excess soot built up during the idle period. The applicable CUEDC for the vehicle weight category was then selected from the dynamometer control menu, and the driver's load/speed command switch placed in the load position. The test drive and exhaust sampling was then commenced.

The vehicle was then driven according to the 'driver's aid' speed trace displayed on the monitor. Between each of the four 'traffic flow' sequences, the vehicle was kept stationary and gas sampling was interrupted while toxic canisters, filters and cartridges were changed.

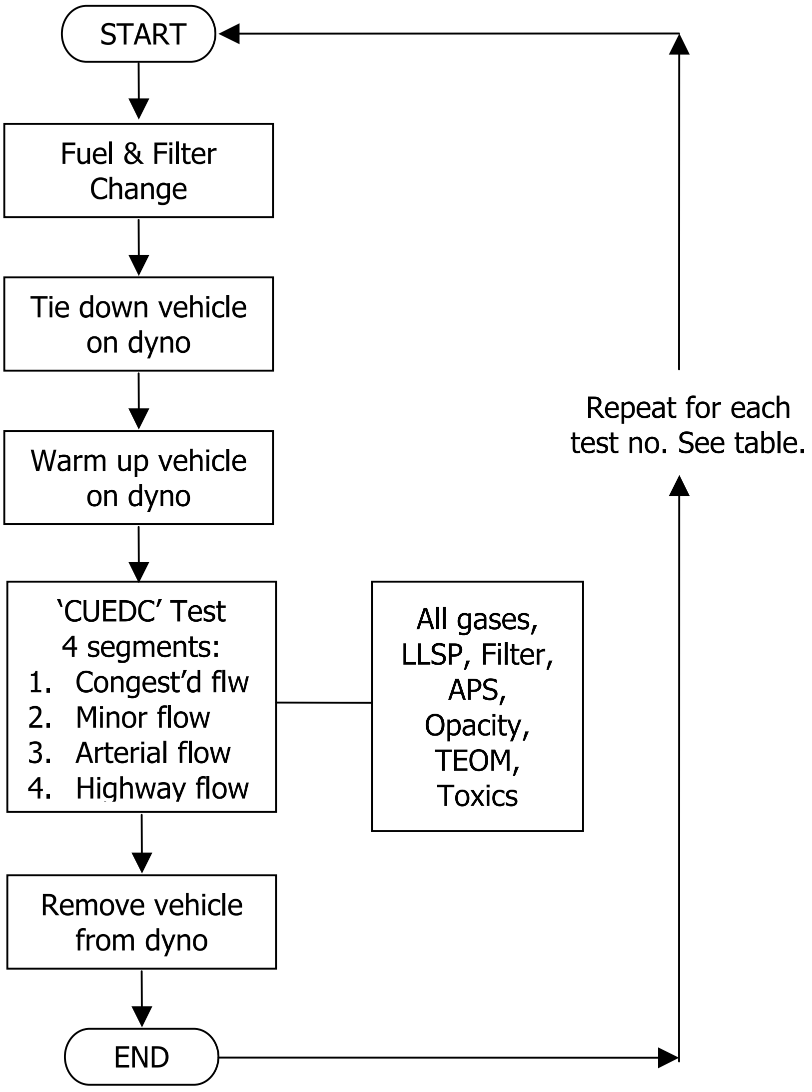
Following completion of the four road modes (approximately 40 minutes), the vehicle's engine was stopped, a background air analysis was made, and the analytical instruments were re-calibrated in readiness for the next vehicle.

The vehicle's exhaust was disconnected from the sampling system and the vehicle dismounted from the dynamometer.

#### *3.5.2.2 Part B*

As Part B focussed of the emissions comparison between fuels only two vehicles were tested and as such only the NA and NC CUEDC drive cycles (figures 3.8 and 3.11 above) used.

All fuels were tested over a three-week block following the completion of Part A of the Study. The two vehicles were tested using the test sequence illustrated in figure 3.13 below.



| **Test No** | **Fuel Type** | **Vehicle** |
|---|---|---|
| 1 | CG | Vehicle 1 (NA) |
| 2 | E2 | |
| 3 | E2 | |
| 4 | E3 | |
| 5 | E3 | |
| 6 | E4 | |
| 7 | WW | |
| 8 | CARB | |
| 9 | CARB | |
| 10 | CG | Vehicle 2 (NC) |
| 11 | E2 | |
| 12 | E3 | |
| 13 | E4 | |
| 14 | E4 | |
| 15 | WW | |
| 16 | WW | |
| 17 | CARB | |

CG: Commercial Grade
E2: Euro 2
E3: Euro 3
E4: Euro 4
WW: World Wide
CARB Californian

*Figure 3.13: Part B test sequence*

# 4 ANALYSIS OF RESULTS.

## 4.1 Air toxic emissions – Parts A and B

The results of the laboratory analyses for 12 vehicles in Part A, and for the two vehicles used in Part B driven through the CUEDC with the various fuels, are presented in the following summary sheets. In the case of the PAHs, results are presented for all vehicles and tests, but a contract analysis laboratory obtained some of these results. In that case, an identical method (supplied by CSIRO) was used, and the analytical files were processed by CSIRO procedures identical to those for the samples analysed in house by the CSIRO.

The graphs in Appendix 2 show the VOCs, aldehydes and total PAHs emissions for the four CUEDC segments respectively for each of the 12 vehicles tested. Note that the total PAHs shown was calculated as the sum of the 16 individual PAH compounds determined. The graph on the right, of each sheet, shows the distribution of PAHs for each segment. A table of all results is also provided on each sheet. Where a zero value appears in the table, the concentration of that compound was below the minimum quantifiable limit of the analysis.

As an example, one of the pages from Appendix 2 is included on the following page.

The first bar chart shows emissions of VOCs (Benzene, Toluene, Xylenes and 1,3 butadiene) for each of the four segments of the CUEDC. The second chart illustrates the Aldehyde emissions (Formaldehyde and Acetaldehyde) for each of the four driving sequences. The next chart shows the emissions of Total PAHs for each of the driving segments and the last chart shows the emission rates for each of the 16 PAHs for each of the four driving segments.

The table included provides a detailed tabulation of all of the emission results.

These results indicate that for each of the emissions reported the highest result was recorded for Segment 1 decreasing with the lowest recorded in the fourth segment. This decrease in emission rates for the various segments was generally repeated for each vehicle.

After the 12 pages of detailed results included in Appendix 2, there are 3 pages, illustrating for each of the vehicles, the VOCs, Aldehyde and PAH emissions for each segment of the CUEDC drive cycle.

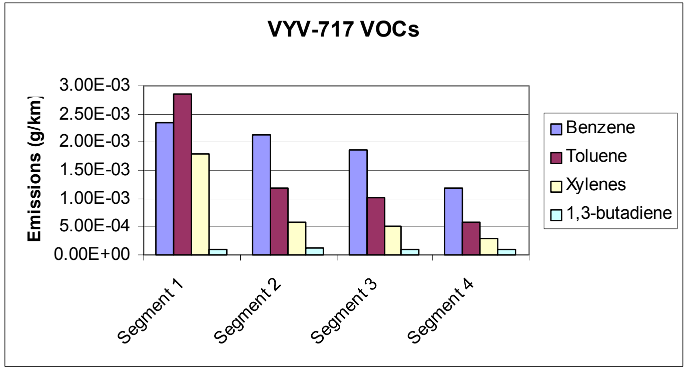
Appendix 3 provides the detailed results of the testing carried out, for Part B, with the six different fuel blends on the two vehicles. Appendix 3 also includes the results of repeat tests carried out comparing VOCs, Aldehydes and PAH results.

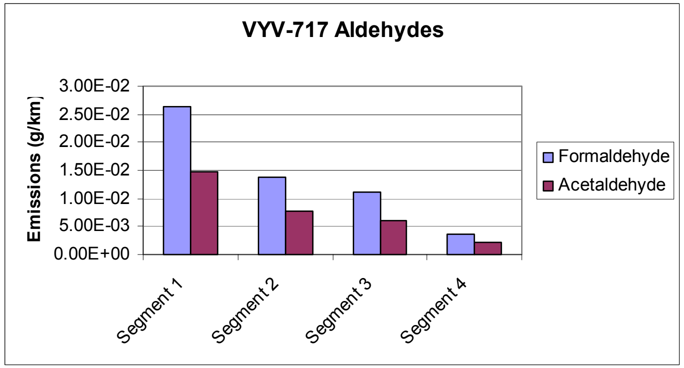
An example of a set of five repeat VOC tests, using different fuel blends, is shown on the following page. The results for benzene, toluene, xylenes and 1,3 butadiene are all illustrated.

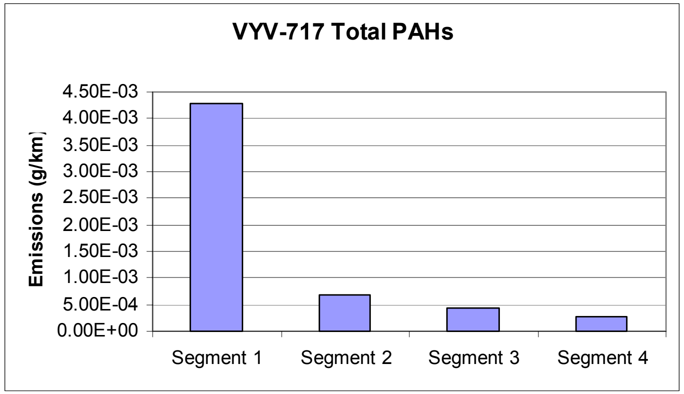
Whilst it can be seen that there is some variation in these two sets of results generally the same order of magnitude of the emission results is recorded in each case.

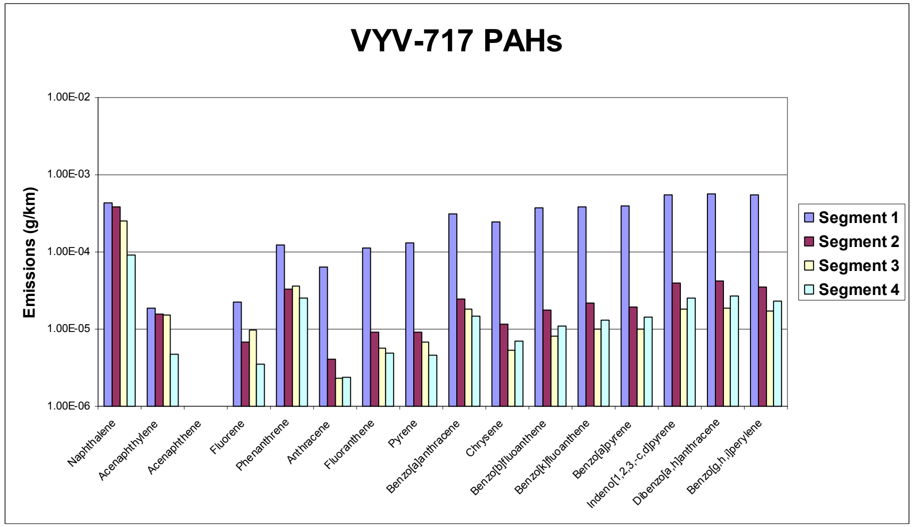
Reproducibility of measurements of emission rates of these species was similar to those reported in previous overseas studies (Siegel *et al* (1999)).

## 1995 Nissan Navara, Class MC



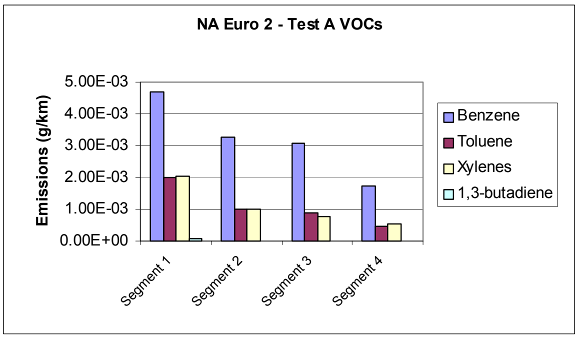


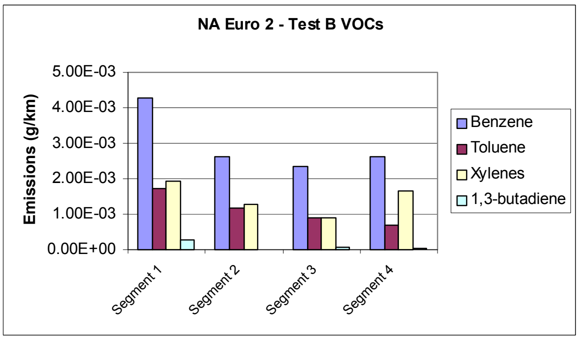


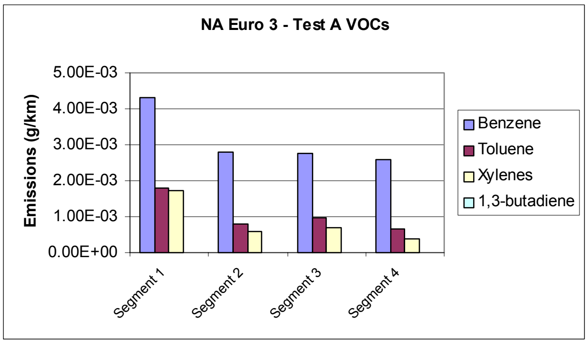


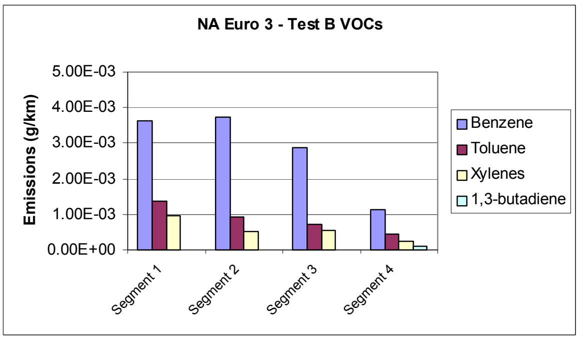
| Class MC | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Summary** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.34E-03 | 2.13E-03 | 1.86E-03 | 1.18E-03 |
| Toluene | 2.85E-03 | 1.18E-03 | 1.01E-03 | 5.83E-04 |
| Xylenes | 1.79E-03 | 5.91E-04 | 5.12E-04 | 2.79E-04 |
| 1,3-butadiene | 8.71E-05 | 1.21E-04 | 9.37E-05 | 1.08E-04 |
| | | | | |
| Formaldehyde | 2.64E-02 | 1.39E-02 | 1.11E-02 | 3.60E-03 |
| Acetaldehyde | 1.49E-02 | 7.70E-03 | 6.14E-03 | 2.21E-03 |
| | | | | |
| Naphthalene | 4.27E-04 | 3.80E-04 | 2.51E-04 | 9.18E-05 |
| Acenaphthylene | 1.86E-05 | 1.58E-05 | 1.54E-05 | 4.74E-06 |
| Acenaphthene | | | | |
| Fluorene | 2.27E-05 | 6.77E-06 | 9.71E-06 | 3.55E-06 |
| Phenanthrene | 1.24E-04 | 3.35E-05 | 3.58E-05 | 2.55E-05 |
| Anthracene | 6.40E-05 | 4.13E-06 | 2.34E-06 | 2.37E-06 |
| Fluoranthene | 1.13E-04 | 9.02E-06 | 5.69E-06 | 4.93E-06 |
| Pyrene | 1.30E-04 | 9.02E-06 | 6.69E-06 | 4.54E-06 |
| Benzo[a]anthracene | 3.12E-04 | 2.48E-05 | 1.81E-05 | 1.46E-05 |
| Chrysene | 2.43E-04 | 1.17E-05 | 5.36E-06 | 6.91E-06 |
| Benzo[b]fluoanthene | 3.69E-04 | 1.77E-05 | 8.03E-06 | 1.11E-05 |
| Benzo[k]fluoanthene | 3.82E-04 | 2.18E-05 | 1.00E-05 | 1.32E-05 |
| Benzo[a]pyrene | 3.96E-04 | 1.92E-05 | 1.00E-05 | 1.42E-05 |
| Indeno[1,2,3,-c,d]pyrene | 5.55E-04 | 3.95E-05 | 1.84E-05 | 2.55E-05 |
| Dibenzo[a,h]anthracene | 5.74E-04 | 4.25E-05 | 1.87E-05 | 2.68E-05 |
| Benzo[g,h,i]perylene | 5.51E-04 | 3.50E-05 | 1.71E-05 | 2.29E-05 |
| **Total PAH** | **4.28E-03** | **6.70E-04** | **4.32E-04** | **2.73E-04** |

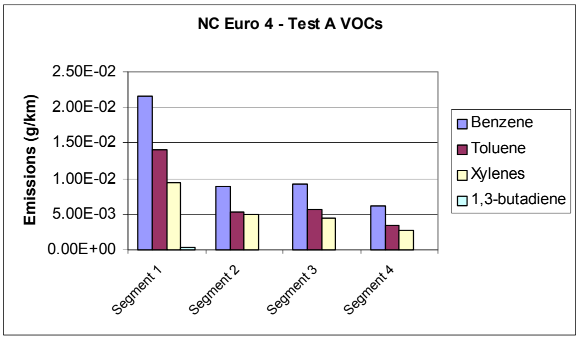
# VOC duplicate tests

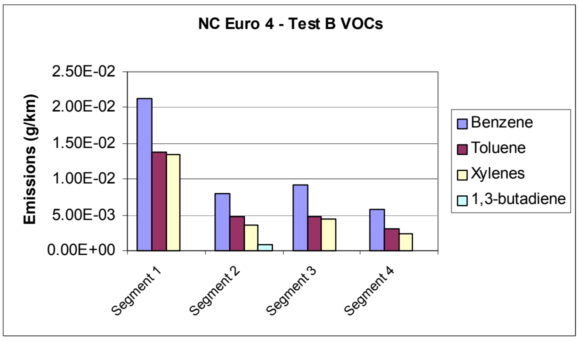


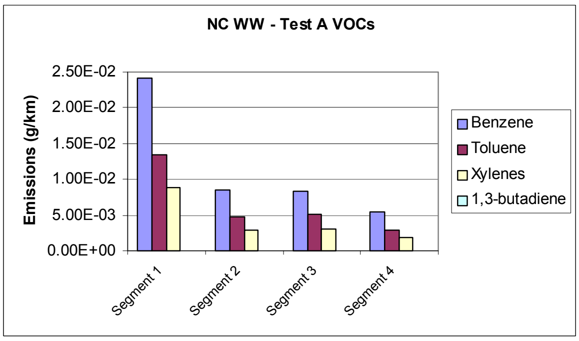


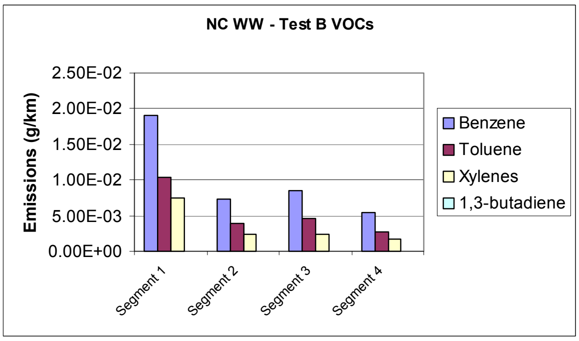


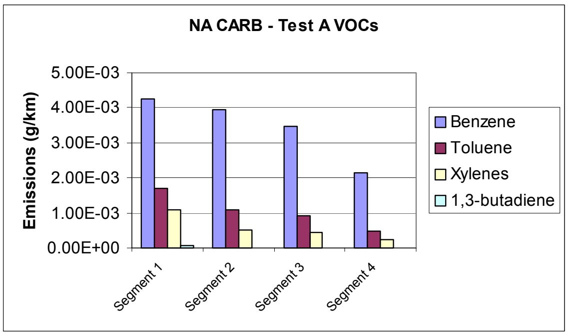


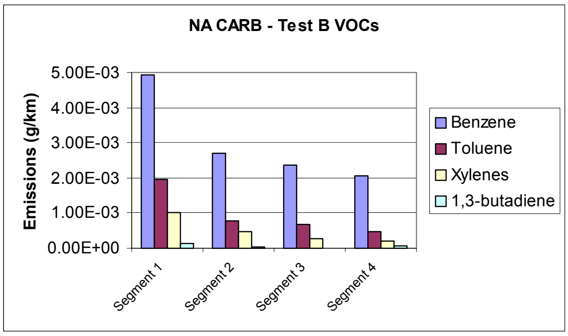












### 4.1.1 Discussion

Most previous work on diesel exhaust speciation has been aimed at characterising the composition of diesel exhaust, often in great detail. There have however been a number of studies, which report emission rates. These studies use a variety of approaches, and diesel fuel of often-unspecified quality, so that direct comparisons with the results of the present study should be done carefully.

Westerholm *et al* (1991) report exhaust emissions from a heavy-duty diesel truck (Scania 143 H) during transient driving conditions using a drive cycle developed at the Technische Hochschule in Braunschweig, Germany. Results are reported, for this and other studies, and summarised in Table 3.1, for VOCs and PAHs.

Rogge *et al* (1993) report emission rates of more than 100 organic compounds, including *n*-alkanes, *n*-alkanoic acids, benzoic acids, benzaldehydes, PAH, oxy-PAH, steranes, pentacyclic triterpanes, azanaphthalenes, and others, from a heavy-duty diesel truck, diven over a diesel driving cycle.

Siegel *et al* (1999) measured speciated gas-phase hydrocarbon and carbonyl emissions from a 2.5 L in-direct injection diesel engine fitted with a production oxidation catalyst for exhaust after-treatment. The vehicle was run on a typical low sulfur (500 ppm S) European diesel fuel and measurements were made over the European MVEG test cycle.

Schauer *et al* (1999) report emissions of organic compounds from 2 late model medium duty diesel trucks, driven through a hot-start Federal Test Procedure (FTP) urban driving cycle. The fuel used was a commercially obtained California reformulated diesel fuel.

Staehlin *et al* (1998) report emission rates derived from tunnel measurements performed in Switzerland, and compare their results to dynamometer measurements reported in Lies *et al* (1988).

The current study appears to be one of the most comprehensive yet performed. Results obtained in Part A, are broadly consistent with those reported previously and summarised in Table 3.2. There are also some significant qualitative similarities in the data of the current and previous studies:

- Benzene is usually the most abundant monoaromatic species
- Aldehyde emission rates usually exceed VOC emission rates, and in some studies are reported to contribute substantially to total VOC emission rates from diesel vehicles (Schaeur *et al* (1999), for example report that $C_1$-$C_{13}$ carbonyls account for 60% of the gas phase organic mass emissions from a diesel truck)
- PAH emission rates are significantly less than VOC and aldehyde emission rates

In Part B, fuel formulation effects on emission rates are determined. Lower sulfur and aromatic content is known to reduce particulate emissions from diesel fuels, hence the justification for improved fuel quality; effects on other emissions are less clear.

The results obtained for VOCs and aldehydes show that lower sulfur and aromatic contents do not have a significant effect on emission of these species (see Table 4.1), where results are presented for segment 2 of the CUEDC and for the two vehicles (NC and NA classes), and the 6 fuels. Similar conclusions would be reached from consideration of the results from other segments of the CUEDC, although, for some reason, results for PAHs for segment 1 are less reproducible than those observed for other segments.

Support for this interpretation is provided by the data presented in table 4.2, which shows data reported by CARB (1998). In the CARB study, a Cummins L10 engine was used with pre-1993 California diesel fuel, on fuel with less than 10% aromatic content, and on a mix of alternative fuels with higher aromatic content that comply with CARB's regulations. VOC and aldehyde emission rates (as mg or µg per bhp-hr) are not significantly affected by fuel properties, but the PAH emission rates are lower for the lower aromatic content fuels.

In the case of the PAHs, there appears to be some effects of fuel quality on emissions. In general PAH emissions are lower for the higher quality fuels (refer Table 4.1). The results included in Appendix 3 indicate that lower aromatic fuels result in lower PAH emissions. (Refer also to complete CSIRO report on "Toxic Emissions from Diesel Vehicles)

*Table 4.1: Emission rates of toxic species in Part B tests; results are for segment 2 (minor roads) of CUEDC*

| | **Emission rate (mg km$^{-1}$)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Commercial base | | Euro 2 | | Euro 3 | | Euro 4 | | WW Cat 3 | | CARB | |
| | NA | NC | NA | NC | NA | NC | NA | NC | NA | NC | NA | NC |
| **Species** | | | | | | | | | | | | |
| Benzene | 3.0 | 8.5 | 2.9 | 7.3 | 3.3 | 8.9 | 3.6 | 8.5 | 4.6 | 7.9 | 3.3 | 7.9 |
| Toluene | 0.93 | 4.1 | 1.1 | 4.2 | 0.86 | 7.3 | 0.89 | 5.1 | 1.5 | 4.3 | 0.92 | 3.8 |
| *m,p*-xylenes | 0.60 | 3.8 | 1.1 | 6.3 | 0.56 | 34.8 | 0.53 | 4.3 | 8.4 | 2.7 | 0.49 | 2.5 |
| 1,3-butadiene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0.01 | 0 |
| Formaldehyde | 0.33 | 15.8 | 1.1 | 31.9 | 1.1 | 23.2 | 1.5 | 22.1 | 3.1 | 18.7 | 2.0 | 0.2 |
| Acetaldehyde | 0.46 | 10.2 | 0.79 | 14.9 | 0.87 | 8.1 | 1.7 | 6.2 | 1.4 | 5.1 | 0.68 | 1.2 |
| | **Emission rate (µg km$^{-1}$)** | | | | | | | | | | | |
| Naphthalene | 2000 | 4790 | 933 | 3240 | 814 | 5130 | 562 | 2720 | 890 | 2980 | 1540 | 3720 |
| Acenaphthalyne | 38 | 278 | 32 | 162 | 24.5 | 208 | 15.7 | 103 | 33.3 | 68.4 | 21.1 | 78.1 |
| Acenaphthene | 13 | 154 | 8.2 | 56.8 | 4.3 | 110 | 2.8 | 35.7 | 9.2 | 17.0 | 3.2 | 26.8 |
| Fluorene | 34 | 247 | 16 | 106 | 8.0 | 159 | 5.2 | 51.6 | 24.3 | 25.0 | 6.9 | 33.4 |
| Phenanthrene | 120 | 167 | 95 | 59.6 | 57 | 71.8 | 33 | 110 | 117 | 63.4 | 58.4 | 34.0 |
| Anthracene | 6 | 7.5 | 4.3 | 2.3 | 2.5 | 1.2 | 1.5 | 6.3 | 5.6 | 3.4 | 3.4 | 1.2 |
| Fluoranthene | 18 | 20.2 | 12 | 8.5 | 10.3 | 9.0 | 5.6 | 8.1 | 8.7 | 7.1 | 9.1 | 7.1 |
| Pyrene | 17 | 43.1 | 12.7 | 17 | 10.1 | 16.8 | 5.6 | 13.8 | 10.8 | 13.3 | 10.9 | 11.9 |
| Benz(*a*)anthracene | 1.8 | 7.5 | 0.9 | 1.7 | 0.55 | 1.8 | 0.6 | 0.6 | 0.5 | 0.8 | 0.7 | 1.8 |
| Chrysene | 2.7 | 1.3 | 2.1 | 8.5 | 1.7 | 6.6 | 0.9 | 1.6 | 0.8 | 1.7 | 1.3 | 2.4 |
| Benzo(*b*)fluoranthene | 1.5 | 5.9 | 1.9 | 2.3 | 1.8 | 4.2 | 0.6 | 1.6 | 1.0 | 1.7 | 0.8 | 1.2 |
| Benzo(*k*)fluoranthene | 1.5 | 4.8 | 0.9 | 2.3 | 0.97 | 1.8 | 0.6 | 1.6 | 0.8 | 0.8 | 0.8 | 1.8 |
| Benzo(*a*)pyrene | 2.1 | 4.3 | 1.6 | 2.3 | 1.5 | 3.0 | 0.6 | 1.6 | 1.0 | 1.7 | 1.3 | 1.8 |
| Indeno(1,2,3-*cd*)pyrene | | 1.6 | 0.5 | 0.6 | 0.13 | 0.6 | 0.3 | | 0.5 | 0 | 0.4 | |
| Dibenz(*a,h*)anthracene | | | | | | | | | | | | |
| Benzo(*g,h,i*)perylene | 0.9 | 2.7 | 1.0 | 2.3 | 1.4 | 1.8 | 0.6 | 1.3 | 1.0 | 1.7 | 0.8 | 0.6 |

*Table 4.2: Effects of fuel formulation on diesel toxic emission rates; data from CARB (1998), part A (Exposure assessment)*

| | **Emission rate (mg / bhp-hr)** | | |
|---|---|---|---|
| | Pre-1993 Fuel | Alternative formulation | Low aromatic |
| *4.1.1.1 Species* | | | |
| Benzene | 5.9 | 5.8 | 8.0 |
| Toluene | 1.9 | 1.9 | 2.3 |
| *m,p*-xylenes | 2.1 | 2.1 | 1.2 |
| Formaldehyde | 57.1 | 59.8 | 58.7 |
| Acetaldehyde | 18.2 | 19.9 | 19.1 |
| | **Emission rate (μg / bhp-hr)** | | |
| Naphthalene | 2400 | 1950 | 1450 |
| Acenaphthalyne | | | |
| Acenaphthene | | | |
| Fluorene | | | |
| Phenanthrene | | | |
| Anthracene | 38.9 | 26.2 | 18.5 |
| Fluoranthene | | | |
| Pyrene | | | |
| Benz(*a*)anthracene | | | |
| Chrysene | 17.4[a] | 12.2[a] | 10.4[a] |
| Benzo(*b*)fluoranthene | | | |
| Benzo(*k*)fluoranthene | | | |
| Benzo(*a*)pyrene | 20.5 | 20.6 | 16.5 |
| Indeno(1,2,3-*cd*)pyrene | | | |
| Dibenz(*a,h*)anthracene | 1.5 | 1.5 | 0.9 |
| Benzo(*g,h,i*)perylene | | | |

[a] includes triphenylene

[b] includes dibenz[a,c]anthracene

## 4.2 Gaseous and particulate emissions – Part B

This section discusses the effect of using a variety of diesel fuels on the particulate and gaseous emissions from two current technology diesel vehicles when tested using the CUEDC test procedure.

In particular the effect of using diesel fuels with varying amounts of sulfur, decreasing Cetane index, density, heavy end distillation temperatures, and aromatic content is examined.

A series of tests were carried out on two diesel vehicles using the CUEDC test procedure with six different types of diesel fuel.

As a part of the strategy to reduce harmful emissions from diesel vehicles there is a worldwide move to modify the formulation of commercial diesel fuel. This test program has used the recently developed CUEDC test procedure as a means of examining the effect on the emissions of the two diesel vehicles tested using these different fuels.

The following tables detail the results of the tests carried out on the two vehicles.

*Table 4.3: Results Summary - Vehicle 1 (Light Commercial Vehicle)*

| | $CO_2$ (g/km) | CO (g/km) | NOx (g/km) | HC (g/km) | LLSP Mass (mg/km) | TEOM Mass (mg/km) | Filter mass (mg/km) | Ave Opacity (%) | Max Opacity (%) | Mass PM1.0 (mg/km) | Mass PM2.5 (mg/km) | Mass PM10 (mg/km) | FC (l/100km) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Fuel | 463.78 | 3.16 | 1.62 | 0.04 | 421.32 | 707.86 | 741.45 | 12.54 | 79.26 | 712.8 | 713.3 | 731.3 | 18.21 |
| Euro 2 | 444.33 | 1.15 | 1.47 | 0.02 | 190.35 | 324.12 | 353.42 | 7.57 | 63.91 | 315.7 | 316.4 | 340.1 | 18.22 |
| Euro 3 | 435.49 | 0.74 | 1.49 | 0.04 | 148.47 | 265.40 | 292.60 | 6.57 | 57.58 | 248.9 | 249.7 | 276.5 | 17.53 |
| Euro 4 | 438.72 | 1.24 | 1.48 | 0.04 | 179.16 | 321.18 | 331.23 | 6.22 | 65.06 | 305.3 | 305.7 | 321.8 | 17.86 |
| World Wide | 451.87 | 1.29 | 1.42 | 0.05 | 141.24 | 272.54 | 301.37 | 5.53 | 57.23 | 275.2 | 275.6 | 291.9 | 18.52 |
| CARB | 438.66 | 1.69 | 1.28 | 0.04 | 235.72 | 409.43 | 418.92 | 8.24 | 67.51 | 384.2 | 384.7 | 407.0 | 17.68 |

*Table 4.4: Results Summary - Vehicle 2 (Rigid Truck)*

| | $CO_2$ (g/km) | CO (g/km) | NOx (g/km) | HC (g/km) | LLSP Mass (mg/km) | TEOM Mass (mg/km) | Filter mass (mg/km) | Ave Opacity (%) | Max Opacity (%) | Mass PM1.0 (mg/km) | Mass PM2.5 (mg/km) | Mass PM10 (mg/km) | FC (l/100km) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Fuel | 782.47 | 3.45 | 10.63 | 1.01 | 182.78 | 265.21 | 447.31 | 1.08 | 12.75 | 423.8 | 424.4 | 438.7 | 32.92 |
| Euro 2 | 719.29 | 2.48 | 10.17 | 0.90 | 187.12 | 191.44 | 380.38 | 2.27 | 25.17 | 364.5 | 365.0 | 374.8 | 30.18 |
| Euro 3 | 746.26 | 2.75 | 10.47 | 0.95 | 157.00 | 237.80 | 312.75 | 1.29 | 17.66 | 273.6 | 274.8 | 299.5 | 31.22 |
| Euro 4 | 717.77 | 3.13 | 8.66 | 0.73 | 139.74 | 200.32 | 284.44 | 2.22 | 22.36 | 263.2 | 263.7 | 276.8 | 30.53 |
| World Wide | 691.68 | 2.81 | 8.40 | 0.73 | 114.01 | 184.21 | 283.16 | 1.60 | 20.79 | 257.2 | 257.9 | 274.0 | 29.60 |
| CARB | 774.93 | 2.63 | 8.57 | 0.84 | 128.93 | 198.99 | 299.57 | 1.78 | 19.41 | 267.2 | 268.3 | 287.9 | 31.56 |

The following table provides details of the specifications of the six diesel fuels used in this test program.

*Table 4.5: Diesel Fuel Specifications*

| | Cetane No | Cetane Inde | Density 15° (kg/l | T10 (°C) | T50 (°C) | T90 (°C) | T95 (°C) | Sulphu Conten (mg/kg | Mono Aromatic (% | Poly Aromatic (% | Total Aromatic (% | Calorifi Valu (MJ/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base | | 45.5 | 0.86 | 243 | 278 | 326 | | 170 | | | 33 | |
| Euro | | 56 | 0.830 | 210 | 274. | 333. | | 480 | | | | |
| Euro | 53.5 | 51.6 | 0.83 | 225 | 268 | 310 | 336 | 210 | 14.1 | 9.9 | 24 | 42.9 |
| Euro | 58.3 | 57.7 | 0.829 | 231 | 278 | 327 | 340 | 39 | 9.8 | 1.8 | 11.6 | 42.9 |
| World Wide | 55.7 | 58.7 | 0.823 | 224. | 267. | 309. | 321. | 24 | 7.2 | 0.5 | 7.7 | 43.0 |
| CAR | 49.8 | 44 | | 204 | 239 | 313 | | 264 | 19.5 | 1.8 | 21.3 | |

* ppm by vol.

### 4.2.1 $NO_x$ Emissions.

Figure 4.1 illustrates the $NO_x$ emission results for the two vehicles using the six types of diesel fuel.

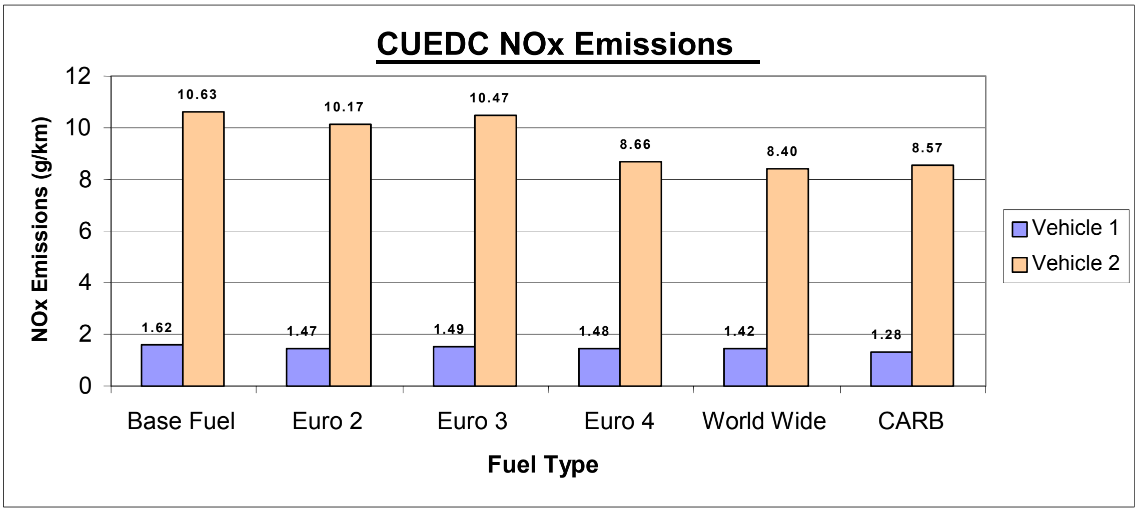


*Figure 4.1: $NO_x$ Emissions*

These results indicate $NO_x$ emissions were progressively reduced as the various fuels were tested.

The reason for the reduction in $NO_x$ emissions from the various fuels is not clearly established by this test program.

However $NO_x$ emissions may be reduced by:

- An increase in cetane number (or index)
- Reducing fuel density
- Reducing the total aromatics content of diesel fuel
- Possibly by decreasing T95 distillation temperature

Considering each of the above possible contributing factors in order:

- The Base Fuel had the lowest Cetane index and the World-Wide Spec the highest. This could indicate that the Cetane index increase has contributed to the decrease in $NO_x$. However the CARB fuel is reported as having the lowest Cetane index of any of the fuels and perhaps the lowest Cetane number (the Cetane number of all the fuels was not reported).
- The Base Fuel had the greatest density and the World-Wide Spec had the lowest reported density (the density of the CARB fuel was not reported).
- This could again indicate that the $NO_x$ emissions have been reduced by the decrease in fuel density.
- The total Aromatics content of the base fuel was the greatest of the fuels tested and the world wide spec fuel had the lowest total aromatics content which could also have contributed to a reduction in the $NO_x$ emissions. The aromatic content of the Euro 2 fuel was not reported and the CARB fuel had a total aromatics content only slightly less than the EURO 3 fuel.

The reduction in the total aromatics content of the fuel could have contributed to the reduction in the $NO_x$ emissions.

- The reported distillation temperatures indicate a reducing trend in the T90 and T95 distillation temperatures of the test fuels, although T90 and T95 distillation temperature reported for the Euro 3 fuel were less than those reported for the Euro 4 fuel.

So reducing T90 and T95 distillation temperatures could have contributed to a reduction in the $NO_x$ emissions.

### 4.2.2 HC Emissions

Figure 4.2 illustrates the HC emission results for the two vehicles using the six types of diesel fuel.

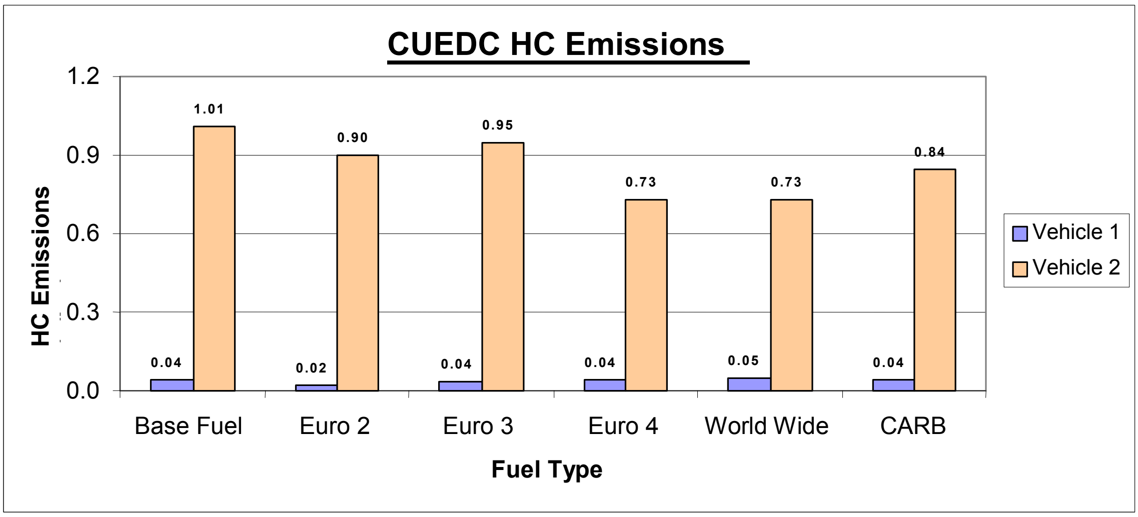


*Figure 4.2: HC Emissions*

Because of the low results for HC emissions reported for Vehicle 1, the smaller vehicle, it is not reasonable to try to examine emission trends for this vehicle.

For Vehicle 2 the results indicated a significant reduction of HC emissions when using Euro 4 and World-Wide Spec fuels. The use of CARB fuel also reduced HC emissions from those reported for the use of the Base fuel.

It is also possible that an increase in the Cetane index can contribute to the decrease in HC emissions.

### 4.2.3 CO Emissions

Figure 4.3 illustrates the CO emission results for the two vehicles using the six types of diesel fuel.

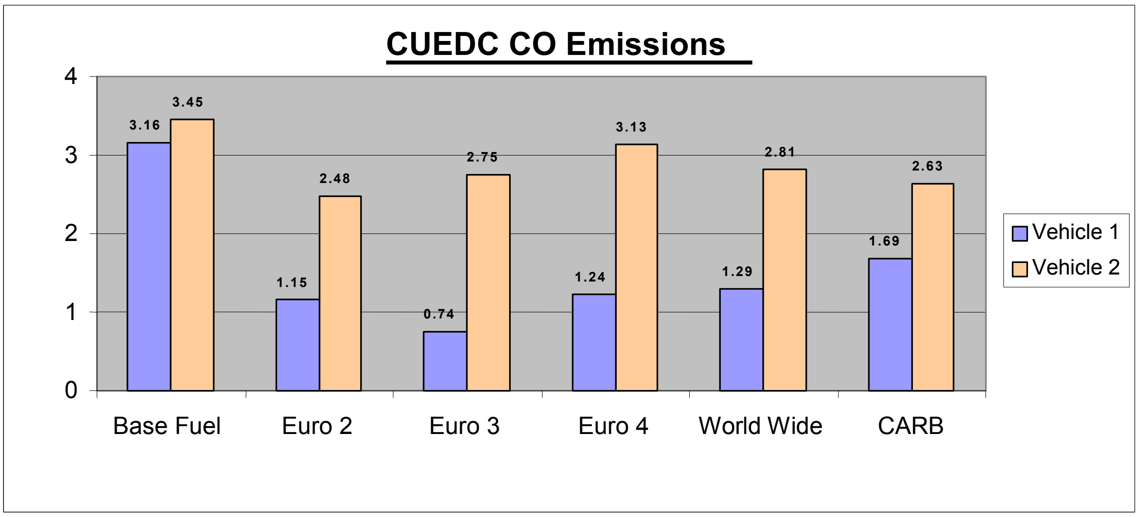


*Figure 4.3: CO Emissions*

These results indicate that both vehicles recorded the highest rate of CO emissions using the base fuel but Vehicle 1 registered its lowest result using EURO 3 fuel (76% reduction) and Vehicle 2 recorded its lowest emissions using the EURO 2 fuel (28% reduction).

It is not possible to establish from this limited program a relationship between the CO emissions from the vehicles and fuel properties.

### 4.2.4 $CO_2$ Emissions

Figure 4.4 illustrates the $CO_2$ emission results for the two vehicles using the six types of diesel fuel.

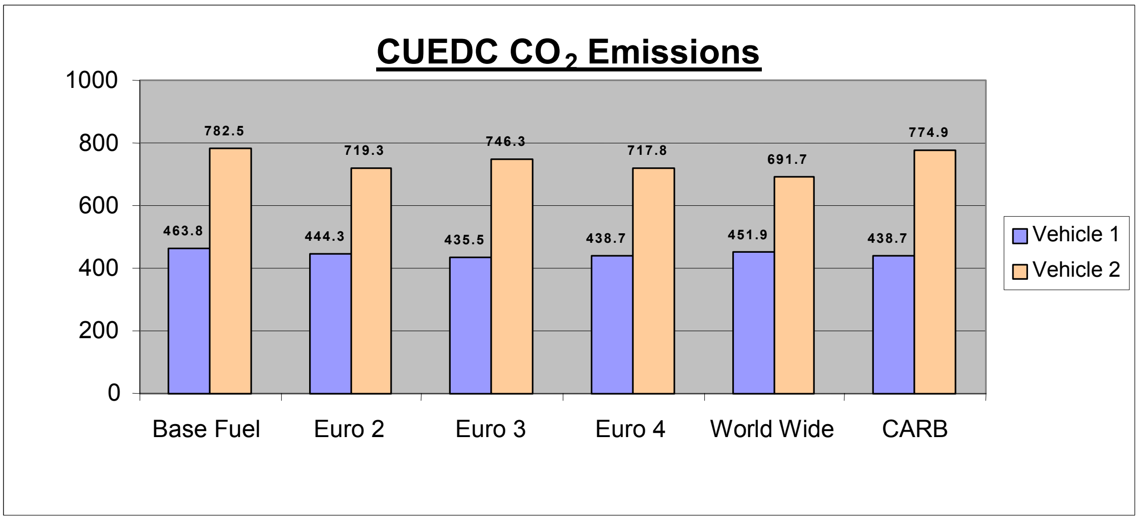


*Figure 4.4: $CO_2$ Emissions*

Test Vehicle 1 recorded its maximum $CO_2$ result when using the Base Fuel and its lowest $CO_2$ result using Euro 3 fuel. The results for Vehicle 1 using fuels Euro 4 and CARB were about the same and only marginally higher than those achieved using the Euro 3 fuel.

Test Vehicle 2 recorded its highest $CO_2$ emission result when using the Base Fuel and its lowest $CO_2$ result when tested using the World-Wide test fuel.

Use of the CARB Fuel produced the second lowest $CO_2$ result for Vehicle 1 but the second highest result for Vehicle 2.

It is not possible to establish any definite pattern for the variation in the $CO_2$ emission results for the various fuels. An increase in the Cetane index of fuels may result in reduced $CO_2$ but such a relationship cannot be deduced from these results.

### 4.2.5 Fuel Consumption

Figure 4.5 illustrates the Fuel Consumption results for the two vehicles using the six types of diesel fuel.

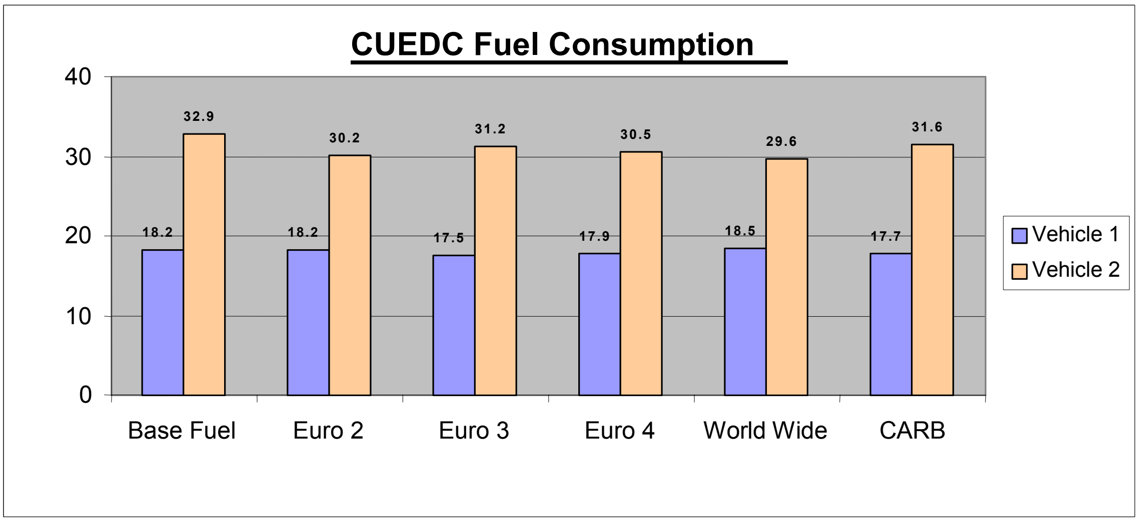


*Figure 4.5: Fuel Consumption*

Test Vehicle 1 recorded its highest fuel consumption when using the World-Wide Fuel and its lowest fuel consumption result using Euro 3 fuel.

Test Vehicle 2 recorded its highest fuel consumption when using the Base Fuel and its lowest fuel consumption result when using the World-Wide Fuel.

The variation in fuel consumption rates for each vehicle was relatively small and there was no apparent pattern for the variation in the results.

Some relationship could have been expected between fuel density and fuel consumption however this test program established no direct relationship.

As would be expected the pattern of results is similar, but not identical, for $CO_2$ and fuel consumption results.

### 4.2.6 LLSP Mass

Figure 4.6 illustrates the LLSP Mass results for the two vehicles using the six types of diesel fuel.

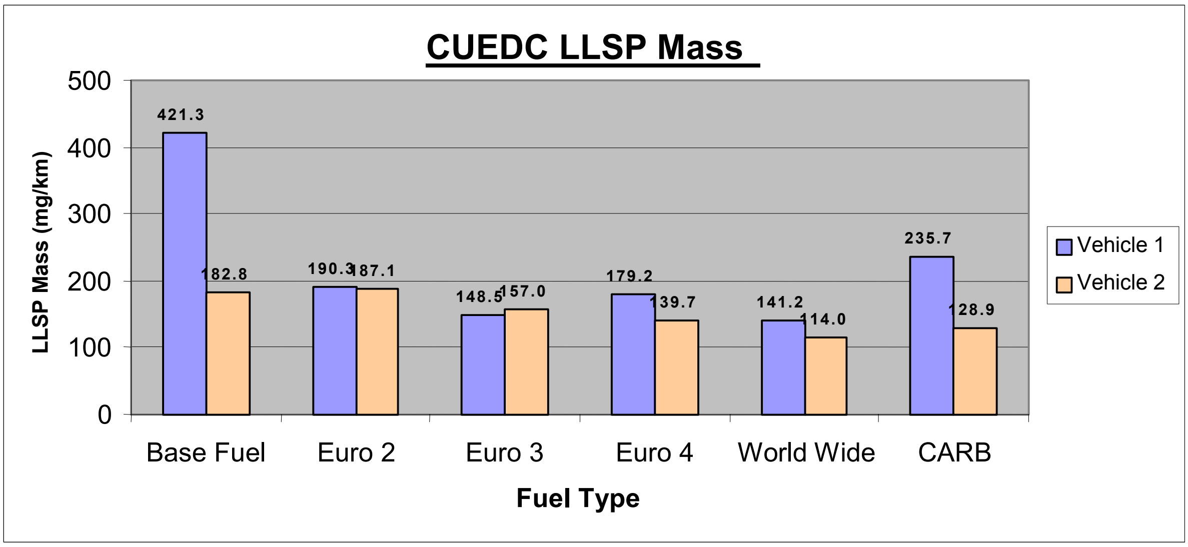


*Figure 4.6: LLSP Mass*

Test Vehicle 1 recorded by far its highest mass emission rate when using the Base Fuel and its lowest mass emission rate when using the World-Wide Fuel.

Test Vehicle 2 recorded its highest mass emission rate when using Euro 2 Fuel and its lowest mass emission rate when using the World-Wide Fuel.

Various fuel properties as well as engine design and operating conditions all contribute to particulate emissions.

Lowering fuel density may reduce particulate emissions. This trend is apparent in tests on Vehicle 1 but is not reflected by the results of the tests on Vehicle 2.

Fuel sulfur content may also affect particulate emissions. However the benefit of reduced sulfur content may be more apparent where vehicles are fitted with catalysts as part of their emission control system. Sulfur also affects the long term conversion efficiency of catalysts.

Particulate emissions may also reduce with the reduction of the Polyaromatic content of the fuel. Whilst not reported it is probable that the polyaromatic content of the Base Fuel would be the highest of the fuels used with the World-Wide fuel having the lowest sulfur content.

These tests indicate that, on average, the LLSP emissions are lowest on the World-Wide fuel and highest on the Base fuel.

### 4.2.7 TEOM Mass

Figure 4.7 illustrates the TEOM Mass emission results for the two vehicles using the six types of diesel fuel.

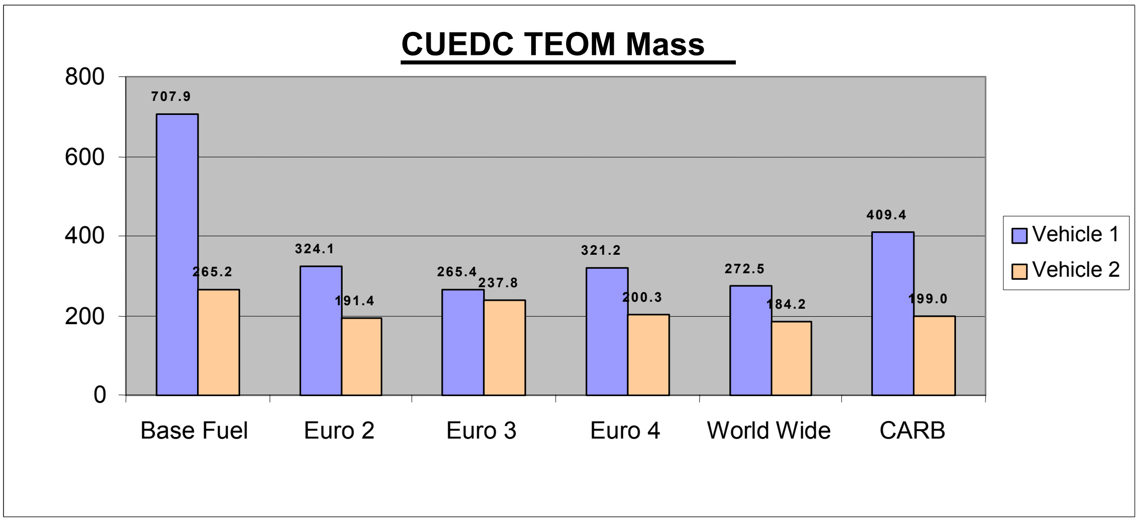


*Figure 4.7: TEOM Mass*

Vehicle 1 had maximum emission rate using the Base fuel and minimum with the Euro 3 fuel. Vehicle 2 had maximum emission rate using the Base fuel and minimum emissions using the World-Wide fuel.

On average the maximum emission rate was recorded using the Baseline fuel and the minimum rate using the World-Wide Fuel.

### 4.2.8 Filter Mass

Figure 4.8a illustrates the Filter Mass results for the two vehicles using the six types of diesel fuel.

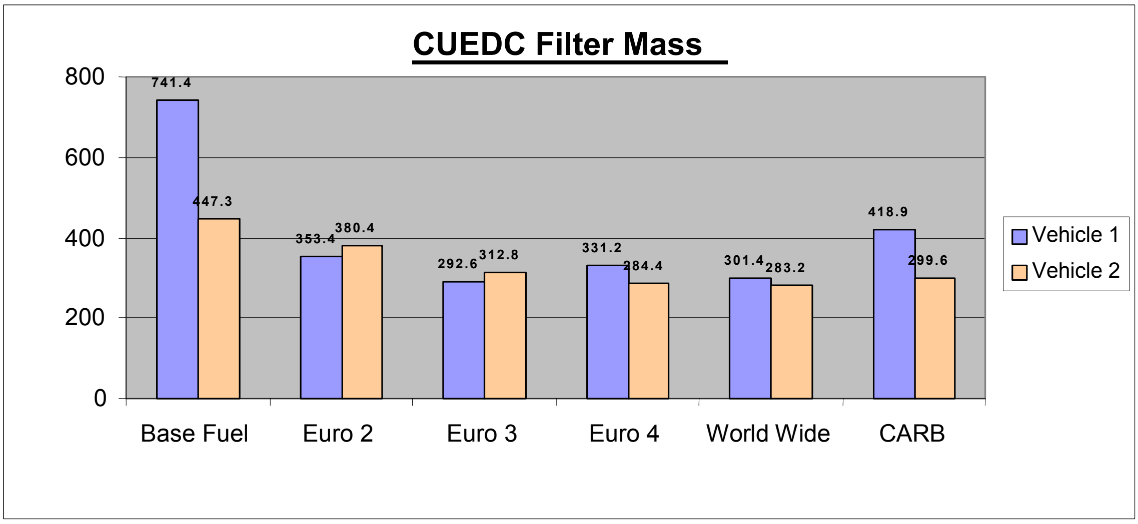


*Figure 4.8a: Filter Mass*

Vehicle 1 recorded its maximum Filter Mass rate using the Base fuel and minimum with the Euro 3 fuel. Vehicle 2 had maximum Filter Mass rate using the Base fuel and minimum using the World-Wide fuel.

On average the maximum Filter Mass rate was recorded using the Base fuel and the minimum using World-Wide fuel.

Figure 4.8b plots the relationship between the sulfur content of the fuels used and the Filter Mass.

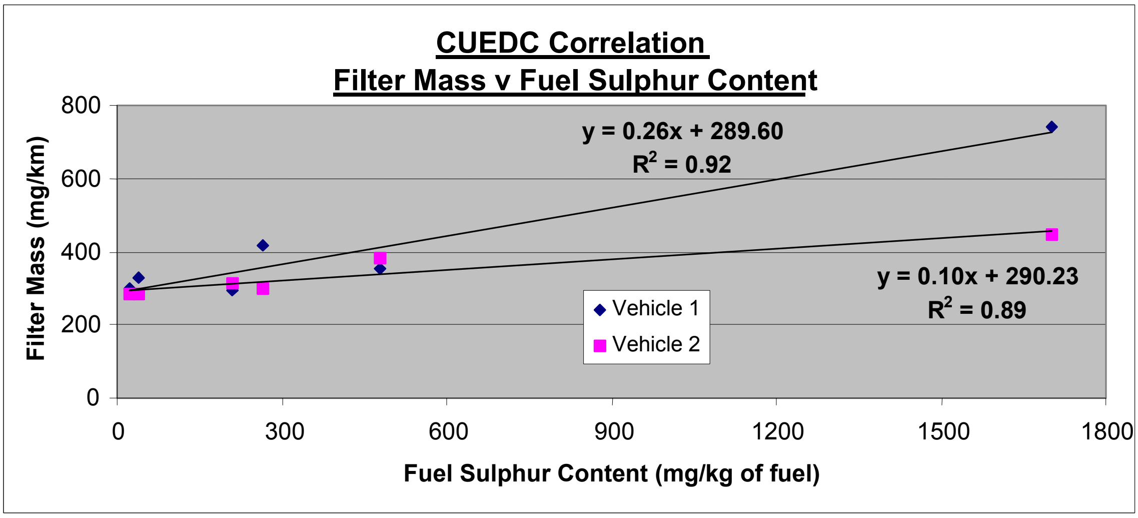


*Figure 4.8b correlation of particulate mass with sulfur content*

These plots indicate a close relationship between the filter mass and fuel sulfur content. This relationship is as would be predicted from results of overseas investigations.

### 4.2.9 Opacity – Average and Maximum

Figures 4.9a and 4.9b illustrate the average and Maximum Opacity results recorded for the two vehicles using the six types of diesel fuel.

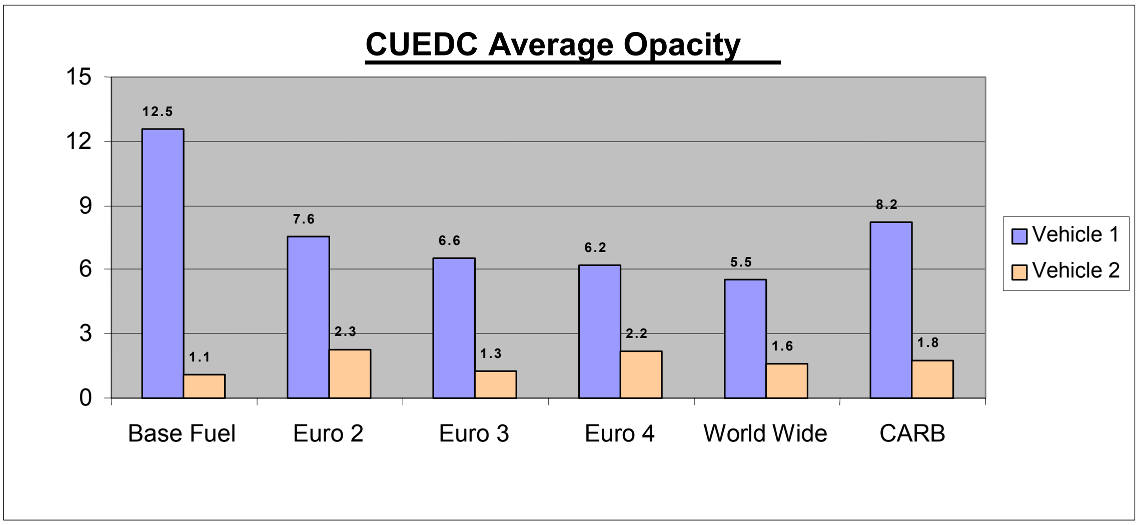


*Figure 4.9a: Average Opacity*

Vehicle 1 recorded its maximum reading of Average Opacity using the Base fuel and its minimum with the CARB fuel. Vehicle 2 had its maximum reading of Average Opacity using Euro2 fuel and its minimum reading with the Base fuel.

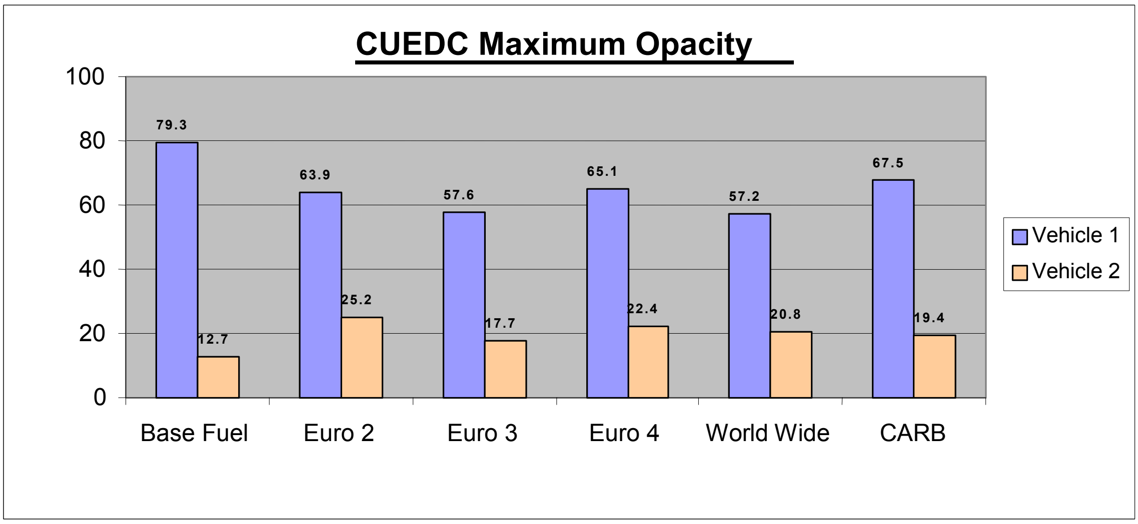


*Figure 4.9b: Maximum Opacity*

Vehicle 1 recorded its Maximum Opacity reading using the base fuel and its minimum value using the World-Wide fuel. Vehicle 2 recorded its maximum Opacity reading with the Euro 2 fuel and its minimum using the base fuel.

Since the values of Average and Maximum Opacity recorded for the two vehicles varied to a significant degree it was not reasonable to compare the average results obtained with the different fuels for these two sets of results.

There is no definite indication from these sets of results as to which fuel would provide the minimum Opacity readings.

### 4.2.10 Particulate Size (PM1.0, PM2.5 and PM10) Emissions

Figures 4.10a, 4.10b and 4.10c indicate the emission rates of PM1.0, 2.5 and10 measured during the test program using the six types of diesel fuel.

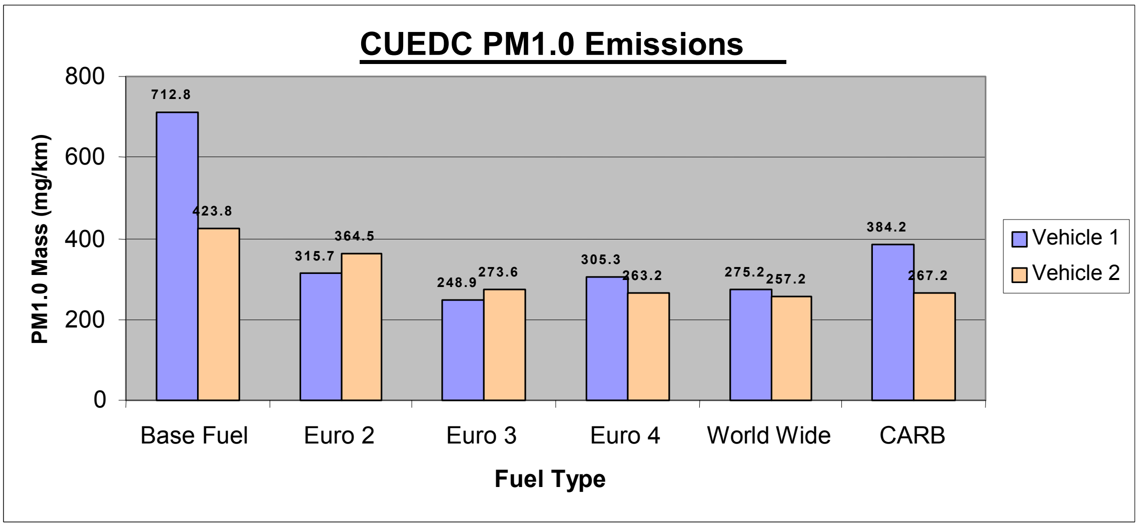


*Figure 4.10a: PM1.0 Emissions*

The maximum PM1.0 emission rate was recorded for both vehicles using the base fuel with only marginal differences recorded for both vehicles with the other fuels.

The PM1.0 emissions for Vehicle 1 was significantly higher with the base fuel than Vehicle 2 but this trend was not repeated for all of the other fuels.

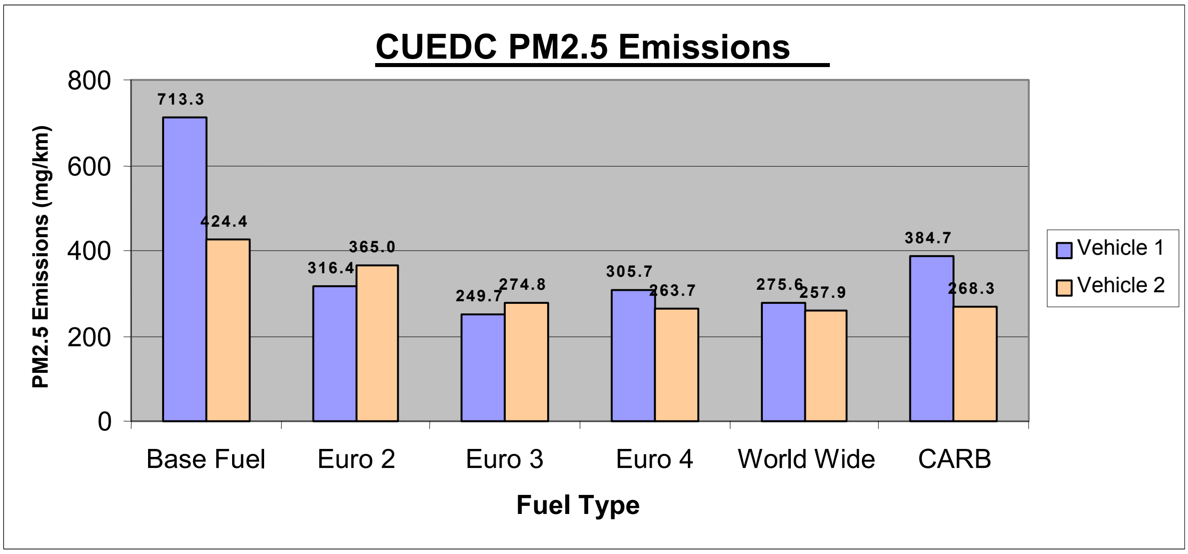


*Figure 4.10b: PM2.5 Emissions*

The pattern of PM 2.5 emissions was similar to that recorded for PM 1.0 emission rates. The highest emission rate for both vehicles was again recorded using the base fuel with the emission rates for Vehicle 1 significantly higher than for Vehicle 2.

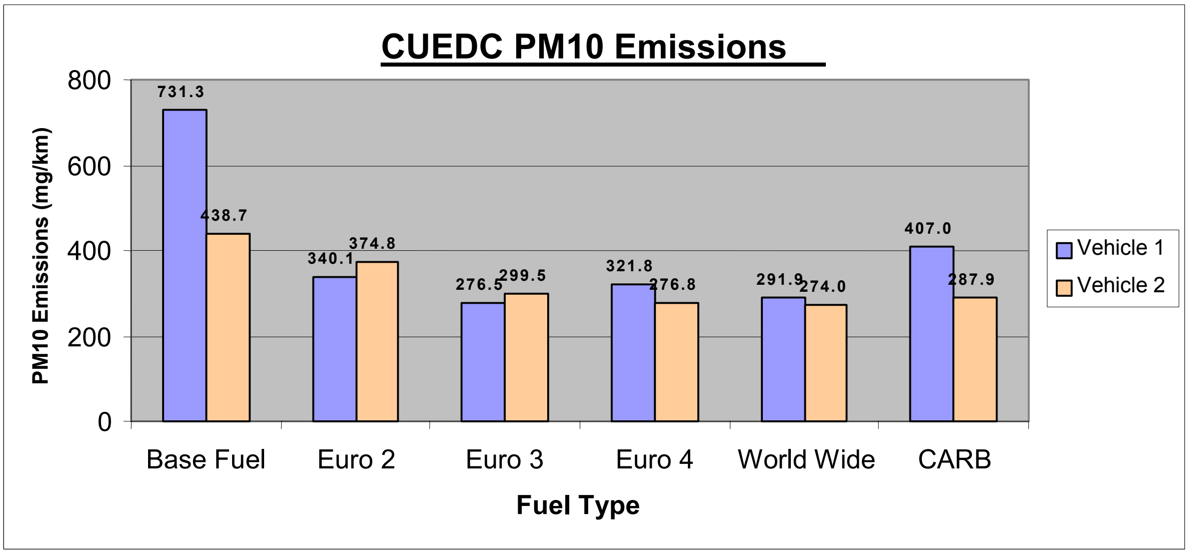


*Figure 4.10c: PM10 Emissions*

Both vehicles again produced their highest emission rate using the base fuel with the PM10 emissions from the Vehicle 1 again significantly higher than for Vehicle 2.

The three sets of results each produced a similar pattern for particulate emissions.

The use of Euro 3 fuel gave, on average, the lowest PM1.0, PM2.5 and PM10 emissions for Vehicle 1. They all reduced by approximately 65% by changing from the Baseline fuel to Euro3 fuel.

However for Vehicle 2, on average the PM1.0, PM2.5 and PM10 emission rates were reduced by approximately 35% using the Worldwide fuel blend and about 39% using Euro4 fuel.

## 4.3 Impact of road flow conditions

The CUEDC drive cycle used for this test program comprises four segments reflecting four different driving conditions.

- Congested urban
- Minor / Residential roads
- Arterial roads
- Highway / Freeway

The following is a comparison of the emission results recorded for the various measured road flow conditions. Only the NOx, Particulate, Smoke and Fuel Consumption graphs are shown below.

Complete details of all figures relating to this study are included in Appendix 1.

### 4.3.1 NO$_x$ Emissions

Testing of Vehicle1 indicated that NO$_x$ emissions were highest on congested driving and lowest on highway driving for each of the fuels. However there was no consistent pattern when Vehicle 2 was tested.

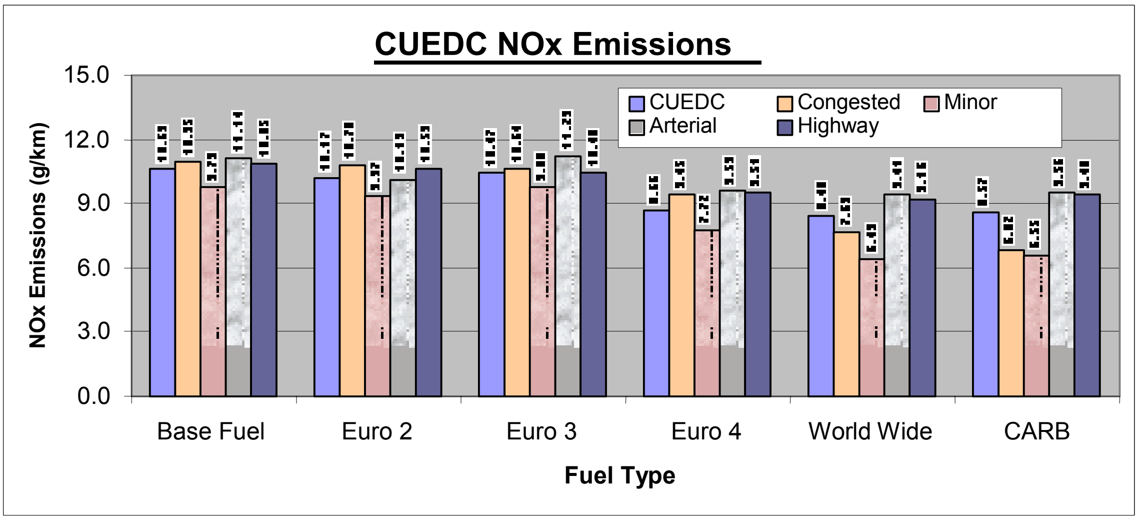


*Figure 4.11. NOx emissions by road mode – rigid truck*

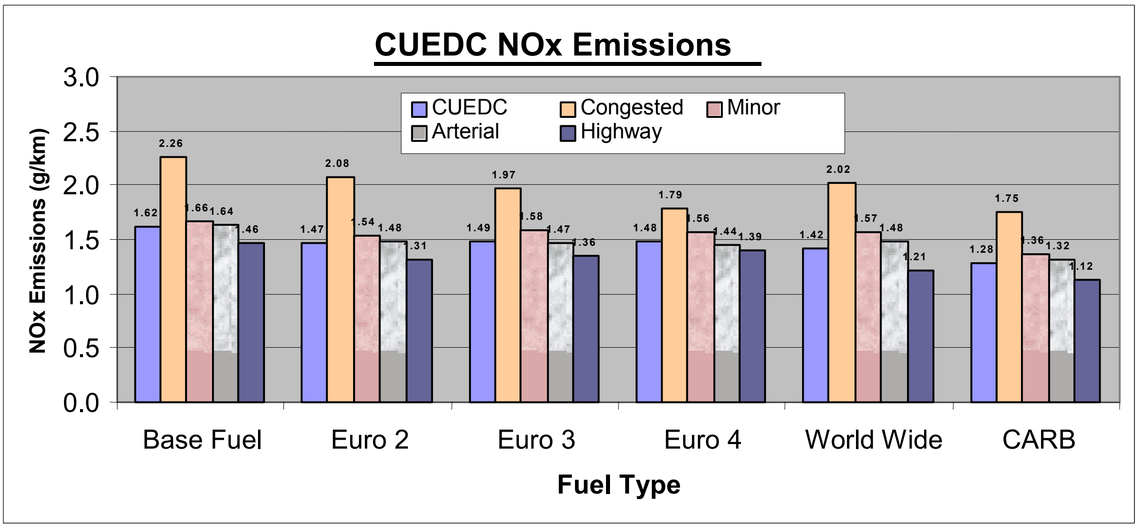


*Figure 4.12. NOx emissions by road mode – light commercial*

### 4.3.2 HC Emissions

HC emissions for Vehicle 1 tended to reduce from the congested driving segment to the highway-driving segment for each of the fuels. Vehicle 2 showed a greater rate of decrease in HC emissions from congested driving to the highway-driving segment

### 4.3.3 CO Emissions

CO emissions tended to increase for each of the fuels as the driving segment changed from the congested segment to the highway segment for Vehicle 1 but for Vehicle 2 the Co emissions were lowest for highway segment and highest for the congested segment.

### 4.3.4 $CO_2$ Emissions

$CO_2$ emissions tended to decrease on both vehicles for each fuel as the driving pattern changed from congested to highway

### 4.3.5 Fuel Consumption

As could be expected the fuel consumption for both vehicles tended to follow the same pattern as for $CO_2$ emissions decreasing for all fuels as the driving segment changed from congested to highway.

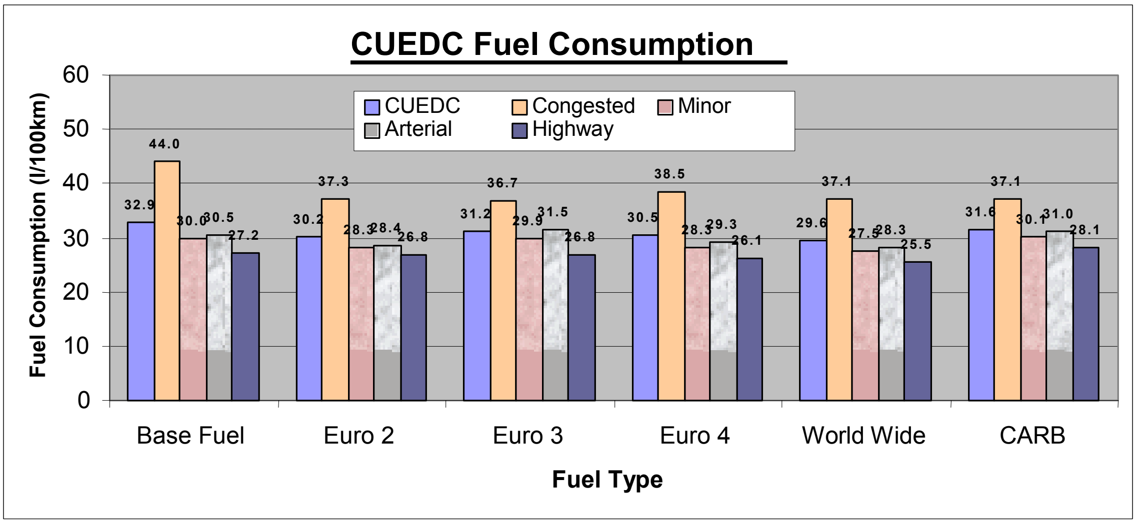


*Figure 4.13. Fuel Consumption – rigid truck*

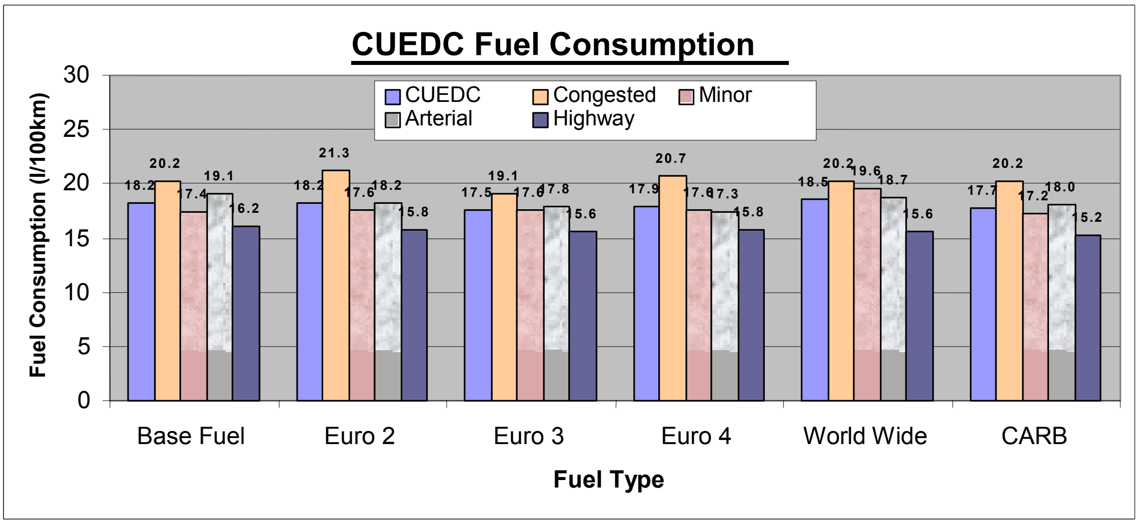


*Figure 4.14. Fuel Consumption – light commercial*

### 4.3.6 LLSP Mass

For Vehicle 1 the LLSP mass tended to increase for each fuel as the driving changed from congested to highway. Vehicle 2 did not provide a consistent pattern of LLSP mass emission rate.

### 4.3.7 TEOM Mass

On average the TEOM mass for Vehicle 1 tended to increase for each fuel as the drive cycle changed from congested to highway and for Vehicle 2 tended to decrease when tested on the Base fuel, increased on Euro 2 fuel but did not have a consistent pattern on the other fuels.

### 4.3.8 Filter Mass

For Vehicle 1 the filter mass increased as the drive cycle changed from congested to highway for all fuels but for Vehicle 2, whilst the trend was not as clear as for Vehicle 1, on average the mass decreased from the congested cycle to the highway cycle.

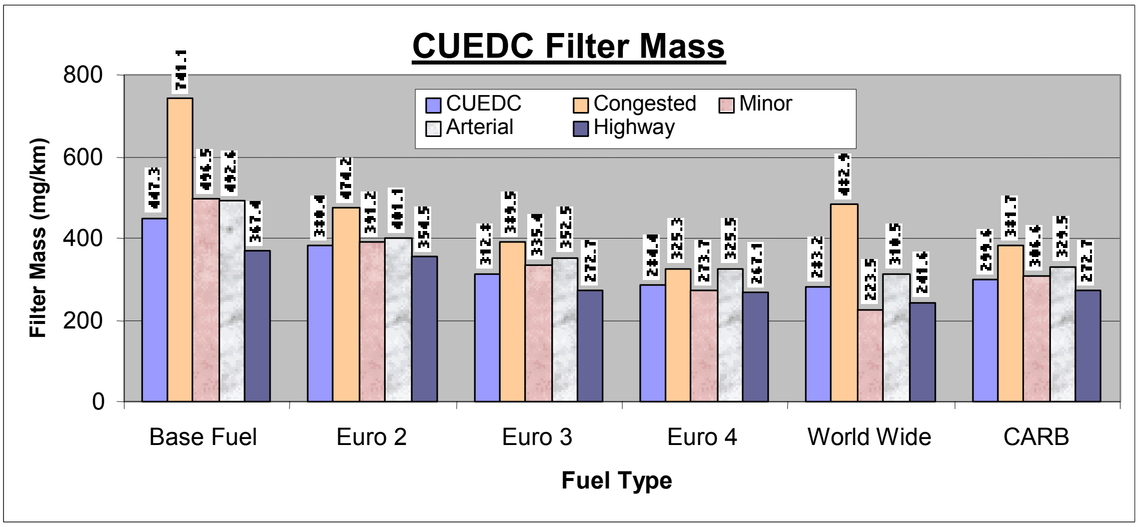


*Figure 4.15. Particulate mass – rigid truck*

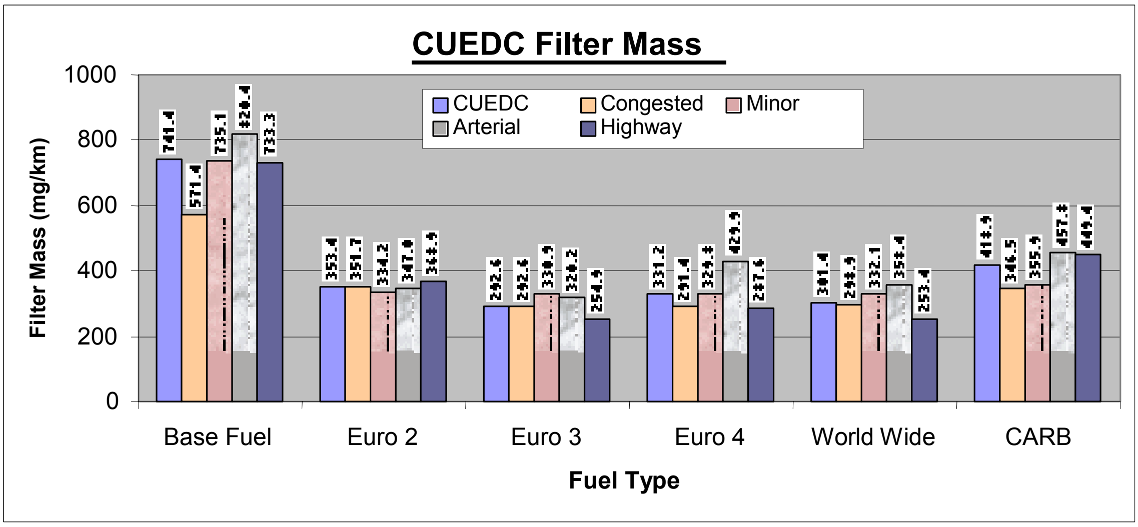


*Figure 4.16. Particulate mass – light commercial*

### 4.3.9 Average Opacity

For both vehicles the average opacity tended to increase as the driving pattern changed from the congested to the highway segment.

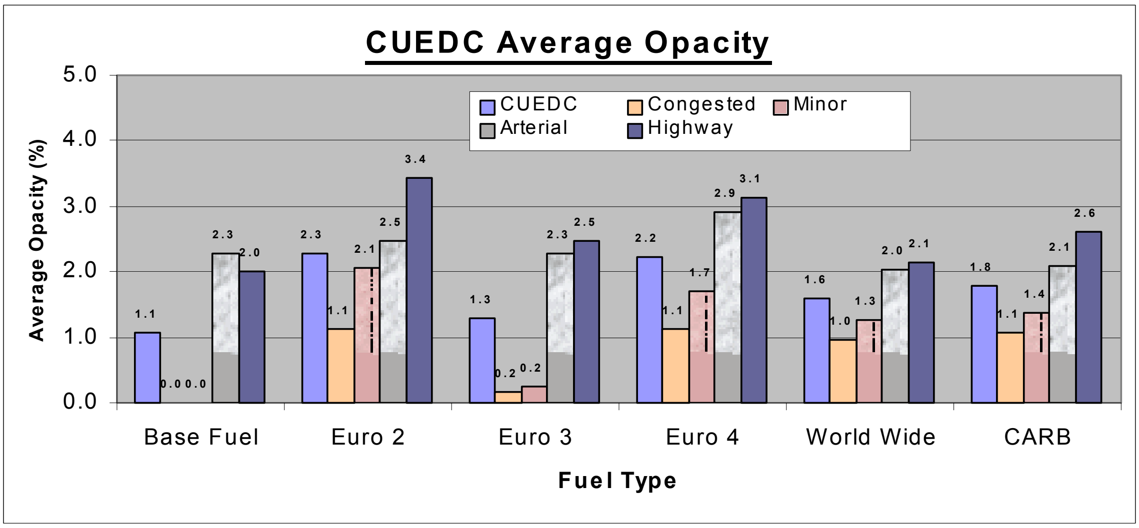


*Figure 4.17. Average Smoke Opacity – rigid truck*

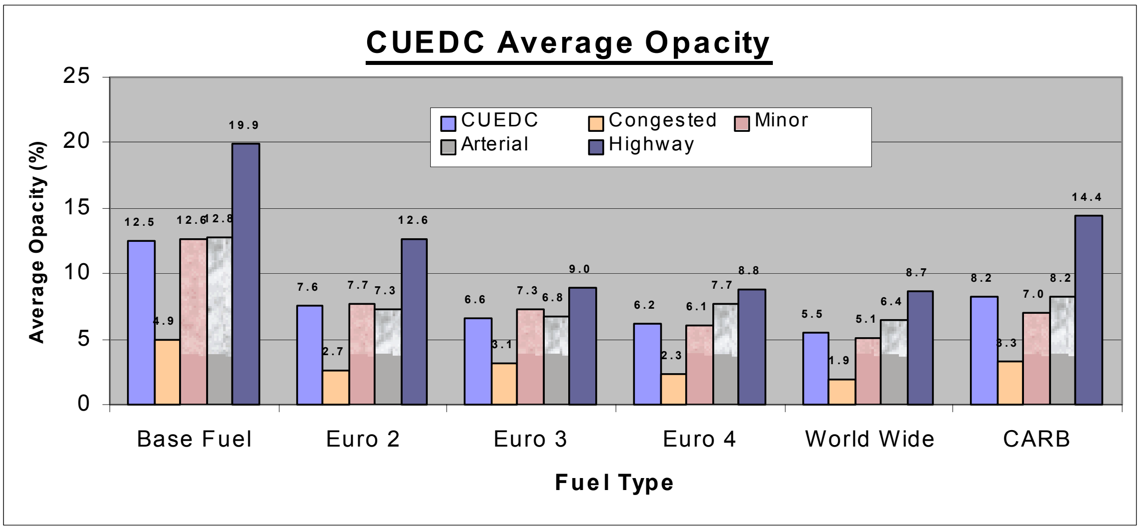


*Figure 4.18. Average Smoke Opacity – light commercial*

### 4.3.10 Maximum Opacity

The trend for the maximum opacity reading was similar to that recorded for average opacity for both vehicles, as could be expected, with the maximum readings increasing as the driving pattern changed from congested to highway.

# 5 CONCLUSIONS

## 5.1 Toxic Emissions – Part A and Part B

Emissions of selected toxic species in diesel exhaust, conducted under Parts A and B of the Supplementary Toxic Study of the Diesel NEPM Preparatory Project 2.2 have been reported.

Sampling and analytical methods were developed and used to measure:

- volatile organics (VOCs, in this case monoaromatics and 1.3-butadiene),
- aldehydes and
- polycyclic aromatic hydrocarbons (PAHs)

Part A involved selecting 12 of the 80 vehicles tested for the NEPM project and measuring the emissions of the target species. Emissions are reported as g/km for each of the four road flow modes of a specially developed urban drive cycle (CUEDC). Vehicles were chosen such that two from each of the six vehicle classes were represented.

In Part B, two vehicles were selected from the previous 12, were driven through the CUEDC with a range of diesel fuel formulations. The fuels ranged in sulfur content from 24-1700 ppm, and in total aromatics from 7.7-33 mass%. Emission rates (g/km) were determined for the same species.

The results of Part A, viewed in conjunction with previously reported overseas data, indicate:

- Benzene is usually the most abundant monoaromatic species
- Aldehyde emission rates exceed VOC emission rates, and in some studies are reported to contribute substantially to total VOC emission rates from diesel vehicles
- PAH emission rates are significantly less than VOC and aldehyde emission rates
- Lower sulfur and aromatic content of the fuels did not have a significant effect on emissions of VOCs and aldehydes
- Fuel formulation appears to have little effect on emissions of the VOCs and aldehydes, suggesting that the combustion process controls the formation of these species in diesel exhaust.
- Lower aromatic content fuels result in lower PAH emission rates

Complete details of the results obtained for the “Toxic Emissions from Diesel Vehicles” are available in the separate comprehensive CSIRO report by S.J. Day et al of June 2000.

## 5.2 Gaseous and Particulates – Part B

Gaseous and particulate emissions from two diesel vehicles, when operated with six different diesel fuel blends have been examined.

The two vehicles were driven over the Composite Urban Emission Drive Cycle (CUEDC) appropriate for their Australian Design Rule (ADR) category using fuels of different compositions and their emissions measured. The six fuels represented a variety of diesel fuels currently being used or proposed for use around the world.

In order to achieve the emission reductions required to improve air quality and decrease the potential adverse health impacts of diesel emissions changes to fuel specifications have been found necessary in other countries to accompany engine design modifications and the fitting of exhaust after-treatment devices.

The need to reduce the sulfur content of diesel fuels has been acknowledged as an important component of improved fuel formulations. However the more stringent control of a number of other fuel components forms part of the emission reduction strategy.

The results indicated that, on average, gaseous and particulate emissions were minimised with the use of the World-Wide Spec fuel.

The results of overseas testing would suggest that the use of World-Wide specification diesel fuel would provide the maximum reduction of gaseous and particulate emissions. However the full potential benefits from using this fuel will only be achieved when it is used in vehicles fitted with engines designed to comply with more stringent emission standards and fitted with exhaust gas treatment devices.

This project has shown that there is a potential to reduce particulate and gaseous emissions from current model vehicles with the introduction of these new fuel specifications. No adverse effects were observed from using the new fuel formulations.

Whilst a relationship between a reduction in particulate emissions and fuel sulfur content was demonstrated, other important fuel specifications were also changed in these fuels (ie Cetane Index, density, aromatic content, density and T90 distillation temperature). It is not therefore, possible to determine the separate effect of sulfur content on the gaseous and particulate emissions.

It is also important to remember that all of the benefit of reduced sulfur content of diesel fuel is not available when used on older technology vehicles. Sulfur in diesel fuel can affect the long term effectiveness, durability and efficiency of exhaust treatment devices fitted to vehicles built to comply with the latest and future overseas emission standards.

# 6 RECOMMENDATIONS

This project has provided some valuable information on gaseous, toxic and particulate emissions from current model vehicles and an indication of the potential benefit from using new diesel fuel formulations.

However further testing would be needed to enable projections of the total toxic, aldehyde and PAH emissions from the whole in-service fleet.

In addition, to obtain a more precise estimate of the benefit of introducing new diesel fuels a larger sample of vehicles would need to be tested.

It is recommended that:

- A larger sample of vehicles are measured to collect more precise data on the toxic, Aldehyde and PAH emissions from the diesel fleet using commercially available fuel and an advanced specification fuel such as either World-Wide spec fuel or Euro 4 fuel.

- To determine a more precise estimate for the potential benefits from introducing new diesel fuels, testing is carried out on a greater sample of vehicles using two fuels – commercially available fuel (as a baseline fuel) and an advanced specification fuel such as either World-Wide category 3 spec fuel or Euro 4 fuel.

# 7 SUPPLEMENTAL METALS REPORT

The investigation of metals emitted from diesel vehicles operating on a number of future (low sulfur) fuels was undertaken as a supplementary study to the main Toxic Emissions Study.

The following information has been obtained from CSIRO who undertook the measurement and analysis of metal results.

## 7.1 Summary

Particulate samples collected from two diesel vehicles fuelled with a range of fuels have been analysed for selected metals. The study initially involved the collection of samples on glass fibre filters during the operation of each vehicle across a transient drive cycle referred to as a Composite Urban Emission Drive cycle (CUEDC). Unfortunately the tests were only partially successful, largely due to the high background concentrations of metals in the glass fibre filters used to collect the samples.

A second attempt was made using a teflon filter when another study (Ultra-fine Particulate Study) was commissioned by Environment Australia to evaluate fine particulate matter across the same range of vehicles and fuels. However, the test protocol used in the Particle Study was not the CUEDC but a steady state short test referred to as the D550. As the metals study was principally aimed at assessing the comparative difference between fuels, the change in test protocol (CUEDC to D550) was considered not to adversely impact on the outcomes of the study.

Results from the D550 tests using teflon filter were more successful than the CUEDC test using glass fiber filters. The results from the Ultra-fine particulate study obtained during the D550 test have been previously reported (Nelson *et al*¸2000).

The initial CUEDC samples were analysed by inductively coupled plasma- mass spectrometry (ICP-MS), hydride generation / atomic fluoresence spectrometry (HG/AFS), and X-ray fluoresence (XRF). In most cases the detection limits of the metals were not high enough for quantitative measurements, because of the high background concentrations in the glass fibre filters. Mercury could be quantitatively measured by HG/AFS, and emission rates of 0.5-2.5 µg/km were determined. It was not possible to detect an influence of fuel composition on the emission rate.

The samples collected on teflon filters during the D550 test were analysed using proton induced X-ray emission (PIXE). Detectable amounts of Si, P, S, Cl, K, Ca, Ti, Fe and Zn could be measured in at least some of these samples. The possible importance of lubricant and component degradation derived contributions to the observed concentrations may be important. Future measurements of the metals in diesel exhaust emissions, and the determination of the effects of fuel composition on the emissions, would require a more controlled series of emission tests and measurements than those conducted here.

## 7.2 Background

Emissions of particulate material from industrial sources have received considerable attention for many years. In the past, the interest was related to a number of effects, including visibility reduction. In recent years this interest has increased as a consequence of concerns about the health impacts of fine particles. As a consequence, the issue of fine particulate material is of great current research and community interest, and the sources, formation, and transformations of fine particles in the atmosphere are likely to be the most important issues in air pollutant research in the next 10 years.

Studies of urban air pollution in the United States, Europe and Australia have revealed a strong correlation between fine particle concentrations and mortality (Schwartz *et al*, 1996). While it is possible to question whether this correlation is a result of a causal effect, there is a need to deal with the immediate response to these findings. The USEPA, for example, has recently drafted a major downward revision of the Air Quality Standard for $PM_{2.5}$ (to 15 $\mu g/m^3$, annual mean, and 50 $\mu g/m^3$, 24 hour average). Hence, emissions of fine particles will come under increasing scrutiny.

Diesel vehicles are a major source of fine particle emissions in urban locations, and an accurate characterisation of the composition of particulate emissions from diesel vehicles is a high priority. Previous work has identified a number of metals and metallic compounds in diesel exhaust particulate material. Diesel emissions are reported (Dieselnet, 2000) to include:

- metal oxides - several engine lubricating oil additives include metallo-organic compounds resulting in some metal oxide emissions including such metals as phosphorus, zinc, and calcium.
- Fuel additives researched as a means of diesel emission control may result in emissions of iron, copper, cerium, or other metals.

The toxic air contaminants antimony compounds, arsenic, beryllium compounds, cadmium, chromium compounds, cobalt compounds, inorganic lead, manganese compounds, mercury compounds, nickel and selenium compounds have been reported by the Californian Air Resources Board (CARB, 1998) in diesel emissions.

In the current study samples collected during the Diesel NEPM project were examined for the presence of metals. The samples included those collected from 2 vehicles driven over the:

a) composite urban drive cycle (CUEDC) developed for Project 2 of the Diesel NEPM preparatory work and,

b) from the D550 short test also developed for Project 2 of the DNEPM preparatory work.

The vehicles were representatives of ADR class NA (light commercial, Toyota Hilux) and of class ADR NC (rigid truck 12.5-25 tonne GVM, Isuzu 900SUR). The vehicles were fuelled with a range of fuels of varying specifications (commercial base fuel, Euro 2, Euro 3, Euro 4, CARB and a world wide fuel (WWF) formulation). The fuels ranged in sulfur content from 24-1700 ppm, and in total aromatics from 7.7-33 mass % as listed in table 7.1.

*Table 7.1: Fuel properties*

| Fuel | Sulfur content (ppm) | Total aromatics (% mass) |
|---|---|---|
| Base fuel | 1700 | 33 |
| Euro 2 | 480 | |
| Euro 3 | 210 | 24 |
| Euro 4 | 39 | 11.6 |
| World Wide Spec (Category 3) | 24 | 7.7 |
| CARB | 264 | 21.3 |

## 7.3 Methods

The two methods used – CUEDC tests and D550 tests are described under separate headings as are the results in section 7.4.

### 7.3.1 Sampling and Analysis of Particulate Material on Filters during the CUEDC

Samples were collected during each segment of the CUEDC on the glass fibre filters used for gravimetric determination of particulate emissions. Subsequently each of the filters was halved; one section was kept for analysis by a multi-element technique, either inductively coupled plasma mass spectrometry (ICP-MS) or energy dispersive X-ray fluorescence spectrometry (EDXRF). The other section was used for the determination of mercury.

### 7.3.2 Determination of mercury

The mass of mercury on the each half filter was determined by hydride generation / atomic fluorescence spectrometry (HG/AFS).

The section of filter was digested at reflux temperature with sulfuric and nitric acids in a borosilicate glass apparatus designed to condense the acid fumes and trap any elemental mercury vapour that may be formed. The complete dissolution of the carbonaceous particulate matter was achieved.

The digest solution was diluted to volume with “18 MΩ/cm” water and the mercury in solution determined using a P.S. Analytical Ltd Mercury Fluorescence System. The accuracy of the procedure was confirmed by the analysis of a Certified Reference Material (NIST 1630a, coal).

### 7.3.3 Estimation of other trace elements on the filter

A number of procedures were attempted.

The possibility of using the solution obtained for the determination of mercury was considered. The solution was diluted and the resulting solution analysed by ICP-MS (VG Elemental PQ ExCell). The high levels of sulfuric acid necessitate a high dilution prior to measurement. The concentrations present were similar to those present in the blank.

A section of one sample filter and blank filter were extracted with reverse aqua regia in a closed digestion vessel in a microwave oven. This does not dissolve the carbonaceous matter but it is highly probable any trace elements present would be dissolved. The resulting extracts were analysed by ICP-MS. Again, the concentrations found were similar to those present in the extract of the blank filter. The detection limit was approximately 1 µg per filter paper for most trace elements using this procedure.

The other procedure attempted was the use of EDXRF (SPECTRO X-LAB 2000). The filter was exposed to X-rays and the fluoescence spectra measured. The instrument was calibrated using the Certified Reference Material, NIST 3087a, Materials on Filter Media. Detection limits were approximately 50 – 100 ng/cm$^2$. This is equivalent to approximately 0.15 – 0.3 µg per filter paper. Other than elements present in the filter matrix (eg. Na, Mg, Al, K. Ca, Zn, Sr), no trace elements of interest were detected.

### 7.3.4 Determination of metals from D550 tests using PIXE/PIGME analysis

A total of 12 filters (2 vehicles fuelled with 6 fuels) collected during the D550 short test was analysed using PIXE/PIGME. Material was collected on 25 mm Teflon filters. Although a black or grey deposit could be seen on all the filters, the amount of material collected was very small. The deposit was not uniform across the filter due to masking by components of the filter assembly. The before and after weights of the filters were not substantially different.

The filters were analysed in the accelerator with a proton energy of 2.6MeV. The accelerator was calibrated with known samples. A collection time of 15 minutes was used to improve statistics. Note that, the normal collection time used by ANSTO for their standard aerosol filter analysis is 5 minutes with a deposit weight of about 40 mg. The diameter of the sample area was 8 mm. The total collection charge was 9 µC and the target current within the range 12 to 15 nA.

## 7.4 Results and Discussion

### 7.4.1 Samples collected from initial CUEDC tests

A summary of the sampling and analyses performed is given in Table 7.2. A previous report (Day *et al*, 2000) has reported the effects of fuel composition on the emissions of organic toxic species such as volatile aromatics (e.g., benzene and toluene), aldehydes and polycyclic aromatic hydrocarbons (PAHs). It was intended to obtain similar data for toxic metals.

*Table 7.2: Details of sampling and analysis for metal emissions from Diesel vehicles*

| | ***CUEDC Testing*** |
|---|---|
| Vehicle Tests | 4 cycles of CUEDC (4 samples per vehicle and fuel tested) |
| Vehicles Tested | NA class (Toyota Hilux, light commercial)<br>NC class (Isuzu truck, rigid truck 12.5-25 tonnes GVM) |
| Fuels tested | Commercial grade<br>Euro 2<br>Euro 3<br>Euro 4<br>CARB<br>WWF |
| Sampling media | Glass fibre filters |
| Analysis techniques | Mercury by hydride generation / atomic fluorescence spectrometry (HG/AFS)<br>Other elements by inductively coupled plasma mass spectrometry (ICP-MS)<br>Energy dispersive X-ray fluorescence spectrometry (EDXRF) also attempted |
| Comments | Mercury determined successfully for NA class vehicle<br>High background concentrations of metals in glass fibre filters made detection difficult for other elements |
| | |
| | ***D550 short test*** |
| Vehicle Tests | D550 Short Test (1 sample per vehicle and fuel tested) |
| Vehicles Tested | NA class (Toyota Hilux, light commercial)<br>NC class (Isuzu truck, rigid truck 12.5-25 tonnes GVM) |
| Fuels tested | Commercial grade |

| | |
|---|---|
| | Euro 2<br>Euro 3<br>Euro 4<br>CARB<br>WWF |
| Sampling media | Teflon membrane filters |
| Analysis techniques | Proton induced X-ray emission (PIXE) |
| Comments | Low loadings on filters made detection of metals difficult<br>Detectable amounts of Si, P, S, Cl, K, Ca, Ti, Fe and Zn could be measured in some of the samples |

There were significant problems encountered in this study in achieving sufficient detection sensitivity for the metals of interest. Some of these problems are discussed in Section 7.3, above and summarised in Table 7.2 (comments sections). The major problem in the initial samples collected from the CUEDC was the high background concentration of metals in the glass fibre samples. It was not possible to determine trace elements other than mercury on the filters, with any confidence. The HG/AFS technique enabled the detection of mercury at a level close to one nanogram per filter. The sensitivity obtained for the other trace elements was two to three orders of magnitude greater than that obtained for the mercury.

This problem is best illustrated by consideration of the data in Table 7.3, which shows results of analyses of blank filters and those obtained from two filters collected from segments of CUEDC tests. Twenty-six elements (not including mercury) were determined, but in all cases the results obtained were not significantly greater than those obtained for the blank filters, reflecting the high background content of metals in the glass fibre filters. These determinations were performed on filters very highly loaded with particulates, and represent a “best case” situation for detection of the metals; filters with lower loadings would suffer from even more significant problems due to the background concentrations of metals in the filters. These filters are commonly used for gravimetric determination of metals. Therefore only the results for two samples in Table 7.3 have been presented for the initial CUEDC tests to illustrate the problem of filter background.

*Table 7.3: Metal results (µg/filter paper) for blank filters and samples collected from CUEDC tests*

| Metal | Blank Filter | Sample 1 | Sample 2 | Metal | Blank Filter | Sample 1 | Sample 2 |
|---|---|---|---|---|---|---|---|
| Al | 11 | 15 | 15 | Mn | 0.03 | 0.04 | 0.04 |
| As | <0.1 | <0.1 | <0.1 | Mo | 0.01 | 0.01 | 0.02 |
| B | 10 | 20 | 20 | Na | 140 | 150 | 150 |
| Ba | 23 | 29 | 31 | Ni | 0.3 | 0.3 | 0.2 |
| Be | <0.1 | <0.1 | <0.1 | P | <0.5 | <0.5 | <0.5 |
| Ca | 9.3 | 12 | 12 | Pb | 0.23 | 0.43 | 0.38 |
| Cd | 0.01 | 0.004 | 0.003 | Se | <0.5 | <0.5 | <0.5 |
| Co | 0.003 | 0.006 | 0.01 | Si | 8 | 16 | 19 |
| Cr | <0.1 | <0.1 | <0.1 | Sn | <0.1 | <0.1 | <0.1 |
| Cu | 0.2 | 0.8 | 0.3 | Sr | 0.2 | 0.2 | 0.2 |
| Fe | 1.2 | 1.7 | 1.7 | Ti | <0.1 | <0.1 | <0.1 |
| K | 41 | 43 | 41 | V | <0.5 | <0.5 | <0.5 |
| Mg | 7.1 | 2.0 | 2.0 | Zn | 18 | 25 | 29 |

As noted above more successful analyses were achieved for mercury. A mercury specific technique was used, for which a sensitivity of 1 ng Hg per filter paper could be achieved, significantly higher than that of the ICP technique on which the results in Table 3 are based. In spite of this much higher sensitivity for mercury, only one of the vehicles (the NA class Toyota Hilux) measured over the CUEDC segments exceeded 1 ng Hg per filter paper for most fuel samples. The other vehicle (NC class Isuzu truck) gave results of less than 1 ng Hg per filter paper for 23 out of 28 samples collected, so that a discussion of fuel or drive cycle effects is not possible for that vehicle.

The results for the NA class vehicle are given in Figure 7.1, which shows mass emissions of mercury (g/km) for the fuels tested, and for the drive cycle segments. Some of the tests involve duplicate sampling (for the Euro 2 and Euro 3 fuels). Agreement between the results obtained for duplicate sampling and analysis is reasonable.

### 7.4.2 Discussion of Mercury results

As illustrated in Figure 7.1, emissions of mercury are low, and of order 0.5-2.5 µg/km for most samples. For the Euro 4 fuel much higher emissions of ~15 µg/km were observed, but this result appears anomalous. It is not possible to determine whether there is an influence of fuel composition on emissions of mercury from this data, given the small differences observed and the repeatability of duplicate tests. In any case the source of the mercury could be unrelated to the fuel composition.

## 7.5 Samples collected from the D550 short tests

Samples of the exhaust particulate emissions were collected on teflon membrane filters and sent to ANSTO for analysis by Proton induced X-ray emission (PIXE). This technique has been widely used to characterise the composition of fine particles in urban and other locations in Australia (Ayers *et al*, 1999).

Figures 7.2 and 7.3 give results for the NA and NC class vehicles respectively for selected elements. The results are given as mass per unit area (µg/cm$^2$) of filter. Conversion of these numbers to emission rates (g/km) is not justified for reasons given below.

Based on the results, it is not possible to determine the effects of fuel composition on emissions of the metals. Rather some comments about detected species and their possible sources can be made.

Detection limits for metals using the teflon filters and PIXE analysis were approximately 1-10 ng cm$^{-2}$. Nickel and manganese concentrations have not been reported since the loadings of these metals were less than this detection limit.

Detectable amounts of Si, P, S, Cl, K, Ca, Ti, Fe and Zn could be measured in at least some of these samples. The following observations related to the results can be made:

- Correlation between the known lubricant components P, Ca, and Zn is poor.
- K could originate from the lubricant.
- The origin of Si could be the lubricant but is more likely to be silica from other sources.
- The sulfur present in all but one sample is probably derived from the fuel but there appears to be little correlation between fuel sulfur content and sulfur detected on the filters; it is unclear whether sulfuric acid collected on the filters would still be present when the PIXE analysis was conducted.
- Diesel engine component degradation is probably responsible for the presence of Ti and Fe.
- The origin of F is likely to be from the Teflon but a contribution from elsewhere cannot be discounted.
- The possible importance of lubricant and component degradation derived contributions to the observed concentrations is important. This suggests that measurements of the metals in diesel exhaust emissions, and the determination of the effects of fuel composition on the emissions would require a more controlled series of measurements than those conducted here.

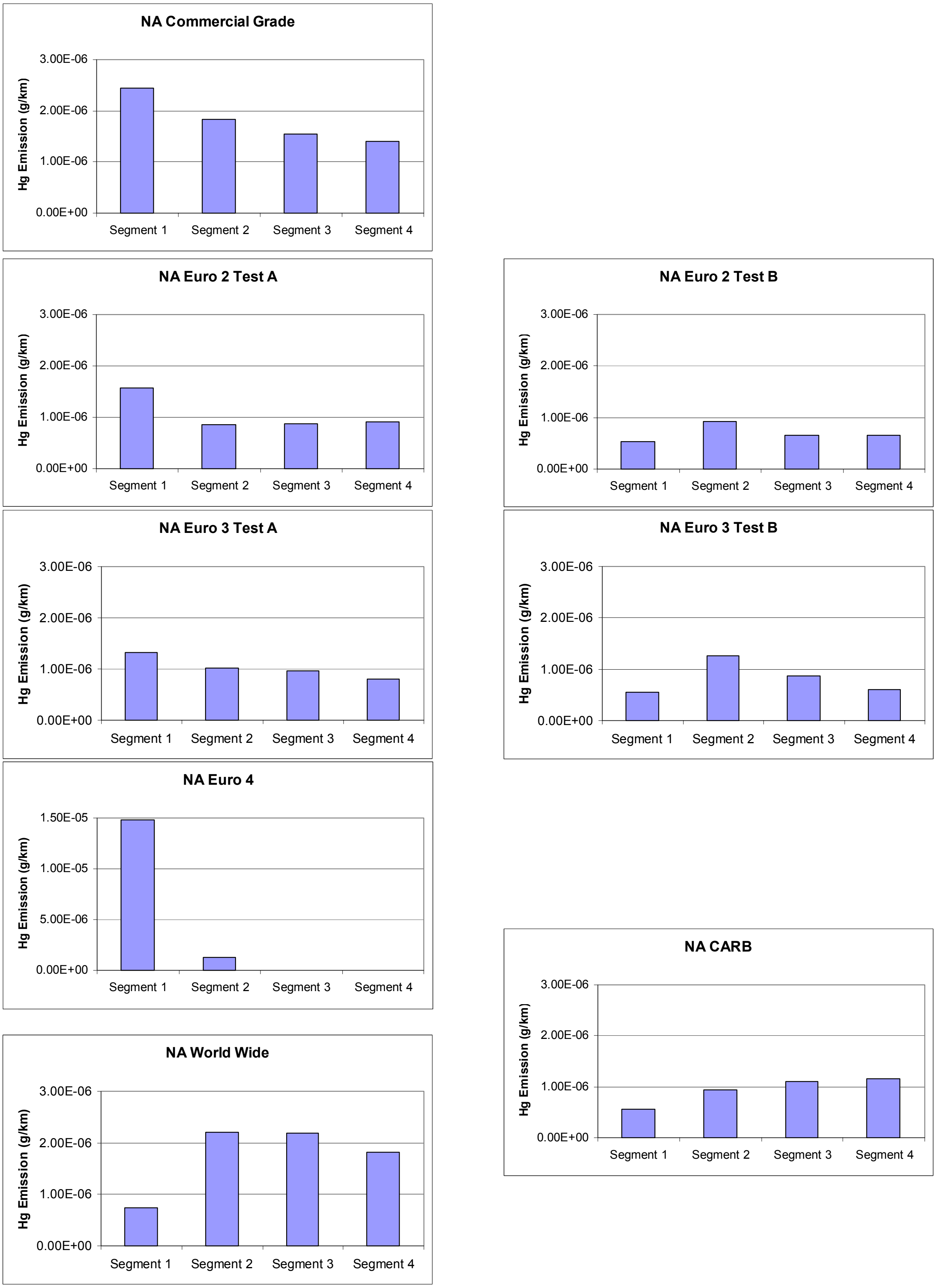


*Figure 7.1: Emissions of Hg (g/km) for selected fuels; class NA vehicle (Toyota Hilux)*

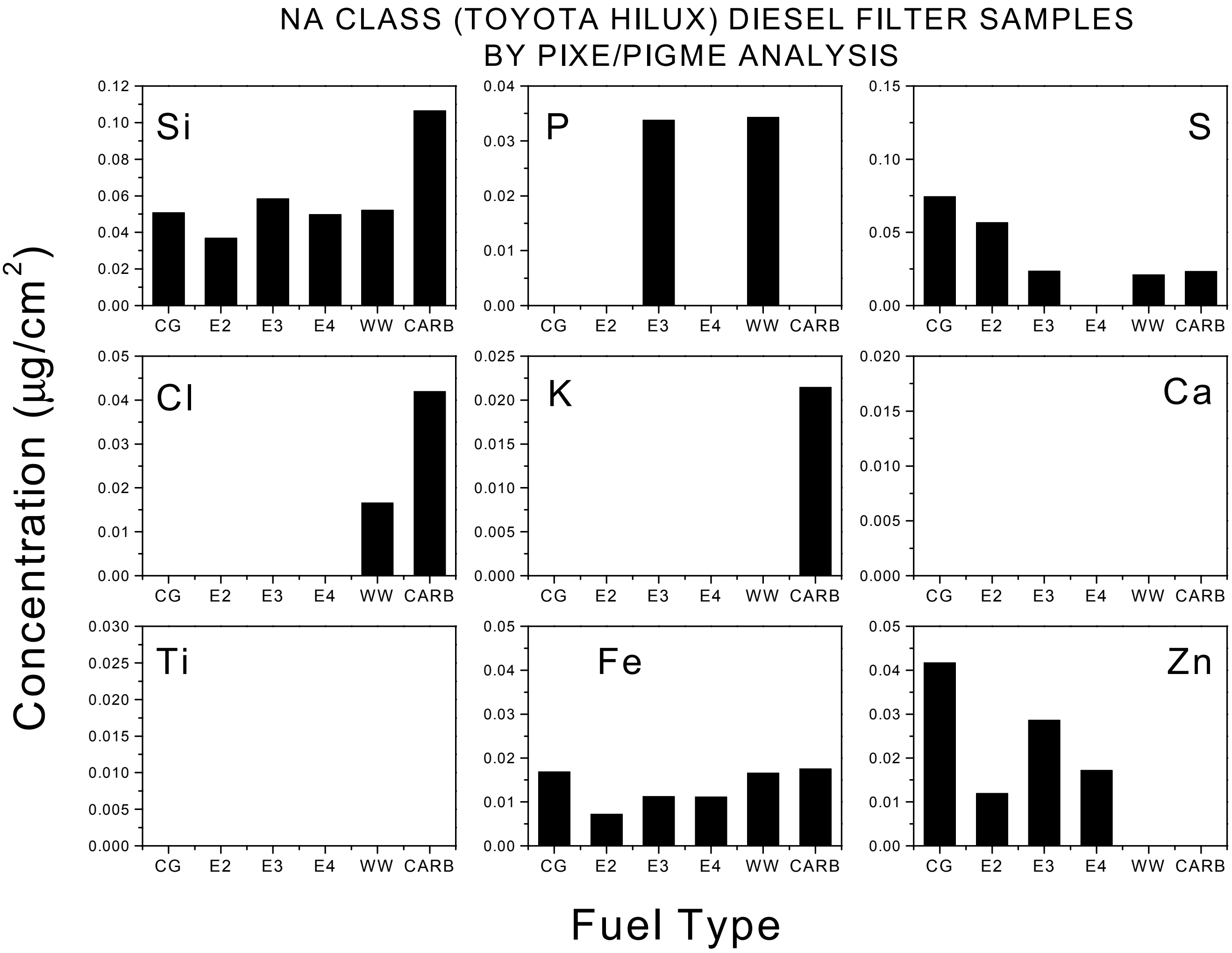


*Figure 7.2: Results of PIXE analysis of D550 samples; NA class vehicle; Fuel key: CG= commercial grade; E2, E3, E4 = Euro 2, 3 and 4; WW= World wide formulation; CARB = Californian Air Resources Board*

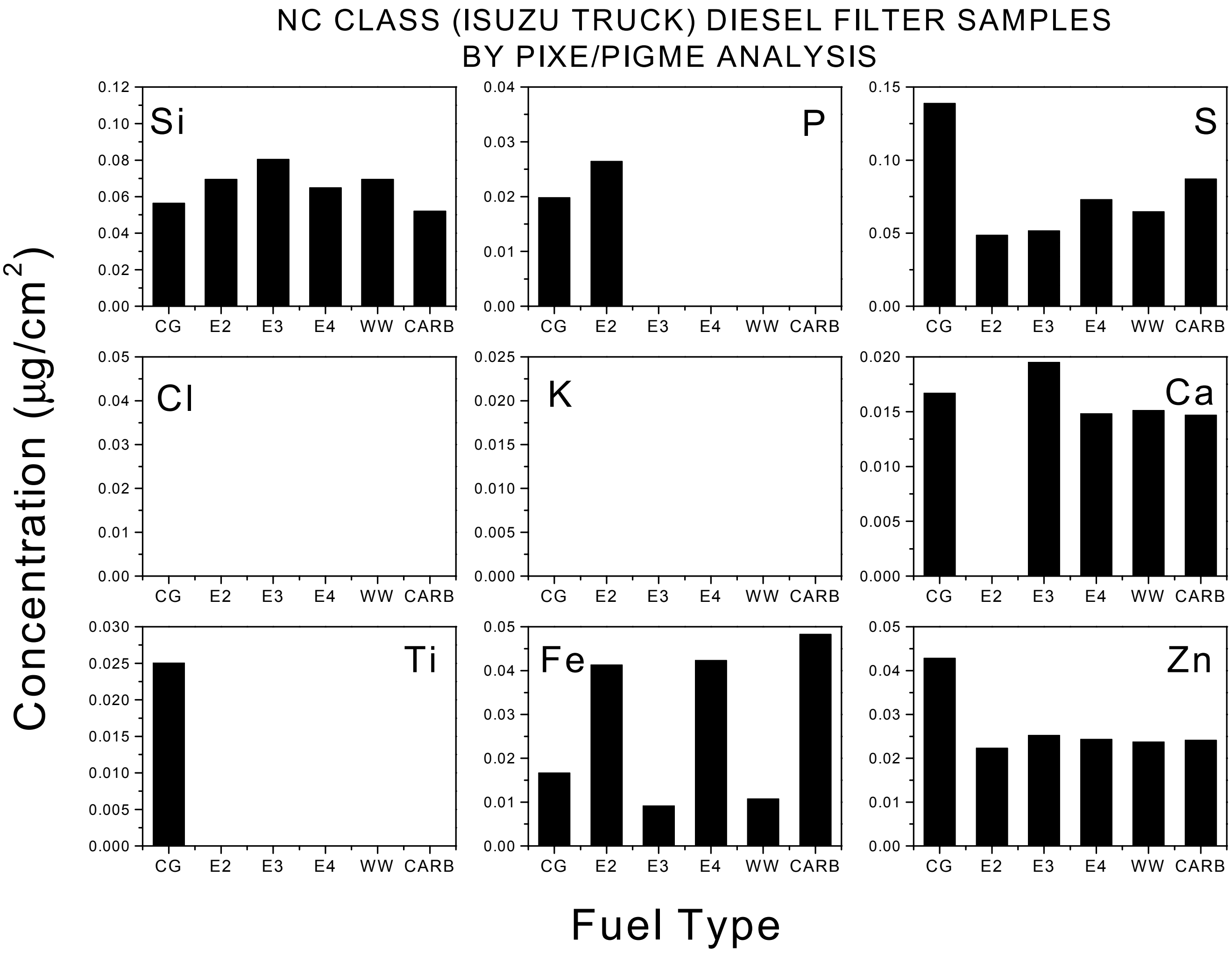


*Figure 7.3: Results of PIXE analysis of D550 samples; NC class vehicle; Fuel key: CG= commercial grade; E2, E3, E4 = Euro 2, 3 and 4; WW= World wide formulation; CARB = Californian Air Resources Board*

## 7.6 Conclusion

The two sampling methods trialed did not fully quantify the emissions of metals from vehicles nor did it attribute metals to a specific source – fuel type or oil burn. However it has been established that a more sensitive detection method is required to detect specific elements of interest such as nickel and manganese and that a more controlled set of parameters is required.

It is recommended that the following measurements would form a minimum set of data to examine this issue adequately:

Measurement of target metal compounds in the diesel fuels and lubricating oils used in the tests

- Use of the same and new lubricating oil for all tests
- Sampling of significantly higher quantities of particulate samples on membrane filters, and analysis of target metals using optimised instrumental techniques.

## 7.7 References

Ayers G.P. Keywood M.D. Gras J.L. Cohen D. Garton D. and Bailey G.M. (1999) Chemical and physical properties of Australian fine particles: a pilot study. Final report to Environment Australia, June 1999, 97 pp.

CARB (1998). *Diesel Exhaust as a Toxic Air Contaminant,* See downloadable version of this report at http://www.arb.ca.gov/toxics/diesel/diesel.htm

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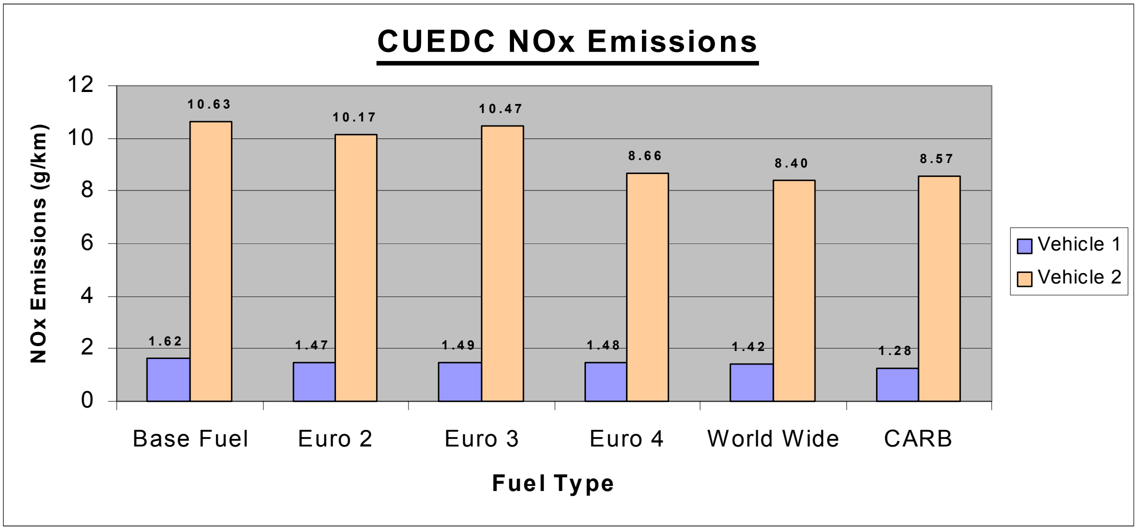
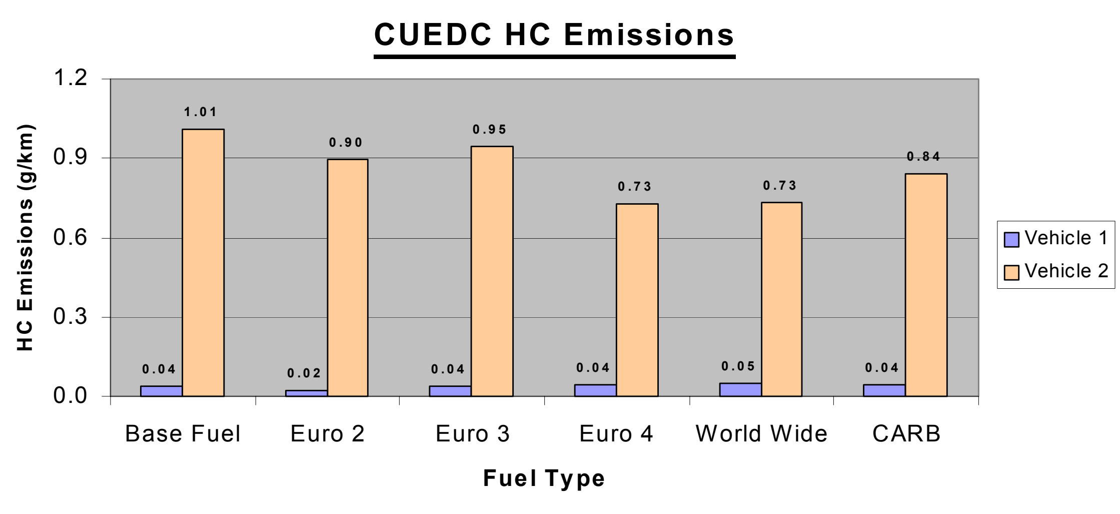
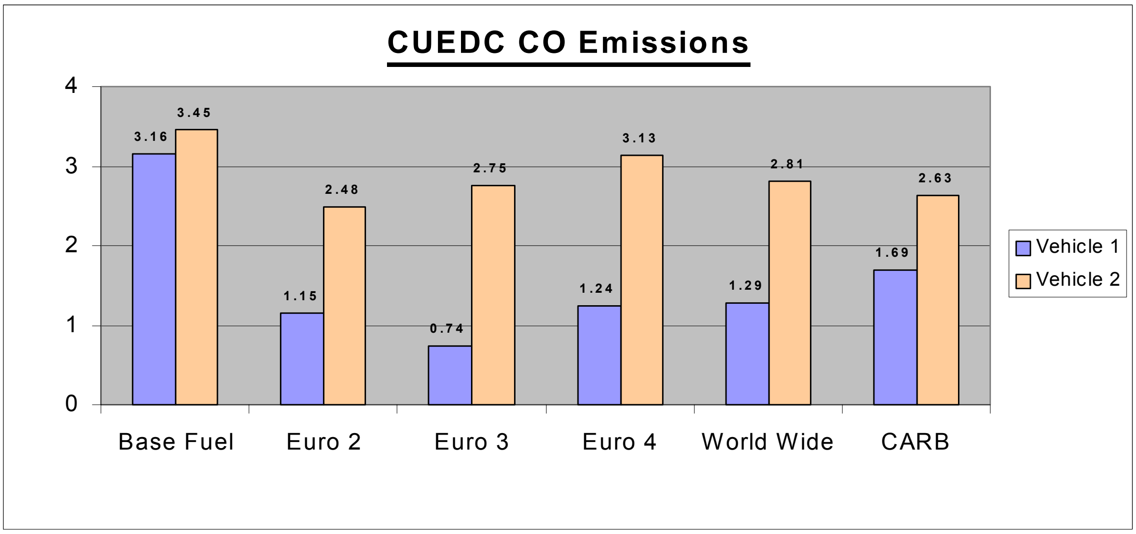
Day S.J. Heywood R. Nelson P.F. Roberts D.B. and Tibbett A.R. (2000) Toxic emissions from diesel vehicles, Final report to Parsons Australia Pty Ltd. CSIRO Energy Technology Investigation Report ET/344.

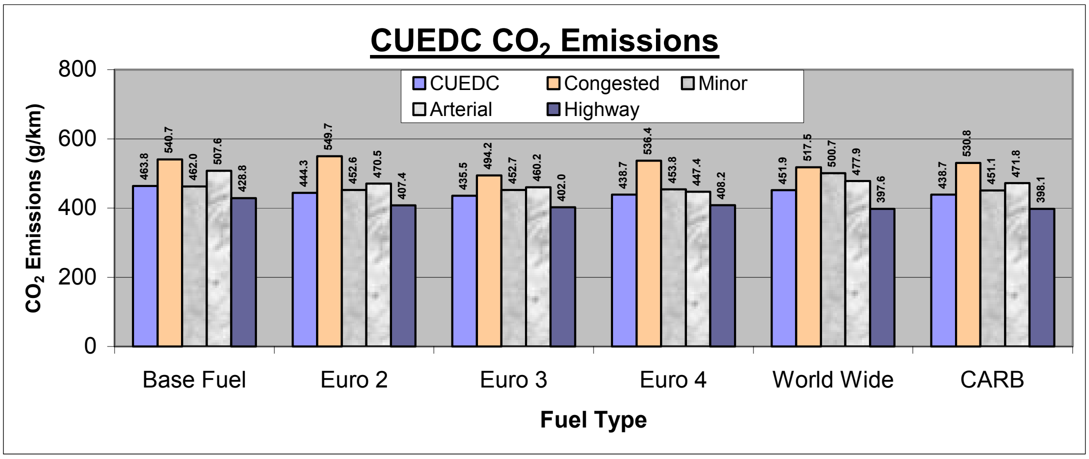
Nelson P.F. Halliburton B. Angove D.E. (2000) Fine particle measurements from diesel vehicles - effects of fuel formulation. Report to Parsons Australia, 16 pp.

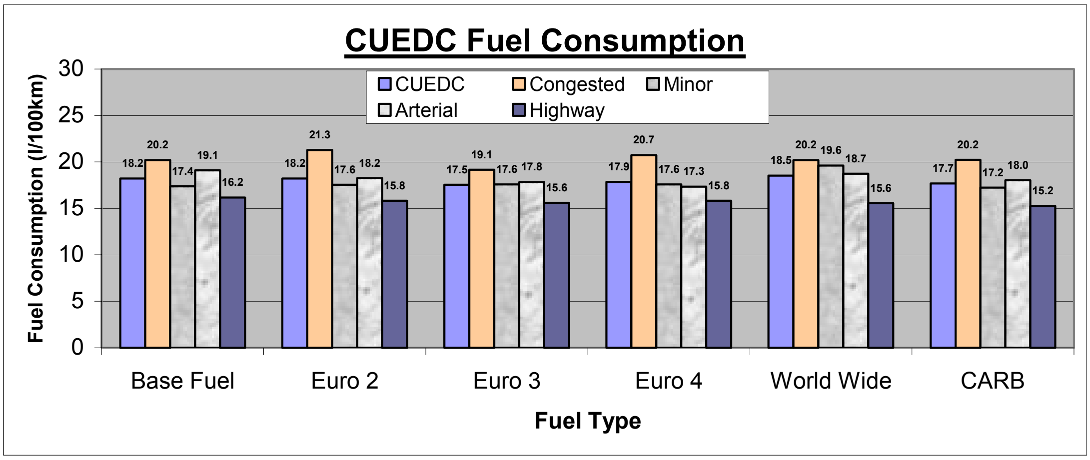
# Appendix 1:  Gaseous and Particulate Results  (Part B)

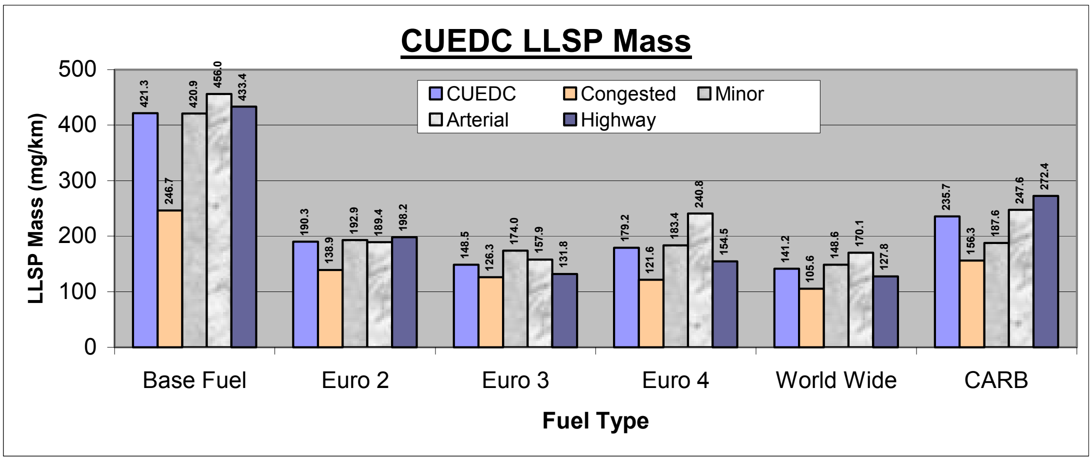


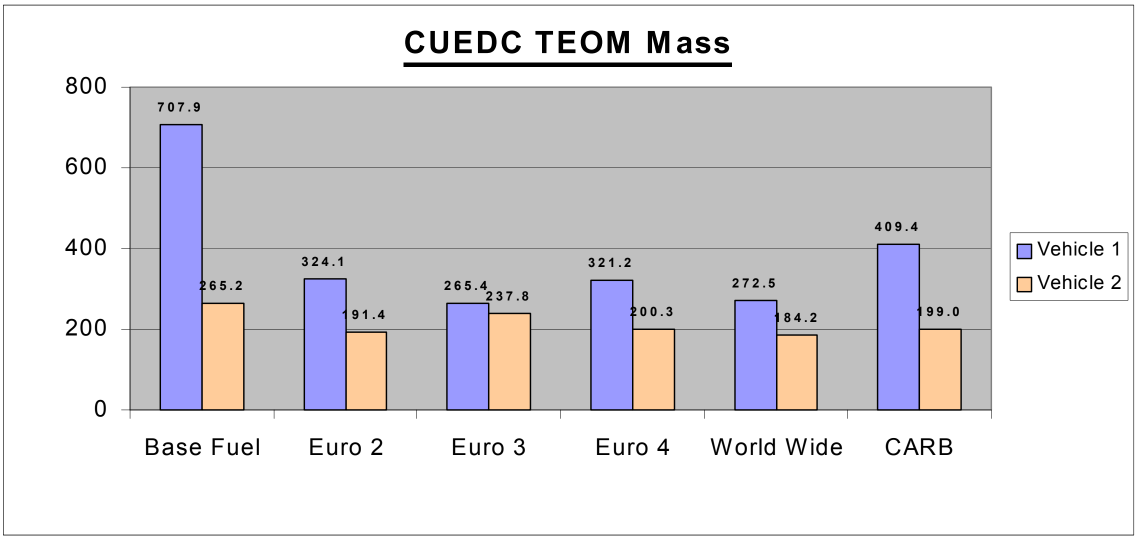


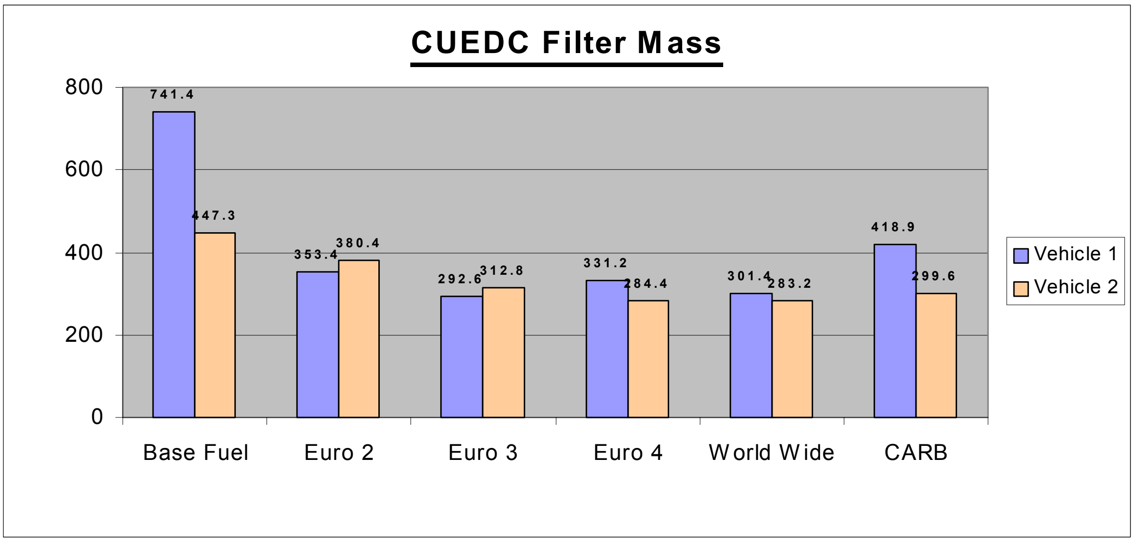


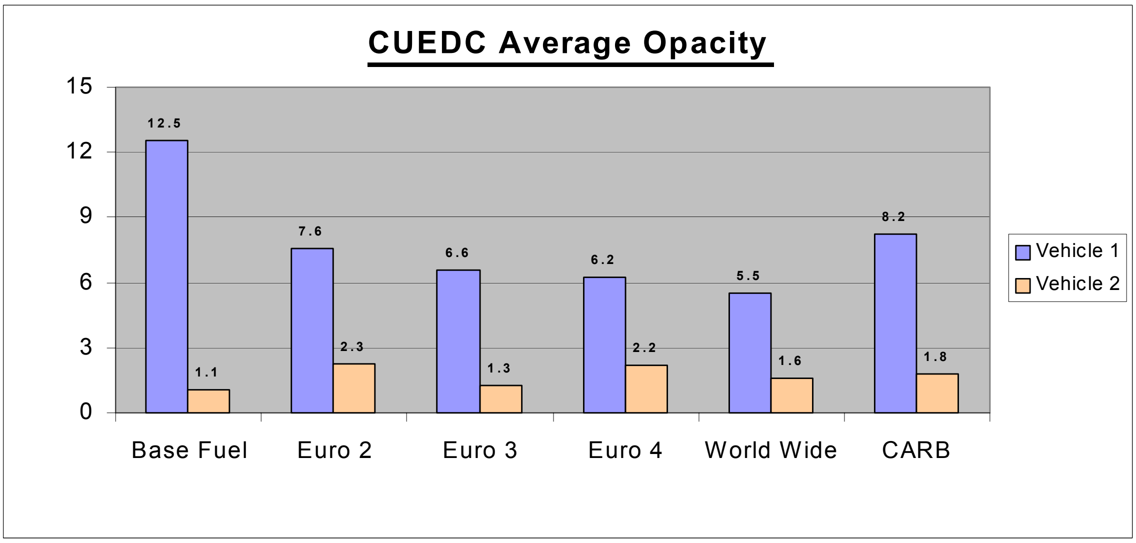

CUEDC CO$_2$ Emissions
CUEDC
Congested
Minor
Arterial
Highway
CO$_2$ Emissions (g/km)
800
600
400
200
0
463.8
540.7
462.0
507.6
428.8
444.3
549.7
452.6
470.5
407.4
435.5
494.2
452.7
460.2
402.0
438.7
536.4
453.8
447.4
408.2
451.9
517.5
500.7
477.9
397.6
438.7
530.8
451.1
471.8
398.1
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

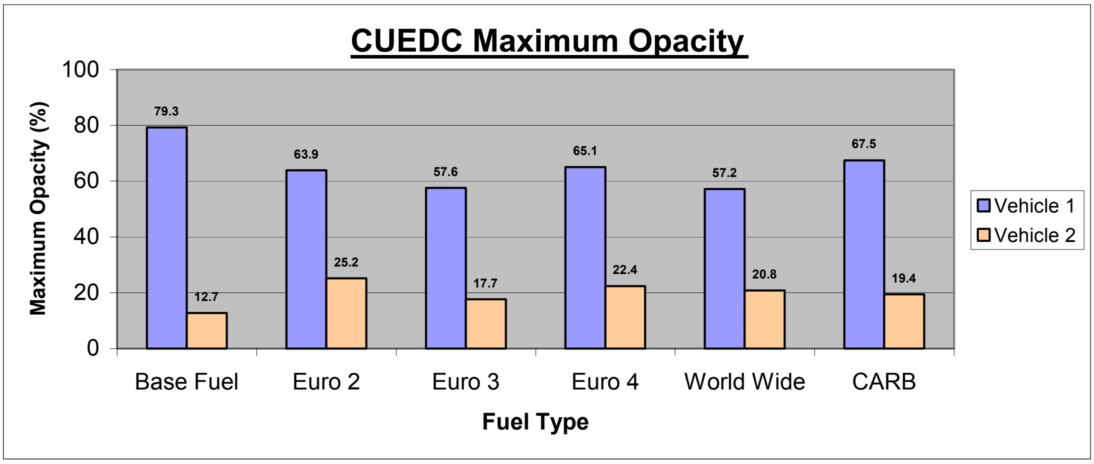

CUEDC Fuel Consumption
CUEDC
Congested
Minor
Arterial
Highway
Fuel Consumption (l/100km)
30
25
20
15
10
5
0
18.2
20.2
17.4
19.1
16.2
18.2
21.3
17.6
18.2
15.8
17.5
19.1
17.6
17.8
15.6
17.9
20.7
17.6
17.3
15.8
18.5
20.2
19.6
18.7
15.6
17.7
20.2
17.2
18.0
15.2
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

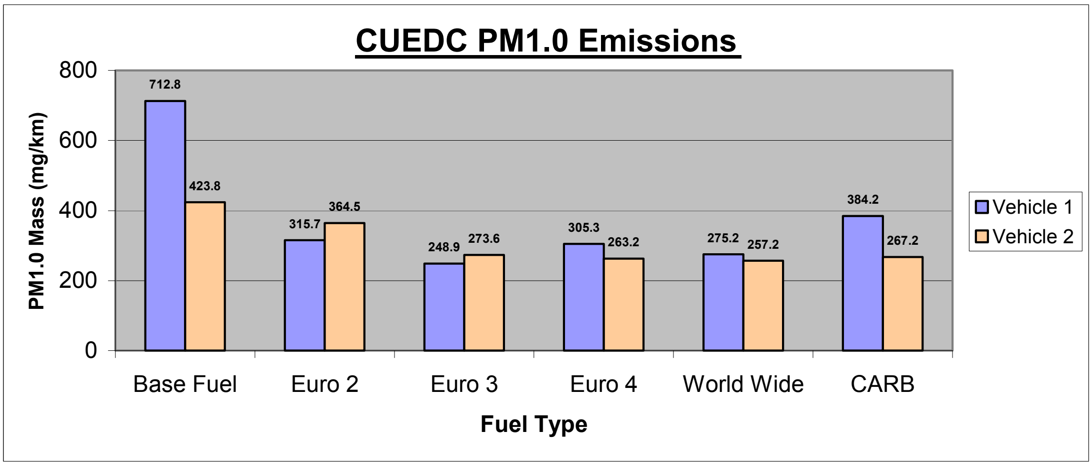

CUEDC LLSP Mass
CUEDC
Congested
Minor
Arterial
Highway
LLSP Mass (mg/km)
500
400
300
200
100
0
421.3
246.7
420.9
456.0
433.4
190.3
138.9
192.9
189.4
198.2
148.5
126.3
174.0
157.9
131.8
179.2
121.6
183.4
240.8
154.5
141.2
105.6
148.6
170.1
127.8
235.7
156.3
187.6
247.6
272.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

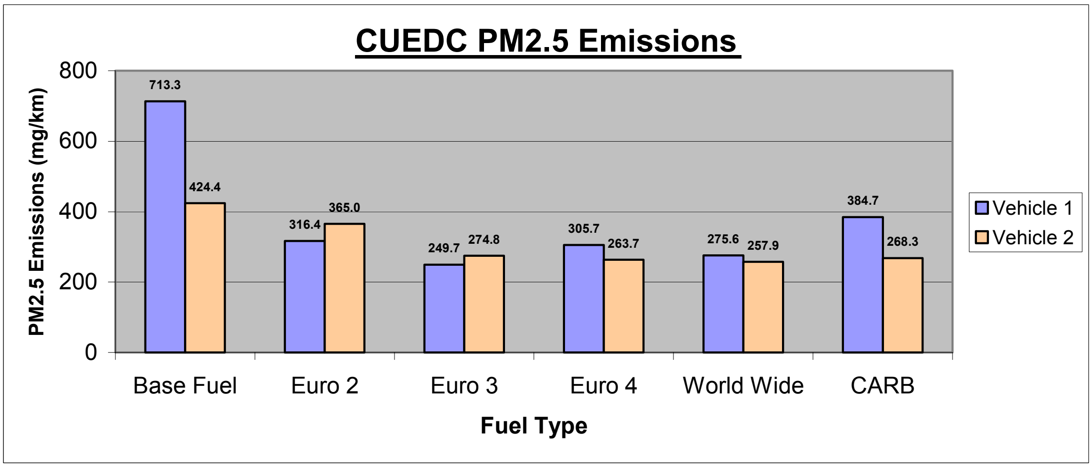

CUEDC TEOM Mass
800
600
400
200
0
707.9
265.2
324.1
191.4
265.4
237.8
321.2
200.3
272.5
184.2
409.4
199.0
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Vehicle 1
Vehicle 2

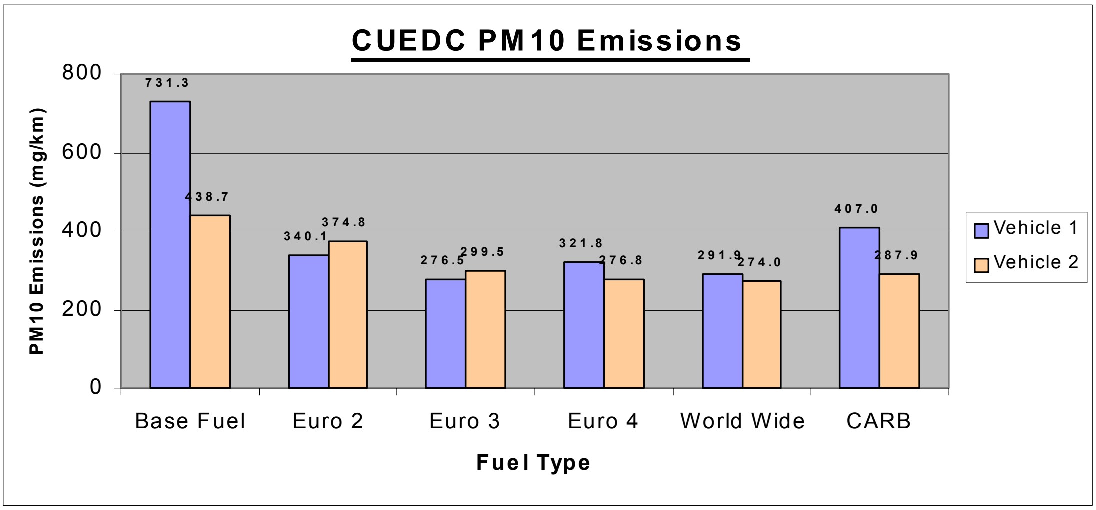

CUEDC Filter Mass
800
600
400
200
0
741.4
447.3
353.4
380.4
292.6
312.8
331.2
284.4
301.4
283.2
418.9
299.6
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Vehicle 1
Vehicle 2


CUEDC Average Opacity
15
12
9
6
3
0
12.5
1.1
7.6
2.3
6.6
1.3
6.2
2.2
5.5
1.6
8.2
1.8
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Vehicle 1
Vehicle 2

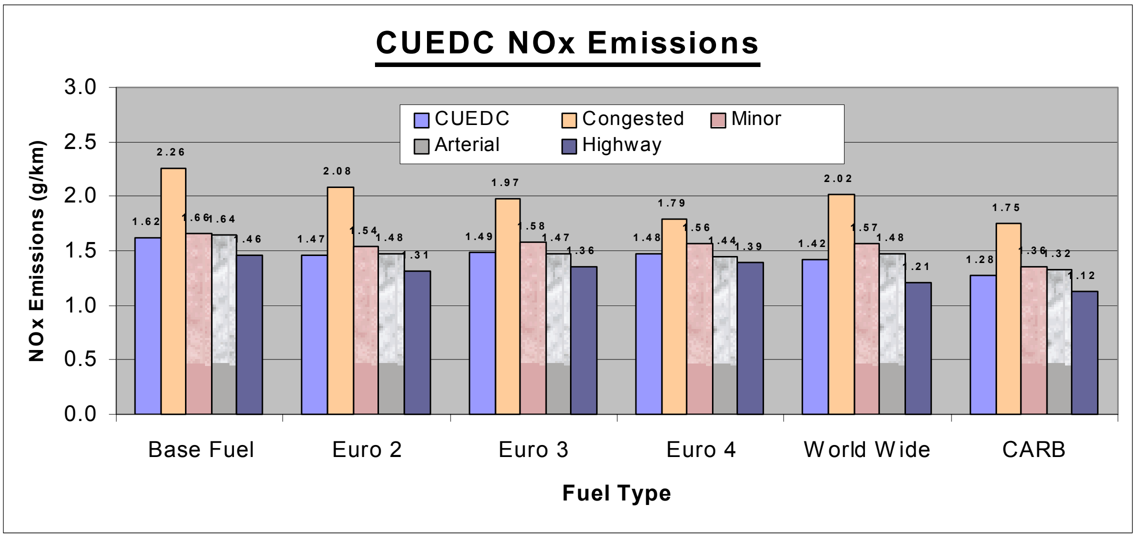

CUEDC Maximum Opacity
Maximum Opacity (%)
100
80
60
40
20
0
79.3
12.7
63.9
25.2
57.6
17.7
65.1
22.4
57.2
20.8
67.5
19.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type
Vehicle 1
Vehicle 2

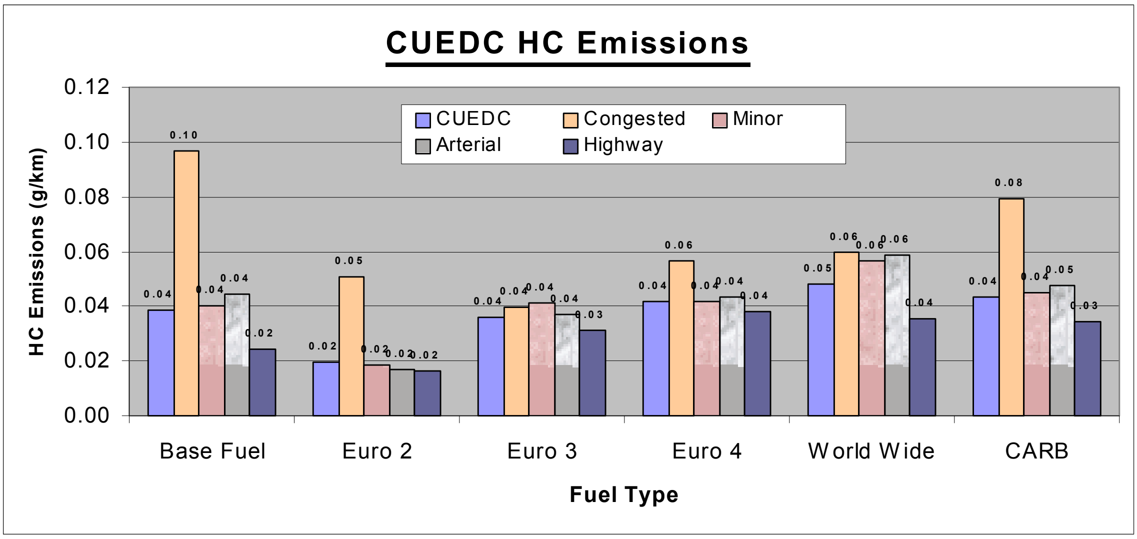

CUEDC PM1.0 Emissions
PM1.0 Mass (mg/km)
800
600
400
200
0
712.8
423.8
315.7
364.5
248.9
273.6
305.3
263.2
275.2
257.2
384.2
267.2
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type
Vehicle 1
Vehicle 2

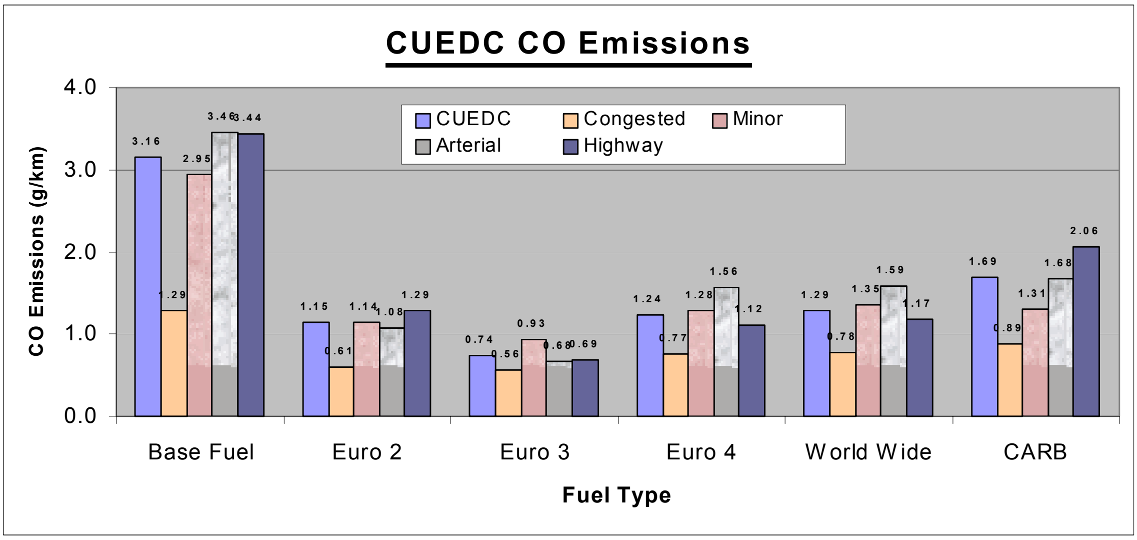

CUEDC PM2.5 Emissions
PM2.5 Emissions (mg/km)
800
600
400
200
0
713.3
424.4
316.4
365.0
249.7
274.8
305.7
263.7
275.6
257.9
384.7
268.3
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type
Vehicle 1
Vehicle 2

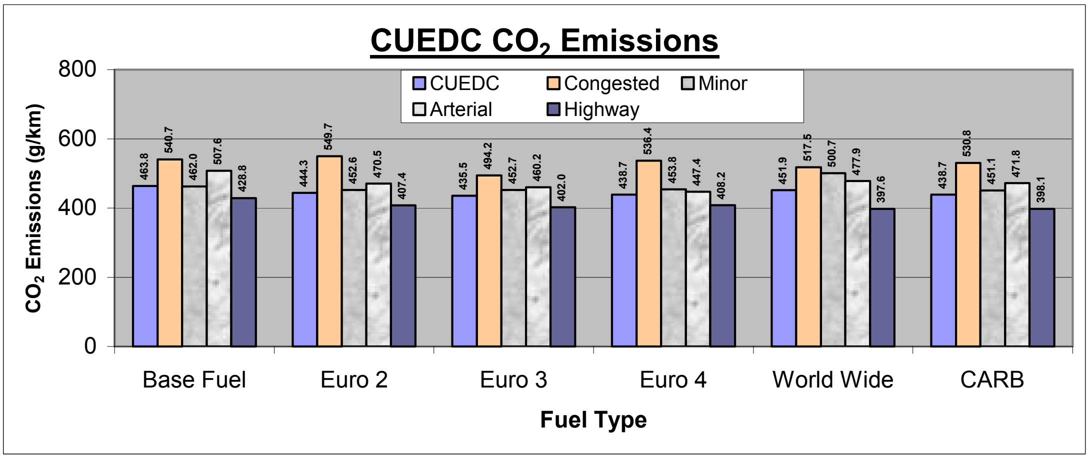

CUEDC PM10 Emissions
PM10 Emissions (mg/km)
800
600
400
200
0
731.3
438.7
340.1
374.8
276.5
299.5
321.8
276.8
291.9
274.0
407.0
287.9
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type
Vehicle 1
Vehicle 2

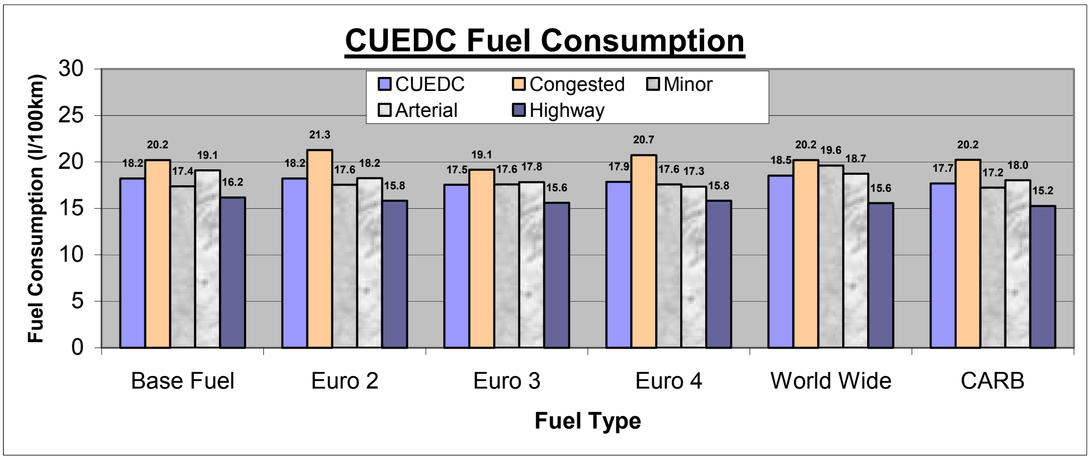
# Light Commercial Vehicle

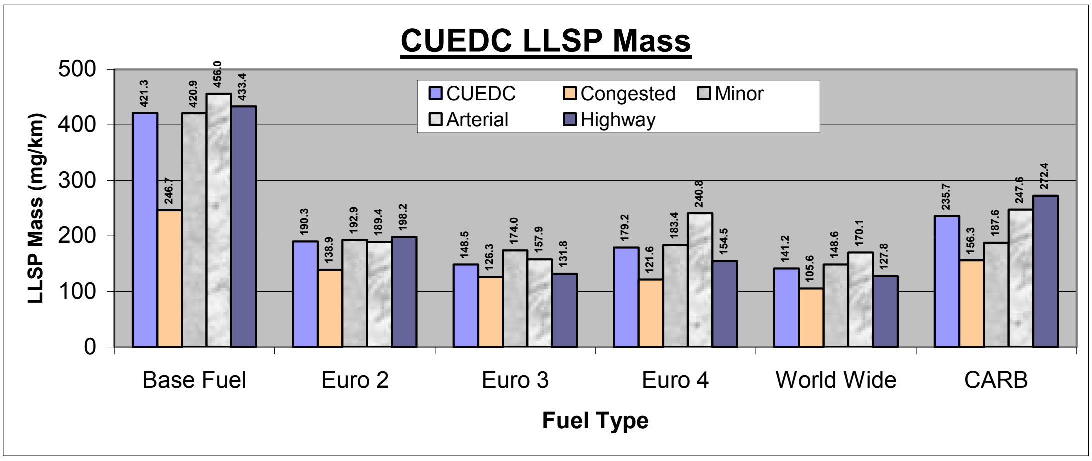


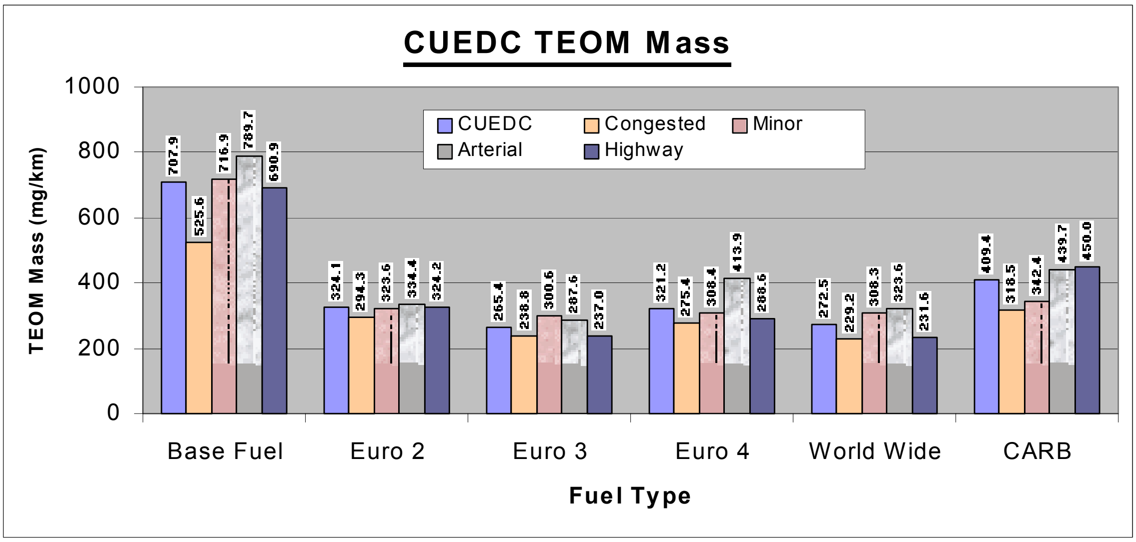


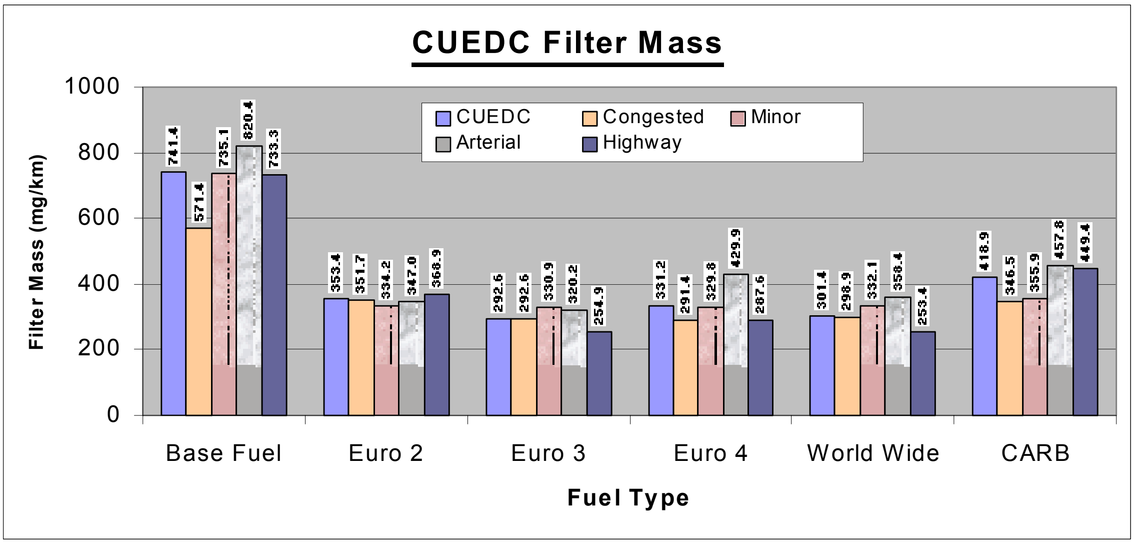


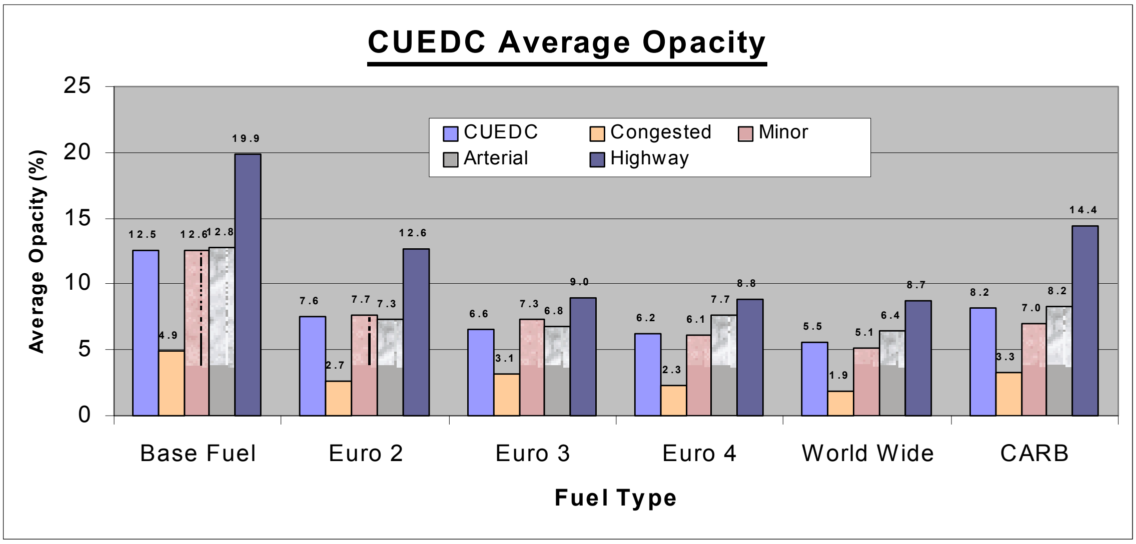

CUEDC CO$_2$ Emissions
CUEDC
Congested
Minor
Arterial
Highway
CO$_2$ Emissions (g/km)
0
200
400
600
800
463.8
540.7
462.0
507.6
428.8
444.3
549.7
452.6
470.5
407.4
435.5
494.2
452.7
460.2
402.0
438.7
536.4
453.8
447.4
408.2
451.9
517.5
500.7
477.9
397.6
438.7
530.8
451.1
471.8
398.1
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

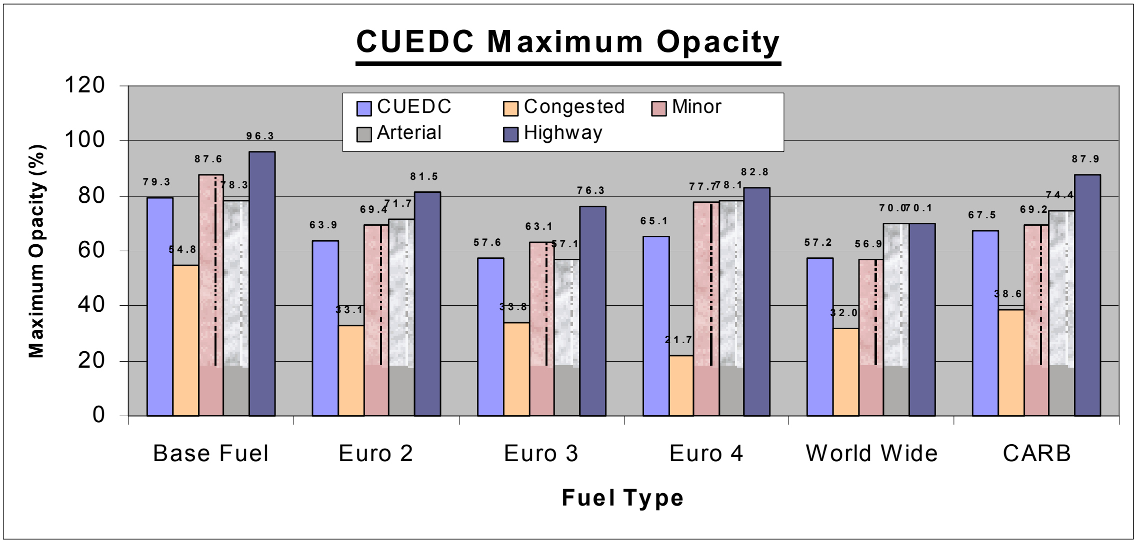

CUEDC Fuel Consumption
CUEDC
Congested
Minor
Arterial
Highway
Fuel Consumption (l/100km)
0
5
10
15
20
25
30
18.2
20.2
17.4
19.1
16.2
18.2
21.3
17.6
18.2
15.8
17.5
19.1
17.6
17.8
15.6
17.9
20.7
17.6
17.3
15.8
18.5
20.2
19.6
18.7
15.6
17.7
20.2
17.2
18.0
15.2
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type


CUEDC LLSP Mass
CUEDC
Congested
Minor
Arterial
Highway
LLSP Mass (mg/km)
0
100
200
300
400
500
421.3
246.7
420.9
456.0
433.4
190.3
138.9
192.9
189.4
198.2
148.5
126.3
174.0
157.9
131.8
179.2
121.6
183.4
240.8
154.5
141.2
105.6
148.6
170.1
127.8
235.7
156.3
187.6
247.6
272.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

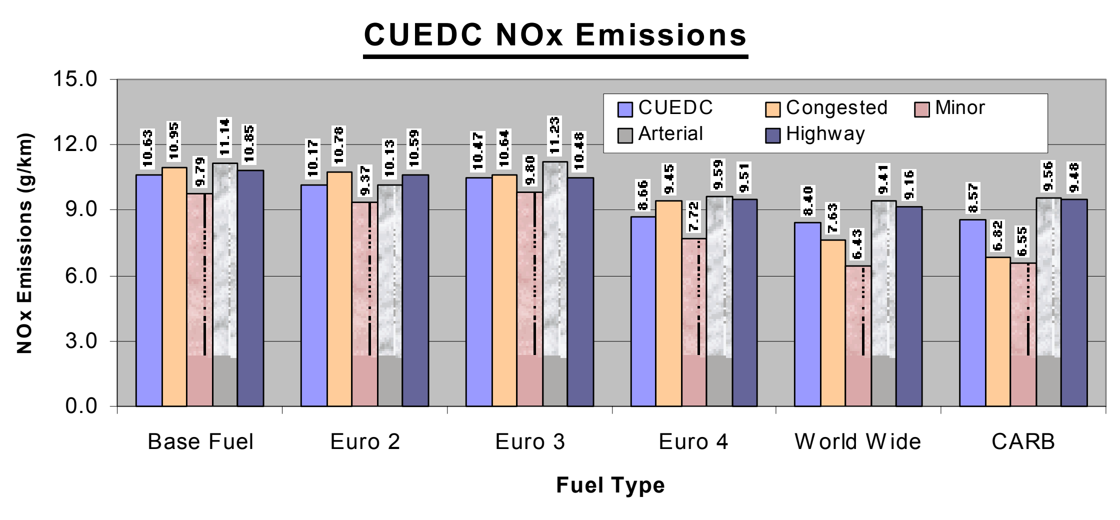

CUEDC TEOM Mass
TEOM Mass (mg/km)
1000
800
600
400
200
0
CUEDC
Congested
Minor
Arterial
Highway
707.9
525.6
716.9
789.7
690.9
324.1
294.3
323.6
334.4
324.2
265.4
238.8
300.6
287.6
237.0
321.2
275.4
308.4
413.9
288.6
272.5
229.2
308.3
323.6
231.6
409.4
318.5
342.4
439.7
450.0
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

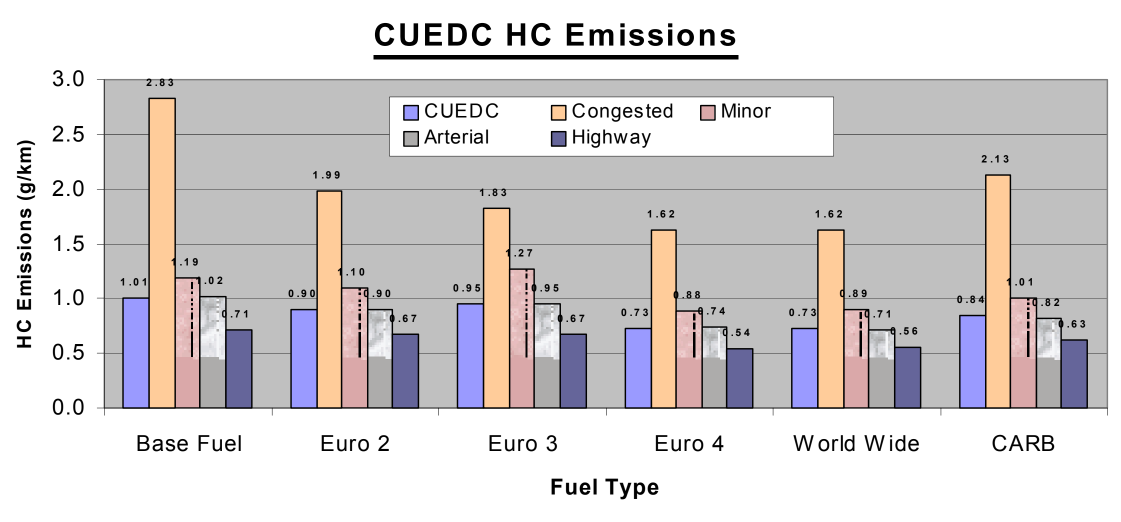

CUEDC Filter Mass
Filter Mass (mg/km)
1000
800
600
400
200
0
CUEDC
Congested
Minor
Arterial
Highway
741.4
571.4
735.1
820.4
733.3
353.4
351.7
334.2
347.0
368.9
292.6
292.6
330.9
320.2
254.9
331.2
291.4
329.8
429.9
287.6
301.4
298.9
332.1
358.4
253.4
418.9
346.5
355.9
457.8
449.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

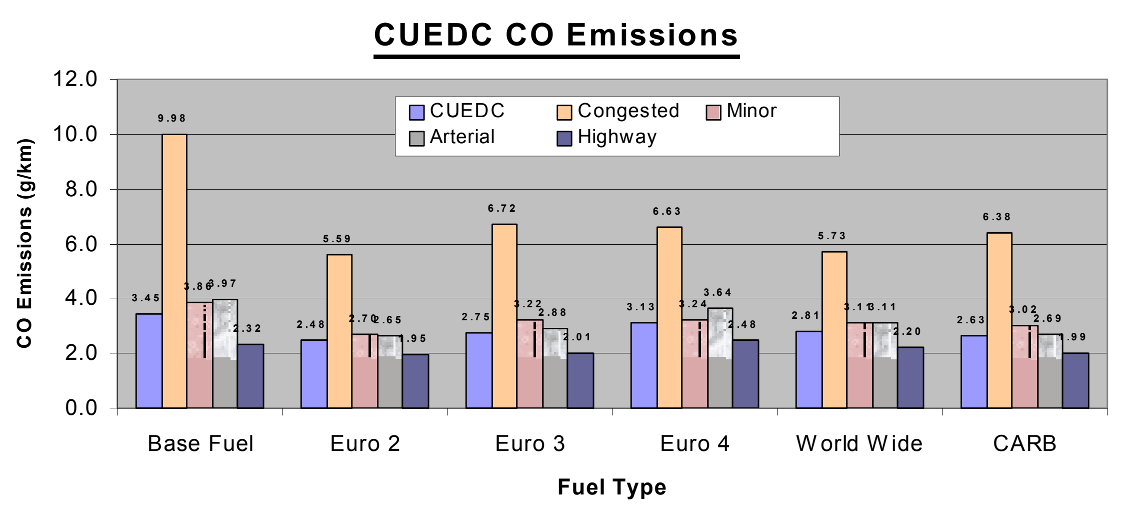

CUEDC Average Opacity
Average Opacity (%)
25
20
15
10
5
0
CUEDC
Congested
Minor
Arterial
Highway
12.5
4.9
12.6
12.8
19.9
7.6
2.7
7.7
7.3
12.6
6.6
3.1
7.3
6.8
9.0
6.2
2.3
6.1
7.7
8.8
5.5
1.9
5.1
6.4
8.7
8.2
3.3
7.0
8.2
14.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

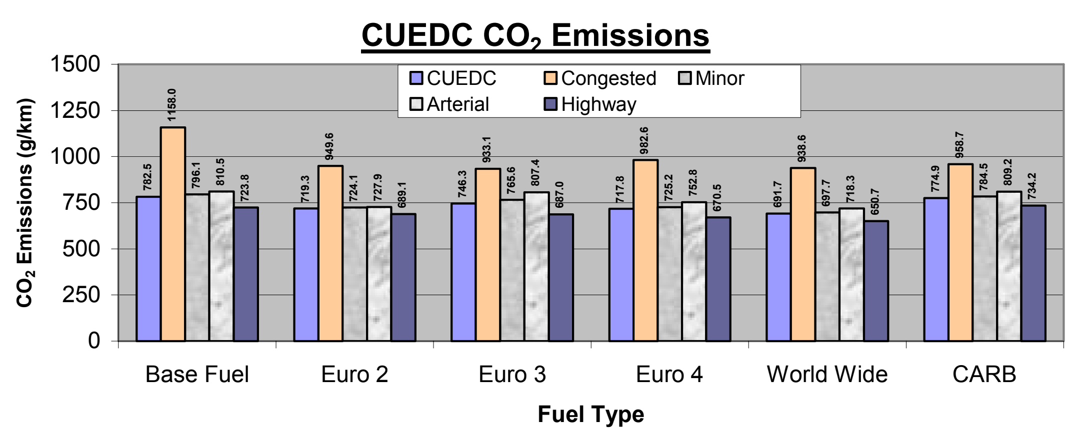

CUEDC Maximum Opacity
Maximum Opacity (%)
0
20
40
60
80
100
120
CUEDC
Congested
Minor
Arterial
Highway
79.3
54.8
87.6
78.3
96.3
63.9
33.1
69.4
71.7
81.5
57.6
33.8
63.1
57.1
76.3
65.1
21.7
77.7
78.1
82.8
57.2
32.0
56.9
70.0
70.1
67.5
38.6
69.2
74.4
87.9
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

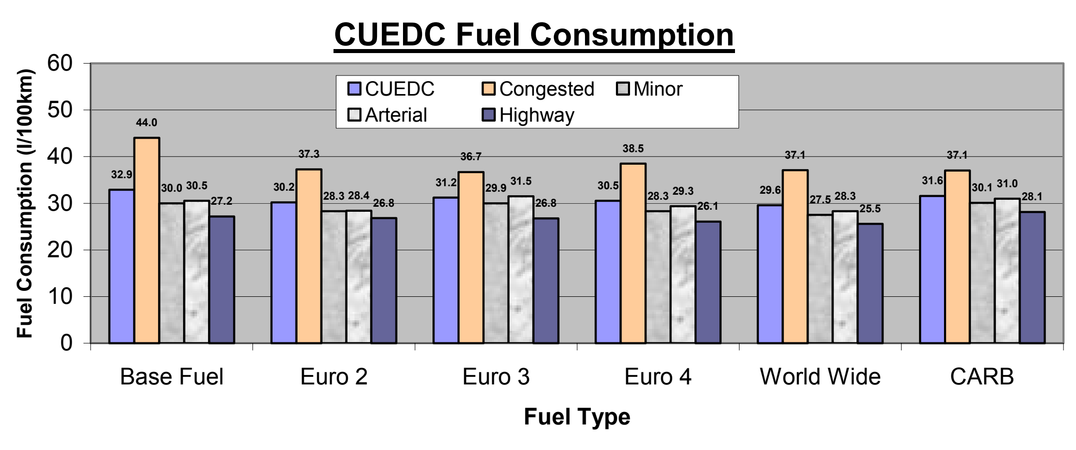
# Rigid Truck

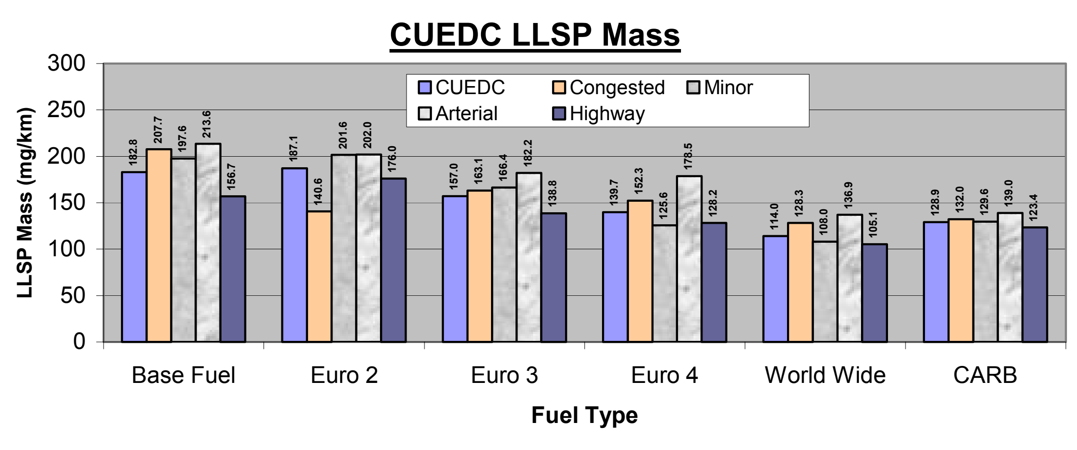

CUEDC NOx Emissions
NOx Emissions (g/km)
15.0
12.0
9.0
6.0
3.0
0.0
CUEDC
Congested
Minor
Arterial
Highway
10.63
10.95
9.79
11.14
10.85
10.17
10.78
9.37
10.13
10.59
10.47
10.64
9.80
11.23
10.48
8.66
9.45
7.72
9.59
9.51
8.40
7.63
6.43
9.41
9.16
8.57
6.82
6.55
9.56
9.48
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

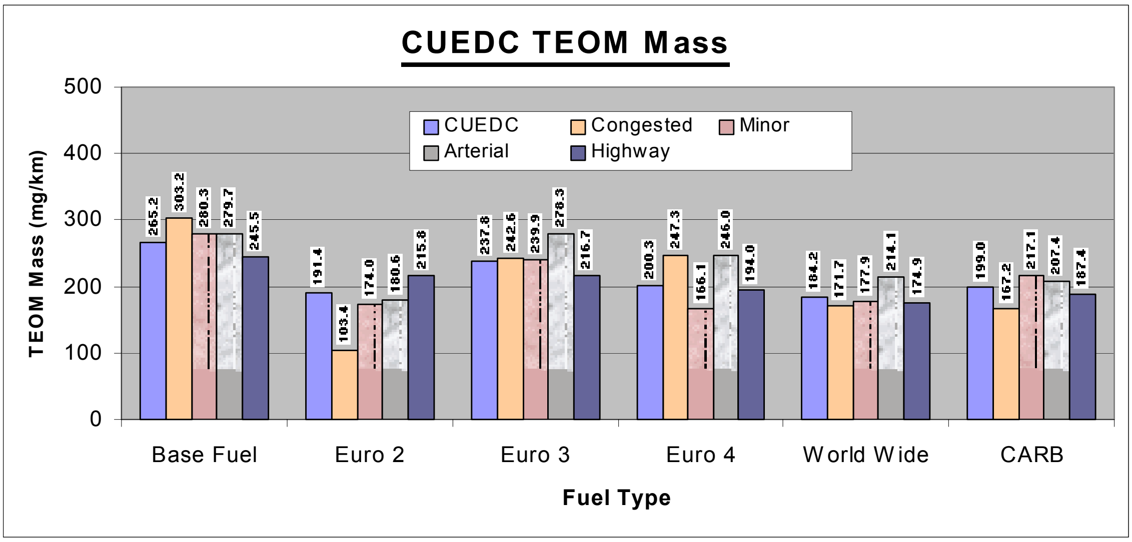

CUEDC HC Emissions
HC Emissions (g/km)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
CUEDC
Congested
Minor
Arterial
Highway
1.01
2.83
1.19
1.02
0.71
0.90
1.99
1.10
0.90
0.67
0.95
1.83
1.27
0.95
0.67
0.73
1.62
0.88
0.74
0.54
0.73
1.62
0.89
0.71
0.56
0.84
2.13
1.01
0.82
0.63
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

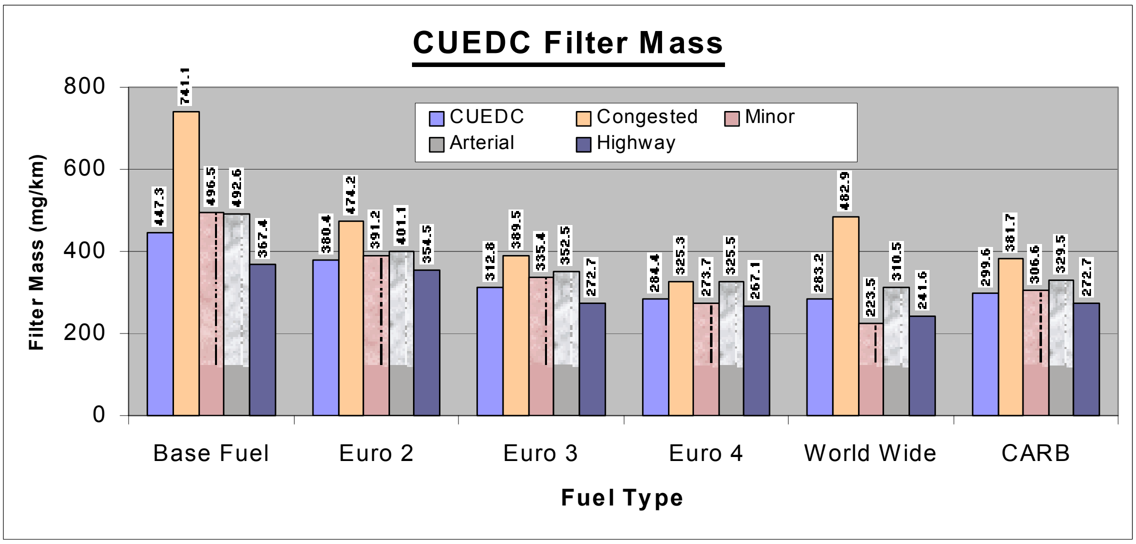

CUEDC CO Emissions
CO Emissions (g/km)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
CUEDC
Congested
Minor
Arterial
Highway
3.45
9.98
3.86
3.97
2.32
2.48
5.59
2.70
2.65
1.95
2.75
6.72
3.22
2.88
2.01
3.13
6.63
3.24
3.64
2.48
2.81
5.73
3.11
3.11
2.20
2.63
6.38
3.02
2.69
1.99
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

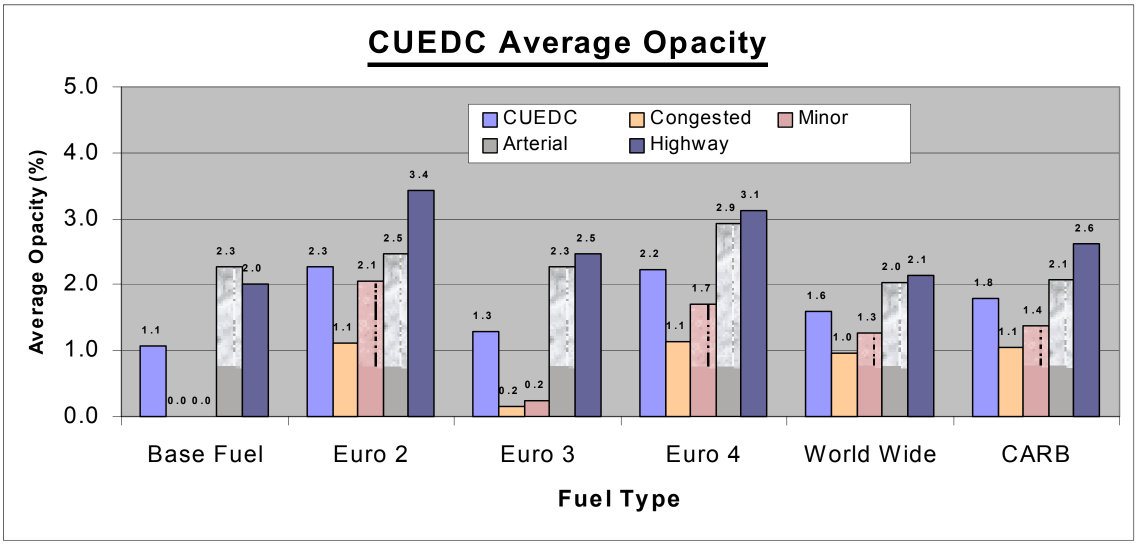

CUEDC CO₂ Emissions
CO₂ Emissions (g/km)
1500
1250
1000
750
500
250
0
CUEDC
Congested
Minor
Arterial
Highway
782.5
1158.0
796.1
810.5
723.8
719.3
949.6
724.1
727.9
689.1
746.3
933.1
765.6
807.4
687.0
717.8
982.6
725.2
752.8
670.5
691.7
938.6
697.7
718.3
650.7
774.9
958.7
784.5
809.2
734.2
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

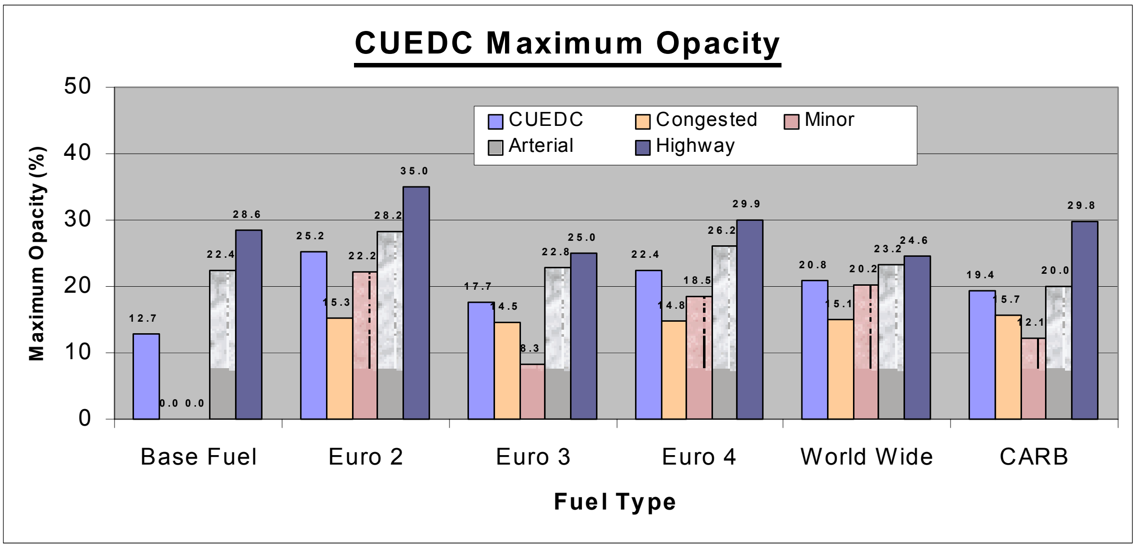

CUEDC Fuel Consumption
Fuel Consumption (l/100km)
60
50
40
30
20
10
0
CUEDC
Congested
Minor
Arterial
Highway
32.9
44.0
30.0
30.5
27.2
30.2
37.3
28.3
28.4
26.8
31.2
36.7
29.9
31.5
26.8
30.5
38.5
28.3
29.3
26.1
29.6
37.1
27.5
28.3
25.5
31.6
37.1
30.1
31.0
28.1
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

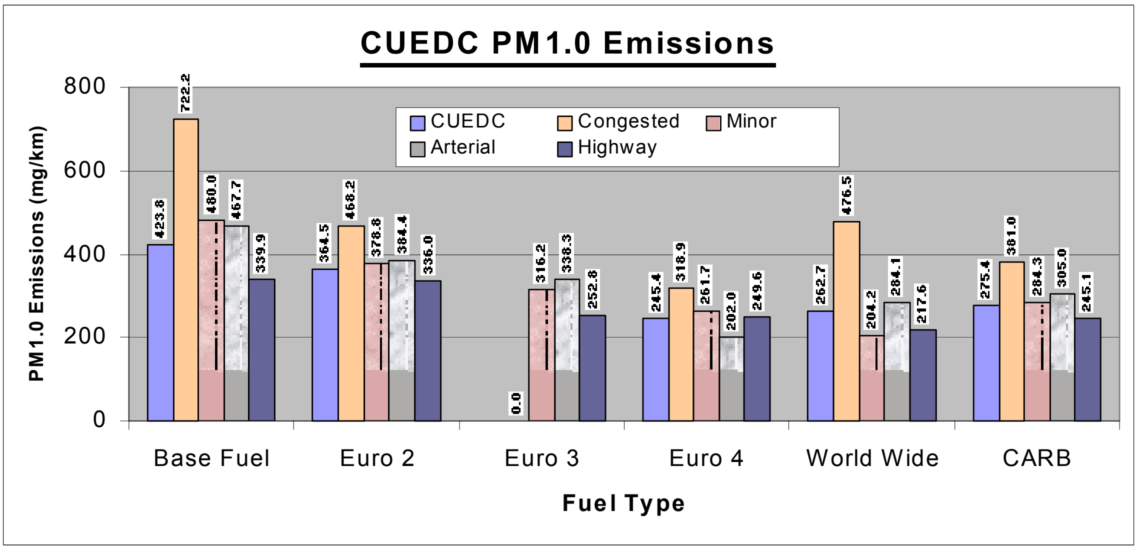

CUEDC LLSP Mass
LLSP Mass (mg/km)
300
250
200
150
100
50
0
CUEDC
Congested
Minor
Arterial
Highway
182.8
207.7
197.6
213.6
156.7
187.1
140.6
201.6
202.0
176.0
157.0
163.1
166.4
182.2
138.8
139.7
152.3
125.6
178.5
128.2
114.0
128.3
108.0
136.9
105.1
128.9
132.0
129.6
139.0
123.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

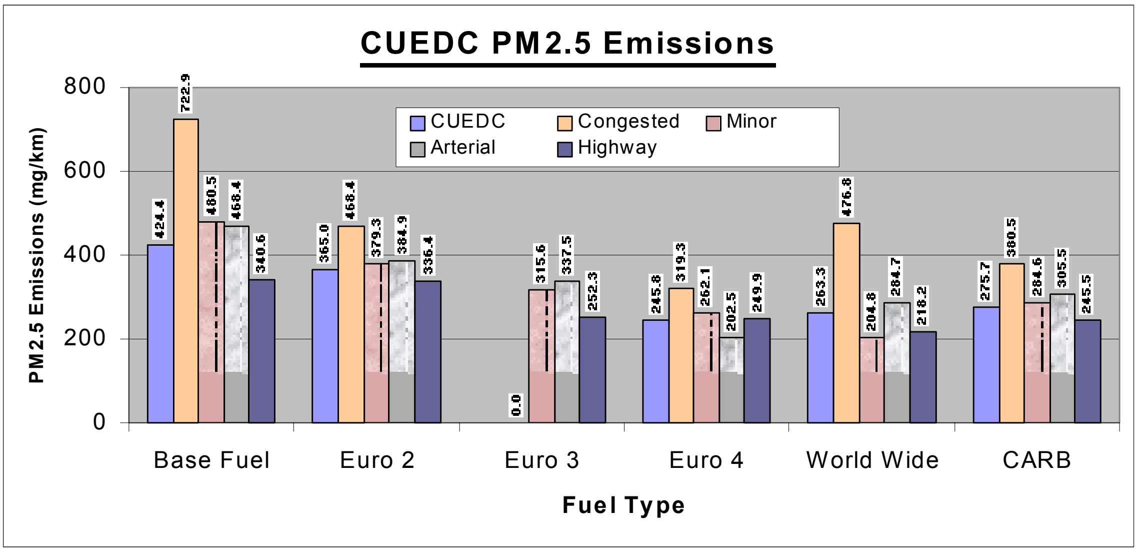

CUEDC TEOM Mass
TEOM Mass (mg/km)
500
400
300
200
100
0
CUEDC
Congested
Minor
Arterial
Highway
265.2
303.2
280.3
279.7
245.5
191.4
103.4
174.0
180.6
215.8
237.8
242.6
239.9
278.3
216.7
200.3
247.3
166.1
246.0
194.0
184.2
171.7
177.9
214.1
174.9
199.0
167.2
217.1
207.4
187.4
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

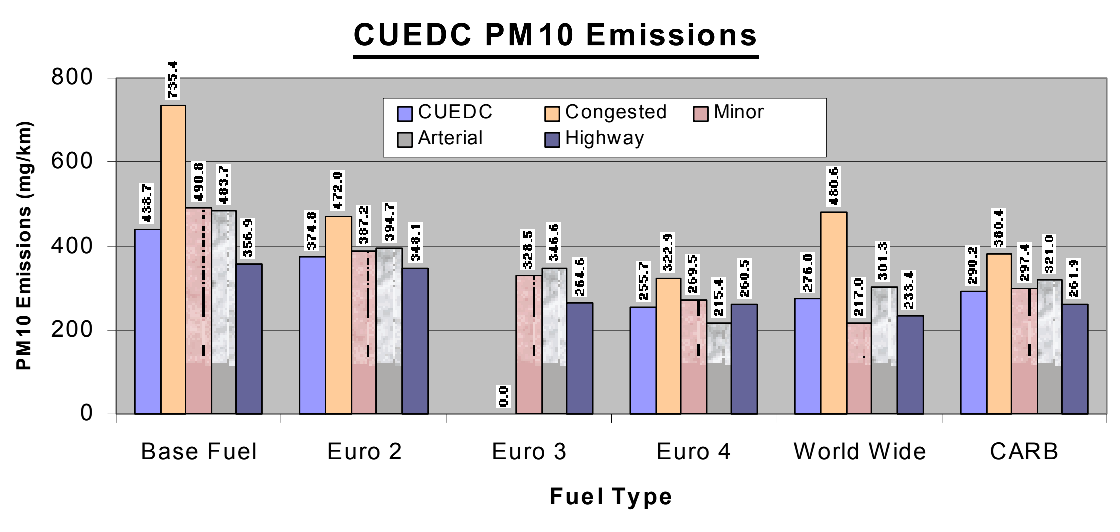

CUEDC Filter Mass
Filter Mass (mg/km)
800
600
400
200
0
CUEDC
Congested
Minor
Arterial
Highway
447.3
741.1
496.5
492.6
367.4
380.4
474.2
391.2
401.1
354.5
312.8
389.5
335.4
352.5
272.7
284.4
325.3
273.7
325.5
267.1
283.2
482.9
223.5
310.5
241.6
299.6
381.7
306.6
329.5
272.7
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

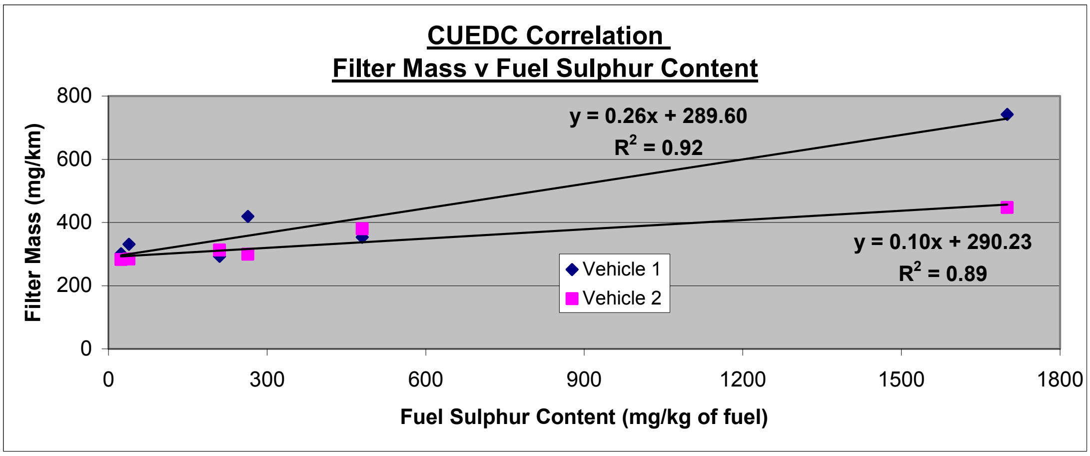

CUEDC Average Opacity
Average Opacity (%)
5.0
4.0
3.0
2.0
1.0
0.0
CUEDC
Congested
Minor
Arterial
Highway
1.1
0.0
0.0
2.3
2.0
2.3
1.1
2.1
2.5
3.4
1.3
0.2
0.2
2.3
2.5
2.2
1.1
1.7
2.9
3.1
1.6
1.0
1.3
2.0
2.1
1.8
1.1
1.4
2.1
2.6
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

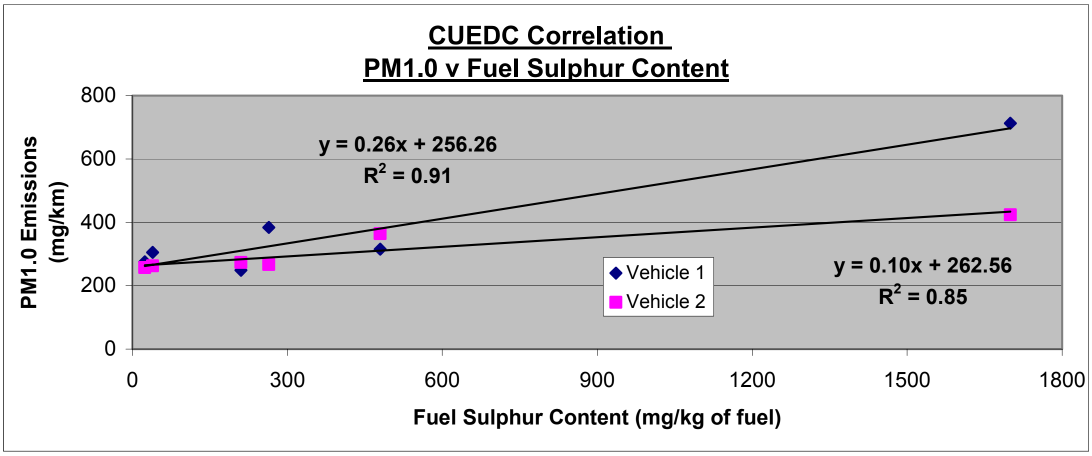

CUEDC Maximum Opacity
Maximum Opacity (%)
50
40
30
20
10
0
CUEDC
Congested
Minor
Arterial
Highway
12.7
0.0
0.0
22.4
28.6
25.2
15.3
22.2
28.2
35.0
17.7
14.5
8.3
22.8
25.0
22.4
14.8
18.5
26.2
29.9
20.8
15.1
20.2
23.2
24.6
19.4
15.7
12.1
20.0
29.8
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

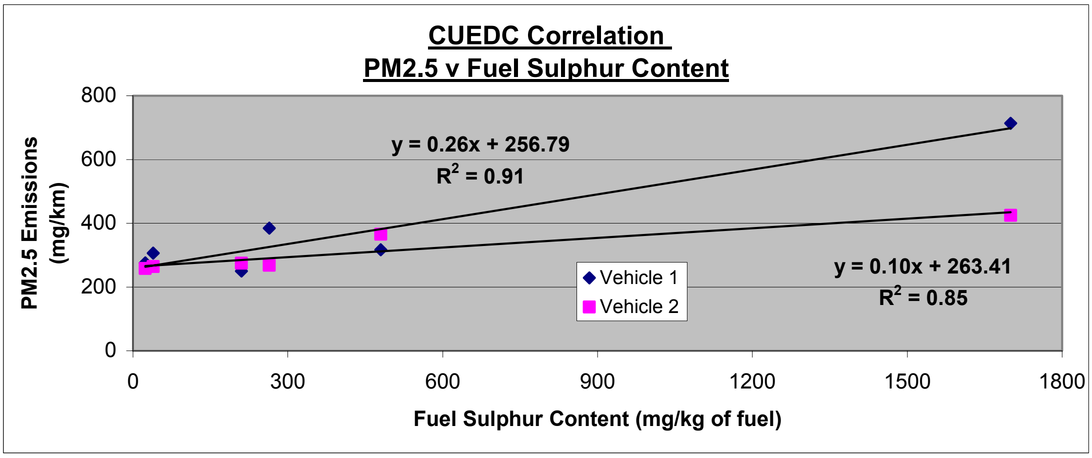

CUEDC PM1.0 Emissions
PM1.0 Emissions (mg/km)
800
600
400
200
0
CUEDC
Congested
Minor
Arterial
Highway
423.8
722.2
480.0
467.7
339.9
364.5
468.2
378.8
384.4
336.0
0.0
316.2
338.3
252.8
245.4
318.9
261.7
202.0
249.6
262.7
476.5
204.2
284.1
217.6
275.4
381.0
284.3
305.0
245.1
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type

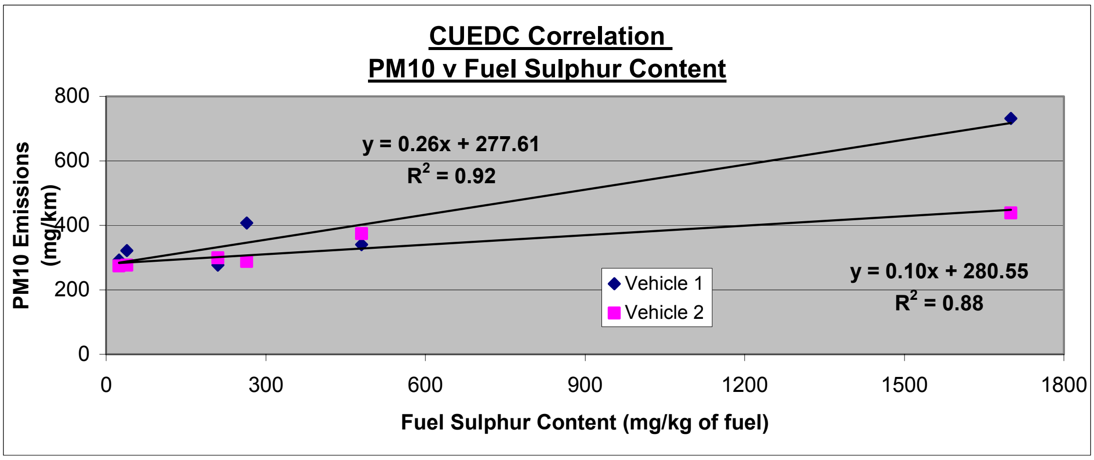

CUEDC PM2.5 Emissions
PM2.5 Emissions (mg/km)
800
600
400
200
0
CUEDC
Congested
Minor
Arterial
Highway
424.4
722.9
480.5
468.4
340.6
365.0
468.4
379.3
384.9
336.4
0.0
315.6
337.5
252.3
245.8
319.3
262.1
202.5
249.9
263.3
476.8
204.8
284.7
218.2
275.7
380.5
284.6
305.5
245.5
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type


CUEDC PM10 Emissions
PM10 Emissions (mg/km)
800
600
400
200
0
CUEDC
Congested
Minor
Arterial
Highway
438.7
735.4
490.8
483.7
356.9
374.8
472.0
387.2
394.7
348.1
0.0
328.5
346.6
264.6
255.7
322.9
269.5
215.4
260.5
276.0
480.6
217.0
301.3
233.4
290.2
380.4
297.4
321.0
261.9
Base Fuel
Euro 2
Euro 3
Euro 4
World Wide
CARB
Fuel Type


CUEDC Correlation
Filter Mass v Fuel Sulphur Content
Filter Mass (mg/km)
800
600
400
200
0
0
300
600
900
1200
1500
1800
Fuel Sulphur Content (mg/kg of fuel)
y = 0.26x + 289.60
R² = 0.92
y = 0.10x + 290.23
R² = 0.89
◆ Vehicle 1
■ Vehicle 2

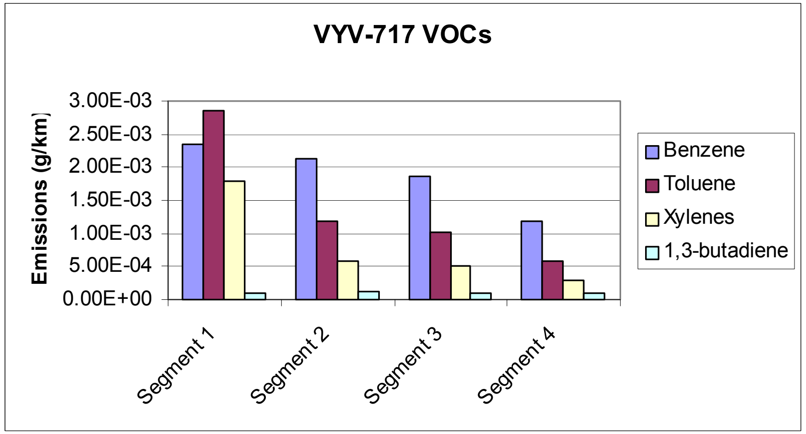

CUEDC Correlation
PM1.0 v Fuel Sulphur Content
PM1.0 Emissions (mg/km)
800
600
400
200
0
0
300
600
900
1200
1500
1800
Fuel Sulphur Content (mg/kg of fuel)
y = 0.26x + 256.26
R² = 0.91
y = 0.10x + 262.56
R² = 0.85
◆ Vehicle 1
■ Vehicle 2

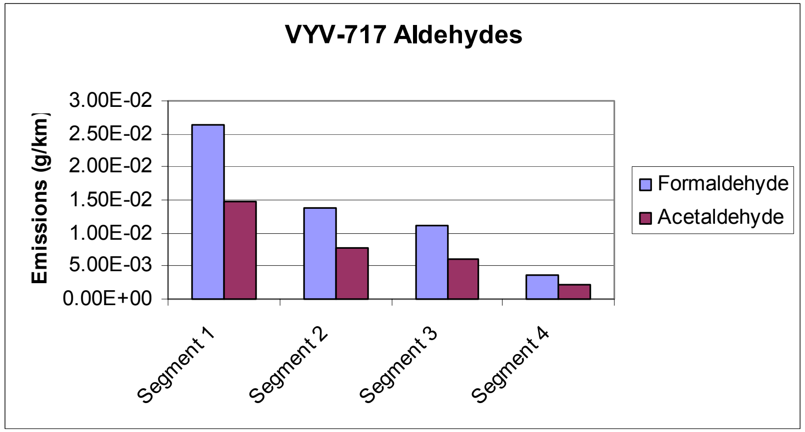

CUEDC Correlation
PM2.5 v Fuel Sulphur Content
PM2.5 Emissions (mg/km)
800
600
400
200
0
y = 0.26x + 256.79
R2 = 0.91
y = 0.10x + 263.41
R2 = 0.85
Vehicle 1
Vehicle 2
0
300
600
900
1200
1500
1800
Fuel Sulphur Content (mg/kg of fuel)

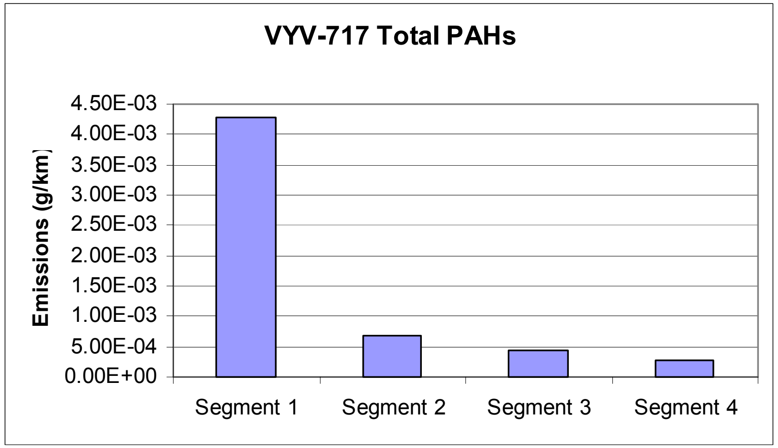

CUEDC Correlation
PM10 v Fuel Sulphur Content
PM10 Emissions (mg/km)
800
600
400
200
0
y = 0.26x + 277.61
R2 = 0.92
y = 0.10x + 280.55
R2 = 0.88
Vehicle 1
Vehicle 2
0
300
600
900
1200
1500
1800
Fuel Sulphur Content (mg/kg of fuel)

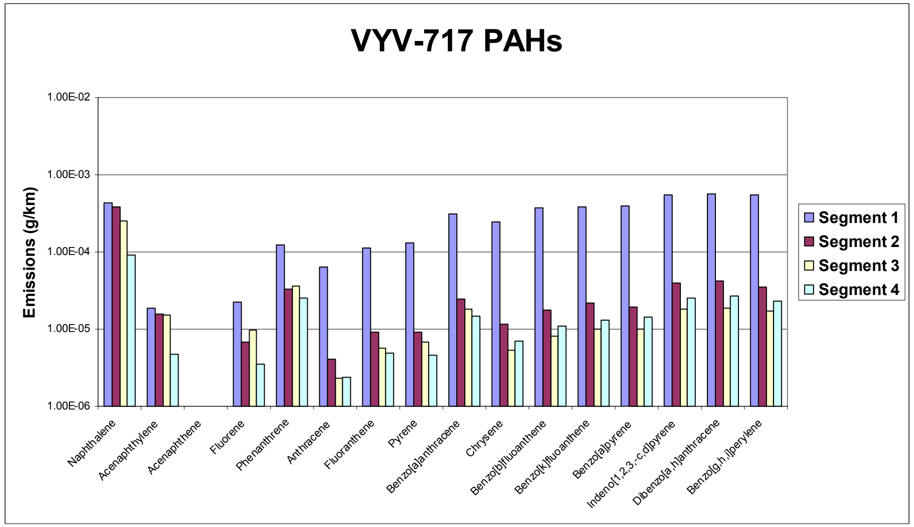
# Appendix 2: Toxics Results (12 Vehicles – Base Case) (Part A)

# 1995 Nissan Navara, Class MC



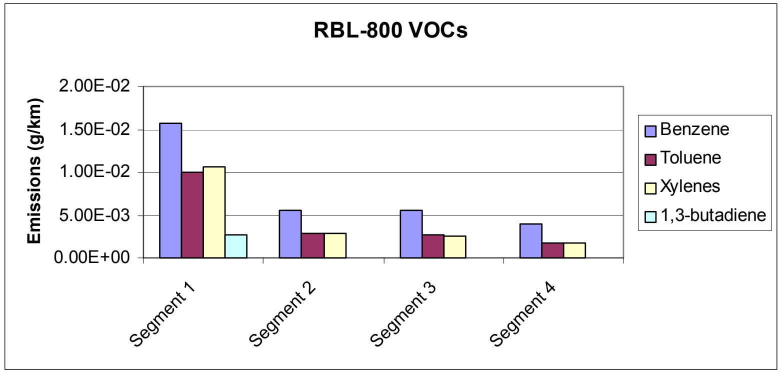


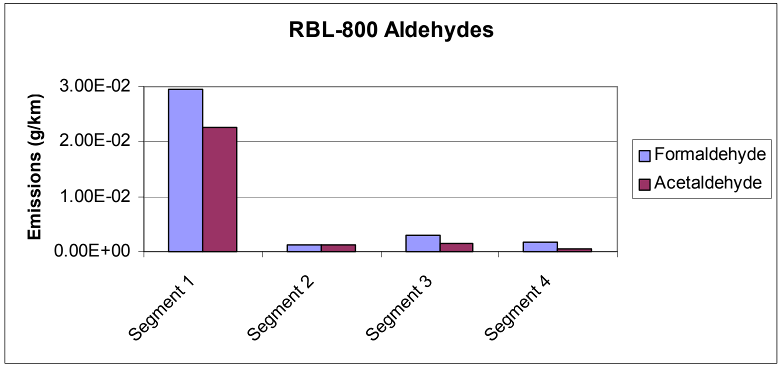


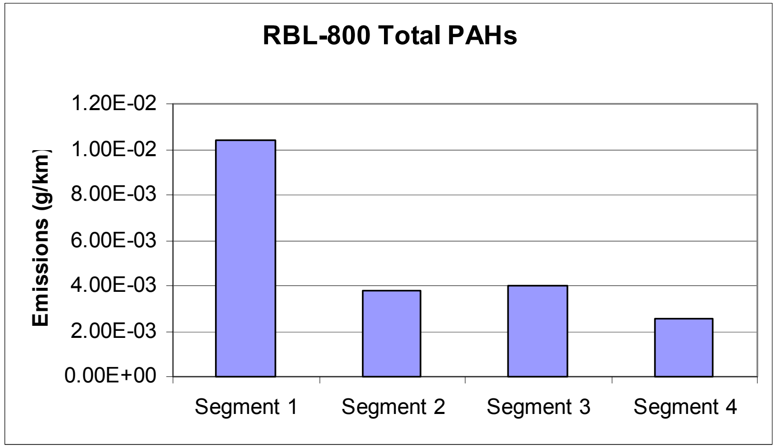


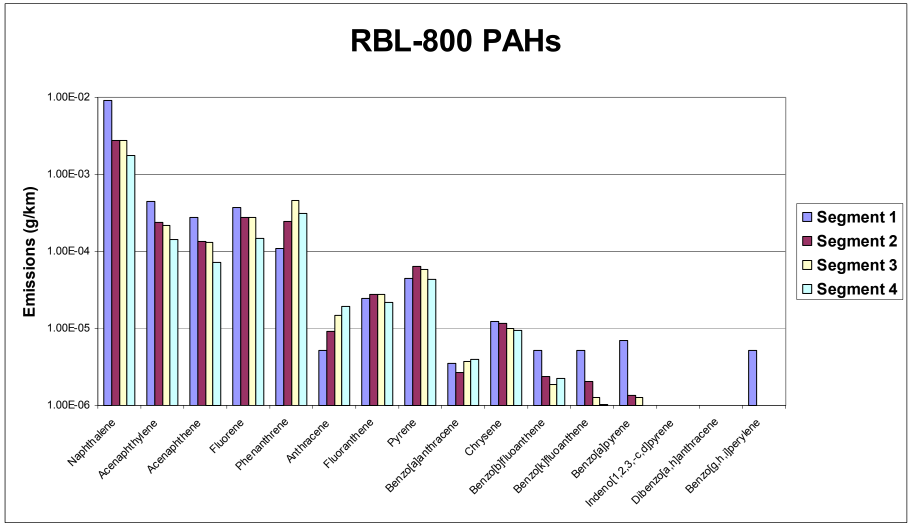
| **Class MC** | **Emissions (g/km)** | | | |
|---|---|---|---|---|
| **Summary** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.34E-03 | 2.13E-03 | 1.86E-03 | 1.18E-03 |
| Toluene | 2.85E-03 | 1.18E-03 | 1.01E-03 | 5.83E-04 |
| Xylenes | 1.79E-03 | 5.91E-04 | 5.12E-04 | 2.79E-04 |
| 1,3-butadiene | 8.71E-05 | 1.21E-04 | 9.37E-05 | 1.08E-04 |
| | | | | |
| Formaldehyde | 2.64E-02 | 1.39E-02 | 1.11E-02 | 3.60E-03 |
| Acetaldehyde | 1.49E-02 | 7.70E-03 | 6.14E-03 | 2.21E-03 |
| | | | | |
| Naphthalene | 4.27E-04 | 3.80E-04 | 2.51E-04 | 9.18E-05 |
| Acenaphthylene | 1.86E-05 | 1.58E-05 | 1.54E-05 | 4.74E-06 |
| Acenaphthene | | | | |
| Fluorene | 2.27E-05 | 6.77E-06 | 9.71E-06 | 3.55E-06 |
| Phenanthrene | 1.24E-04 | 3.35E-05 | 3.58E-05 | 2.55E-05 |
| Anthracene | 6.40E-05 | 4.13E-06 | 2.34E-06 | 2.37E-06 |
| Fluoranthene | 1.13E-04 | 9.02E-06 | 5.69E-06 | 4.93E-06 |
| Pyrene | 1.30E-04 | 9.02E-06 | 6.69E-06 | 4.54E-06 |
| Benzo[a]anthracene | 3.12E-04 | 2.48E-05 | 1.81E-05 | 1.46E-05 |
| Chrysene | 2.43E-04 | 1.17E-05 | 5.36E-06 | 6.91E-06 |
| Benzo[b]fluoanthene | 3.69E-04 | 1.77E-05 | 8.03E-06 | 1.11E-05 |
| Benzo[k]fluoanthene | 3.82E-04 | 2.18E-05 | 1.00E-05 | 1.32E-05 |
| Benzo[a]pyrene | 3.96E-04 | 1.92E-05 | 1.00E-05 | 1.42E-05 |
| Indeno[1,2,3,-c,d]pyrene | 5.55E-04 | 3.95E-05 | 1.84E-05 | 2.55E-05 |
| Dibenzo[a,h]anthracene | 5.74E-04 | 4.25E-05 | 1.87E-05 | 2.68E-05 |
| Benzo[g,h,i]perylene | 5.51E-04 | 3.50E-05 | 1.71E-05 | 2.29E-05 |
| **Total PAH** | **4.28E-03** | **6.70E-04** | **4.32E-04** | **2.73E-04** |

# 1986 Toyota Landcruiser LX Turbo, Class MC



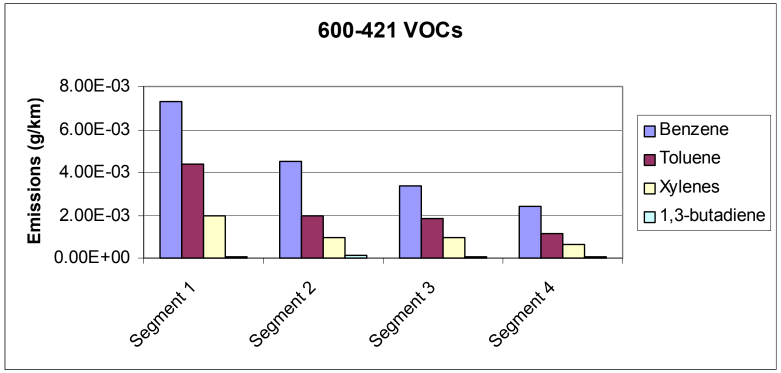


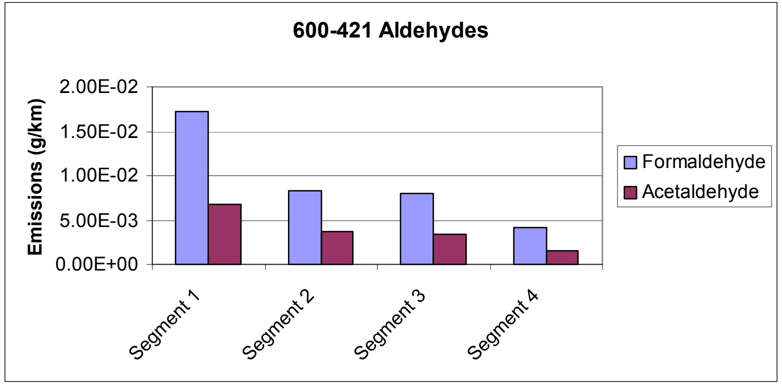


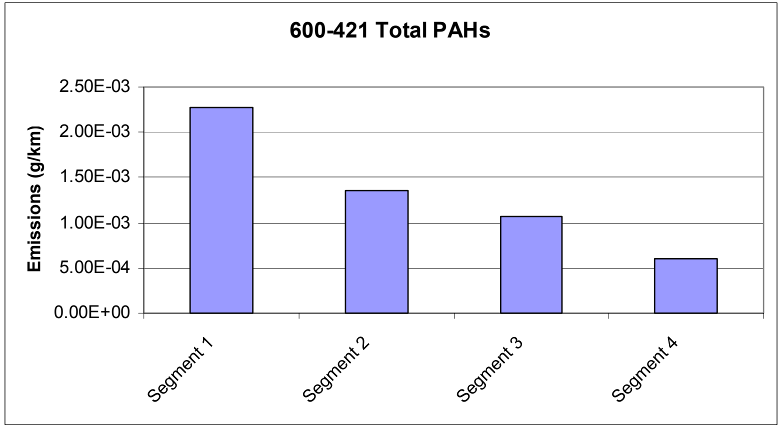


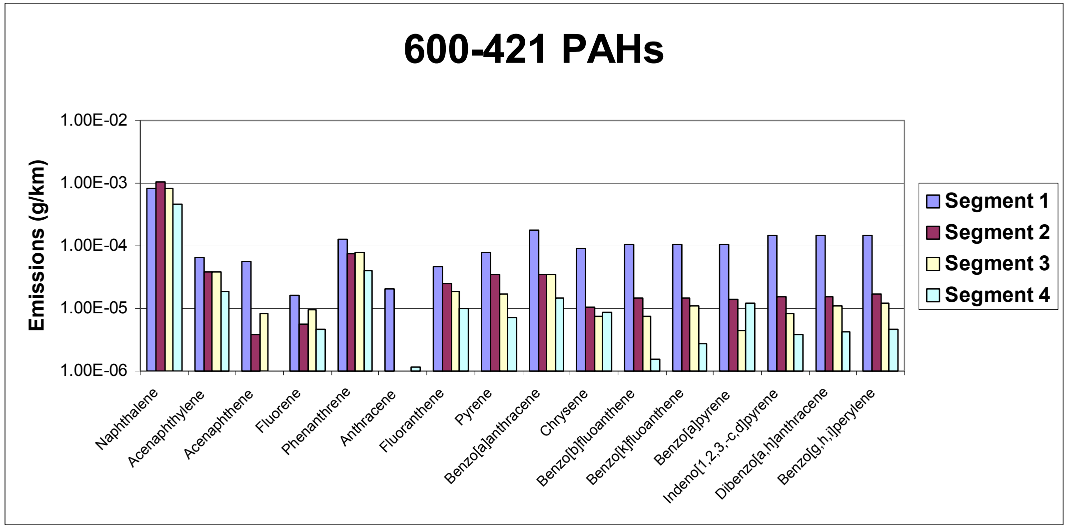
| Class MC | Emissions (g/km) | | | |
|---|---|---|---|---|
| **600-421** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 1.6E-02 | 5.6E-03 | 5.5E-03 | 3.9E-03 |
| Toluene | 1.0E-02 | 2.9E-03 | 2.7E-03 | 1.8E-03 |
| Xylenes | 1.1E-02 | 2.8E-03 | 2.6E-03 | 1.7E-03 |
| 1,3-butadiene | 2.7E-03 | 6.8E-05 | 5.2E-05 | 3.8E-05 |
| | | | | |
| Formaldehyde | 3.0E-02 | 1.2E-03 | 2.9E-03 | 1.8E-03 |
| Acetaldehyde | 2.3E-02 | 1.3E-03 | 1.5E-03 | 5.6E-04 |
| | | | | |
| Naphthalene | 9.08E-03 | 2.79E-03 | 2.80E-03 | 1.76E-03 |
| Acenaphthylene | 4.40E-04 | 2.37E-04 | 2.21E-04 | 1.44E-04 |
| Acenaphthene | 2.73E-04 | 1.37E-04 | 1.30E-04 | 7.23E-05 |
| Fluorene | 3.74E-04 | 2.81E-04 | 2.80E-04 | 1.46E-04 |
| Phenanthrene | 1.09E-04 | 2.47E-04 | 4.58E-04 | 3.12E-04 |
| Anthracene | 5.21E-06 | 9.09E-06 | 1.48E-05 | 1.91E-05 |
| Fluoranthene | 2.43E-05 | 2.80E-05 | 2.74E-05 | 2.15E-05 |
| Pyrene | 4.52E-05 | 6.47E-05 | 5.80E-05 | 4.35E-05 |
| Benzo[a]anthracene | 3.48E-06 | 2.69E-06 | 3.78E-06 | 3.99E-06 |
| Chrysene | 1.22E-05 | 1.15E-05 | 1.01E-05 | 9.54E-06 |
| Benzo[b]fluoanthene | 5.21E-06 | 2.36E-06 | 1.89E-06 | 2.25E-06 |
| Benzo[k]fluoanthene | 5.21E-06 | 2.02E-06 | 1.26E-06 | 1.04E-06 |
| Benzo[a]pyrene | 6.95E-06 | 1.35E-06 | 1.26E-06 | 5.20E-07 |
| Indeno[1,2,3,-c,d]pyrene | 1.00E-13 | 3.37E-07 | 3.15E-07 | 1.00E-13 |
| Dibenzo[a,h]anthracene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E-13 |
| Benzo[g,h,i]perylene | 5.21E-06 | 1.01E-06 | 9.45E-07 | 8.67E-07 |
| **Total PAH** | **1.04E-02** | **3.81E-03** | **4.01E-03** | **2.54E-03** |

## 1993 Toyota Hilux, Class NA



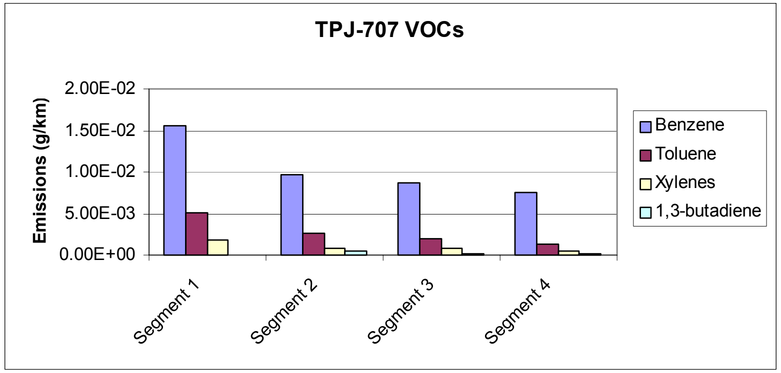


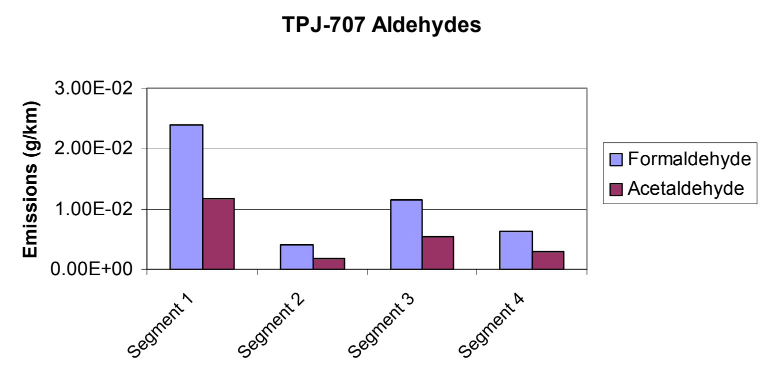


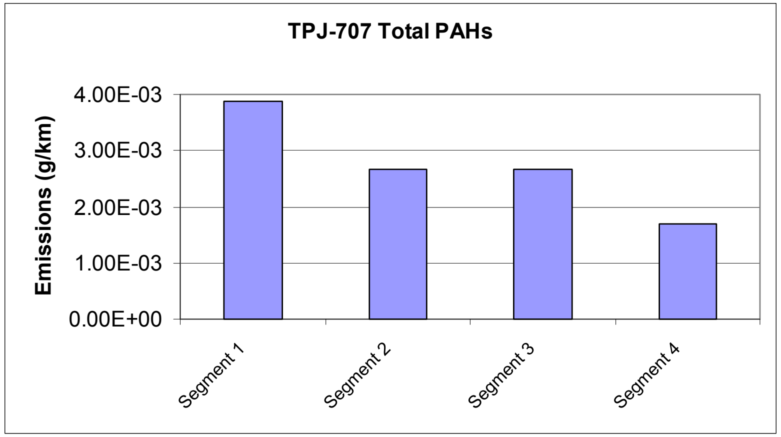


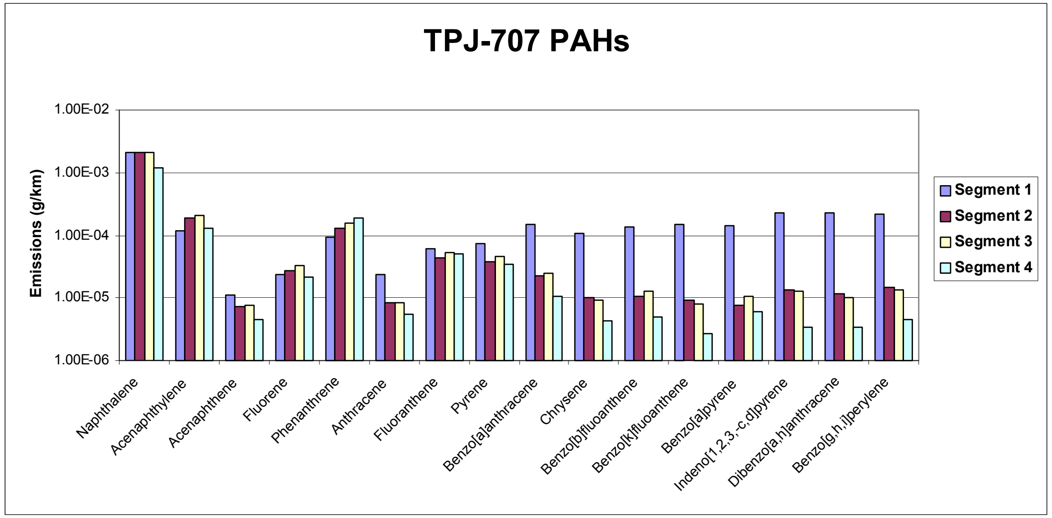
| Class NA | Emissions (g/km) | | | |
|---|---|---|---|---|
| **600-421** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 7.3E-03 | 4.5E-03 | 3.4E-03 | 2.4E-03 |
| Toluene | 4.4E-03 | 1.9E-03 | 1.9E-03 | 1.1E-03 |
| Xylenes | 1.9E-03 | 9.8E-04 | 9.7E-04 | 6.1E-04 |
| 1,3-butadiene | 8.9E-05 | 1.3E-04 | 4.4E-05 | 7.2E-05 |
| | | | | |
| Formaldehyde | 1.7E-02 | 8.3E-03 | 8.0E-03 | 4.1E-03 |
| Acetaldehyde | 6.8E-03 | 3.7E-03 | 3.4E-03 | 1.6E-03 |
| | | | | |
| Naphthalene | 8.4E-04 | 1.0E-03 | 8.1E-04 | 4.7E-04 |
| Acenaphthylene | 6.4E-05 | 3.8E-05 | 3.8E-05 | 1.8E-05 |
| Acenaphthene | 5.6E-05 | 3.8E-06 | 8.2E-06 | 0.0E+00 |
| Fluorene | 1.6E-05 | 5.7E-06 | 9.7E-06 | 4.7E-06 |
| Phenanthrene | 1.3E-04 | 7.4E-05 | 7.9E-05 | 4.0E-05 |
| Anthracene | 2.1E-05 | 6.3E-07 | 0.0E+00 | 1.2E-06 |
| Fluoranthene | 4.7E-05 | 2.5E-05 | 1.9E-05 | 9.8E-06 |
| Pyrene | 7.8E-05 | 3.5E-05 | 1.7E-05 | 7.0E-06 |
| Benzo[a]anthracene | 1.8E-04 | 3.5E-05 | 3.5E-05 | 1.4E-05 |
| Chrysene | 9.1E-05 | 1.1E-05 | 7.5E-06 | 8.6E-06 |
| Benzo[b]fluoanthene | 1.0E-04 | 1.4E-05 | 7.5E-06 | 1.6E-06 |
| Benzo[k]fluoanthene | 1.0E-04 | 1.4E-05 | 1.1E-05 | 2.7E-06 |
| Benzo[a]pyrene | 1.1E-04 | 1.4E-05 | 4.5E-06 | 1.2E-05 |
| Indeno[1,2,3,-c,d]pyrene | 1.5E-04 | 1.5E-05 | 8.2E-06 | 3.9E-06 |
| Dibenzo[a,h]anthracene | 1.5E-04 | 1.6E-05 | 1.1E-05 | 4.3E-06 |
| Benzo[g,h,i]perylene | 1.5E-04 | 1.7E-05 | 1.2E-05 | 4.7E-06 |
| **Total PAH** | **2.3E-03** | **1.4E-03** | **1.1E-03** | **6.0E-04** |

# 1995 Ford Econovan Maxi, Class NA



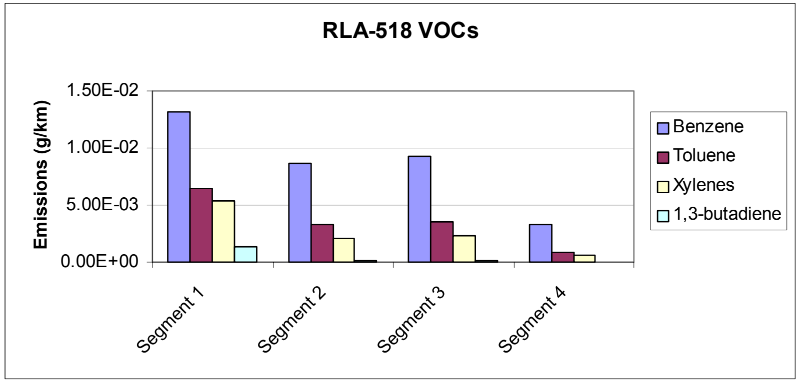


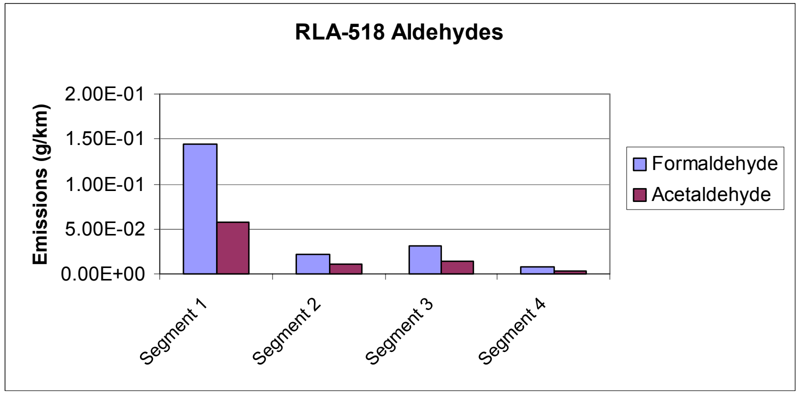


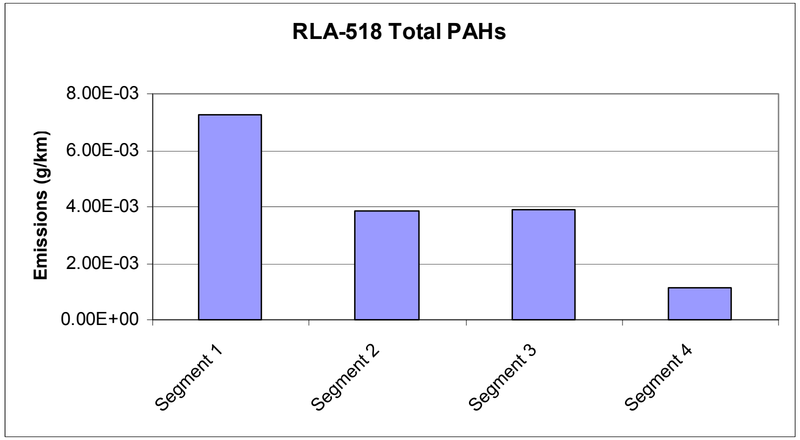


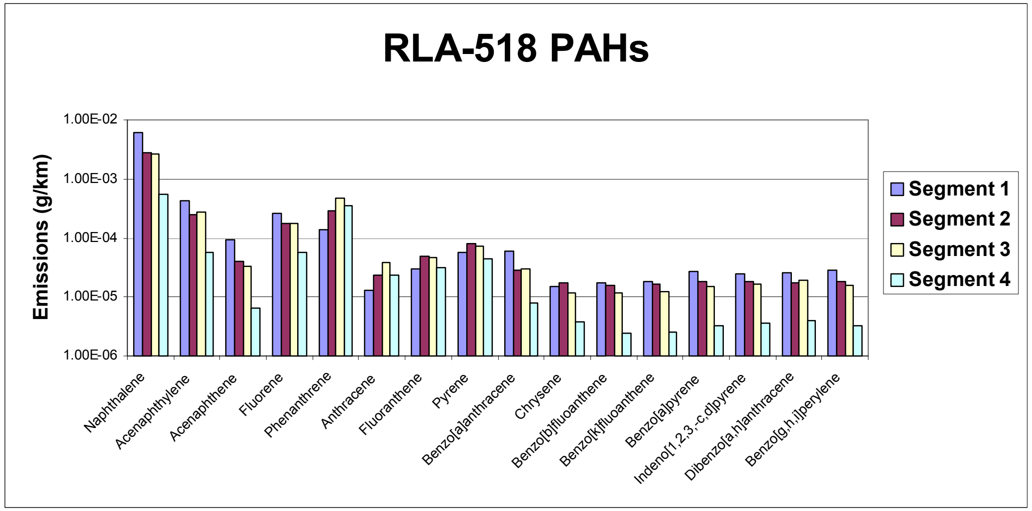
| Class NA | Emissions (g/km) | | | |
|---|---|---|---|---|
| **TPJ-707** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 1.6E-02 | 9.7E-03 | 8.8E-03 | 7.6E-03 |
| Toluene | 5.0E-03 | 2.6E-03 | 2.0E-03 | 1.3E-03 |
| Xylenes | 1.9E-03 | 8.7E-04 | 8.2E-04 | 5.0E-04 |
| 1,3-butadiene | 8.2E-05 | 4.4E-04 | 1.1E-04 | 1.1E-04 |
| | | | | |
| Formaldehyde | 2.4E-02 | 4.0E-03 | 1.2E-02 | 6.3E-03 |
| Acetaldehyde | 1.2E-02 | 1.9E-03 | 5.3E-03 | 2.9E-03 |
| | | | | |
| Naphthalene | 2.1E-03 | 2.1E-03 | 2.1E-03 | 1.2E-03 |
| Acenaphthylene | 1.2E-04 | 1.8E-04 | 2.1E-04 | 1.3E-04 |
| Acenaphthene | 1.1E-05 | 7.3E-06 | 7.4E-06 | 4.5E-06 |
| Fluorene | 2.3E-05 | 2.7E-05 | 3.3E-05 | 2.1E-05 |
| Phenanthrene | 9.3E-05 | 1.3E-04 | 1.6E-04 | 1.9E-04 |
| Anthracene | 2.3E-05 | 8.3E-06 | 8.6E-06 | 5.4E-06 |
| Fluoranthene | 6.2E-05 | 4.4E-05 | 5.4E-05 | 5.1E-05 |
| Pyrene | 7.3E-05 | 3.9E-05 | 4.7E-05 | 3.5E-05 |
| Benzo[a]anthracene | 1.5E-04 | 2.2E-05 | 2.5E-05 | 1.1E-05 |
| Chrysene | 1.1E-04 | 1.0E-05 | 9.3E-06 | 4.3E-06 |
| Benzo[b]fluoanthene | 1.3E-04 | 1.1E-05 | 1.3E-05 | 5.0E-06 |
| Benzo[k]fluoanthene | 1.5E-04 | 9.2E-06 | 7.8E-06 | 2.7E-06 |
| Benzo[a]pyrene | 1.4E-04 | 7.6E-06 | 1.1E-05 | 5.9E-06 |
| Indeno[1,2,3,-c,d]pyrene | 2.2E-04 | 1.4E-05 | 1.3E-05 | 3.4E-06 |
| Dibenzo[a,h]anthracene | 2.2E-04 | 1.2E-05 | 1.0E-05 | 3.4E-06 |
| Benzo[g,h,i]perylene | 2.1E-04 | 1.5E-05 | 1.3E-05 | 4.5E-06 |
| **Total PAH** | **3.9E-03** | **2.7E-03** | **2.7E-03** | **1.7E-03** |

## 1990 Mitsubishi Canter, Class NB



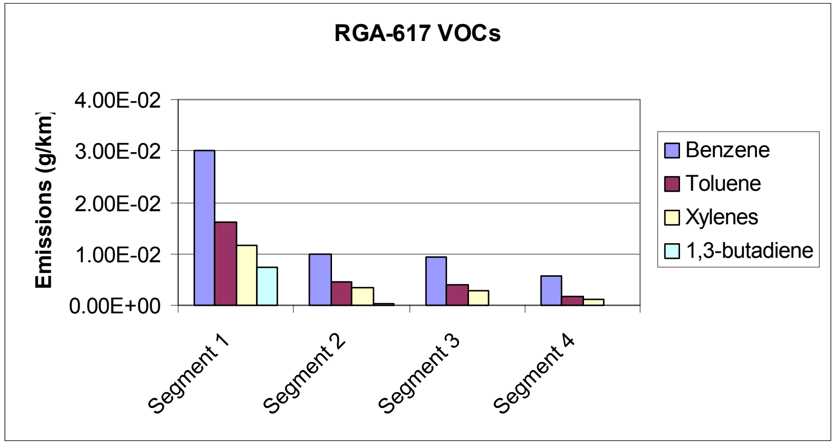


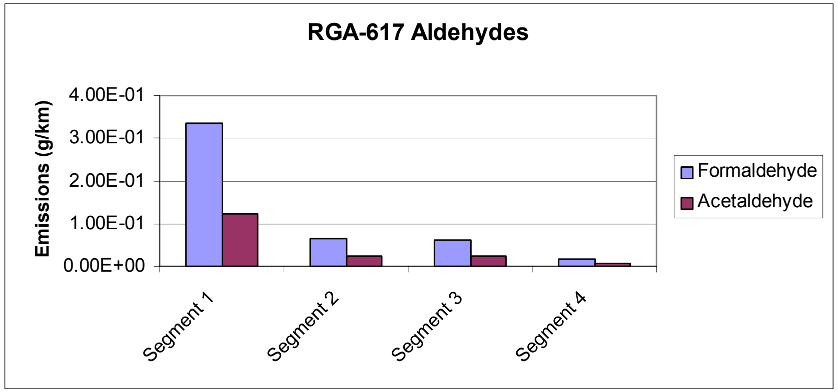


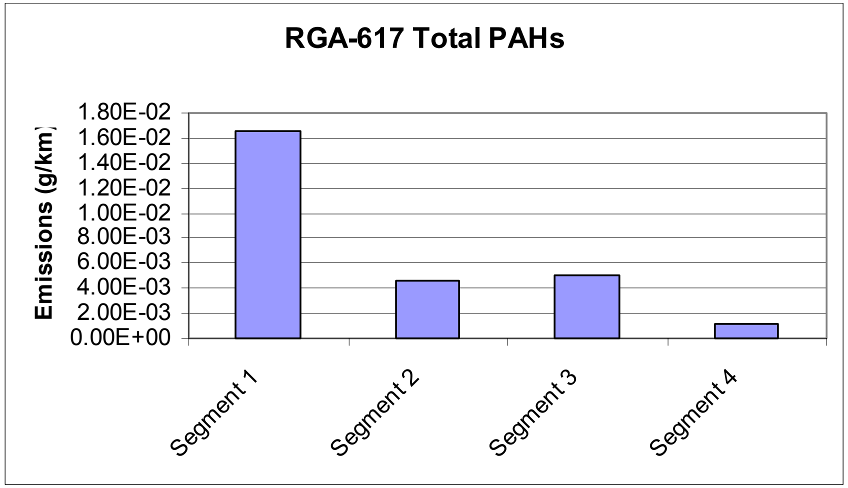


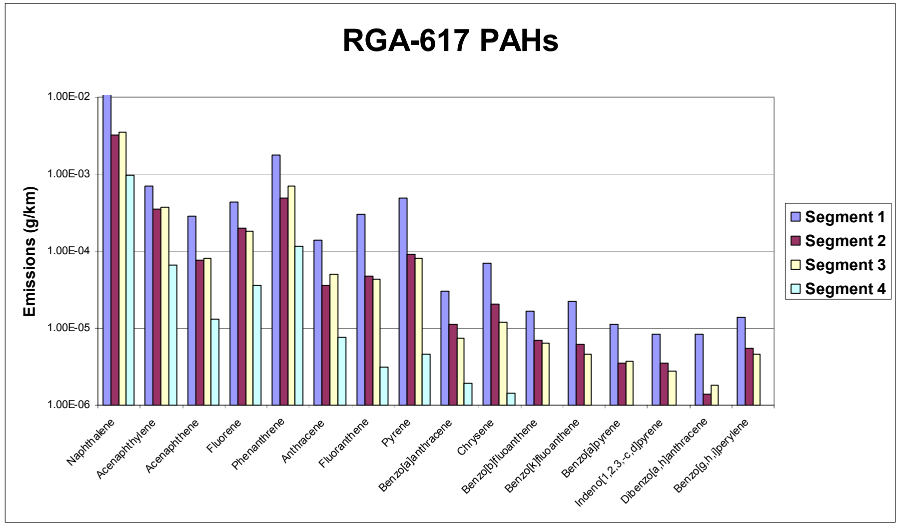
| Class NB | Emissions (g/km) | | | |
|---|---|---|---|---|
| RLA-518 | Segment 1 | Segment 2 | Segment 3 | Segment 4 |
| Benzene | 1.3E-02 | 8.6E-03 | 9.2E-03 | 3.3E-03 |
| Toluene | 6.5E-03 | 3.3E-03 | 3.5E-03 | 9.1E-04 |
| Xylenes | 5.3E-03 | 2.1E-03 | 2.3E-03 | 5.5E-04 |
| 1,3-butadiene | 1.3E-03 | 1.1E-04 | 1.2E-04 | 1.9E-05 |
| | | | | |
| Formaldehyde | 1.4E-01 | 2.1E-02 | 3.1E-02 | 7.6E-03 |
| Acetaldehyde | 5.7E-02 | 1.1E-02 | 1.4E-02 | 3.8E-03 |
| | | | | |
| Naphthalene | 6.0E-03 | 2.8E-03 | 2.7E-03 | 5.6E-04 |
| Acenaphthylene | 4.2E-04 | 2.5E-04 | 2.7E-04 | 5.7E-05 |
| Acenaphthene | 9.4E-05 | 4.0E-05 | 3.3E-05 | 6.5E-06 |
| Fluorene | 2.6E-04 | 1.7E-04 | 1.7E-04 | 5.7E-05 |
| Phenanthrene | 1.4E-04 | 2.9E-04 | 4.7E-04 | 3.5E-04 |
| Anthracene | 1.3E-05 | 2.3E-05 | 3.8E-05 | 2.4E-05 |
| Fluoranthene | 3.0E-05 | 4.9E-05 | 4.7E-05 | 3.1E-05 |
| Pyrene | 5.6E-05 | 8.0E-05 | 7.3E-05 | 4.3E-05 |
| Benzo[a]anthracene | 5.9E-05 | 2.8E-05 | 3.0E-05 | 7.9E-06 |
| Chrysene | 1.5E-05 | 1.8E-05 | 1.2E-05 | 3.7E-06 |
| Benzo[b]fluoanthene | 1.7E-05 | 1.6E-05 | 1.2E-05 | 2.4E-06 |
| Benzo[k]fluoanthene | 1.9E-05 | 1.7E-05 | 1.2E-05 | 2.5E-06 |
| Benzo[a]pyrene | 2.7E-05 | 1.8E-05 | 1.5E-05 | 3.3E-06 |
| Indeno[1,2,3,-c,d]pyrene | 2.4E-05 | 1.8E-05 | 1.6E-05 | 3.6E-06 |
| Dibenzo[a,h]anthracene | 2.6E-05 | 1.7E-05 | 1.9E-05 | 3.9E-06 |
| Benzo[g,h,i]perylene | 2.8E-05 | 1.9E-05 | 1.6E-05 | 3.3E-06 |
| **Total PAH** | **7.3E-03** | **3.8E-03** | **3.9E-03** | **1.2E-03** |

## 1990 Toyota Dyna, Class NB



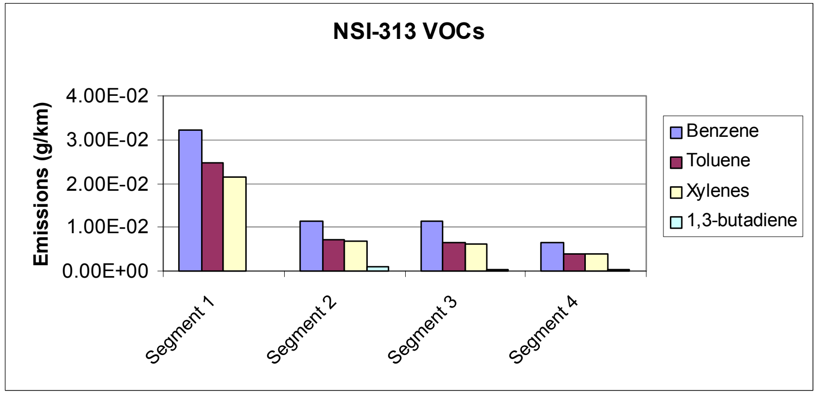


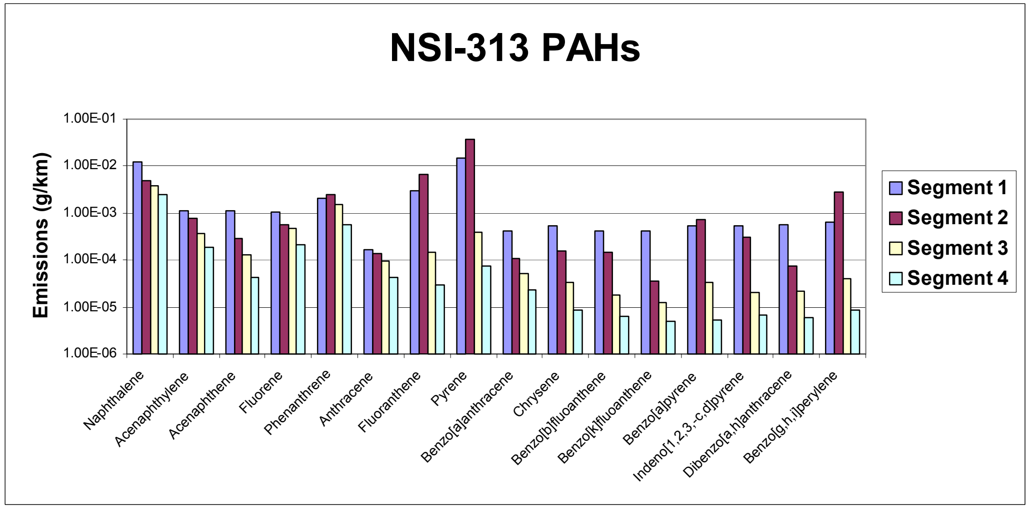


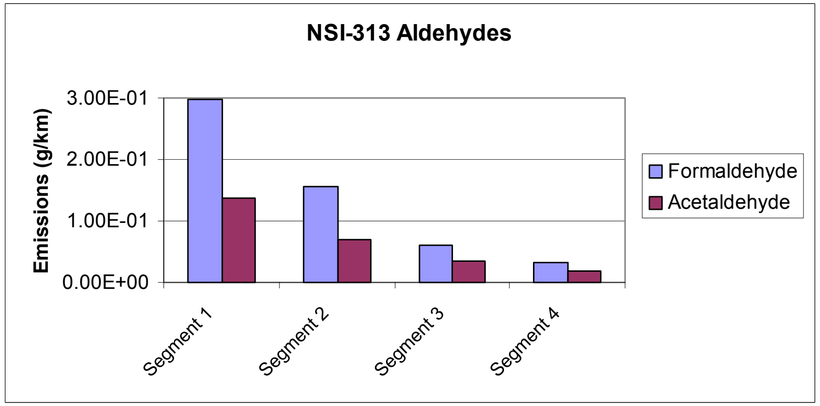


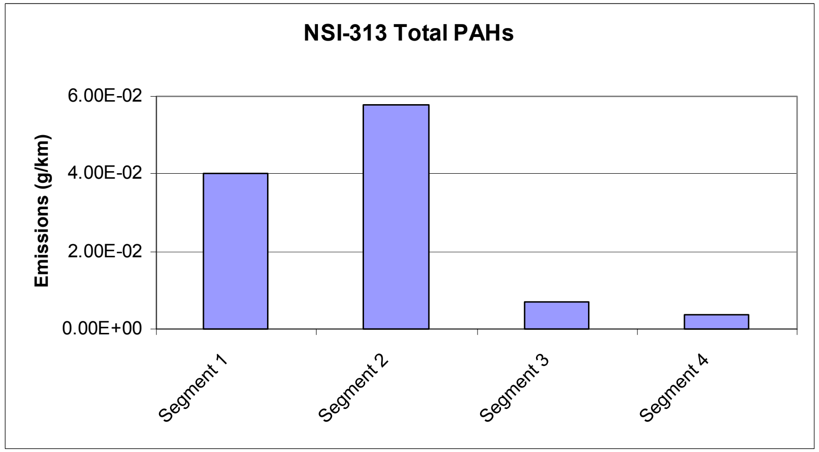
| Class NB | Emissions (g/km) | | | |
|---|---|---|---|---|
| **RGA-617** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 3.00E-02 | 9.87E-03 | 9.50E-03 | 5.65E-03 |
| Toluene | 1.63E-02 | 4.55E-03 | 3.96E-03 | 1.77E-03 |
| Xylenes | 1.18E-02 | 3.28E-03 | 2.72E-03 | 1.11E-03 |
| 1,3-butadiene | 7.45E-03 | 1.66E-04 | 0.00E+00 | 1.42E-04 |
| | | | | |
| Formaldehyde | 3.36E-01 | 6.36E-02 | 6.05E-02 | 1.72E-02 |
| Acetaldehyde | 1.22E-01 | 2.43E-02 | 2.27E-02 | 7.54E-03 |
| | | | | |
| Naphthalene | 1.23E-02 | 3.22E-03 | 3.56E-03 | 9.58E-04 |
| Acenaphthylene | 6.99E-04 | 3.46E-04 | 3.70E-04 | 6.64E-05 |
| Acenaphthene | 2.81E-04 | 7.60E-05 | 8.18E-05 | 1.32E-05 |
| Fluorene | 4.32E-04 | 2.02E-04 | 1.79E-04 | 3.66E-05 |
| Phenanthrene | 1.75E-03 | 4.81E-04 | 6.88E-04 | 1.16E-04 |
| Anthracene | 1.39E-04 | 3.63E-05 | 4.96E-05 | 7.70E-06 |
| Fluoranthene | 3.06E-04 | 4.67E-05 | 4.32E-05 | 3.13E-06 |
| Pyrene | 4.90E-04 | 9.07E-05 | 8.00E-05 | 4.57E-06 |
| Benzo[a]anthracene | 3.06E-05 | 1.12E-05 | 7.35E-06 | 1.93E-06 |
| Chrysene | 6.96E-05 | 2.02E-05 | 1.19E-05 | 1.44E-06 |
| Benzo[b]fluoanthene | 1.67E-05 | 6.98E-06 | 6.43E-06 | 4.81E-07 |
| Benzo[k]fluoanthene | 2.23E-05 | 6.28E-06 | 4.60E-06 | 4.81E-07 |
| Benzo[a]pyrene | 1.11E-05 | 3.49E-06 | 3.68E-06 | 7.22E-07 |
| Indeno[1,2,3,-c,d]pyrene | 8.35E-06 | 3.49E-06 | 2.76E-06 | 2.41E-07 |
| Dibenzo[a,h]anthracene | 8.35E-06 | 1.40E-06 | 1.84E-06 | 1.00E-13 |
| Benzo[g,h,i]perylene | 1.39E-05 | 5.58E-06 | 4.60E-06 | 4.81E-07 |
| **Total PAH** | **1.65E-02** | **4.55E-03** | **5.09E-03** | **1.21E-03** |

# 1995 Isuzu 900 SVR, Class NC



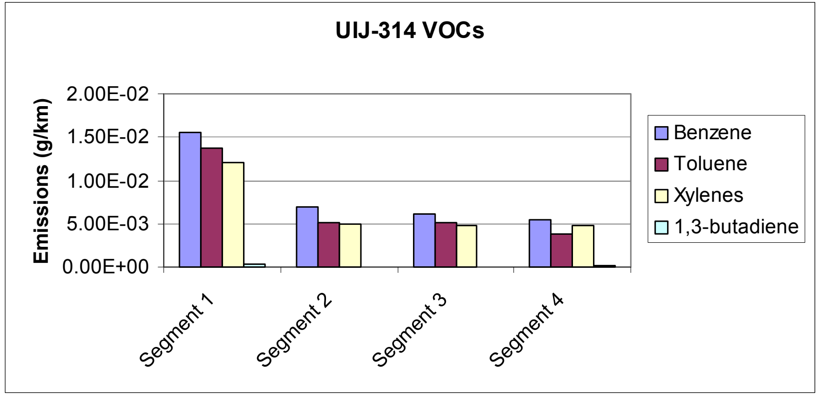


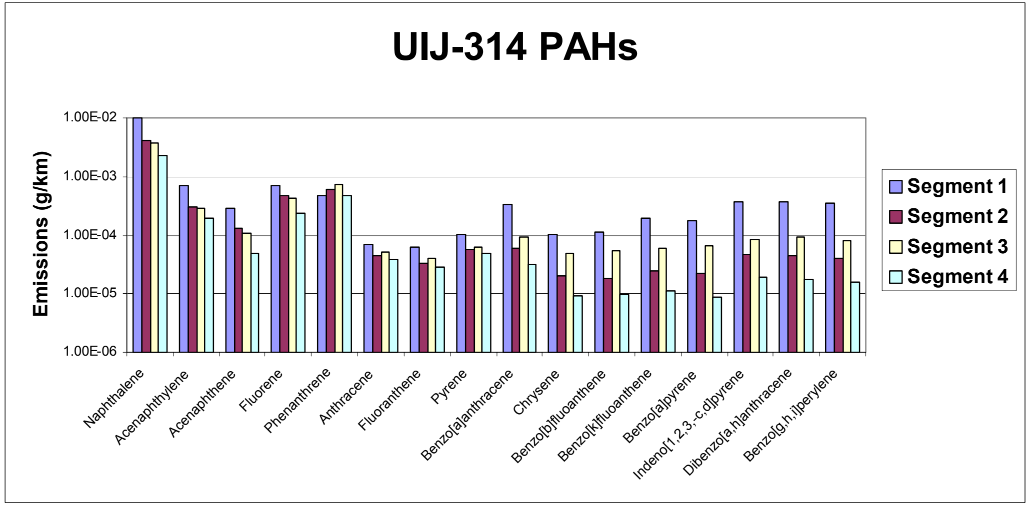


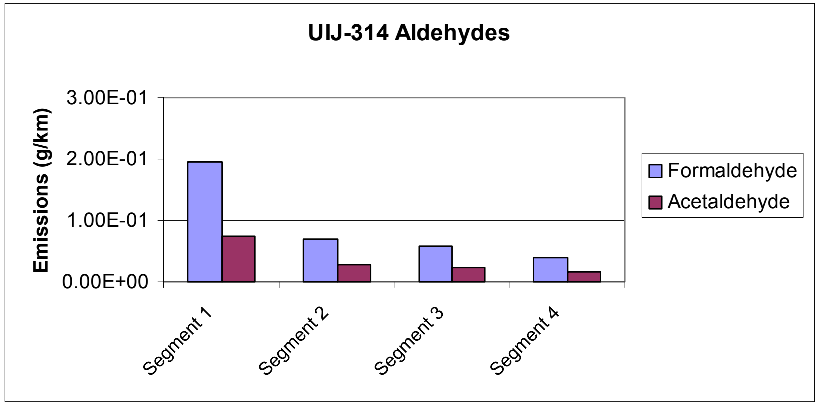


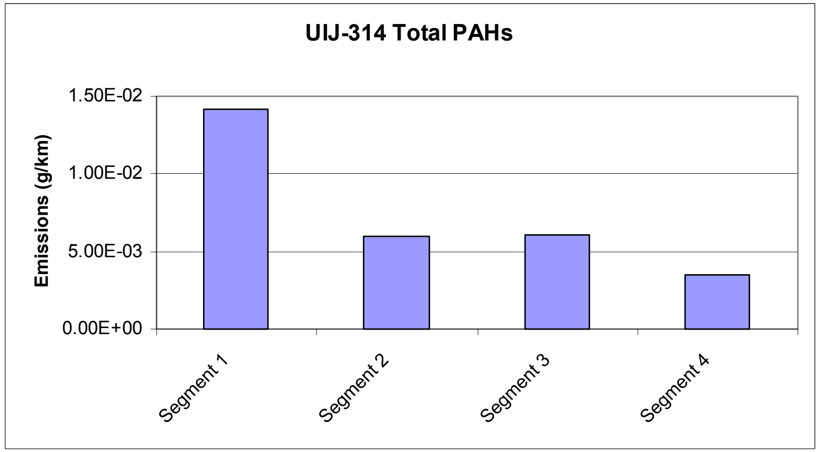
| Class NC | Emissions (g/km) | | | |
|---|---|---|---|---|
| **NSI-313** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 3.2E-02 | 1.1E-02 | 1.2E-02 | 6.6E-03 |
| Toluene | 2.5E-02 | 7.2E-03 | 6.6E-03 | 3.9E-03 |
| Xylenes | 2.1E-02 | 6.9E-03 | 6.0E-03 | 4.0E-03 |
| 1,3-butadiene | 1.6E-04 | 1.0E-03 | 4.7E-04 | 3.2E-04 |
| | | | | |
| Formaldehyde | 3.0E-01 | 1.6E-01 | 6.0E-02 | 3.2E-02 |
| Acetaldehyde | 1.4E-01 | 6.9E-02 | 3.5E-02 | 1.8E-02 |
| | | | | |
| Naphthalene | 1.3E-02 | 4.9E-03 | 3.7E-03 | 2.4E-03 |
| Acenaphthylene | 1.1E-03 | 7.9E-04 | 3.6E-04 | 1.9E-04 |
| Acenaphthene | 1.1E-03 | 2.9E-04 | 1.3E-04 | 4.3E-05 |
| Fluorene | 1.0E-03 | 5.8E-04 | 4.8E-04 | 2.1E-04 |
| Phenanthrene | 2.1E-03 | 2.5E-03 | 1.5E-03 | 5.7E-04 |
| Anthracene | 1.7E-04 | 1.4E-04 | 9.6E-05 | 4.2E-05 |
| Fluoranthene | 3.0E-03 | 6.9E-03 | 1.4E-04 | 3.0E-05 |
| Pyrene | 1.5E-02 | 3.7E-02 | 3.9E-04 | 7.3E-05 |
| Benzo[a]anthracene | 4.2E-04 | 1.1E-04 | 5.2E-05 | 2.3E-05 |
| Chrysene | 5.3E-04 | 1.5E-04 | 3.3E-05 | 8.9E-06 |
| Benzo[b]fluoanthene | 4.1E-04 | 1.5E-04 | 1.8E-05 | 6.4E-06 |
| Benzo[k]fluoanthene | 4.1E-04 | 3.6E-05 | 1.3E-05 | 5.0E-06 |
| Benzo[a]pyrene | 5.3E-04 | 7.4E-04 | 3.3E-05 | 5.3E-06 |
| Indeno[1,2,3,-c,d]pyrene | 5.2E-04 | 3.1E-04 | 2.1E-05 | 6.8E-06 |
| Dibenzo[a,h]anthracene | 5.6E-04 | 7.3E-05 | 2.2E-05 | 6.0E-06 |
| Benzo[g,h,i]perylene | 6.6E-04 | 2.9E-03 | 4.1E-05 | 8.9E-06 |
| **Total PAH** | **4.0E-02** | **5.8E-02** | **7.1E-03** | **3.6E-03** |

# 1996 Mitsubishi Superframe Turbo, Class NC



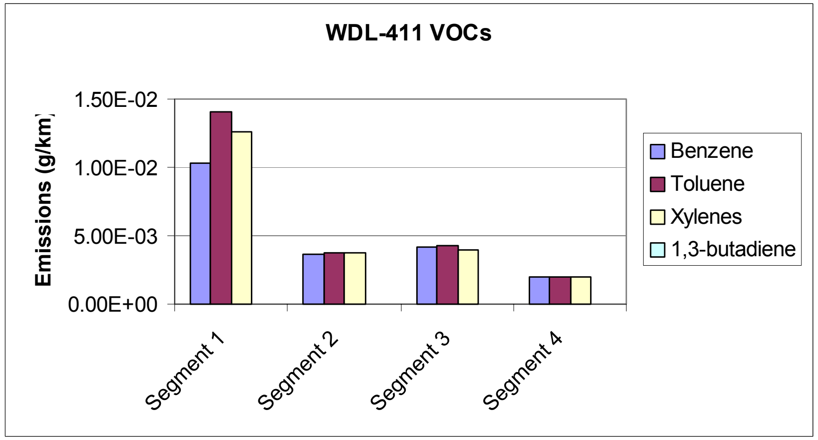


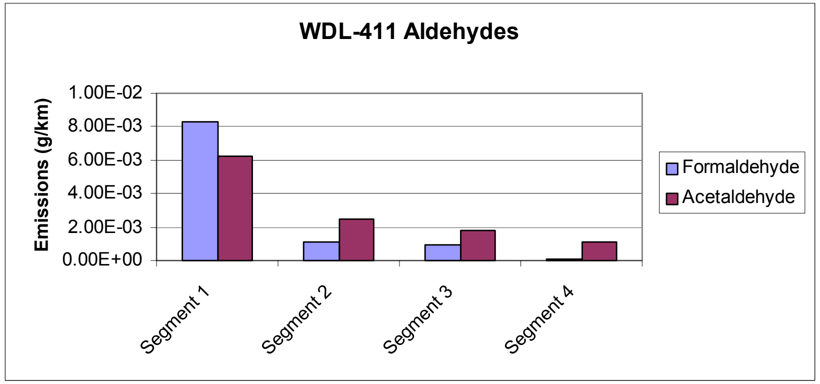


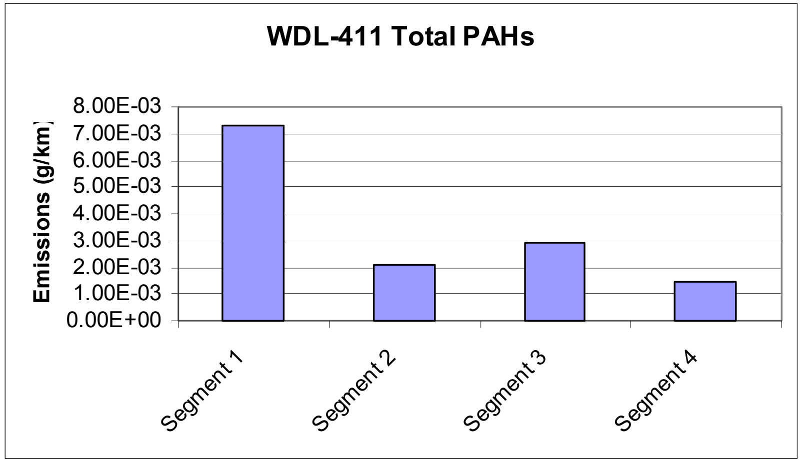


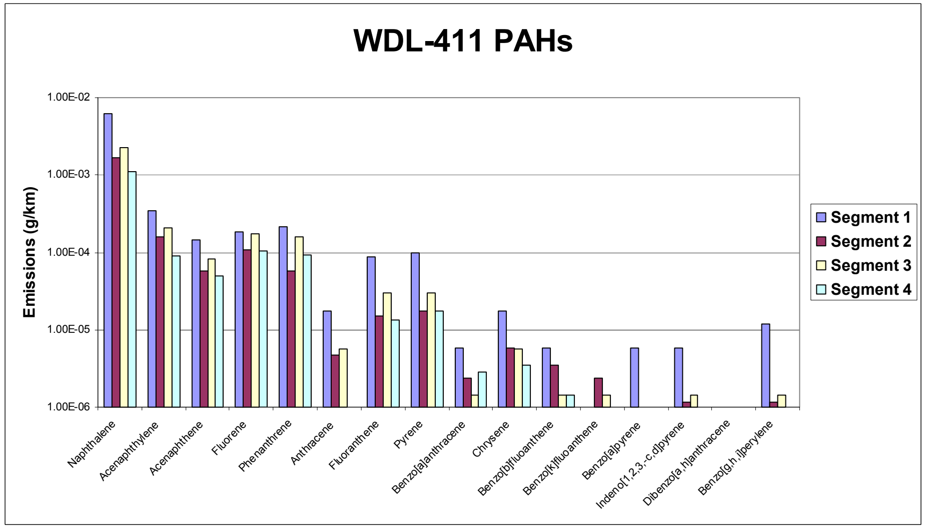
| Class NC | Emissions (g/km) | | | |
|---|---|---|---|---|
| **UIJ-314** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 1.5E-02 | 6.9E-03 | 6.1E-03 | 5.5E-03 |
| Toluene | 1.4E-02 | 5.0E-03 | 5.1E-03 | 3.8E-03 |
| Xylenes | 1.2E-02 | 4.9E-03 | 4.8E-03 | 4.8E-03 |
| 1,3-butadiene | 3.3E-04 | 0.0E+00 | 0.0E+00 | 1.7E-04 |
| | | | | |
| Formaldehyde | 2.0E-01 | 7.1E-02 | 5.9E-02 | 3.9E-02 |
| Acetaldehyde | 7.5E-02 | 2.9E-02 | 2.4E-02 | 1.6E-02 |
| | | | | |
| Naphthalene | 9.8E-03 | 4.1E-03 | 3.8E-03 | 2.3E-03 |
| Acenaphthylene | 6.9E-04 | 3.1E-04 | 2.9E-04 | 1.9E-04 |
| Acenaphthene | 2.8E-04 | 1.3E-04 | 1.1E-04 | 5.0E-05 |
| Fluorene | 7.0E-04 | 4.7E-04 | 4.3E-04 | 2.4E-04 |
| Phenanthrene | 4.7E-04 | 6.0E-04 | 7.3E-04 | 4.8E-04 |
| Anthracene | 6.9E-05 | 4.4E-05 | 5.2E-05 | 3.8E-05 |
| Fluoranthene | 6.3E-05 | 3.3E-05 | 4.1E-05 | 2.8E-05 |
| Pyrene | 1.0E-04 | 5.5E-05 | 6.3E-05 | 5.0E-05 |
| Benzo[a]anthracene | 3.3E-04 | 5.8E-05 | 9.4E-05 | 3.1E-05 |
| Chrysene | 1.0E-04 | 2.0E-05 | 4.9E-05 | 9.2E-06 |
| Benzo[b]fluoanthene | 1.1E-04 | 1.8E-05 | 5.5E-05 | 9.8E-06 |
| Benzo[k]fluoanthene | 1.9E-04 | 2.5E-05 | 6.1E-05 | 1.1E-05 |
| Benzo[a]pyrene | 1.7E-04 | 2.2E-05 | 6.6E-05 | 8.7E-06 |
| Indeno[1,2,3,-c,d]pyrene | 3.6E-04 | 4.7E-05 | 8.6E-05 | 1.9E-05 |
| Dibenzo[a,h]anthracene | 3.7E-04 | 4.4E-05 | 9.2E-05 | 1.7E-05 |
| Benzo[g,h,i]perylene | 3.4E-04 | 4.0E-05 | 8.0E-05 | 1.6E-05 |
| **Total PAH** | **1.4E-02** | **6.0E-03** | **6.1E-03** | **3.5E-03** |

# 1998 Iveco INT 9200, Class NC-H



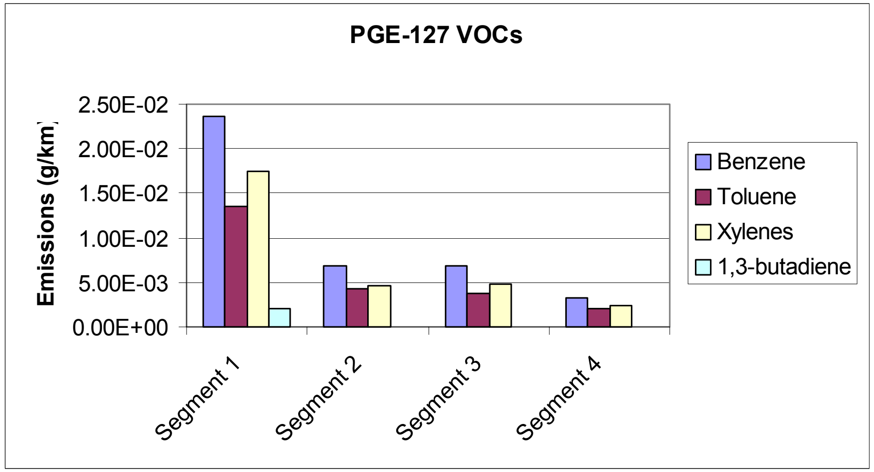


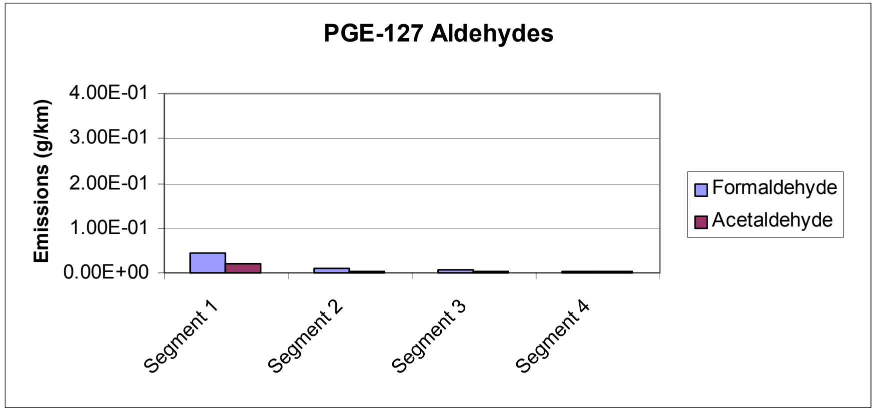


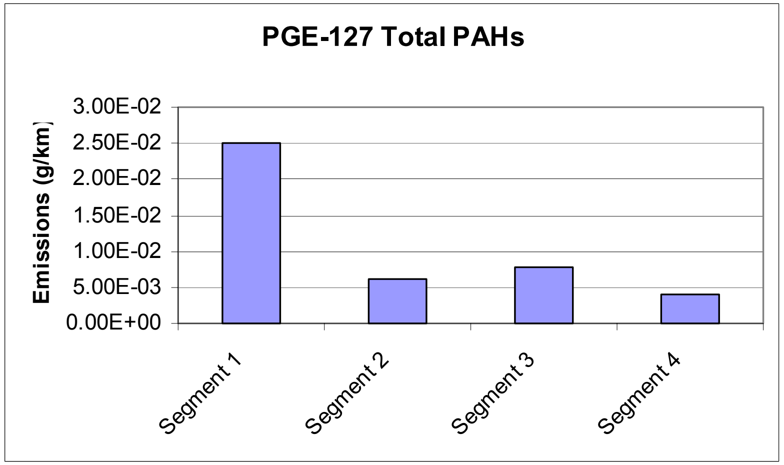


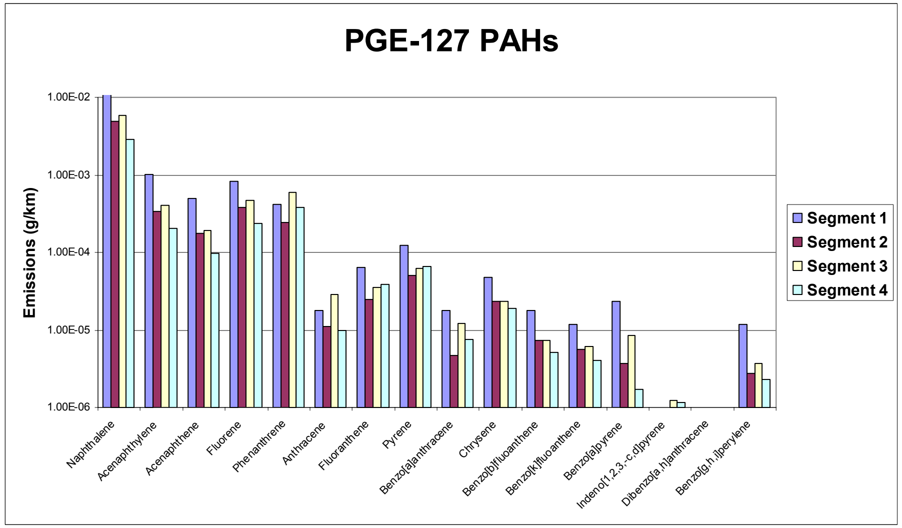
| Class NC-H | Emissions (g/km) | | | |
|---|---|---|---|---|
| **WDL-411** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 1.03E-02 | 3.63E-03 | 4.15E-03 | 2.02E-03 |
| Toluene | 1.41E-02 | 3.72E-03 | 4.25E-03 | 1.96E-03 |
| Xylenes | 1.26E-02 | 3.77E-03 | 3.91E-03 | 1.94E-03 |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 8.29E-03 | 1.11E-03 | 9.50E-04 | 5.19E-05 |
| Acetaldehyde | 6.21E-03 | 2.47E-03 | 1.80E-03 | 1.09E-03 |
| | | | | |
| Naphthalene | 6.15E-03 | 1.68E-03 | 2.23E-03 | 1.09E-03 |
| Acenaphthylene | 3.40E-04 | 1.57E-04 | 2.10E-04 | 9.07E-05 |
| Acenaphthene | 1.47E-04 | 5.74E-05 | 8.13E-05 | 5.03E-05 |
| Fluorene | 1.82E-04 | 1.09E-04 | 1.73E-04 | 1.05E-04 |
| Phenanthrene | 2.17E-04 | 5.74E-05 | 1.57E-04 | 9.21E-05 |
| Anthracene | 1.76E-05 | 4.68E-06 | 5.71E-06 | 7.09E-07 |
| Fluoranthene | 8.80E-05 | 1.52E-05 | 3.00E-05 | 1.35E-05 |
| Pyrene | 9.97E-05 | 1.76E-05 | 3.00E-05 | 1.77E-05 |
| Benzo[a]anthracene | 5.86E-06 | 2.34E-06 | 1.43E-06 | 2.83E-06 |
| Chrysene | 1.76E-05 | 5.85E-06 | 5.71E-06 | 3.54E-06 |
| Benzo[b]fluoanthene | 5.86E-06 | 3.51E-06 | 1.43E-06 | 1.42E-06 |
| Benzo[k]fluoanthene | 1.00E-13 | 2.34E-06 | 1.43E-06 | 7.09E-07 |
| Benzo[a]pyrene | 5.86E-06 | 1.00E-13 | 1.00E-13 | 8.50E-07 |
| Indeno[1,2,3,-c,d]pyrene | 5.86E-06 | 1.17E-06 | 1.43E-06 | 7.09E-07 |
| Dibenzo[a,h]anthracene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E-13 |
| Benzo[g,h,i]perylene | 1.17E-05 | 1.17E-06 | 1.43E-06 | 7.09E-07 |
| **Total PAH** | **7.29E-03** | **2.11E-03** | **2.93E-03** | **1.47E-03** |

# 1998 Hino Ranger 50, Class NC-H



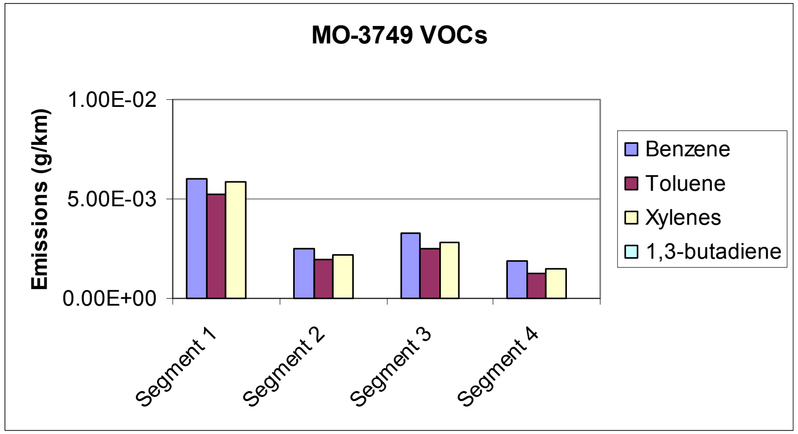


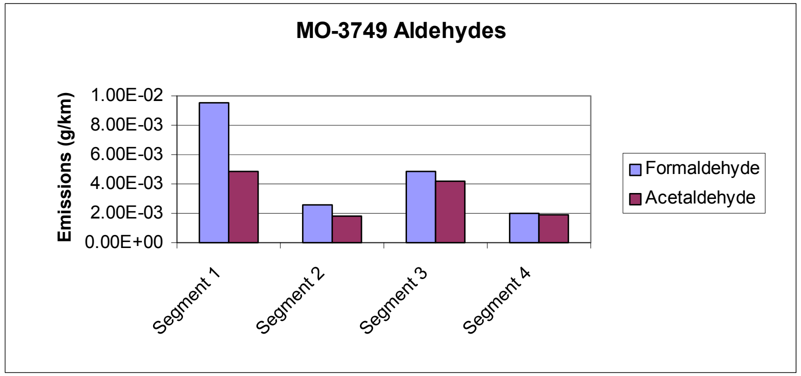


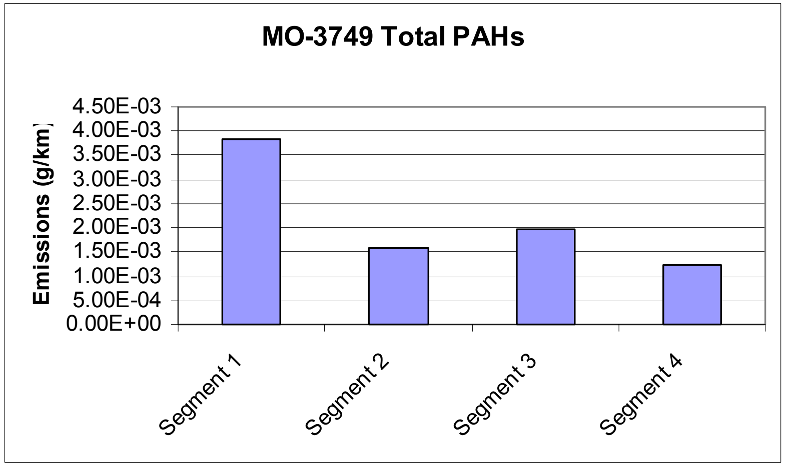


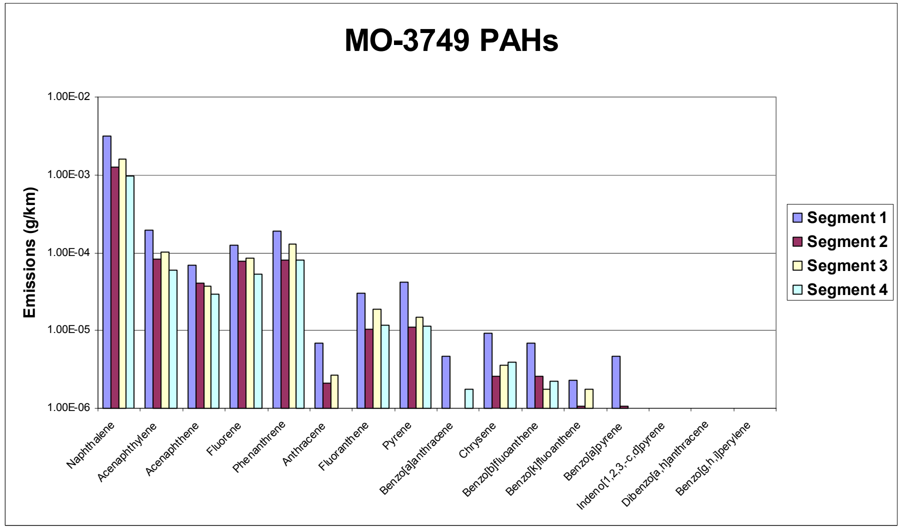
| Class NC-H | Emissions (g/km) | | | |
|---|---|---|---|---|
| **PGE-127** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.36E-02 | 6.77E-03 | 6.86E-03 | 3.17E-03 |
| Toluene | 1.36E-02 | 4.22E-03 | 3.71E-03 | 1.99E-03 |
| Xylenes | 1.74E-02 | 4.62E-03 | 4.73E-03 | 2.42E-03 |
| 1,3-butadiene | 2.12E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 4.41E-02 | 9.31E-03 | 7.36E-03 | 2.72E-03 |
| Acetaldehyde | 2.04E-02 | 4.04E-03 | 2.68E-03 | 2.28E-03 |
| | | | | |
| Naphthalene | 2.20E-02 | 4.84E-03 | 5.91E-03 | 2.84E-03 |
| Acenaphthylene | 1.01E-03 | 3.41E-04 | 4.03E-04 | 2.06E-04 |
| Acenaphthene | 4.92E-04 | 1.74E-04 | 1.93E-04 | 9.75E-05 |
| Fluorene | 8.32E-04 | 3.80E-04 | 4.72E-04 | 2.35E-04 |
| Phenanthrene | 4.22E-04 | 2.45E-04 | 5.95E-04 | 3.81E-04 |
| Anthracene | 1.76E-05 | 1.11E-05 | 2.83E-05 | 9.75E-06 |
| Fluoranthene | 6.45E-05 | 2.50E-05 | 3.57E-05 | 3.84E-05 |
| Pyrene | 1.23E-04 | 5.10E-05 | 6.27E-05 | 6.60E-05 |
| Benzo[a]anthracene | 1.76E-05 | 4.63E-06 | 1.23E-05 | 7.46E-06 |
| Chrysene | 4.69E-05 | 2.32E-05 | 2.34E-05 | 1.89E-05 |
| Benzo[b]fluoanthene | 1.76E-05 | 7.41E-06 | 7.38E-06 | 5.16E-06 |
| Benzo[k]fluoanthene | 1.17E-05 | 5.56E-06 | 6.15E-06 | 4.02E-06 |
| Benzo[a]pyrene | 2.35E-05 | 3.71E-06 | 8.61E-06 | 1.72E-06 |
| Indeno[1,2,3,-c,d]pyrene | 1.00E-13 | 9.26E-07 | 1.23E-06 | 1.15E-06 |
| Dibenzo[a,h]anthracene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E-13 |
| Benzo[g,h,i]perylene | 1.17E-05 | 2.78E-06 | 3.69E-06 | 2.29E-06 |
| **Total PAH** | **2.51E-02** | **6.11E-03** | **7.77E-03** | **3.91E-03** |

## 1996 Scania L113CRL, Class ME



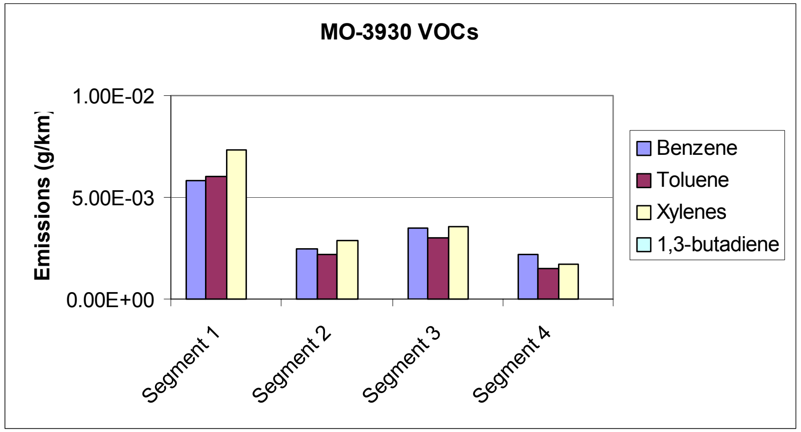


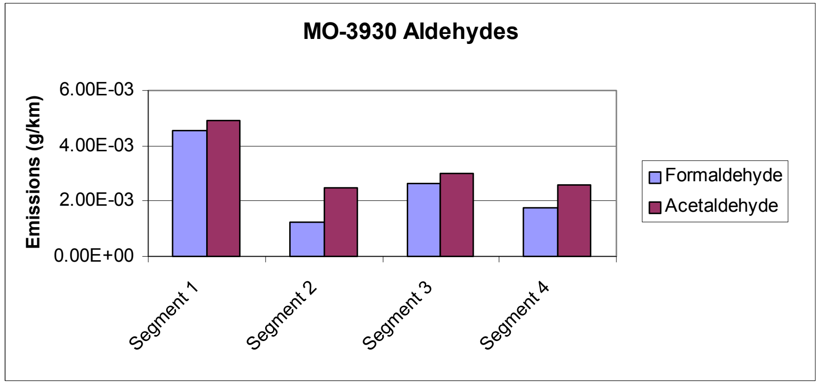


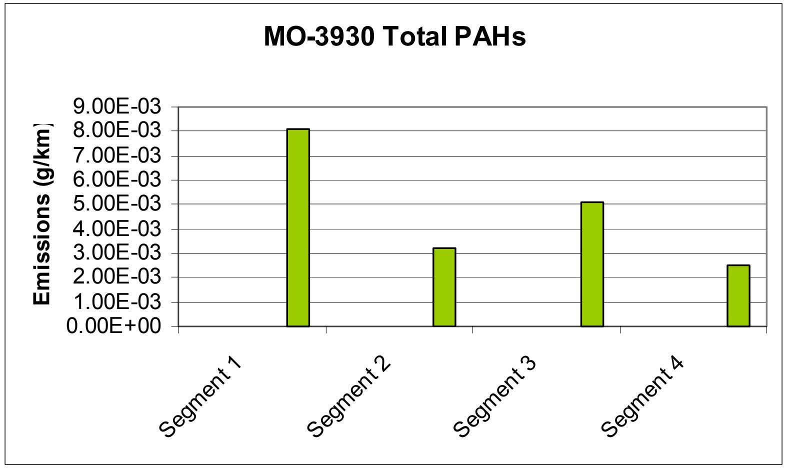


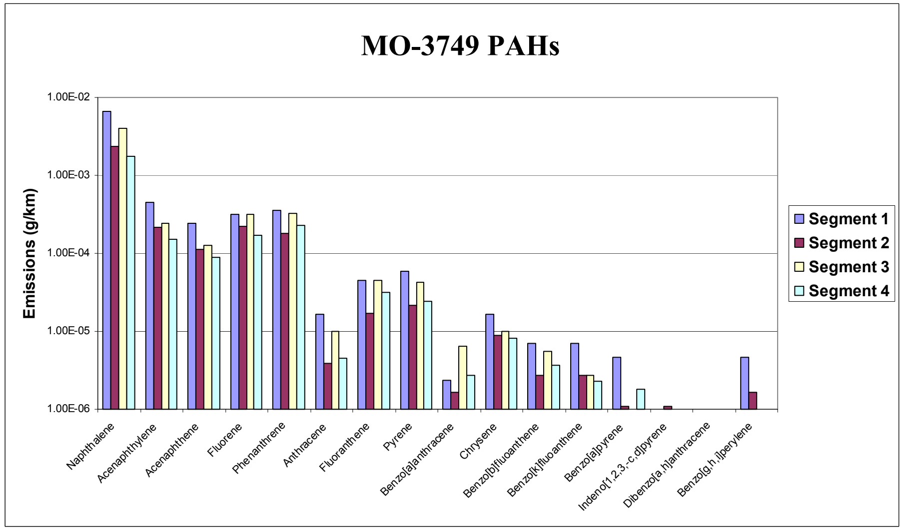
| Class ME | Emissions (g/km) | | | |
|---|---|---|---|---|
| MO-3749 | Segment 1 | Segment 2 | Segment 3 | Segment 4 |
| Benzene | 6.04E-03 | 2.46E-03 | 3.25E-03 | 1.89E-03 |
| Toluene | 5.24E-03 | 1.98E-03 | 2.47E-03 | 1.29E-03 |
| Xylenes | 5.84E-03 | 2.18E-03 | 2.78E-03 | 1.51E-03 |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 9.49E-03 | 2.59E-03 | 4.83E-03 | 1.98E-03 |
| Acetaldehyde | 4.84E-03 | 1.85E-03 | 4.15E-03 | 1.88E-03 |
| | | | | |
| Naphthalene | 3.14E-03 | 1.26E-03 | 1.57E-03 | 9.60E-04 |
| Acenaphthylene | 1.96E-04 | 8.37E-05 | 1.01E-04 | 5.92E-05 |
| Acenaphthene | 6.91E-05 | 4.08E-05 | 3.70E-05 | 2.89E-05 |
| Fluorene | 1.24E-04 | 7.74E-05 | 8.45E-05 | 5.22E-05 |
| Phenanthrene | 1.91E-04 | 7.95E-05 | 1.30E-04 | 8.11E-05 |
| Anthracene | 6.91E-06 | 2.09E-06 | 2.64E-06 | 8.77E-07 |
| Fluoranthene | 3.00E-05 | 1.05E-05 | 1.85E-05 | 1.18E-05 |
| Pyrene | 4.15E-05 | 1.10E-05 | 1.50E-05 | 1.14E-05 |
| Benzo[a]anthracene | 4.61E-06 | 5.23E-07 | 8.81E-07 | 1.75E-06 |
| Chrysene | 9.22E-06 | 2.62E-06 | 3.52E-06 | 3.95E-06 |
| Benzo[b]fluoanthene | 6.91E-06 | 2.62E-06 | 1.76E-06 | 2.19E-06 |
| Benzo[k]fluoanthene | 2.30E-06 | 1.05E-06 | 1.76E-06 | 8.77E-07 |
| Benzo[a]pyrene | 4.61E-06 | 1.05E-06 | 8.81E-07 | 1.00E-13 |
| Indeno[1,2,3,-c,d]pyrene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E-13 |
| Dibenzo[a,h]anthracene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E-13 |
| Benzo[g,h,i]perylene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E-13 |
| **Total PAH** | **3.83E-03** | **1.57E-03** | **1.97E-03** | **1.21E-03** |

## 1998 Volvo B10BLE, Class ME

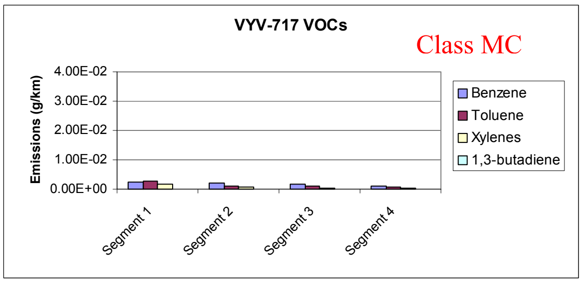


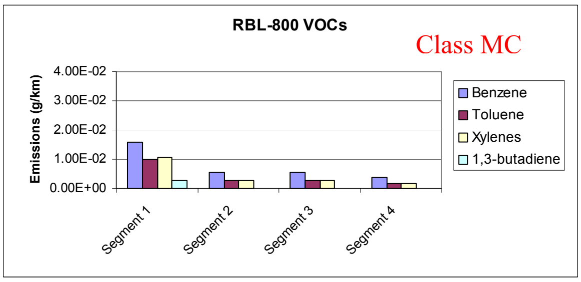


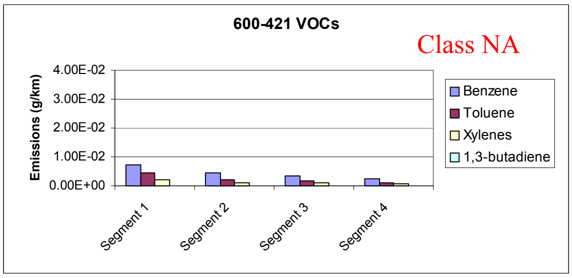


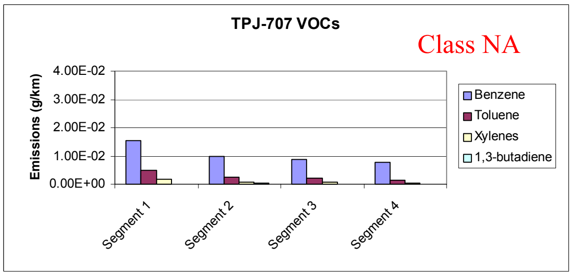


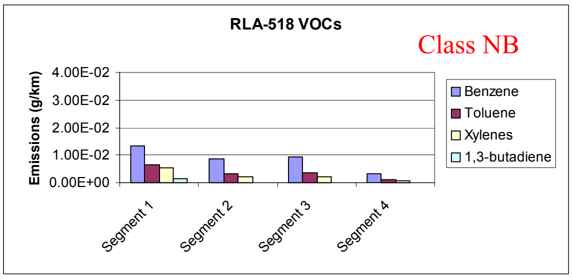
| Class ME | Emissions (g/km) | | | |
|---|---|---|---|---|
| MO-3930 | Segment 1 | Segment 2 | Segment 3 | Segment |
| Benzene | 5.85E-03 | 2.46E-03 | 3.50E-03 | 2.18E- |
| Toluene | 6.00E-03 | 2.21E-03 | 3.00E-03 | 1.51E- |
| Xylenes | 7.31E-03 | 2.84E-03 | 3.56E-03 | 1.69E- |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+ |
| | | | | |
| Formaldehyde | 4.57E-03 | 1.24E-03 | 2.64E-03 | 1.75E- |
| Acetaldehyde | 4.92E-03 | 2.49E-03 | 2.98E-03 | 2.60E- |
| | | | | |
| Naphthalene | 6.59E-03 | 2.38E-03 | 3.97E-03 | 1.78E- |
| Acenaphthylene | 4.48E-04 | 2.13E-04 | 2.43E-04 | 1.53E- |
| Acenaphthene | 2.39E-04 | 1.12E-04 | 1.27E-04 | 8.78E- |
| Fluorene | 3.19E-04 | 2.23E-04 | 3.15E-04 | 1.70E- |
| Phenanthrene | 3.58E-04 | 1.80E-04 | 3.25E-04 | 2.26E- |
| Anthracene | 1.64E-05 | 3.83E-06 | 1.01E-05 | 4.55E- |
| Fluoranthene | 4.45E-05 | 1.70E-05 | 4.49E-05 | 3.18E- |
| Pyrene | 5.86E-05 | 2.13E-05 | 4.21E-05 | 2.41E- |
| Benzo[a]anthracene | 2.34E-06 | 1.64E-06 | 6.41E-06 | 2.73E- |
| Chrysene | 1.64E-05 | 8.76E-06 | 1.01E-05 | 8.19E- |
| Benzo[b]fluoanthene | 7.03E-06 | 2.74E-06 | 5.50E-06 | 3.64E- |
| Benzo[k]fluoanthene | 7.03E-06 | 2.74E-06 | 2.75E-06 | 2.27E- |
| Benzo[a]pyrene | 4.69E-06 | 1.09E-06 | 1.00E-13 | 1.82E- |
| Indeno[1,2,3,-c,d]pyrene | 1.00E-13 | 1.09E-06 | 9.16E-07 | 9.10E- |
| Dibenzo[a,h]anthracene | 1.00E-13 | 1.00E-13 | 1.00E-13 | 1.00E- |
| Benzo[g,h,i]perylene | 4.69E-06 | 1.64E-06 | 9.16E-07 | 9.10E- |
| **Total PAH** | **8.12E-03** | **3.17E-03** | **5.10E-03** | **2.49E-** |

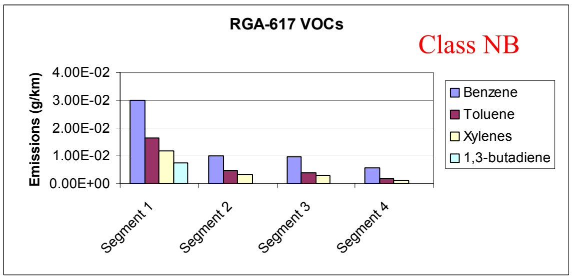

VYV-717 VOCs
Class MC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

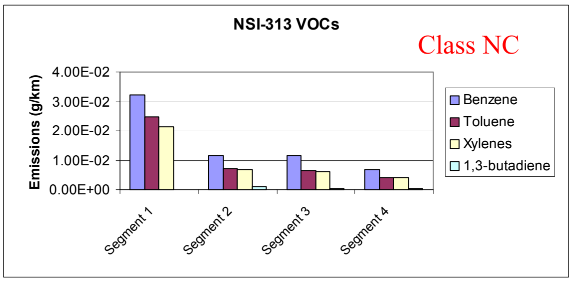

RBL-800 VOCs
Class MC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

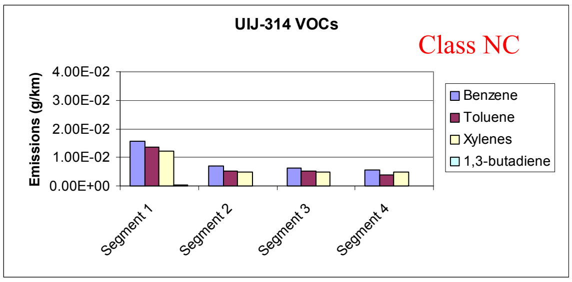

600-421 VOCs
Class NA
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

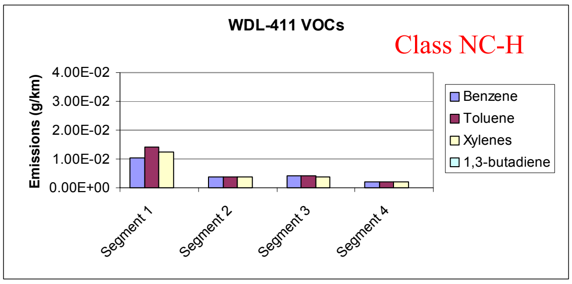

TPJ-707 VOCs
Class NA
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

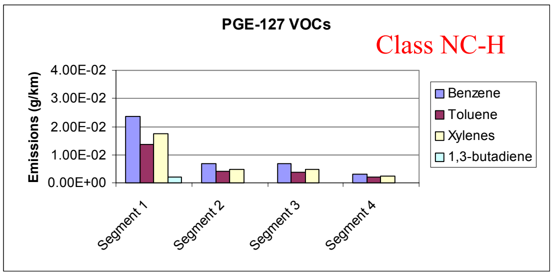

RLA-518 VOCs
Class NB
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

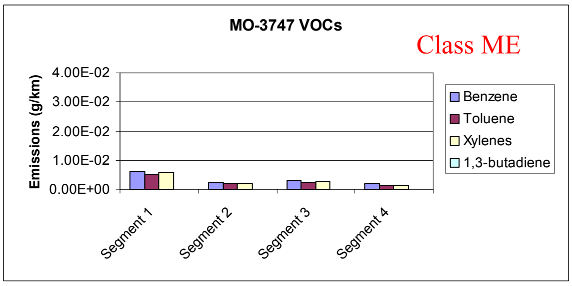

RGA-617 VOCs
Class NB
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

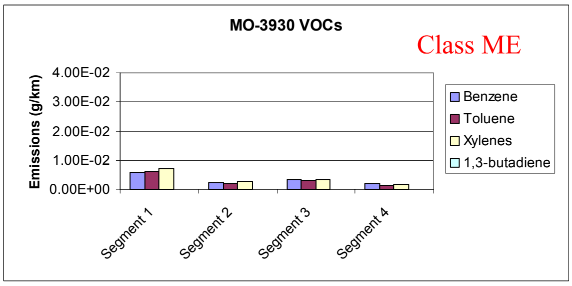

NSI-313 VOCs
Class NC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

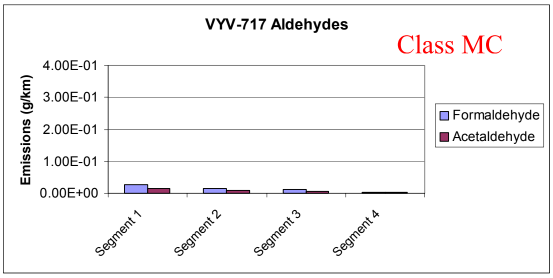

UIJ-314 VOCs
Class NC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

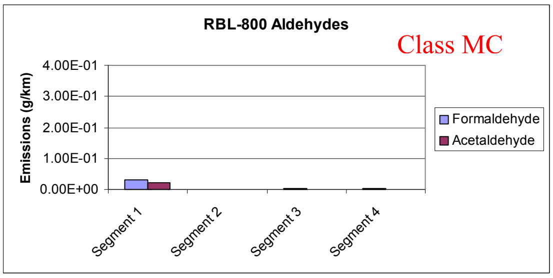

WDL-411 VOCs
Class NC-H
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

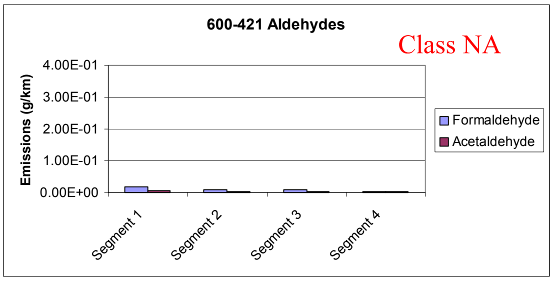

PGE-127 VOCs
Class NC-H
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

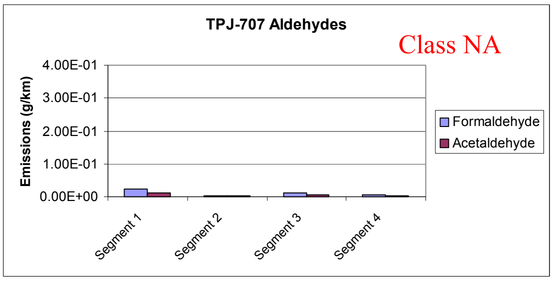

MO-3747 VOCs
Class ME
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

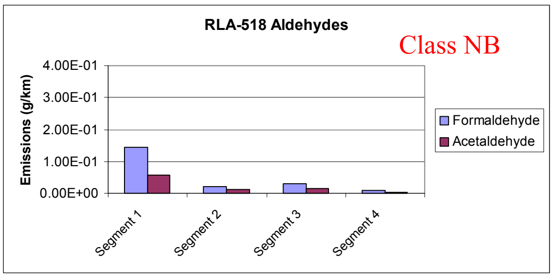

MO-3930 VOCs
Class ME
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Benzene
Toluene
Xylenes
1,3-butadiene

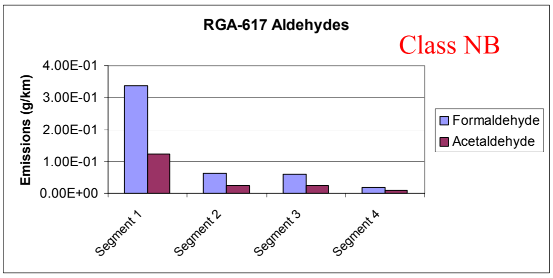

VYV-717 Aldehydes
Class MC
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

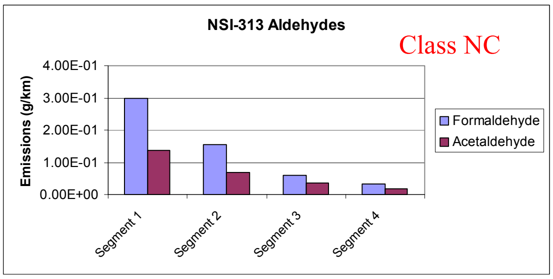

RBL-800 Aldehydes
Class MC
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

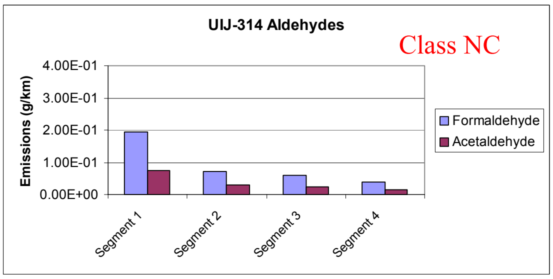

600-421 Aldehydes
Class NA
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

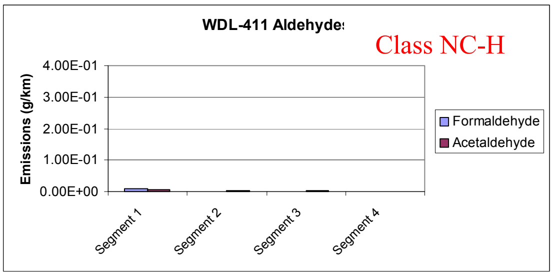

TPJ-707 Aldehydes
Class NA
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

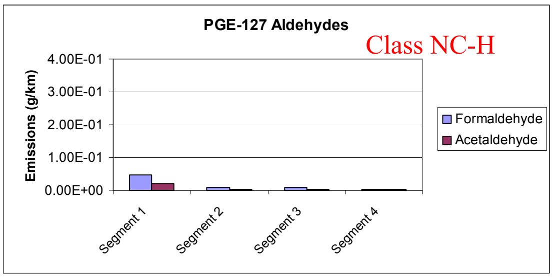

RLA-518 Aldehydes
Class NB
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

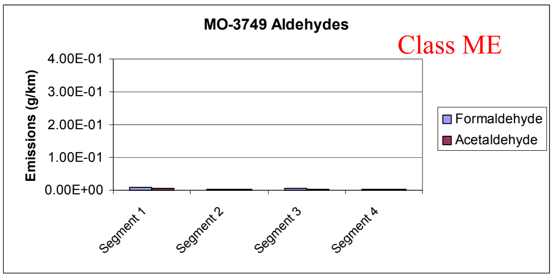

RGA-617 Aldehydes
Class NB
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

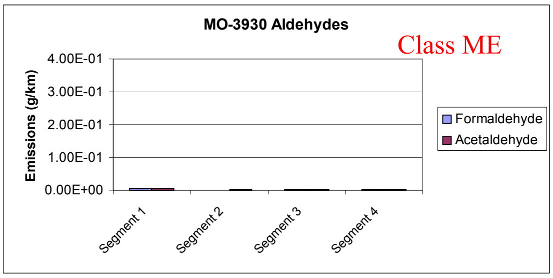

NSI-313 Aldehydes
Class NC
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

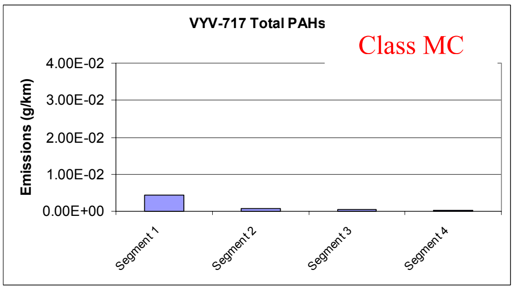

UIJ-314 Aldehydes
Class NC
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

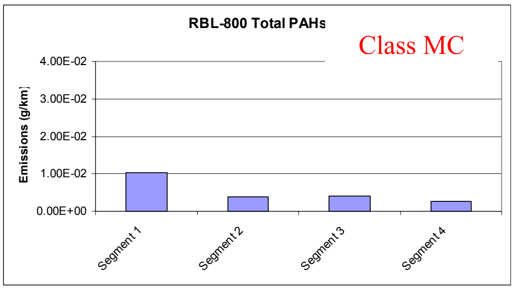

WDL-411 Aldehyde
Class NC-H
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

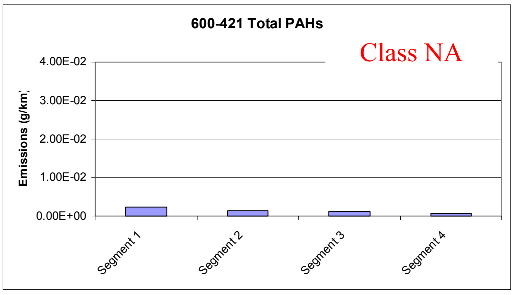

PGE-127 Aldehydes
Class NC-H
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

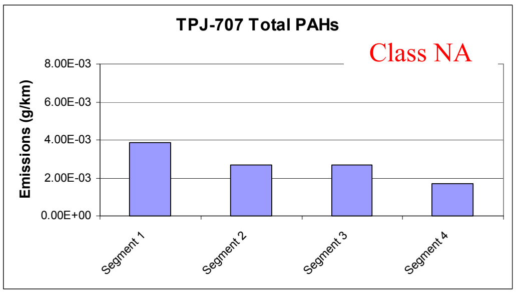

MO-3749 Aldehydes
Class ME
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

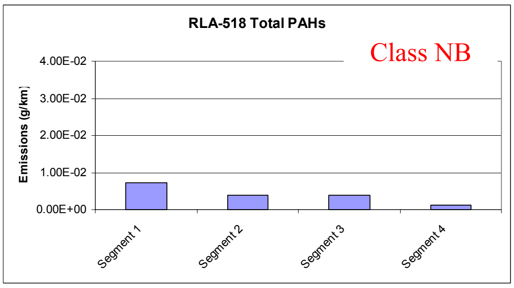

MO-3930 Aldehydes
Class ME
Emissions (g/km)
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4
Formaldehyde
Acetaldehyde

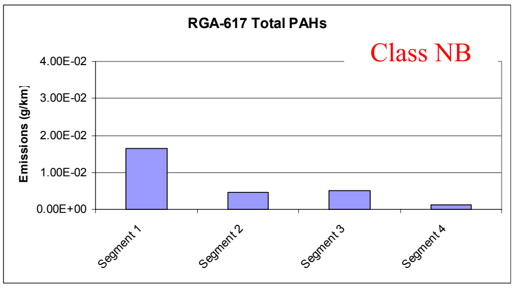

VYV-717 Total PAHs
Class MC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

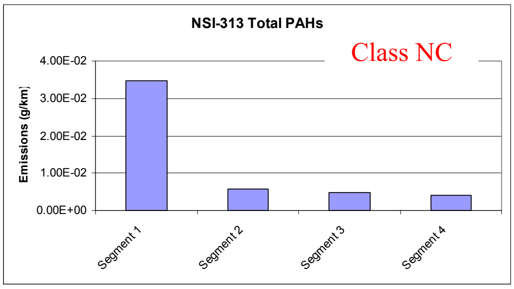

RBL-800 Total PAHs
Class MC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

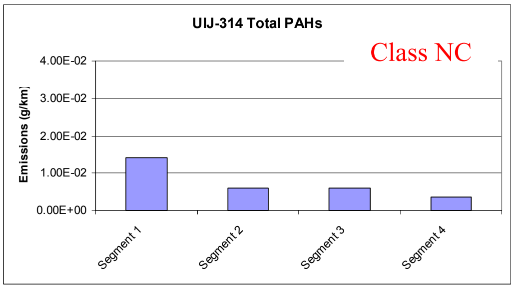

600-421 Total PAHs
Class NA
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

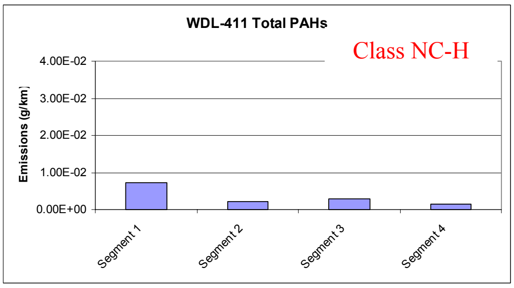

TPJ-707 Total PAHs
Class NA
Emissions (g/km)
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

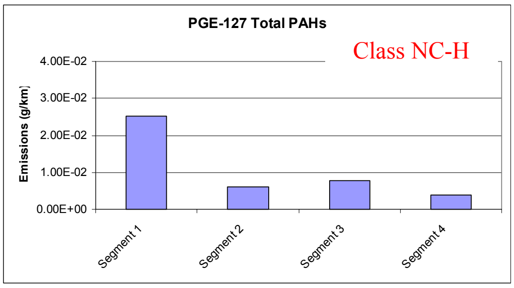

RLA-518 Total PAHs
Class NB
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

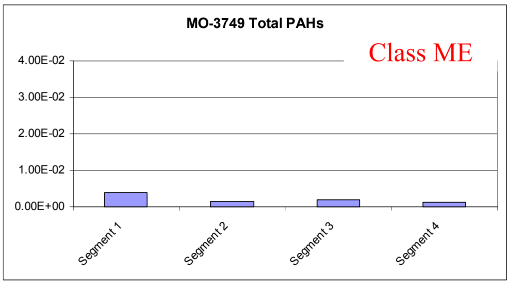

RGA-617 Total PAHs
Class NB
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

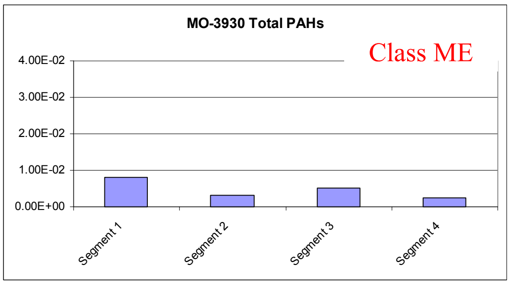

NSI-313 Total PAHs
Class NC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4


UIJ-314 Total PAHs
Class NC
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

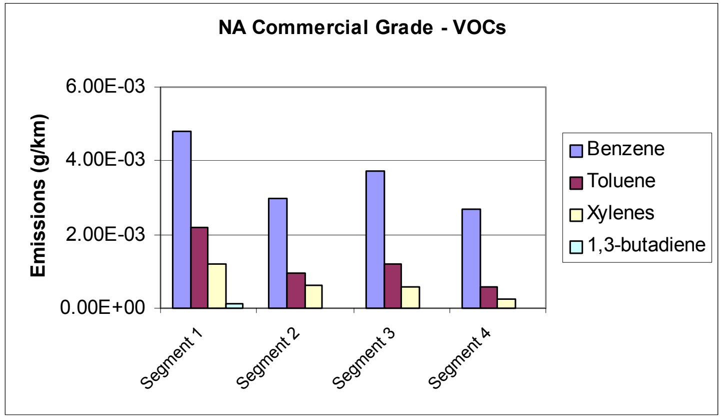

WDL-411 Total PAHs
Class NC-H
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

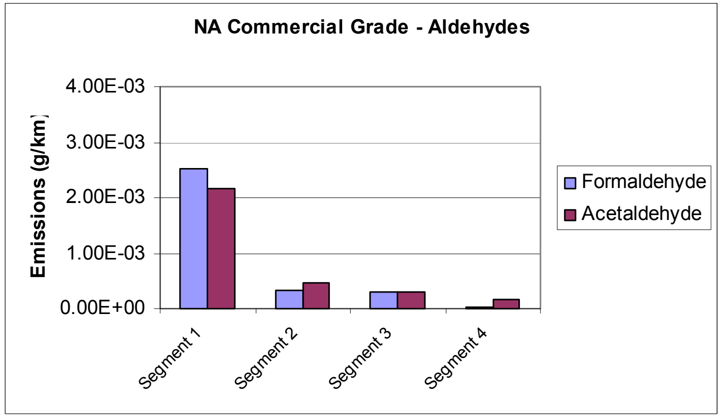

PGE-127 Total PAHs
Class NC-H
Emissions (g/km)
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

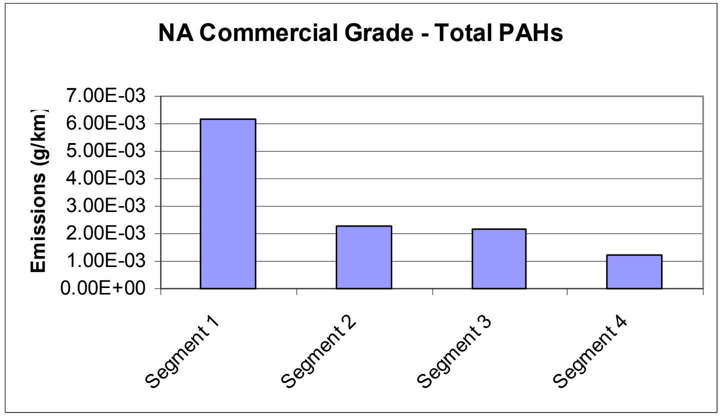

MO-3749 Total PAHs
Class ME
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

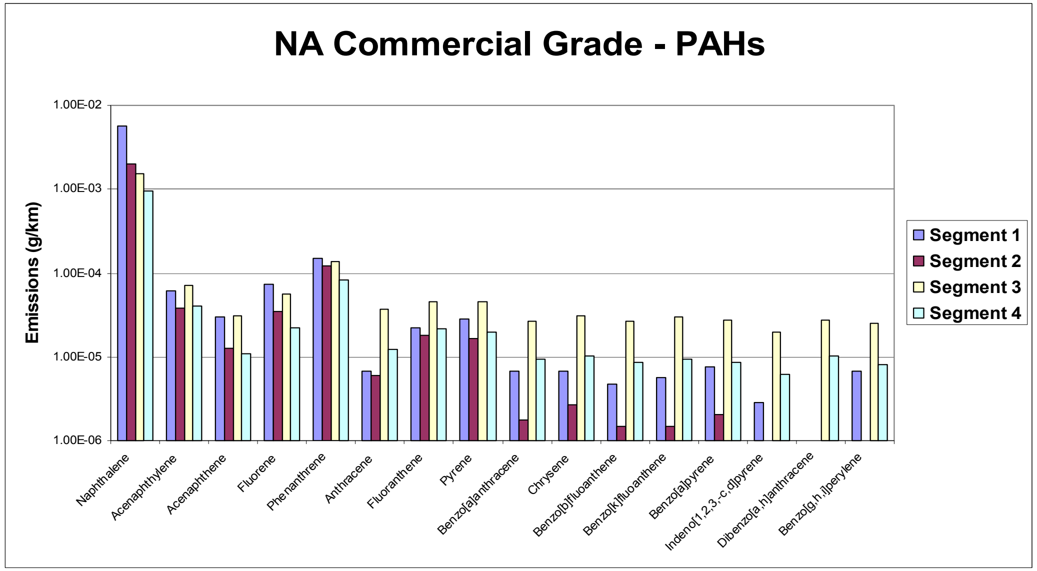

MO-3930 Total PAHs
Class ME
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
Segment 1
Segment 2
Segment 3
Segment 4

# Appendix 3: Toxics Results – 6 Fuels (Part B)

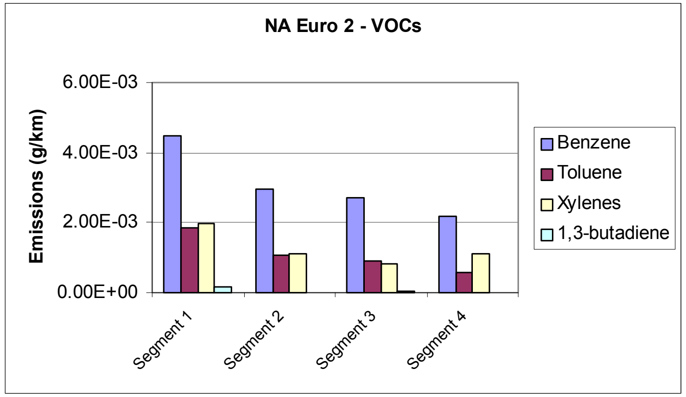


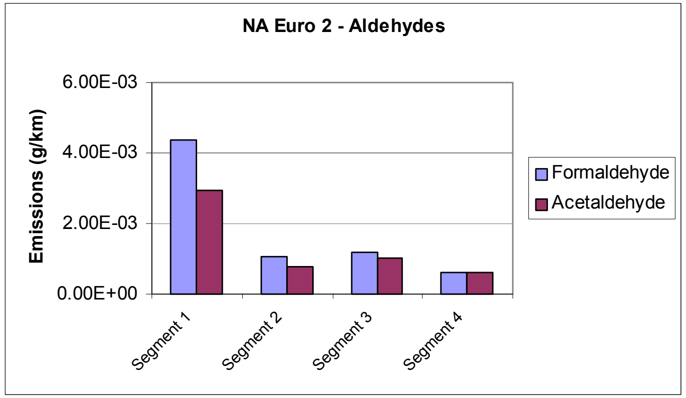


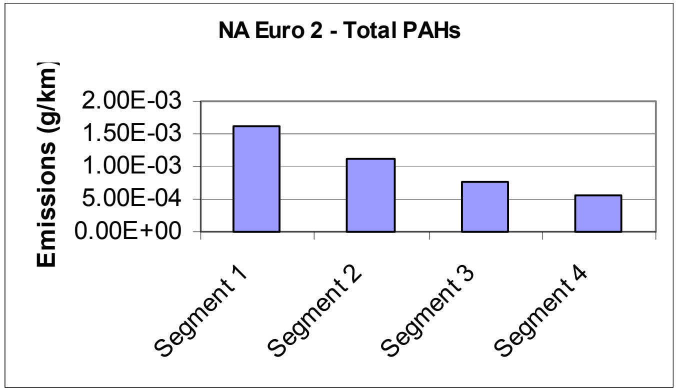


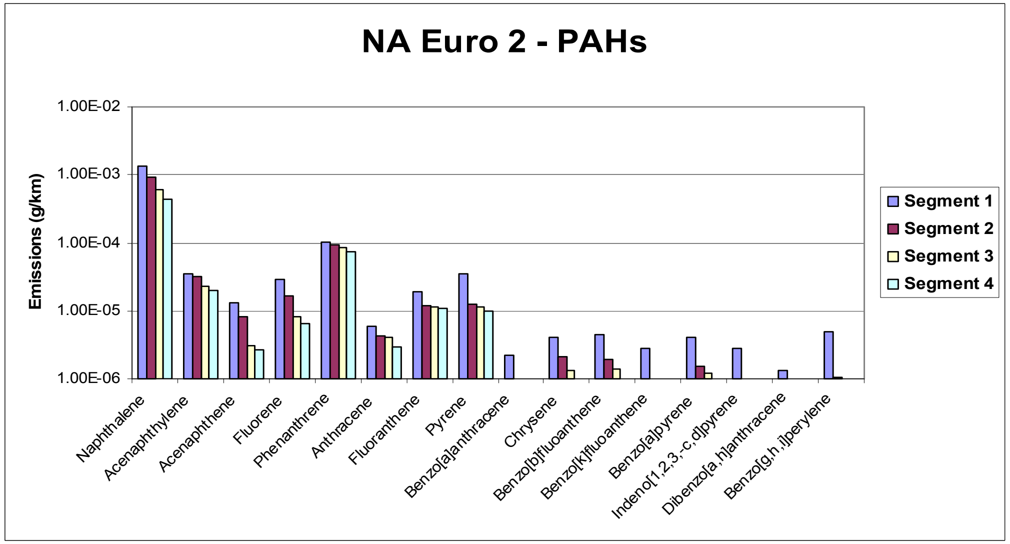


| Commercial Grade | Emissions (g/km) | | | |
|---|---|---|---|---|
| Class NA | Segment 1 | Segment 2 | Segment 3 | Segment 4 |
| Benzene | 4.80E-03 | 3.00E-03 | 3.73E-03 | 2.69E-03 |
| Toluene | 2.20E-03 | 9.31E-04 | 1.20E-03 | 5.75E-04 |
| Xylenes | 1.19E-03 | 6.03E-04 | 5.66E-04 | 2.60E-04 |
| 1,3-butadiene | 1.31E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 2.53E-03 | 3.33E-04 | 2.90E-04 | 2.49E-05 |
| Acetaldehyde | 2.16E-03 | 4.58E-04 | 3.14E-04 | 1.74E-04 |
| | | | | |
| Naphthalene | 5.75E-03 | 2.00E-03 | 1.55E-03 | 9.63E-04 |
| Acenaphthylene | 6.09E-05 | 3.82E-05 | 7.06E-05 | 4.07E-05 |
| Acenaphthene | 2.95E-05 | 1.27E-05 | 3.12E-05 | 1.09E-05 |
| Fluorene | 7.33E-05 | 3.44E-05 | 5.66E-05 | 2.19E-05 |
| Phenanthrene | 1.48E-04 | 1.20E-04 | 1.38E-04 | 8.26E-05 |
| Anthracene | 6.66E-06 | 5.93E-06 | 3.64E-05 | 1.24E-05 |
| Fluoranthene | 2.19E-05 | 1.78E-05 | 4.59E-05 | 2.14E-05 |
| Pyrene | 2.85E-05 | 1.66E-05 | 4.49E-05 | 1.96E-05 |
| Benzo[a]anthracene | 6.66E-06 | 1.78E-06 | 2.67E-05 | 9.47E-06 |
| Chrysene | 6.66E-06 | 2.67E-06 | 3.06E-05 | 1.03E-05 |
| Benzo[b]fluoanthene | 4.76E-06 | 1.48E-06 | 2.63E-05 | 8.49E-06 |
| Benzo[k]fluoanthene | 5.71E-06 | 1.48E-06 | 2.96E-05 | 9.31E-06 |
| Benzo[a]pyrene | 7.61E-06 | 2.07E-06 | 2.73E-05 | 8.65E-06 |
| Indeno[1,2,3,-c,d]pyrene | 2.85E-06 | | 1.98E-05 | 6.20E-06 |
| Dibenzo[a,h]anthracene | | | 2.70E-05 | 1.03E-05 |
| Benzo[g,h,i]perylene | 6.66E-06 | 8.89E-07 | 2.47E-05 | 8.00E-06 |
| **Total PAH** | **6.16E-03** | **2.26E-03** | **2.19E-03** | **1.24E-03** |

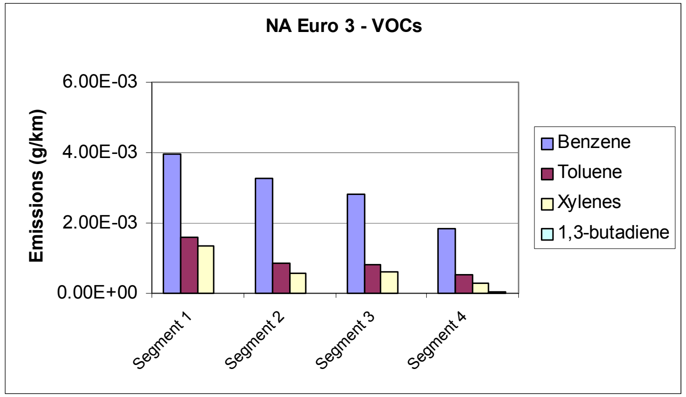


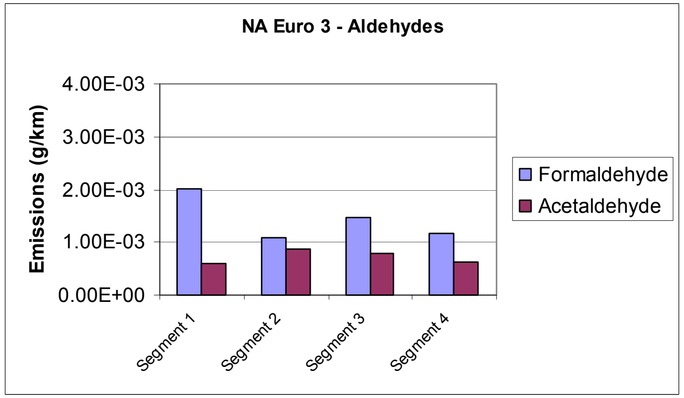


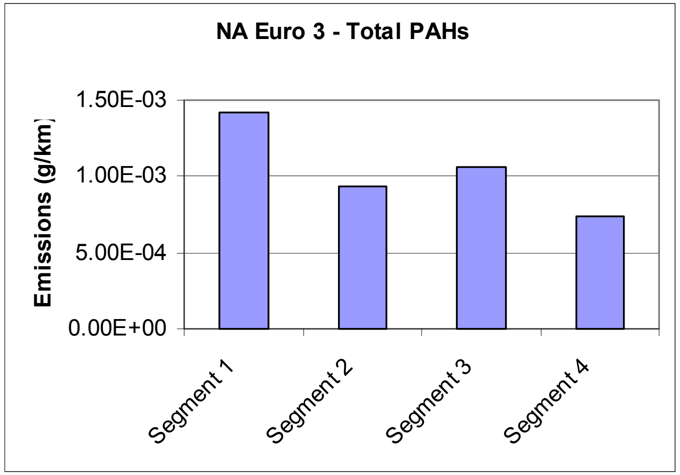


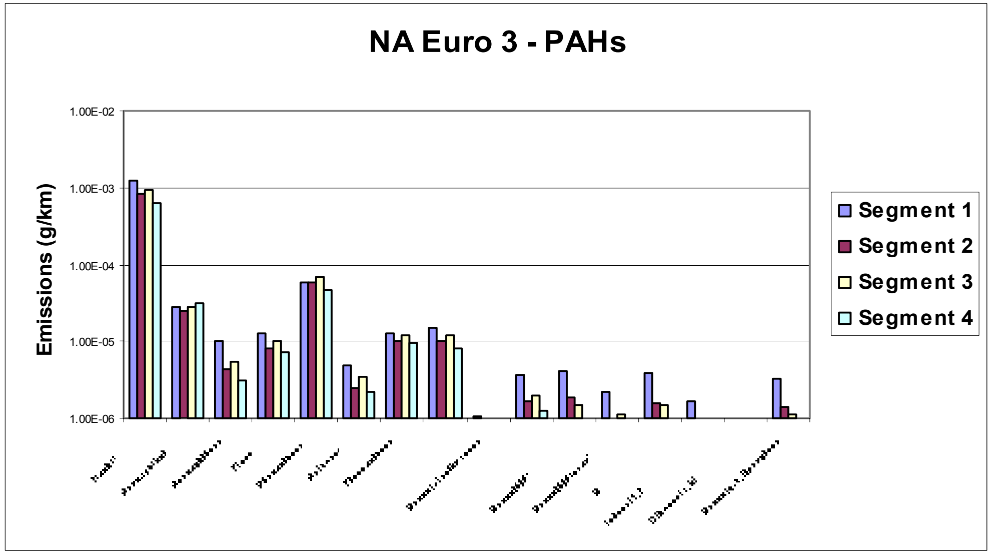


| Euro 2 | Emissions (g/km) | | | |
|---|---|---|---|---|
| Class NA | Segment 1 | Segment 2 | Segment 3 | Segment 4 |
| Benzene | 4.48E-03 | 2.94E-03 | 2.71E-03 | 2.17E-03 |
| Toluene | 1.86E-03 | 1.08E-03 | 8.85E-04 | 5.75E-04 |
| Xylenes | 1.99E-03 | 1.12E-03 | 8.39E-04 | 1.10E-03 |
| 1,3-butadiene | 1.71E-04 | 0.00E+00 | 2.63E-05 | 1.90E-05 |
| | | | | |
| Formaldehyde | 4.37E-03 | 1.07E-03 | 1.19E-03 | 5.98E-04 |
| Acetaldehyde | 2.92E-03 | 7.91E-04 | 1.01E-03 | 6.17E-04 |
| | | | | |
| Naphthalene | 1.35E-03 | 9.33E-04 | 6.02E-04 | 4.29E-04 |
| Acenaphthylene | 3.52E-05 | 3.23E-05 | 2.29E-05 | 2.00E-05 |
| Acenaphthene | 1.29E-05 | 8.19E-06 | 3.03E-06 | 2.65E-06 |
| Fluorene | 2.85E-05 | 1.62E-05 | 8.13E-06 | 6.56E-06 |
| Phenanthrene | 1.04E-04 | 9.54E-05 | 8.42E-05 | 7.25E-05 |
| Anthracene | 5.92E-06 | 4.27E-06 | 4.05E-06 | 2.86E-06 |
| Fluoranthene | 1.86E-05 | 1.20E-05 | 1.12E-05 | 1.06E-05 |
| Pyrene | 3.53E-05 | 1.27E-05 | 1.16E-05 | 9.84E-06 |
| Benzo[a]anthracene | 2.26E-06 | 9.08E-07 | 6.03E-07 | 2.39E-07 |
| Chrysene | 4.10E-06 | 2.07E-06 | 1.35E-06 | 9.63E-07 |
| Benzo[b]fluoanthene | 4.54E-06 | 1.93E-06 | 1.36E-06 | 8.88E-07 |
| Benzo[k]fluoanthene | 2.74E-06 | 9.03E-07 | 9.04E-07 | 4.83E-07 |
| Benzo[a]pyrene | 4.11E-06 | 1.55E-06 | 1.21E-06 | 5.67E-07 |
| Indeno[1,2,3,-c,d]pyrene | 2.74E-06 | 5.17E-07 | 2.96E-07 | |
| Dibenzo[a,h]anthracene | 1.35E-06 | | | |
| Benzo[g,h,i]perylene | 5.01E-06 | 1.03E-06 | 8.99E-07 | 2.44E-07 |
| Total PAH | 1.62E-03 | 1.12E-03 | 7.53E-04 | 5.57E-04 |

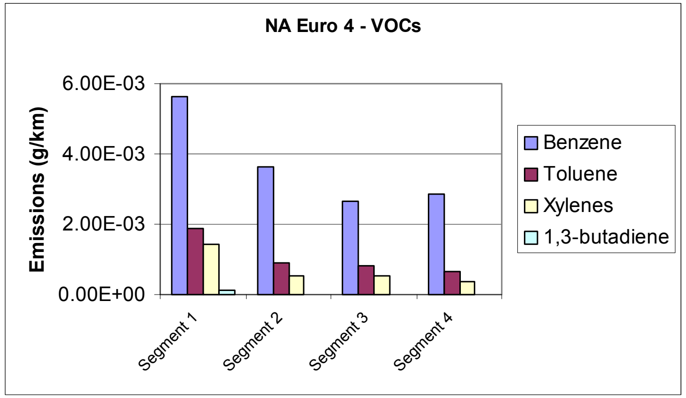


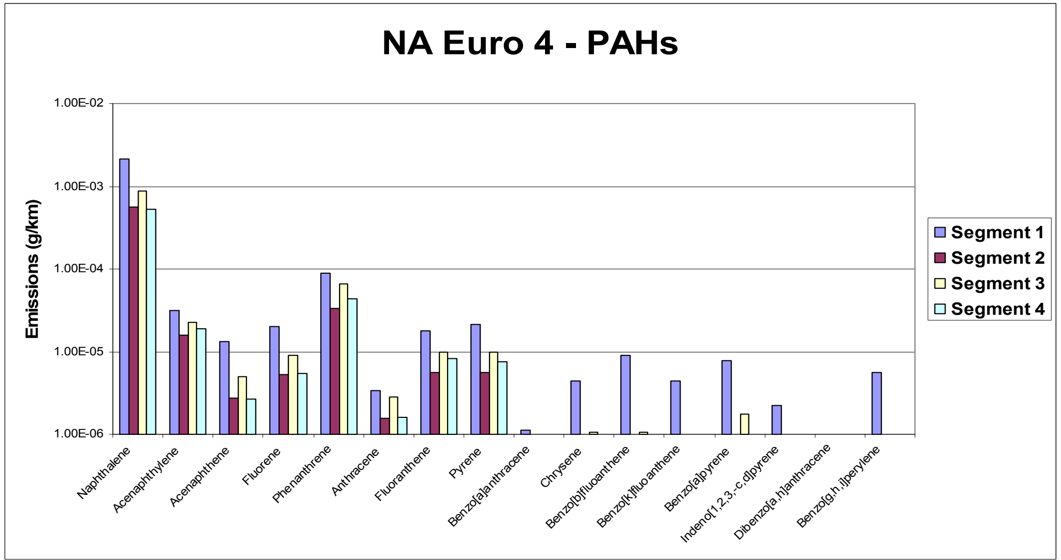


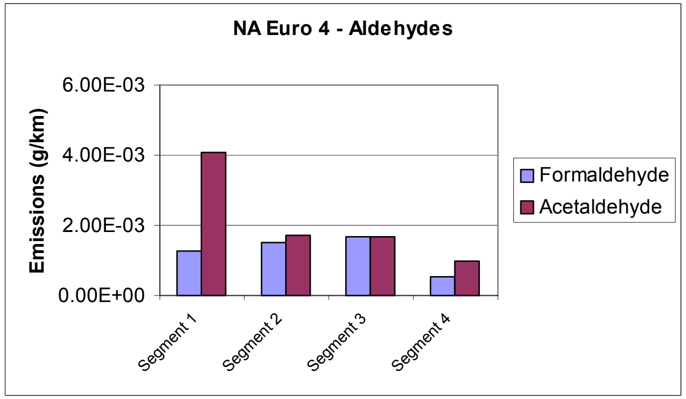


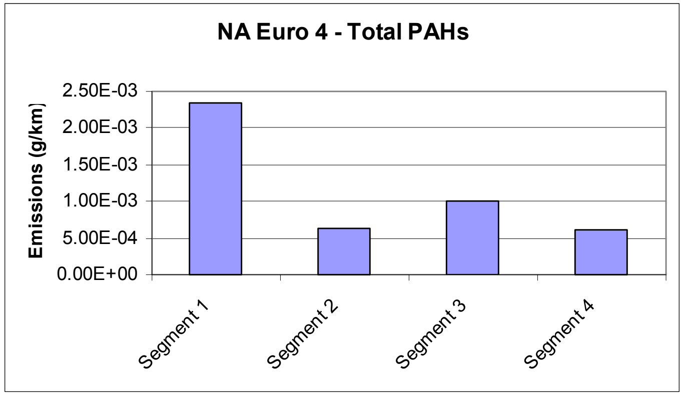


| Euro 3 | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Class NA** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 3.96E-03 | 3.27E-03 | 2.82E-03 | 1.86E-03 |
| Toluene | 1.59E-03 | 8.64E-04 | 8.35E-04 | 5.43E-04 |
| Xylenes | 1.35E-03 | 5.58E-04 | 6.15E-04 | 3.01E-04 |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 5.69E-05 |
| | | | | |
| Formaldehyde | 2.02E-03 | 1.09E-03 | 1.46E-03 | 1.16E-03 |
| Acetaldehyde | 5.99E-04 | 8.69E-04 | 7.79E-04 | 6.22E-04 |
| | | | | |
| Naphthalene | 1.26E-03 | 8.14E-04 | 9.10E-04 | 6.24E-04 |
| Acenaphthylene | 2.79E-05 | 2.45E-05 | 2.80E-05 | 3.13E-05 |
| Acenaphthene | 1.02E-05 | 4.28E-06 | 5.51E-06 | 3.13E-06 |
| Fluorene | 1.27E-05 | 8.03E-06 | 9.88E-06 | 7.11E-06 |
| Phenanthrene | 5.86E-05 | 5.73E-05 | 6.98E-05 | 4.75E-05 |
| Anthracene | 4.85E-06 | 2.49E-06 | 3.41E-06 | 2.20E-06 |
| Fluoranthene | 1.28E-05 | 1.03E-05 | 1.22E-05 | 9.77E-06 |
| Pyrene | 1.49E-05 | 1.01E-05 | 1.20E-05 | 7.93E-06 |
| Benzo[a]anthracene | 1.05E-06 | 5.54E-07 | 6.48E-07 | 4.21E-07 |
| Chrysene | 3.71E-06 | 1.66E-06 | 1.94E-06 | 1.27E-06 |
| Benzo[b]fluoanthene | 4.20E-06 | 1.81E-06 | 1.46E-06 | 1.01E-06 |
| Benzo[k]fluoanthene | 2.18E-06 | 9.65E-07 | 1.13E-06 | 6.77E-07 |
| Benzo[a]pyrene | 3.80E-06 | 1.54E-06 | 1.46E-06 | 7.60E-07 |
| Indeno[1,2,3,-c,d]pyrene | 1.62E-06 | 1.34E-07 | 3.24E-07 | 1.69E-07 |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 3.23E-06 | 1.38E-06 | 1.13E-06 | 7.60E-07 |
| **Total PAH** | **1.42E-03** | **9.39E-04** | **1.06E-03** | **7.38E-04** |

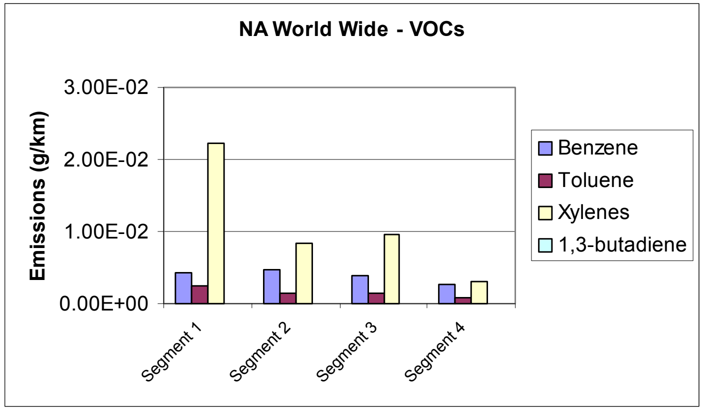


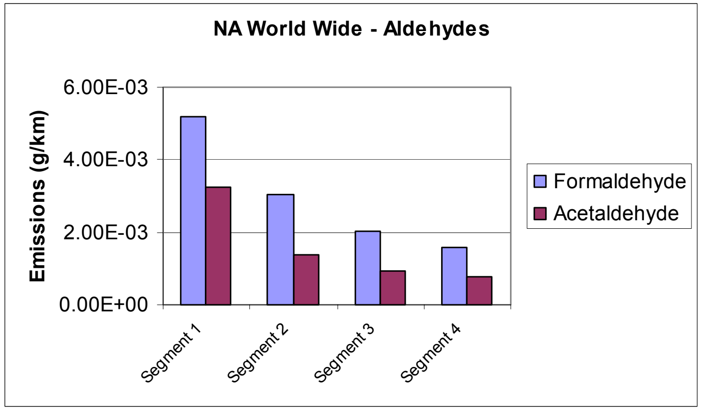


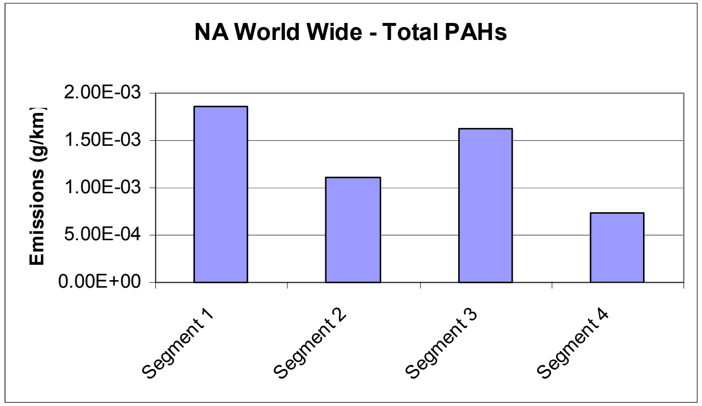


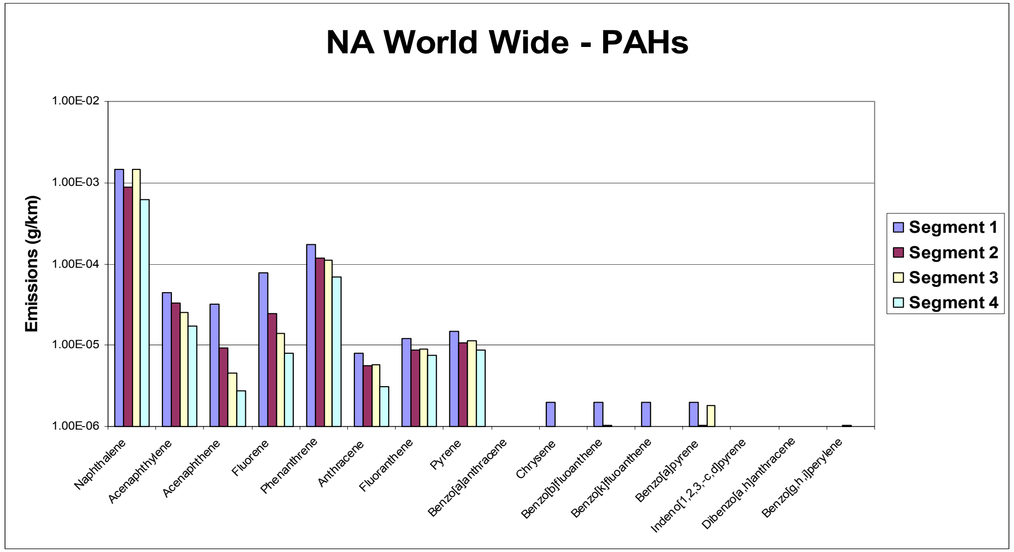


| **Euro 4** | **Emissions (g/km)** | | | |
|---|---|---|---|---|
| **Class NA** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 5.63E-03 | 3.65E-03 | 2.63E-03 | 2.87E-03 |
| Toluene | 1.86E-03 | 8.93E-04 | 8.21E-04 | 6.38E-04 |
| Xylenes | 1.42E-03 | 5.32E-04 | 5.44E-04 | 3.70E-04 |
| 1,3-butadiene | 1.20E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 1.26E-03 | 1.50E-03 | 1.67E-03 | 5.30E-04 |
| Acetaldehyde | 4.09E-03 | 1.73E-03 | 1.69E-03 | 9.83E-04 |
| | | | | |
| Naphthalene | 2.12E-03 | 5.62E-04 | 8.65E-04 | 5.29E-04 |
| Acenaphthylene | 3.12E-05 | 1.57E-05 | 2.27E-05 | 1.92E-05 |
| Acenaphthene | 1.34E-05 | 2.77E-06 | 4.98E-06 | 2.69E-06 |
| Fluorene | 2.00E-05 | 5.24E-06 | 8.89E-06 | 5.38E-06 |
| Phenanthrene | 8.80E-05 | 3.30E-05 | 6.50E-05 | 4.31E-05 |
| Anthracene | 3.34E-06 | 1.54E-06 | 2.84E-06 | 1.62E-06 |
| Fluoranthene | 1.78E-05 | 5.55E-06 | 9.95E-06 | 8.26E-06 |
| Pyrene | 2.12E-05 | 5.55E-06 | 9.95E-06 | 7.54E-06 |
| Benzo[a]anthracene | 1.11E-06 | 6.17E-07 | 3.55E-07 | 1.79E-07 |
| Chrysene | 4.46E-06 | 9.25E-07 | 1.07E-06 | 7.18E-07 |
| Benzo[b]fluoanthene | 8.91E-06 | 6.17E-07 | 1.07E-06 | 7.18E-07 |
| Benzo[k]fluoanthene | 4.46E-06 | 6.17E-07 | 7.11E-07 | 5.38E-07 |
| Benzo[a]pyrene | 7.80E-06 | 6.17E-07 | 1.78E-06 | 7.18E-07 |
| Indeno[1,2,3,-c,d]pyrene | 2.23E-06 | 3.08E-07 | | |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 5.57E-06 | 6.17E-07 | | |
| **Total PAH** | **2.35E-03** | **6.35E-04** | **9.95E-04** | **6.20E-04** |

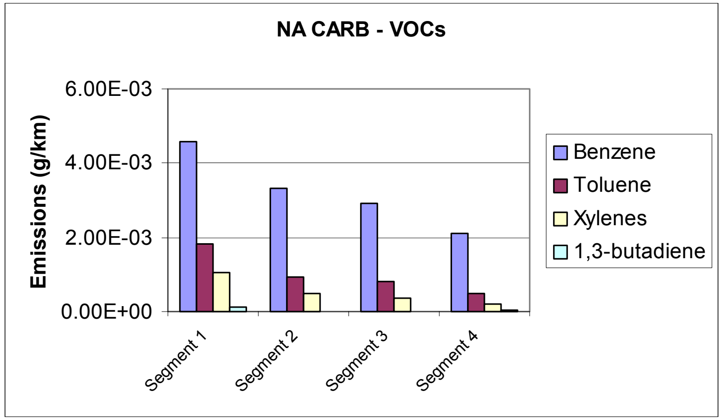


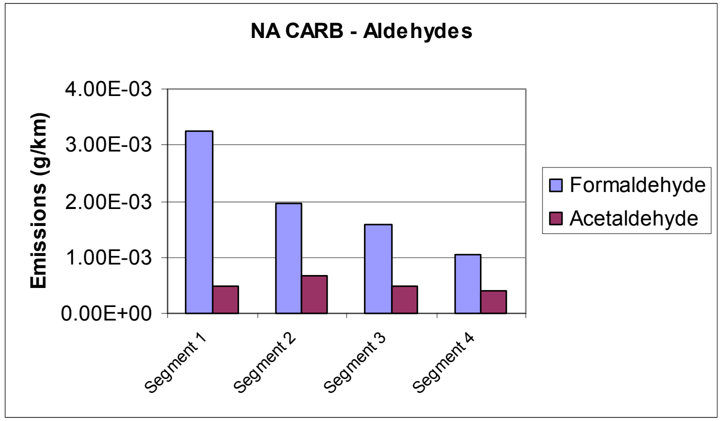


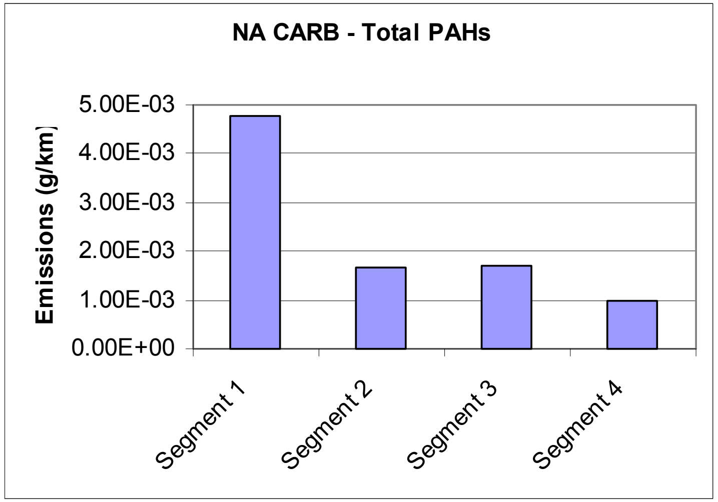


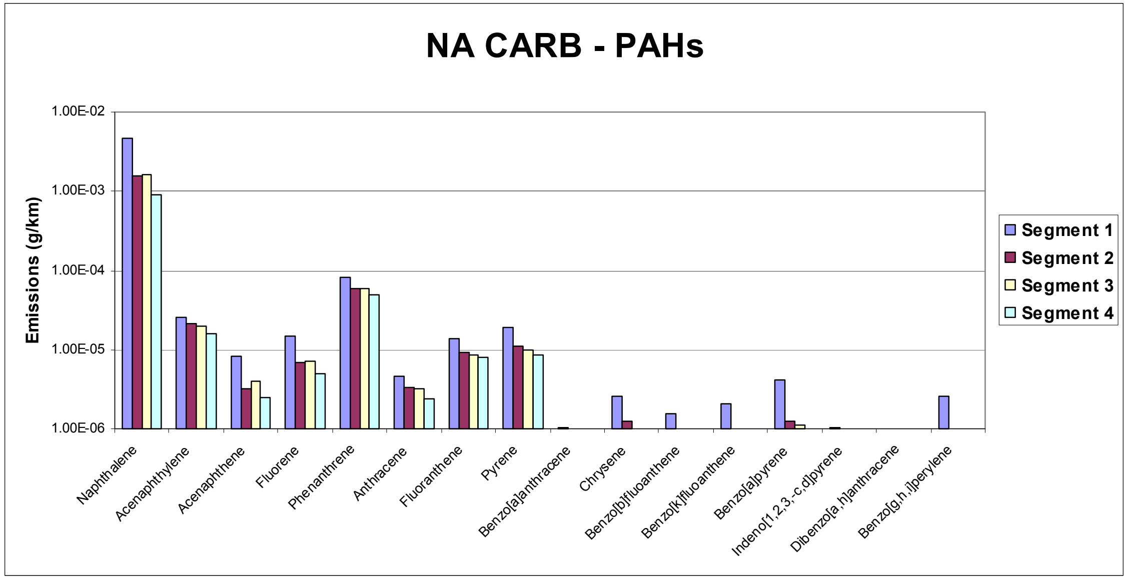


| World Wide | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Class NA** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 4.34E-03 | 4.61E-03 | 3.85E-03 | 2.68E-03 |
| Toluene | 2.42E-03 | 1.53E-03 | 1.48E-03 | 8.58E-04 |
| Xylenes | 2.22E-02 | 8.38E-03 | 9.61E-03 | 3.04E-03 |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 5.21E-03 | 3.06E-03 | 2.03E-03 | 1.58E-03 |
| Acetaldehyde | 3.25E-03 | 1.36E-03 | 9.45E-04 | 7.89E-04 |
| | | | | |
| Naphthalene | 1.48E-03 | 8.90E-04 | 1.44E-03 | 6.11E-04 |
| Acenaphthylene | 4.47E-05 | 3.33E-05 | 2.55E-05 | 1.71E-05 |
| Acenaphthene | 3.18E-05 | 9.22E-06 | 4.50E-06 | 2.78E-06 |
| Fluorene | 7.85E-05 | 2.43E-05 | 1.38E-05 | 7.84E-06 |
| Phenanthrene | 1.75E-04 | 1.17E-04 | 1.12E-04 | 6.89E-05 |
| Anthracene | 7.94E-06 | 5.64E-06 | 5.70E-06 | 3.10E-06 |
| Fluoranthene | 1.19E-05 | 8.71E-06 | 8.99E-06 | 7.51E-06 |
| Pyrene | 1.49E-05 | 1.08E-05 | 1.14E-05 | 8.66E-06 |
| Benzo[a]anthracene | 9.93E-07 | 5.12E-07 | 3.00E-07 | 3.27E-07 |
| Chrysene | 1.99E-06 | 7.68E-07 | 5.99E-07 | 6.53E-07 |
| Benzo[b]fluoanthene | 1.99E-06 | 1.02E-06 | 5.99E-07 | 3.27E-07 |
| Benzo[k]fluoanthene | 1.99E-06 | 7.68E-07 | 5.99E-07 | 3.27E-07 |
| Benzo[a]pyrene | 1.99E-06 | 1.02E-06 | 1.80E-06 | 3.27E-07 |
| Indeno[1,2,3,-c,d]pyrene | 9.93E-07 | 5.12E-07 | 3.00E-07 | 1.63E-07 |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 9.93E-07 | 1.02E-06 | 5.99E-07 | 3.27E-07 |
| **Total PAH** | **1.85E-03** | **1.10E-03** | **1.63E-03** | **7.29E-04** |

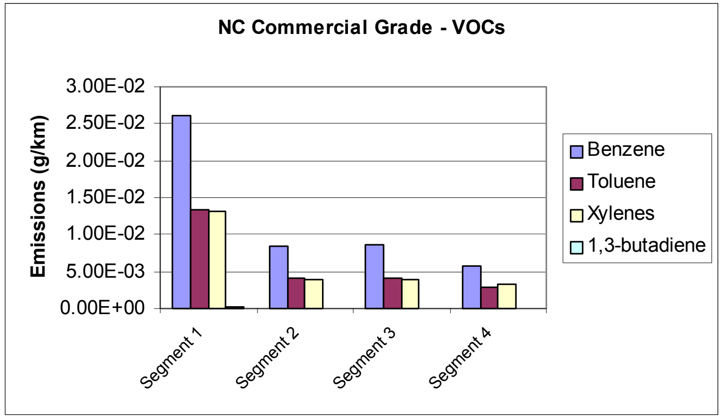


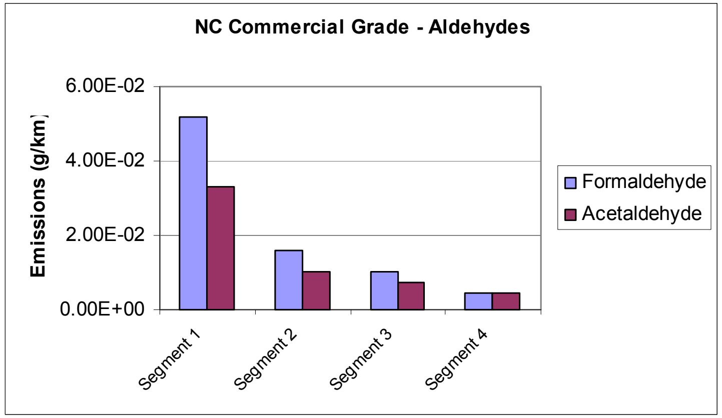


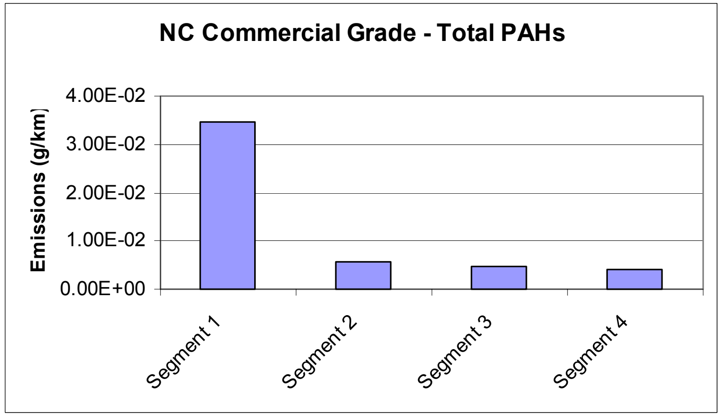


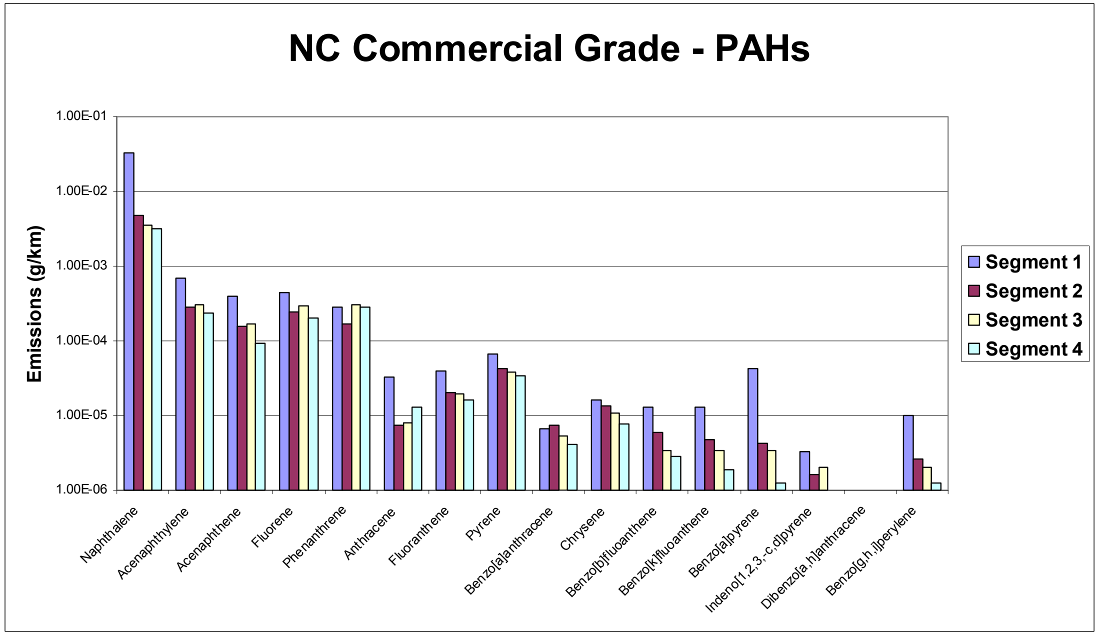


| **CARB** | **Emissions (g/km)** | | | |
|---|---|---|---|---|
| **Class NA** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 4.59E-03 | 3.34E-03 | 2.92E-03 | 2.11E-03 |
| Toluene | 1.83E-03 | 9.24E-04 | 8.05E-04 | 4.77E-04 |
| Xylenes | 1.05E-03 | 4.85E-04 | 3.60E-04 | 2.22E-04 |
| 1,3-butadiene | 1.09E-04 | 1.05E-05 | 7.37E-06 | 3.20E-05 |
| | | | | |
| Formaldehyde | 3.25E-03 | 1.97E-03 | 1.58E-03 | 1.04E-03 |
| Acetaldehyde | 4.92E-04 | 6.82E-04 | 4.77E-04 | 4.11E-04 |
| | | | | |
| Naphthalene | 4.60E-03 | 1.54E-03 | 1.60E-03 | 8.89E-04 |
| Acenaphthylene | 2.52E-05 | 2.11E-05 | 1.97E-05 | 1.58E-05 |
| Acenaphthene | 8.28E-06 | 3.22E-06 | 3.94E-06 | 2.50E-06 |
| Fluorene | 1.50E-05 | 6.86E-06 | 7.24E-06 | 4.90E-06 |
| Phenanthrene | 8.15E-05 | 5.84E-05 | 5.91E-05 | 4.85E-05 |
| Anthracene | 4.65E-06 | 3.36E-06 | 3.15E-06 | 2.42E-06 |
| Fluoranthene | 1.39E-05 | 9.10E-06 | 8.49E-06 | 7.93E-06 |
| Pyrene | 1.91E-05 | 1.09E-05 | 1.01E-05 | 8.50E-06 |
| Benzo[a]anthracene | 1.03E-06 | 7.01E-07 | 4.74E-07 | 3.15E-07 |
| Chrysene | 2.58E-06 | 1.26E-06 | 9.47E-07 | 5.62E-07 |
| Benzo[b]fluoanthene | 1.54E-06 | 8.43E-07 | 4.80E-07 | |
| Benzo[k]fluoanthene | 2.07E-06 | 8.43E-07 | 4.80E-07 | |
| Benzo[a]pyrene | 4.14E-06 | 1.27E-06 | 1.10E-06 | 6.40E-07 |
| Indeno[1,2,3,-c,d]pyrene | 1.03E-06 | 4.22E-07 | 1.60E-07 | |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 2.60E-06 | 8.43E-07 | 6.34E-07 | 1.60E-07 |
| **Total PAH** | **4.79E-03** | **1.65E-03** | **1.72E-03** | **9.81E-04** |

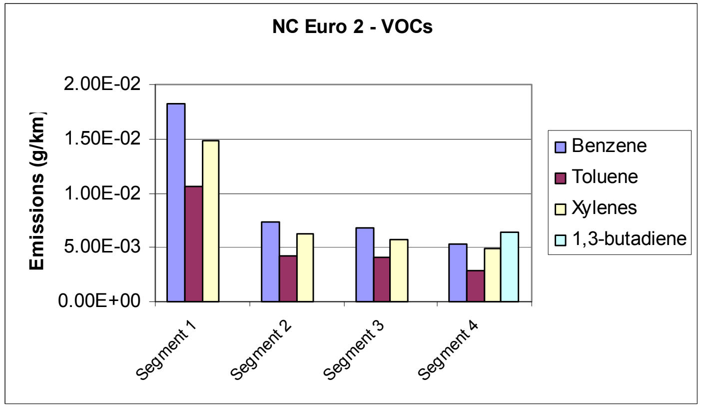


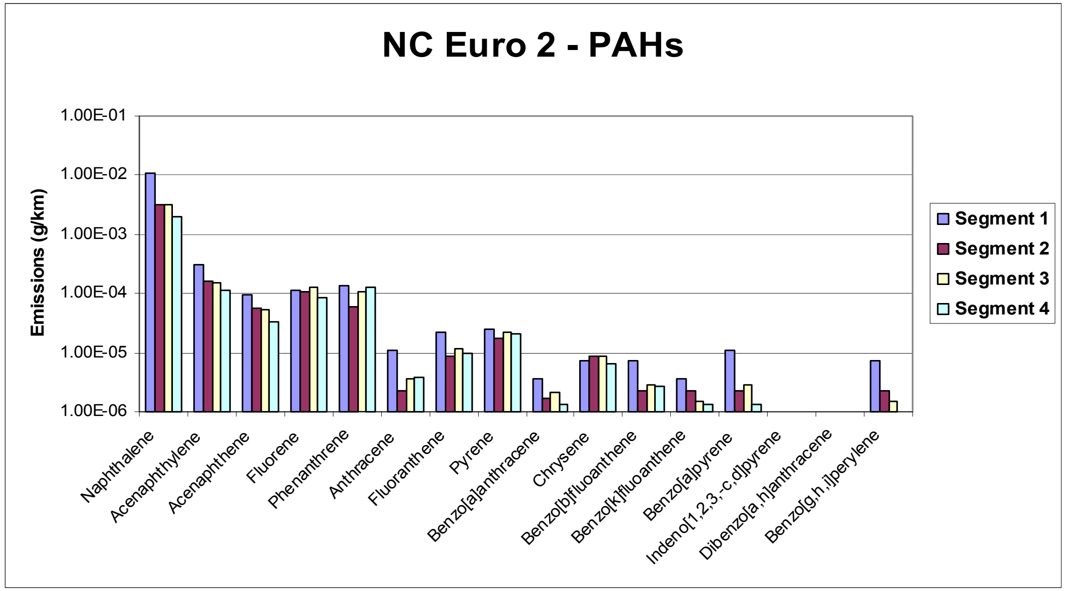


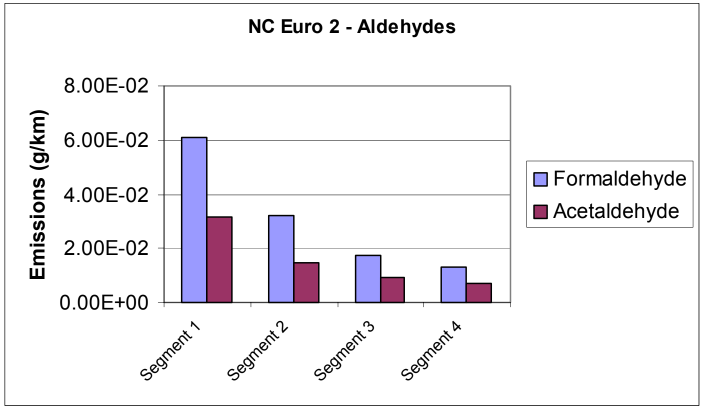


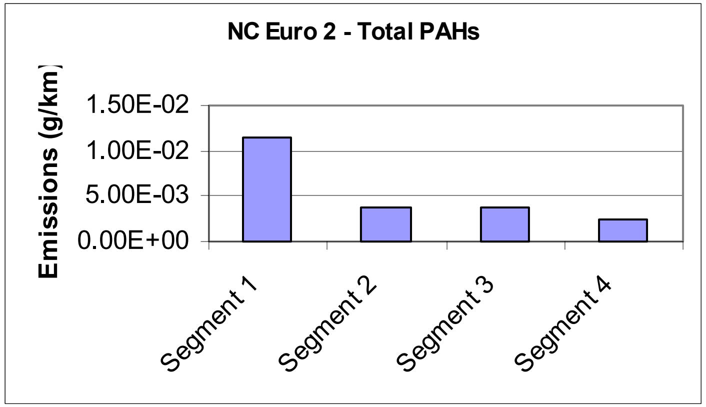


| Commercial Grade | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Class NC** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.60E-02 | 8.47E-03 | 8.60E-03 | 5.77E-03 |
| Toluene | 1.33E-02 | 4.10E-03 | 4.07E-03 | 2.78E-03 |
| Xylenes | 1.32E-02 | 3.82E-03 | 3.99E-03 | 3.23E-03 |
| 1,3-butadiene | 2.95E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 5.17E-02 | 1.58E-02 | 1.01E-02 | 4.69E-03 |
| Acetaldehyde | 3.32E-02 | 1.02E-02 | 7.32E-03 | 4.44E-03 |
| | | | | |
| Naphthalene | 3.27E-02 | 4.79E-03 | 3.59E-03 | 3.17E-03 |
| Acenaphthylene | 6.82E-04 | 2.78E-04 | 3.05E-04 | 2.39E-04 |
| Acenaphthene | 3.90E-04 | 1.54E-04 | 1.66E-04 | 9.34E-05 |
| Fluorene | 4.46E-04 | 2.47E-04 | 2.94E-04 | 2.00E-04 |
| Phenanthrene | 2.85E-04 | 1.67E-04 | 3.08E-04 | 2.84E-04 |
| Anthracene | 3.28E-05 | 7.46E-06 | 8.07E-06 | 1.29E-05 |
| Fluoranthene | 3.93E-05 | 2.02E-05 | 1.95E-05 | 1.60E-05 |
| Pyrene | 6.56E-05 | 4.31E-05 | 3.77E-05 | 3.45E-05 |
| Benzo[a]anthracene | 6.56E-06 | 7.46E-06 | 5.38E-06 | 4.08E-06 |
| Chrysene | 1.64E-05 | 1.33E-05 | 1.08E-05 | 7.84E-06 |
| Benzo[b]fluoanthene | 1.31E-05 | 5.86E-06 | 3.36E-06 | 2.82E-06 |
| Benzo[k]fluoanthene | 1.31E-05 | 4.79E-06 | 3.36E-06 | 1.88E-06 |
| Benzo[a]pyrene | 4.26E-05 | 4.26E-06 | 3.36E-06 | 1.25E-06 |
| Indeno[1,2,3,-c,d]pyrene | 3.28E-06 | 1.60E-06 | 2.02E-06 | 6.27E-07 |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 9.84E-06 | 2.66E-06 | 2.02E-06 | 1.25E-06 |
| **Total PAH** | **3.47E-02** | **5.75E-03** | **4.76E-03** | **4.07E-03** |

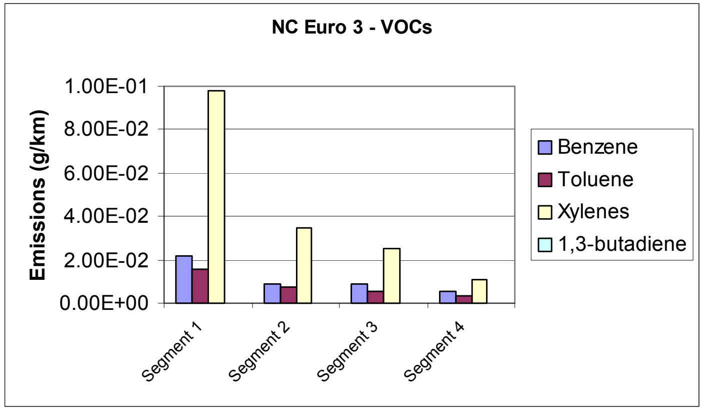

NC Euro 2 - VOCs

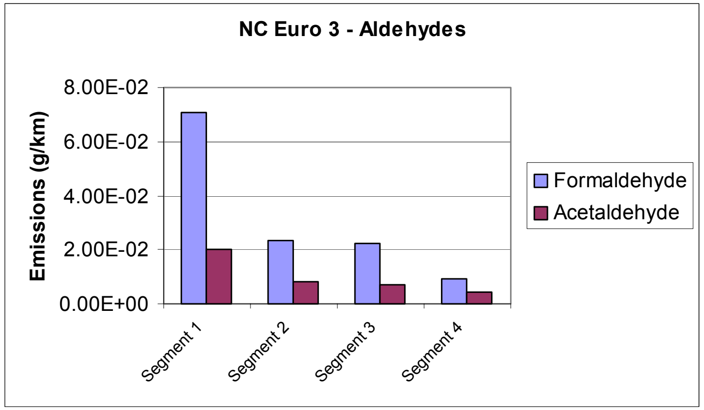

NC Euro 2 - PAHs

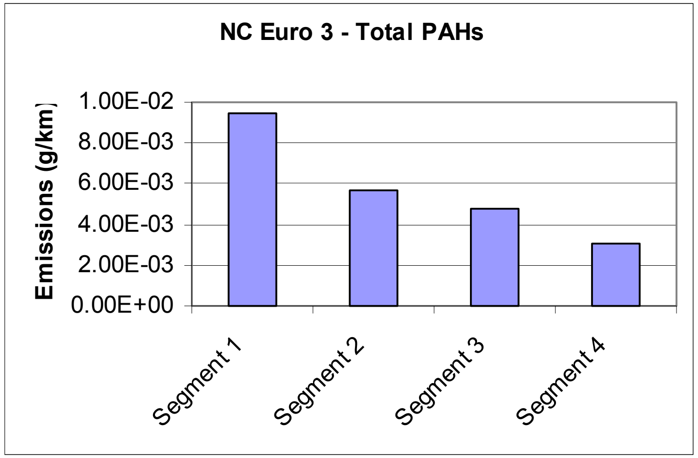

NC Euro 2 - Aldehydes

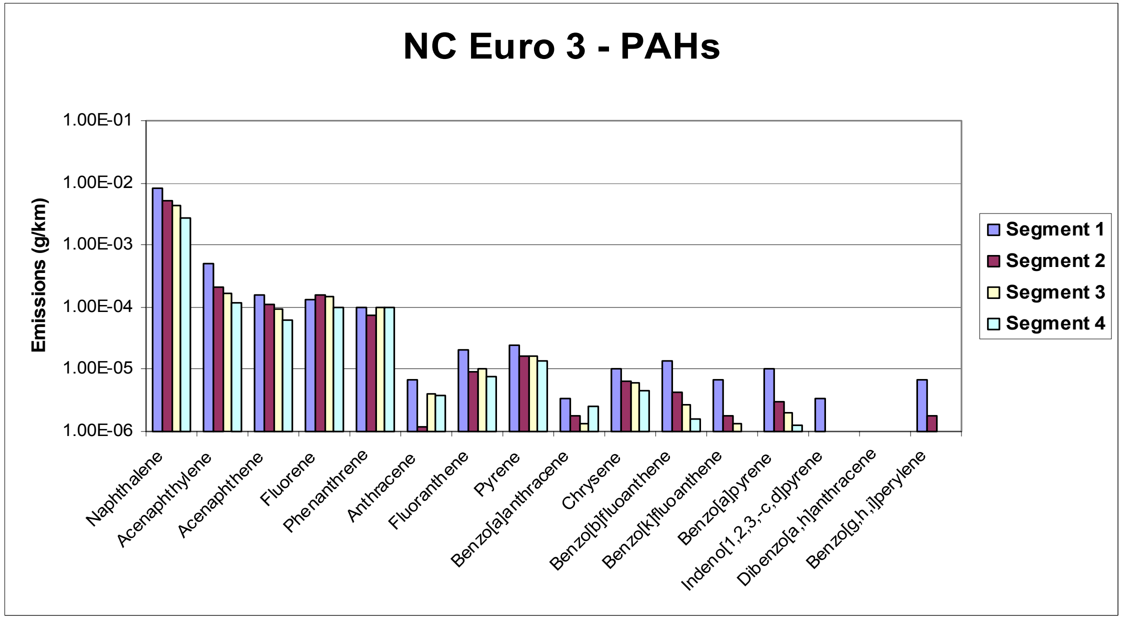

NC Euro 2 - Total PAHs

| Euro 2 | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Class NC** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 1.82E-02 | 7.31E-03 | 6.85E-03 | 5.37E-03 |
| Toluene | 1.06E-02 | 4.24E-03 | 4.02E-03 | 2.85E-03 |
| Xylenes | 1.48E-02 | 6.30E-03 | 5.72E-03 | 4.83E-03 |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.33E-03 |
| | | | | |
| Formaldehyde | 6.09E-02 | 3.19E-02 | 1.74E-02 | 1.31E-02 |
| Acetaldehyde | 3.16E-02 | 1.49E-02 | 9.22E-03 | 6.93E-03 |
| | | | | |
| Naphthalene | 1.07E-02 | 3.24E-03 | 3.18E-03 | 1.97E-03 |
| Acenaphthylene | 3.14E-04 | 1.62E-04 | 1.48E-04 | 1.11E-04 |
| Acenaphthene | 9.39E-05 | 5.68E-05 | 5.43E-05 | 3.40E-05 |
| Fluorene | 1.12E-04 | 1.06E-04 | 1.25E-04 | 8.46E-05 |
| Phenanthrene | 1.37E-04 | 5.96E-05 | 1.06E-04 | 1.28E-04 |
| Anthracene | 1.08E-05 | 2.27E-06 | 3.67E-06 | 3.78E-06 |
| Fluoranthene | 2.17E-05 | 8.51E-06 | 1.17E-05 | 9.63E-06 |
| Pyrene | 2.53E-05 | 1.70E-05 | 2.27E-05 | 2.03E-05 |
| Benzo[a]anthracene | 3.61E-06 | 1.70E-06 | 2.20E-06 | 1.38E-06 |
| Chrysene | 7.22E-06 | 8.51E-06 | 8.80E-06 | 6.53E-06 |
| Benzo[b]fluoanthene | 7.22E-06 | 2.27E-06 | 2.93E-06 | 2.75E-06 |
| Benzo[k]fluoanthene | 3.61E-06 | 2.27E-06 | 1.47E-06 | 1.38E-06 |
| Benzo[a]pyrene | 1.08E-05 | 2.27E-06 | 2.93E-06 | 1.38E-06 |
| Indeno[1,2,3,-c,d]pyrene | | 5.68E-07 | 7.34E-07 | 3.44E-07 |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 7.22E-06 | 2.27E-06 | 1.47E-06 | 6.88E-07 |
| **Total PAH** | **1.15E-02** | **3.67E-03** | **3.67E-03** | **2.38E-03** |

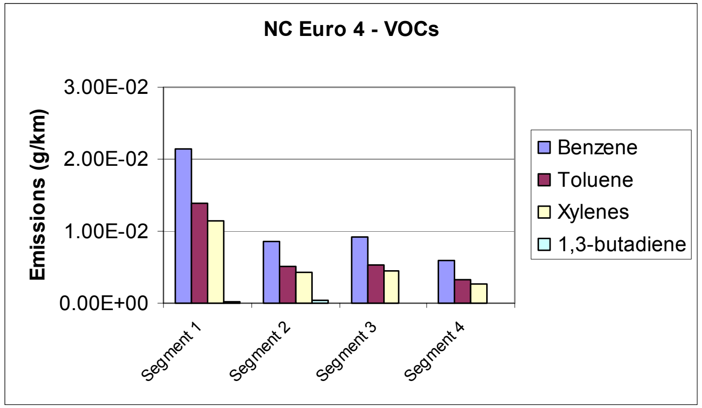


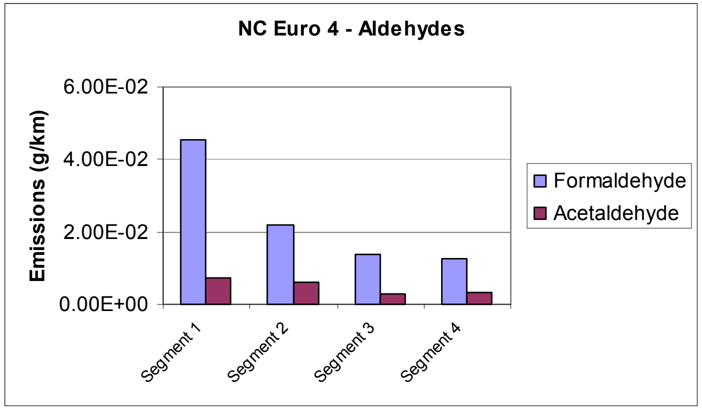


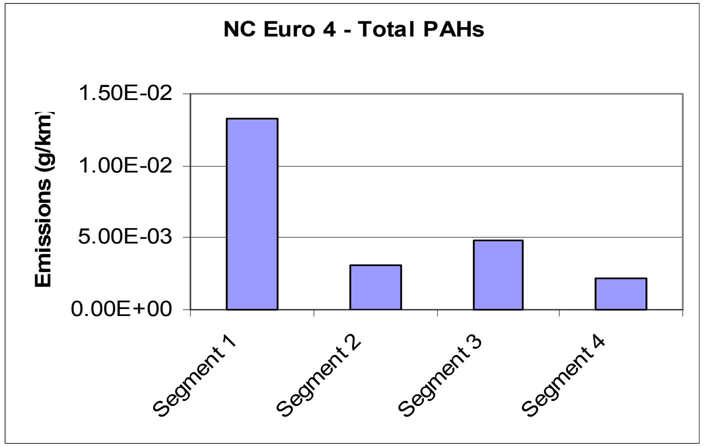


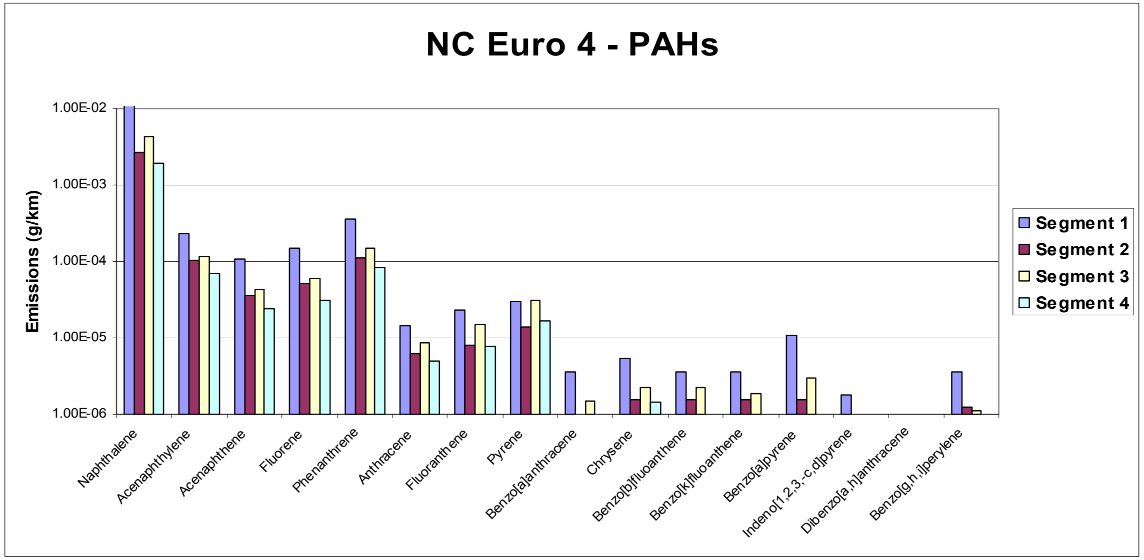


| Euro 3 | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Class NC** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.19E-02 | 8.94E-03 | 8.67E-03 | 5.26E-03 |
| Toluene | 1.59E-02 | 7.31E-03 | 5.73E-03 | 3.32E-03 |
| Xylenes | 9.76E-02 | 3.48E-02 | 2.50E-02 | 1.08E-02 |
| 1,3-butadiene | 3.04E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 7.05E-02 | 2.32E-02 | 2.22E-02 | 9.22E-03 |
| Acetaldehyde | 2.02E-02 | 8.12E-03 | 7.27E-03 | 4.16E-03 |
| | | | | |
| Naphthalene | 8.43E-03 | 5.13E-03 | 4.24E-03 | 2.66E-03 |
| Acenaphthylene | 4.91E-04 | 2.08E-04 | 1.70E-04 | 1.19E-04 |
| Acenaphthene | 1.60E-04 | 1.10E-04 | 9.55E-05 | 6.29E-05 |
| Fluorene | 1.33E-04 | 1.59E-04 | 1.50E-04 | 9.83E-05 |
| Phenanthrene | 9.89E-05 | 7.18E-05 | 1.01E-04 | 9.95E-05 |
| Anthracene | 6.82E-06 | 1.20E-06 | 4.09E-06 | 3.83E-06 |
| Fluoranthene | 2.05E-05 | 8.98E-06 | 1.02E-05 | 7.66E-06 |
| Pyrene | 2.39E-05 | 1.68E-05 | 1.64E-05 | 1.34E-05 |
| Benzo[a]anthracene | 3.41E-06 | 1.80E-06 | 1.36E-06 | 2.55E-06 |
| Chrysene | 1.02E-05 | 6.58E-06 | 6.14E-06 | 4.47E-06 |
| Benzo[b]fluoanthene | 1.36E-05 | 4.19E-06 | 2.73E-06 | 1.60E-06 |
| Benzo[k]fluoanthene | 6.82E-06 | 1.80E-06 | 1.36E-06 | 9.57E-07 |
| Benzo[a]pyrene | 1.02E-05 | 2.99E-06 | 2.05E-06 | 1.28E-06 |
| Indeno[1,2,3,-c,d]pyrene | 3.41E-06 | 5.98E-07 | 6.82E-07 | 3.19E-07 |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 6.82E-06 | 1.80E-06 | 6.82E-07 | 3.19E-07 |
| **Total PAH** | **9.42E-03** | **5.72E-03** | **4.80E-03** | **3.07E-03** |

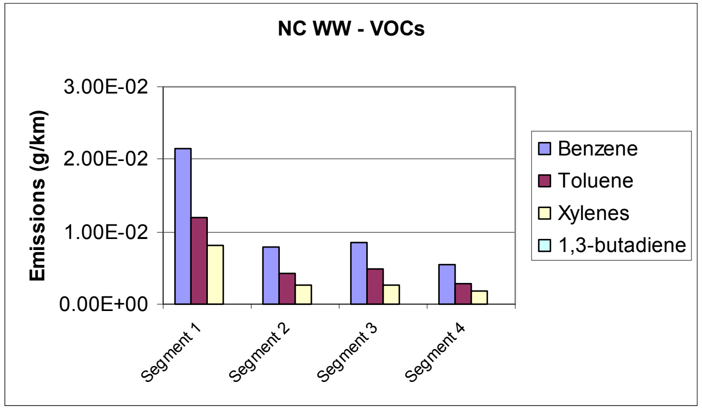


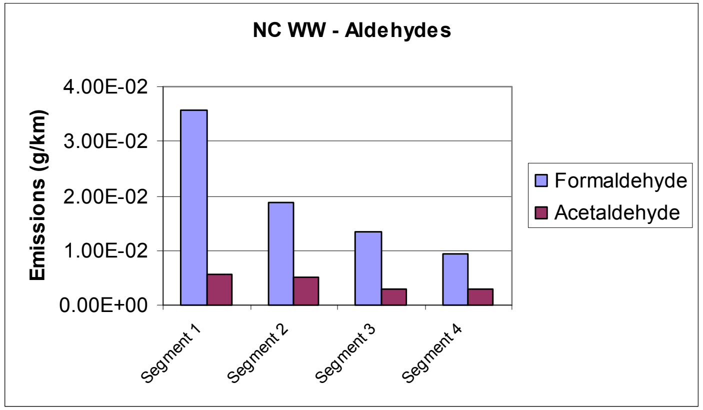


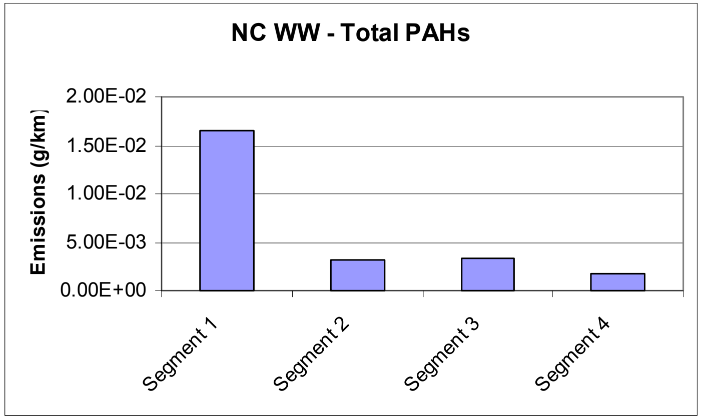


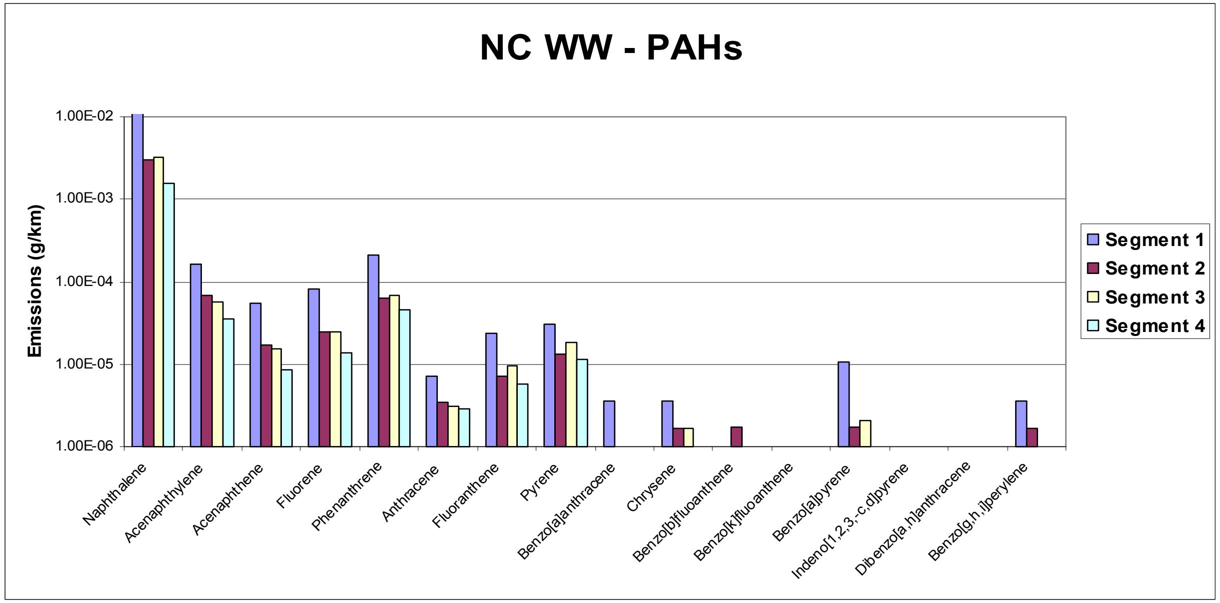


| **Euro 4** | **Emissions (g/km)** | | | |
|---|---|---|---|---|
| **Class NC** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.14E-02 | 8.49E-03 | 9.21E-03 | 5.95E-03 |
| Toluene | 1.39E-02 | 5.06E-03 | 5.24E-03 | 3.26E-03 |
| Xylenes | 1.14E-02 | 4.25E-03 | 4.39E-03 | 2.58E-03 |
| 1,3-butadiene | 1.93E-04 | 4.15E-04 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 4.53E-02 | 2.21E-02 | 1.38E-02 | 1.24E-02 |
| Acetaldehyde | 7.41E-03 | 6.18E-03 | 2.66E-03 | 3.41E-03 |
| | | | | |
| Naphthalene | 1.23E-02 | 2.72E-03 | 4.39E-03 | 1.94E-03 |
| Acenaphthylene | 2.33E-04 | 1.03E-04 | 1.14E-04 | 6.84E-05 |
| Acenaphthene | 1.07E-04 | 3.57E-05 | 4.37E-05 | 2.41E-05 |
| Fluorene | 1.51E-04 | 5.16E-05 | 5.98E-05 | 3.08E-05 |
| Phenanthrene | 3.58E-04 | 1.10E-04 | 1.47E-04 | 8.29E-05 |
| Anthracene | 1.43E-05 | 6.29E-06 | 8.59E-06 | 5.07E-06 |
| Fluoranthene | 2.33E-05 | 8.12E-06 | 1.49E-05 | 7.79E-06 |
| Pyrene | 3.05E-05 | 1.38E-05 | 3.06E-05 | 1.69E-05 |
| Benzo[a]anthracene | 3.59E-06 | 6.24E-07 | 1.49E-06 | 5.41E-07 |
| Chrysene | 5.37E-06 | 1.57E-06 | 2.24E-06 | 1.45E-06 |
| Benzo[b]fluoanthene | 3.59E-06 | 1.57E-06 | 2.24E-06 | 9.13E-07 |
| Benzo[k]fluoanthene | 3.59E-06 | 1.57E-06 | 1.87E-06 | 7.27E-07 |
| Benzo[a]pyrene | 1.07E-05 | 1.57E-06 | 2.99E-06 | 9.04E-07 |
| Indeno[1,2,3,-c,d]pyrene | 1.81E-06 | | | |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 3.59E-06 | 1.25E-06 | 1.12E-06 | 3.63E-07 |
| **Total PAH** | **1.33E-02** | **3.06E-03** | **4.82E-03** | **2.18E-03** |

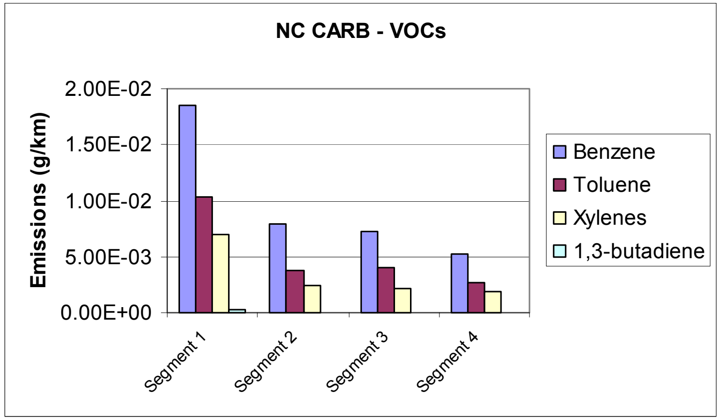


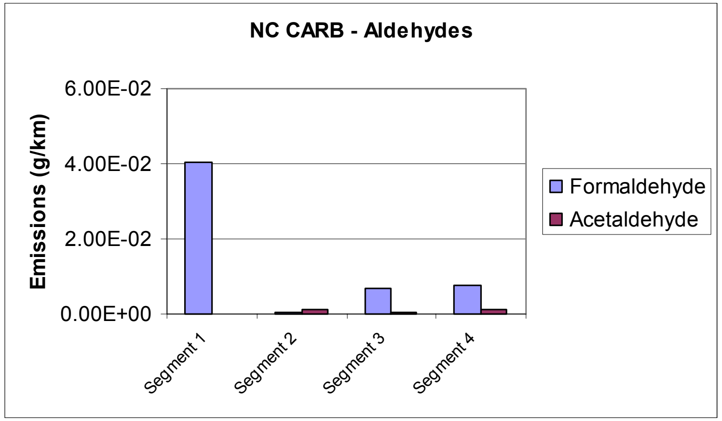


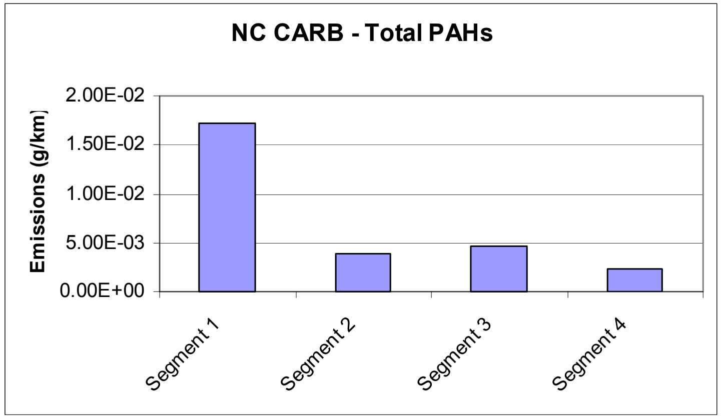


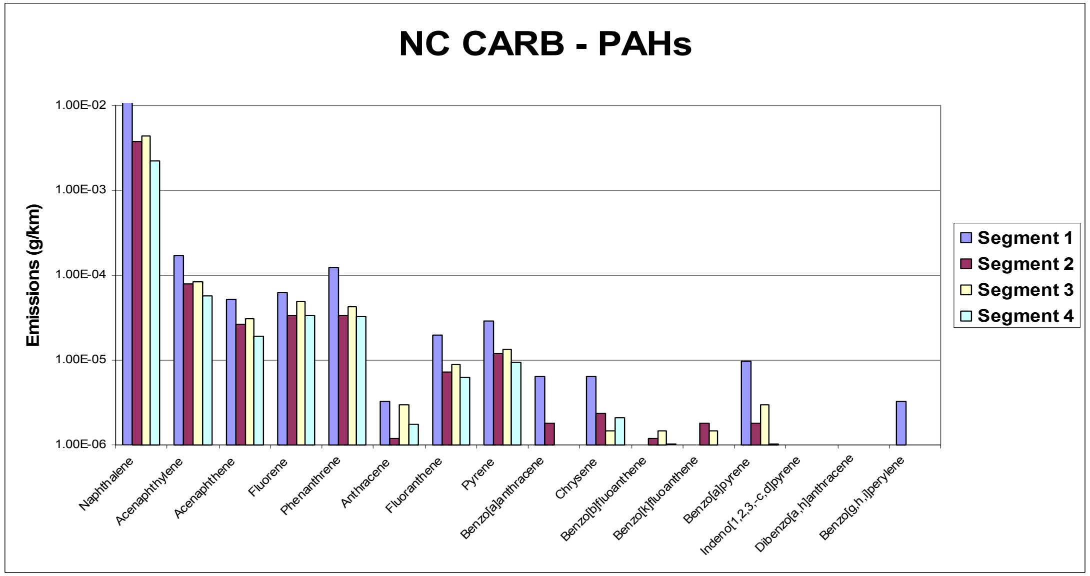


| **World Wide** | **Emissions (g/km)** | | | |
|---|---|---|---|---|
| **Class NC** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 2.16E-02 | 7.90E-03 | 8.43E-03 | 5.44E-03 |
| Toluene | 1.19E-02 | 4.29E-03 | 4.82E-03 | 2.79E-03 |
| Xylenes | 8.20E-03 | 2.65E-03 | 2.72E-03 | 1.74E-03 |
| 1,3-butadiene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| | | | | |
| Formaldehyde | 3.58E-02 | 1.87E-02 | 1.34E-02 | 9.50E-03 |
| Acetaldehyde | 5.63E-03 | 5.09E-03 | 3.01E-03 | 3.06E-03 |
| | | | | |
| Naphthalene | 1.58E-02 | 2.98E-03 | 3.20E-03 | 1.59E-03 |
| Acenaphthylene | 1.64E-04 | 6.84E-05 | 5.73E-05 | 3.48E-05 |
| Acenaphthene | 5.41E-05 | 1.70E-05 | 1.56E-05 | 8.43E-06 |
| Fluorene | 8.12E-05 | 2.50E-05 | 2.44E-05 | 1.36E-05 |
| Phenanthrene | 2.13E-04 | 6.34E-05 | 6.91E-05 | 4.58E-05 |
| Anthracene | 7.21E-06 | 3.42E-06 | 3.05E-06 | 2.90E-06 |
| Fluoranthene | 2.34E-05 | 7.08E-06 | 9.48E-06 | 5.83E-06 |
| Pyrene | 3.06E-05 | 1.33E-05 | 1.83E-05 | 1.14E-05 |
| Benzo[a]anthracene | 3.61E-06 | 8.42E-07 | 1.02E-06 | 6.14E-07 |
| Chrysene | 3.61E-06 | 1.68E-06 | 1.69E-06 | 9.20E-07 |
| Benzo[b]fluoanthene | 0.00E+00 | 1.72E-06 | 0.00E+00 | 6.14E-07 |
| Benzo[k]fluoanthene | 0.00E+00 | 8.42E-07 | 0.00E+00 | 6.14E-07 |
| Benzo[a]pyrene | 1.08E-05 | 1.70E-06 | 2.04E-06 | 9.20E-07 |
| Indeno[1,2,3,-c,d]pyrene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Dibenzo[a,h]anthracene | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Benzo[g,h,i]perylene | 3.61E-06 | 1.67E-06 | 0.00E+00 | 1.51E-07 |
| **Total PAH** | **1.64E-02** | **3.18E-03** | **3.40E-03** | **1.72E-03** |





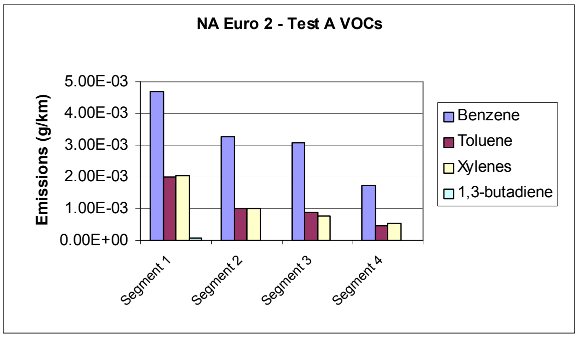


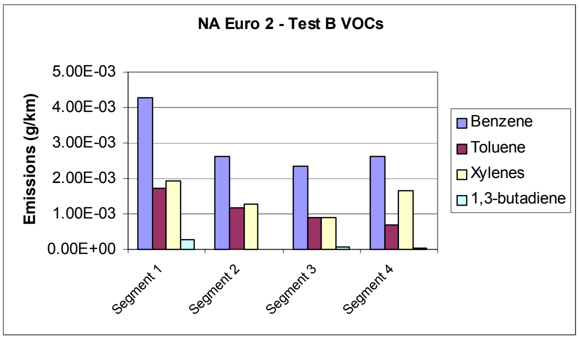


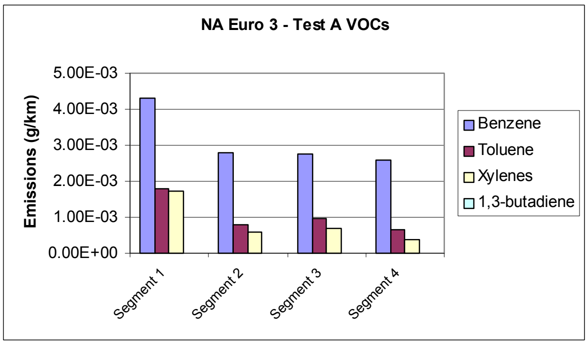
| CARB | Emissions (g/km) | | | |
|---|---|---|---|---|
| **Class NC** | **Segment 1** | **Segment 2** | **Segment 3** | **Segment 4** |
| Benzene | 1.85E-02 | 7.85E-03 | 7.20E-03 | 5.17E-03 |
| Toluene | 1.04E-02 | 3.75E-03 | 3.98E-03 | 2.73E-03 |
| Xylenes | 7.00E-03 | 2.45E-03 | 2.15E-03 | 1.92E-03 |
| 1,3-butadiene | 2.44E-04 | 0.00E+00 | 0.00E+00 | 2.55E-05 |
| | | | | |
| Formaldehyde | 4.03E-02 | 2.15E-04 | 6.71E-03 | 7.79E-03 |
| Acetaldehyde | 0.00E+00 | 1.24E-03 | 4.75E-04 | 1.39E-03 |
| | | | | |
| Naphthalene | 1.67E-02 | 3.72E-03 | 4.34E-03 | 2.23E-03 |
| Acenaphthylene | 1.69E-04 | 7.81E-05 | 8.41E-05 | 5.64E-05 |
| Acenaphthene | 5.20E-05 | 2.68E-05 | 3.05E-05 | 1.94E-05 |
| Fluorene | 6.17E-05 | 3.34E-05 | 4.91E-05 | 3.35E-05 |
| Phenanthrene | 1.23E-04 | 3.40E-05 | 4.24E-05 | 3.25E-05 |
| Anthracene | 3.25E-06 | 1.19E-06 | 2.98E-06 | 1.73E-06 |
| Fluoranthene | 1.95E-05 | 7.15E-06 | 8.93E-06 | 6.22E-06 |
| Pyrene | 2.92E-05 | 1.19E-05 | 1.34E-05 | 9.34E-06 |
| Benzo[a]anthracene | 6.50E-06 | 1.79E-06 | 7.44E-07 | 6.92E-07 |
| Chrysene | 6.50E-06 | 2.38E-06 | 1.49E-06 | 2.07E-06 |
| Benzo[b]fluoanthene | | 1.19E-06 | 1.49E-06 | 1.04E-06 |
| Benzo[k]fluoanthene | | 1.79E-06 | 1.49E-06 | 6.92E-07 |
| Benzo[a]pyrene | 9.74E-06 | 1.79E-06 | 2.98E-06 | 1.04E-06 |
| Indeno[1,2,3,-c,d]pyrene | | | | |
| Dibenzo[a,h]anthracene | | | | |
| Benzo[g,h,i]perylene | 3.25E-06 | 5.96E-07 | 7.44E-07 | 3.46E-07 |
| **Total PAH** | **1.72E-02** | **3.92E-03** | **4.58E-03** | **2.40E-03** |

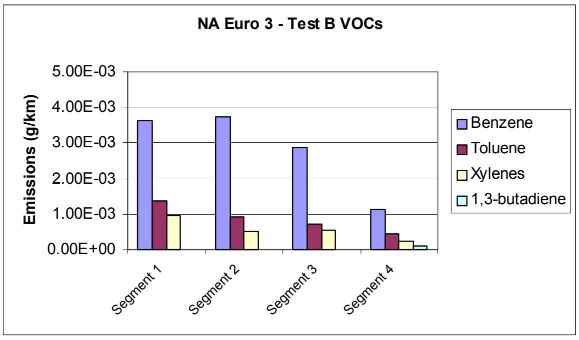
# REPEATABILITY TESTS

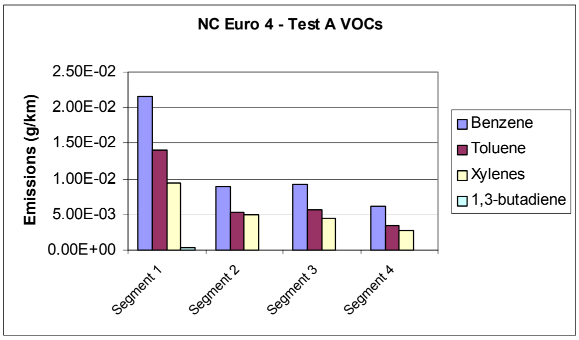
## VOC Duplicates

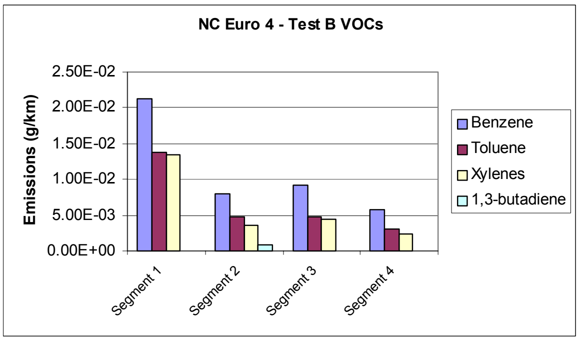


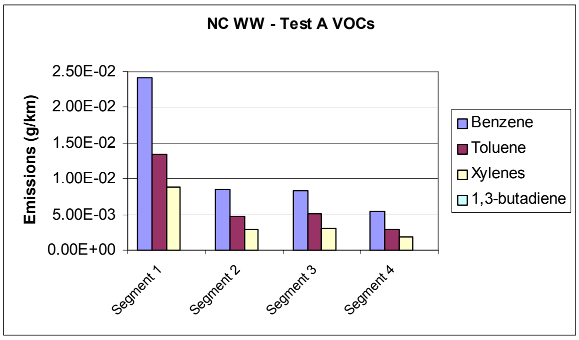


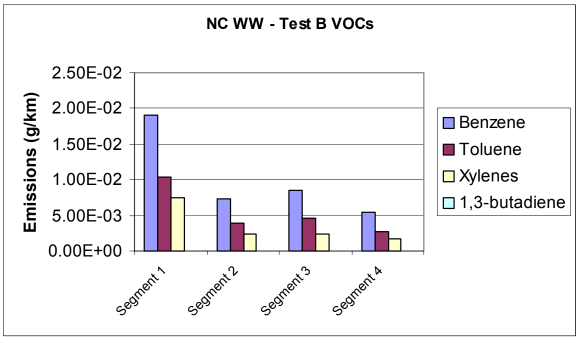


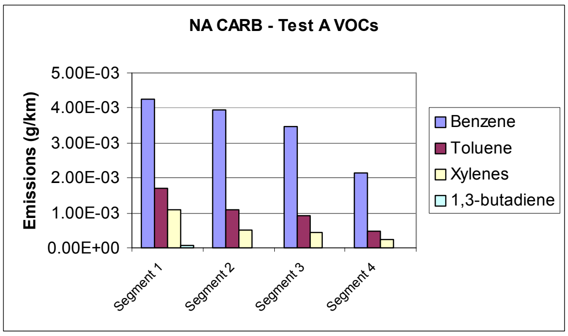


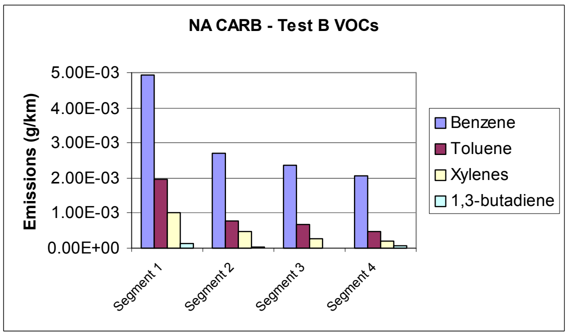




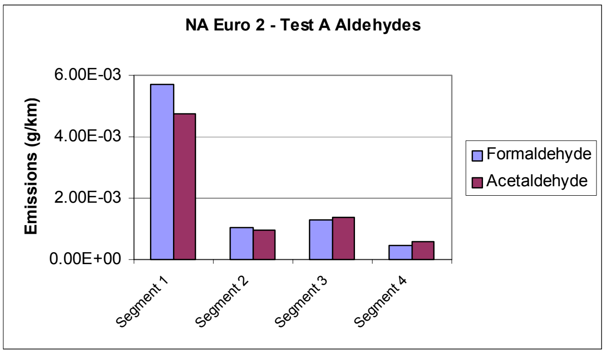


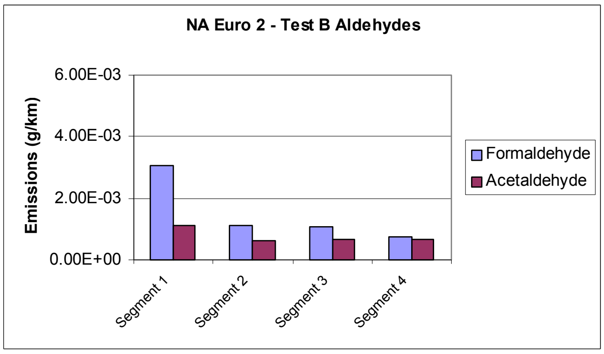


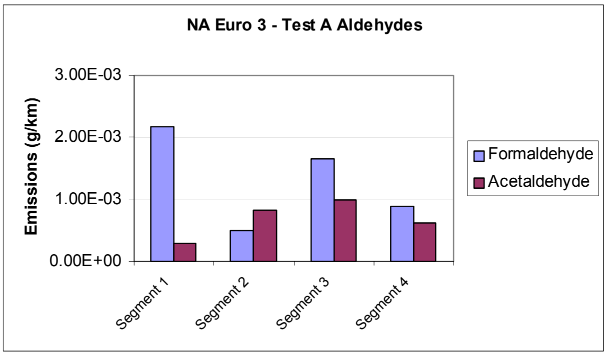


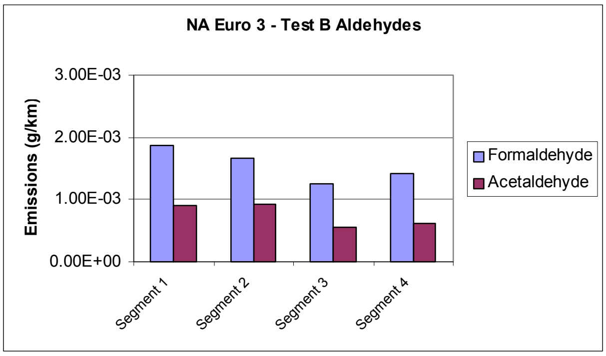


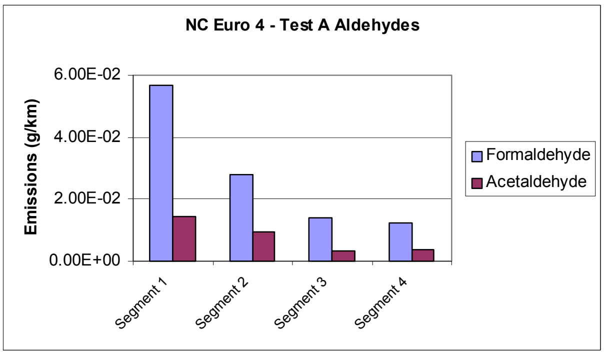
# Aldehyde Duplicates


NA Euro 2 - Test A Aldehydes


NA Euro 2 - Test B Aldehydes


NA Euro 3 - Test A Aldehydes


NA Euro 3 - Test B Aldehydes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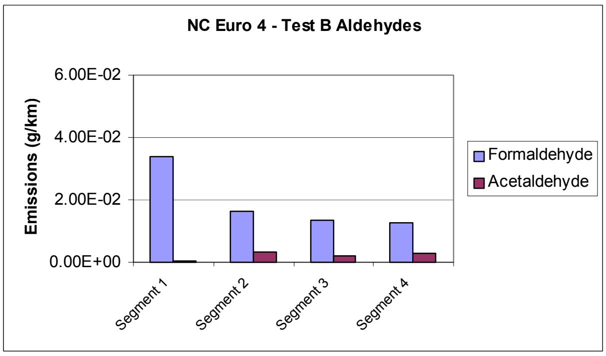
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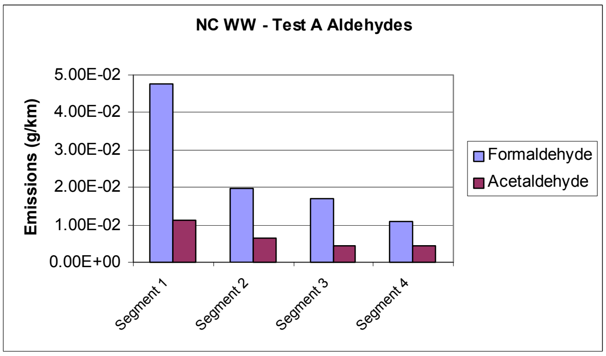
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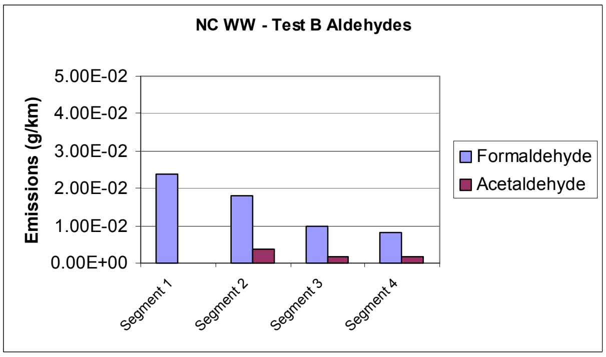
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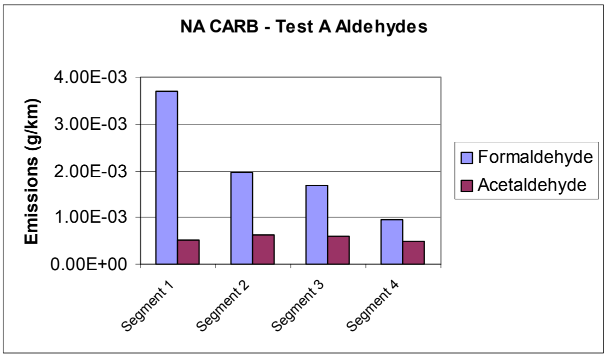
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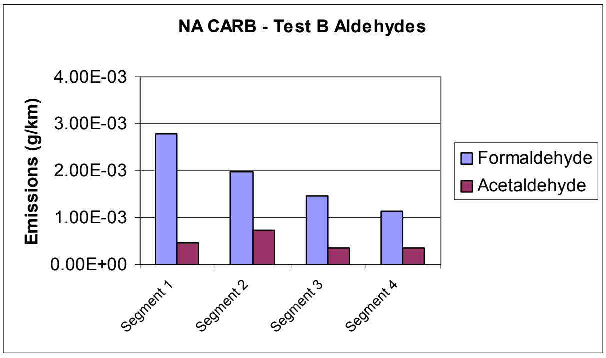
NA CARB - Test B Aldehydes

# PAH Duplicates