MZ. Ristovski
Queensland University of Technology
Brisbane
Australia

Nanoparticle emissions from petrol to CNG and LPG converted spark ignition engines

EMISSIONS FROM A VEHICLE FITTED TO OPERATE ON EITHER PETROL OR COMPRESSED NATURAL GAS

Z.D. RISTOVSKI, R. JAYARATNE, G.AYOKO, M. LIM AND L.MORAWSKA

Centre for Medical, Health and Environmental Physics, Queensland University of Technology, GPO Box 2434, Brisbane QLD, 4001, Australia.

There is not a lot of information available on particle emission levels from spark ignition (SI) engines and it is only recently that some information has been published about the effects of vehicle and fuel type on particle size from spark ignition engines[1,2,3,4]. SI vehicle particulate matter is emitted at levels lower than a milligram per kilometer and because it is emitted at such low levels, it is difficult to measure it accurately. Total particle mass emissions from SI vehicles are significantly lower than diesel emissions, and are usually well below any emission standards[4,5,6]. It has been noted however, that while particle emissions from individual SI vehicles are lower than individual emissions from diesel vehicles, the total contribution of both types of vehicles to air emissions could be similar, due to the exceedingly higher number of spark ignition vehicles than diesel fuelled vehicles. The low mass concentration of emissions from spark ignition engines is related to a lower number concentration in the emissions, and also to the fact that the emitted particles are smaller than particles from diesel emissions[7].

One measure that has been considered to reduce pollutant emissions from SI vehicles is conversion of existing SI engines that operate on unleaded petrol (ULP) to vehicles that can operate on either petrol or other alternative fuels such as compressed natural gas (CNG) or LPG. Only recently a dedicated LPG vehicle appeared on the Australian market, but no dedicated CNG vehicle is still available. Emissions from CNG/LPG operating vehicles are in general assessed to be lower than emissions from petrol operating vehicles and thus as a result of the conversion the expected emission levels should be lower.

The purposes of this work was to evaluate the physical and chemical properties of emission products from spark ignition engines operating on alternative fuels such as compressed natural gas (CNG) and liquefied petrol gas (LPG). For this purpose a serious of tests were conducted on a 6-cylinder SI engine before and after it has been converted to CNG, and a serious of test on a similar 6-cylinder SI engine, of the same type and manufacturer as the previous, but factory fitted such that it is dedicated to run exclusively on LPG.

The specific focus of the measurements was on emission levels and characteristics of ultra fine particles (nanoparticles), the emission levels of which together with the emissions of gaseous pollutants for a range of operating conditions before and up to three months after the vehicle was converted are presented and discussed in the paper.

The investigations showed that converting a ULP operating vehicle to CNG has the potential of reducing some of the emissions and thus risks, while it does not appear to have an impact on others. In particular there was no statistically significant change in the emission of nanoparticles for the vehicle operating on petrol, before the conversion, compared to the emissions for the vehicle operating on CNG, after the conversion. There was a significant lowering of emissions of total PAHs and formaldehyde when the vehicle was operated on CNG, and a reduction of global warming potential (GWP) was also observed when the vehicle was run on CNG, but the later gain is only at high vehicle speeds/loads, and would thus have to be considered in view of traffic and transport models for the region (in these models vehicle speed is an important parameter).

Similar results were obtained for the dedicated LPG vehicles. In this case six dedicated LPG vehicles and three ULP vehicles (same 6 cylinder, 4L, engine type) were tested. There was no statistically significant difference in the emission of nanoparticles in between the LPG and ULP vehicles over the range of tested modes. A relatively large variability was observed in between the LPG vehicles during the same mode/test. This variability was larger than the difference between the ULP vehicles.

Similar emission levels of nanoparticles obtained for a same type of engine but with different fuels (ULP, CNG, and LPG) would indicate that the fuel type does not play a crucial role in the mechanism of particulate formation, as long as the engine is properly tuned. It is most probable that other factors such as vehicle management system and the consumption of lubricating oil could play major roles in the particulate formation mechanisms. Further if the fuel type does not have a significant influence on the particle emission then the majority of fuel is burned into carbon dioxide and water vapour thus the majority of the formed particles are either volatiles formed during the dilution process or solid ash particles from the combustion of lubricating oils.

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NANOPARTICLE EMISSIONS FROM A PETROL TO CNG CONVERTED AND LPG SPARK IGNITION VEHICLE

Z.D. RISTOVSKI, R. JAYARATNE, G.AYOKO, M. LIM AND L.MORAWSKA

Queensland University of Technology

5. ETH Conference on Nanoparticle -Measurement

Introduction

- Conversion of existing vehicles that operate on petrol to vehicles that can operate on either petrol or compressed natural gas (CNG) or LPG.
- Emissions from CNG/LPG operating vehicles are in general assessed to be lower than emissions from petrol operating?
- The costs associated with the conversion and also the expected gains in terms of reduction of the emissions of all the pollutants that pose environmental or health risks.

Introduction

- Particles from CNG engine emissions range from 0.01-0.7 μm, with majority being between 0.020 and 0.060 μm.
- Very little data is available on particle emissions from CNG/LPG fuelled vehicles.
- Greenwood *et al* (1996) particle concentration levels are similar to those from gasoline engines, and at high loads approach those of diesel engines.
- Ristovski *et al* (2000) - Emissions of CO and NO_x for one of the tested engines, were considerably lower than the maximum allowed by the standards.

Introduction

- The majority of the CNG fuelled vehicles on today's roads were not purposely built for this type of fuel.
- Most of these vehicles are converted spark ignition (SI) petrol driven vehicles with the possibility of driving with both types of fuels, CNG and petrol.
- After the conversion did their performance change?
- After conversion the vehicles could be operated either on petrol or on CNG, with potentially frequent changes of fuel.

The objective of this work

- ***Purpose:*** to evaluate the physical and chemical properties of emission products from a 6-cylinder ULP to CNG converted engine and a LPG dedicated spark ignition engine.
- ***Specific focus*** on emission levels and characteristics of ultra fine particles.
- Such information would assist the Queensland Government’s fleet manager (QFleet) in determining the likely environmental impacts that could arise through the inclusion of these vehicles in the Government's motor fleet .

Experimental Materials And Methods

- Particle Size Distribution Measurements
- Gas Emission Measurements
- Chemical Specifications of the emissions
  - Particle-bound organic compounds
  - Vapour-phase organic compounds
  - Aldehydes
  - Non-methane hydrocarbons

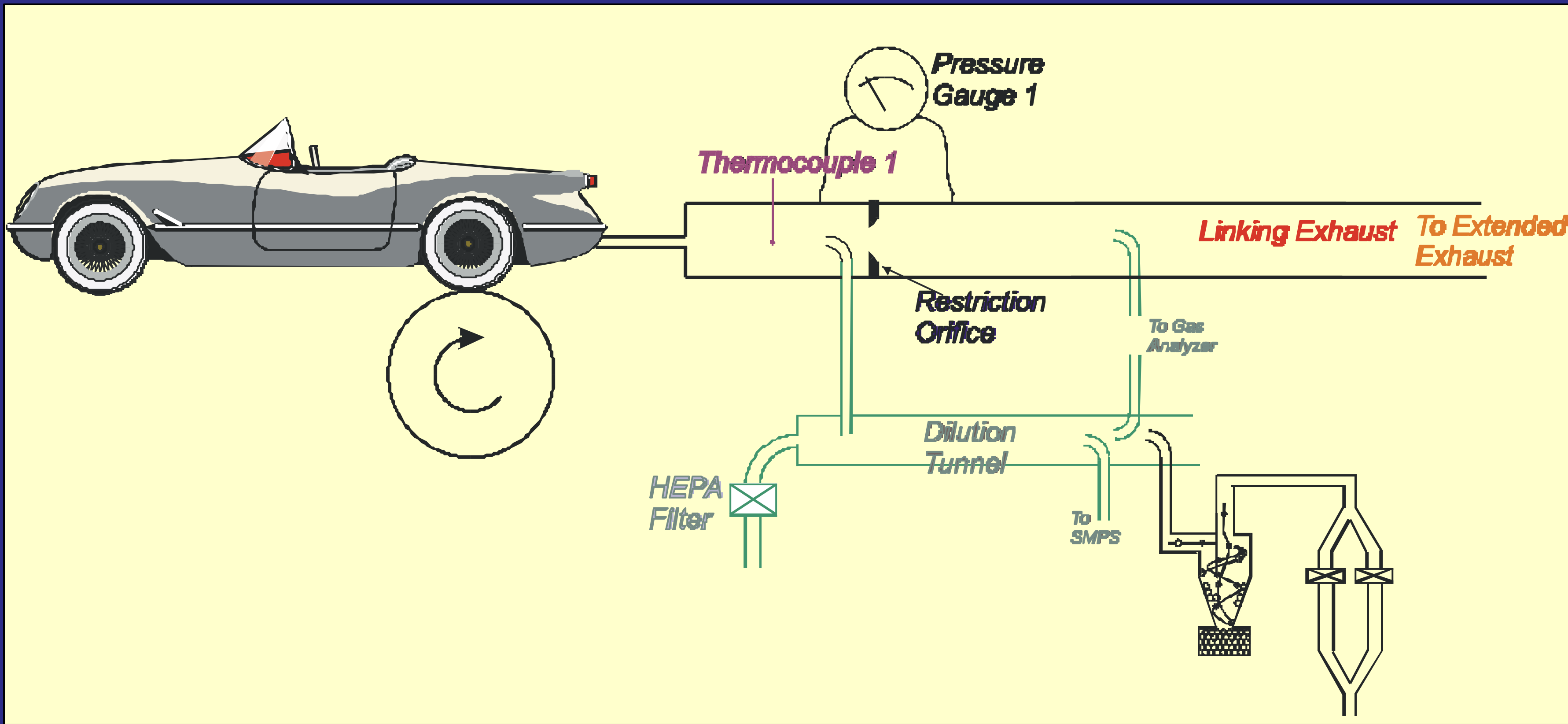
Target pollutants

- The volatile air toxics: benzene, toluene, styrene, 1,3-butadiene, chlorinated hydrocarbons and xylenes.
- The toxic aldehydes: formaldehyde and acetaldehyde.
- The 16 Priority USEPA polycyclic aromatic hydrocarbons.
- The elemental composition of the metal ash.

Sampling Methodologies for individual pollutants

- Particle size distribution:
  - Scanning Mobility Particle Sizer (3071A TSI Electrostatic Classifier and the 3022A CPC).
- Vapour-phase organic compounds:
  - Tenax sorbent tubes
  - 2,4-dinitrophenylhydrazine (DNPH) – coated silica cartridges for very reactive gases (aldehydes)
- Particle-bound organic and metal compounds
  - Quartz fibre filters, organic compounds.
  - Elemental composition 47 mm PTFE membrane filter, pore size 0.2μm
- Non-methane hydrocarbons: Tedlar bags.

Exhaust Measurement and Sampling



PETROL TO CNG CONVERTED SPARK IGNITION VEHICLE

The Measurement Procedure

- Vehicle tested:
  – Ford Falcon, 4L 6 cylinder engine.
- Schedules of tests:

Test	Time [months]	Fuel
Petrol 1	0	Petrol – before conversion
CNG1	1	CNG
CNG2	4	CNG
CNG3	7	CNG
Petrol3	7	Petrol- after conversion

Definition of Test Cycles

Mode	Dynamometer Load [kW]	Dynamometer Speed [kmh^{-1}]
1. Steady mode at road load	6.5	40
2. Steady mode at road load	9.5	60
3. Steady mode at road load	12.5	80
4. Steady mode at road load	18.8	120
5. Idle mode in Neutral	0	0

Results and Discussion

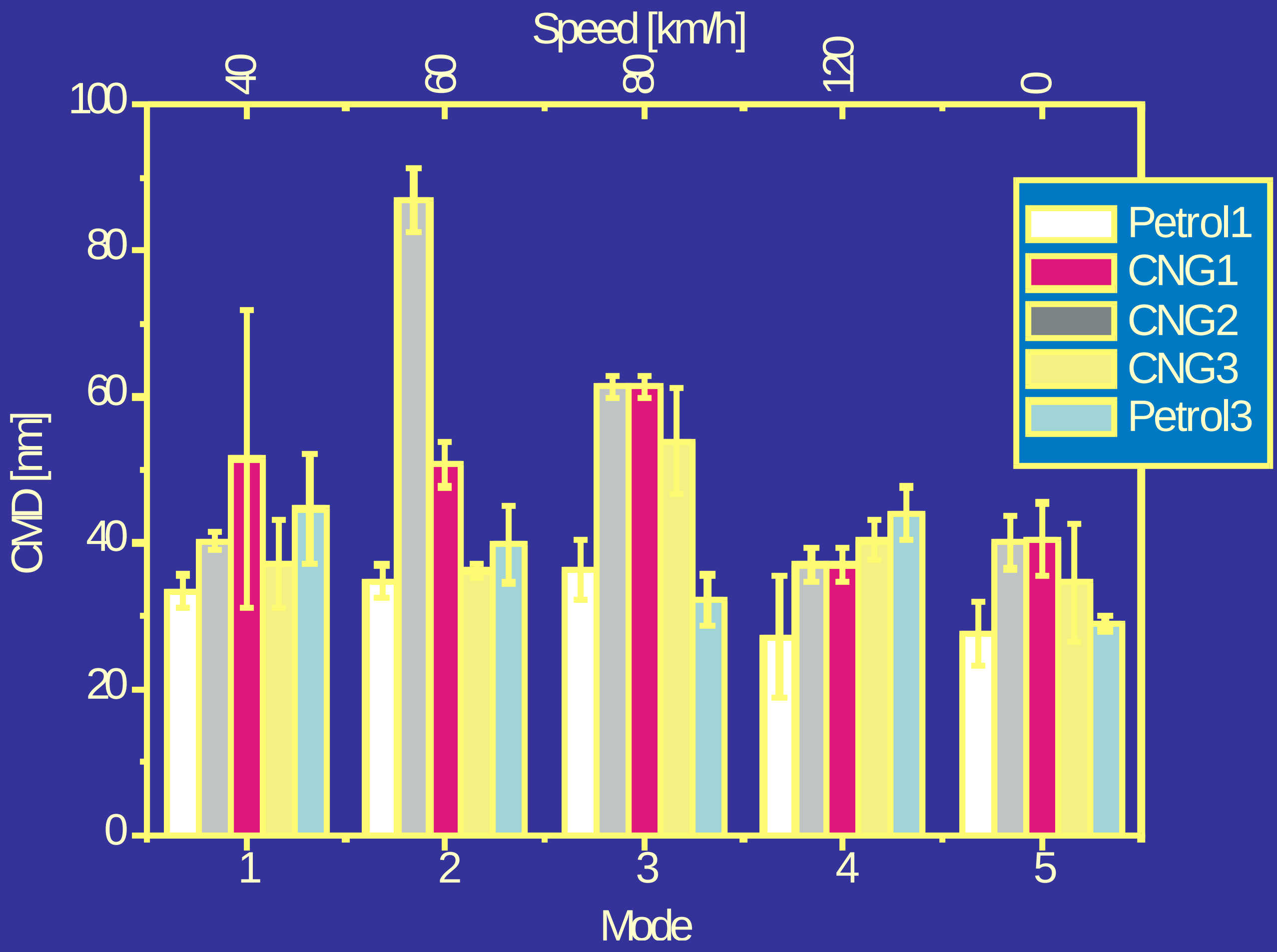


Figure 2: Dependence of particle count median diameter (CMD) on vehicle the load/speed

Results and Discussion

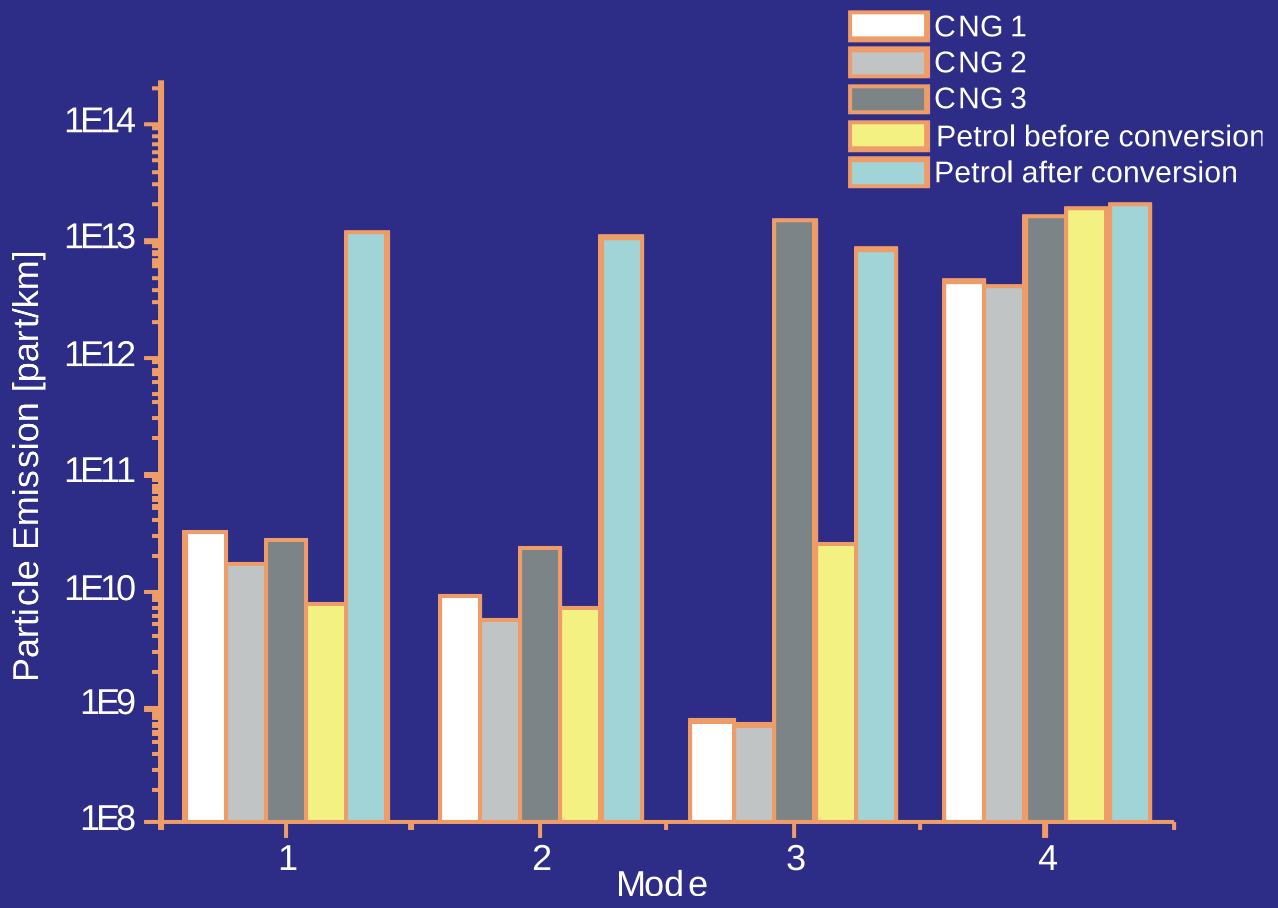


*Figure 3:**Particle number emissions per kilometre.***

Results and Discussion

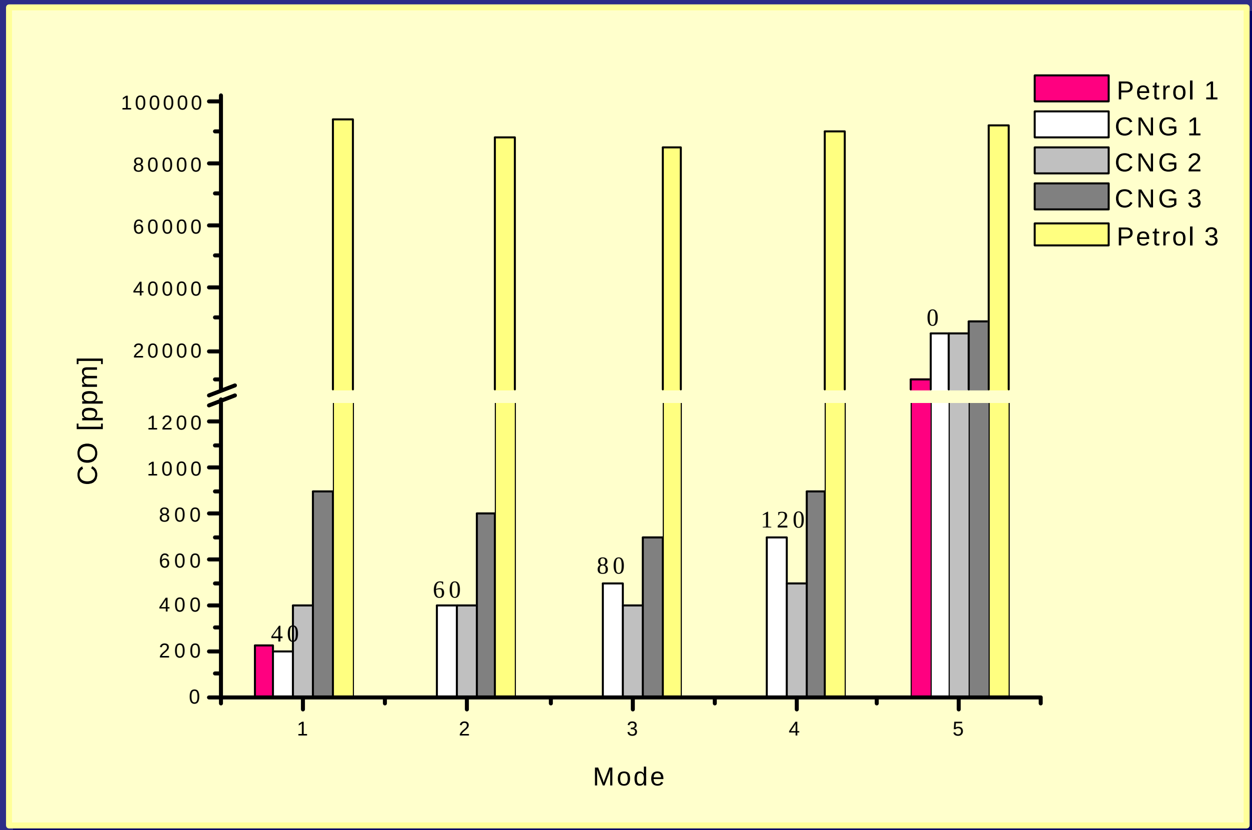


Figure 4: Relationship between engine speed/load and the emission levels of CO, for all five tests.

Results and Discussion

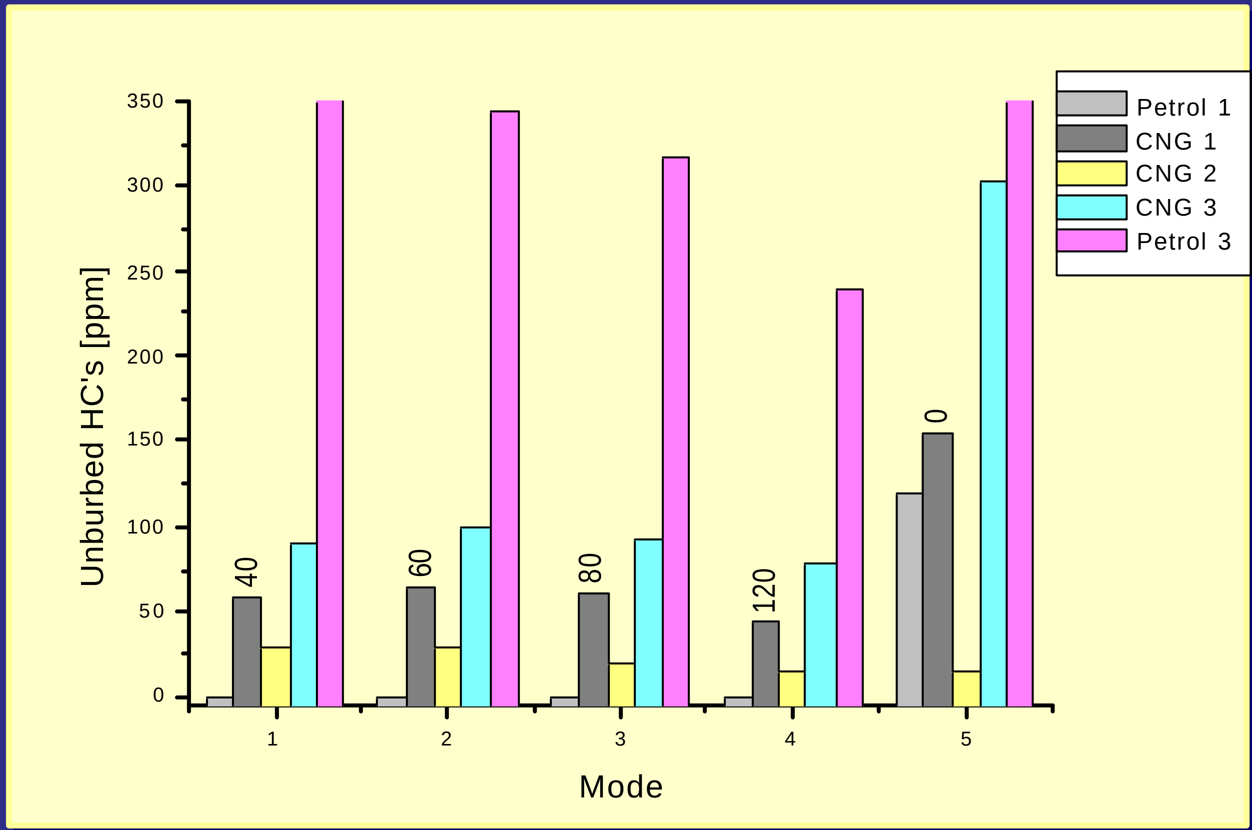


Figure 4: Relationship between engine speed/load and the emission levels of unburned HC's, for all five tests.

Conclusion

- There was no statistically significant change in the emission of fine particles.
- CNG tests showed a decrease in the emission of NO_x compared to the unconverted petrol test.
- A significant increase in particle number emissions as well as CO were displayed when the vehicle was run again on petrol after operating on CNG for some time.

Recommendations

- It does not appear that there is an advantage in converting vehicles from petrol to CNG in terms of particle number emissions
- Once the conversion to CNG takes place, running the vehicle on either of the fuels interchangeably should be avoided.

DEDICATED LPG SPARK IGNITION VEHICLE

The Measurement Procedure

- Vehicle tested:
  - 6, six cylinder, 4L, dedicated LPG engines.
  - Three, ULP engines of the same make model as LPG
- Schedules of tests:
  - Tests every 3 months
  - First set of tests when vehicles were new (<3 months)

Definition of Test Cycles

Mode	Dynamometer Load [kW]	Dynamometer Speed [kmh^{-1}]
Steady mode at road load	6.5	40
Steady mode at road load	9.5	60
Steady mode at road load	12.5	80
Steady mode at road load	15.5	100
Idle mode in Neutral	0	0

Results and Discussion

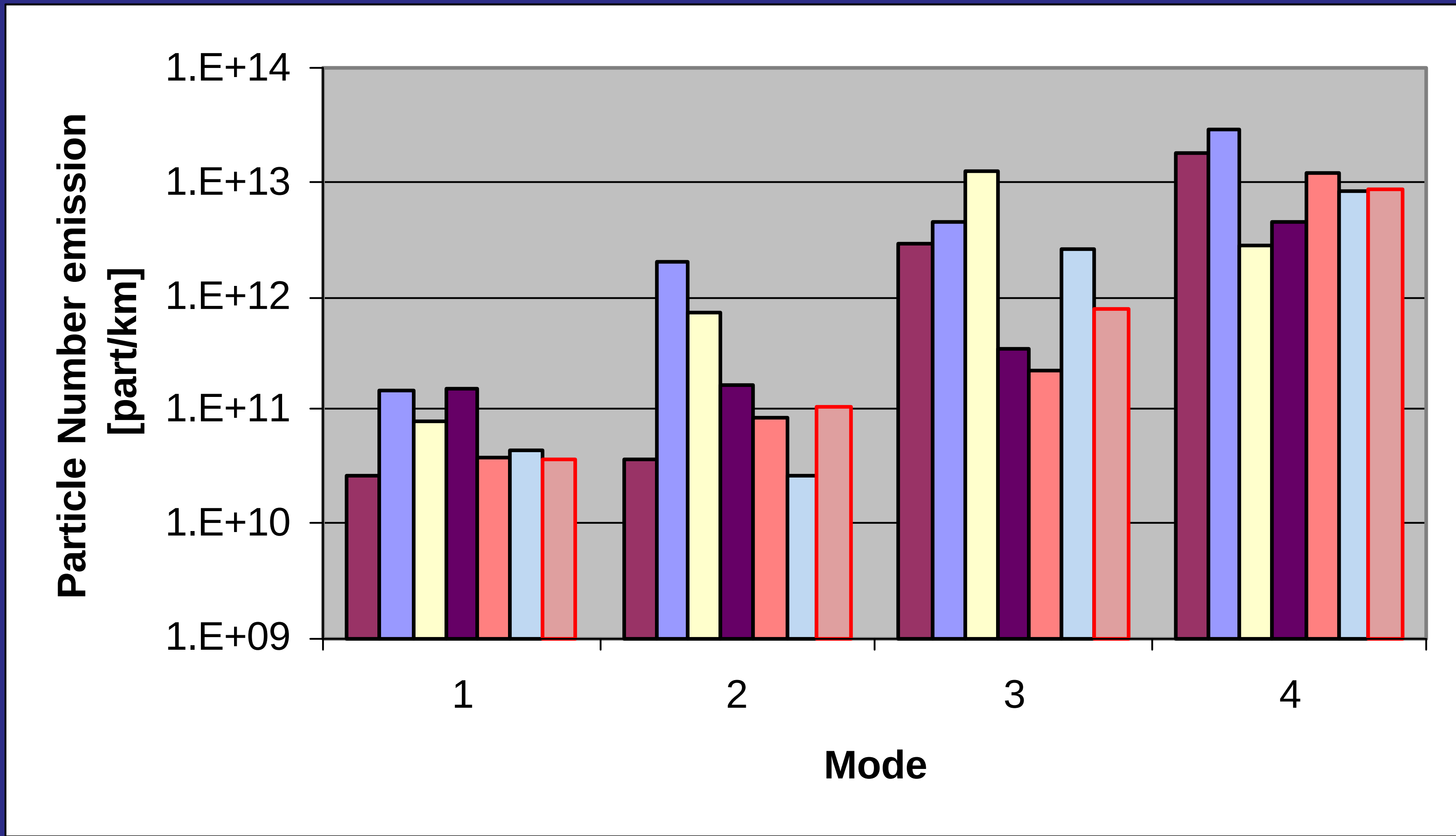


*Figure 6:**Particle number emissions per kilometre LPG vehicles (full bars) and ULP vehicles (patterned bars).***

Results and Discussion

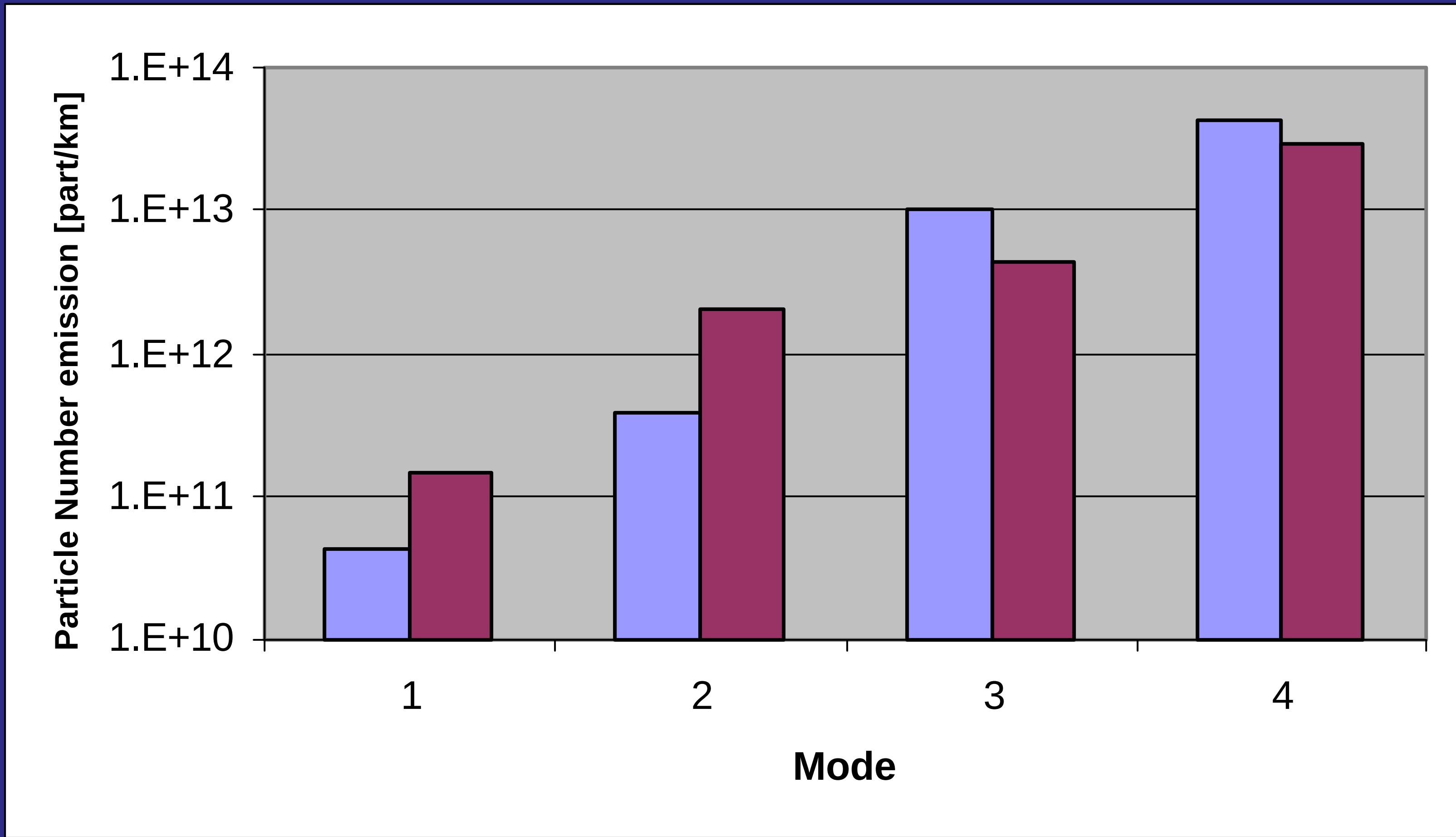
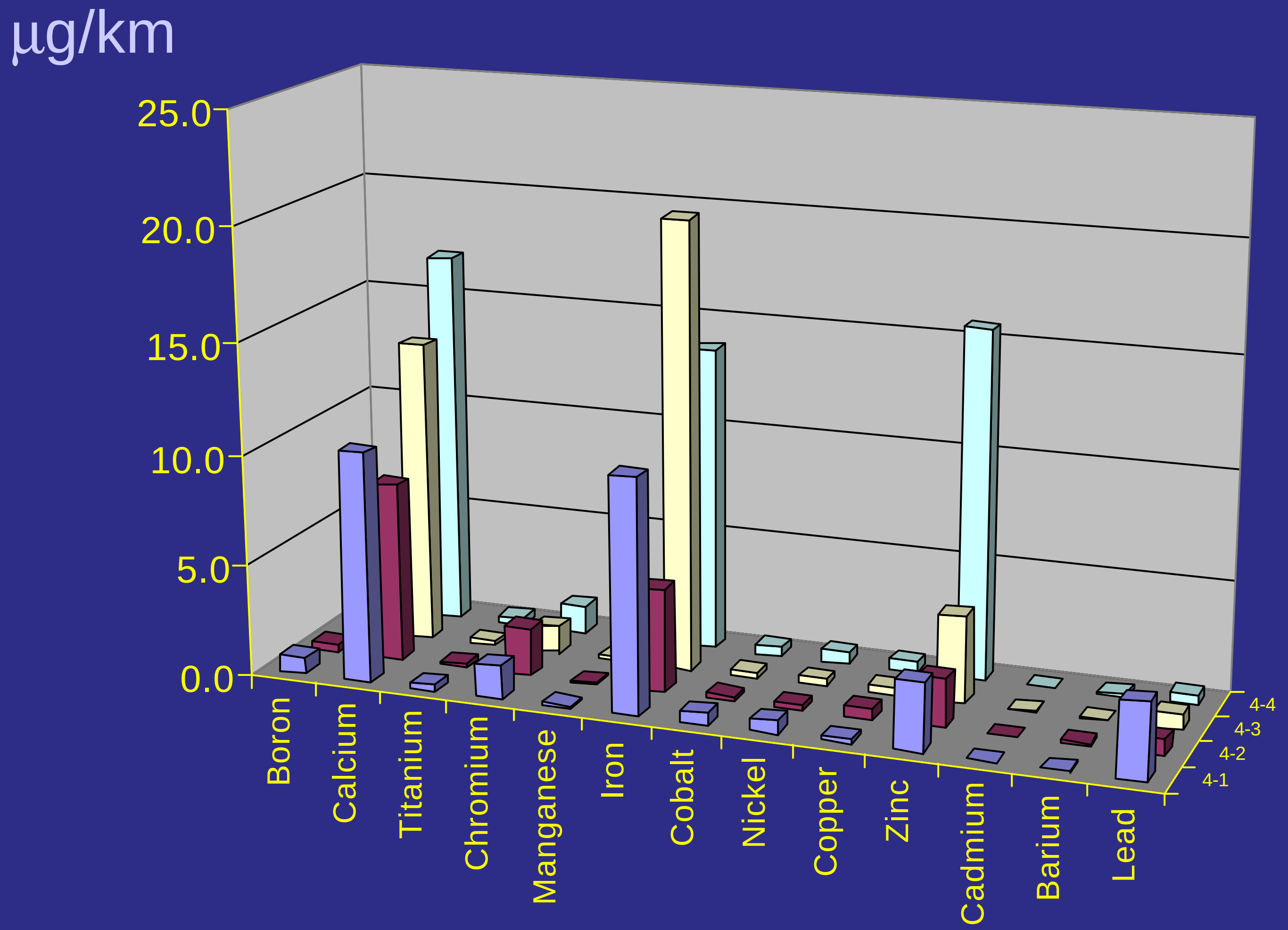
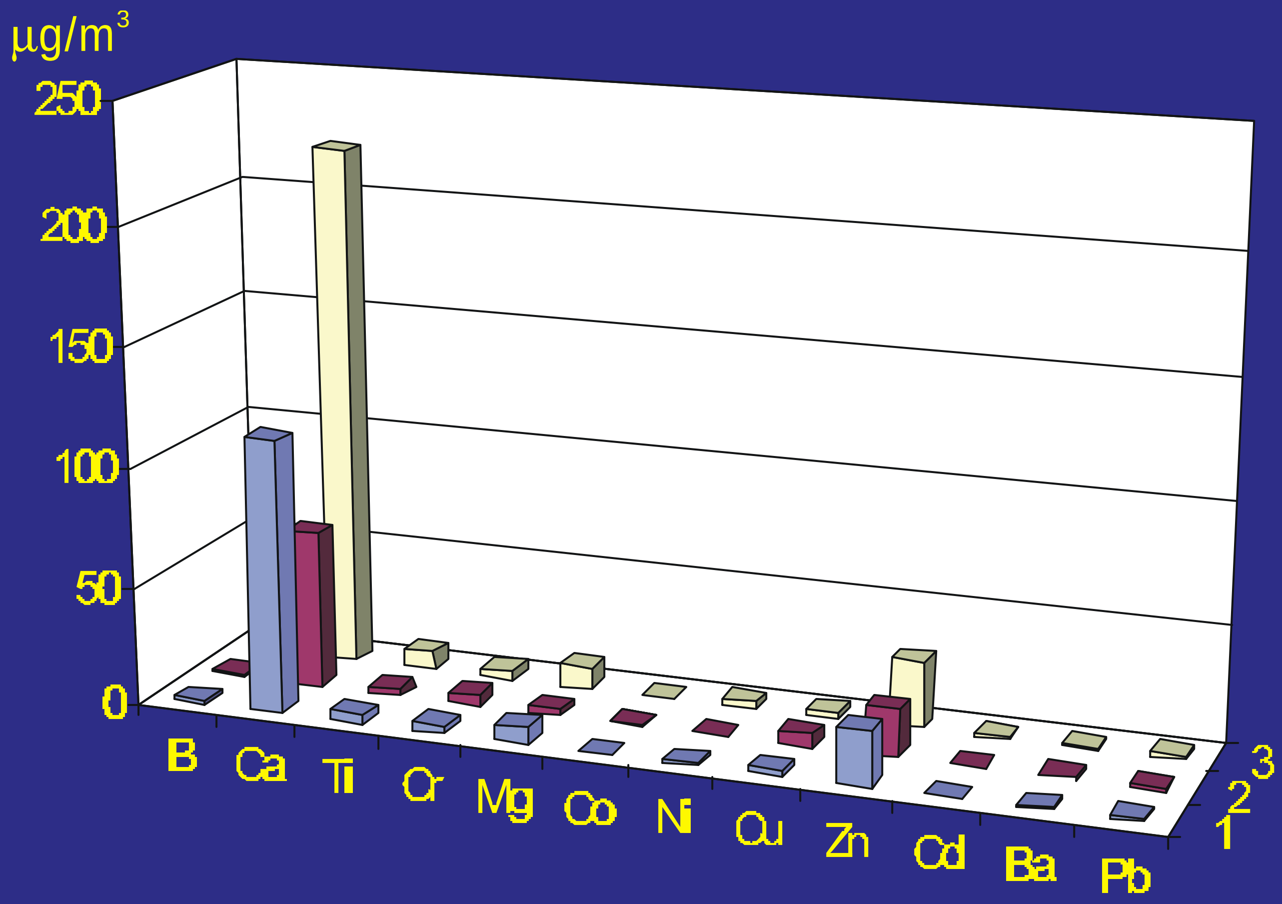


*Figure 7:**Particle number emissions per kilometre for the LPG vehicles 2 different tests, first test in November 2000 and second in February 2001.***

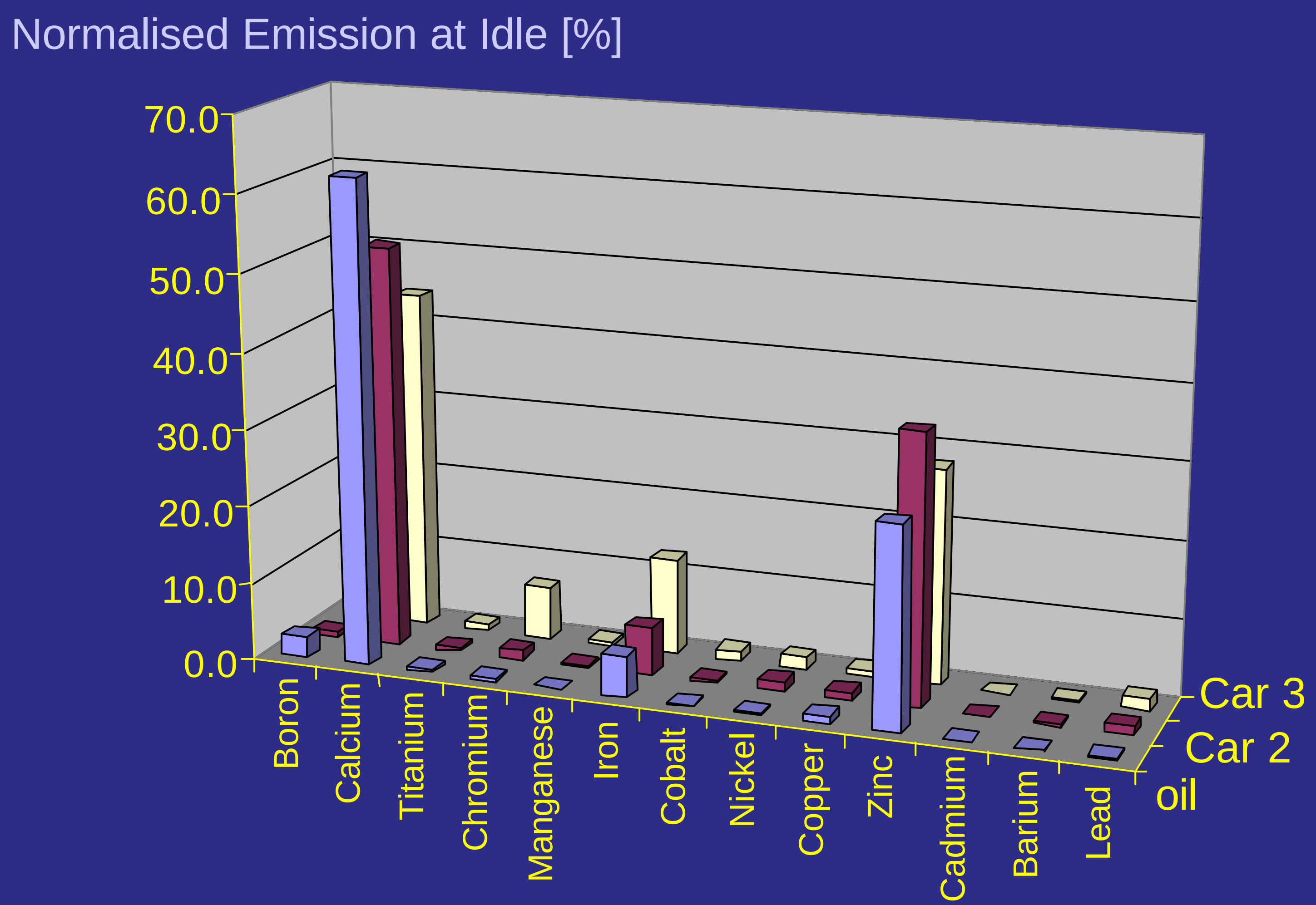
Elemental Composition - ULP



Elemental Composition - LPG



Source of Metal Emission



Conclusion

- There was no statistically significant change in the emission of fine particles.
- Majority of particles come from lubricating oil?
- Elemental composition can be used to determine the lubricating oil consumptions.