Particle Number Emissions from a Large Fleet of Diesel and CNG Buses

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Exhaust emissions were monitored in real-time at the kerb of a busy busway used by a mix of diesel and CNG-powered transport buses. Particle number concentration in the size range 3 nm to 3 µm was measured with a TSI condensation particle counter (CPC 3025). Particle mass ($PM_{2.5}$) was measured with a TSI Dustrak 8520. The CO_2 emissions were measured with a fast response CO_2 analyser (Sable CA-10A). All emission concentrations were recorded in real time at 1 sec resolution, together with the precise passage times of buses. The instantaneous ratio of particle number (or mass) to CO_2 concentration, denoted Z, was used as a measure of the particle number (or mass) emission factor of each passing bus.

All Z values in this paper are presented in units of millions of particles per mg of CO_2 for particle number and in mg of particles per mg of CO_2 for particle mass.

Owing to unfavourable wind direction or buses passing too close together, there were some difficulties in obtaining data from every bus that passed. However, due to the large number of buses, reliable data were obtained over several days from over 300 diesel and 250 CNG bus passages.

As expected, the particle mass emissions from the CNG buses were significantly less than from the diesel buses. The median particle mass Z Ratios for the diesel and CNG buses were $(1.7 \pm 0.1) \times 10^{-3}$ and $(1.3 \pm 0.4) \times 10^{-4}$ respectively, where the uncertainties indicate the standard errors. However, the particle number emissions from the CNG buses were significantly higher than from the diesel buses. The median particle number Z Ratios for the diesel and CNG buses were (1150 ± 67) and (7465 ± 339) million mg^{-1} respectively. This represents a difference of a factor of 6.5.

Both groups of buses exhibited Z Ratio distributions that followed a gamma function with a long tail at the high Z end, indicating that a few buses were responsible for a large proportion of the particle emissions. These were not necessarily the oldest buses in the fleet. We hypothesize that service history plays the major role in determining the particle emission factor of a bus, both diesel and CNG.

The Z Ratio offers a simple and quick method for the identification of high-emitting buses in large fleets without having to take them off the road. This may be of significant benefit to the overall improvement of air quality, especially in large cities.

The low particle mass and high particle number emissions from CNG buses indicate that most of the particles are in the nanoparticle size range. Passing the exhaust sample through a thermodenuder heated to 300°C before entering the CPC cut down the CNG emission particle number Z Ratio by 81%, while the corresponding diesel emission particle number Z Ratio was cut down by just 33%. This suggests that, while the particles produced by CNG buses were composed mainly of volatile material, as expected, the majority of particles from the diesel buses were nonvolatile carbon soot.

It must be stressed that, in this study, the monitoring was conducted at the departure end of a bus platform, where all buses were accelerating from rest. When cruising at a steady speed, the difference in particle number Z Ratio between the two types of buses was not significant.

Thus, it may be concluded that, while the particle number emissions from buses powered by the two types of fuel were comparable at steady speeds, under higher load accelerating conditions the CNG buses emitted more particles than diesel buses with most of them being volatile nanoparticles.

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Greetings from all at ILAQH, Brisbane, Australia

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South Bank
50

Bus Fleet

- 500 Diesel Buses
  Pre-Euro (1982), Euro I (1991) and Euro II (1998)

- 250 CNG Buses
  Gradually replacing diesel buses since 2000.

Method

Particle number and CO_2 concentrations monitored at the kerbside as buses pass by.

$$Z = P\ No\ /\ CO_2$$

(millions of particles per mg of CO_2)

used as an indicator of emission factor.

Z directly proportional to particle number emission factor.

Jayaratne et al. *Atmos. Environ*. 39, 6821, 2005.

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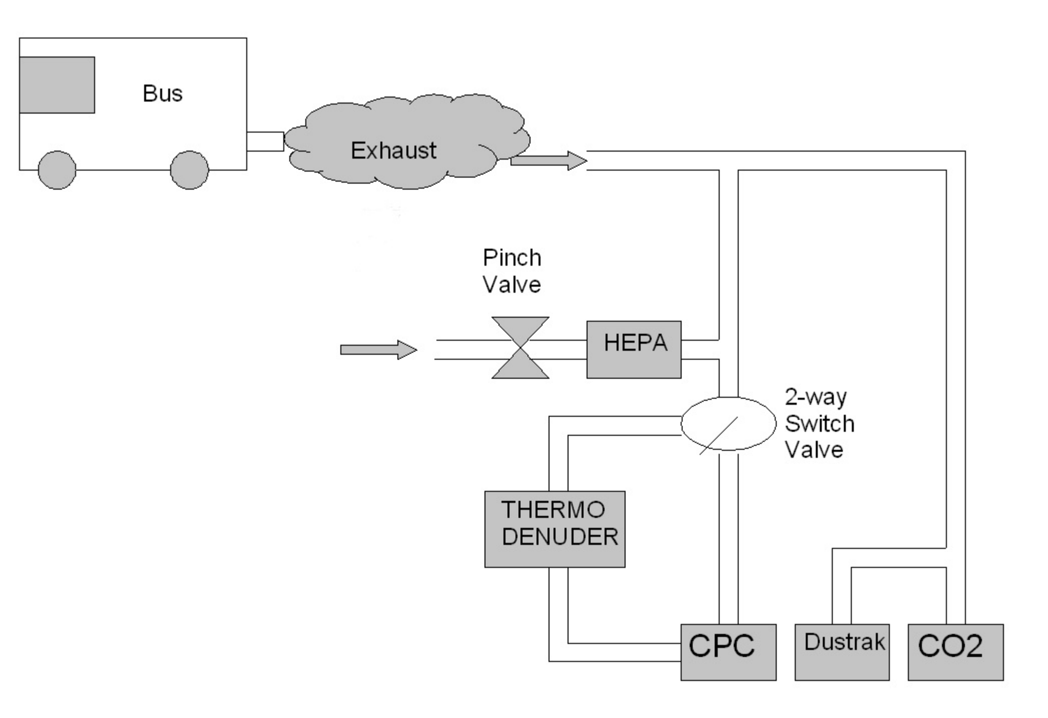
Schematic Diagram of Experimental System



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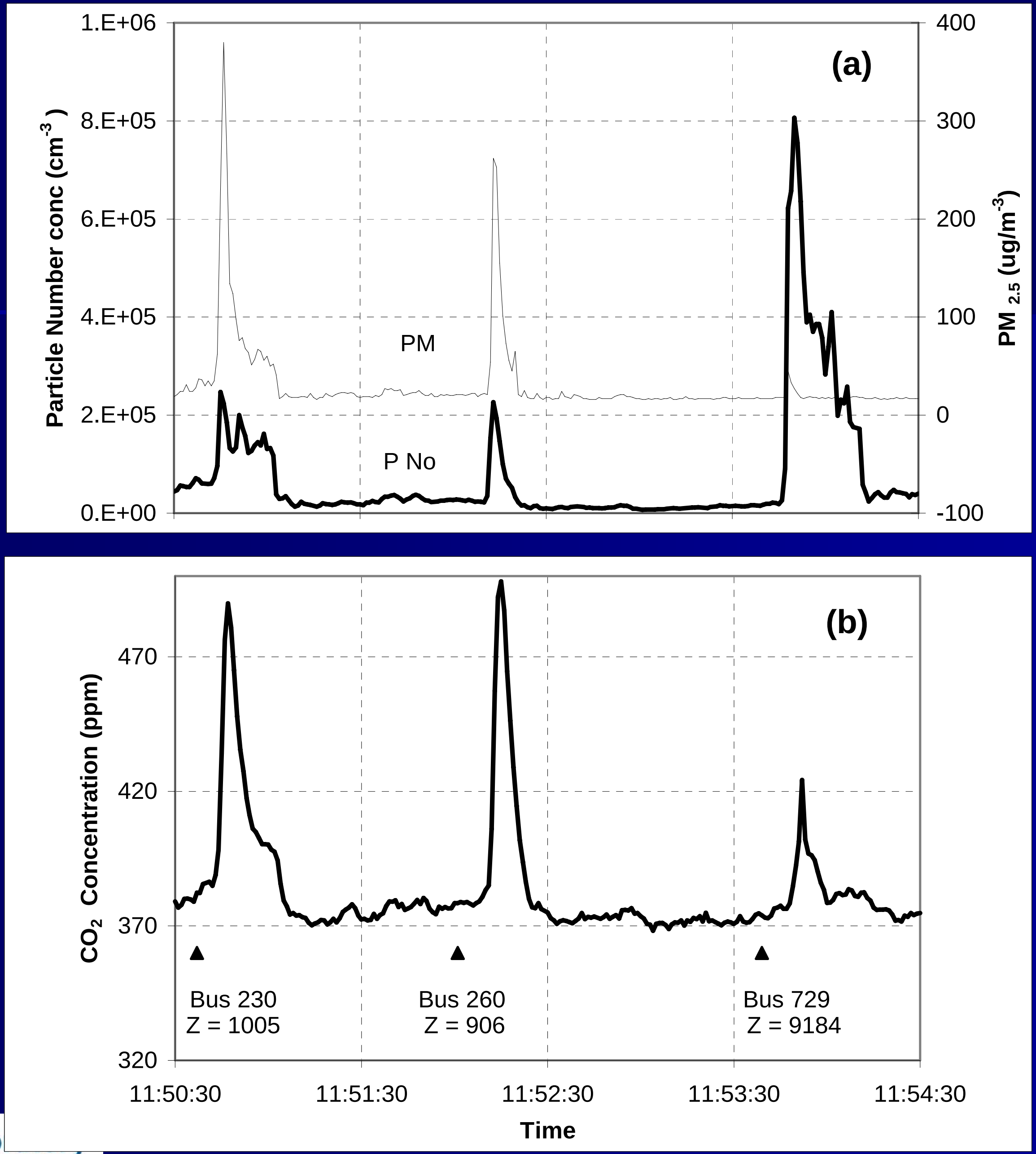

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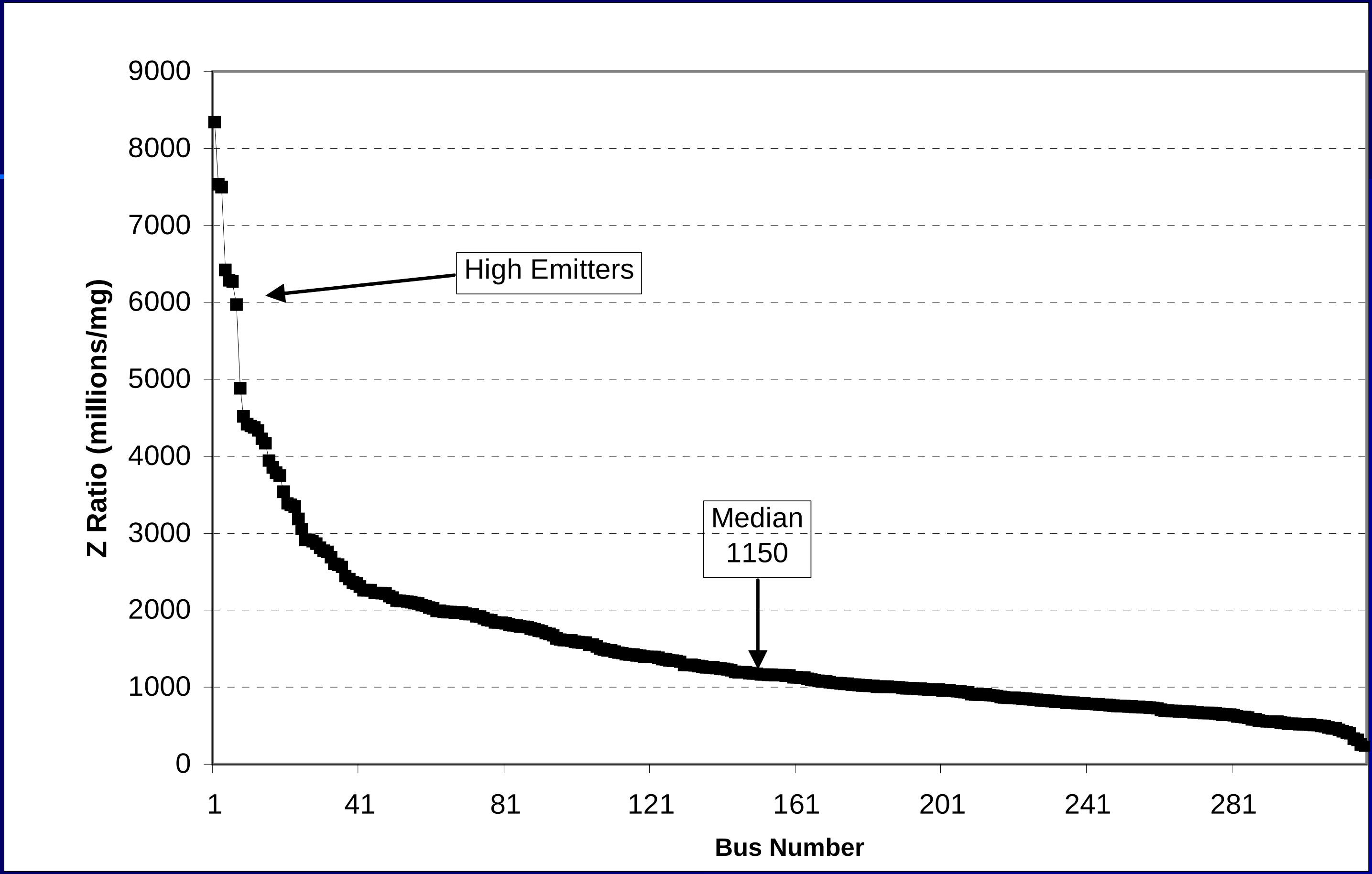
Distribution of Z values for Diesel Buses



25% of particle number emissions come from 10% of buses.

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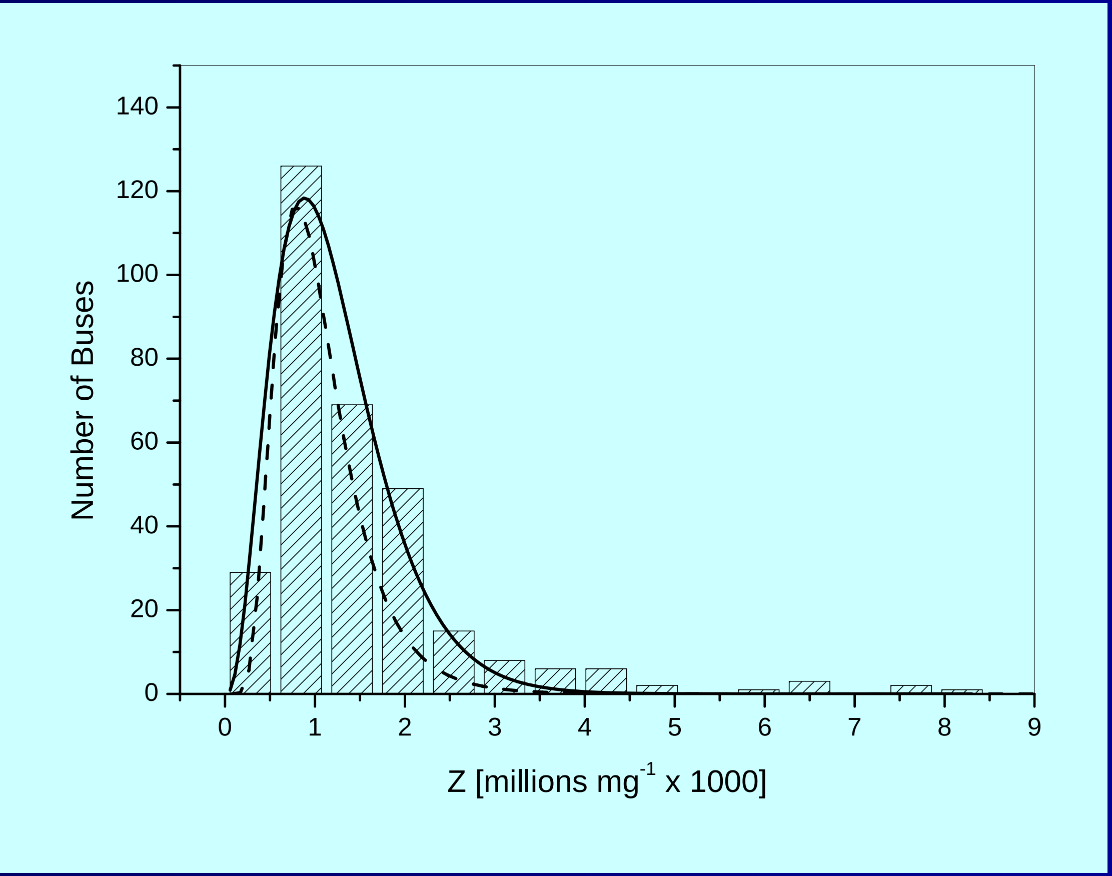
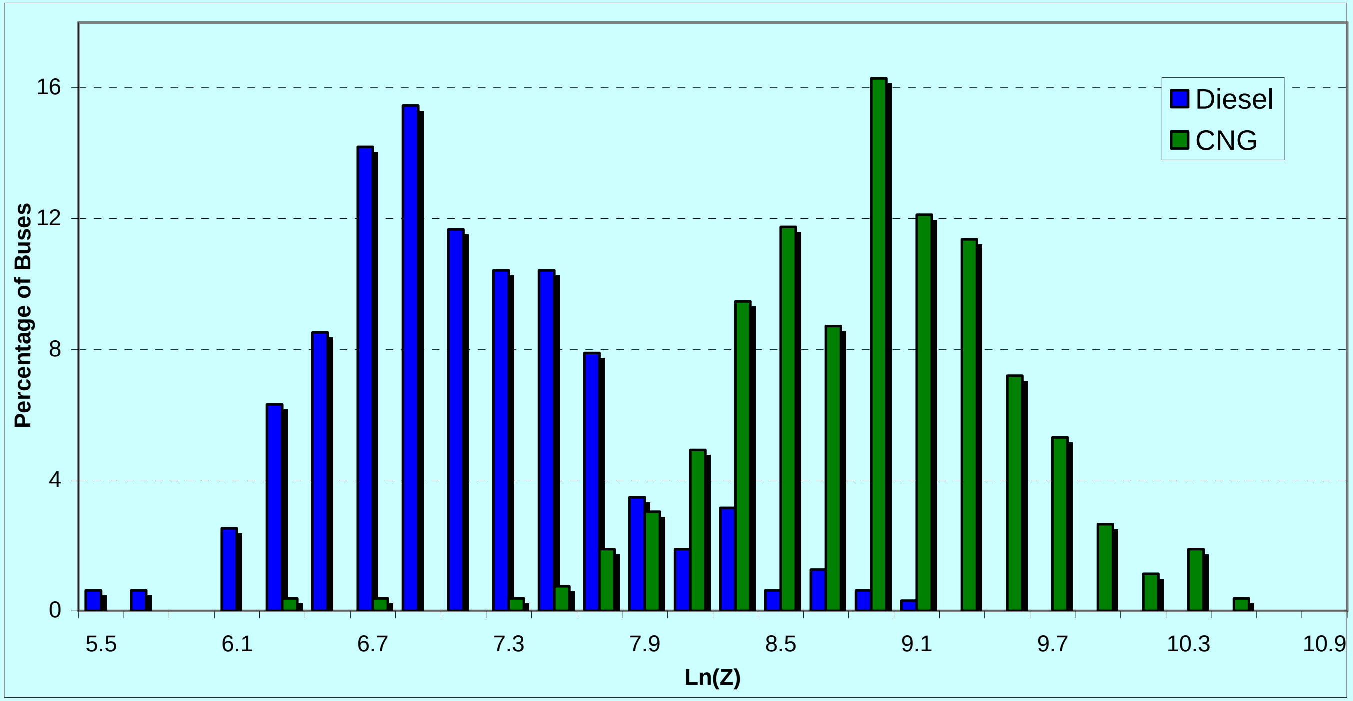
Z (particle number emission factor) follows a Gamma Distribution



Diesel and CNG Particle Number Z Distributions



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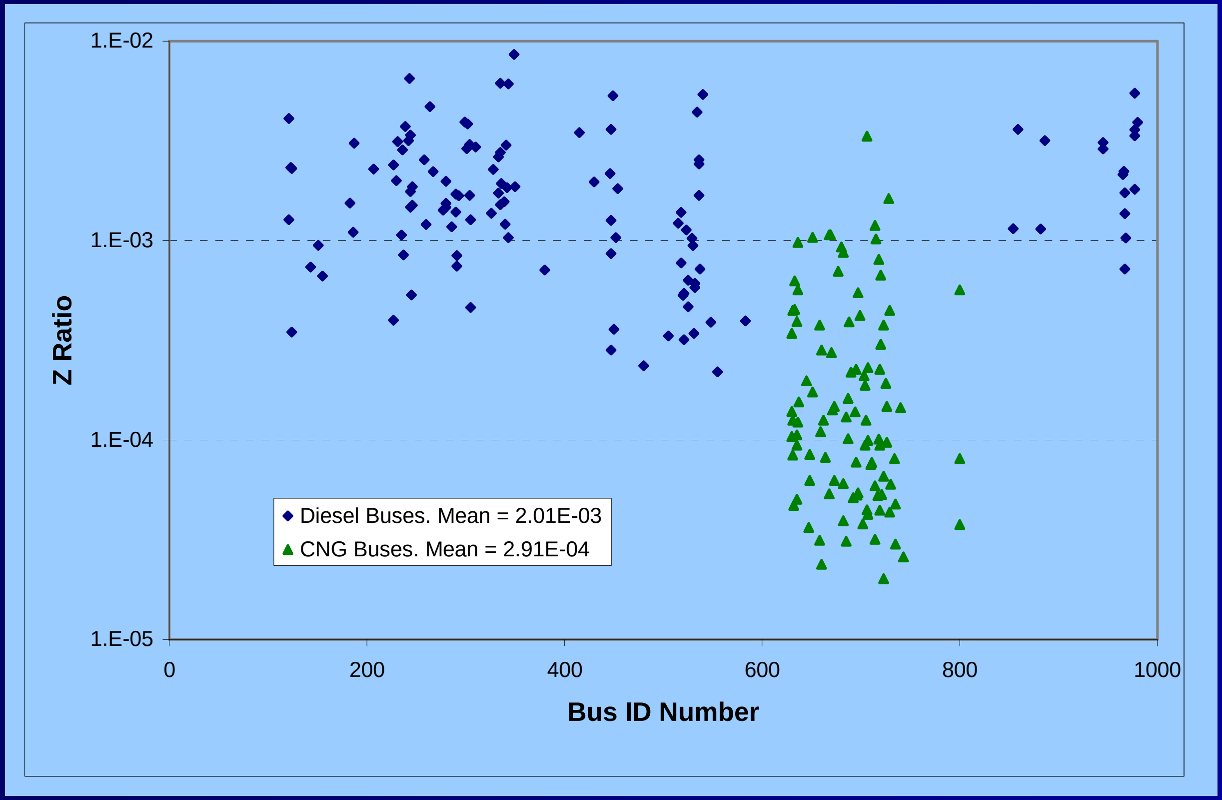
Diesel and CNG Particle Mass (PM2.5) Z Distributions



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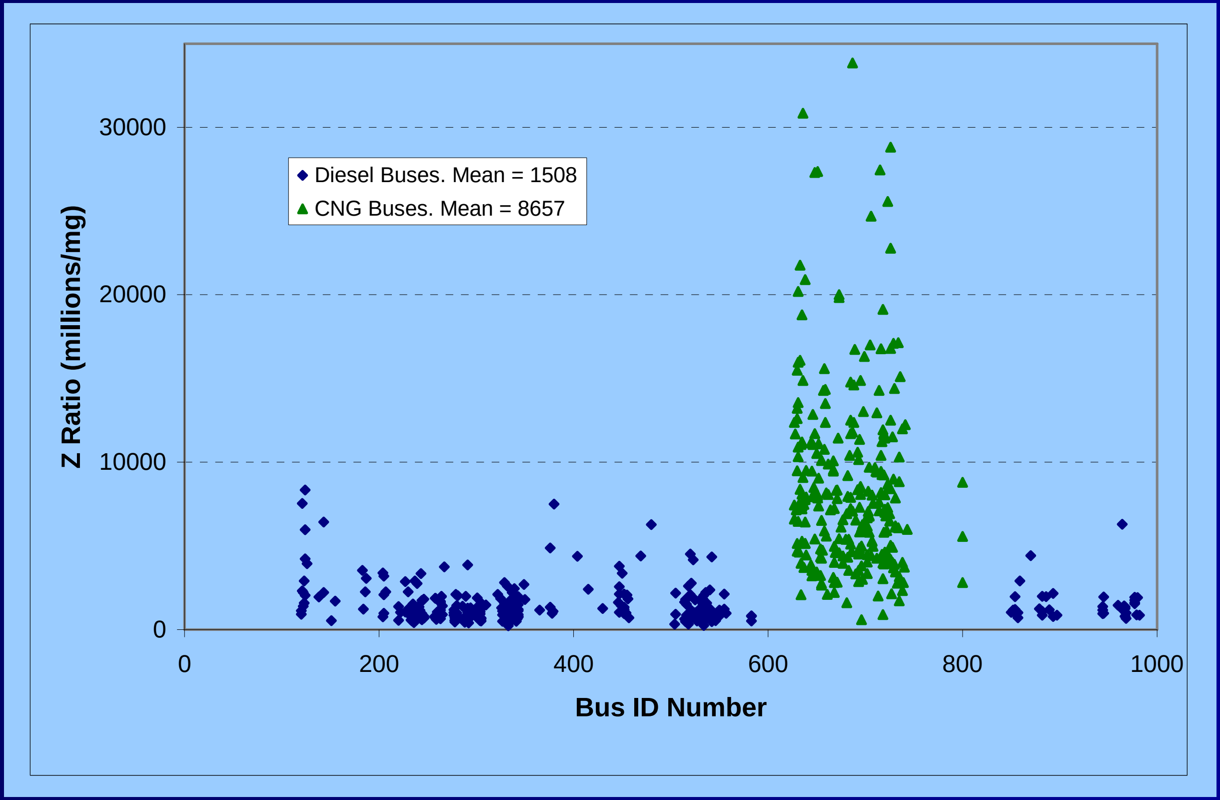
Diesel and CNG Particle Number Z Distributions



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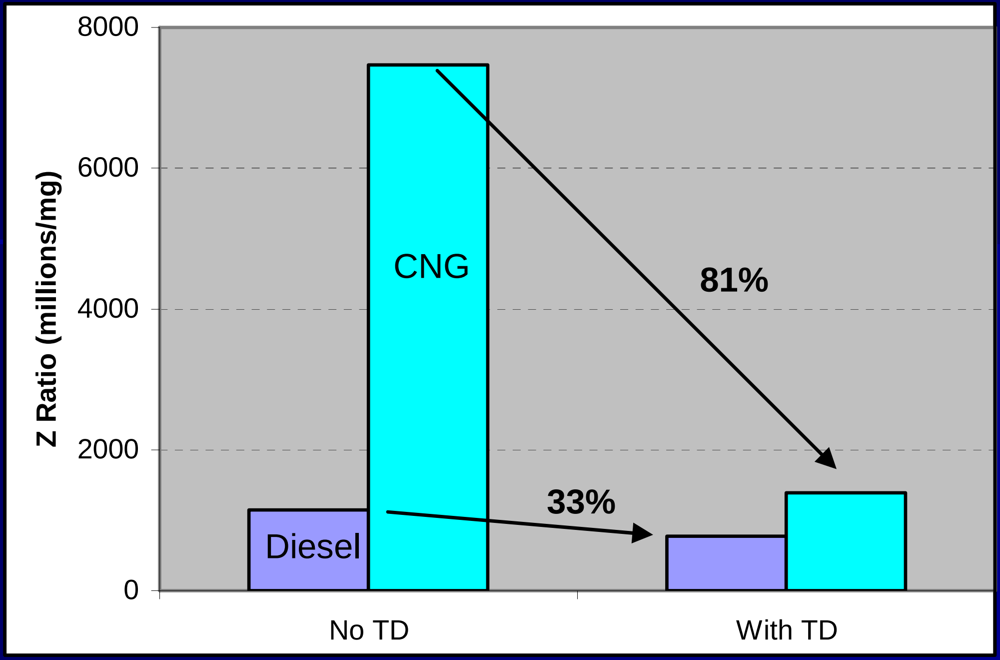
Particle Volatility

Exhaust gas passed through a thermodenuder, heated to 300 °C, before entering the particle counter.

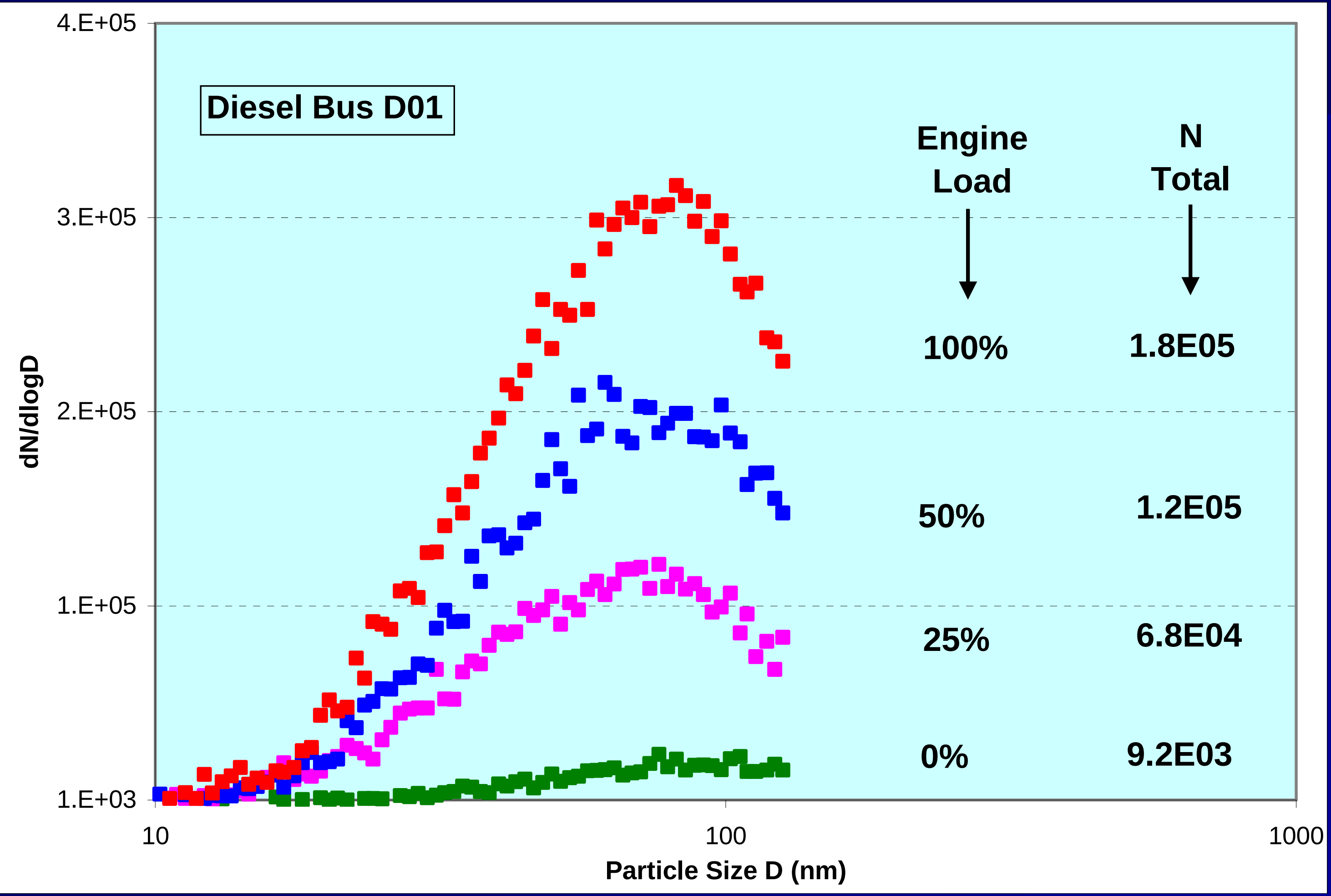


81% of particles from a CNG bus are volatile.
Only 33% of particles from a diesel bus are volatile.

Subsequent Dynamometer Study

- **15 CNG and 5 Diesel buses from the same fleet tested over**
  - 4 steady state modes – 0% (idle), 25%, 50% and 100% max loads
  - DT-80 Transient cycle
- **Pollutants monitored**
  - Particles (Particle number, PM_{10})
  - Carbon Dioxide and Oxides of Nitrogen
  - Methane
  - A wide range of chemical compounds

SMPS Number-size scans



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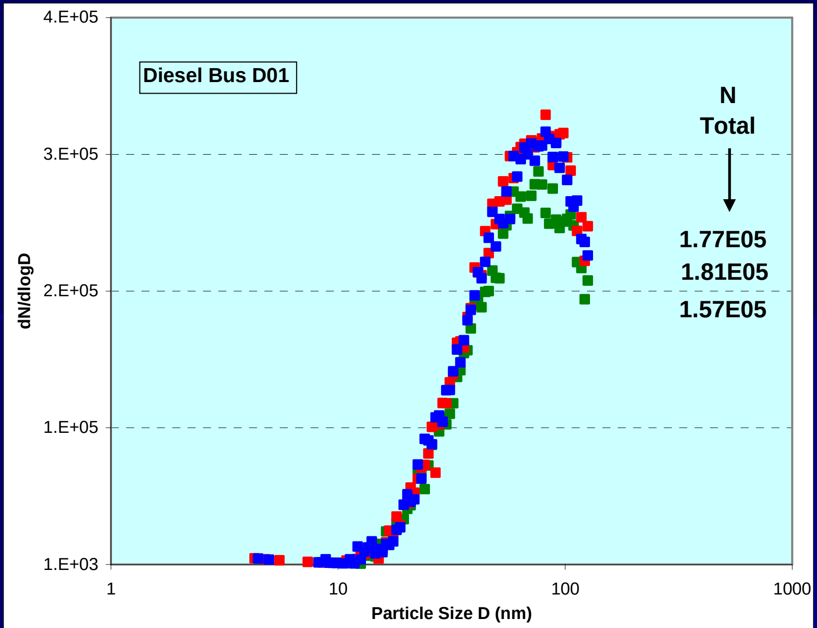

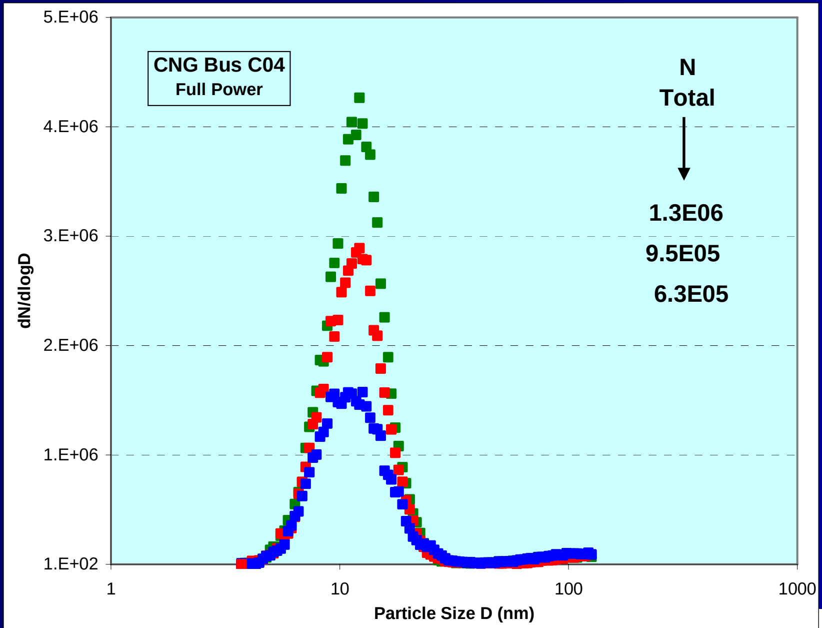

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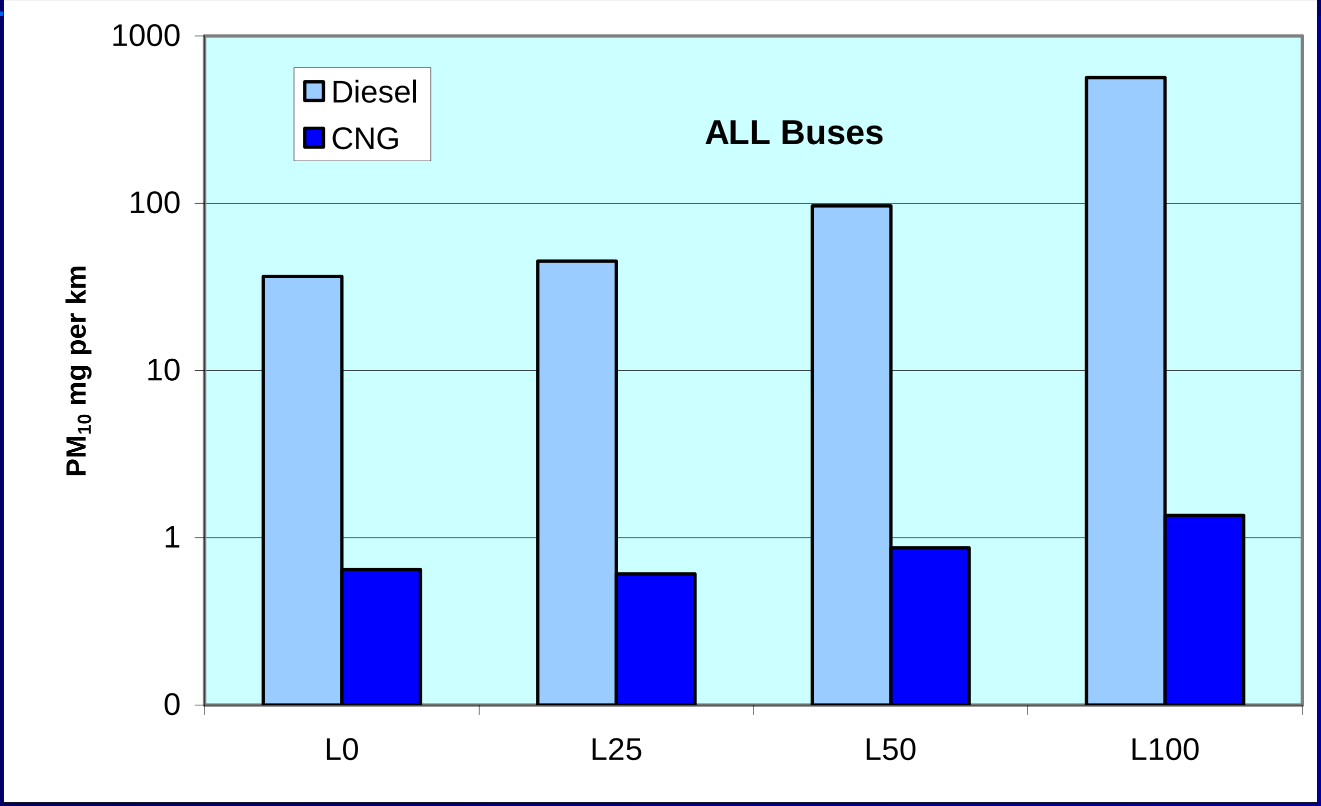
PM_{10}



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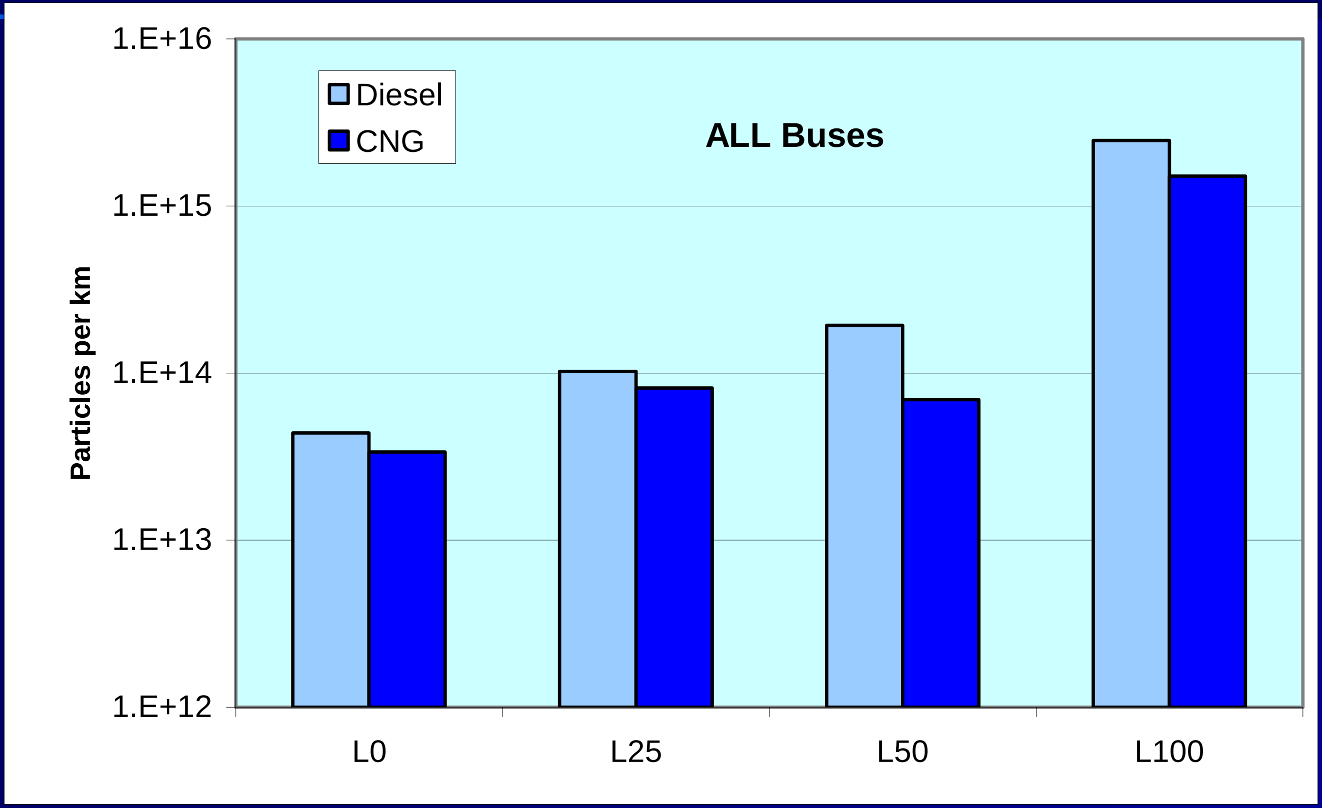
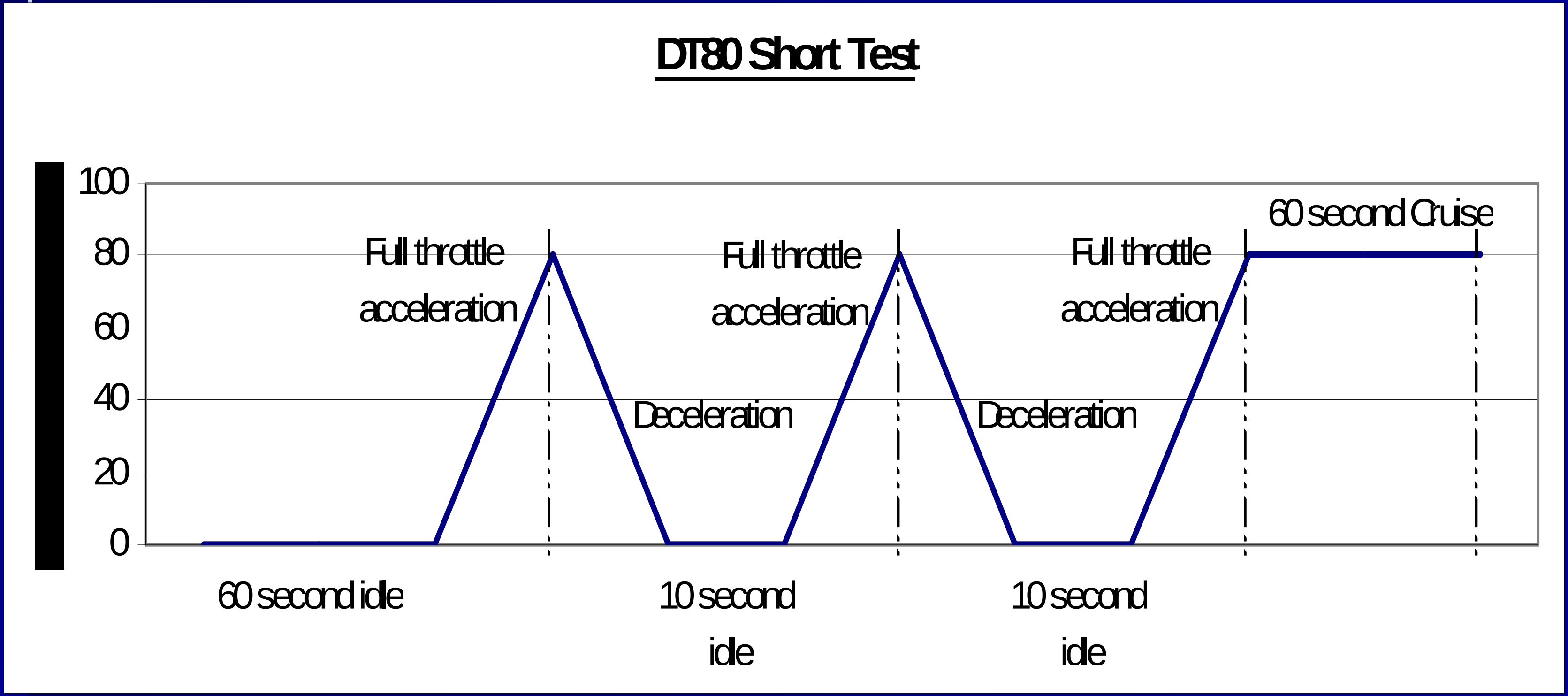
Total Particle Number



Observed Differences in Particle Number Emission Factors

Busway Kerbside Study:	CNG = 6.5 x Diesel
Dyno S/State Cycles:	CNG = 0.7 x Diesel
Dyno Transient Cycles:	CNG = 4.0 x Diesel

The DT-80 Cycle



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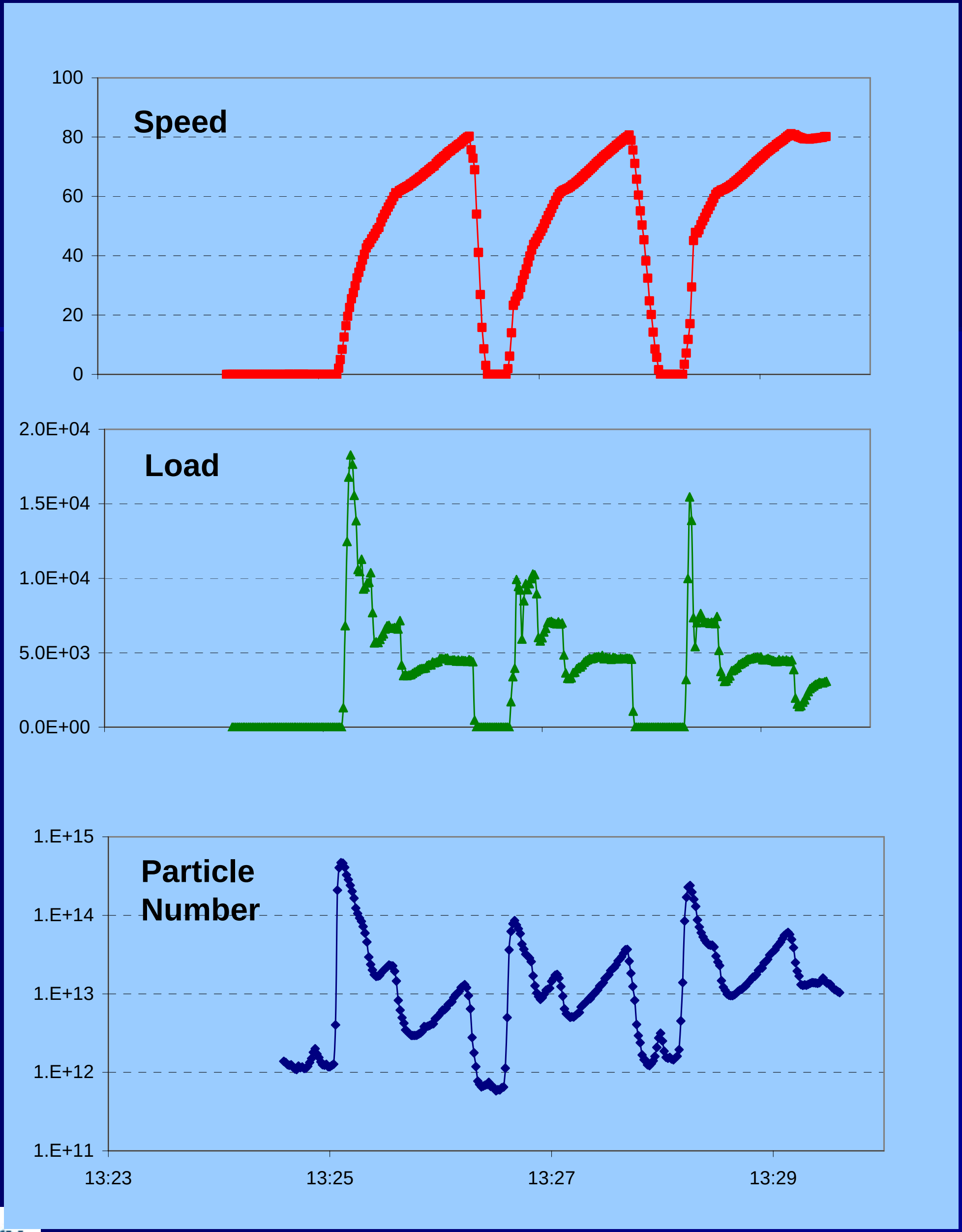
Speed
100
80
60
40
20
0
Load
2.0E+04
1.5E+04
1.0E+04
5.0E+03
0.0E+00
Particle Number
1.E+15
1.E+14
1.E+13
1.E+12
1.E+11
13:23
13:25
13:27
13:29

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