Unregulated Emissions, Particulate Matter Toxicity, Ammonia and Nanoparticle Emissions from a 2010 Heavy-Duty CNG Vehicle

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Objectives

- Global Objective

  To characterize the toxicity, as a function of volatility, of PM emissions from heavy-duty CNG buses

- Specific Objectives
  - To characterize the unregulated species in the exhaust
  - To measure the number concentration and size distribution of ultrafine nanoparticles.
  - Investigate the contribution of carbon fraction and volatile fraction to toxicity responses.

Approach

- Investigate two 2010 compliant heavy-duty CNG transit buses.
- Buses with high and a low mileage were selected to investigate the effect of engine life on PM fractions.
- Collect data over three test cycles
  1. UDDS (triple length)
  2. 45MPH steady state (1 hour)
  3. Idle operation

Approach

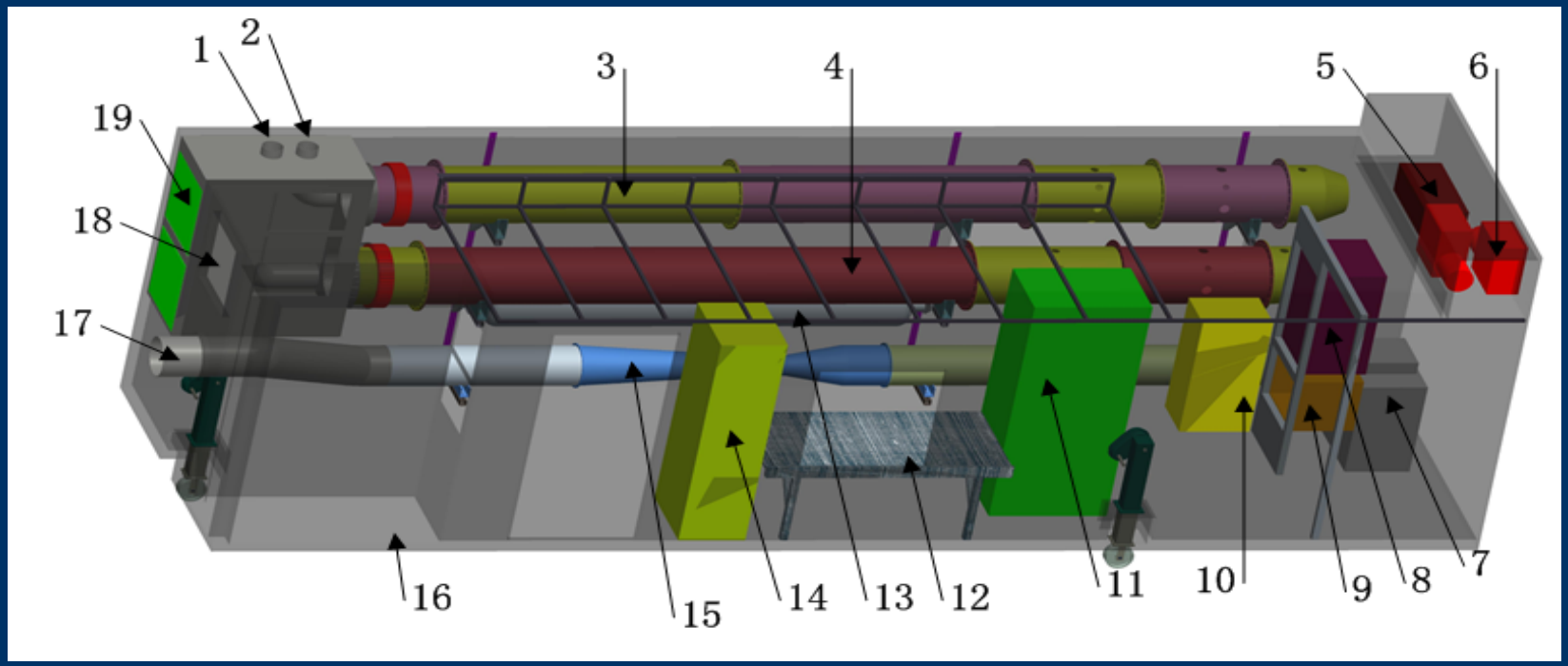
- Vehicles were tested using the WVU transportable heavy-duty chassis dynamometer.
- Vehicles were recruited from the Sacramento transit agency.
- Mobile laboratory was stationed at the CARB laboratory in Stockton, CA.

Engine Manufacturer	Engine Model	Engine Model Year	Displacement/Power (L/HP)	fuelling	NOx/PM (gm/bhp-hr) *
Cummins	ISLG 280	2007	8.9/280	CNG Stoichiometric	0.2/0.01

Test Matrix

	UDDS (40 min duration Cycle)	50 MPH steady state (40 min duration cycle)	Idle (120 min duration)
2010 CNG Bus **(High Mileage)** Mileage = 84994	Unregulated Emissions - 3 runs Toxicity w/ & w/o thermodenuder	Unregulated Emissions - 3 runs Toxicity w/ & w/o thermodenuder	Unregulated Emissions - 3 runs Toxicity w/ & w/o thermodenuder
2010 CNG Bus **(Low Mileage)** Mileage = 77538	Unregulated Emissions - 3 runs Toxicity w/ & w/o thermodenuder	Unregulated Emissions - 3 runs Toxicity w/ & w/o thermodenuder	Unregulated Emissions - 3 runs Toxicity w/ & w/o thermodenuder

Sampling Setup



1- Exhaust inlet of dirty tunnel; 2- Exhaust inlet of clean tunnel; 3- Clean tunnel; 4- Dirty tunnel; 5- Air compressor; 6- Vacuum pumps; 7- Oven; 8- PM sampling box; 9- Glove box; 10- Zero air generator; 11- MEXA-7200D motor exhaust gas analyzer; 12- Computer table; 13- Air tank; 14- DAQ rack; 15- Subsonic venturi; 16- Air conditioner deck; 17- Outlet to blower; 18- Ventilation fan; 19- HEPA filters

Sampling Setup

Thermodenuder gravimetric PM sampling system.
Dekati Thermodenuder
URG Stainless Steel filter holders

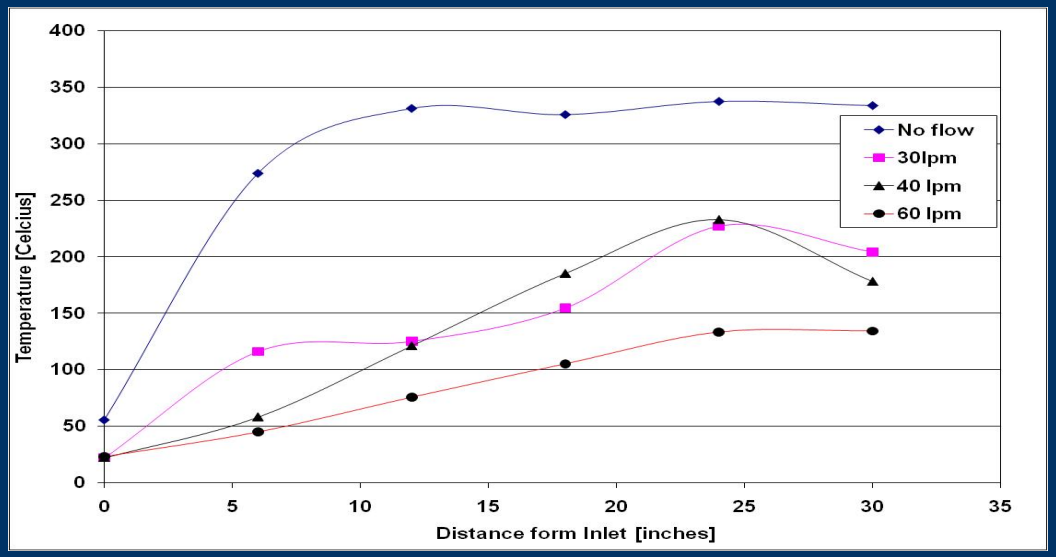
Sample Media and Analysis

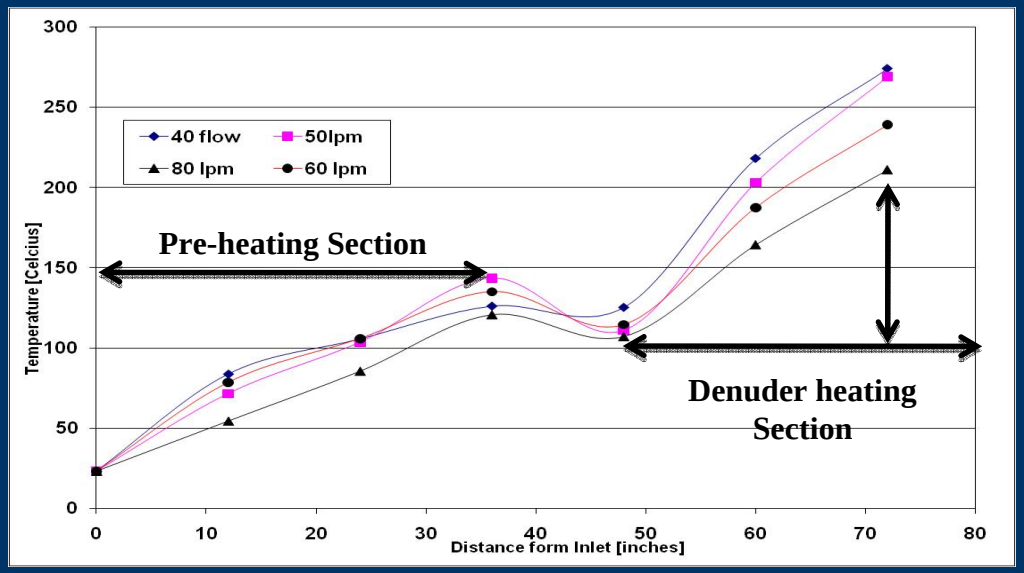
Sample	Sample Media	Flow rate
PM10	T60A20	16.7 lpm
PM2.5	T60A20	16.7 lpm
PM1.0	T60A20	16.7 lpm
Methane	Horiba Non-Methane Cutter	
EC/OC	Pre-fired Quartz (CARB MLD)	2.5 SCFM
VOC	Steel Canister (CARB MLD)	
Carbonyls	DNPH Cartridge (CARB MLD)	2 lpm
Metals/Ions	Teflo Filters (Univ of Wisconsin)	16.7 lpm
PAH	PUF/XAD (SWRI)	200 lpm
Particle Size and Concentration	TSI EEPS/EAD	

Sample	Sample Media	Flow rate
DHBA and DTT assays Denuded Stream	T60A20	50X4 lpm
DHBA and DTT Non-Denuded Stream	T60A20	200lpm
Mutagenicity Denuded	T60A20 (UC Davis)	50X4 lpm
Mutagenicity Non-Denuded	T60A20 (UC Davis)	200 lpm
ROS Toxicity Denuded	T60A20 (Univ Wisconsin)	50X4 lpm
ROS Toxicity Non-Denuded	T60A20 (Univ Wisconsin)	200lpm

Flow Tests with Thermodenuder

Temperature profiles through the heating section of the denuder with varying flow rates



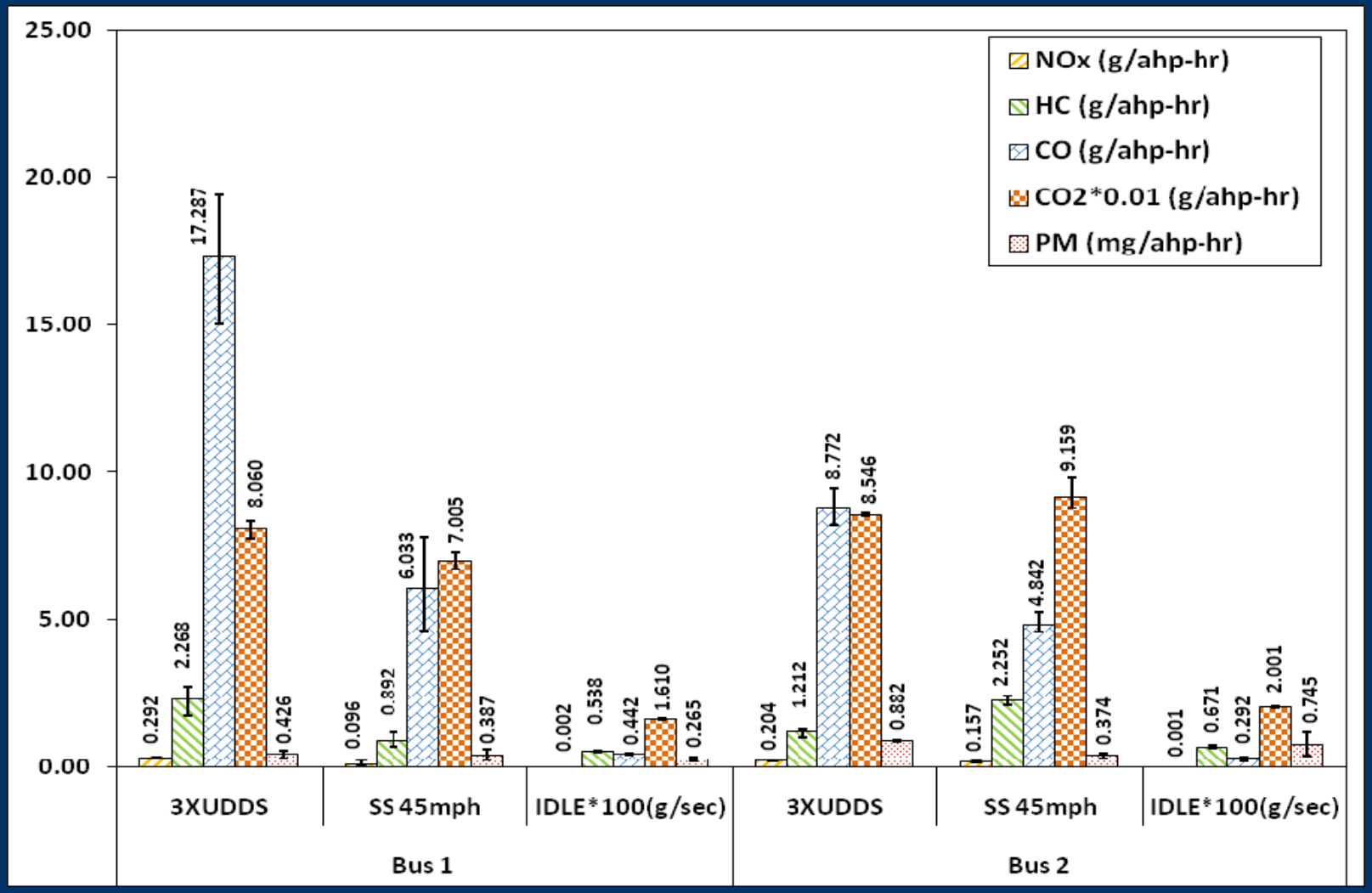


Temperature profiles through the pre-heating section and the heating section of the denuder

- The pre-heating section and the denuder heating sections were set to maximum allowable temperature setting of 300 Deg C.

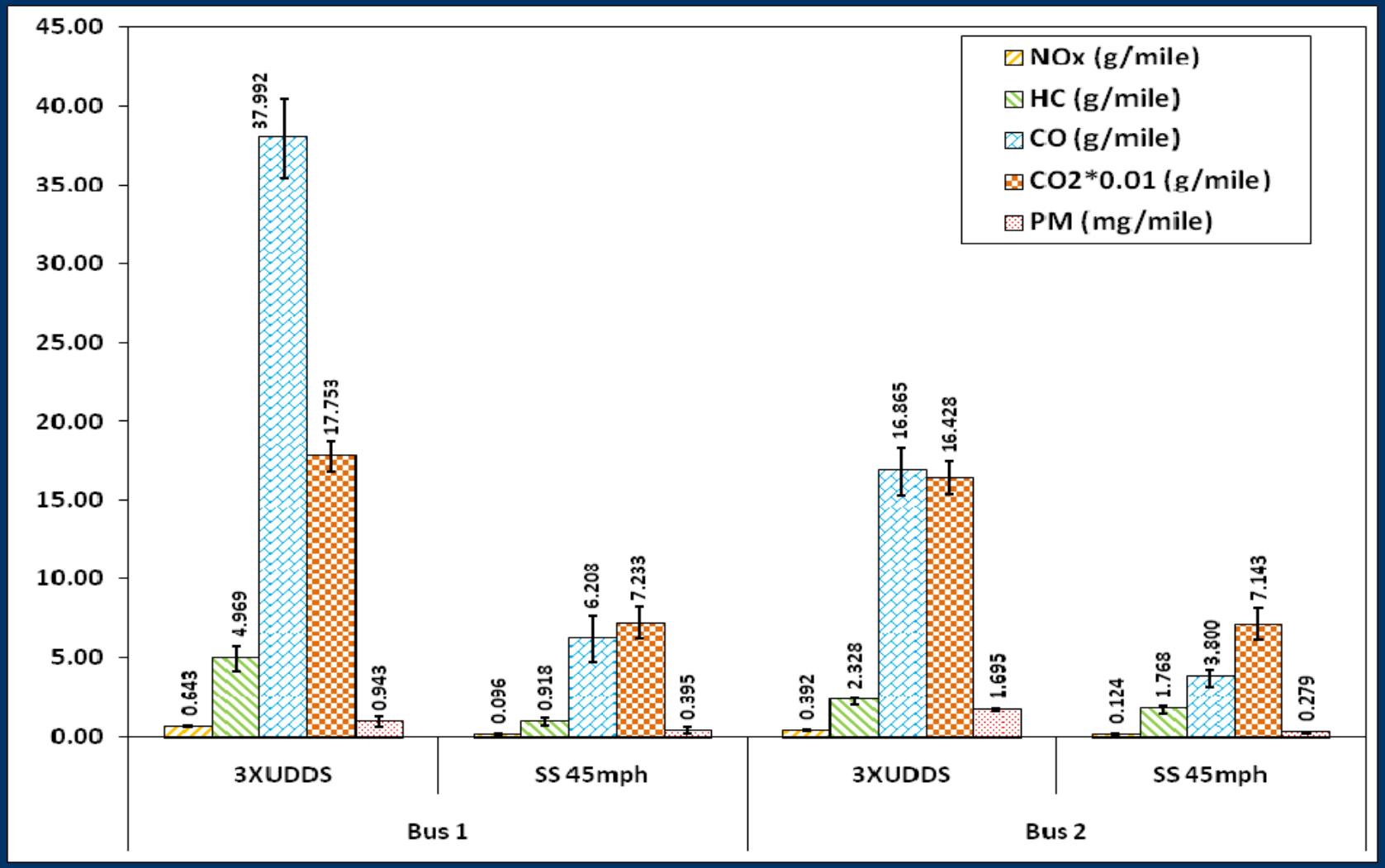
Results

- Axle work specific emissions from the CNG buses

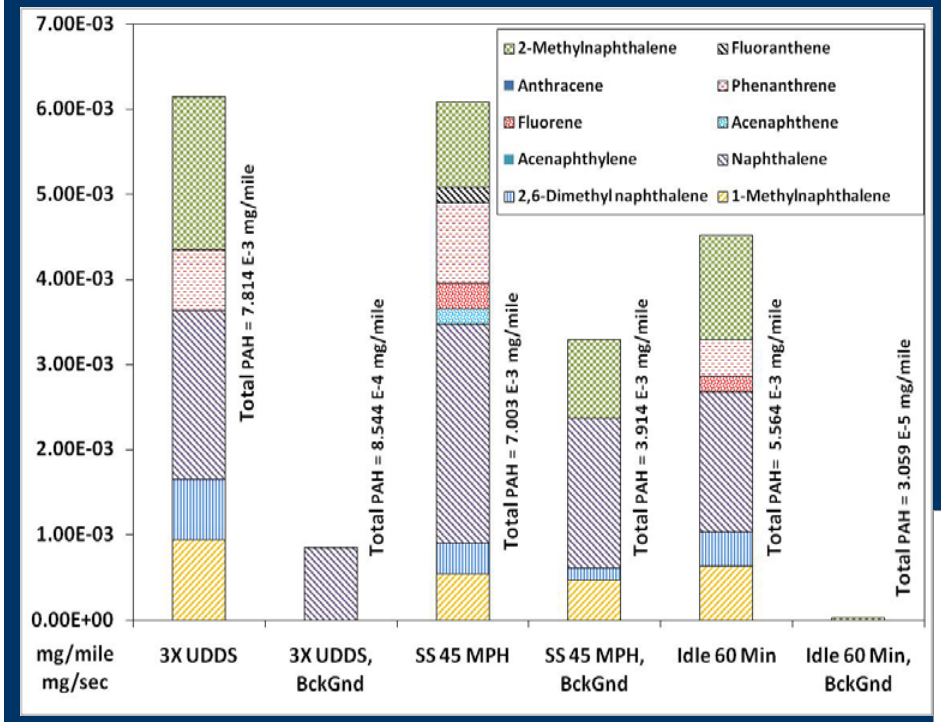


Results

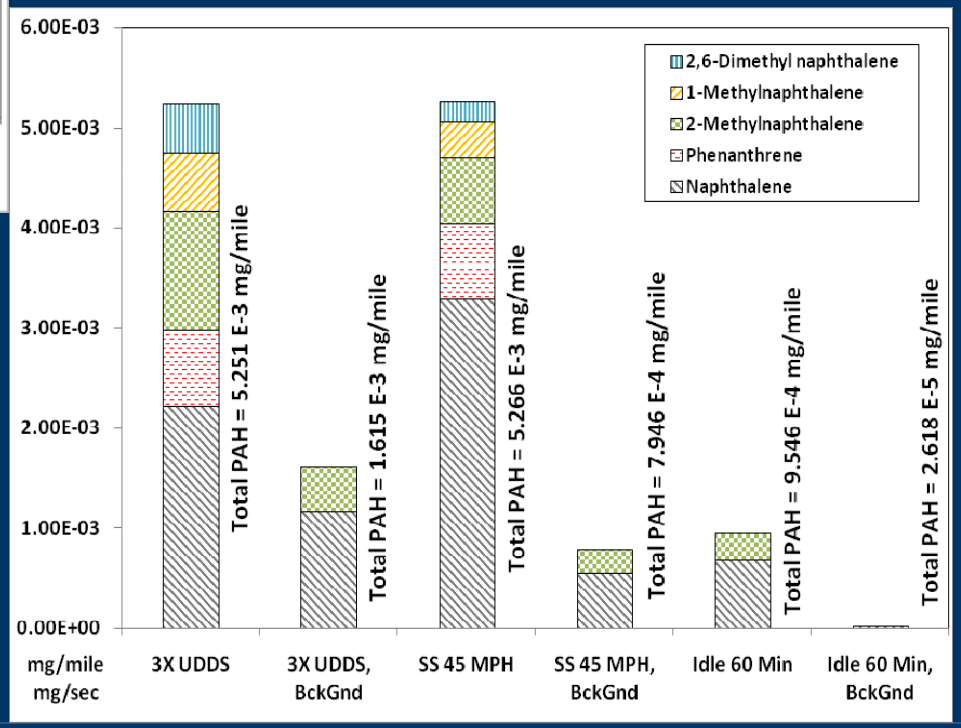
- Distance specific emissions from the CNG buses



Results (Contd.)

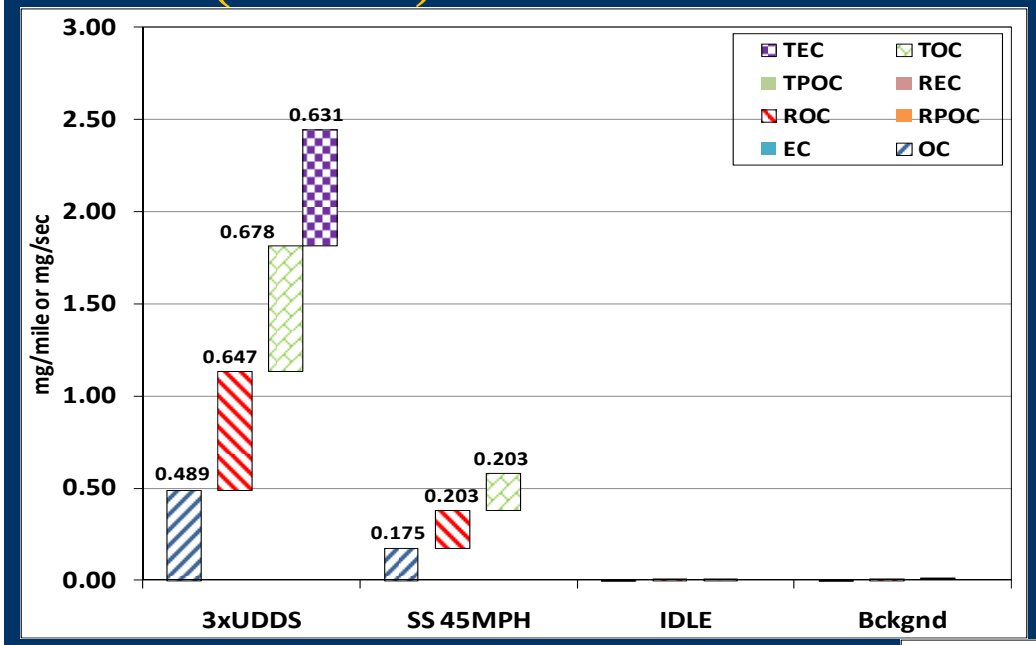


Distance specific PAH emissions from Bus 1



Distance specific PAH emissions from Bus 2

Results (Contd.)



Distance specific EC/OC emissions from Bus 1

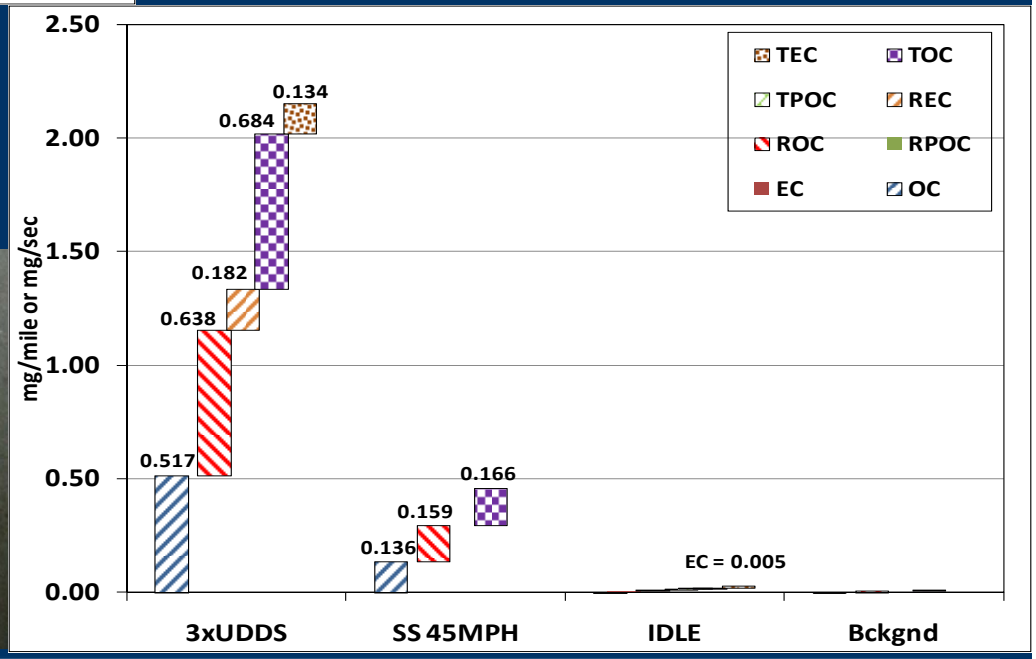
- 64% difference in OC mass between transient and cruise operation
- No detectable EC fraction in PM composition

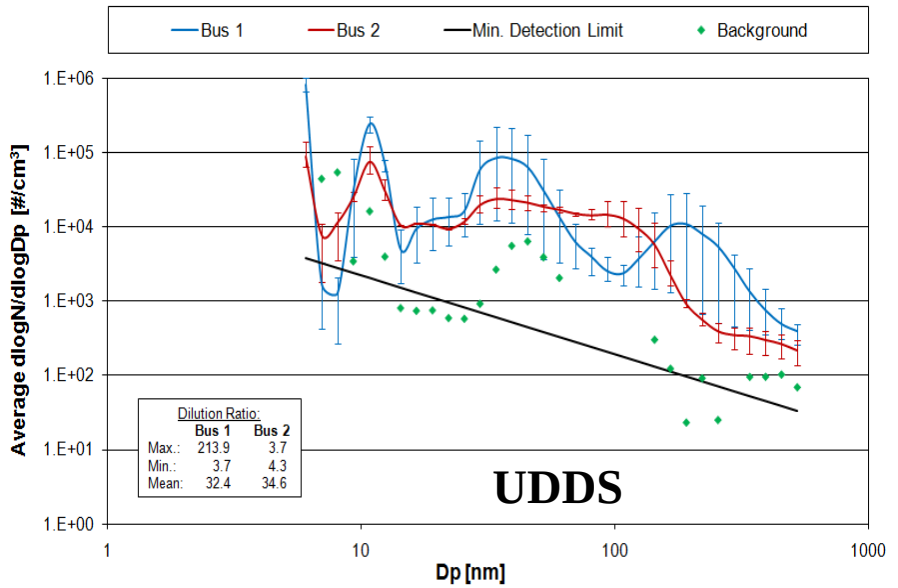
195 mg of EC mass over 9 hrs of Idle

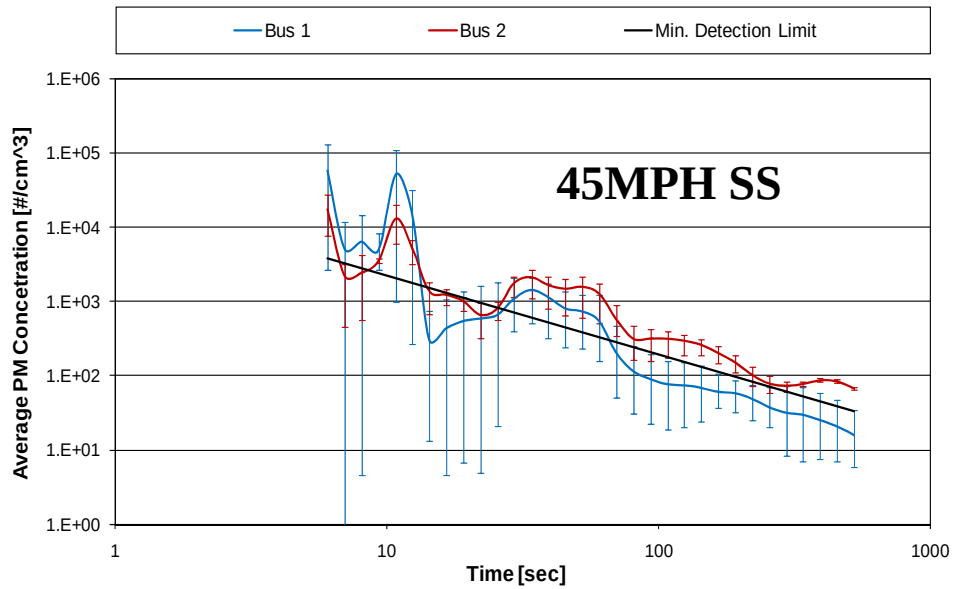
Distance specific PAH emissions from Bus 2

- 0.005 mg/sec of EC composition detected .

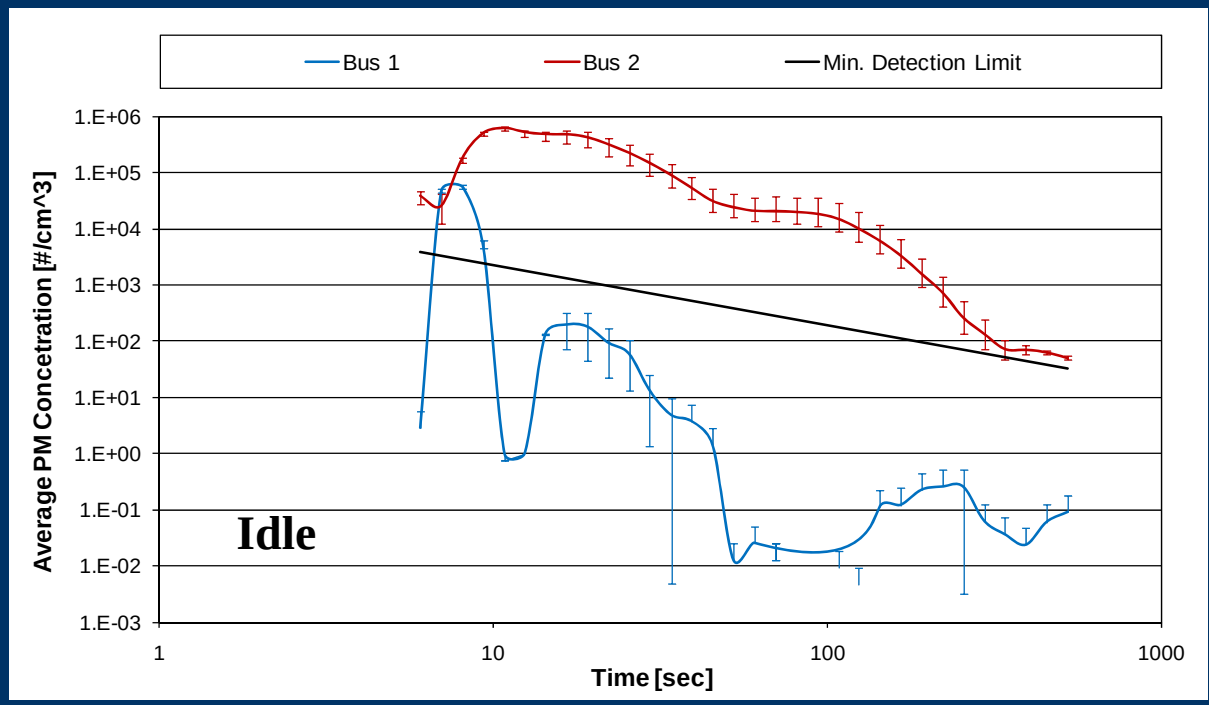
162 mg of EC fraction over 9 hrs of Idle





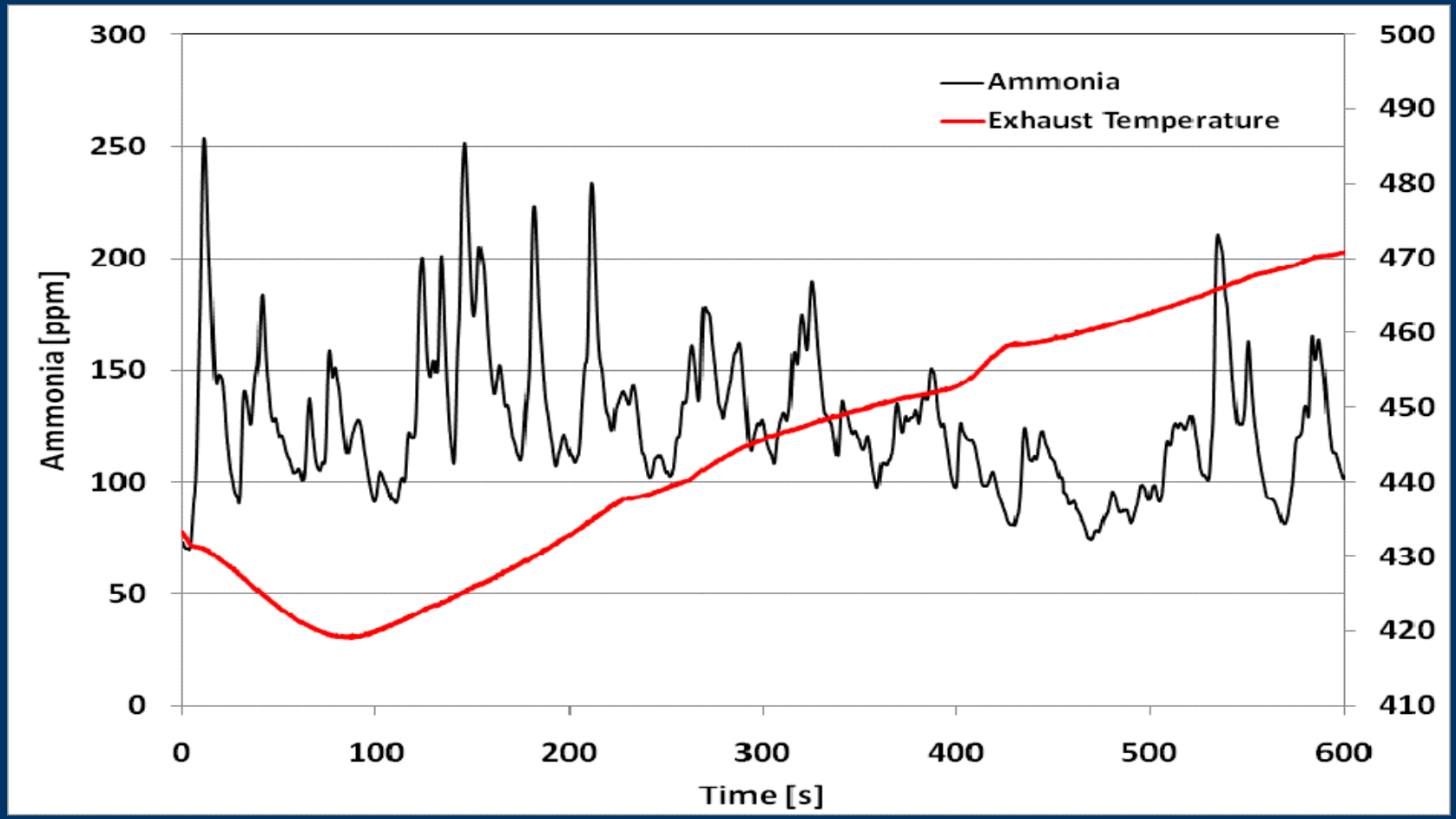


- Particle size distribution averaged over entire cycle, with maximum and minimum error bars.
- Particle concentrations close to detection limit during cruise mode operation.
- Bimodal distribution with significant nucleation mode and accumulation mode particles observed during idle operation



Ammonia Emissions - 20MPH Steady State

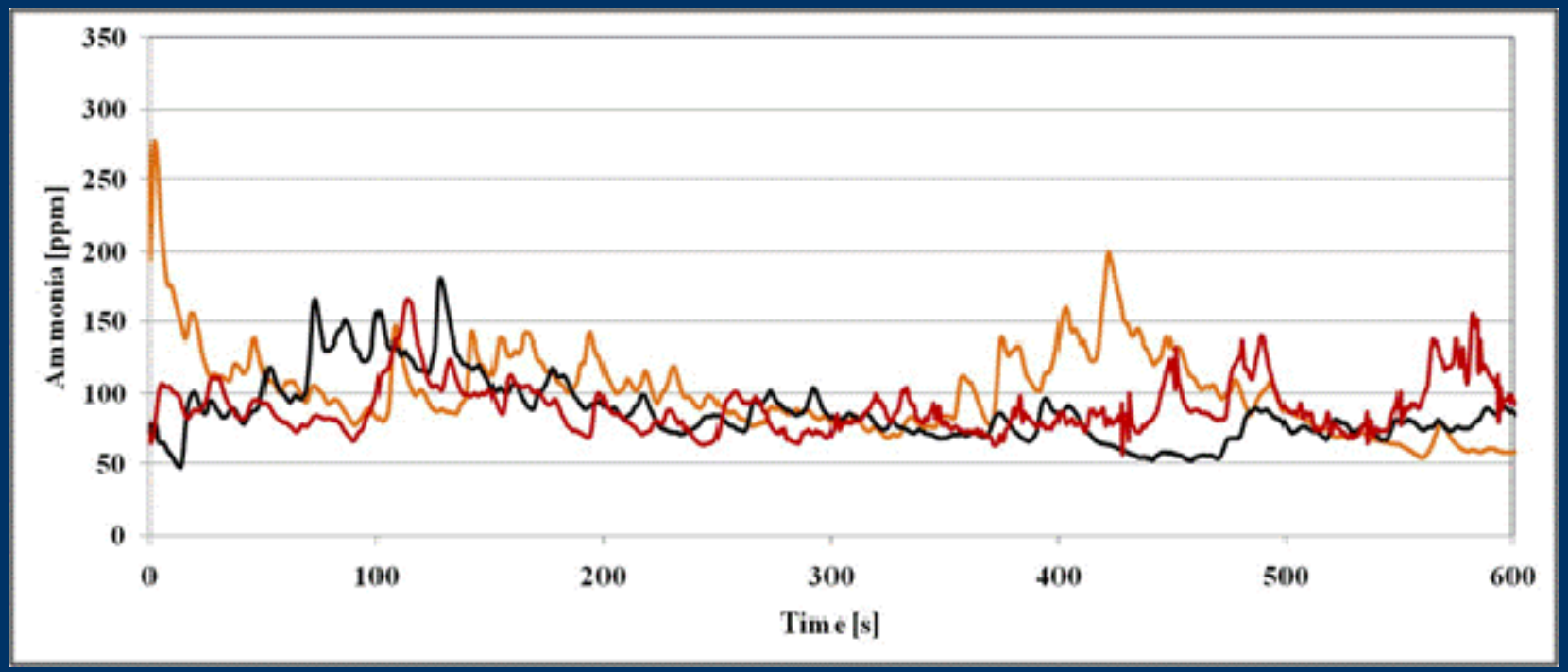
- Average ammonia concentration of 130 ppm.
- Maximum concentration of 261 ppm
- Minimum concentration of 70 ppm



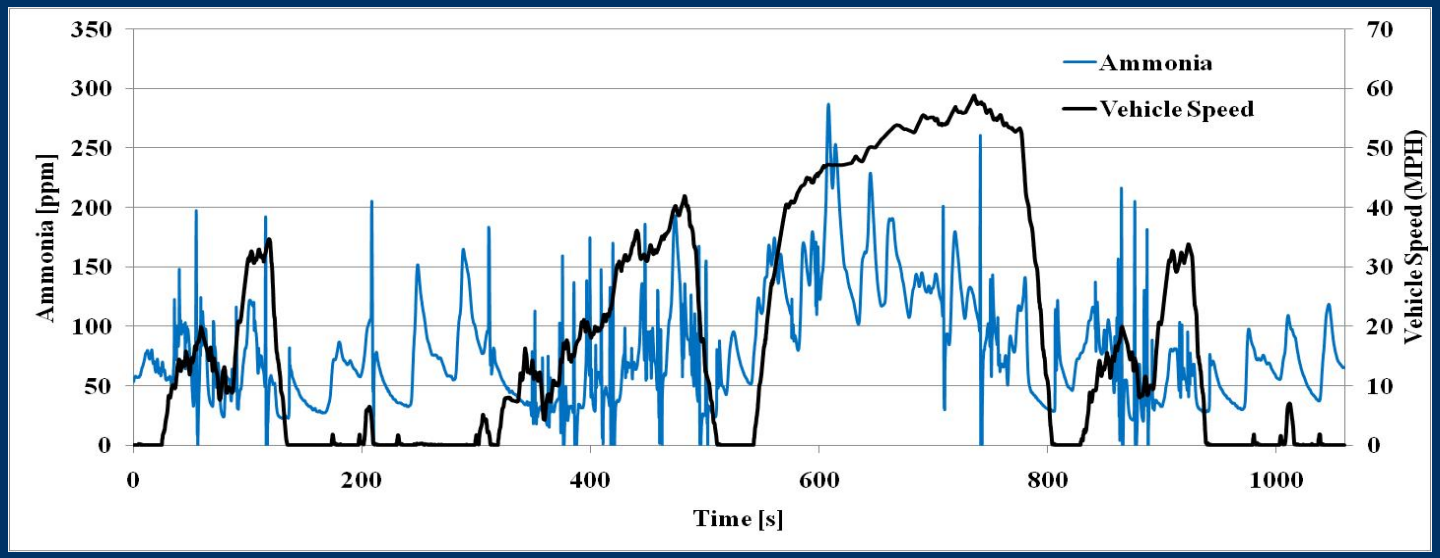
Ammonia Emissions - 40MPH Steady State

• Better air-fuel ratio control at higher vehicle speeds probably results in lower average ammonia emissions

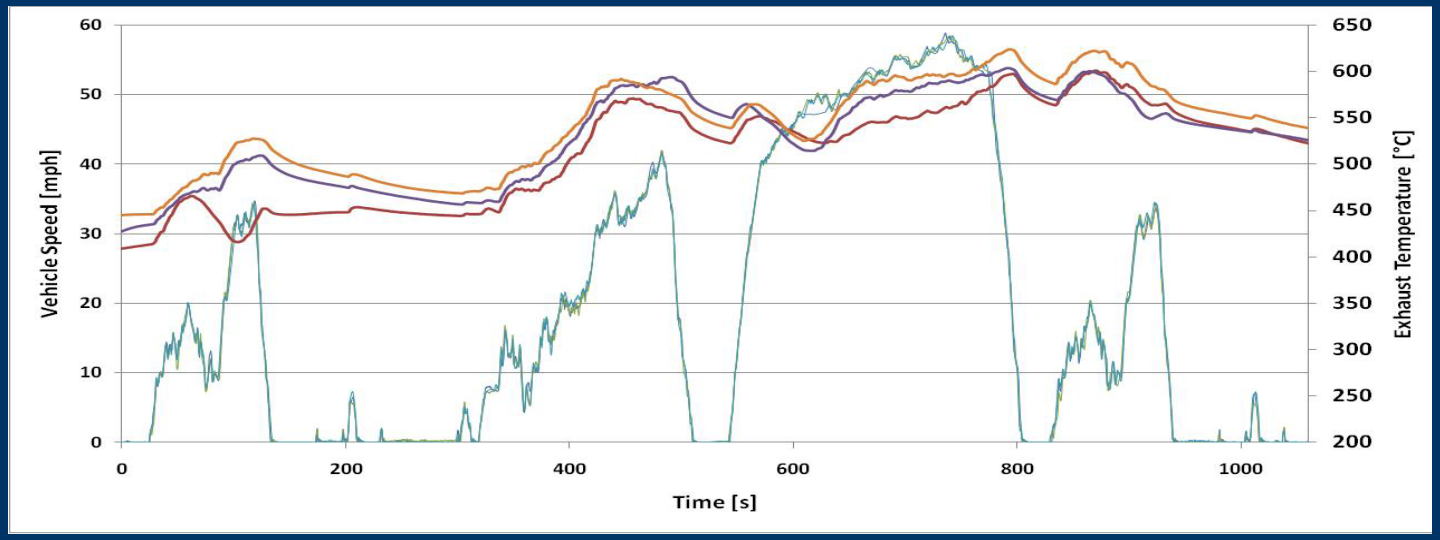
Speed	Average	Maximum	Minimum
20MPH	111	330	35
35MPH	87	230	38
45MPH	88	277	34



Ammonia Emissions - UDDS



Average = 75ppm
Max = 287ppm
Min = 15ppm



Conclusions

- Use of a 3-way catalyst resulted in NOx levels below 0.248g/ahp-hr during transient operation and close to zero during cruise mode operation.
- Bus 1 PM emissions were 52% lower over the UDDS and 64% lower over idle operation in comparison to Bus 2. Indicating possible lube oil combustion.
- Unregulated emissions were found to be below detection limits from both vehicles.
- Almost the entire fraction of hydrocarbon emissions consisted of methane.
- Significantly high levels of ammonia was detected in the tailpipe.
- Further results of toxicity assays are expected back before conclusions can be drawn regarding the contribution of volatile and non-volatile fraction of PM towards toxicity responses.