Emissions of Toxic Pollutants from Compressed Natural Gas and Ultra-low Sulfur Diesel - Fueled Transit Buses

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Overall Objective

Investigate the regulated and toxic pollutant emissions from heavy-duty vehicles with and without control technologies.

Project Aims

- Investigate toxic emissions for CNG and ULSD-fueled heavy duty diesel vehicles
- Investigate the effect of after-treatment control technologies on emissions
- Investigate the effect of test cycles on emission rates
- Investigate ultrafine PM emissions

Project Notes

- Study is a “snap-shot” of the fleet and not a fleet average

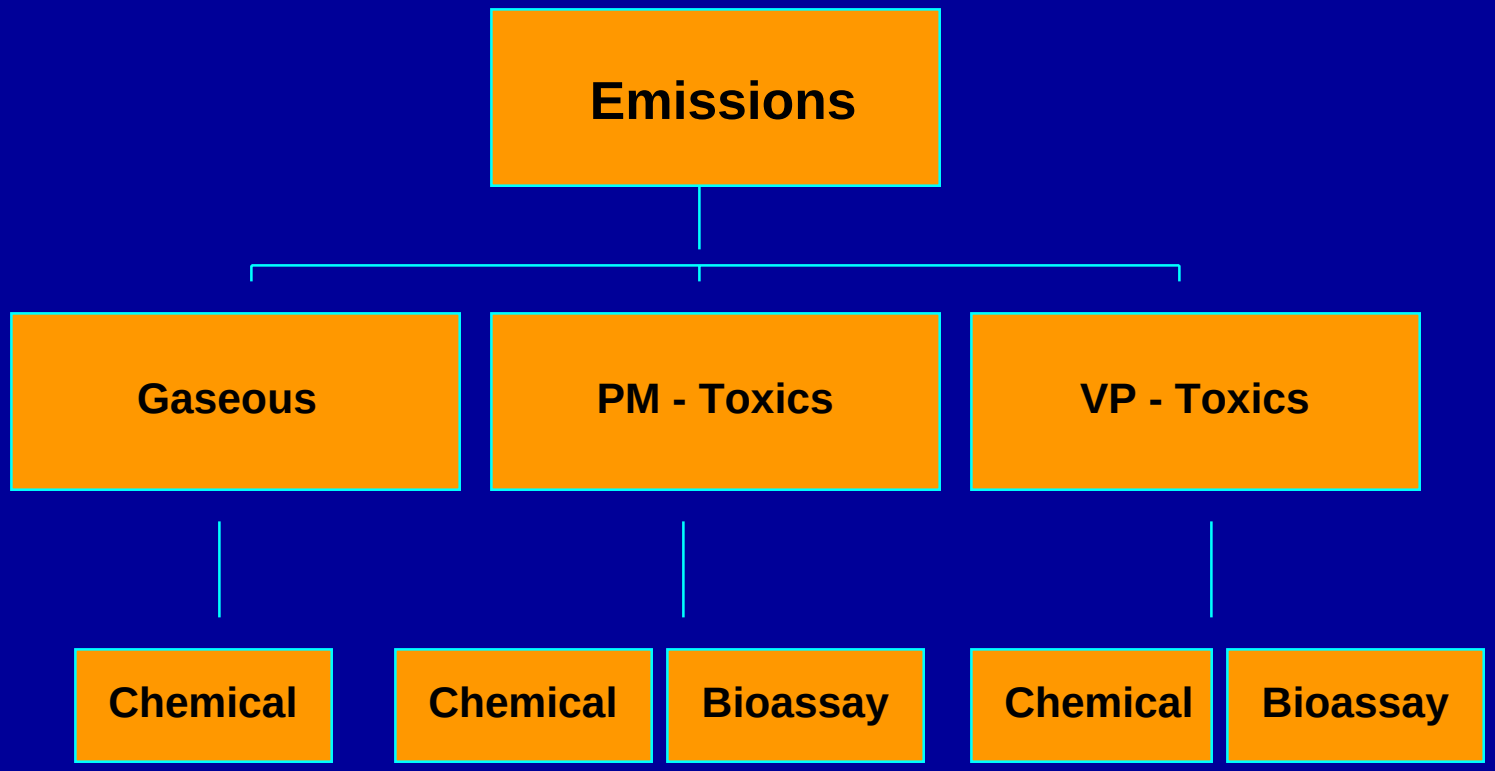
Research Team

- ARB – Research Div, Stationary Source Div., Mobile Source Control Div., Monitoring Laboratory Div. & CAVTC.
- Dept. Environmental Toxicology, UC Davis; Dept. Environmental Engineering, UC Davis.

Contributing:

- South Coast AQMD, UCLA

Experimental Design



Vehicle Configurations

Configuration	Phase 1a (2001)	Phase 1b (2002)
Diesel w/ OC	✓	
Diesel w/ DPF	✓	✓
CNG no OC	✓	
CNG w/ OC		✓ CNG00 ✓ CNG01

Vehicles and After-Treatments

Vehicle	Model Yr	Engine Make	After-Treatment (Study)	Fuel
Diesel	1998	DDC-S50	DOC (1a) OC-DPF (1a)	ULSD
CNG 00	2000	DDC-S50G	None (1a & 1b) OC (1b)	CNG
CNG 01	2001	Cummins-Westport C-Gas Plus	OC (1b)	CNG

Catalyzed Diesel Paticulate Filter (DPF) for DDC 50 Diesel (Johnson-Matthey, Inc)

Oxidative Catalyst for CNG DDC S50G Engine

Fuels

- Ultra-Low Sulfur Diesel (ULSD)
  - < 15 ppm sulfur
- Compressed Natural Gas (CNG)
  - Methane (mole %): > 88%

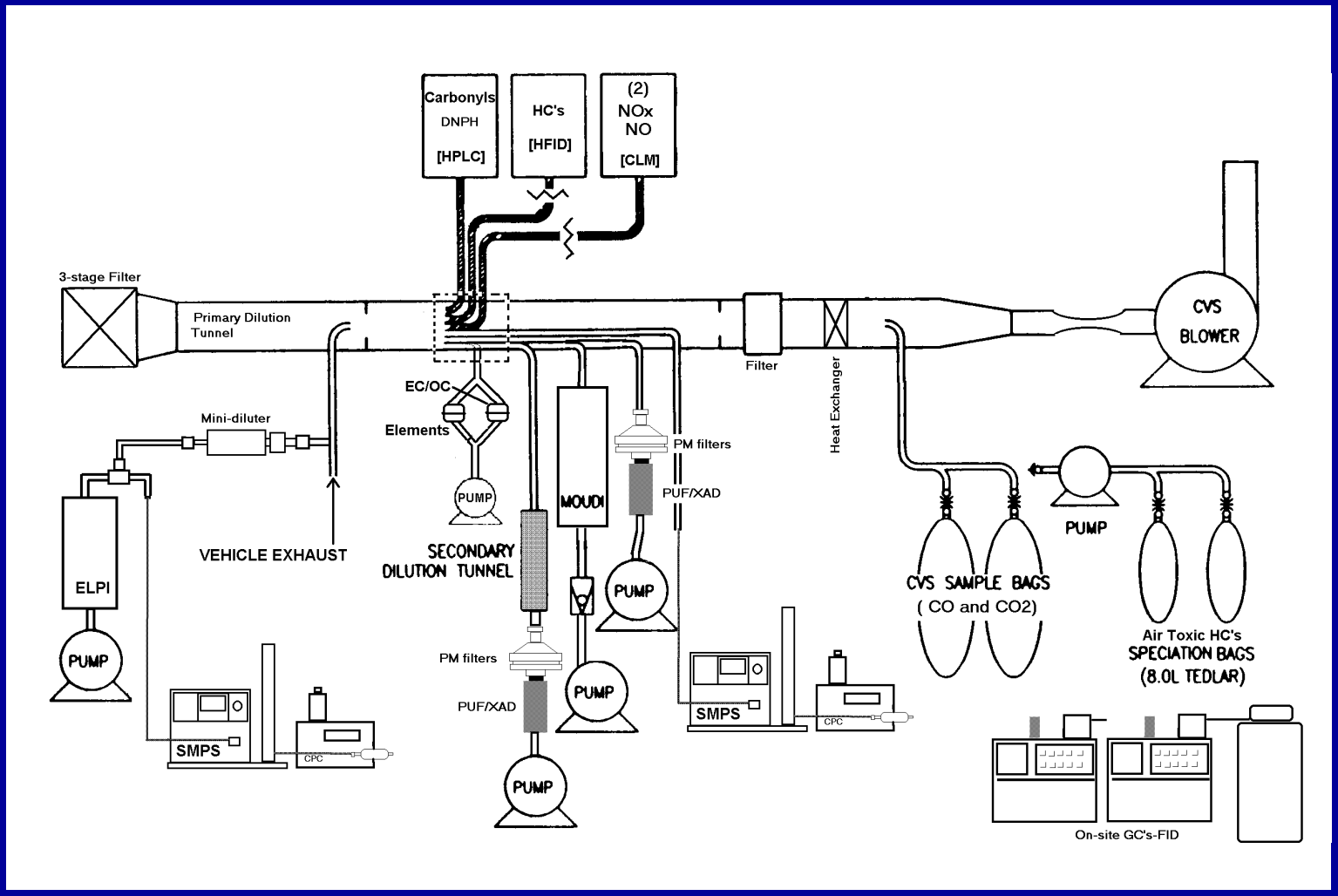
Measurements
Phases 1a & 1b

- Regulated pollutants (TPM, THC/NMHC, NOx, NO_2, CO, CO_2)
- On-site, VOC-GC analyses c matching off-site analyses
- Elemental/Organic Carbon
- Elements
- PM size-segregated mass (1a only), PM number & size

Toxic Pollutant Measurements

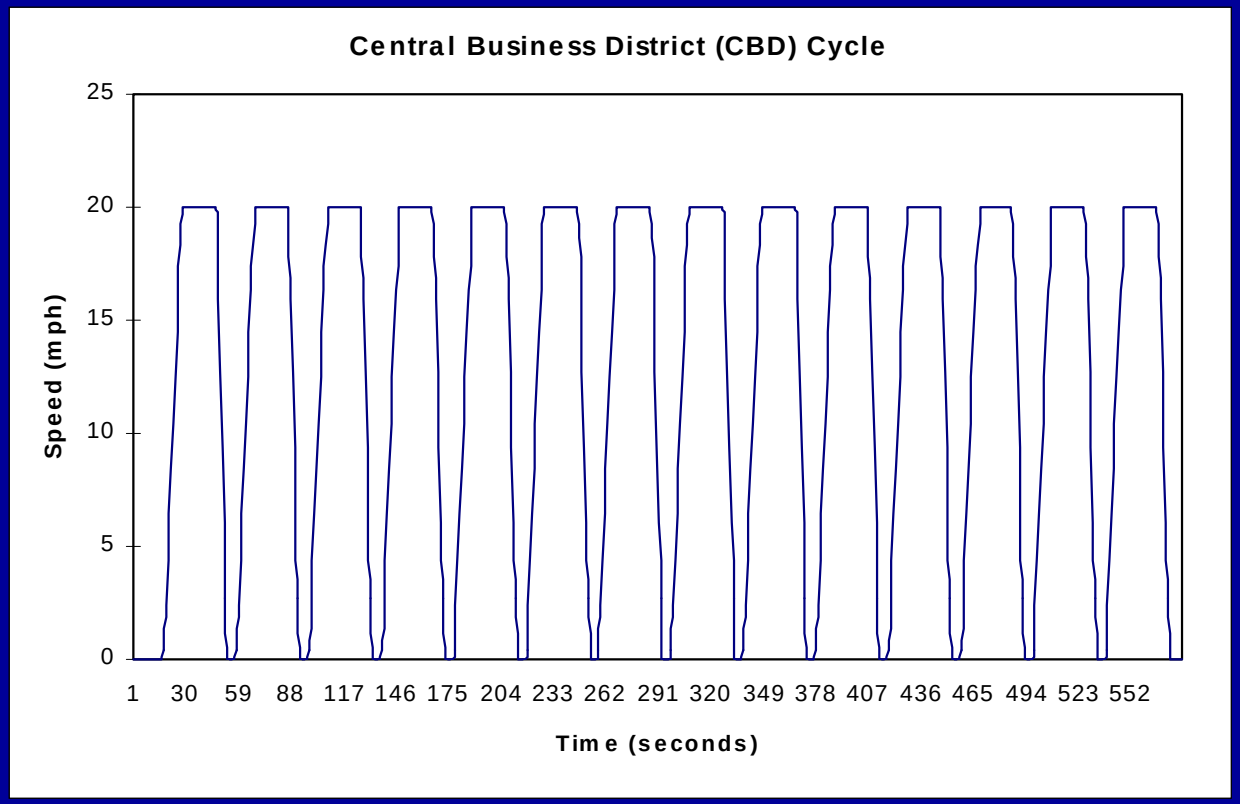
- Polycyclic Aromatic Hydrocarbons (PAHs)
- Carbonyls, BTEX, 1,3 Butadiene
- Bioassay - mutagenicity

Sampling

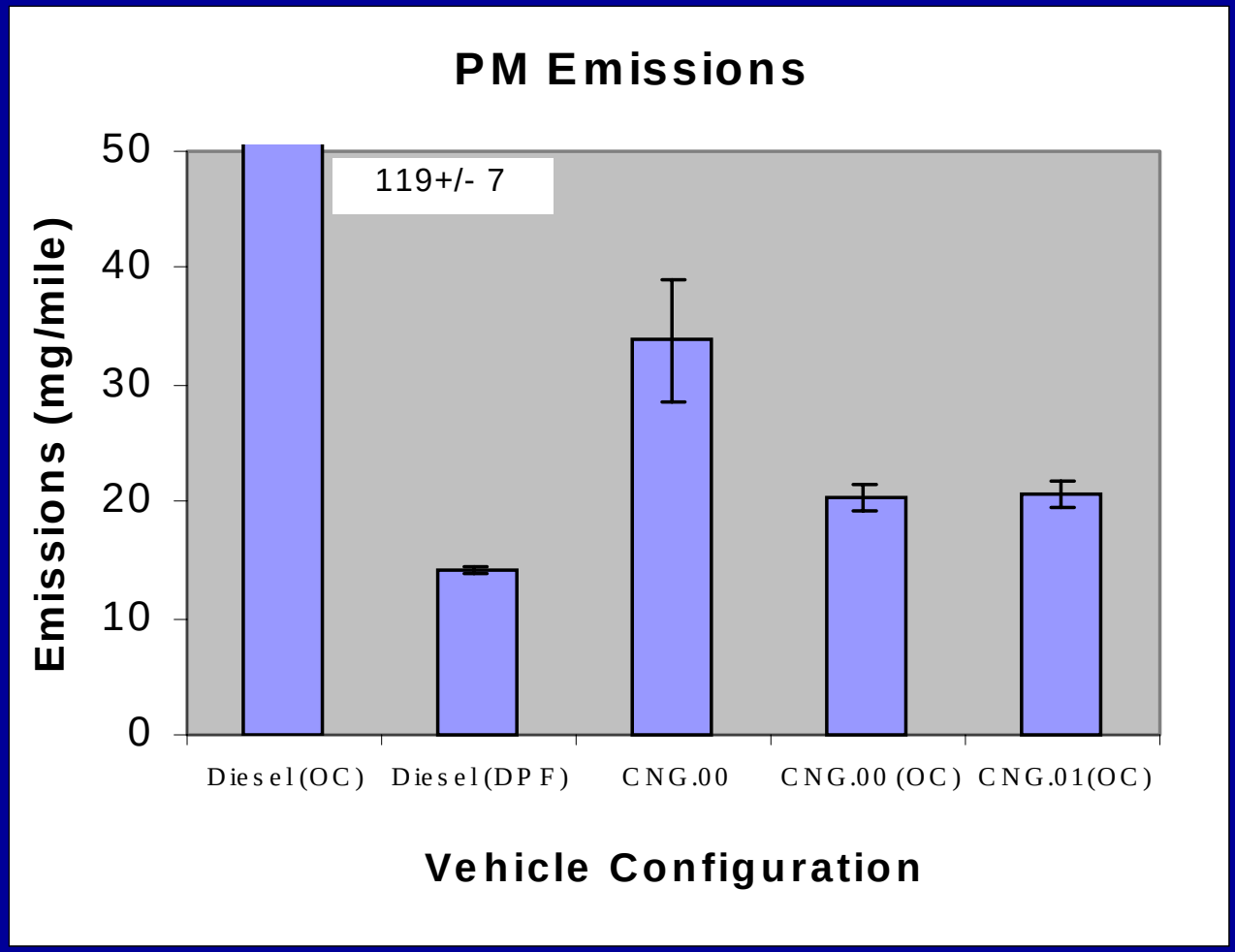

Carbonyls
DNPH
[HPLC]
HC's
[HFID]
(2)
NOx
NO
[CLM]
3-stage Filter
Primary Dilution Tunnel
CVS BLOWER
Filter
Heat Exchanger
EC/OC
Elements
Mini-diluter
PUMP
MOUDI
PM filters
PUF/XAD
VEHICLE EXHAUST
SECONDARY DILUTION TUNNEL
ELPI
PUMP
CVS SAMPLE BAGS
(CO and CO2)
Air Toxic HC's
SPECIATION BAGS
(8.0L TEDLAR)
SMPS
CPC
On-site GC's-FID


115
5300

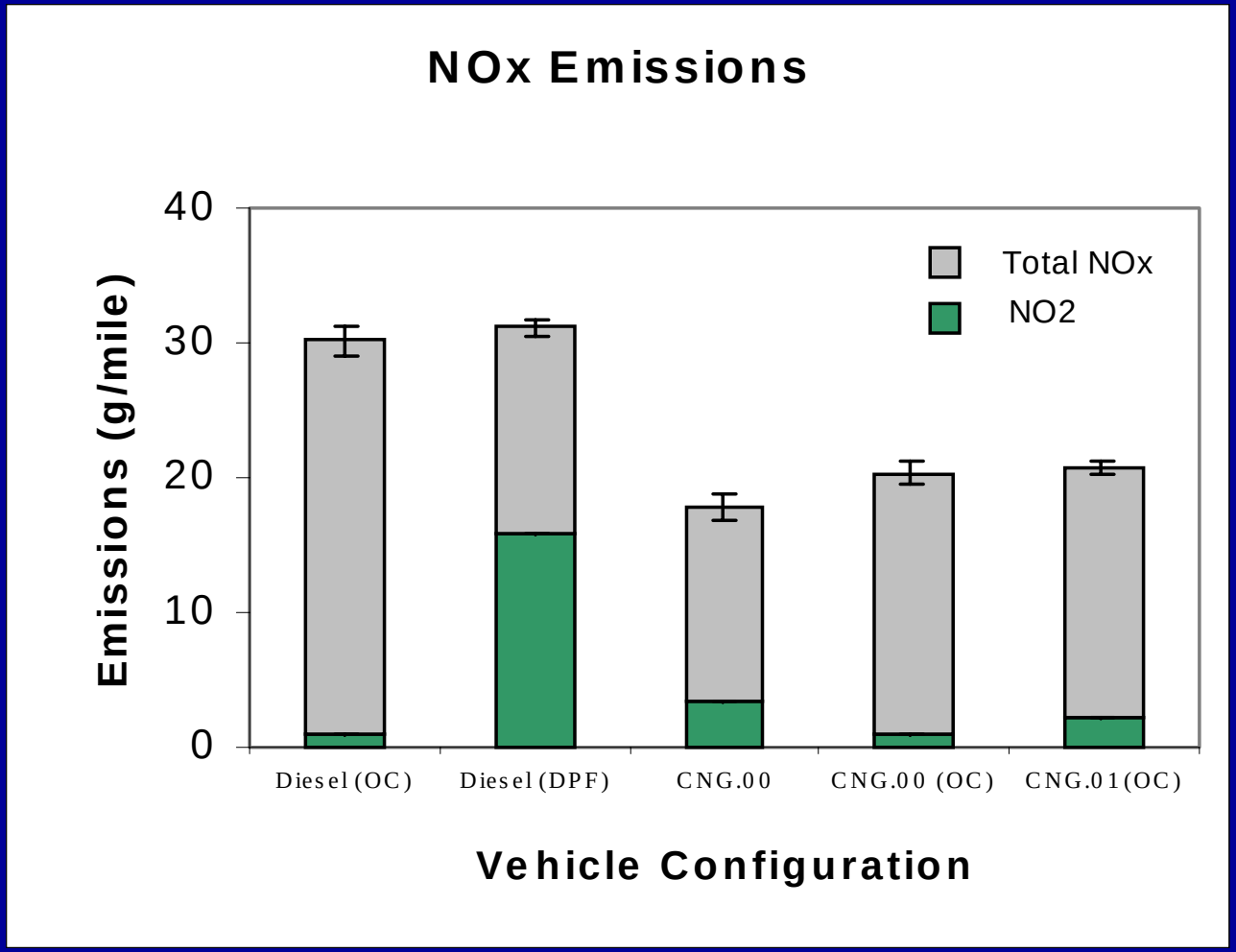
Central Business District Cycle



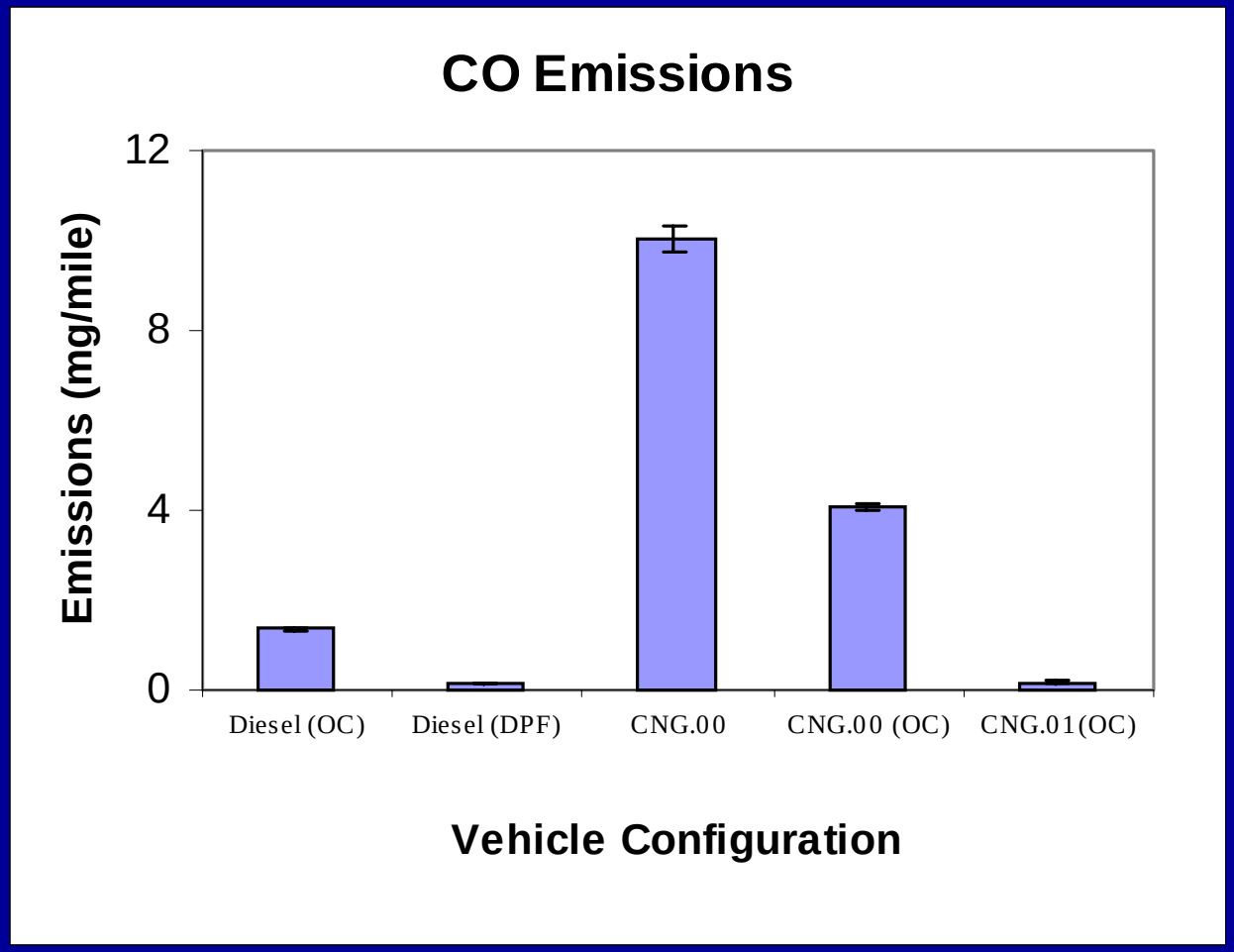
PM Emissions – CBD



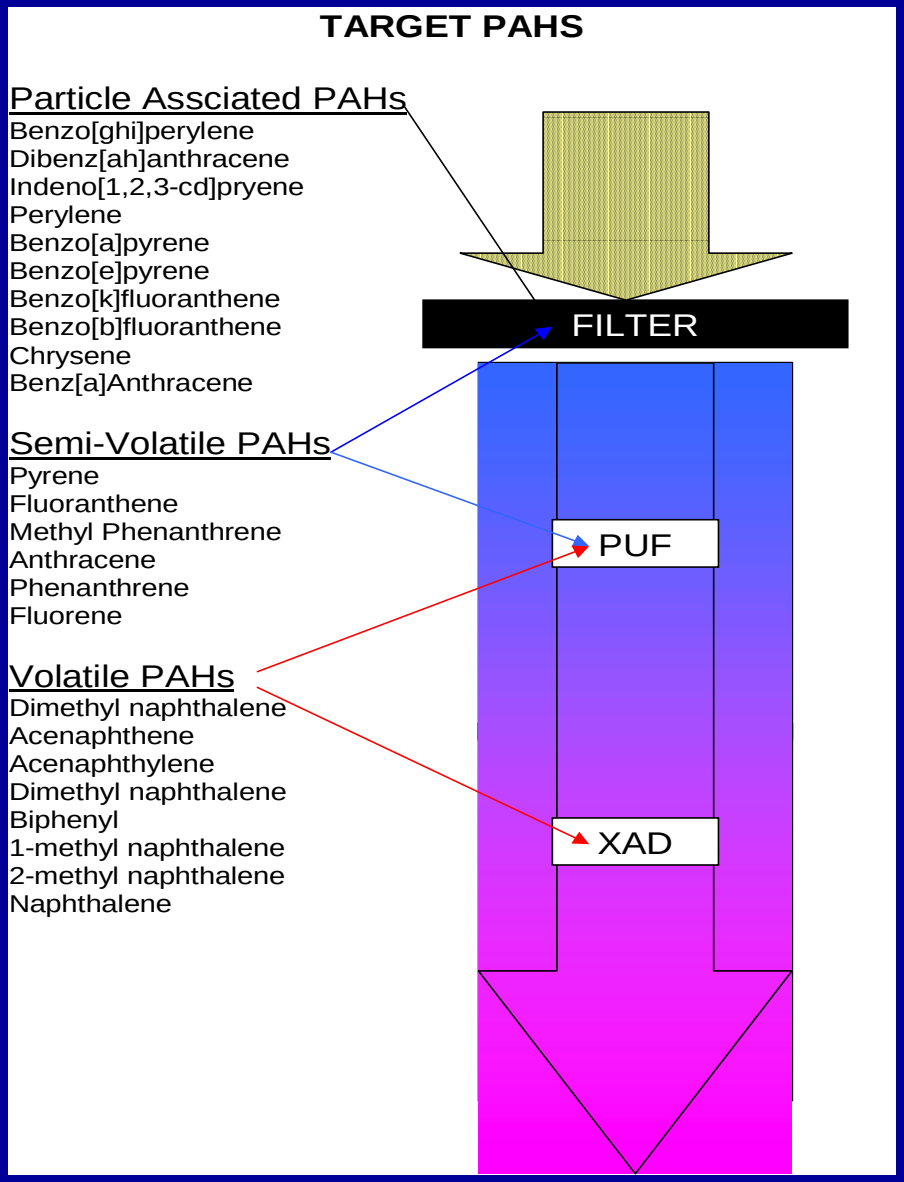
NOx Emissions – CBD



CO Emissions - CBD

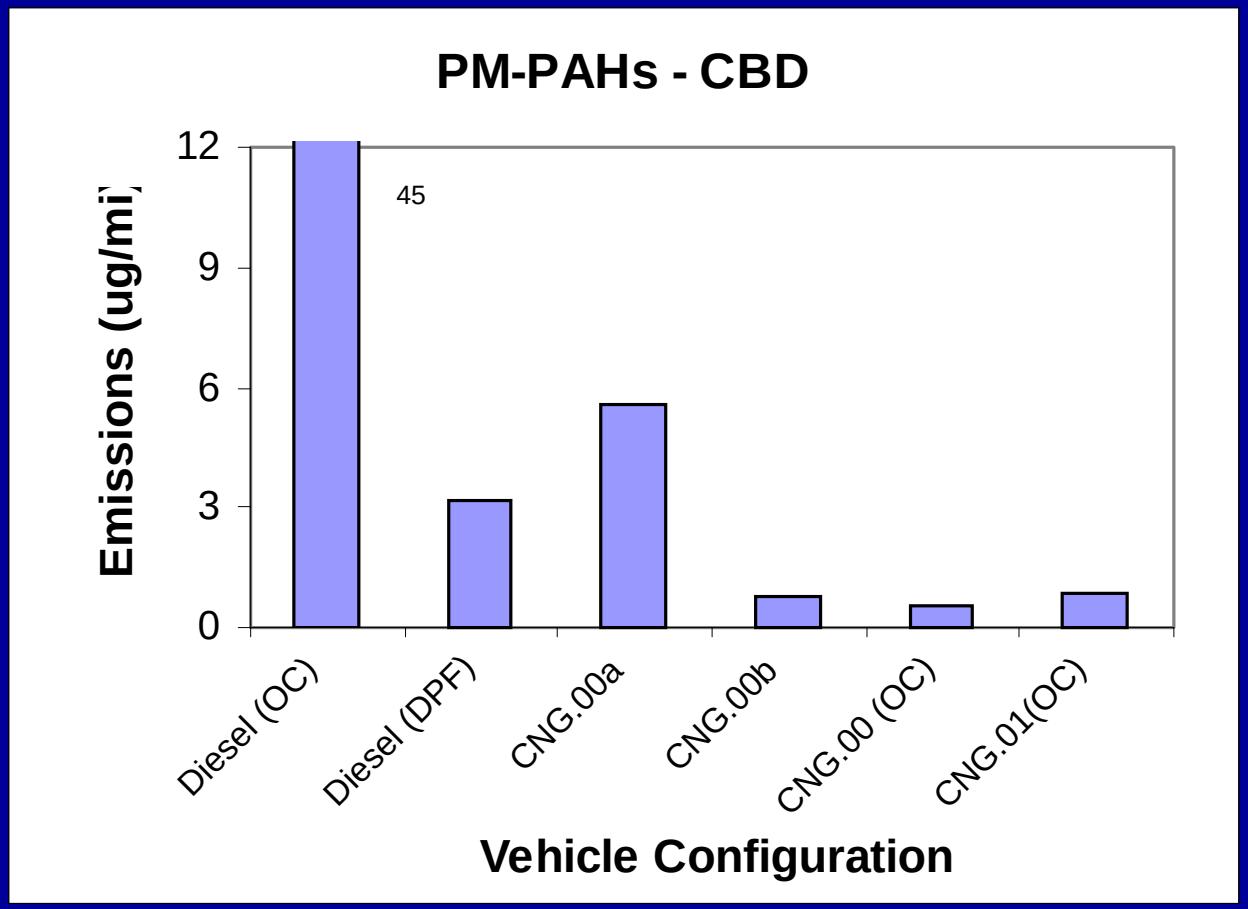


Polycyclic Aromatic Hydrocarbons

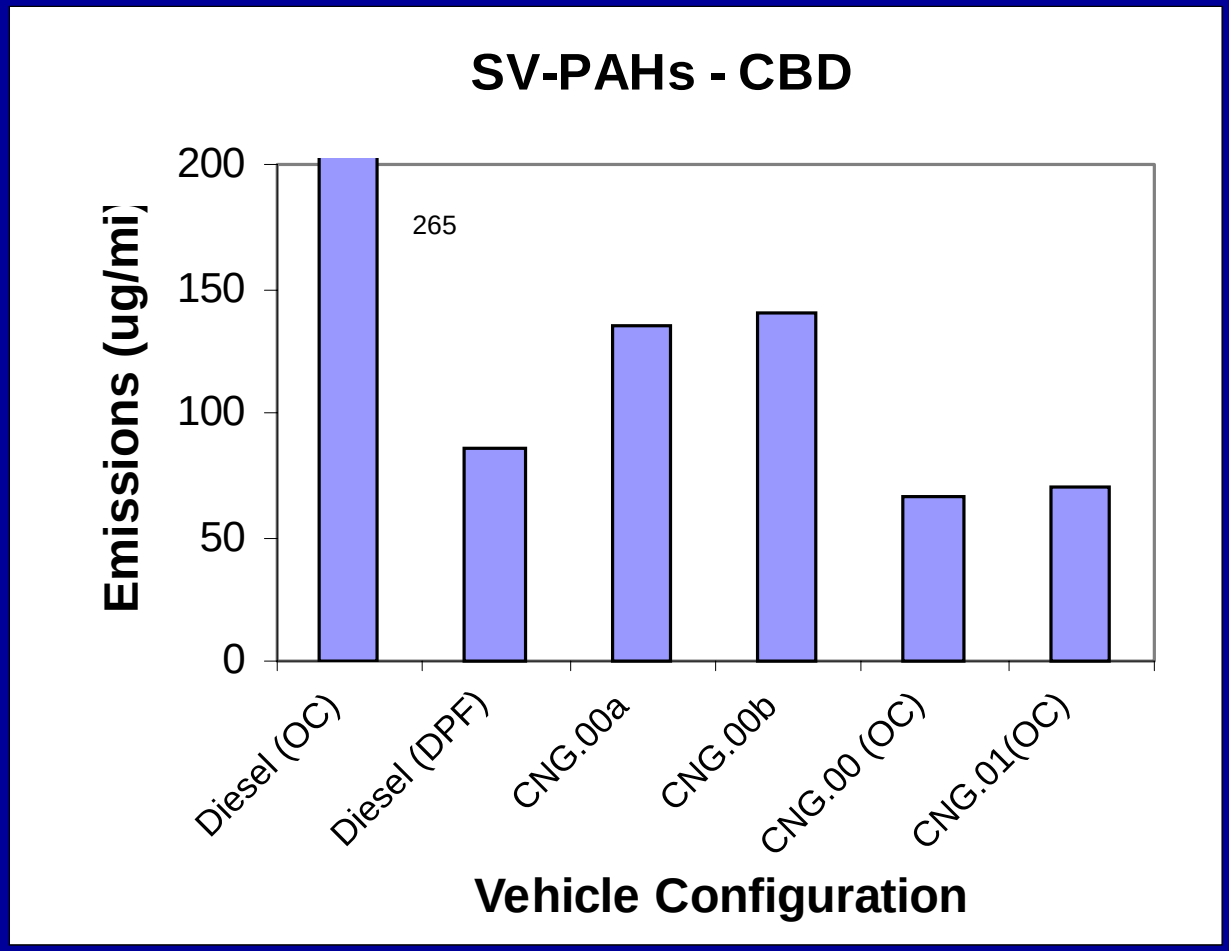


Expected PAH phase distribution in ambient and exhaust samples

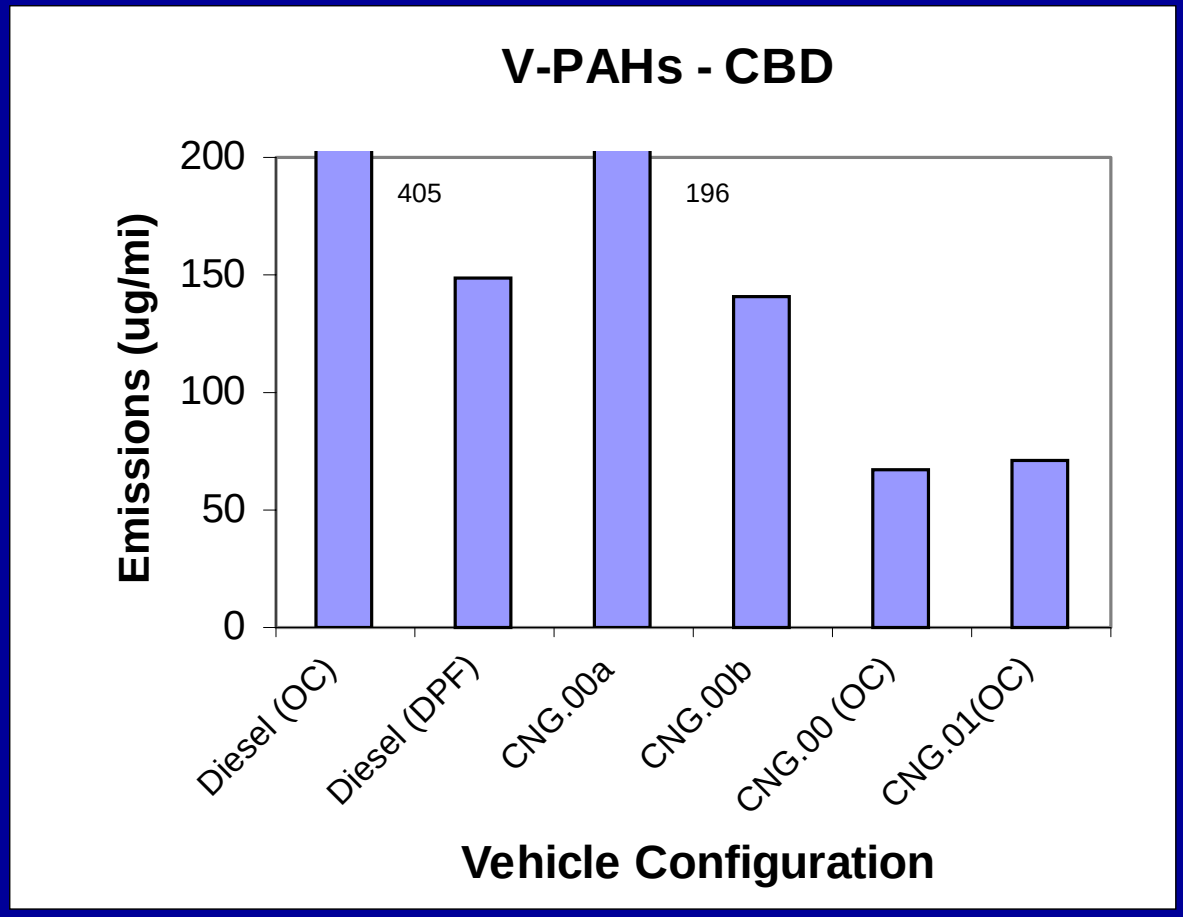
Polycyclic Aromatic Hydrocarbons



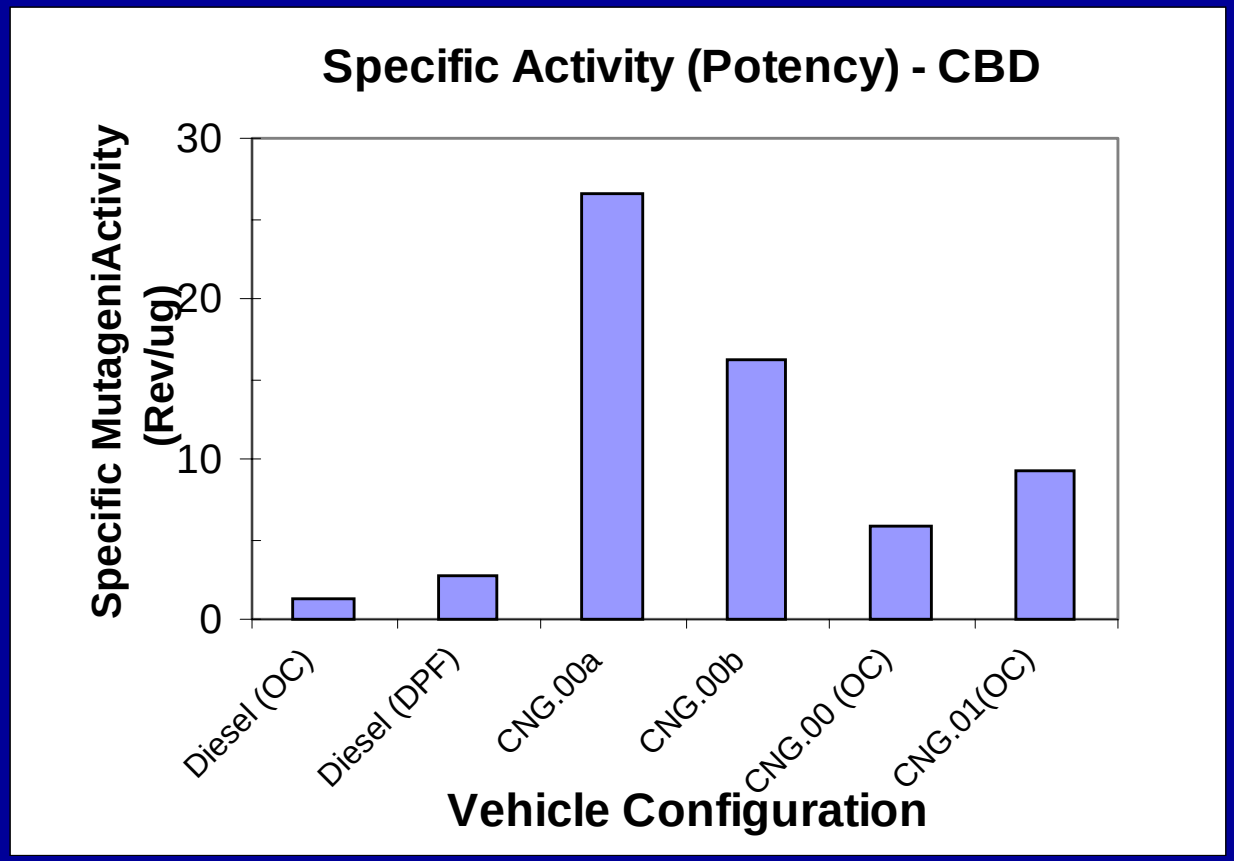
Polycyclic Aromatic Hydrocarbons



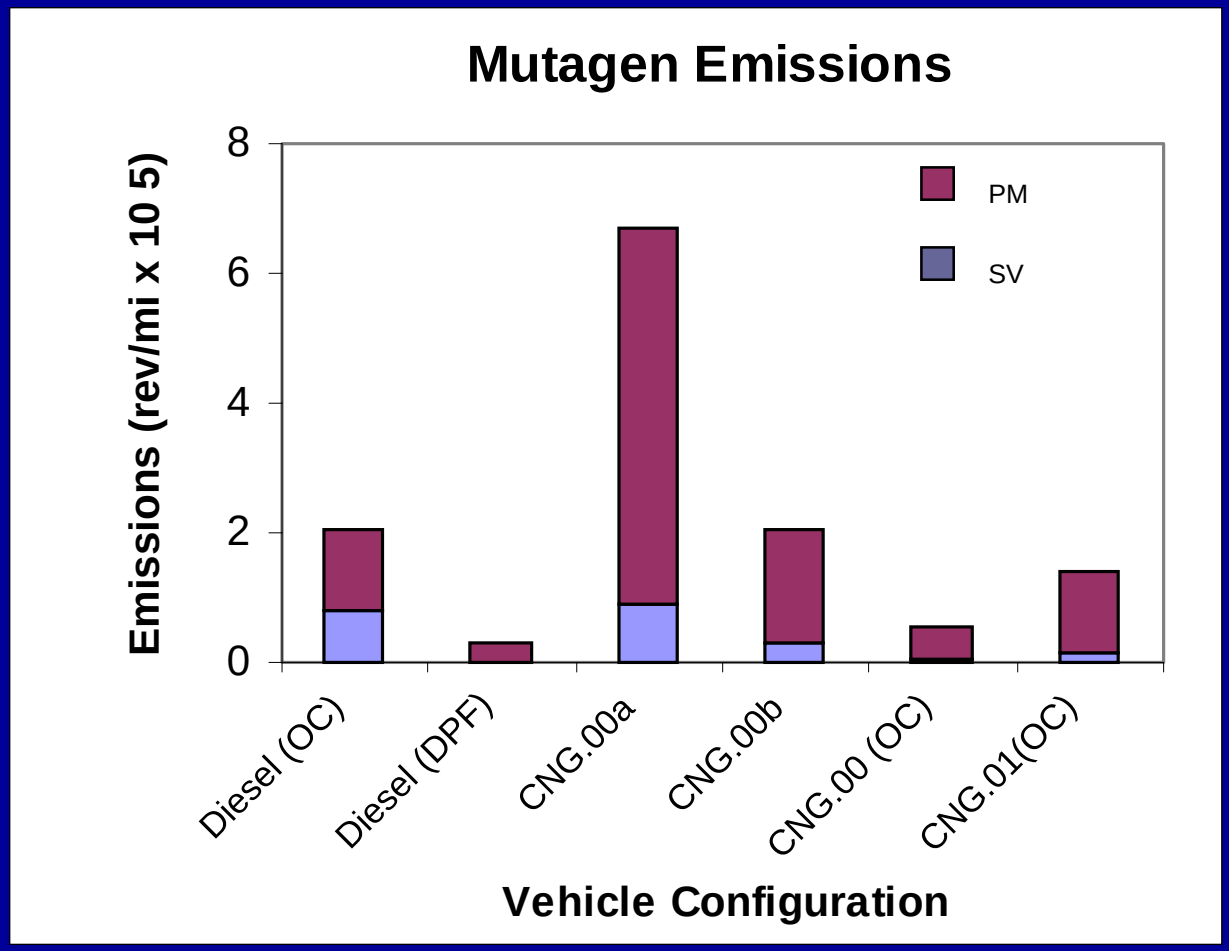
Polycyclic Aromatic Hydrocarbons



Mutagenic Potency



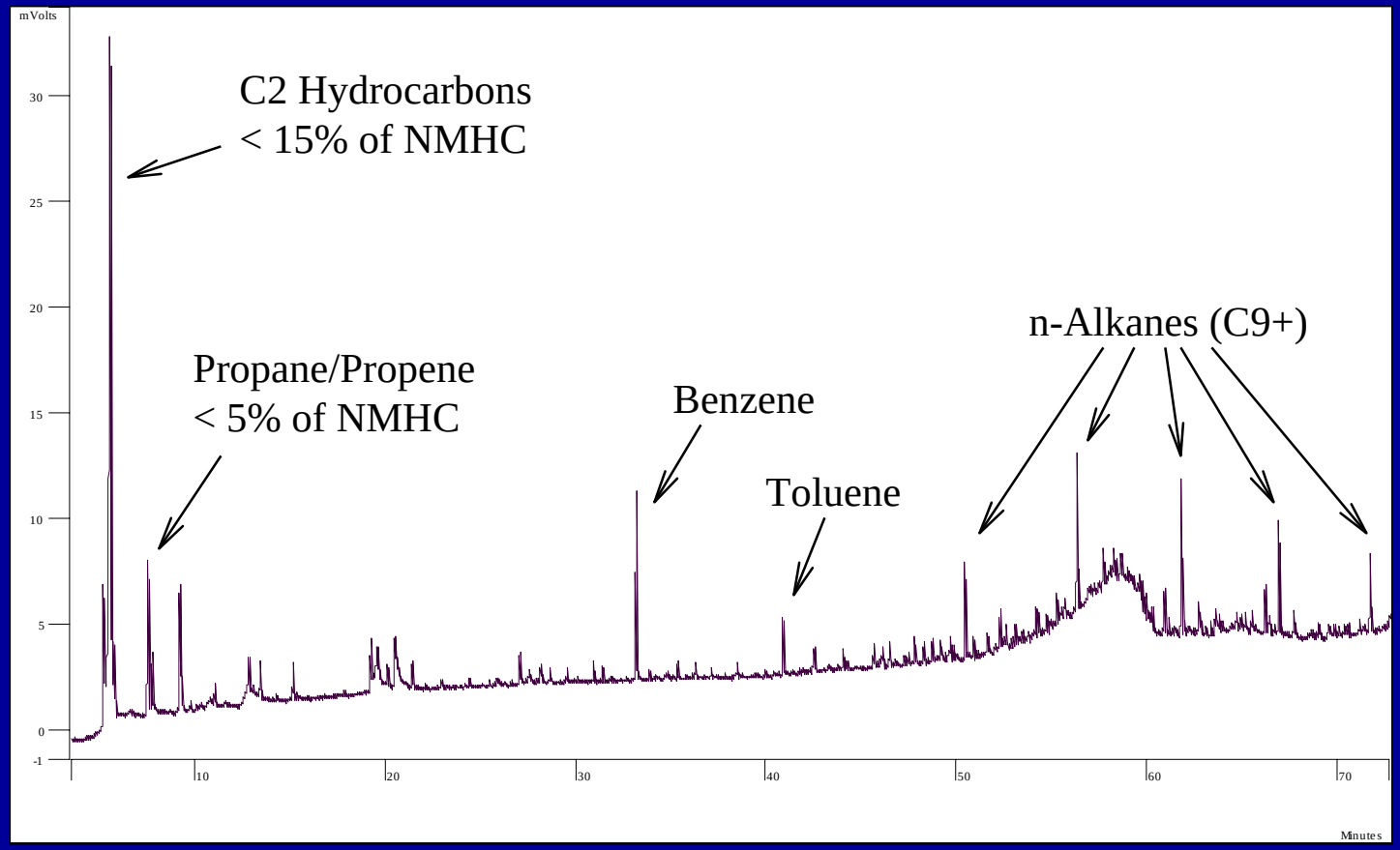
Mutagen Emissions - CBD



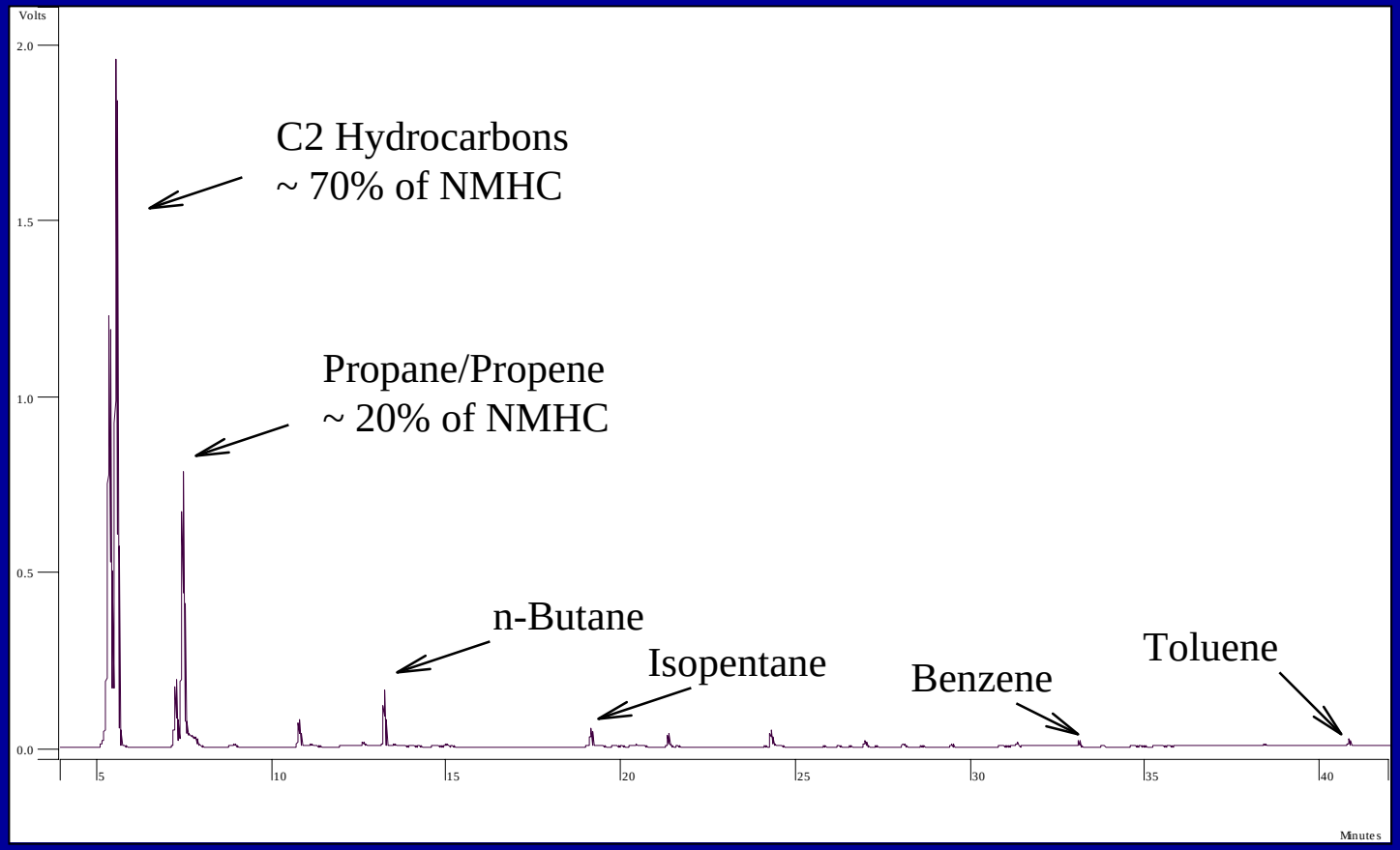
HYDROCARBON ANALYSIS

- Tedlar Bag Sampling
- Onsite GC to limit hold time
- SOP # MLD 102/103
  GC/FID Analysis w/cryo-trapping
  Speciation of C2-C12+
- Report:
  Benzene, Toluene, Ethyl Benzene, Xylenes (BTEX) and
  1,3 Butadiene
- GC/MS Confirmation of BTEX

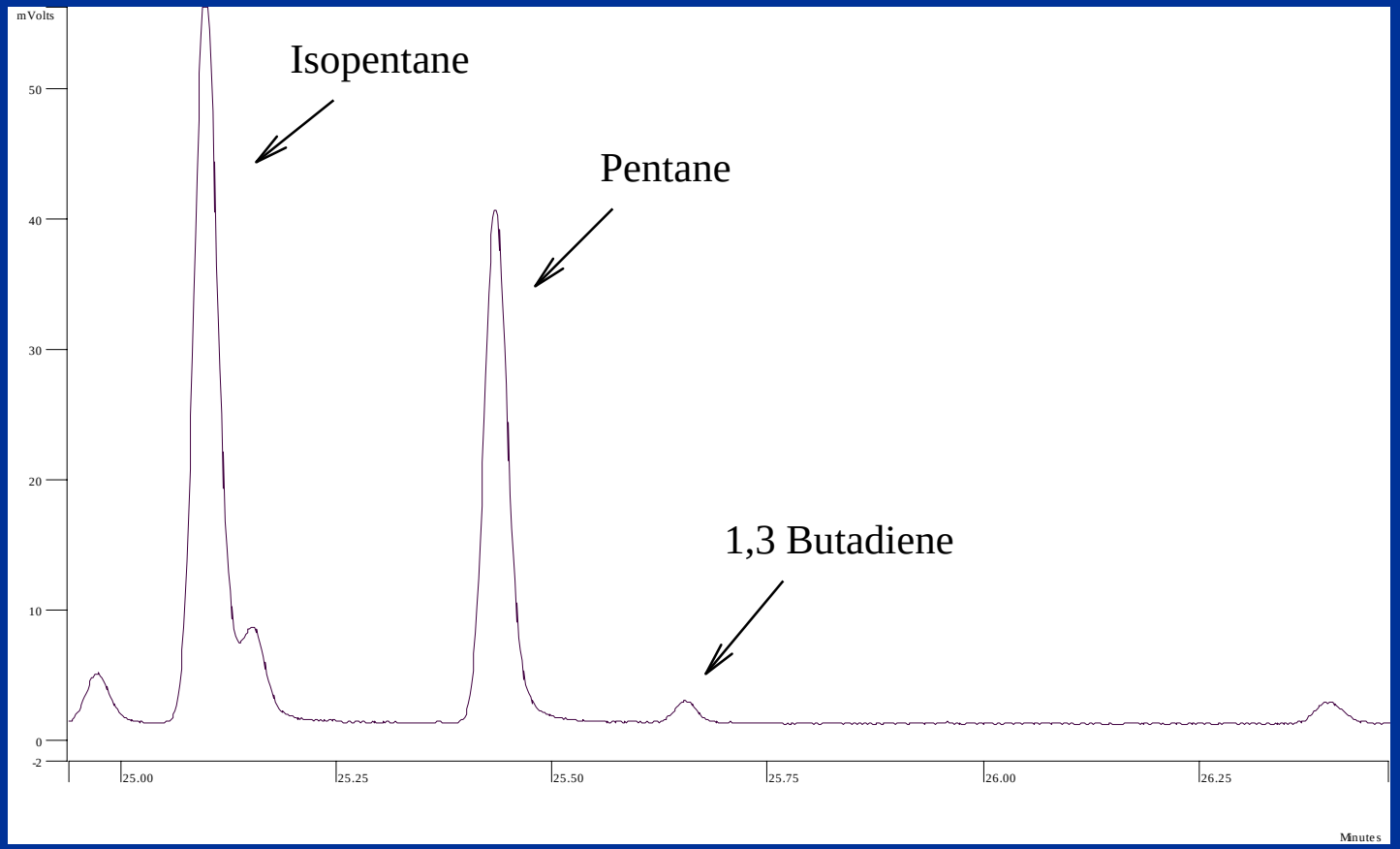
Mid Range Chromatogram (T03013; 04/20/01)
Diesel fueled bus no trap, CBD cycle



Mid Range Chromatogram (T03130; 06/07/01)
CNG fueled bus, CBD cycle



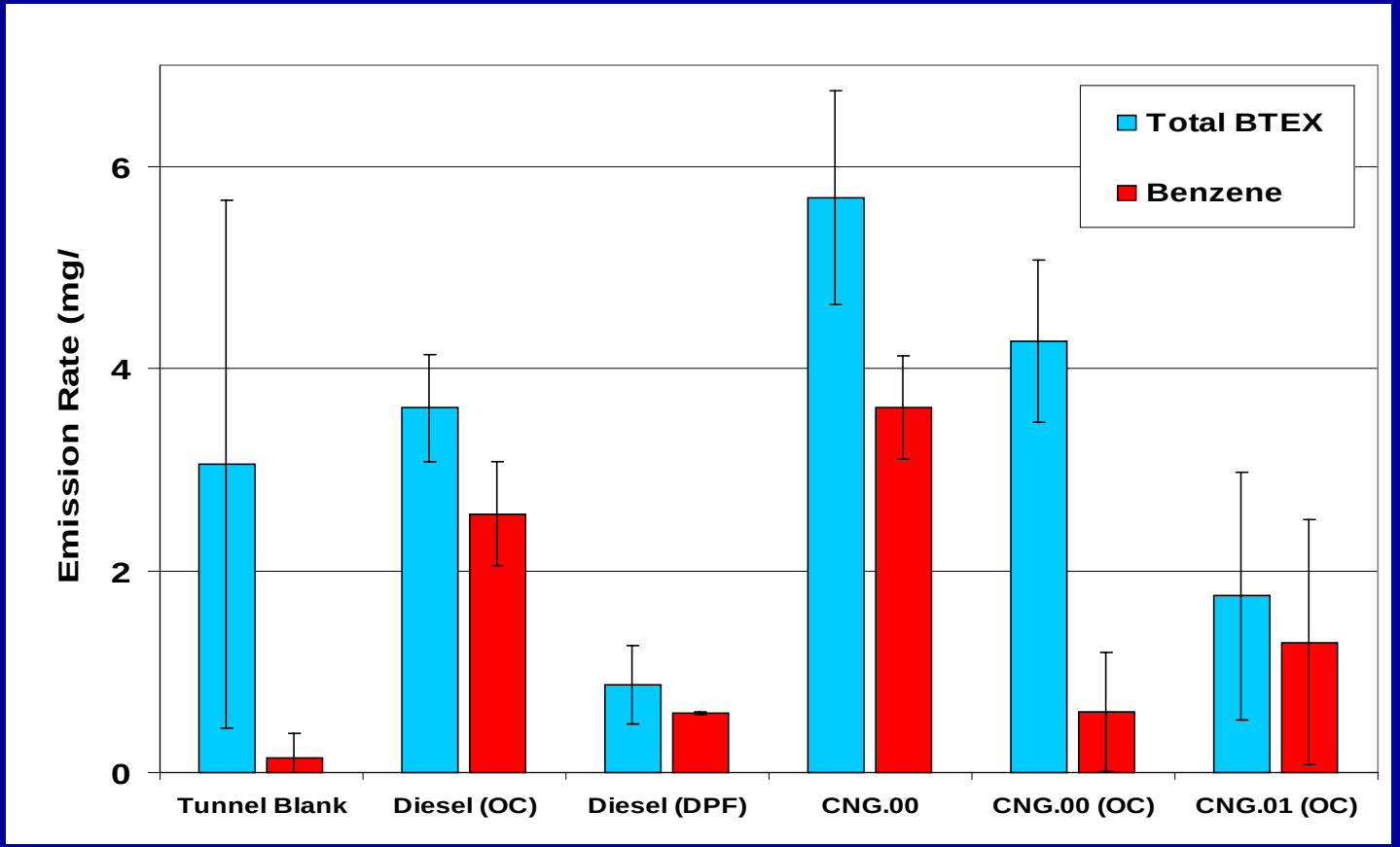
Partial Light End Chromatogram - (04/20/01)
CNG fueled bus; CBD cycle



Total BTEX and Benzene Emission (CBD Cycle)

(Error bars represent 1 std dev of replicate measurements)

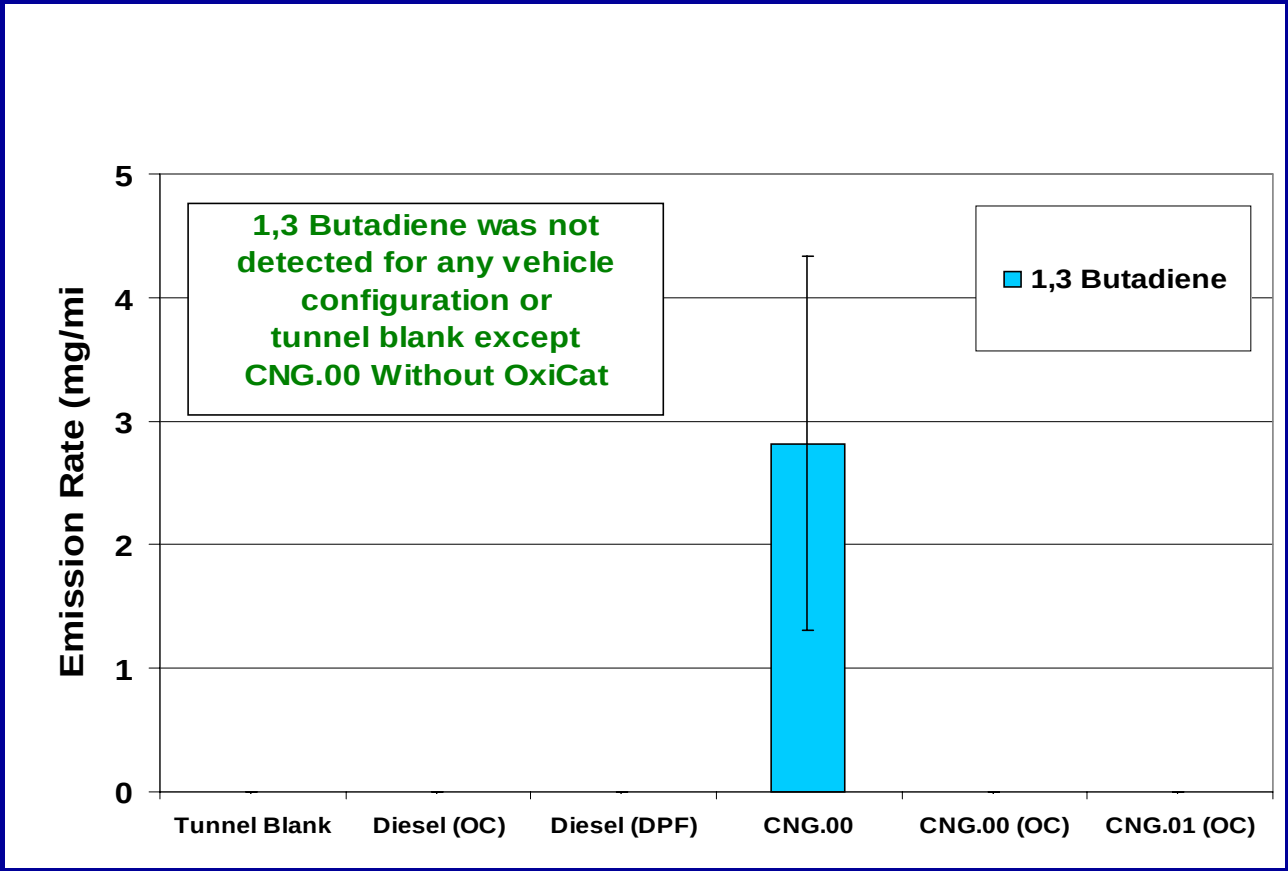
(Tunnel blank value = average of mass emissions/miles per cycle)



1,3 Butadiene Average Emission (CBD Cycle)

(Error bars represent 1 std dev of replicate measurements)

(Tunnel blank value = average of mass emissions/miles per cycle)



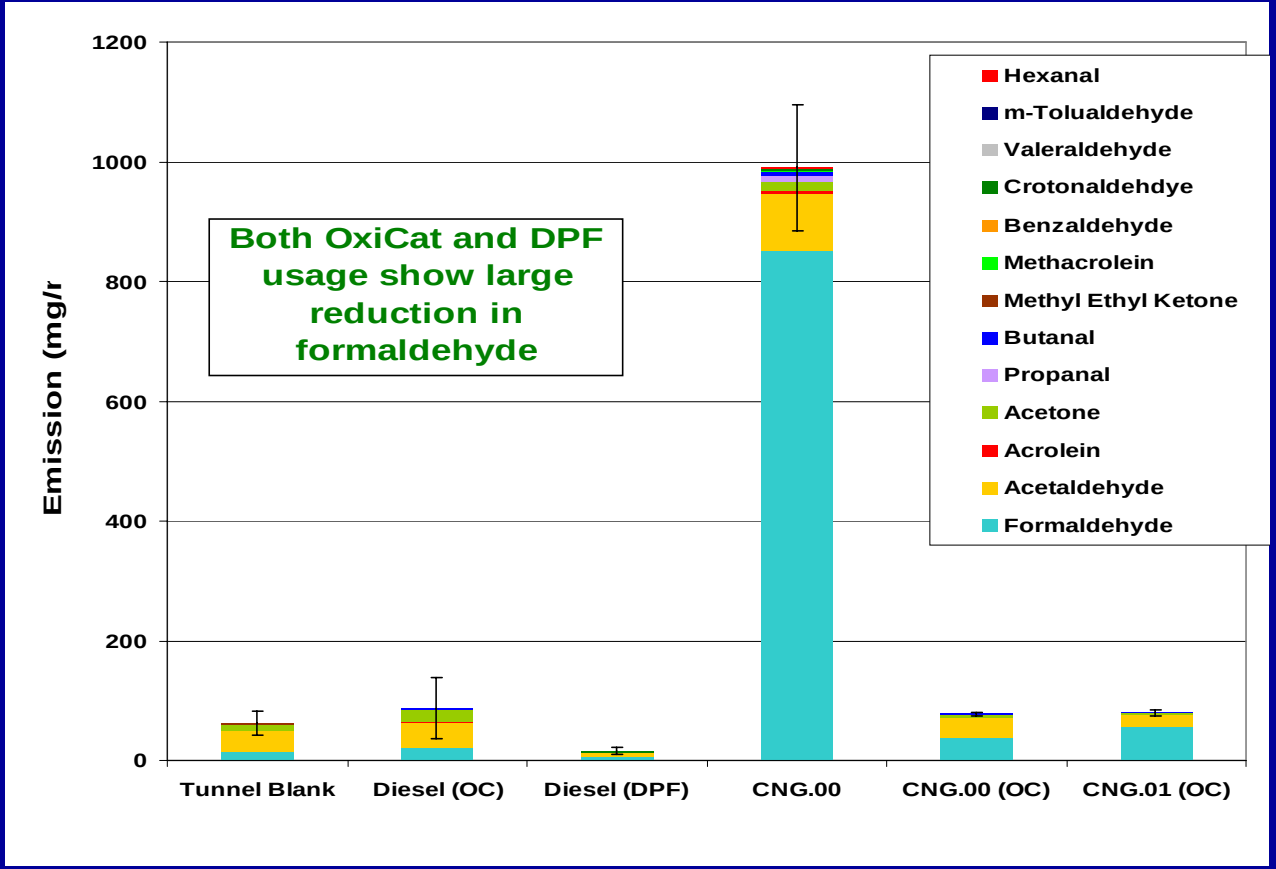
Carbonyl Analysis

- Heated line Sampling
- DNPH Coated Silica Cartridges
- SOP # MLD 104
  Extraction with Acetonitrile
  HPLC analysis w/ UV Detection
  13 Target Compounds

Average Carbonyl Emissions (CBD Driving Cycle)

(Error bars for carbonyl sum derived from 1 std dev of replicate runs)

(Tunnel blank value = average of mass emissions/miles per cycle)



Summary

- DPF reduces PM,, CO, HC, NMHC, EC, OC, elements
- DPF also reduces carbonyls, VOCs, PM-bound and semivolatile PAHs, and PM-bound and semivolatile mutagen emissions

- CNG catalyst reduces PM, OC, CO, HC, NMHC, CH_4
- CNG catalyst also reduces carbonyls, VOCs, semivolatile PAHs, and PM-bound and semivolatile mutagen emissions

Summary

- NO_X from CNG engines approximately 50% lower than NO_X from diesel engine
- DPF-equipped bus has NO_X emissions that contain 50% NO_2
- Although not shown, test cycle differences are seen
- After-treatment durability and deterioration and vehicle maintenance were not evaluated

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