8th Diesel Engine Emissions Reduction Conference

August 25 - 29, 2002, San Diego

Environmental and Health Impacts Session

ARB's Study of Emissions from Diesel and CNG Heavy-duty Transit Buses

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ABSTRACT

The identification of diesel particulate matter (PM) as a Toxic Air Contaminant (TAC) in California triggered the development of control strategies under the Diesel Risk Reduction Program (DRRP), which was recently approved by the California Air Resources Board (ARB). The DRRP aims to reduce PM emissions from diesel-fueled engines and it includes numerous control measures to be phased in over the next several years. These measures are meant to substantially curtail emissions from new and existing on-road and off-road sources. Approaches to reduce the risk of exposure to diesel PM include the use of alternative fuels, like compressed natural gas (CNG), and advanced aftertreatment control for existing and new diesel engines.

Buses fueled by CNG or using diesel particulate filters (DPF) are two "green" alternatives to conventional diesels. These alternatives have been demonstrated to reduce PM emissions. However, additional information is needed on their effect on the emissions profiles of non-regulated species, toxic and otherwise. For this reason, the ARB embarked on a research effort to collect emissions data from late-model, in-use heavy-duty transit buses in different configurations. These are, 1) a CNG bus equipped with a 2000 DDC Series 50G engine, 2) a diesel bus equipped with a 1998 DDC Series 50 engine and a catalyzed muffler, 3) the same diesel vehicle retrofitted with a Johnson Matthey Continuously Regenerating Technology (CRT™) DPF in place of the muffler, and recently 4) a 2001 CNG bus equipped with a Cummins 8.3G Plus engine and an oxidation catalyst. The CNG DDC bus was certified for operation without oxidation catalyst, but has been recently tested again with and without oxidation catalyst. The diesel bus configurations ran on ARCO's (a BP company) Emission Control Diesel (ECD-1) fuel with a measured sulfur content of 11 ppm. The objectives of the study were, 1) to assess driving cycle effects, 2) to characterize the types and amounts of several toxic substances emitted for the various configurations, and 3) to investigate total PM and ultrafine (<100 nm) particle emissions.

This study has shown that, in terms of PM mass, CNG and trap-equipped diesel buses are significantly superior to the conventional diesel bus. However, no single "green" technology is clearly superior to the other for every pollutant indicator measured. Measurable levels of toxic compounds in the exhaust suggest that neither the CNG nor the trap-equipped bus may be clearly superior to the other in all aspects. Most importantly, possible technology improvements have been identified.

Technical Collaborators

ARB

Management: B. Croes, M. Fuentes, W. McMahon, J. Shears

Staff: Dr.L. Zafonte, C. Maddox, J. Horrocks, N.Castillo, G.Gatt, N.Verma, J. Karim, K. Sahay, Dr. B. Dharmawardhana

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S. Barbosa

Project Drivers

- Heightened concern about potential health impact of ultrafine (<100nm) particle emissions
- 1996 HEI Report RE: high ultrafine particle number and low mass emissions from “late-model” diesel engine
- 1999 World Truck Conference emission results for CNG truck: most MOUDI mass in after-filter (<56nm in aero. diameter)

Project Objectives

Take a "snap-shot" of in-use fleet (not a fleet average) and…

- ☐ Assess driving cycle effects
- ☐ Characterize types and amounts of several toxic substances
- ☐ Investigate total PM and ultrafine particle emissions

Scope and Methods

- Cycles: Idle, SS, CBD, NYBC, UDDS
- Chassis dynamometer testing at ARB's HDVEL
- PM: filters and MOUDI
- Total HC's: heated FID
- NO_X, NO_2: chemiluminescence
- CO, CO_2: NDIR
- Carbonyls: DNPH cartridges/HPLC
- Metals: teflon filter/XRF
- Mutagenicity: filter/PUF/XAD, modified Ames assay
- PAH's: filter/PUF/XAD, GC-MS
- EC/OC: quartz filter/TOR
- VOC's and NMHC: tedlar bag/GC
- PM number/size: SMPS & ELPI@micro-diluter and SMPS@CVS

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Test Vehicles

	DDC	Cummins	DDC
Data label	Diesel Baseline and Diesel CRT	Cummins w/Oxi Cat	DDC CNG-1, -2, -3
Vehicle	#3007	#134	#5300
Fleet	Los Angeles MTA	Omnitrans	Los Angeles MTA
Chassis	New Flyer	New Flyer	New Flyer
Capacity	40 passenger	40 passenger	40 passenger
Fuel	ECD-1	CNG	CNG
Engine	Series 50	C 8.3 G-plus	Series 50 G
Model year	1998	2001	2000
Mileage at start:	15,169	18,700	19,629 and 56,600
After-treatment	OC and DPF	Oxidation Catalyst (OC)	OEM* and OC**

**OEM configuration is with no controls* ***1st DDCS50G w/Oxi Cat on New Flyer chassis*

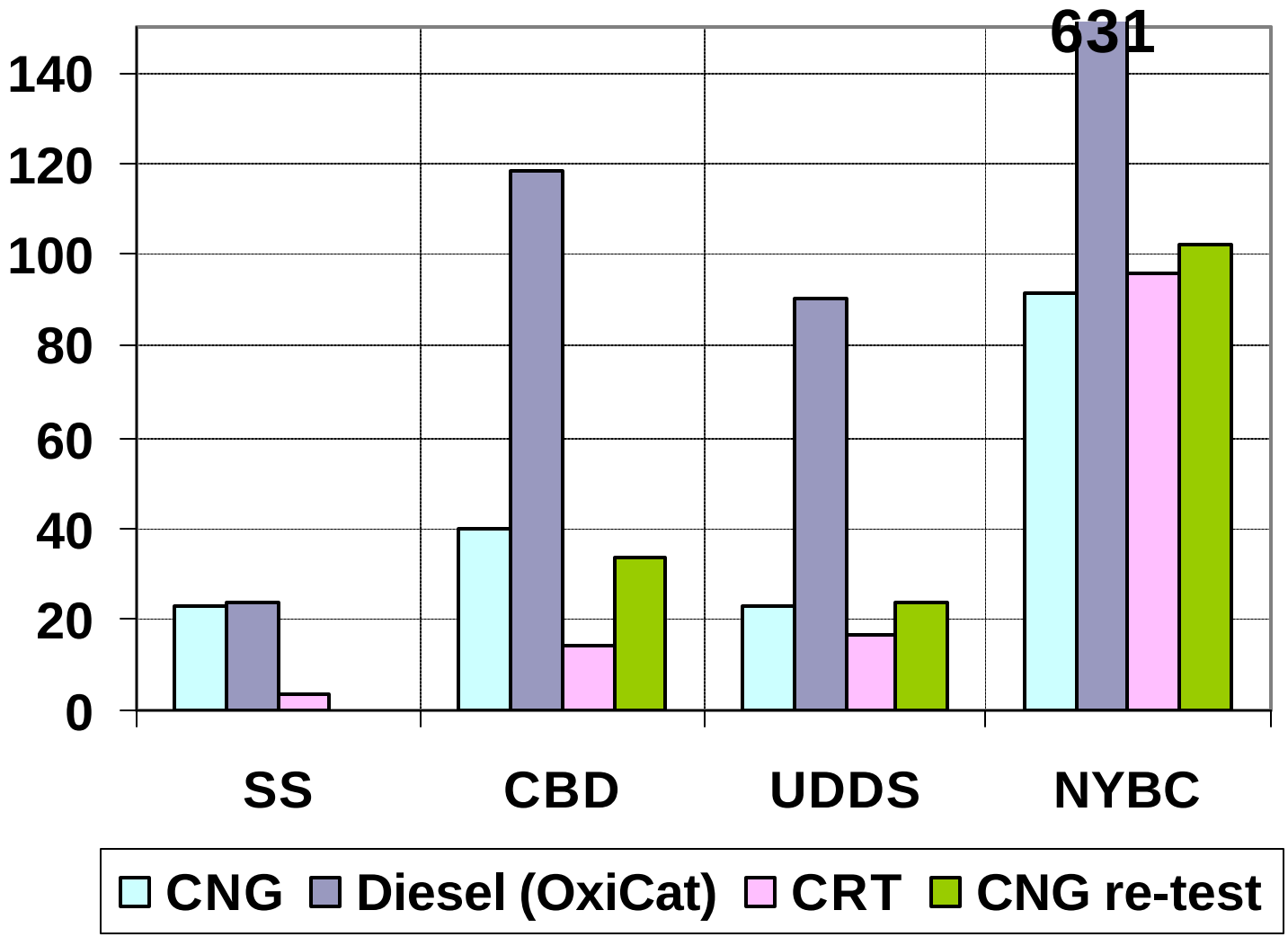
Highlights from 2001 Results:

Two buses powered by DDC engines:

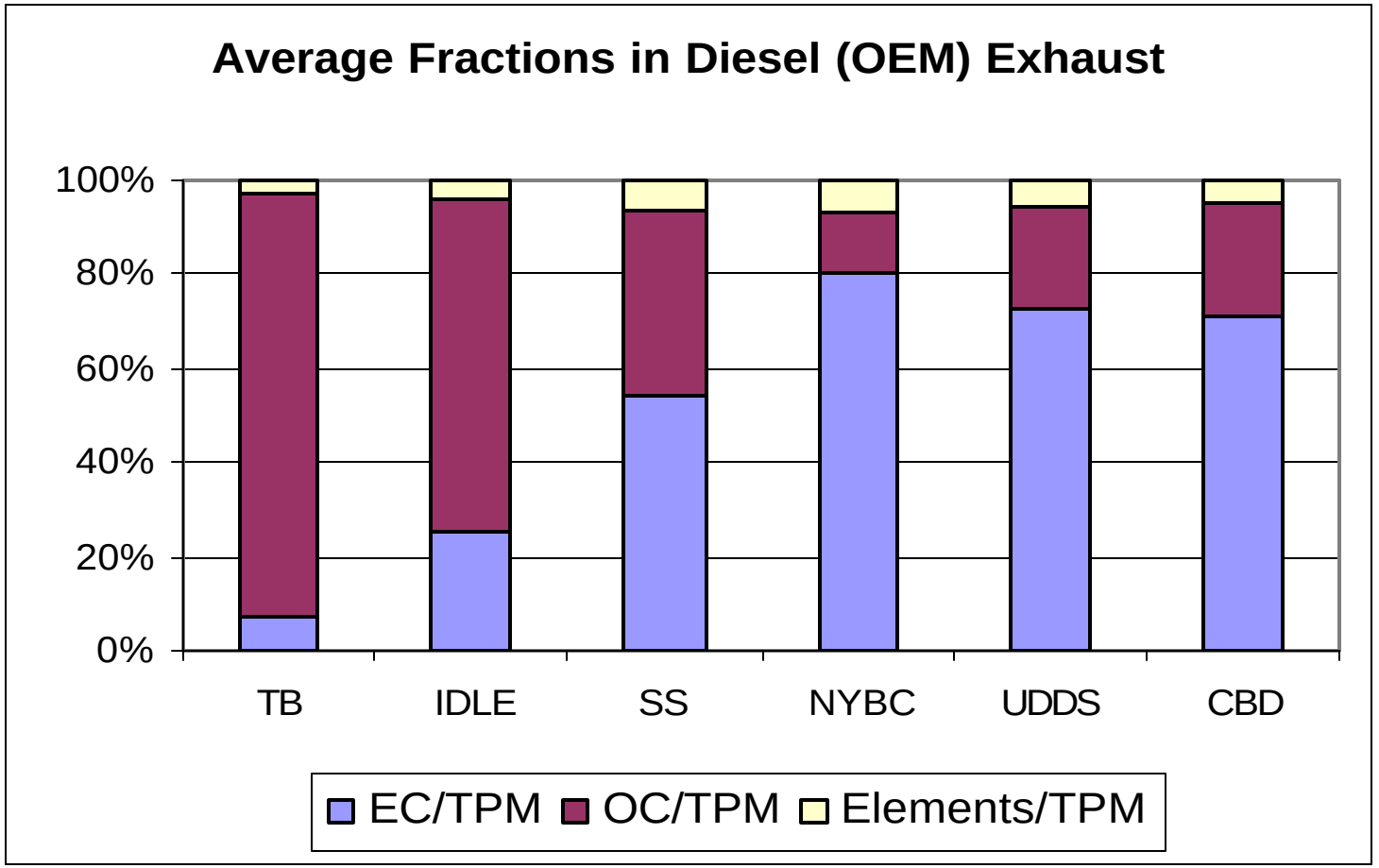
one diesel (ECD-1) = with DOC or DPF

one CNG = no aftertreatment

Uncorrected PM, mg/mi

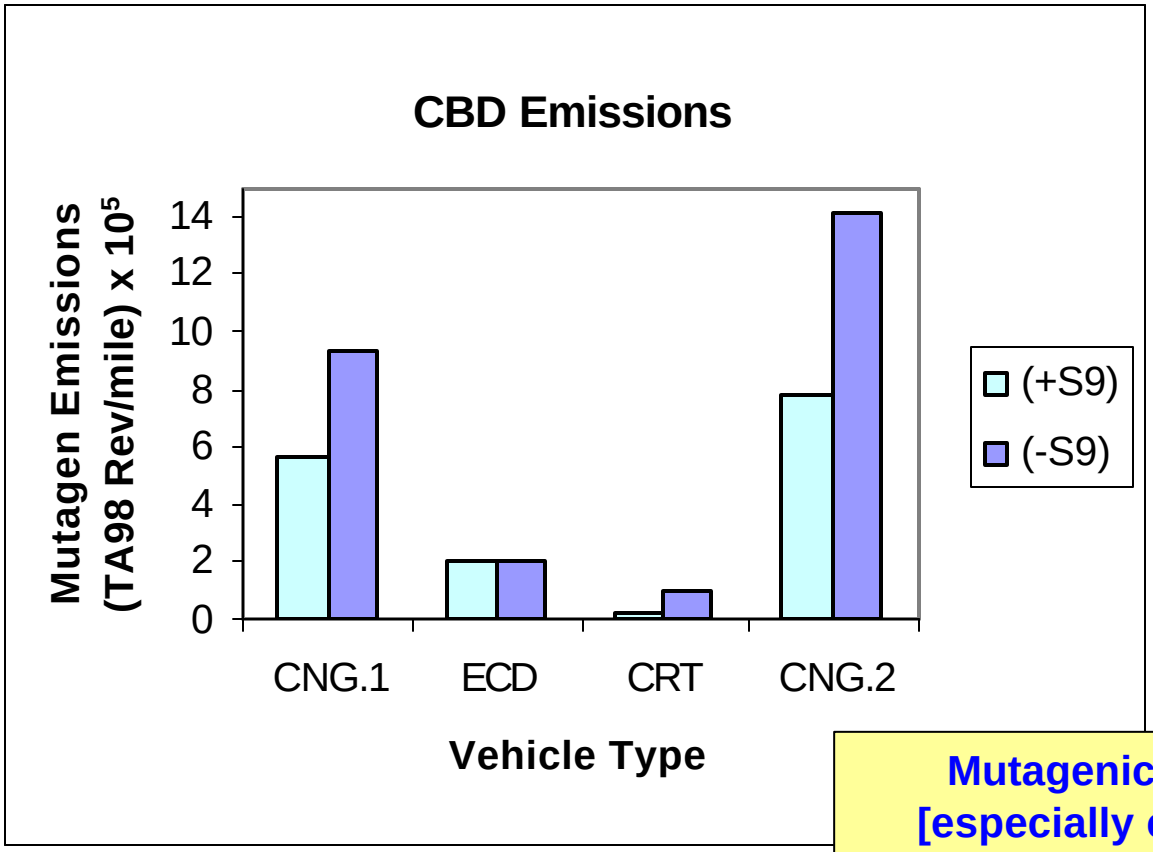


***Note**: PM uncorrected for tunnel background.*



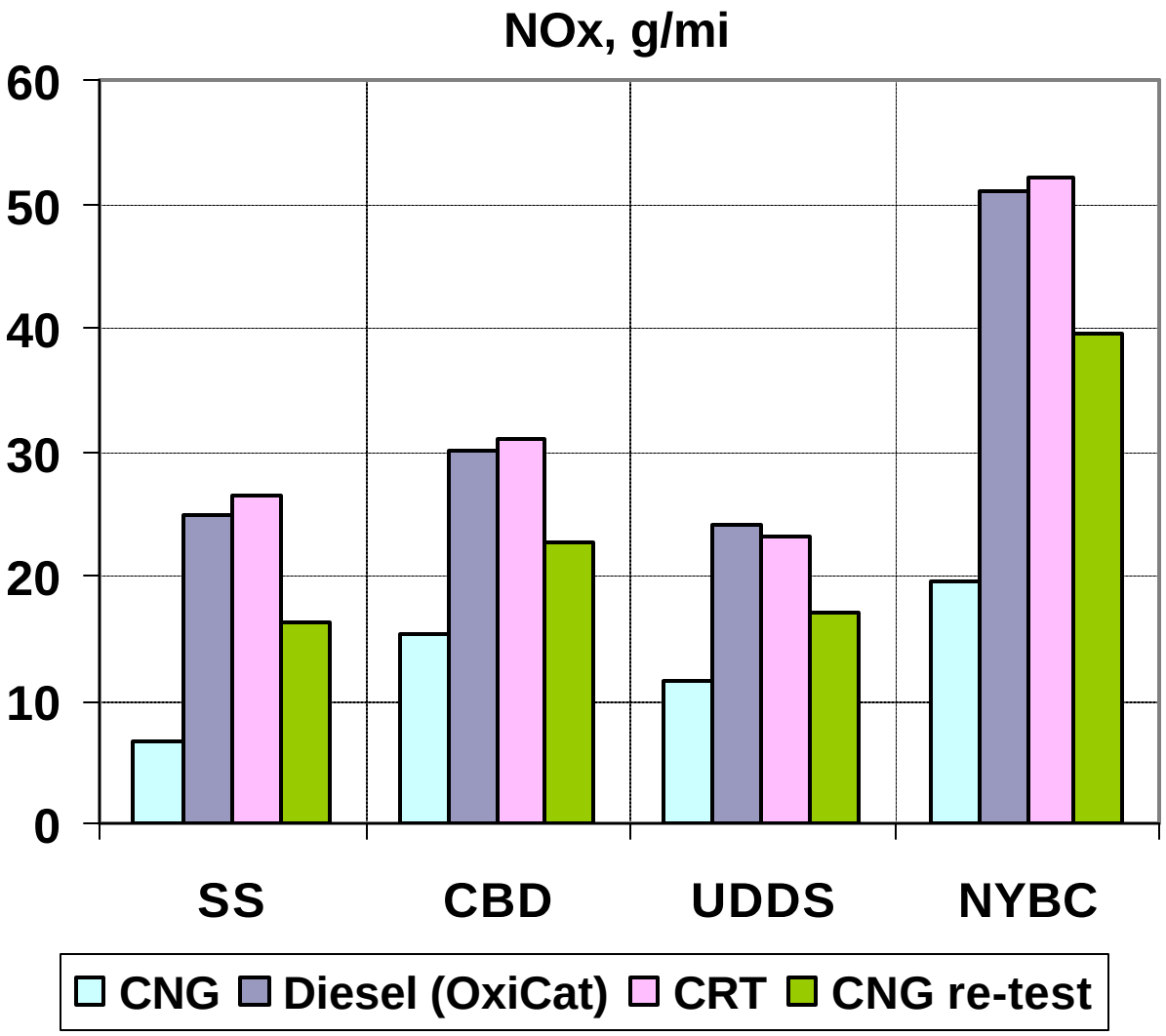
Note: 1) TPM = EC + OC + Elements

2) CRT and CNG carbon samples were primarily OC across all cycles



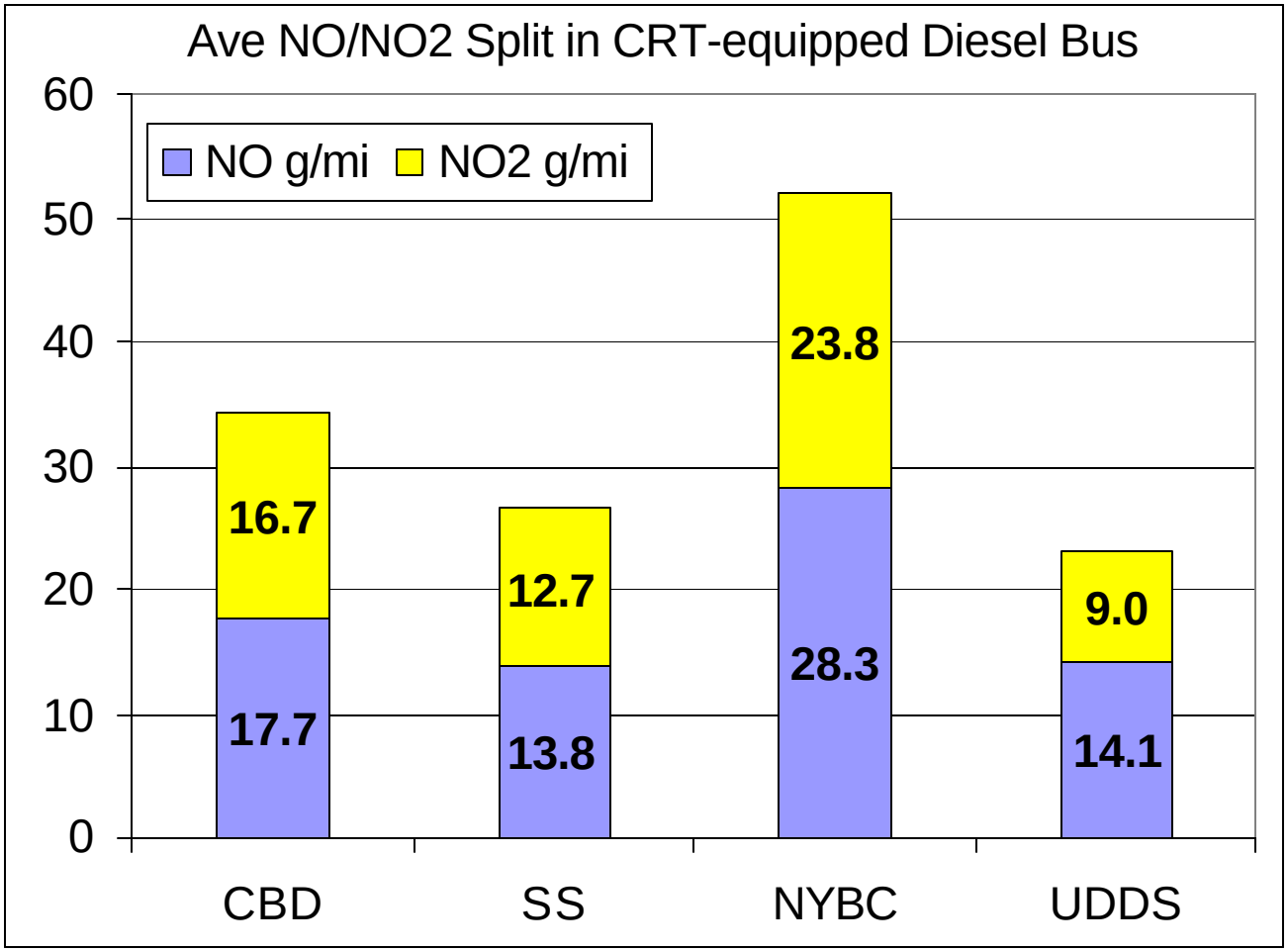
Mutagenicity results [especially comparison between ECD (i.e.,baseline) and CRT] are cycle dependent.

Note: 1) Results include activity in PM and vapor phases



Note: For CNG re-test: fuel quality in question (Methane Number < 80)

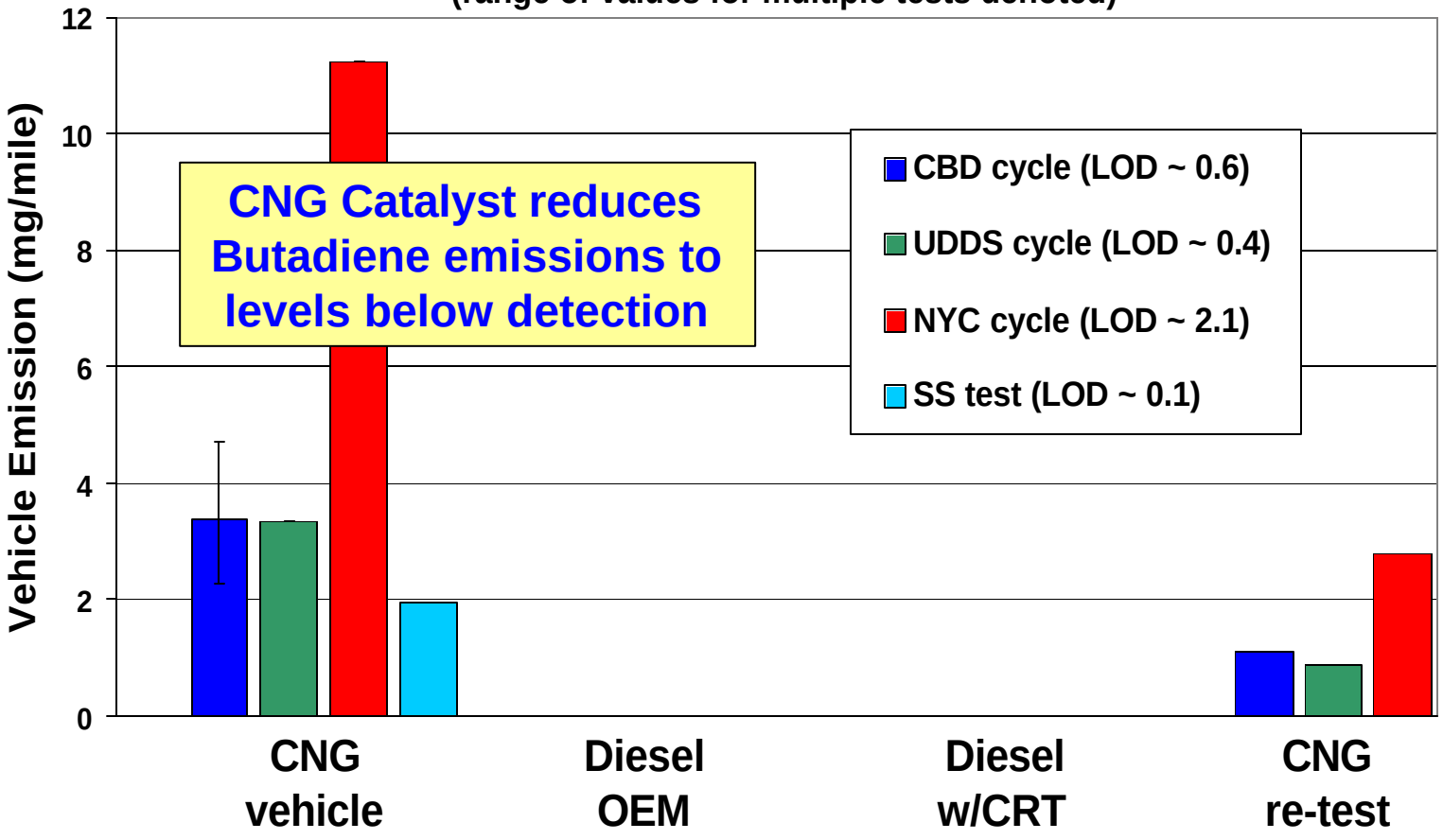
CRT Effect on Diesel Bus NO_X Emissions



ARB's ambient modeling suggest that a modest increase in the NO_2/NO_X fraction (20-25%) results in more benefits than disbenefits

1,3 Butadiene Vehicle Emission

(range of values for multiple tests denoted)

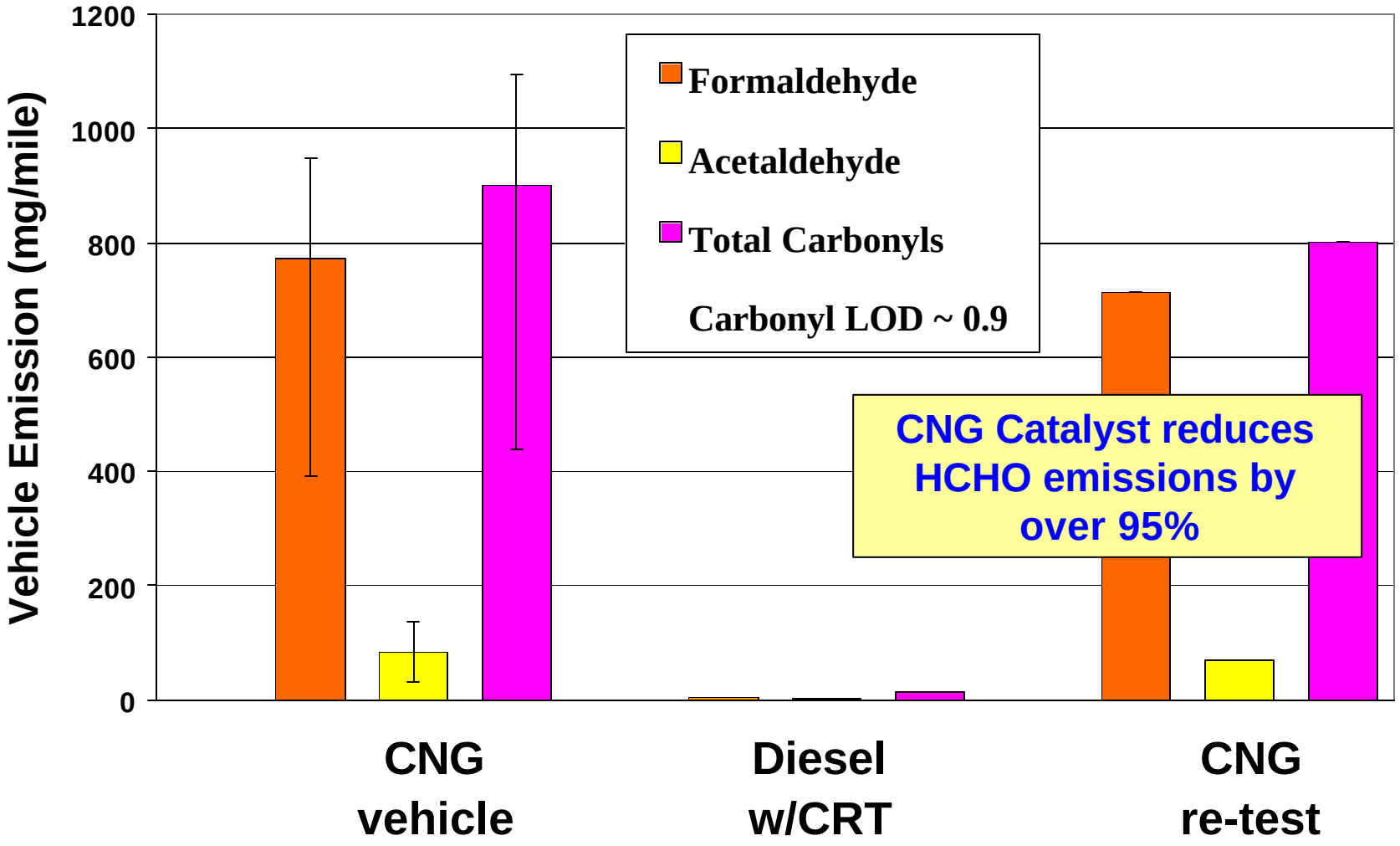


Note: 1) Measurements showed high variability.

2) Tunnel background measurements were below detection limits.

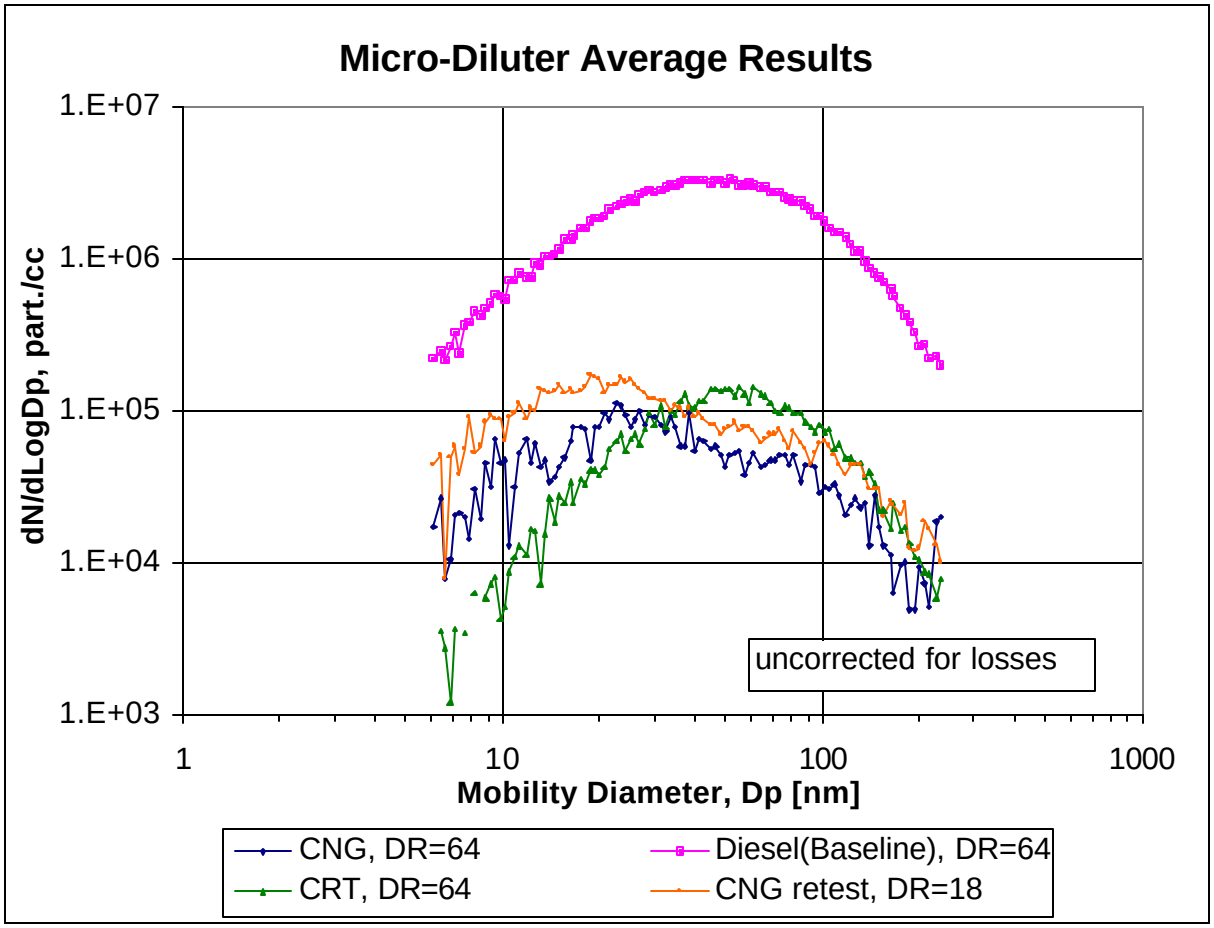
Carbonyl Emission for CBD Cycle

(range of values for multiple tests denoted)



Note: Diesel baseline results exceeded holdtime QC requirement

Steady State (55 mph) Cruise



Note: 1) Diluted exhaust sample temp. ranged from 80F to 90F

2) Tunnel blank concentrations on the order of 10^2 or less

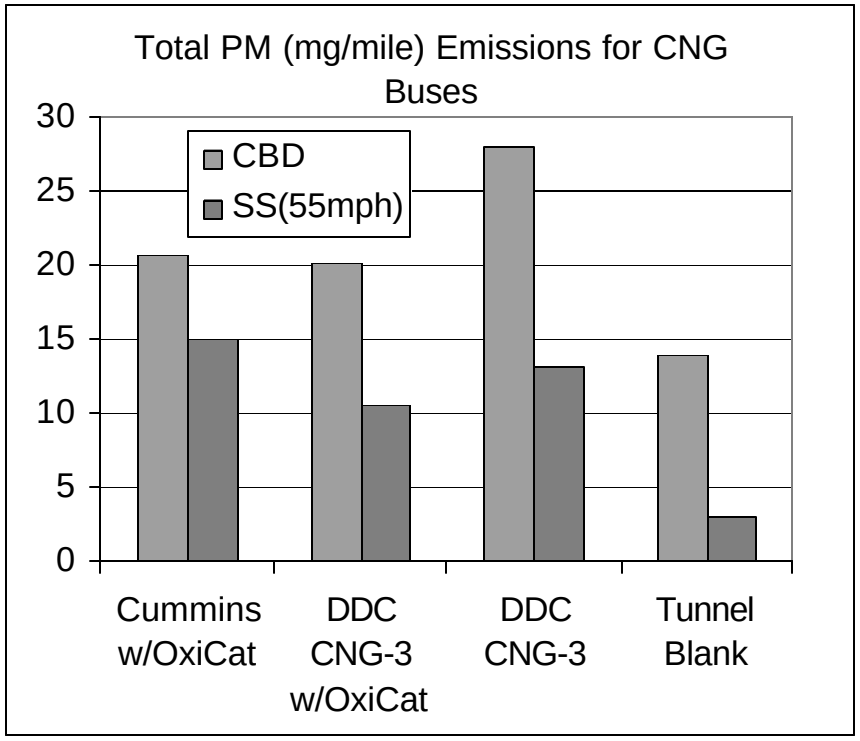
Highlights from 2002 Partial Results:

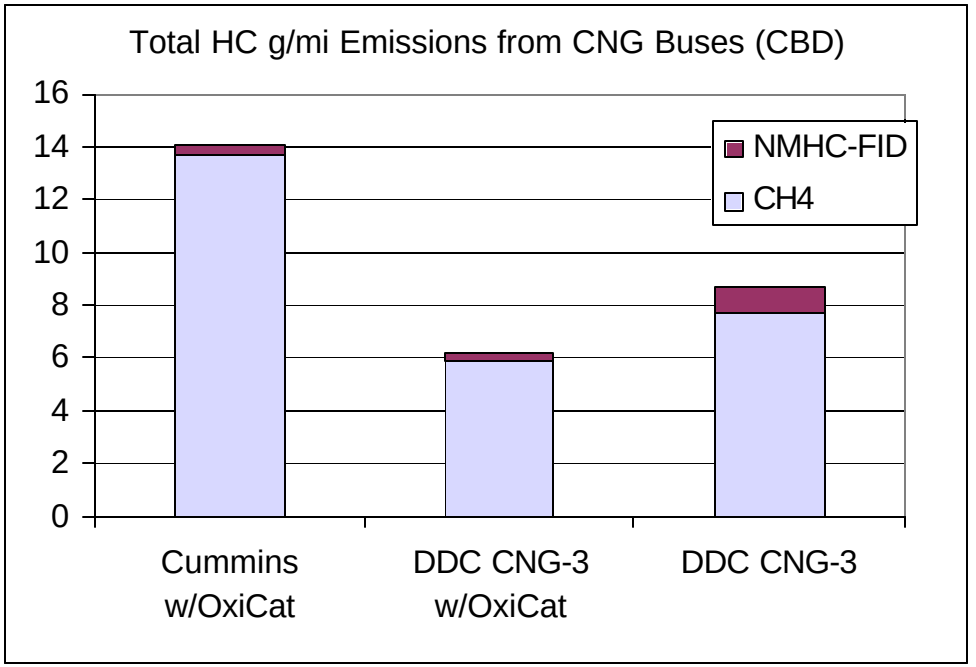
Two Catalyst-equipped CNG Buses:

Cummins = new test vehicle

DDC = same bus as 2001

Oxidation Catalyst for DDC CNG Bus





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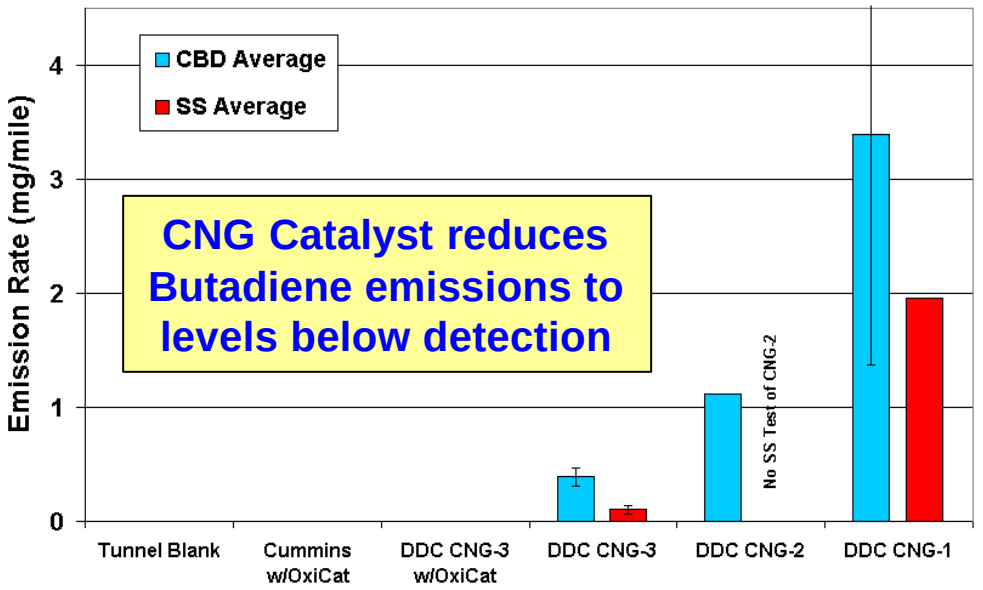
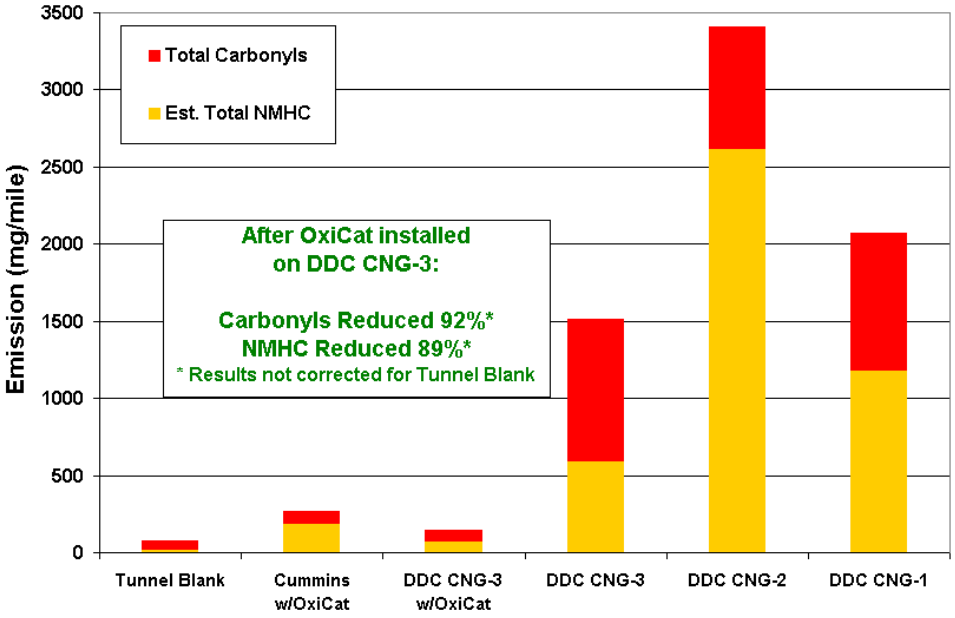
1,3 Butadiene Emission by Driving Cycle

(Error bars represent 2 std dev of replicate measurements)

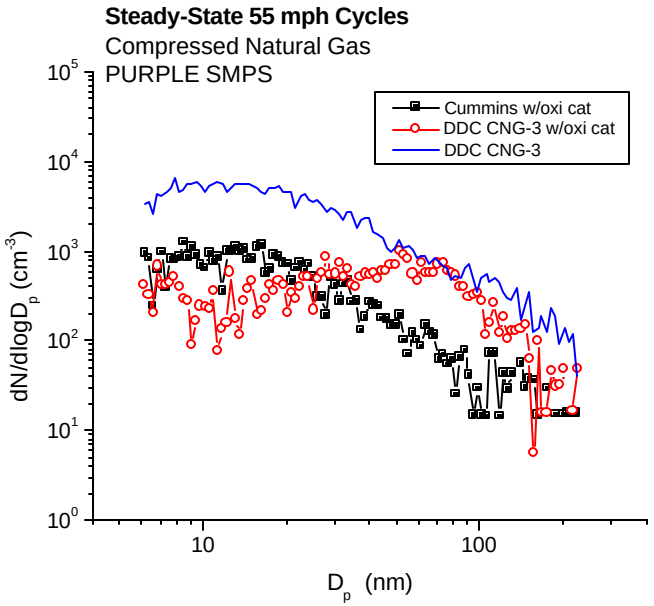


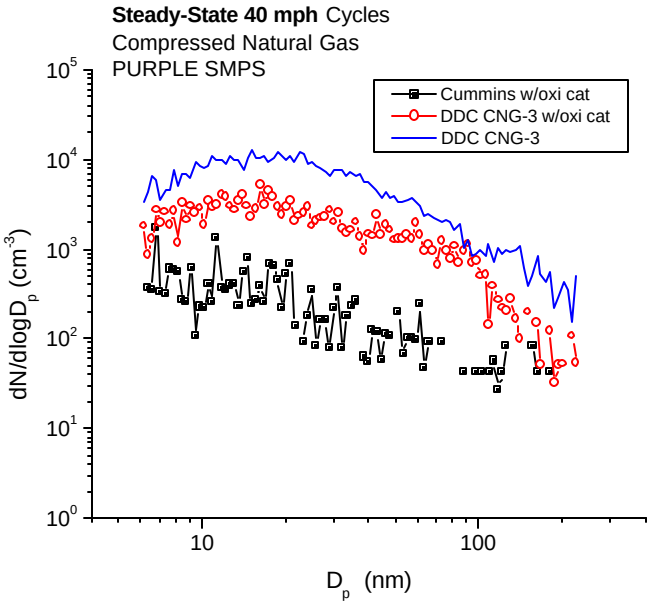
Estimated Total NMOG Emission (CBD Driving Cycle)

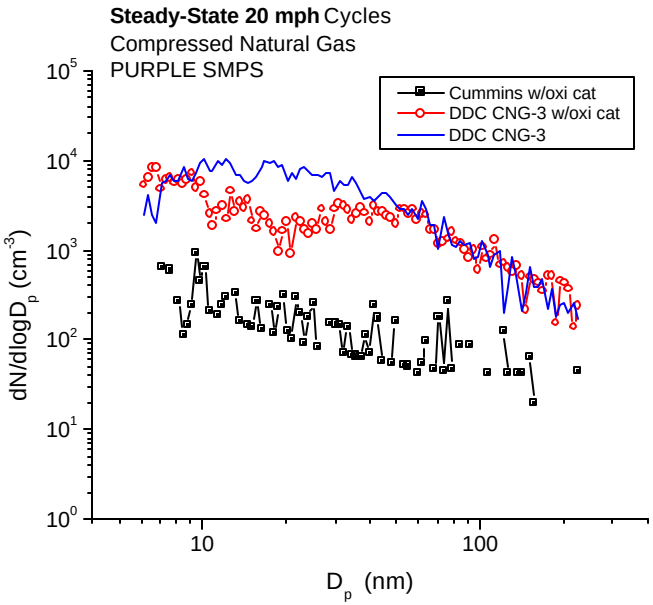
(Estimated NMOG = Carbonyl Tot. + Est. Tot. NMHC by GC)



Average Particle Size Distribution- Steady State Condition Micro-diluter Results (uncorrected for DR or TB)







Number concentrations show strong dependence on engine operating condition

Note: sample number concentrations > TB's

Summary – 1

- “Clean” CNG and diesel vehicles = challenge for current sampling and analytical methodologies.
- Dilution tunnel background an important factor that affects conclusions. Tunnel blank is not constant.
- CNG-fueled and CRT-equipped buses offer significant total PM reduction.
- EC/OC in diesel baseline showed strong cycle dependence. For CNG and CRT, carbon is mostly OC.
- Assay activity in CNG extract > activity in diesel extracts (for both w/ DOC or DPF).
- CNG-fueled bus offers NO_X and NO_2 advantage over CRT-equipped bus.
- NO_2/NO_X emission ratio in CRT-equipped bus ranged between ~ 40% and ~ 50% depending on cycle.
- Ultrafine particles in CNG exhaust appear to be smaller than ultrafine particles in Diesel exhaust.

Summary – 2

- *CNG w/OxiCat data set is not complete. Analyses for PAH's, assay, metals, EC/OC, and transient particle number emissions in progress.*
- Catalyst for CNG shows reduction of total PM and HC's. No effect on methane.
- 1,3-Butadiene and formaldehyde emissions from CNG bus were reduced by the catalyst.
- Catalyst on CNG reduces NMHC emissions.
- Catalyst in CNG reduces number concentrations across size range. Number concentrations are a function of engine operating condition and dilution approach (i.e. micro-diluter vs. CVS).