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**Partial Results : Emissions from Two
CNG Buses with Oxidation Catalyst**

California Air Resources Board

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Background

- **Based on Phase 1.A Study (CNG and Diesel Comparison), CNG bus without aftertreatment has measurable levels of toxic compounds and Ames assay activity**

Phase 1.B Study Objective

- **Investigate effectiveness of oxidation catalyst control for CNG transit bus application**

**Revision of Available Results to Include New Information on
Oxidation Catalyst Control for CNG DDC Bus**

(Listing does not imply emissions have equal importance)

		PHASE 1.A and 1.B STUDY
Emissions Measured		HIGHEST LOWEST
1	NO _x	Diesel Baseline ^a ~ Diesel CRT > CNG ~ CNG w/OxiCat
2	Total PM Mass	Diesel Baseline >> CNG > CNG w/OxiCat ~ Diesel CRT
3	Total Ultrafine Particle Number ^b	Diesel Baseline > CNG ~ CNG w/OxiCat^c ~ Diesel CRT
4	Aldehydes ^d	CNG >> CNG w/OxiCat^e > Diesel CRT
5	Mutagenicity	CNG w/OxiCat Under Analysis
6	PAH Species	CNG w/OxiCat Under Analysis
7	NO ₂ /NO _x	Diesel CRT >> Diesel Baseline ~ CNG > CNG w/OxiCat
8	CO ₂	Diesel CRT > Diesel Baseline > CNG ~ CNG w/OxiCat
9	NMHC	CNG >> Diesel Baseline > Diesel CRT ~ CNG w/OxiCat^f
10a	1-3, Butadiene	CNG > Diesel Baseline ^g ~ CNG w/OxiCat^g ~ Diesel CRT ^g
10b	BTEX ^h	CNG ~ Diesel Baseline > CNG w/OxiCat ~ Diesel CRT
11	CO ⁱ	CNG > CNG w/OxiCat > Diesel Baseline > Diesel CRT

^a Diesel Baseline in this study was a catalyst-equipped diesel bus running on low-sulfur fuel.

^b Ultrafine particles measured for CNG bus appeared to be smaller relative to the diesel particles.

^c Catalyst in CNG bus resulted in reduction of ultrafine particle number concentrations over all sizes measured. Absolute reduction depends on engine operating condition.

^d Diesel Baseline samples exceeded hold time QC requirement.

^e Catalyst in CNG bus reduced HCHO by over 95%.

^f Catalyst in CNG bus reduced non-methane hydrocarbon emissions by over 88%.

^g 1,3-Butadiene emissions were below detection limit.

^h Comparison of results on a relative basis suggests some total BTEX emission reductions by the catalyst. Accurate determination of total BTEX emission levels cannot be made due to high tunnel blank results.

ⁱ These results apply to DDC CNG Bus only. The Cummins CNG Bus had CO emission levels comparable to Diesel CRT.

Note: Table does not include new metals, PAH's, Ames assay, and transient particle number emissions results.

Test Vehicles

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	Cummins	DDC
Data label	Cummins w/Oxi Cat	DDC CNG-3
Vehicle	#134	#5300
Fleet	Omnitrans	Los Angeles MTA
Chassis	New Flyer	New Flyer
Capacity	40 passenger	40 passenger
Fuel	CNG	CNG
Engine	Cummins Westport C Gas Plus	Series 50 G
Model year	2001	2000
Mileage at start:	18,700	56,600
After-treatment	Oxidation Catalyst (OC)	OEM* and OC**
Total miles on OC	18,700	4,300

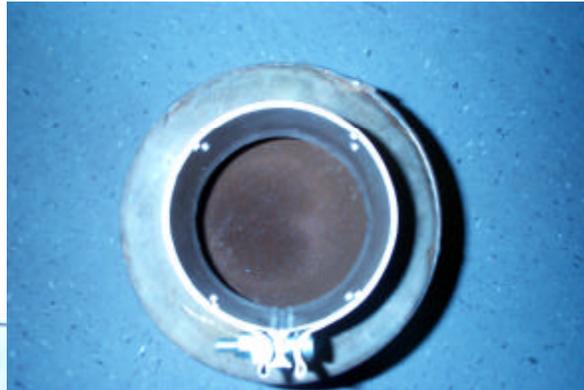
**OEM configuration is with no controls*

***1st DDCS50G w/Oxi Cat on New Flyer chassis*

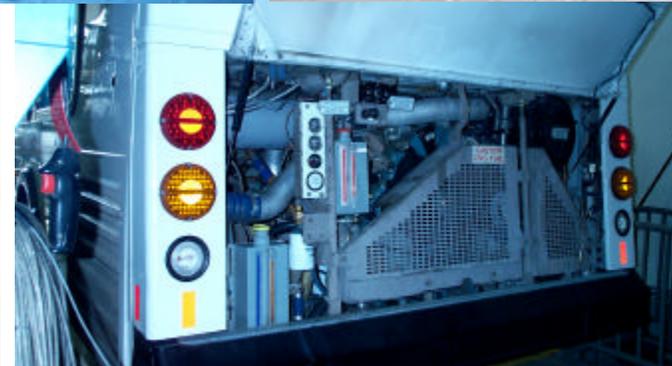
Project Scope

- **Testing at ARB's Heavy-duty Vehicle Emissions Laboratory**
- **Cycles: Steady State (55mph) and Central Business District Cycle (CBD)**
- **Regulated Pollutants, NO₂, CO, CO₂**
- **On-site Speciation of Air Toxic Hydrocarbons - MLD-So.**
- **Carbonyls - MLD-So.**
- **PAH's - SSD + UCD**
- **Ames Bioassay - UCD**
- **Biological effects on animal pulmonary target cells - U of R**
- **Elemental Carbon/Organic Carbon Split - SCAQMD**
- **Metals Analysis - DRI**
- **Particle number and size distribution - RD + UCONN**
- **Fuel and lube oil analysis - Commercial Labs**

Oxidation Catalyst for MTA 5300 Bus ^{DRAFT}



Oxi Cat



OEM Installation of Oxi Cat and Testing of DDC CNG-3

- **March '02 - SCAQMD purchases brand-new cat from OEM (DDC)**
- **April '02 - DDC installs “green” cat on MTA #5300**
- **#5300 in service for 4,300 miles (1 month)**
- **May '02 - Testing of #5300 with “degreened” oxi. cat.**
- **DDC removes oxi. cat**
- **June '02 - Testing of #5300 without oxi. cat.**

Fuel and Lube Oil Analysis

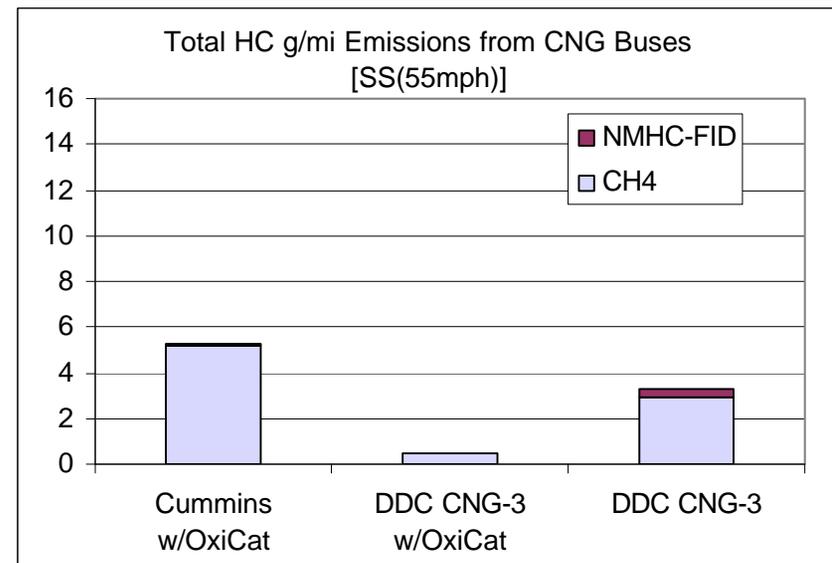
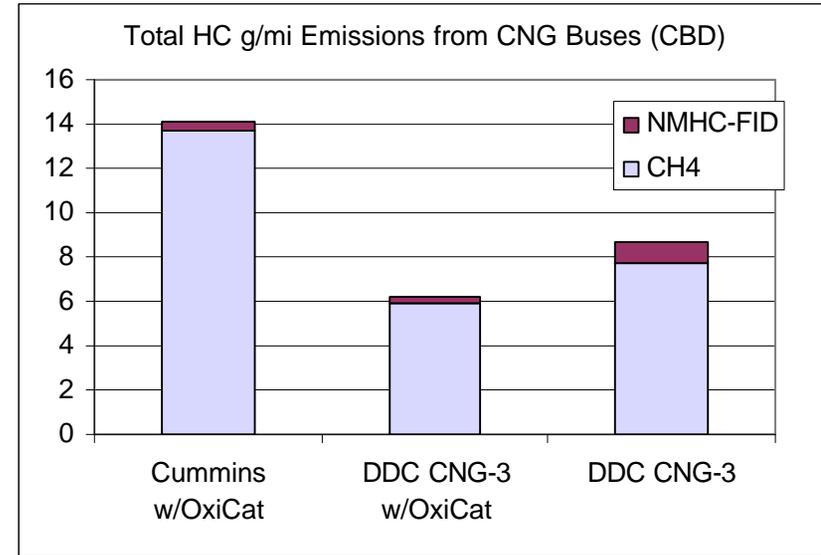
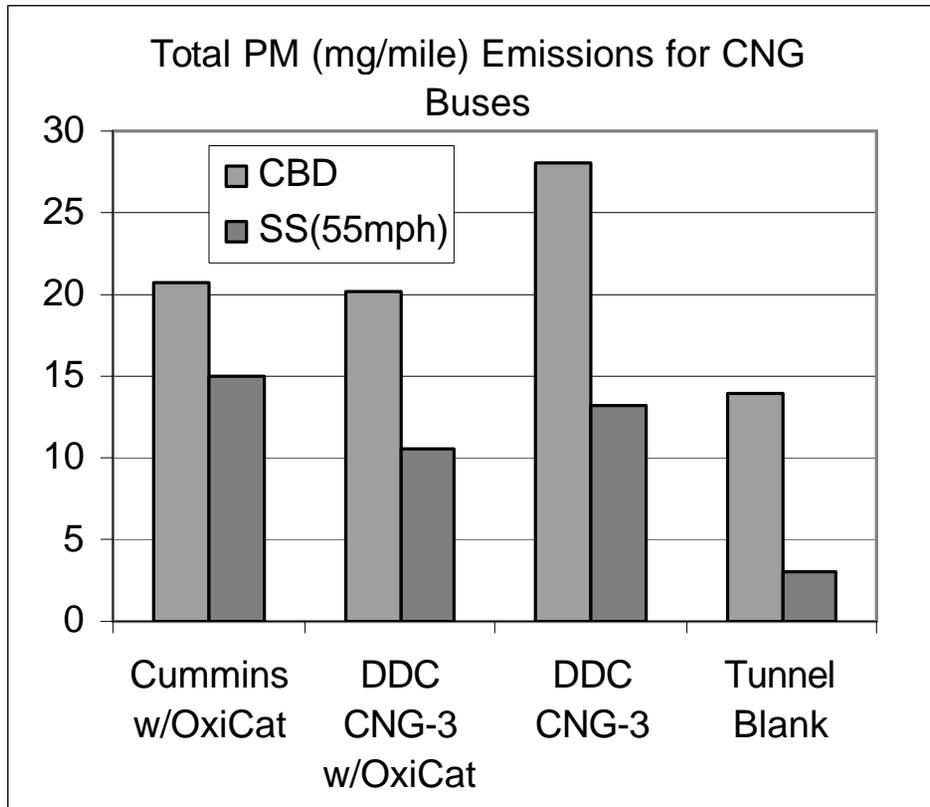
Fuel -

- All 3 CNG fuel samples with Methane No.>100

Oil -

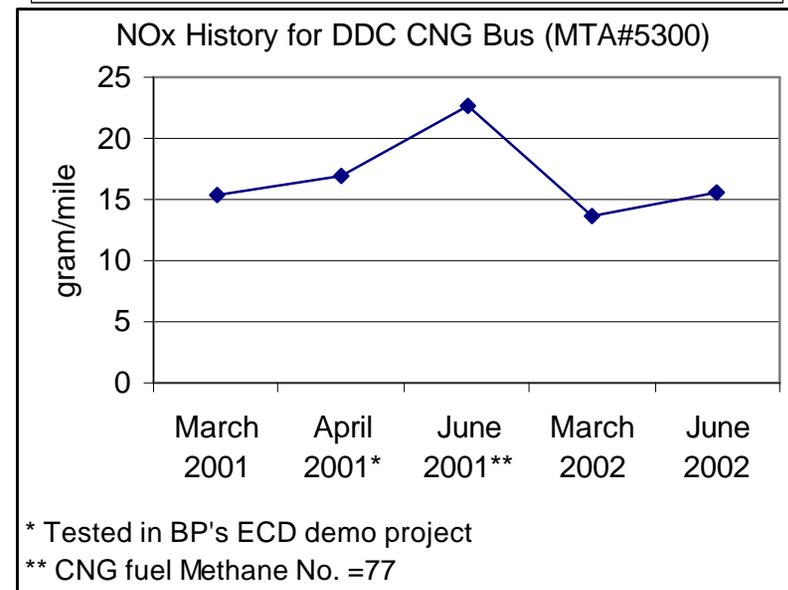
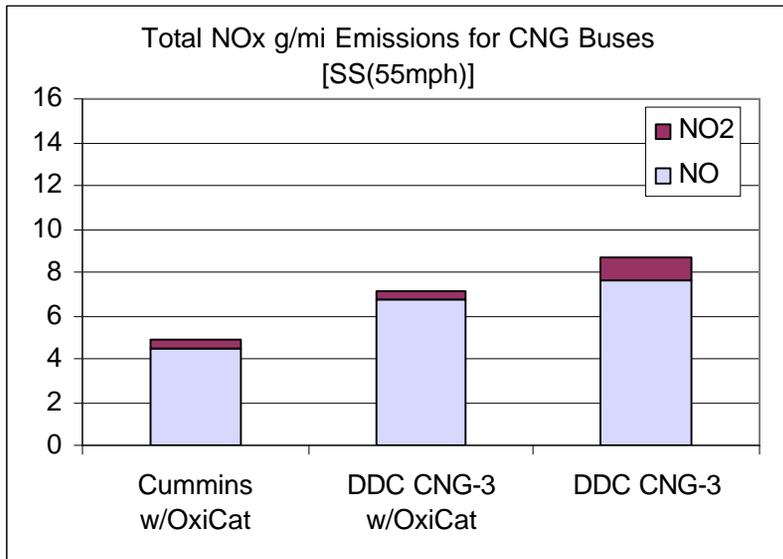
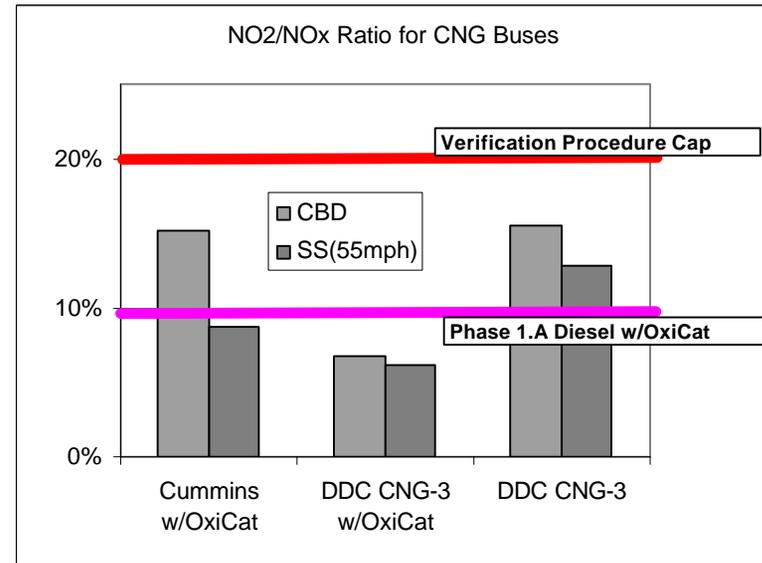
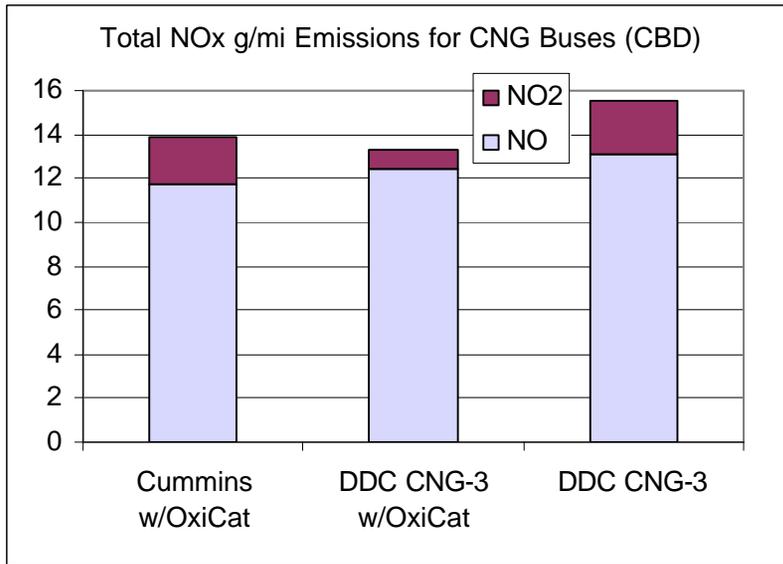
- DDC CNG-3: all additives and wear metals at normal levels. Chlorine at 12-22ppm.
- Cummins w/OxiCat: Abnormally high (73ppm) Cu level (maybe residual in newer engine). Chlorine at 25ppm. All additives and wear metals at normal levels.

Average PM and HC Emissions (Phase 1.B Results)

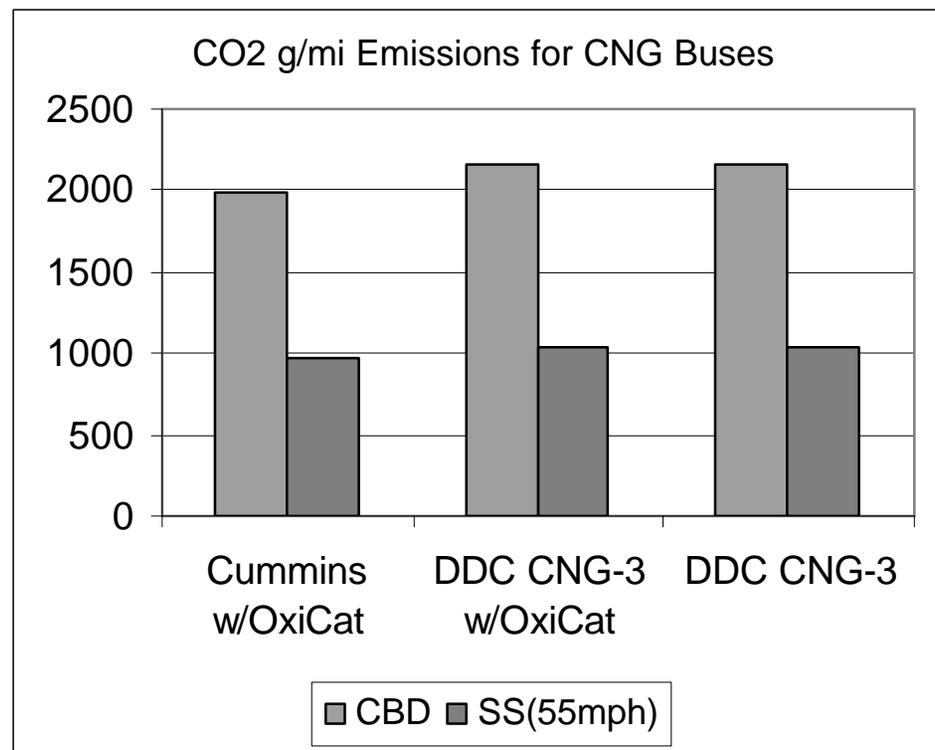
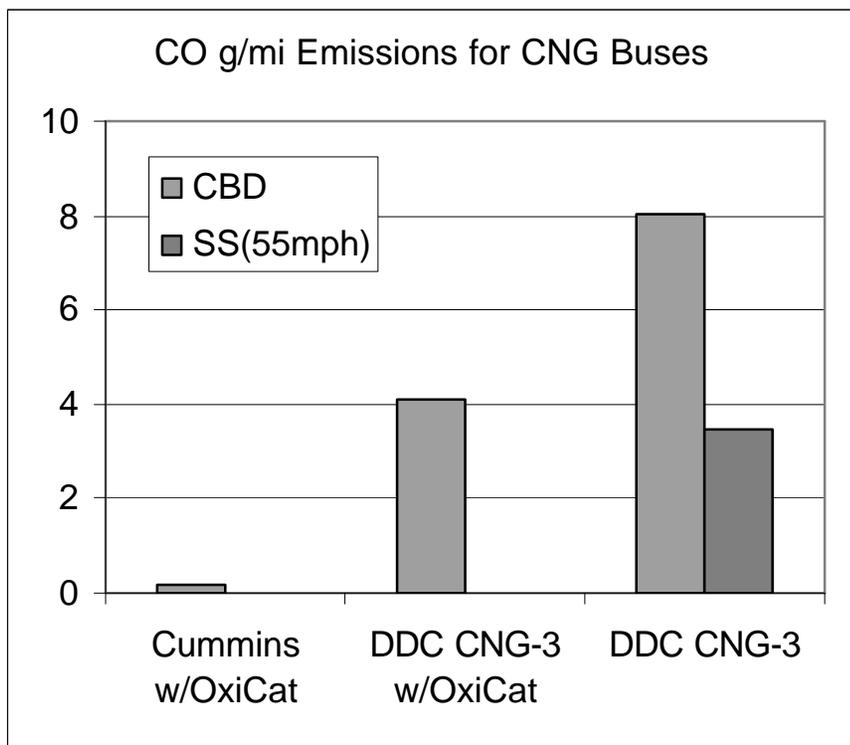


NO_x and NO₂ g/mi Emissions (Phase 1.B Results)

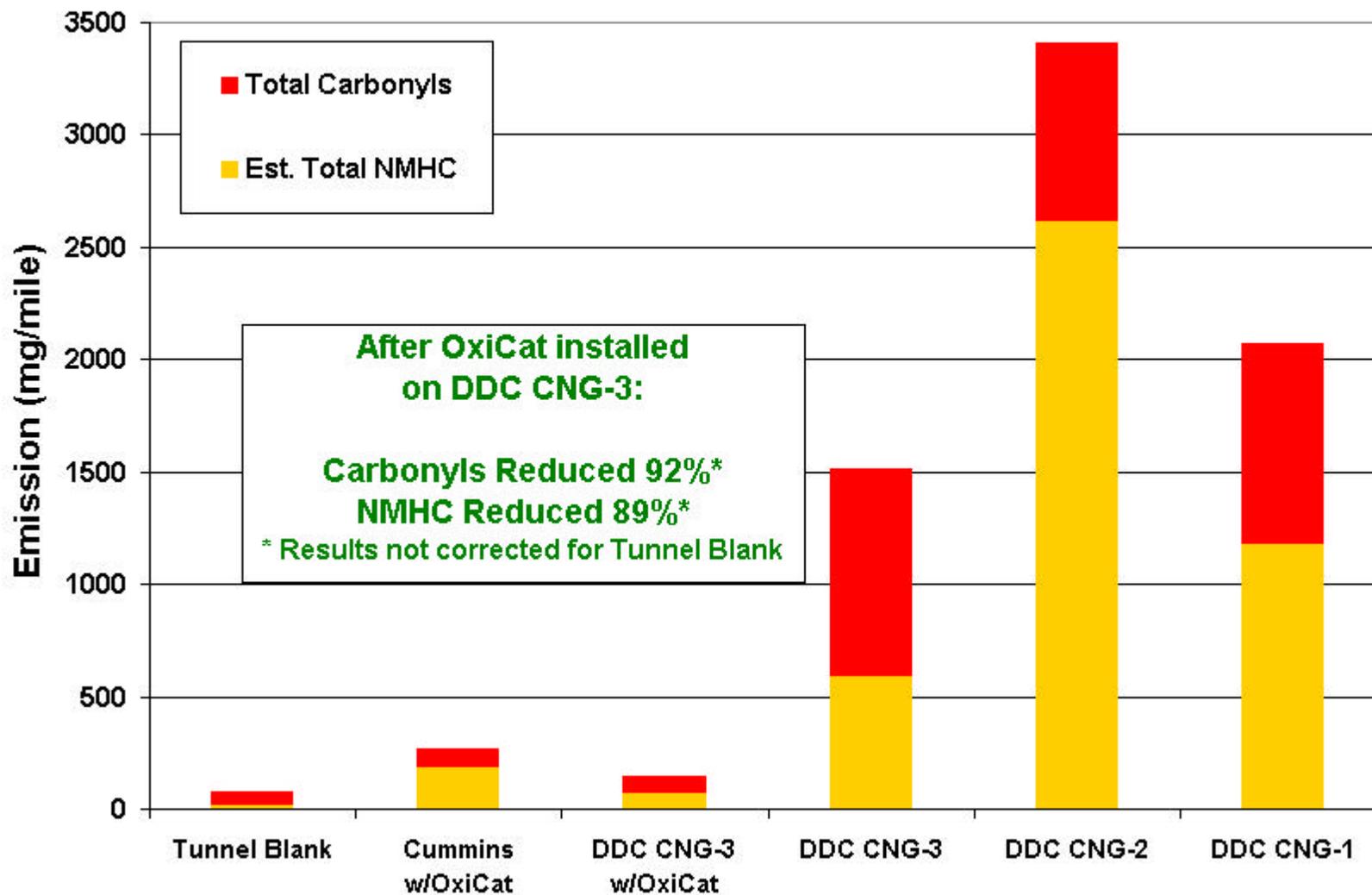
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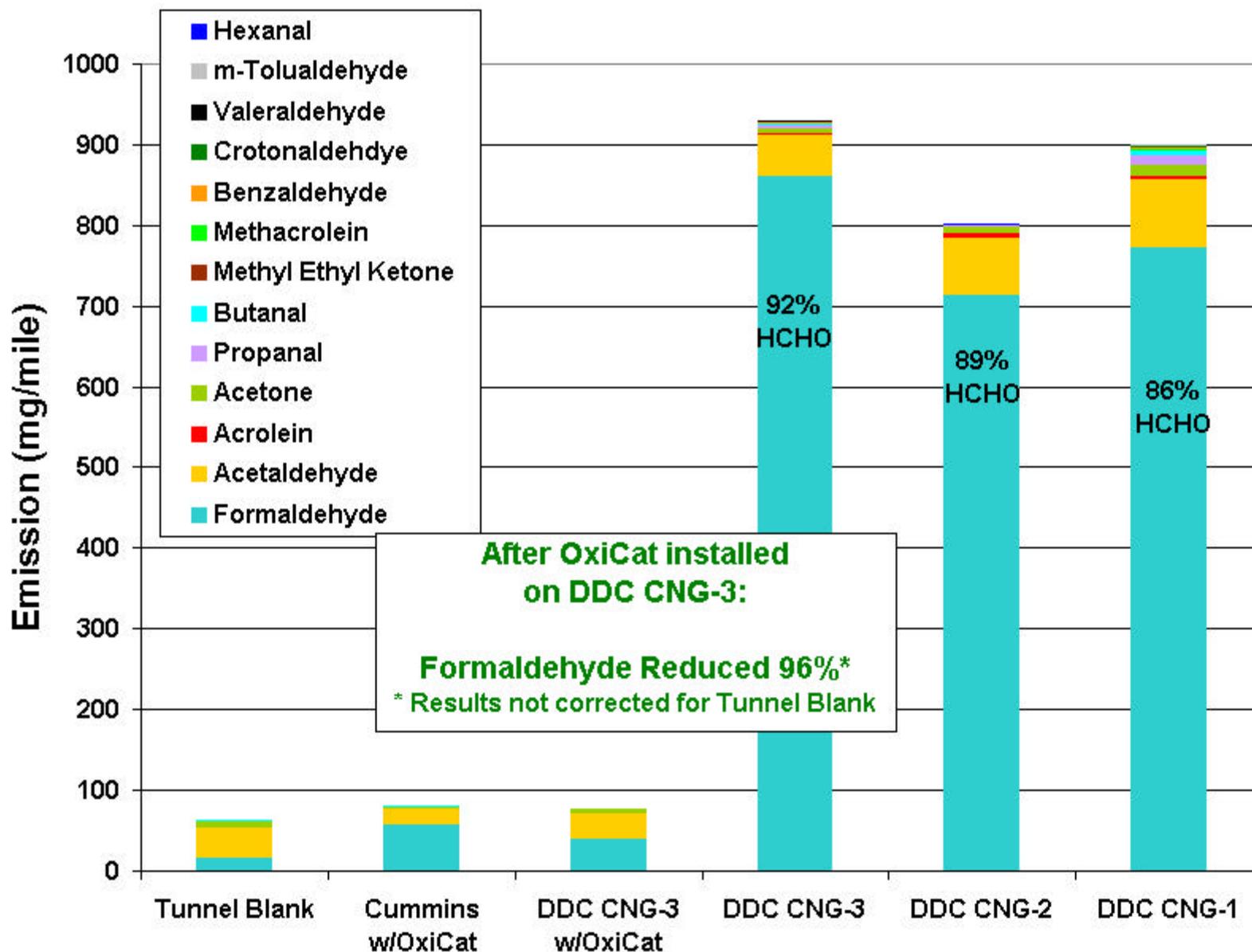
CO and CO₂ Emissions (Phase 1.B Results)



Estimated Total NMOG Emission (CBD Driving Cycle)
 (Estimated NMOG = Carbonyl Tot. + Est. Tot. NMHC by GC)

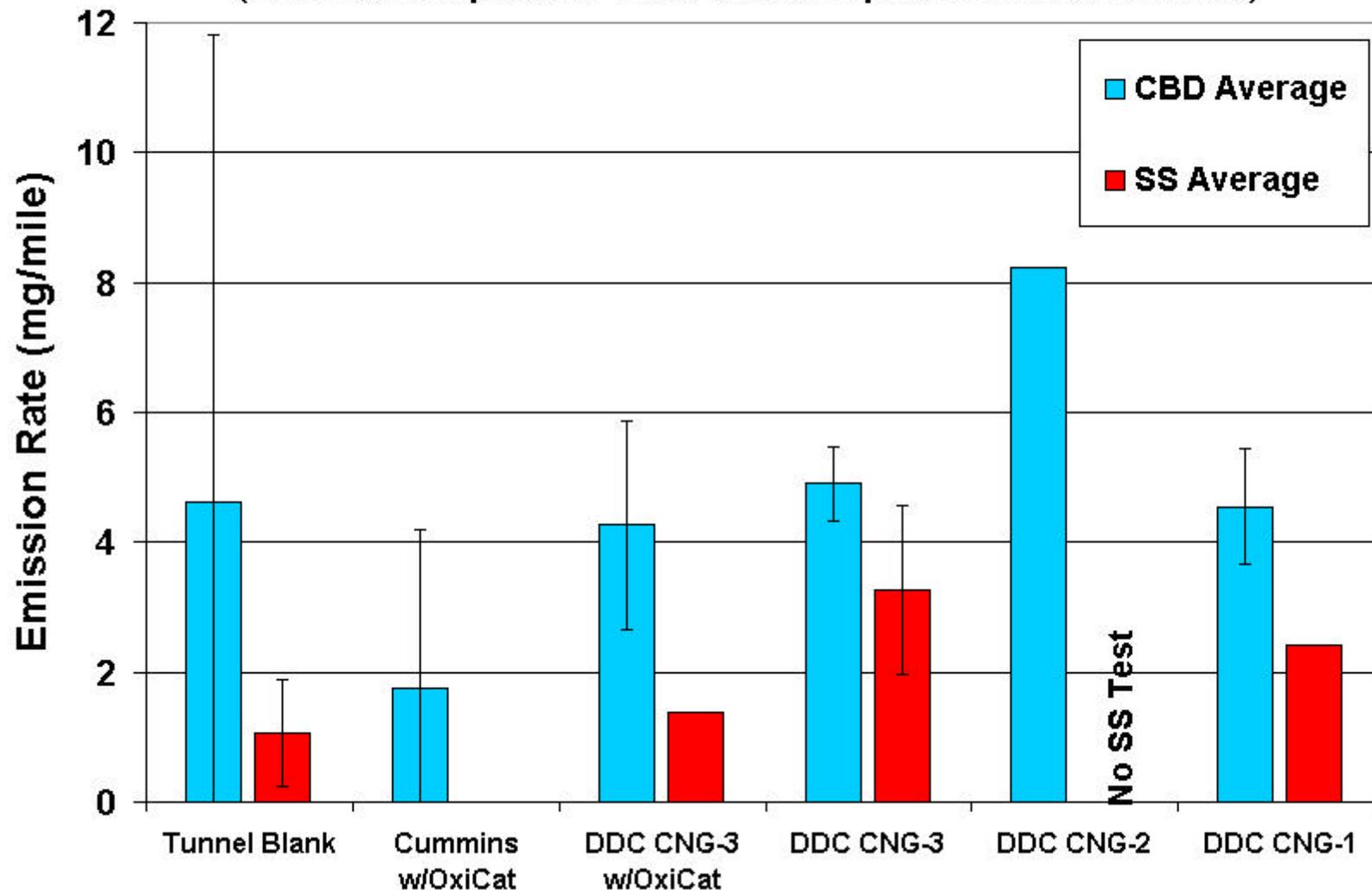


Average Carbonyl Emissions (CBD Driving Cycle)



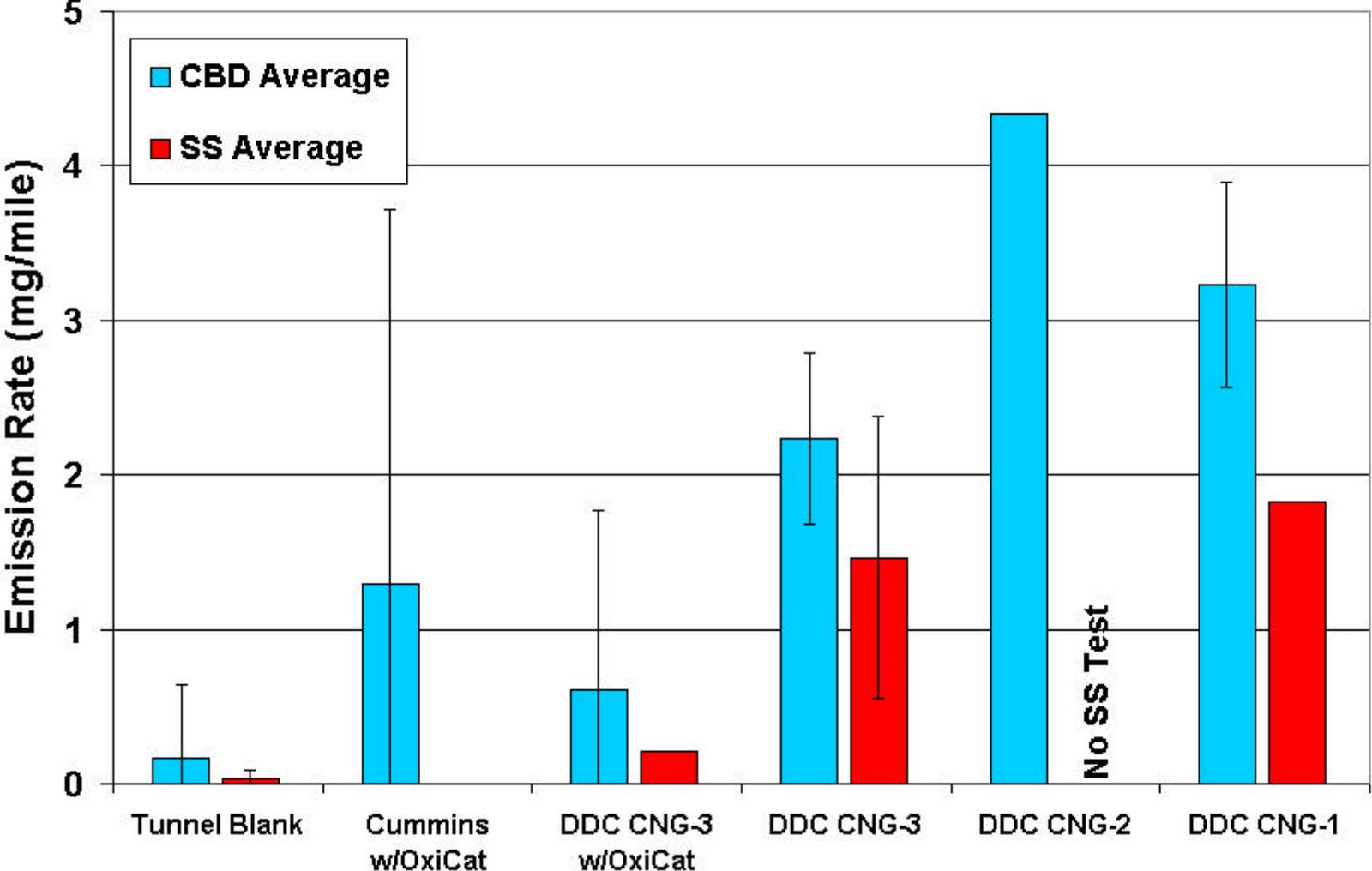
Note: HCHO tunnel blank < samples for 2001 and 2002 CNG results

Total BTEX Emission by Driving Cycle
 (Error bars represent 2 std dev of replicate measurements)

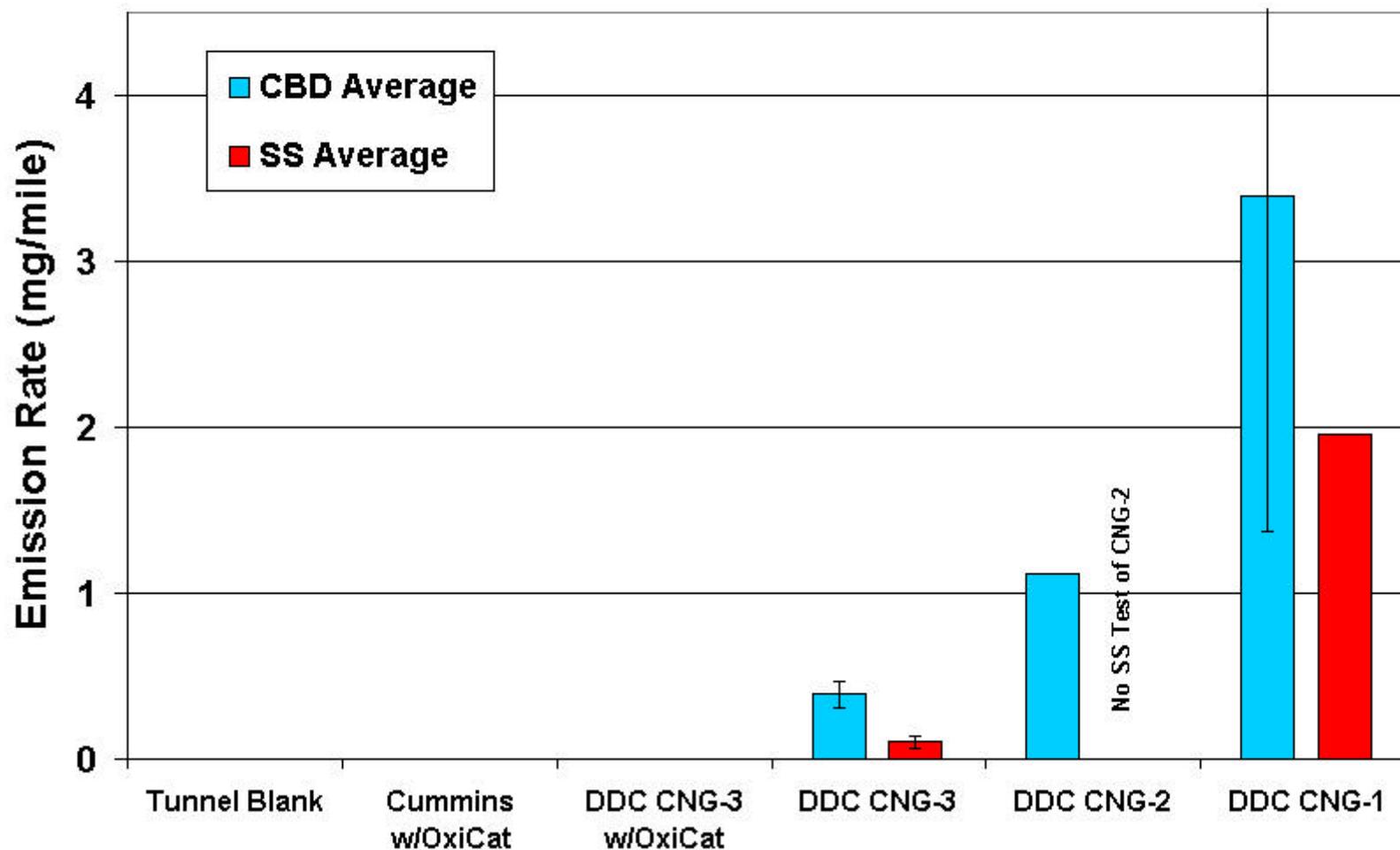


Benzene Emission by Driving Cycle

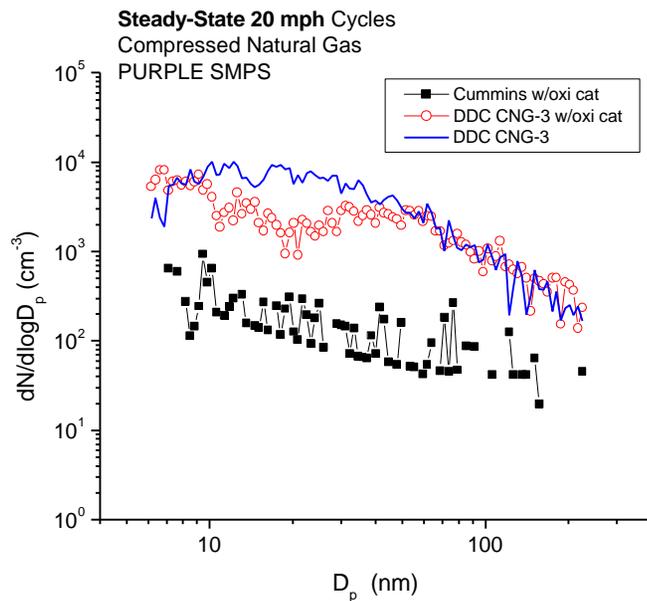
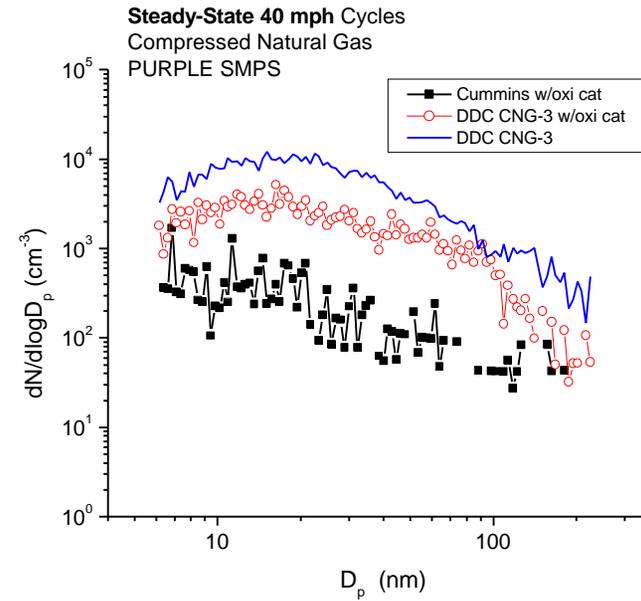
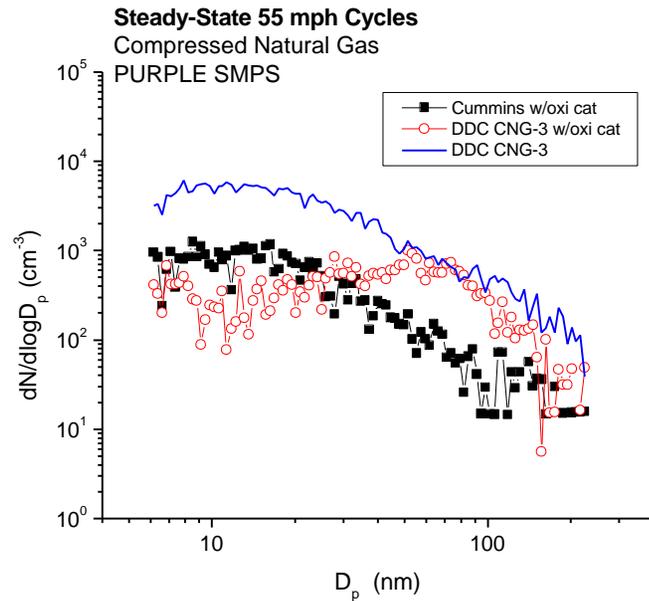
(Error bars represent 2 std. dev. of replicate measurements)



1,3 Butadiene Emission by Driving Cycle
(Error bars represent 2 std dev of replicate measurements)



Average Particle Size Distribution Over Steady State (uncorrected for DR and TB)



Note: sample number concentrations > TB's

Summary

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- OxiCat in CNG bus reduced HCHO by over 95% for both CBD and SS cycles.
- Comparison of results on a relative basis suggests some BTEX emission reduction by the catalyst. Accurate conclusions on BTEX cannot be made due to high tunnel blank results.
- 1,3-Butadiene emissions from CNG were reduced by the catalyst to levels below detection limit.
- OxiCat in CNG bus reduced NMHC emissions by over 88% for both CBD and SS cycles.
- The problem of high NO₂ emission from trap-equipped diesels is not present for CNG-fueled buses with or without oxidation catalyst.
- OxiCat in CNG bus shows reduction of total PM, CO, and total HC.
- OxiCat in CNG bus shows reduction of ultrafine particle number concentrations across the size range of 6nm to 230nm. Absolute reduction depends on engine operating condition.
- No significant effect of OxiCat on CH₄, CO₂, and NO_x.
- OxiCat durability not addressed in this study.