Controlling Nanoparticle and Toxic Emissions from Natural Gas-Fueled Transit Buses

Mridul Gautam

National Research Center for Alternative Fuels, Engines and Emissions

Department of Mechanical and Aerospace Engineering

West Virginia University

Hemanth Kappanna, Scott Wayne,
Bobby John, Dan Carder
Center for Alternative Fuels, Engines and Emissions
Department of Mechanical and Aerospace Engineering
West Virginia University

Adewale Oshinuga
South Coast Air Quality Management District

Ted Tadrous
ECS

Lisa Graham
Environment Canada

Objectives

Global Objective

- **To reduce toxic pollutants and nanoparticle emissions from CNG-fueled heavy-duty transit buses.**

Specific Objectives

- **Characterize the emissions, including particle size distribution from Cummins Westport C8.3G+ natural gas engine with and without OEM aftertreatment device, an oxidation catalyst (PHASE I).**

- **Develop an exhaust aftertreatment device based on the baseline engine emissions results. Test and validate emission reduction potential of the new exhaust aftertreatment device (PHASE II)**
  - **The new "WVU-Lubrizol" Exhaust Aftertreatment System was a combination of a catalyzed PM filter followed by an oxidation catalyst.**

- **Retest the exhaust aftertreatment device after six months of on-road demonstration to evaluate for any deterioration in the emissions reduction performance (PHASE III)**

Test Vehicle and Engine Specifications

Bus Manufacturer	Orion
Bus Model Year	1998
Engine Manufacturer	Cummins Westport
Engine Series	C-Series, Gas Plus
Engine Model Year	2000
Engine Displacement	8.3 liters
No of Cylinders	6
Compression Ratio	10:1
Ignition	Spark Ignited
Fuel Injection	Premixed Air/Fuel
Net Weight	1330 lbs
Fuel Type	Auto Grade Natural Gas
Engine Power rating	280 hp @ 2400rpm
Peak Torque	850 lb-ft @ 1400rpm

Certified with a catalyst for California ULEV levels

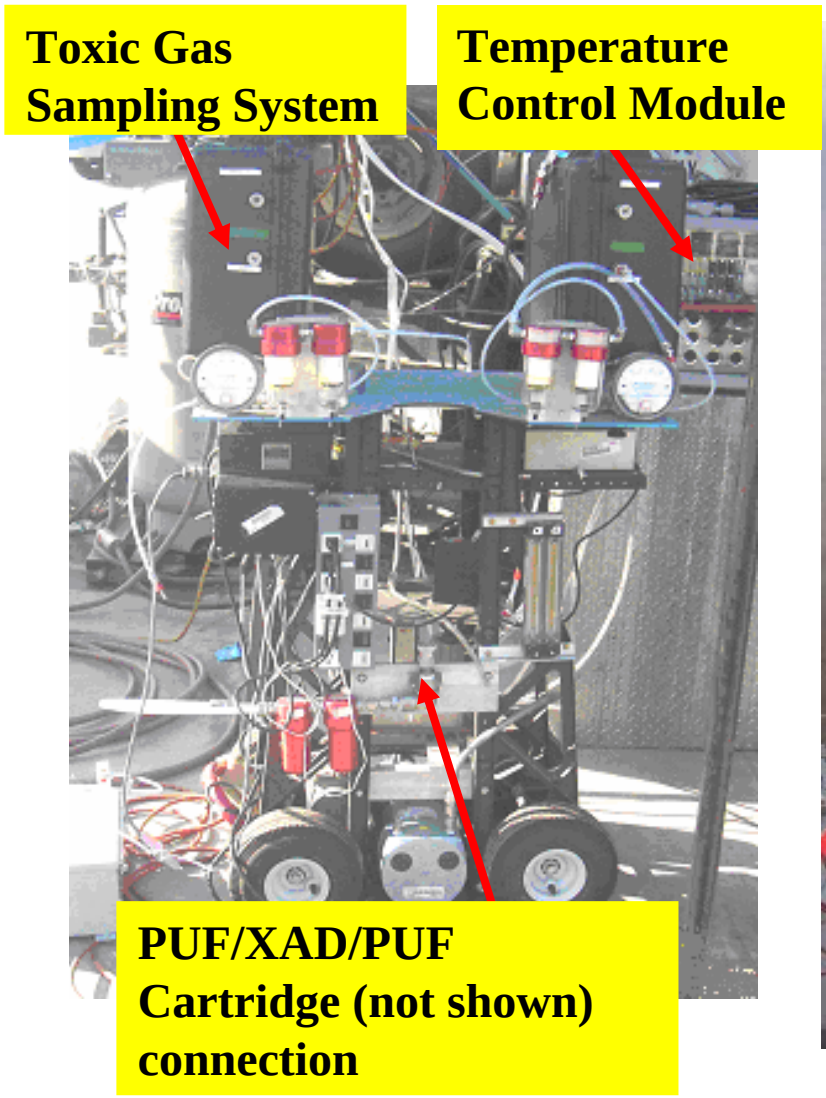
NOx: 1.53 g/bhp-hr
NMHC: 0.21 g/bhp-hr
Total PM: 0.008 g/bhp-hr
CO: 0.8 g/bhp-hr

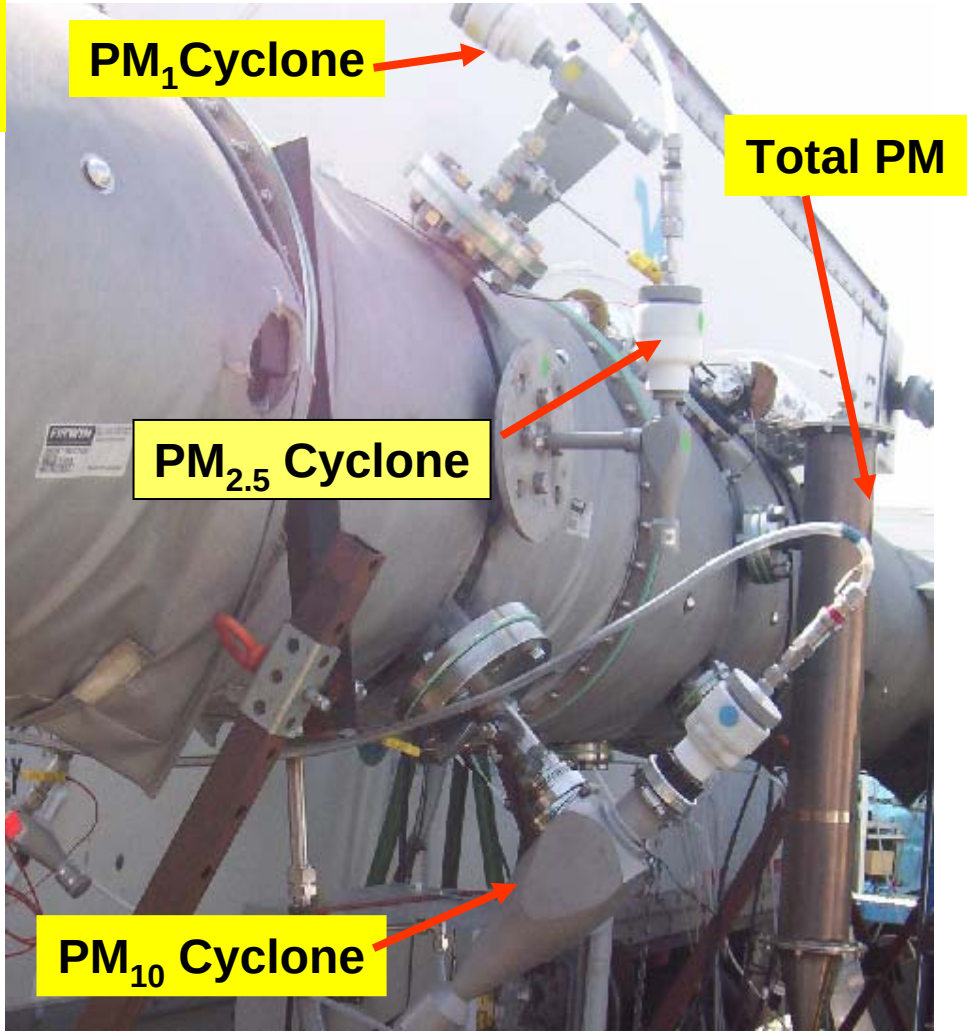
Test Cycle:
Quad – Central Business District Cycle

Test Vehicle:
Orion, standard 40-foot, high-floor design

Transportable Chassis Dynamometer Laboratory

PM and Speciation Sampling System

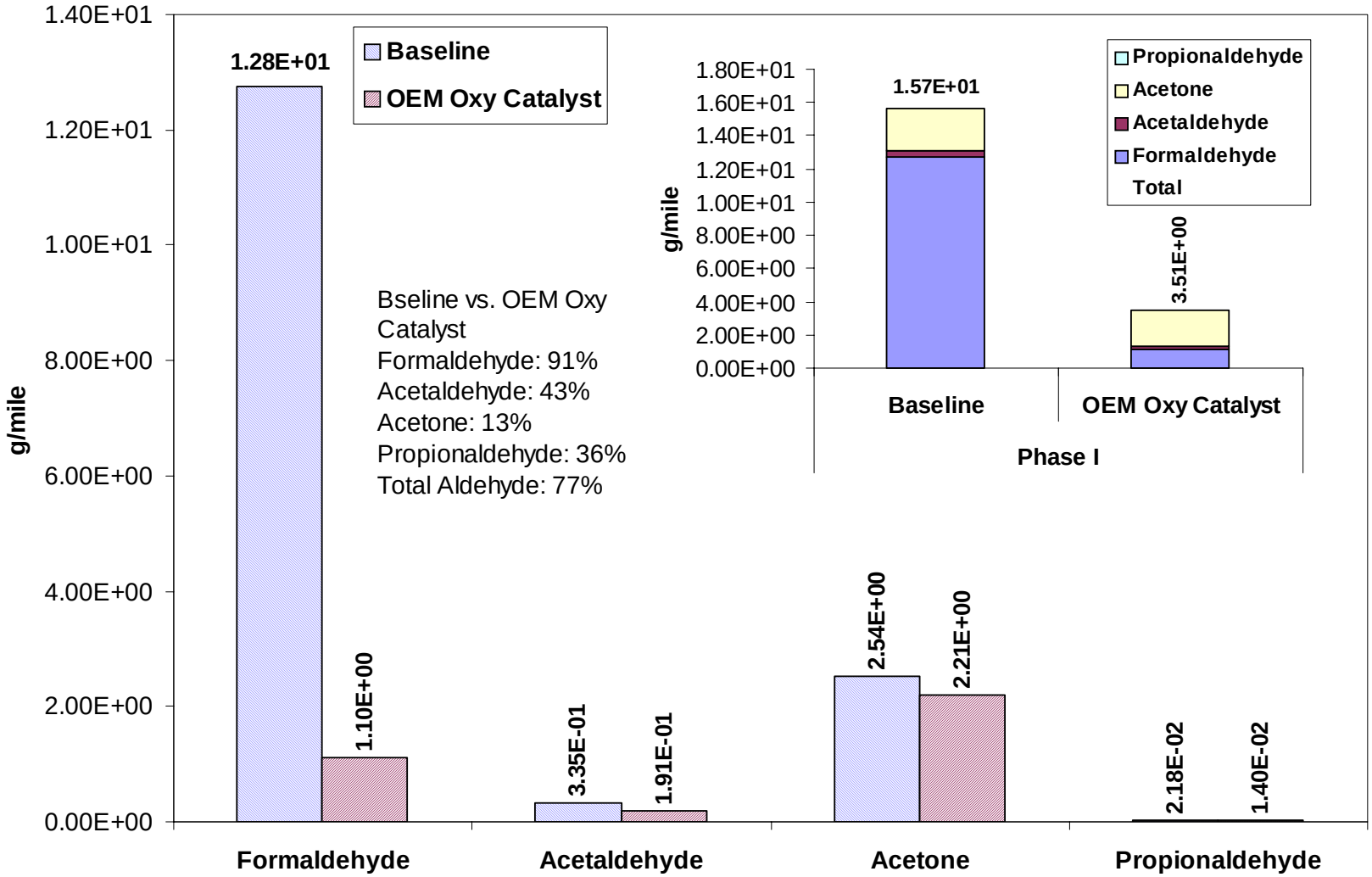




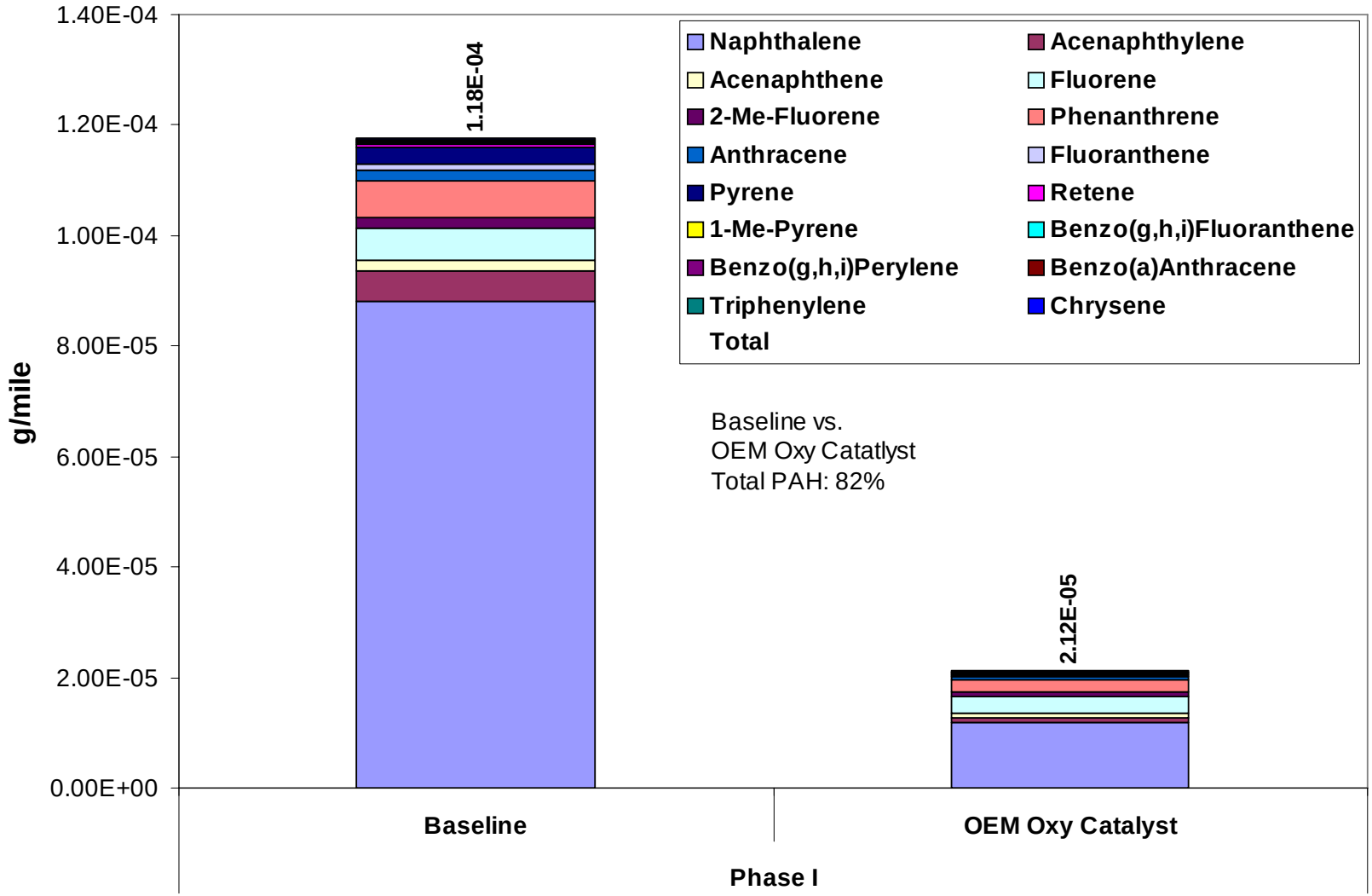
Sampling Media, and Methods used to Analyze Unregulated Emissions

Compound Class	Sampling Media	Flow Rate (lpm)	Method
Volatile Organic Compounds (VOC)	Tedlar bags for onsite analysis and steel canisters for lab analysis	6L @ 10psi(can) 10L bag	GC/MS/FID equipped with pre concentrator
Carbonyl Compounds	Two Sep-Pak cartridges impregnated with acidified 2,4-DNPH	1	High Performance Liquid chromatography (HPLC) for separation and quantization
Metals and elemental analysis	$PM_{2.5}$ cyclonic separator with 47mm teflon filter	16.7	X-Ray Fluorescence metal detection
EC/OC and Inorganic Ions	$PM_{2.5}$ cyclonic separator with 47mm pre-fired quartz filter	16.7	Thermal Optical Reflectance (TOR) for EC/OC. Ion chromatography and automated Colorimetry for inorganic ions
PAHs and nitro-PAHs, Hopanes and Steranes	70 mm teflon-impregnated, glass fiber filter (TX40) backed by PUF/XAD/PUF adsorbing cartridge	60	Accelerated solvent/microwave extraction followed by GC/MS. Nitro-PAHs separated by HPLC before GC/MS.
Total PM mass	70mm teflon coated glass-fiber filter (T60A20)	81	Gravimetric Analysis
PM_{10} mass	Size selective cyclone and 47 mm T60A20 filter	28.3	Gravimetric Analysis
$PM_{2.5}$ mass	Size selective cyclone and 47 mm T60A20 filter	16.7	Gravimetric Analysis
$PM_{1.0}$ mass	Size selective cyclone and 47 mm T60A20 filter	16.7	Gravimetric Analysis

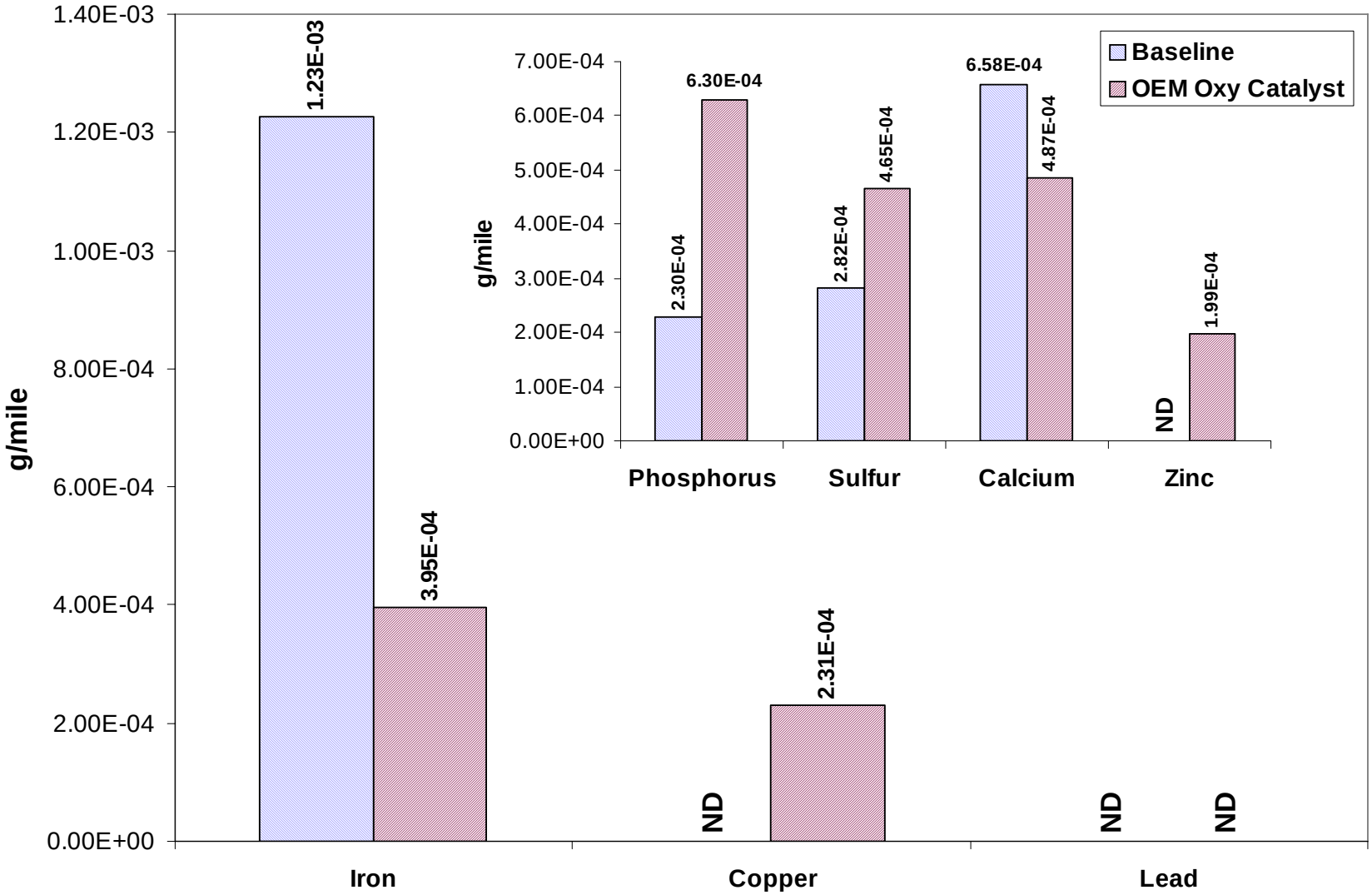
Phase I: Average Carbonyls Emissions



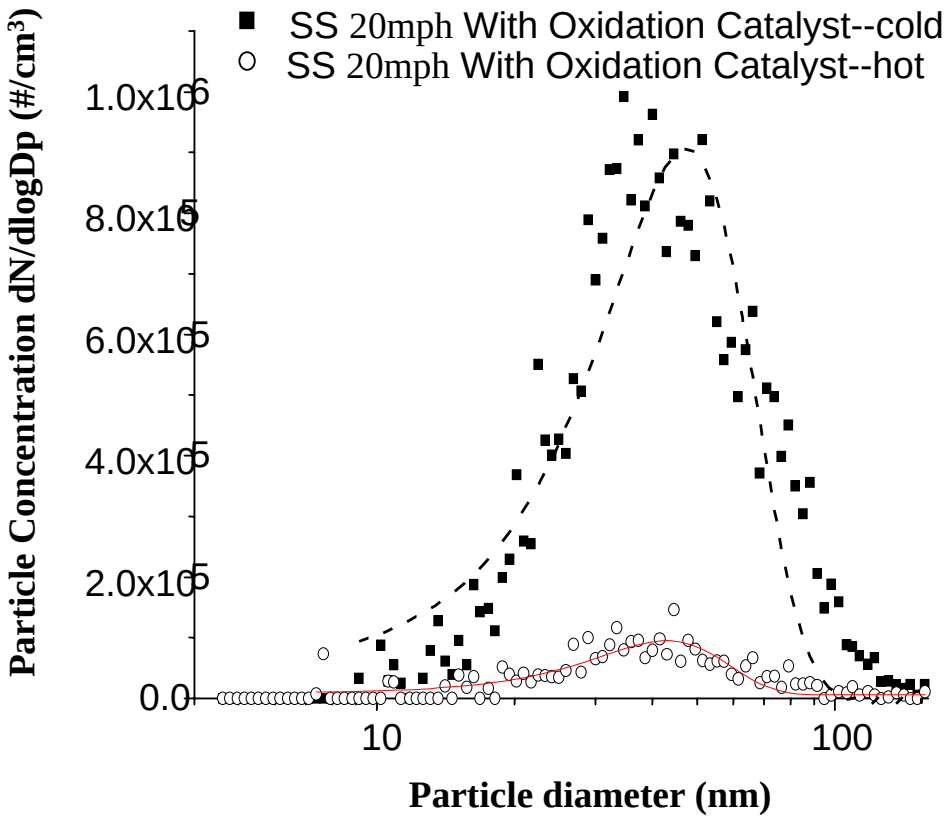
Phase I: Average Poly Aromatic Hydrocarbons Emissions



Phase I: Average Engine Wear & Lube Oil Additive Emissions

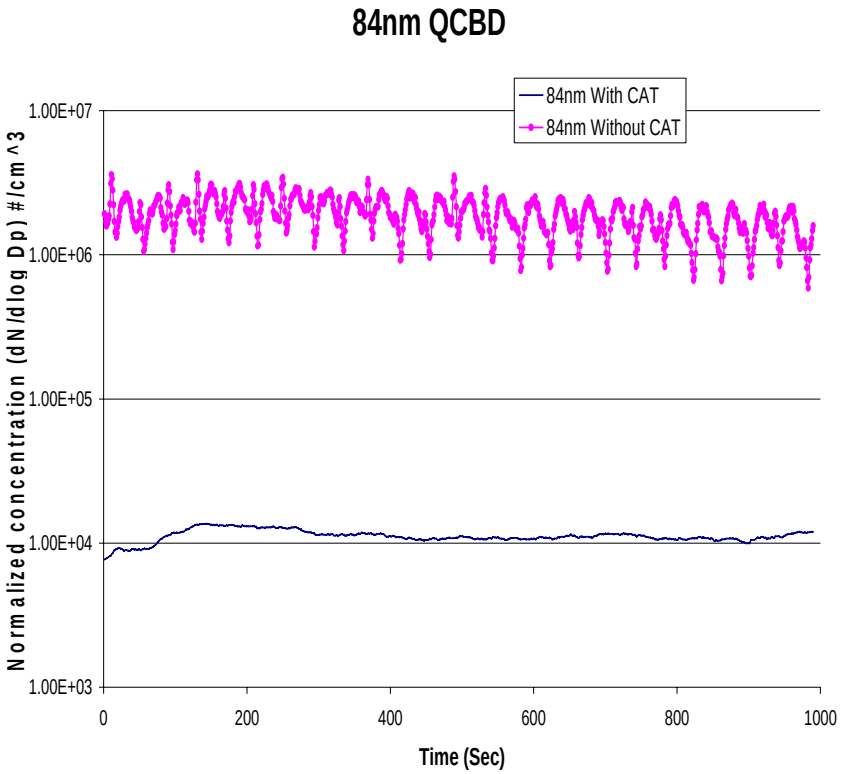


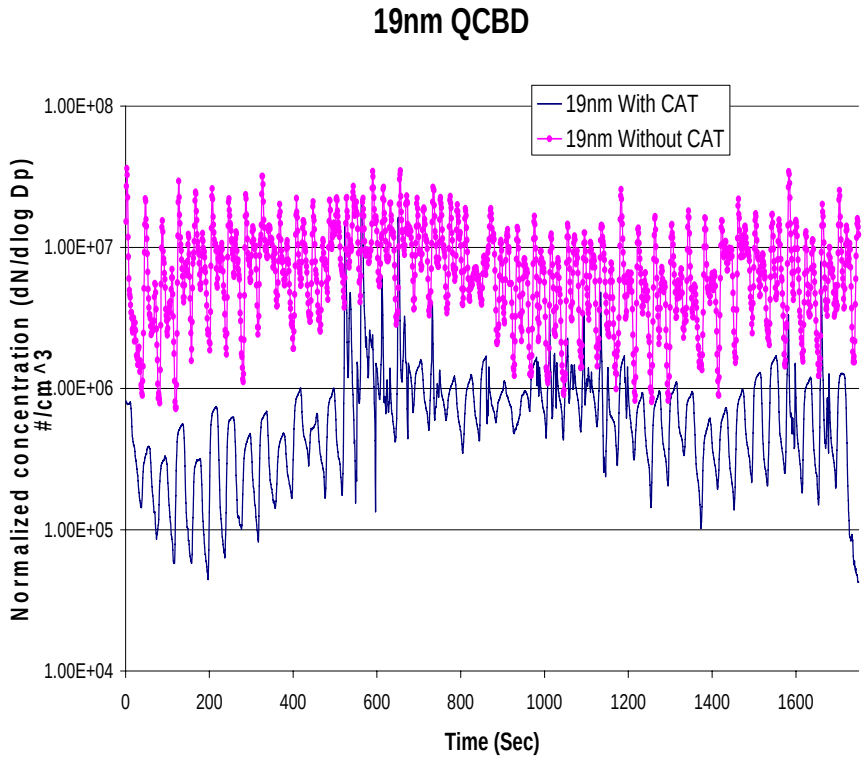
Phase I: Steady State (20 mph) Particle Size Distribution, Cold and Warm Oxidation Catalyst



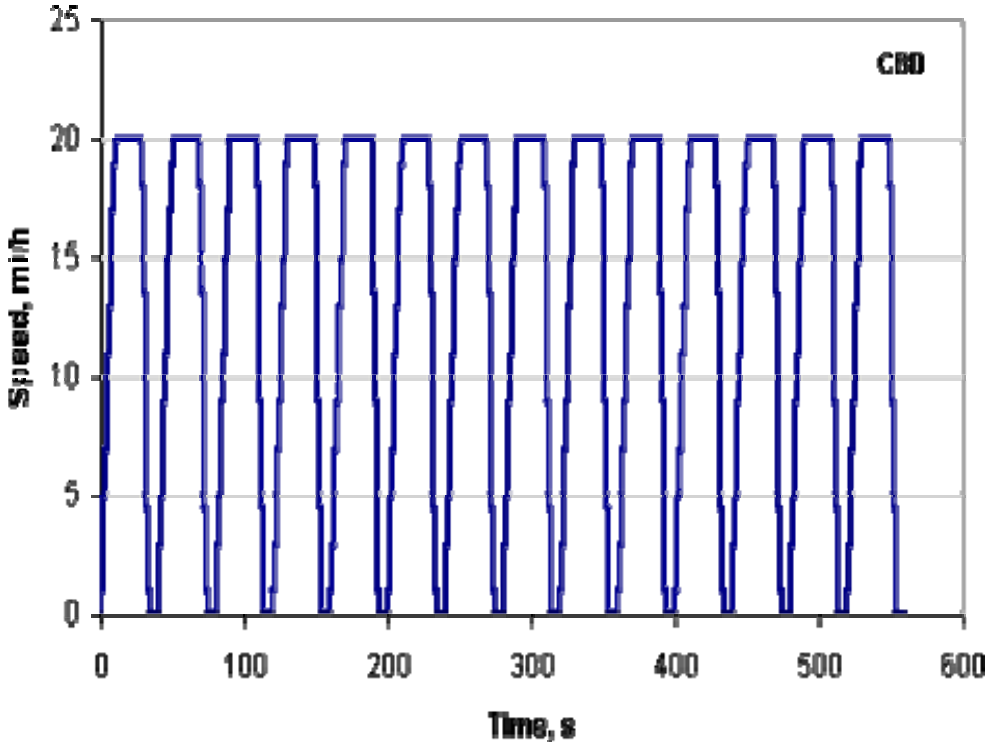
Burlingame, (2004)

Phase I: Concentration Trace of Different Size Particles With and Without the OEM Catalyst





Test Cycle Specification



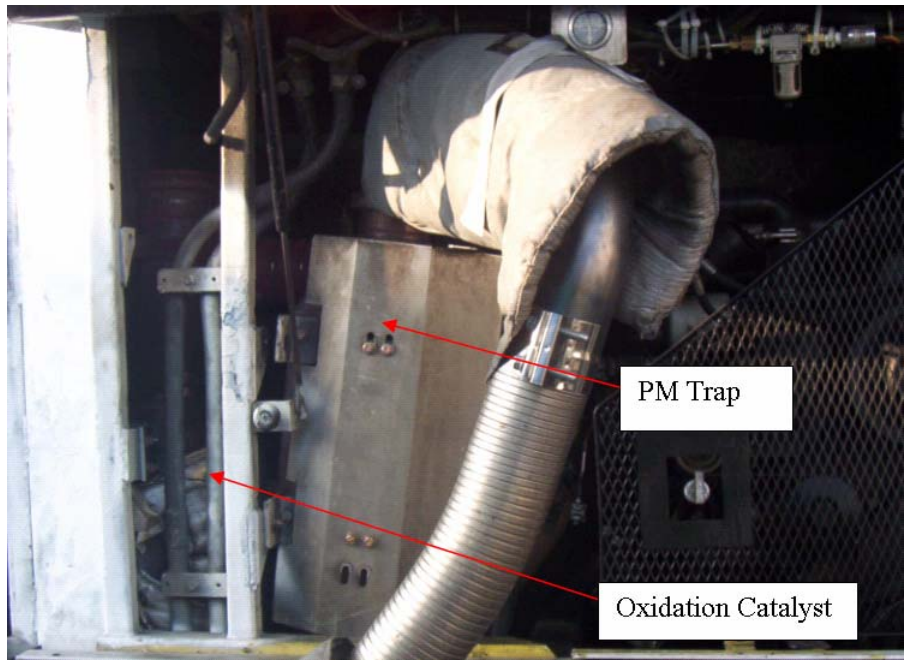
- **Name: Central Business District cycle (CBD)**
- **Duration: 560/590 s**
- **Average Speed: 12.57 mph**
- **Maximum Speed: 20 mph**
- **Driving Distance: 2 miles**
- **Maximum Acceleration: 1.79 m/s^2**

WVU-Lubrizol Aftertreatment System

(Oxidation Catalyst was Located Downstream of the PM Filter)

Diesel Particulate Filter

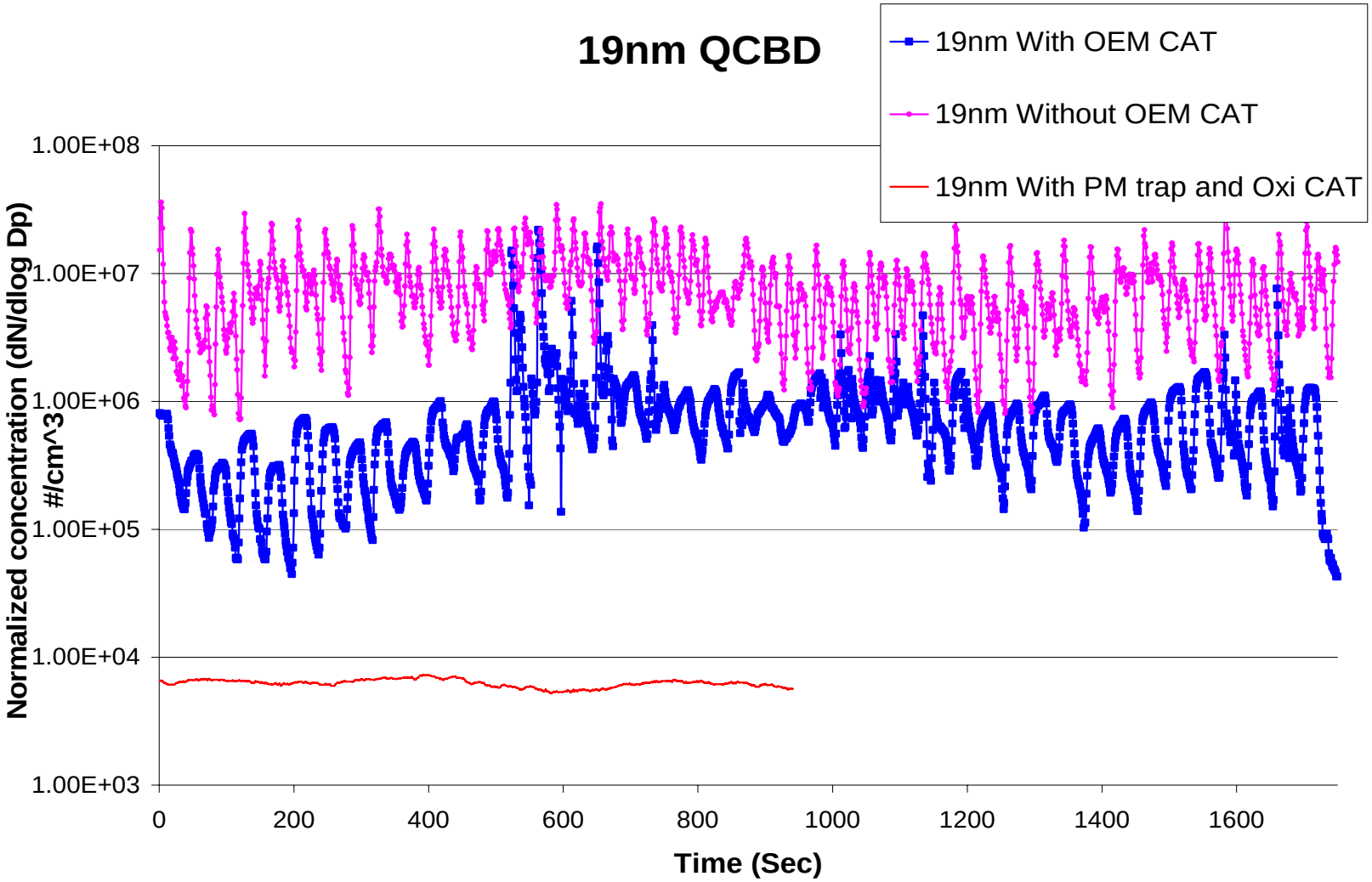
- **Silicon Carbide, segmented honey comb (11.25” X 12”)**
- **200 square CPI cell density**
- **Platinum coated on proprietary wash-coat**
- **Passive regeneration over duty cycles producing exhaust temperature 280^{o}C - 320^{o}C for >25% of the time**



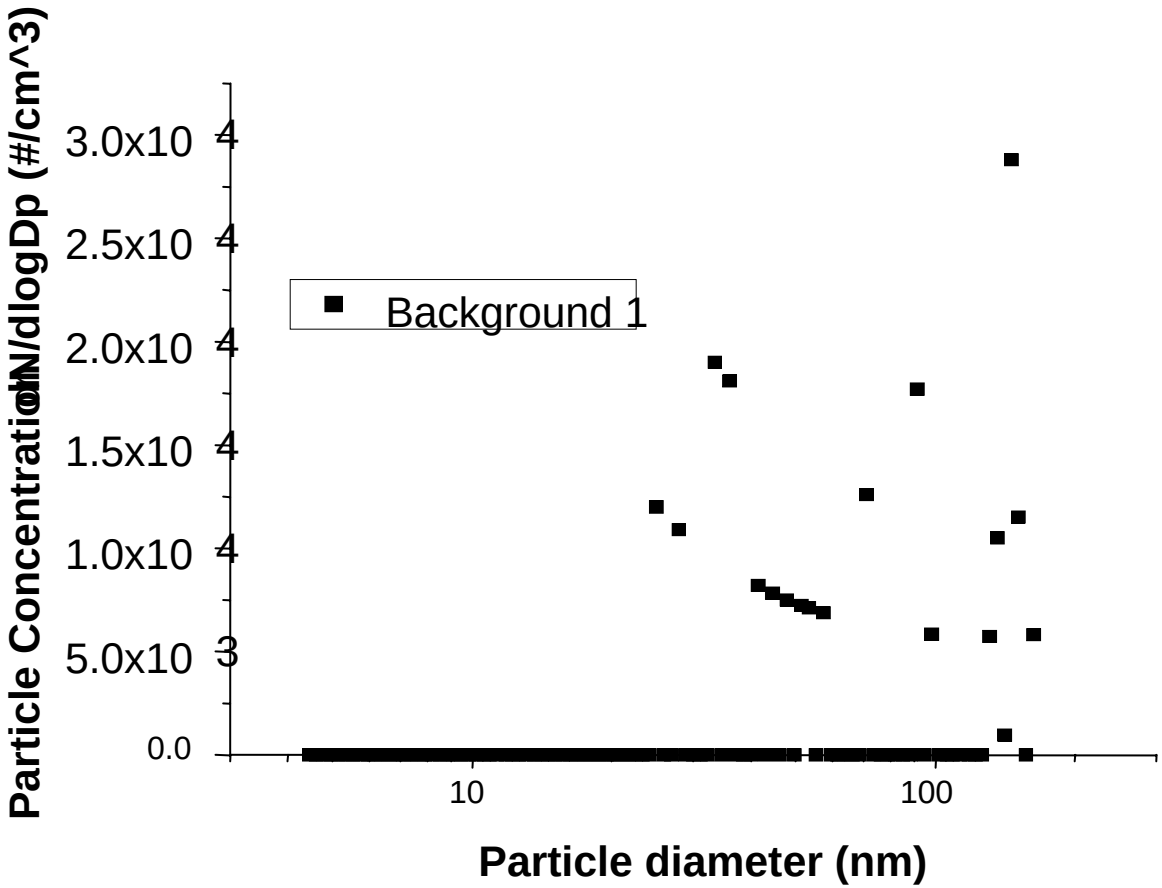
Oxidation Catalyst

- **Cordierite flow-through monolith, (10.5” X 6”)**
- **400 square CPI cell density**
- **Pt and Pd (1:3) coated on proprietary wash-coat**

Phase II: Transient Particle Concentrations



Phase II: Steady State Particle Size Distribution



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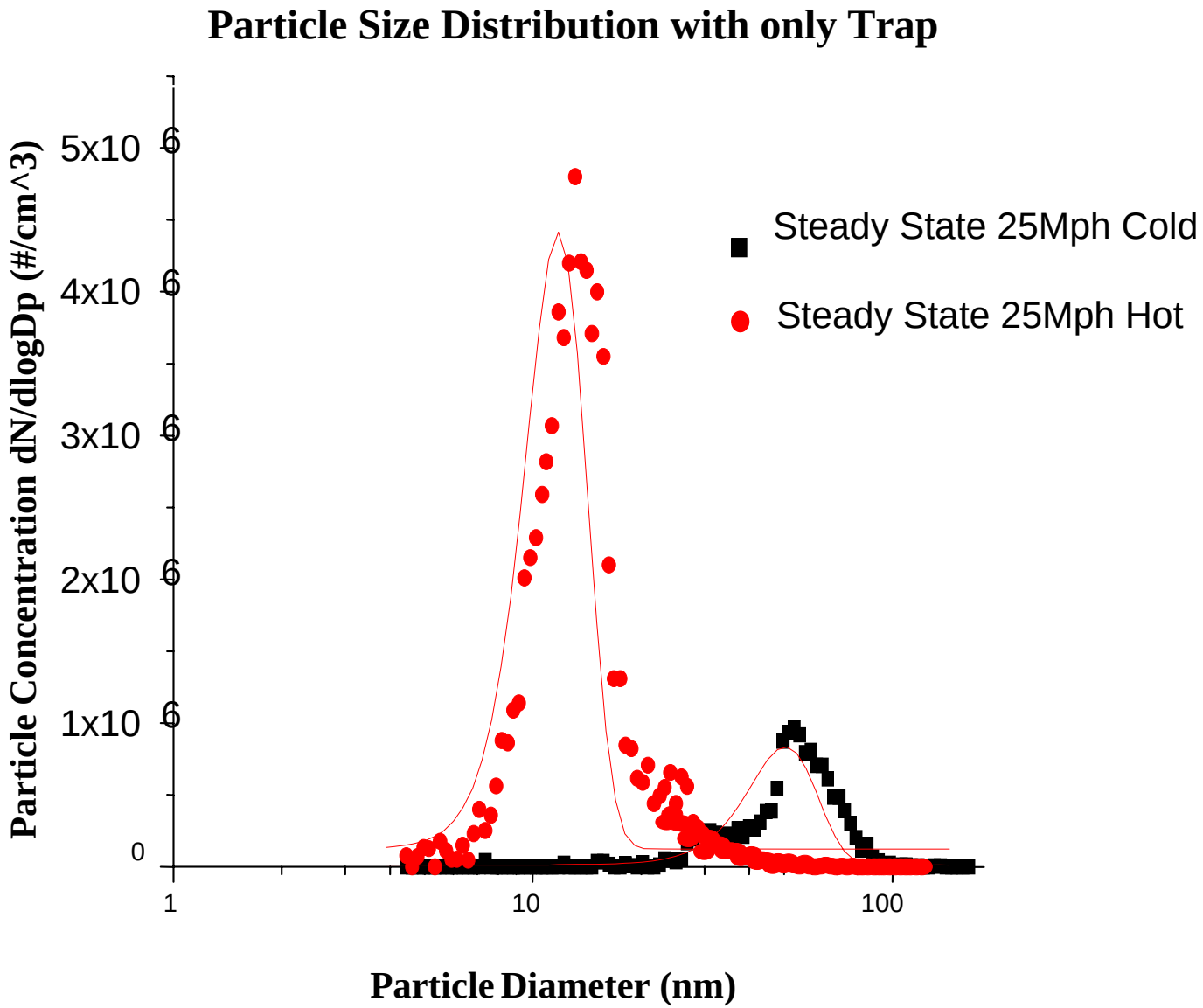

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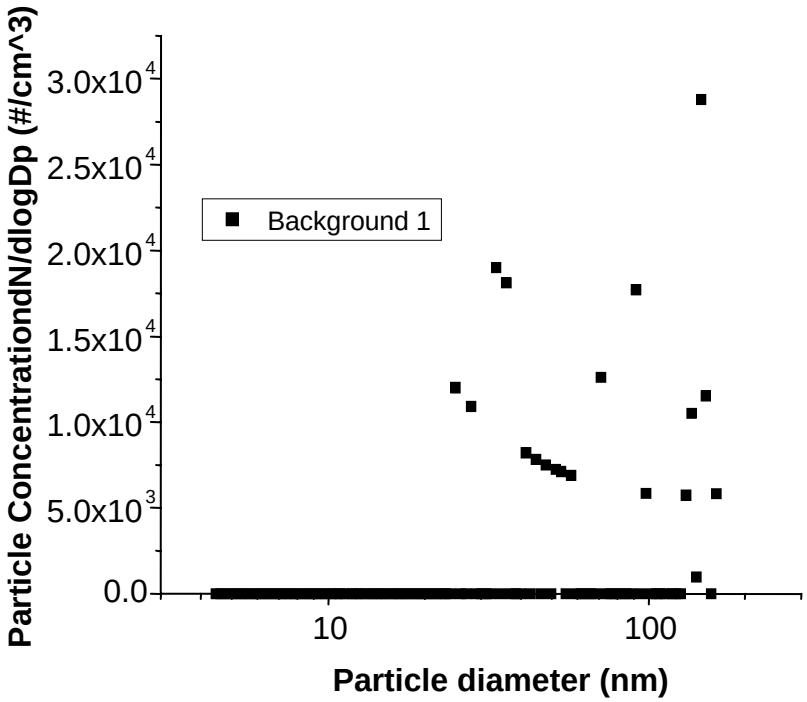
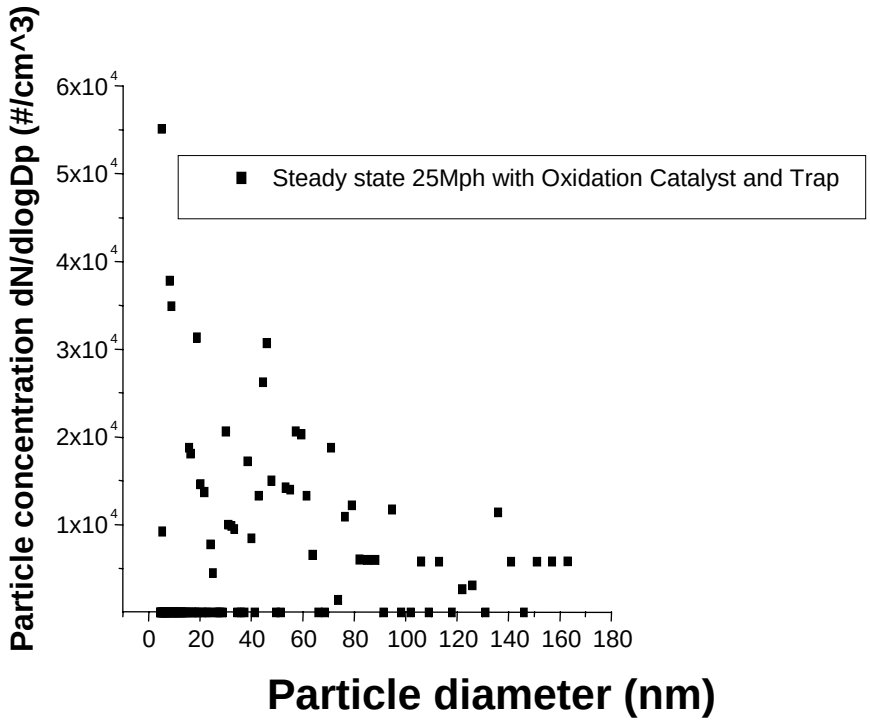
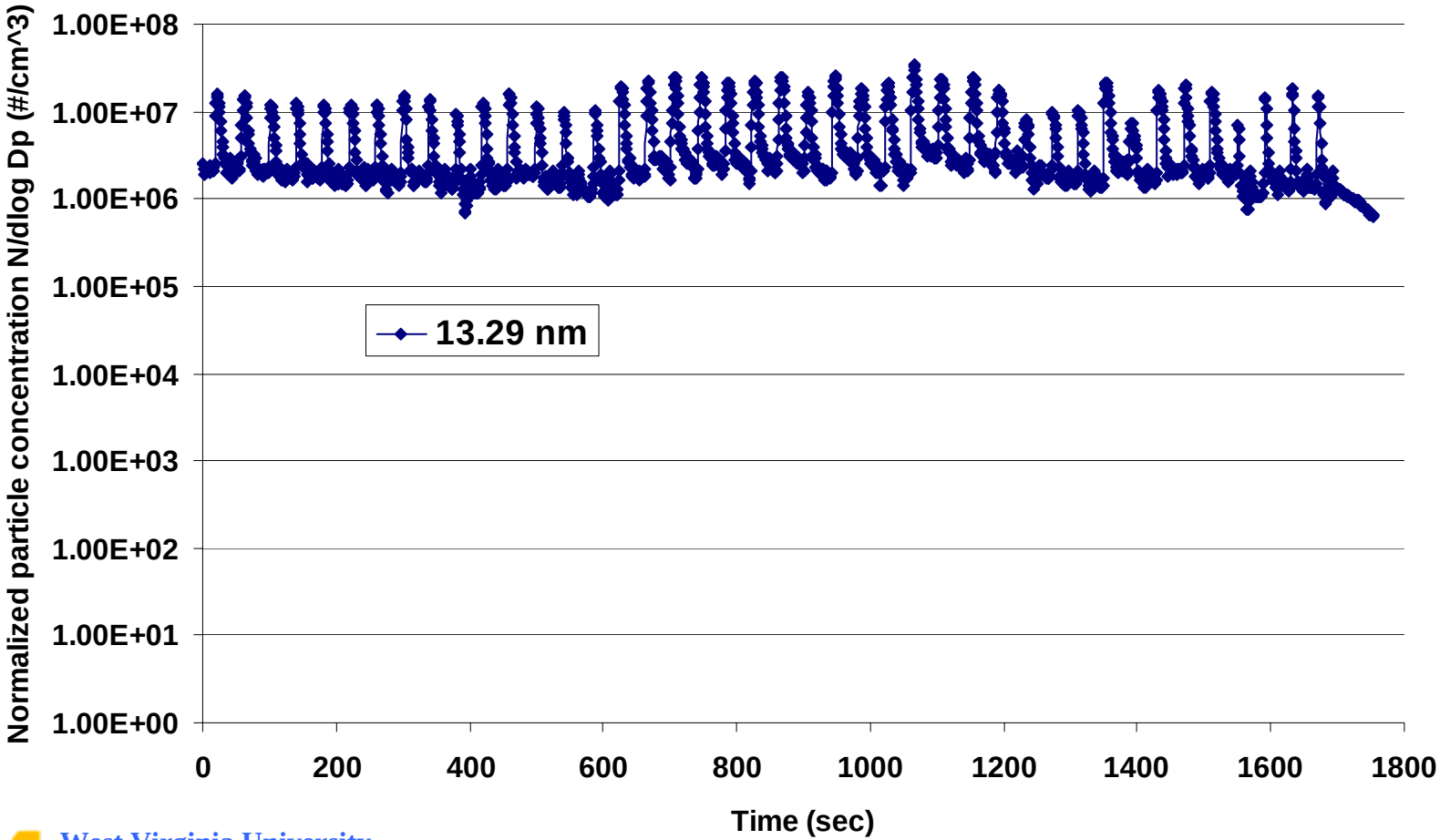




Sunline Transit Bus Transient Operation Quad CBD; Catalyzed PM Filter Only (Phase II)



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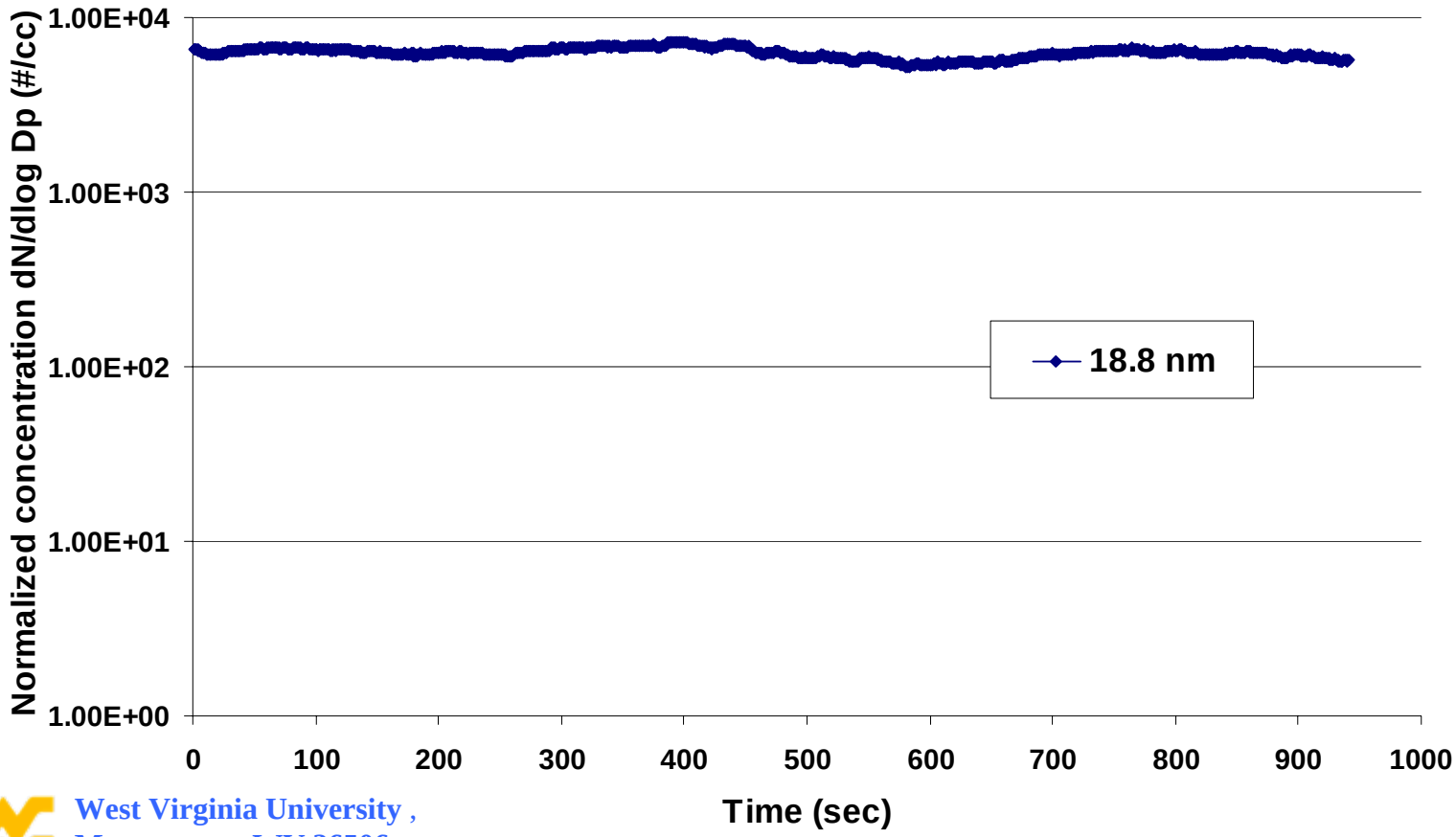
Transit Bus Transient Operation Quad CBD; Catalyzed PM Filter and Oxidation Catalyst (Phase II)



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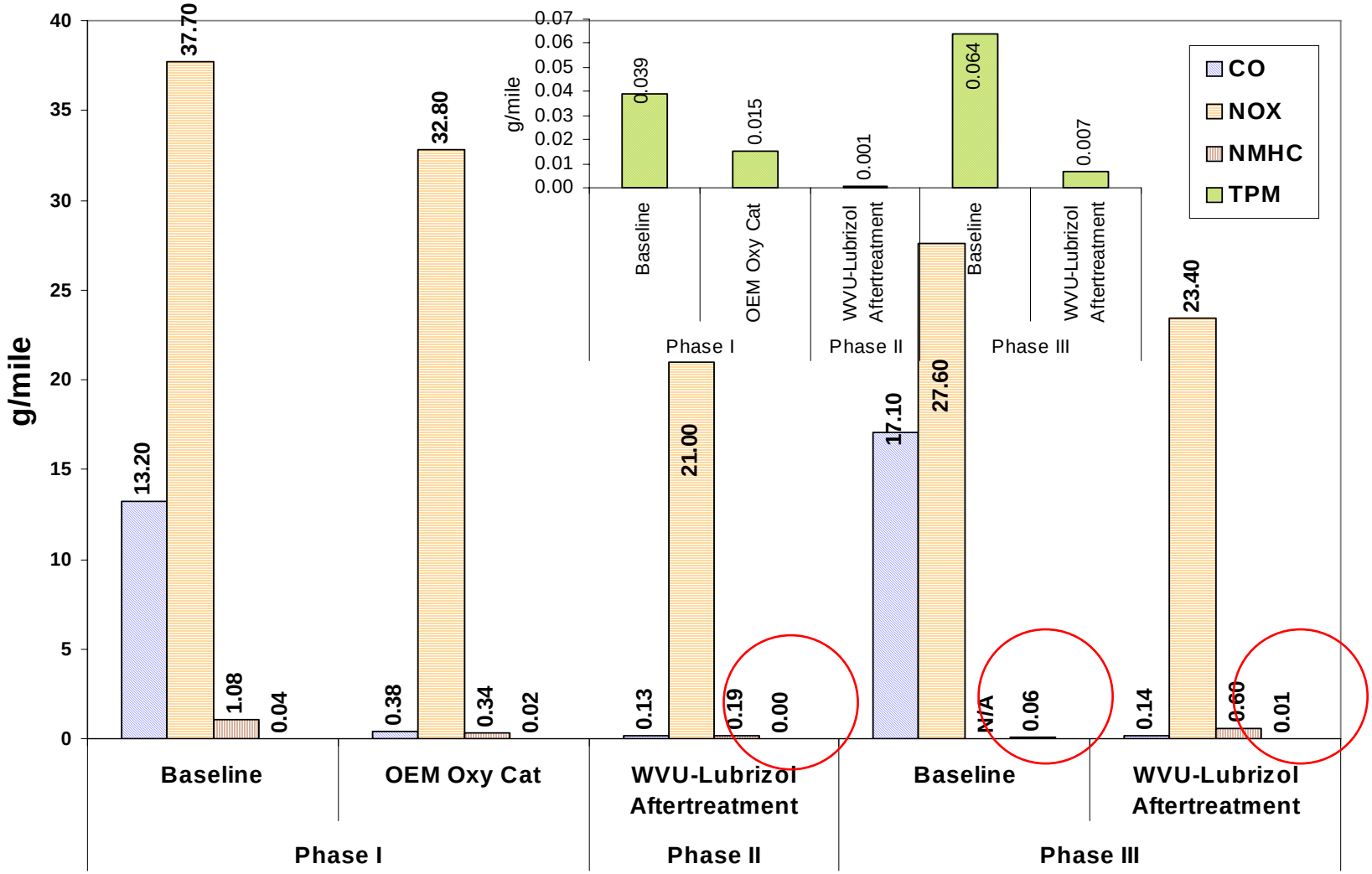
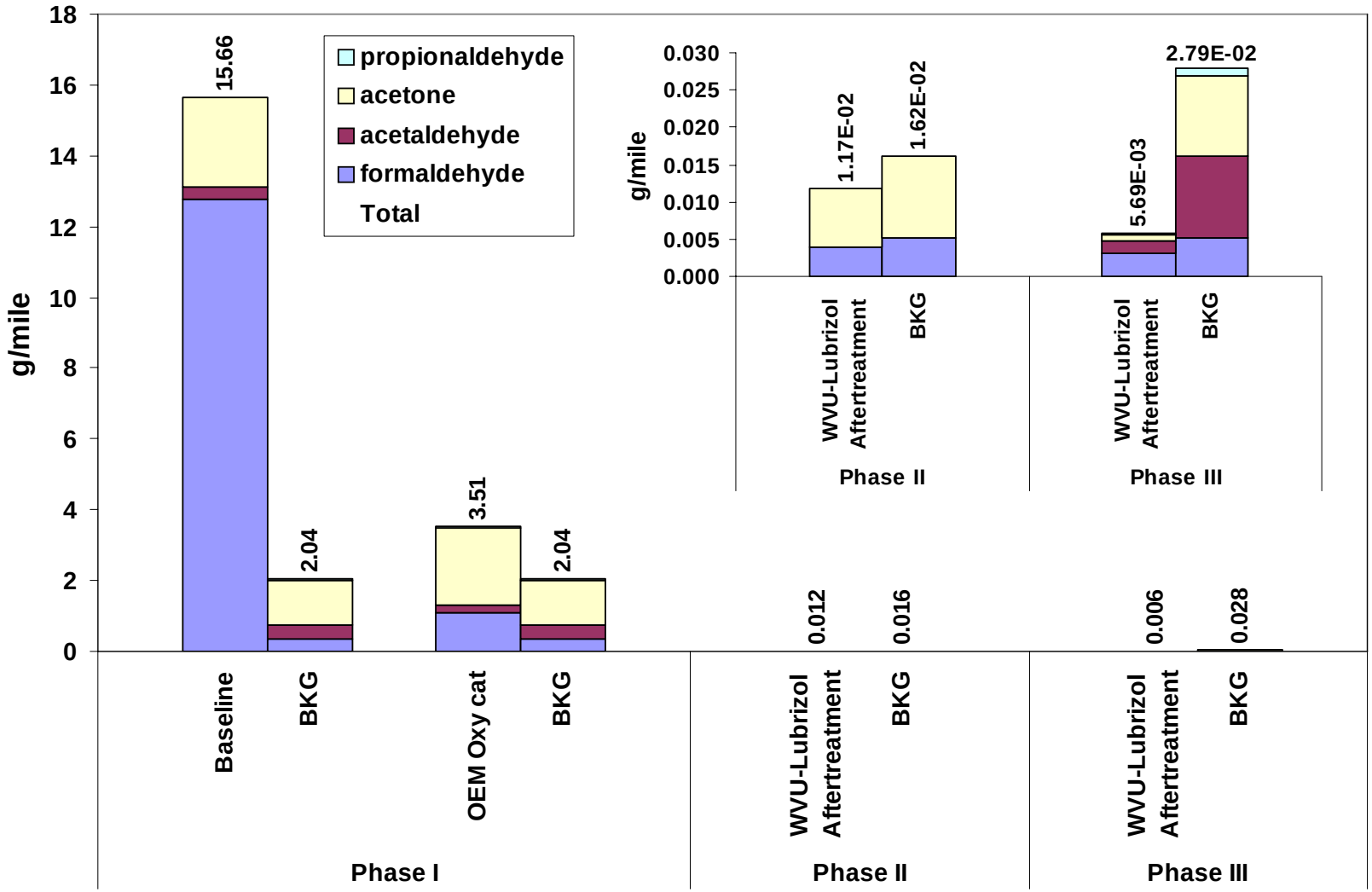
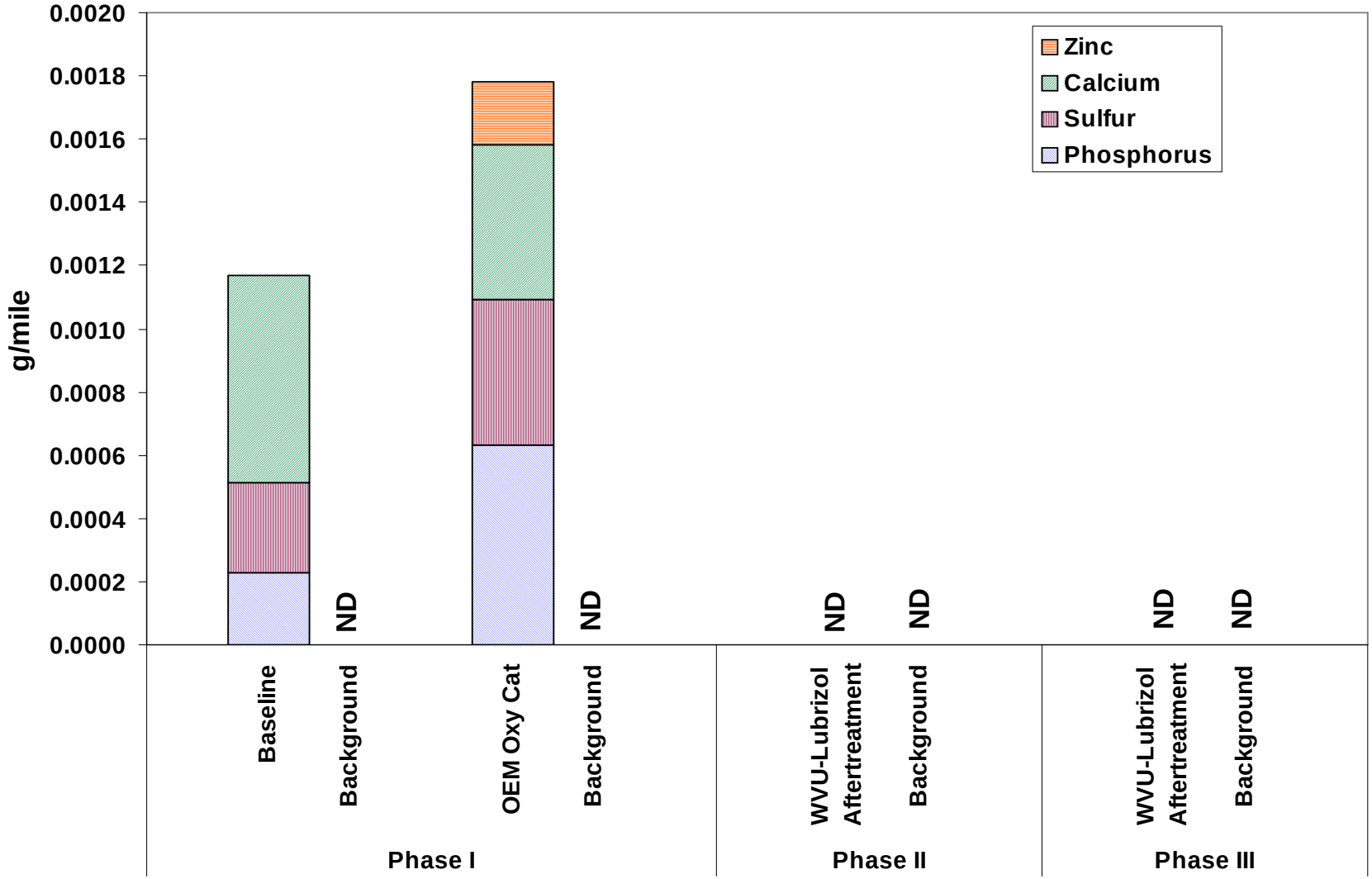
Average Regulated Emissions



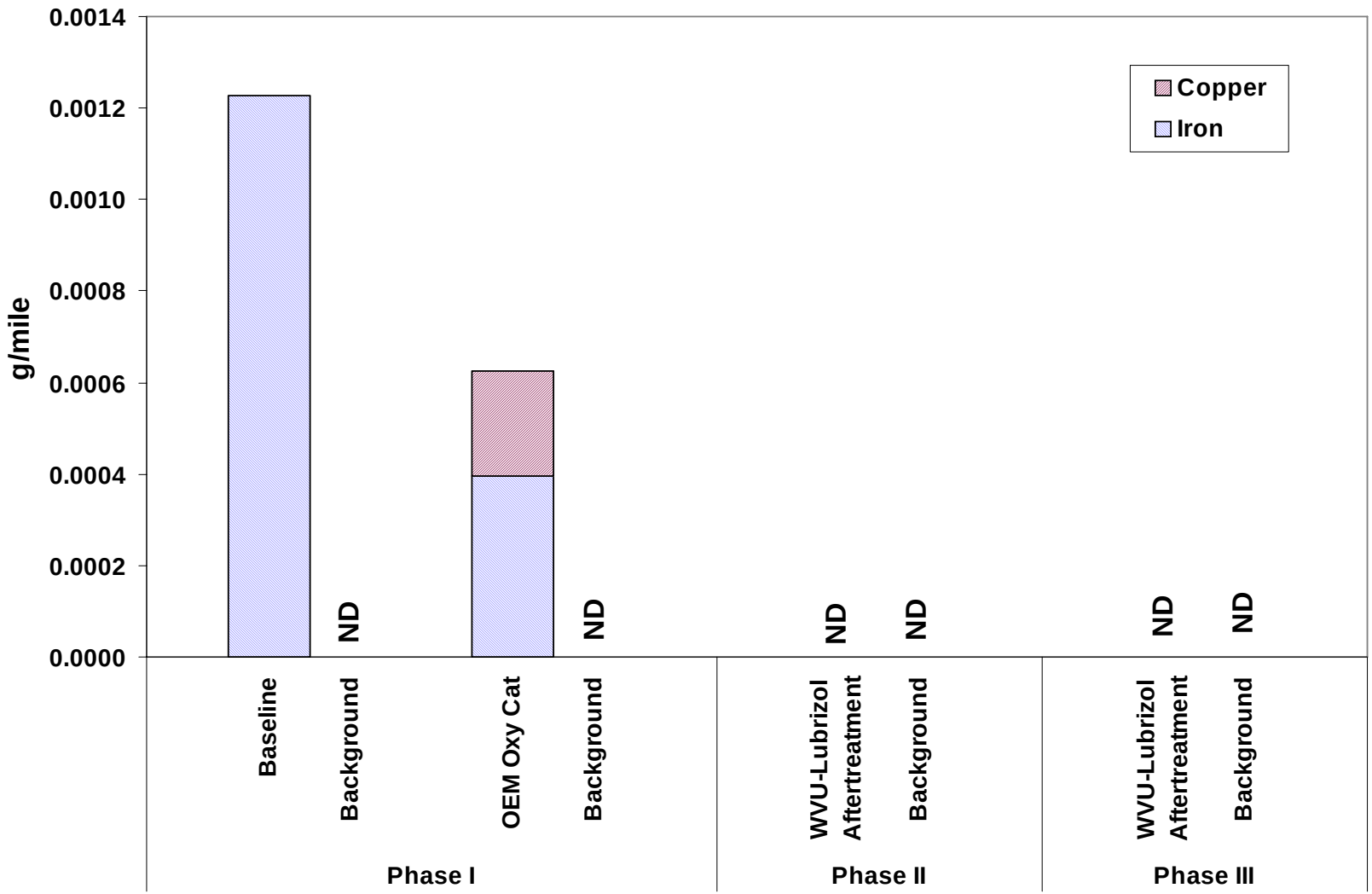
Average Carbonyl Emissions



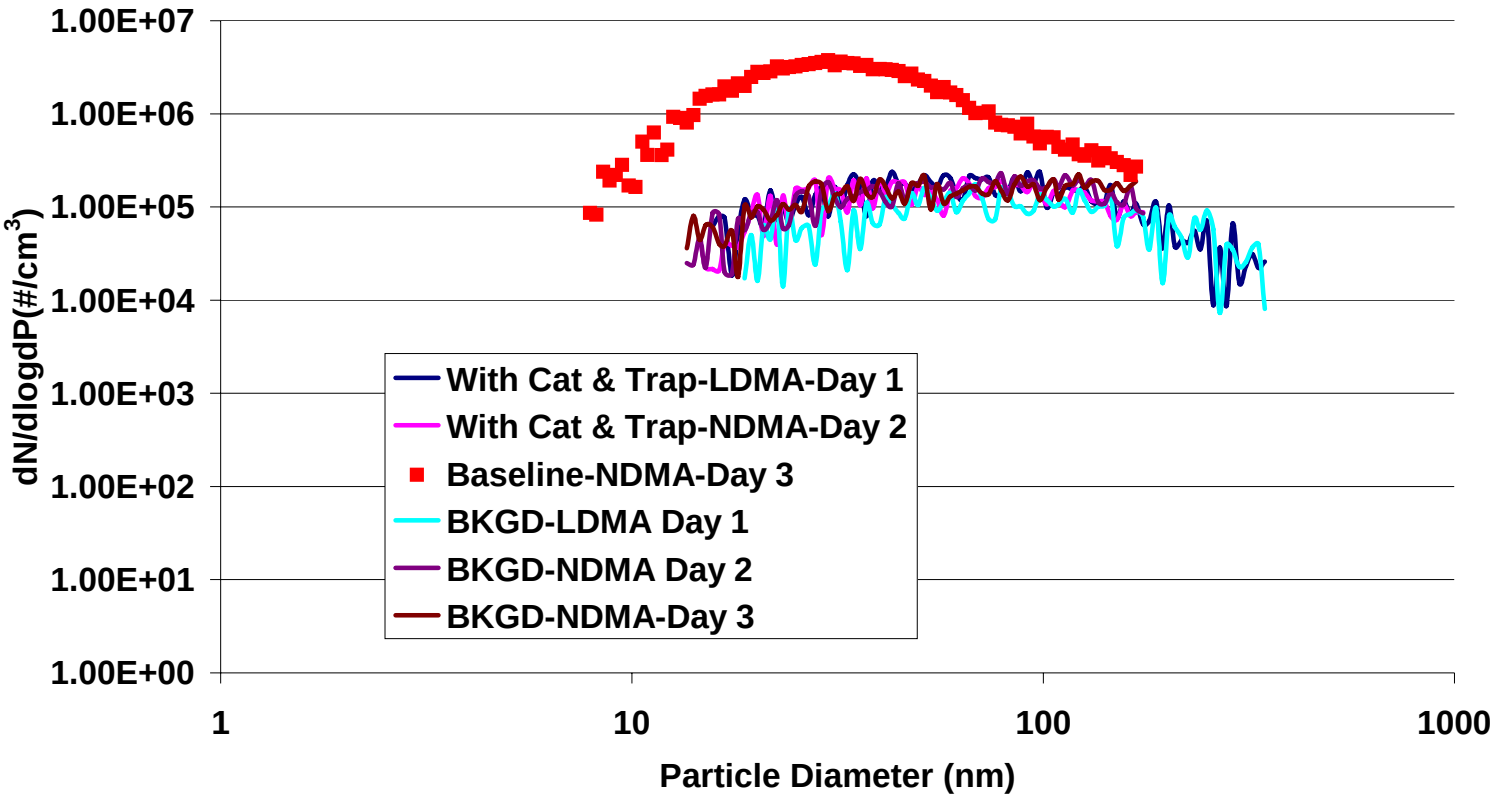
Average Lube Oil Additive Emissions



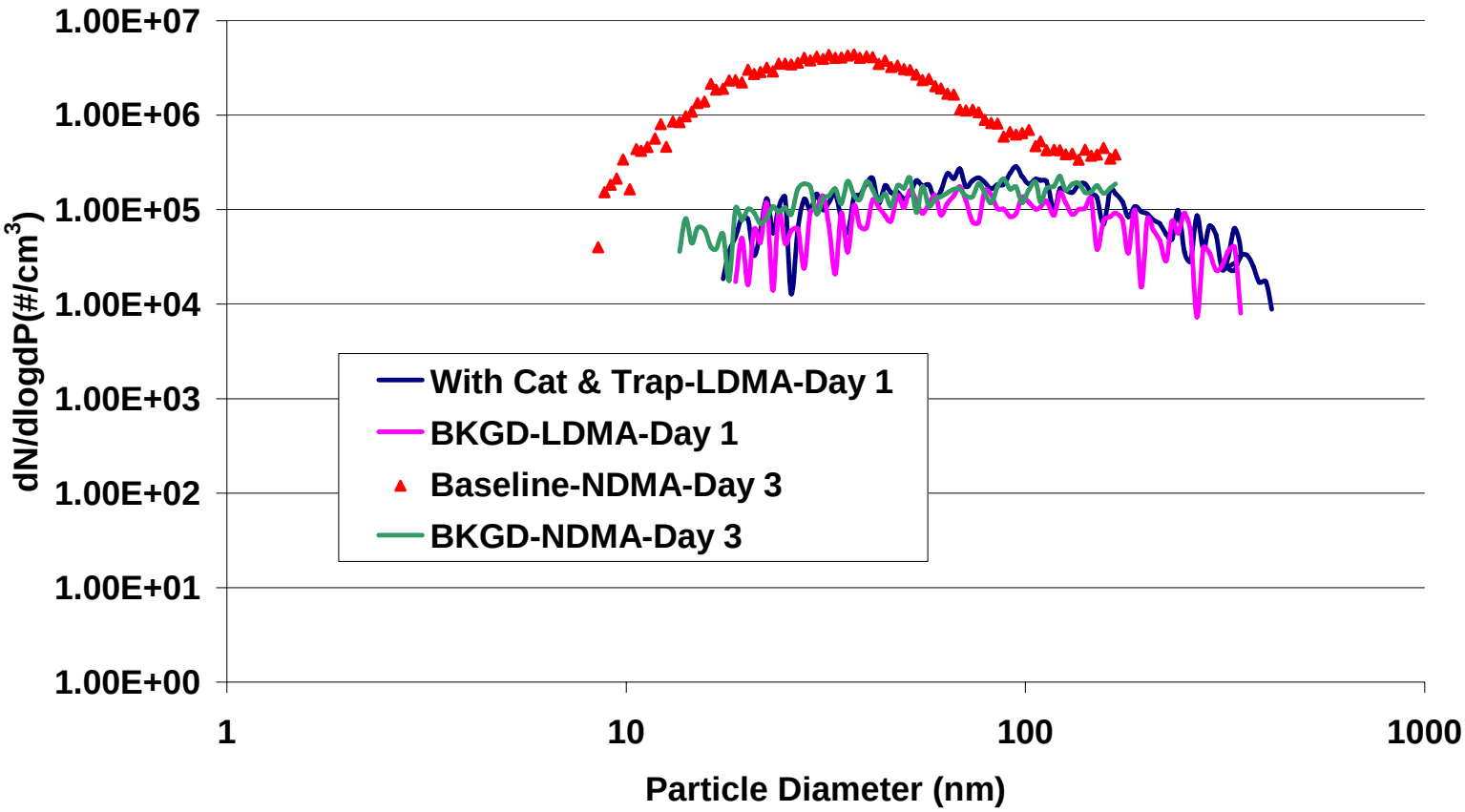
Average Engine Wear Emissions



Phase III: Transit Bus Steady State Operation
25 mph
PM Filter and Oxidation Catalyst



Phase III: Transit Bus Steady State Operation
35 mph
PM Filter and Oxidation Catalyst



Conclusions

- **Distance specific total PM emissions were reduced by 90-98% with WVU-Lubrizol EAS compared to baseline values.**
- **Emissions of TACs were reduced by more than 99% and were below the background levels.**
- **Emissions of carbonyls were reduced below background levels with WVU-Lubrizol EAS.**
- **Emissions of toxic gases (BTEX & 1,3-butadiene) were reduced below background levels with WVU-Lubrizol EAS.**
- **PAH emissions were reduced by 80% and were below the background levels.**
- **Emissions of engine wear elements and lube oil additives were effectively trapped by the WVU-Lubrizol EAS reducing them to below detection levels.**
- **Number concentration of nanoparticles were reduced to the level found in the background both by the new and aged WVU-Lubrizol EAS.**
- **No deterioration was observed in the emissions reduction performance of the in-field demonstrated WVU-Lubrizol EAS.**

Conclusions

Natural gas-fueled vehicles REQUIRE exhaust aftertreatment systems to reduce the toxic and nanoparticle emissions

These systems have to be optimized for natural gas-fueled vehicles

Acknowledgements

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West Virginia University,
Morgantown,WV 26506

Thank You