PM Emissions from Natural Gas and Catalyzed Trap-Equipped Heavy-Duty Diesel Vehicles – Chemical Characteristics and Size Distribution

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Test Vehicles/Engines

Participating Fleets	Vehicle/ Engine Type	Engine Rating (Hp)	Vehicles retrofitted with CRDPF	Mileage Accumulated with CRDPF (9/2000)
San Diego School District	School Bus/ Navistar 530E	275	5	22 – 27,000
ARCO Distribution	Fuel Truck/ Cummins M11	350	5	70 – 110,000
Ralphs Grocery	Grocery Truck/DDC Ser 60	430	5	40 – 60,000
LA MTA	Transit Bus/DDC Ser 50	275	2	15 – 20,000

Test Matrix

Vehicle	Fuel	DPF Type
San Diego School Bus	CARB, ECD,	NONE
	ECD-1, FT	DPX
LA MTA	**ECD-1, CARB**	**NONE**
	ECD, ECD-1	**CRT**
	CNG (2 Vehicles: MY2000 and MY2001)	**NONE**
Ralphs Grocery	CARB, ECD-1	NONE
	ECD, ECD-1	CRT

TESTING AN URBAN TRANSIT BUS

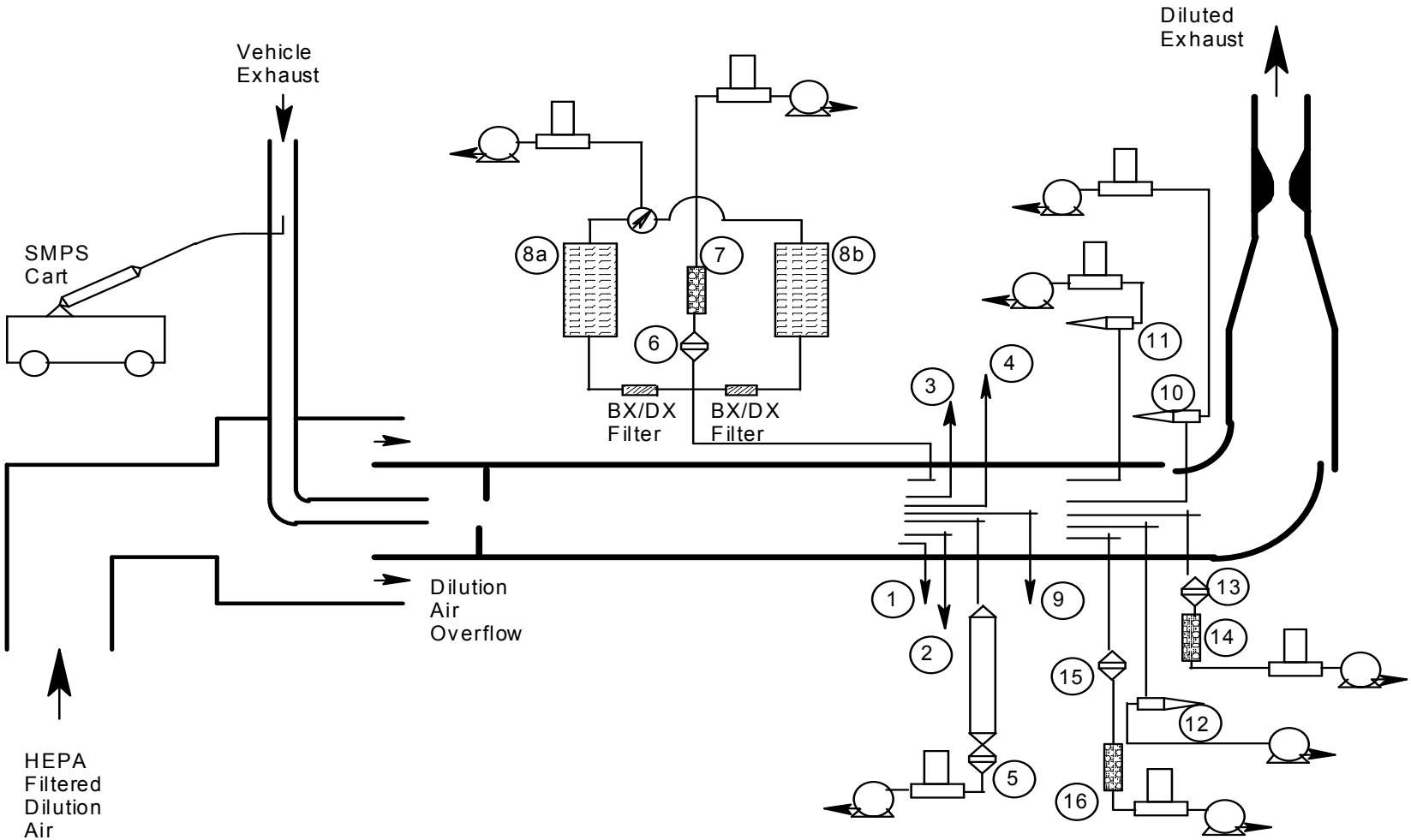
Chemical Characterization

- **Particulate Matter**
  - **Concentration and Size Distribution**
  - **Mass - TPM, PM_{10}, $PM_{2.5}$**
- **Volatile Organic Compounds**
  - **Low molecular weight alkanes and olefins (C_2 – C_5)**
  - **Low molecular weight aromatics (BTEX)**
- **Elemental & Organic Carbon**
- **PAHs and n-PAHs**
- **Elemental Compounds**
- **Ionic Species**
- **Carbonyls**
- **Dioxins and Furans**
- **Bioassays**

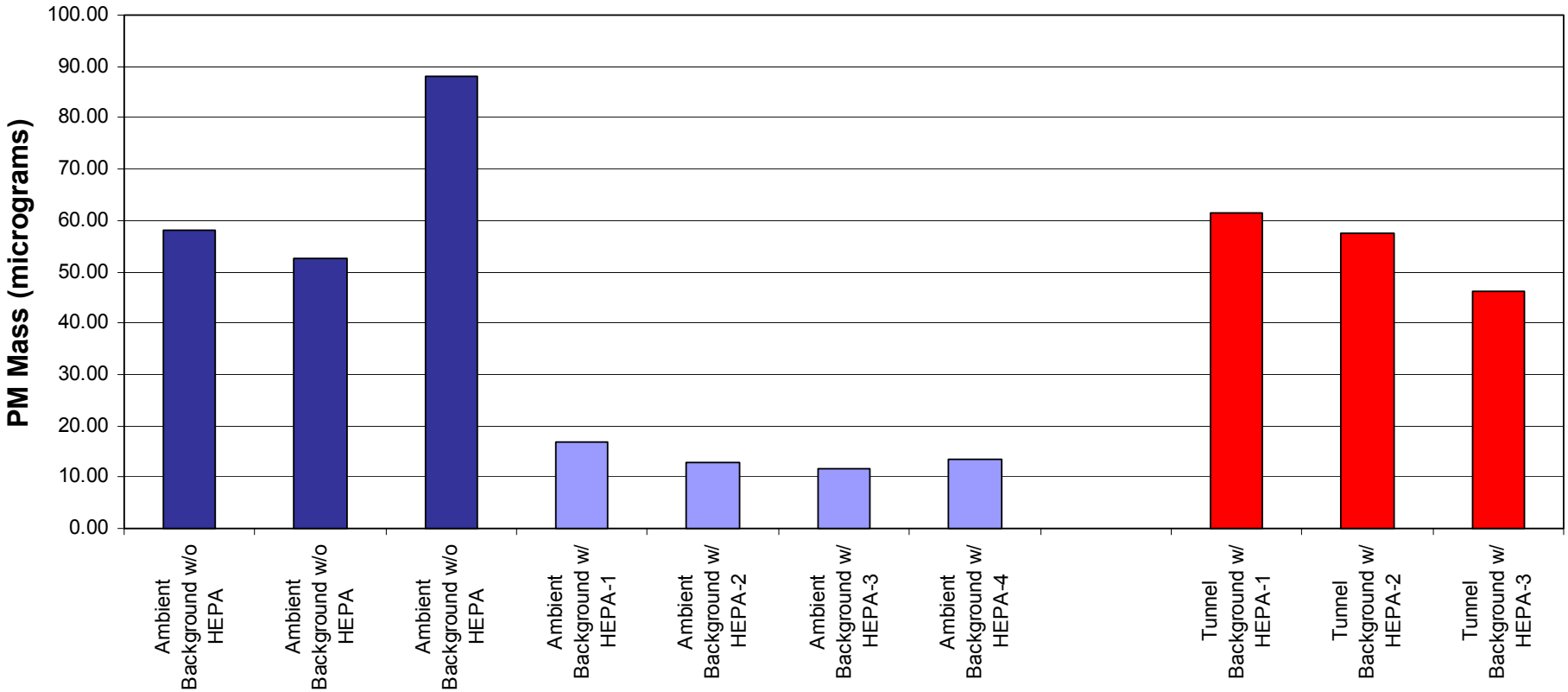
Fuel Analysis

Property	CARB	ECD	ECD-1
Cetane Number	54.1	64.7	51.3
Sulfur, ppm	121	7.4	13.1
SFC Aromatics			
Total, vol%	22.5	10.9	23.8
PNA, wt%	4.1	0.9	2.8

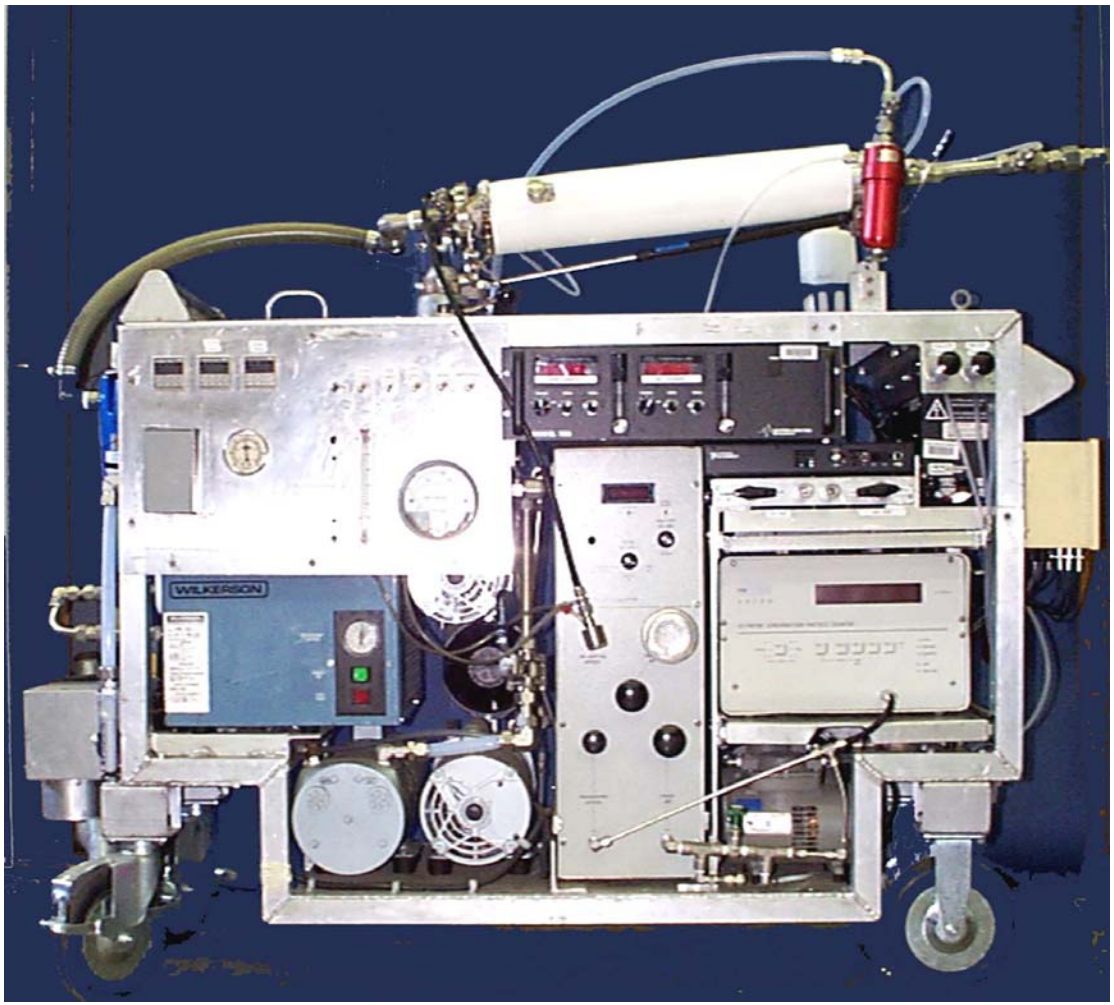
Sampling System



Ralphs Grocery Site PM Background Comparison (Mass)



Particle Sizing Cart



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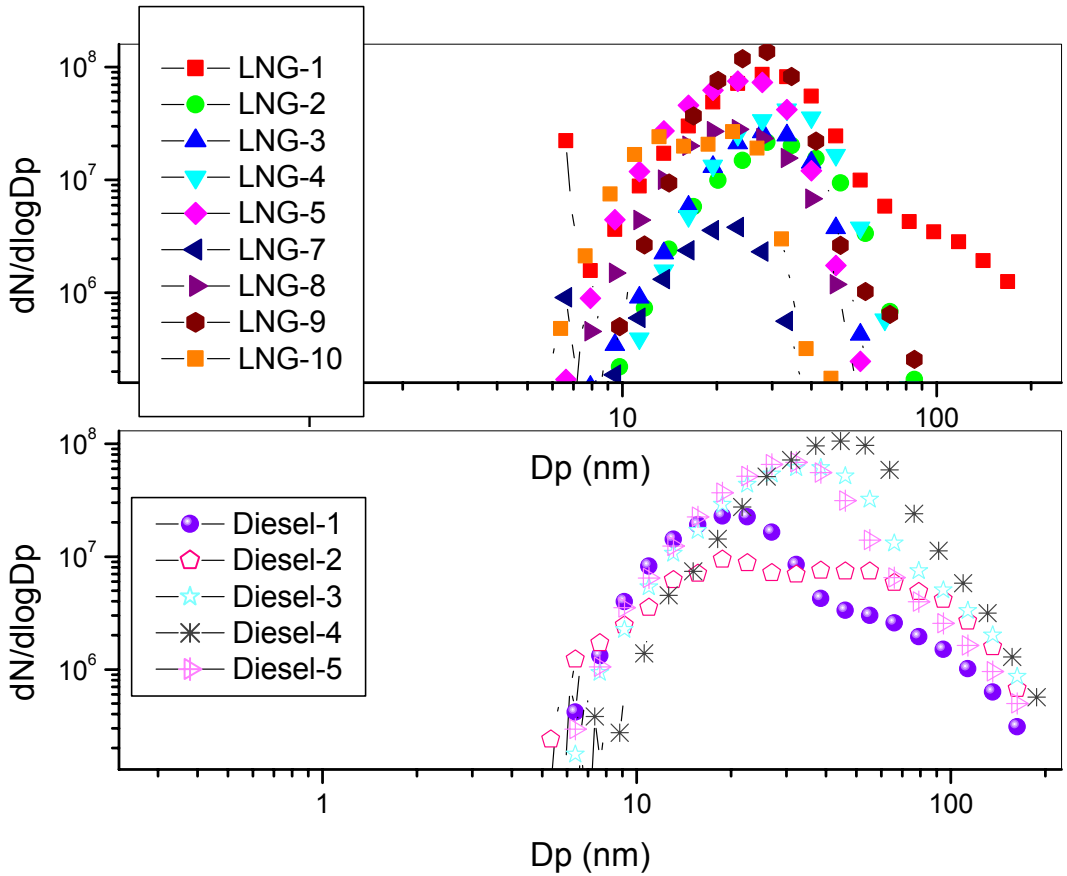
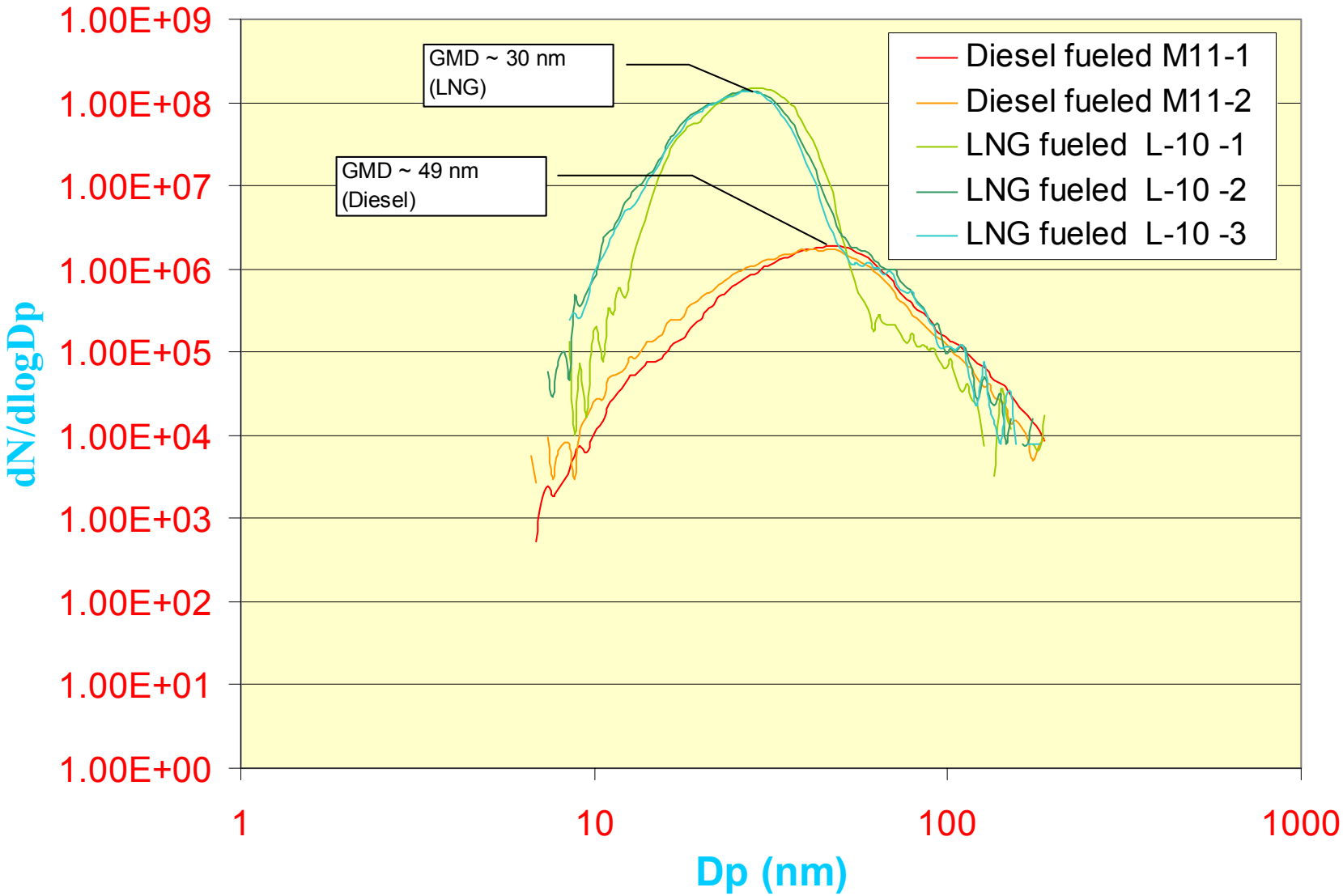
Diesel (M-11) and LNG (L-10 280G) Fueled Heavy-duty Transit Buses (DART)

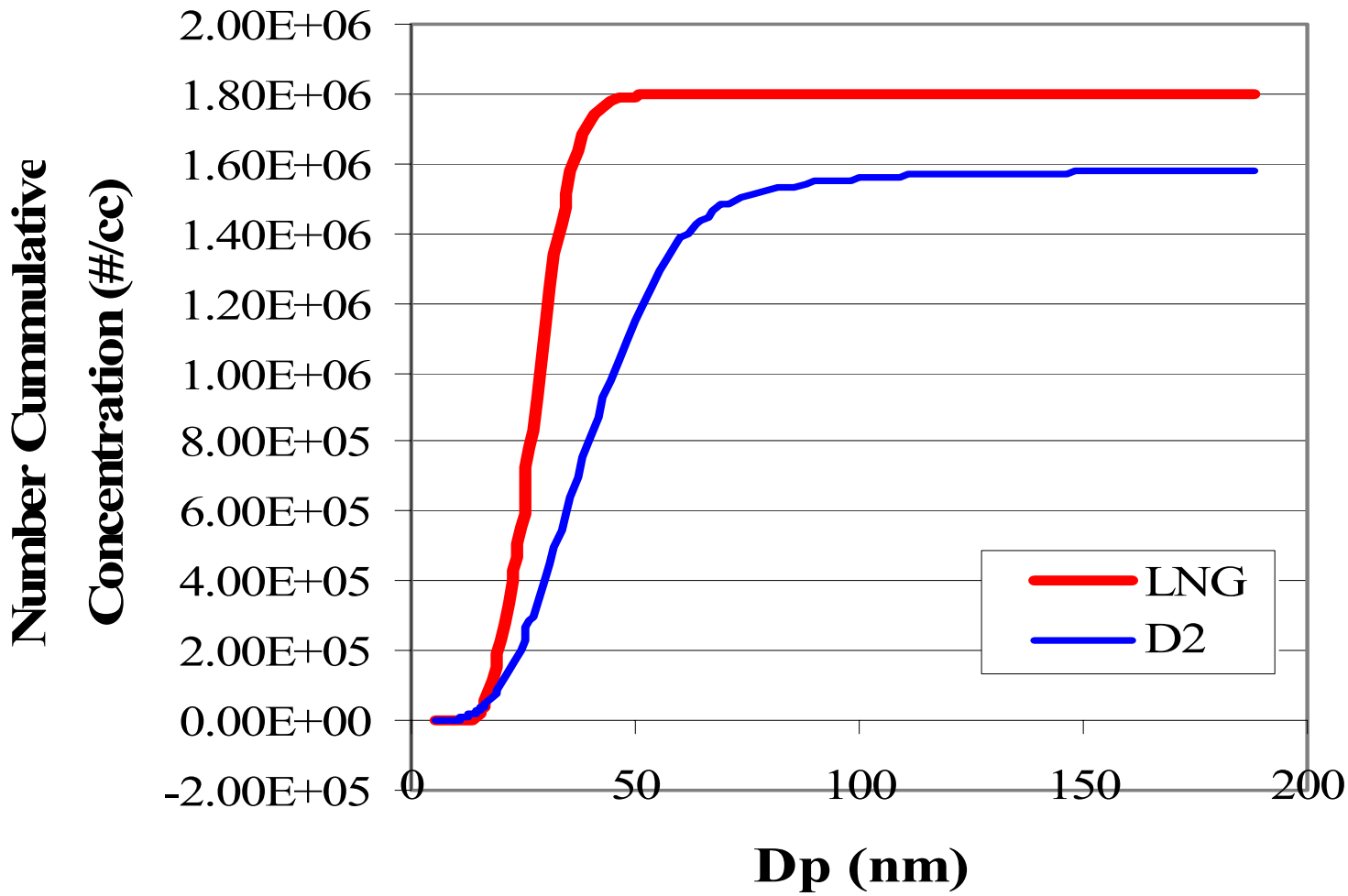


1999 Study

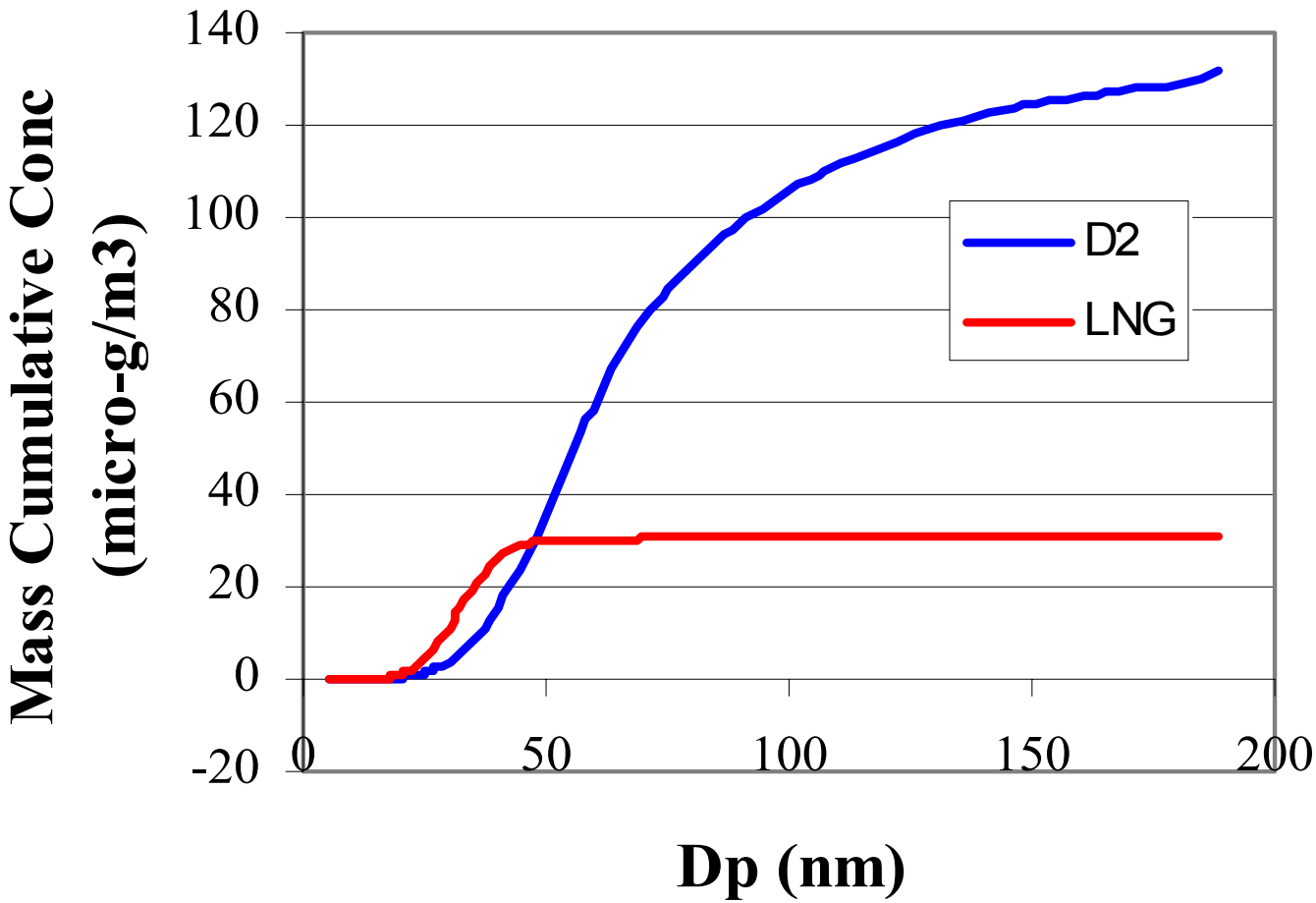
Comparison of Particle Size Distributions LNG-fueled and Diesel-fueled Transit Buses



Diesel (M-11) and LNG (L-10 280G) Fueled Transit Buses: Number Cumulative Concentrations (DART)



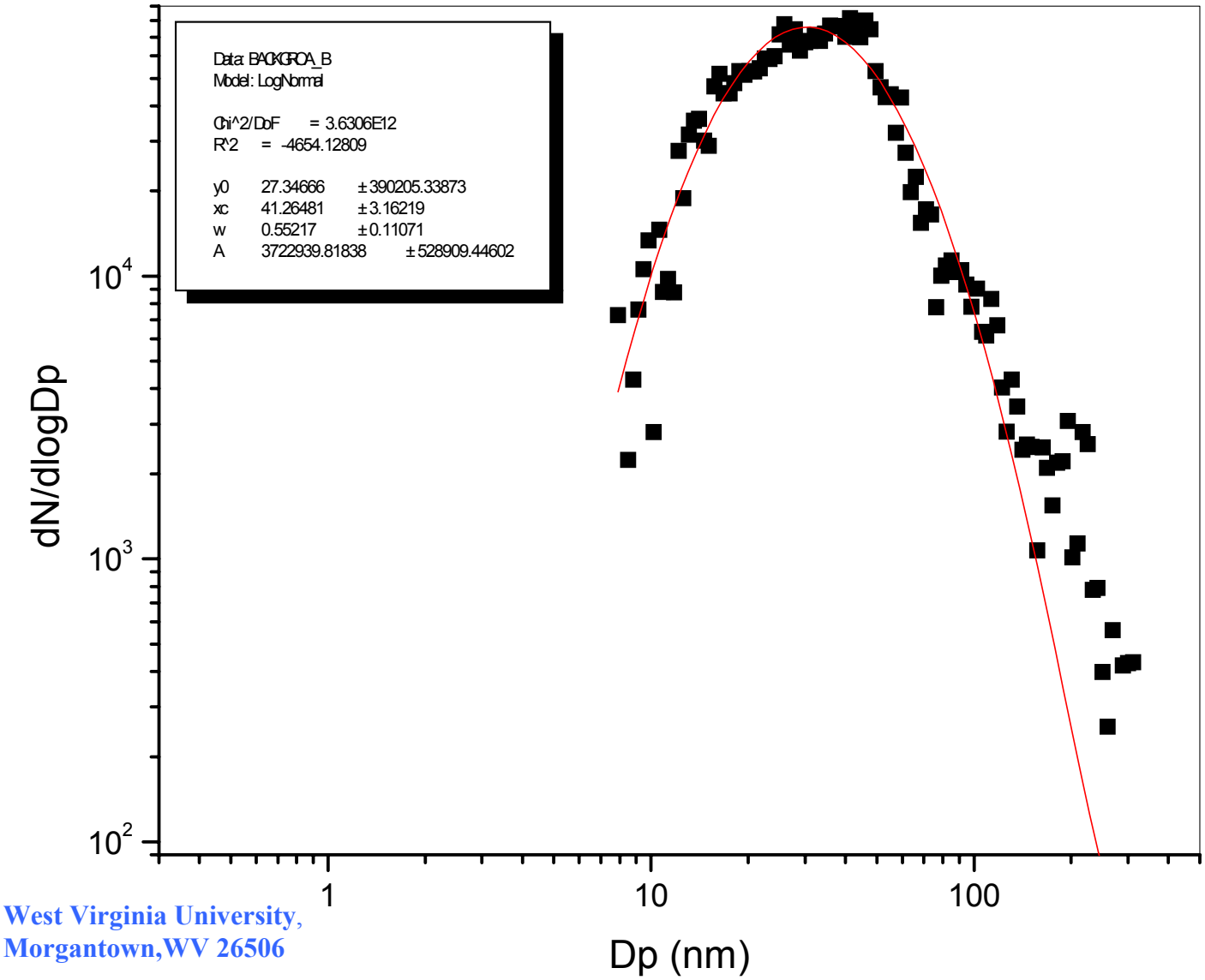
Diesel (M-11) and LNG (L-10 280G) Fueled Transit Buses: Mass Cumulative Concentrations (DART)



Source of PM

- Lube oil contribution to exhaust PM emissions is considerably more significant now than ever before.
- The basic design of current natural gas engines contributes to less than desirable oil consumption. Attention needs to be focused upon cylinder materials, design of ring packs, valve stem seals, etc., to minimize oil consumption.
- Hence, oil formulations need to be modified to counter the need for higher oil consumption in natural gas engines.

TUNNEL BACKGROUND



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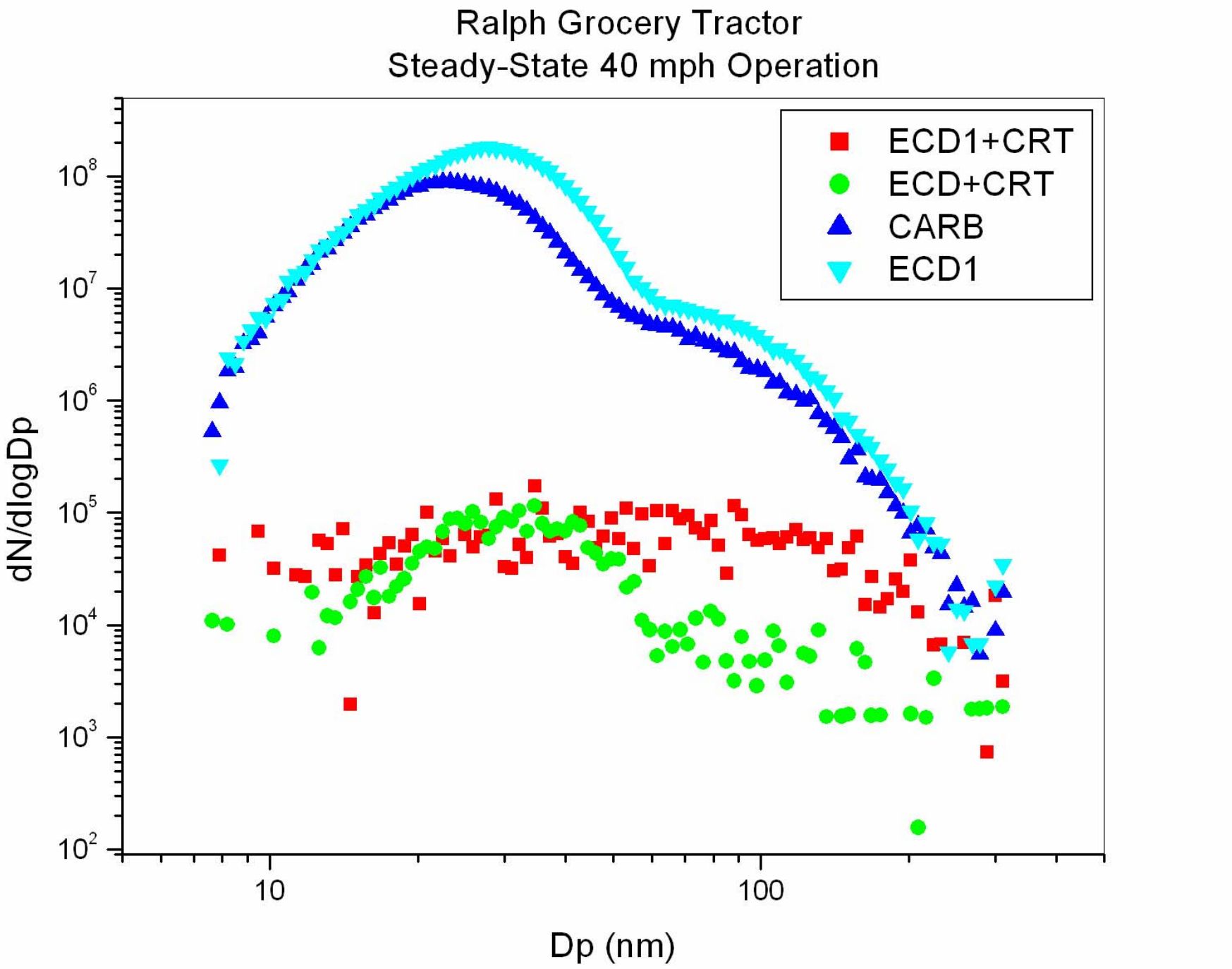
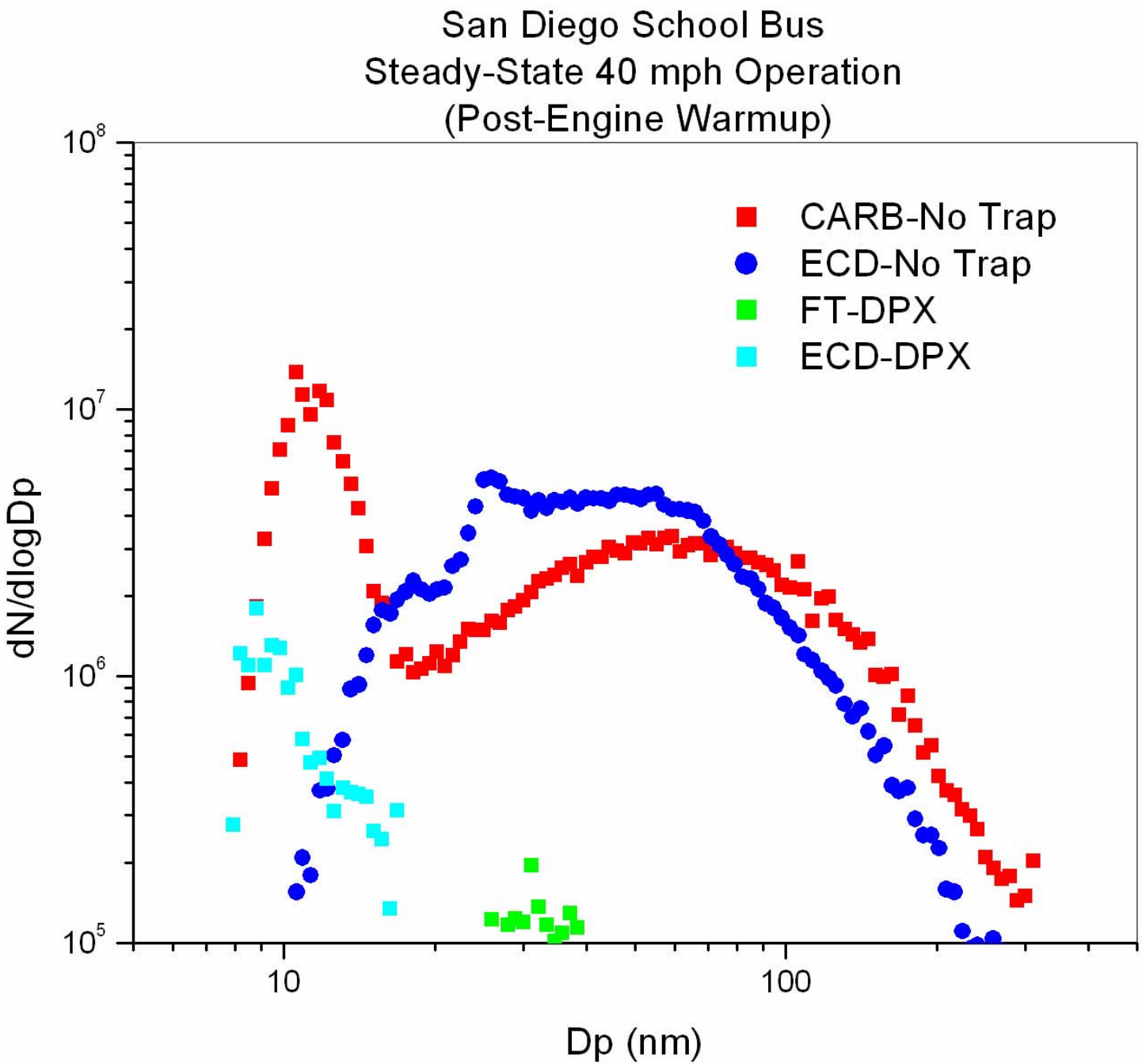
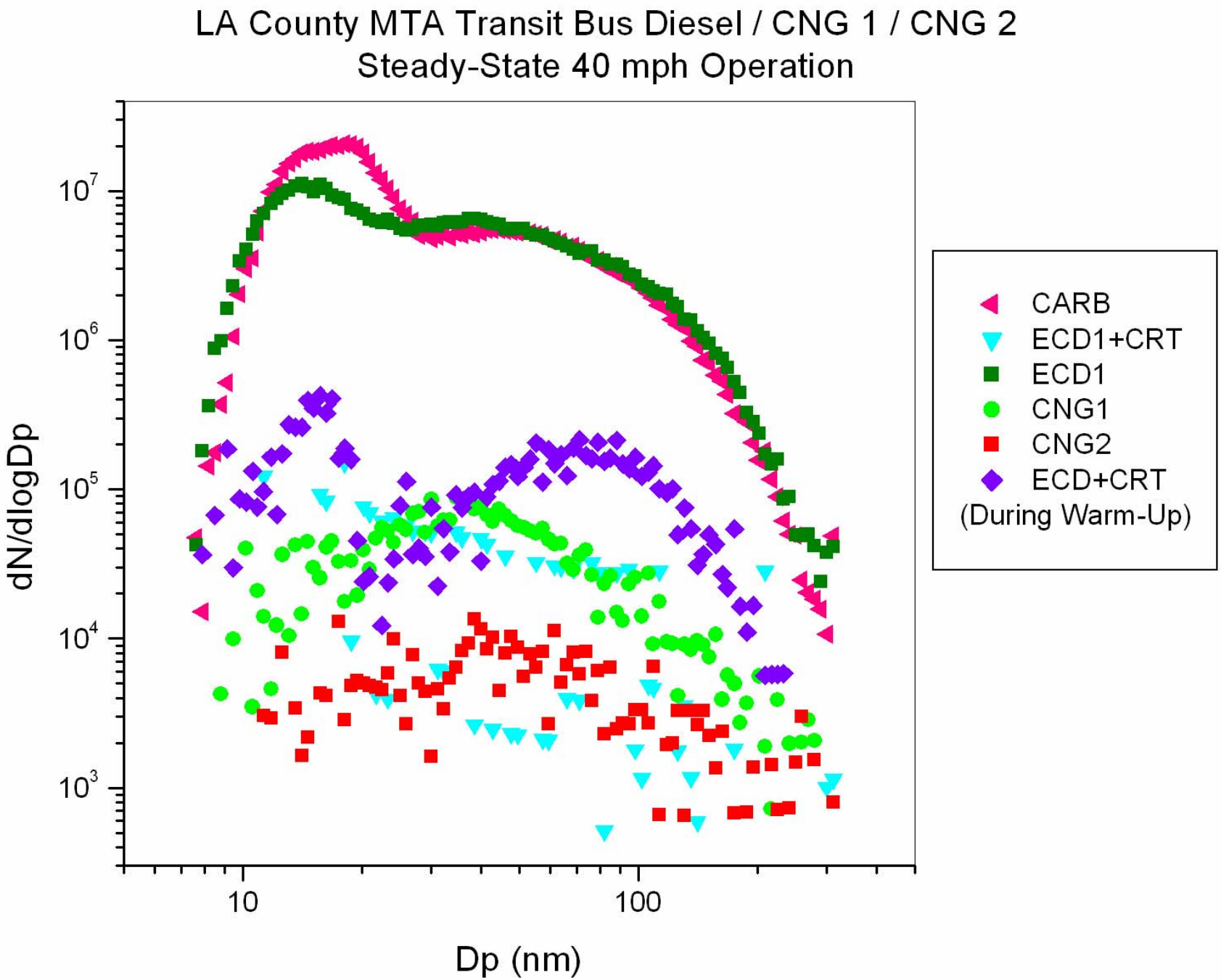
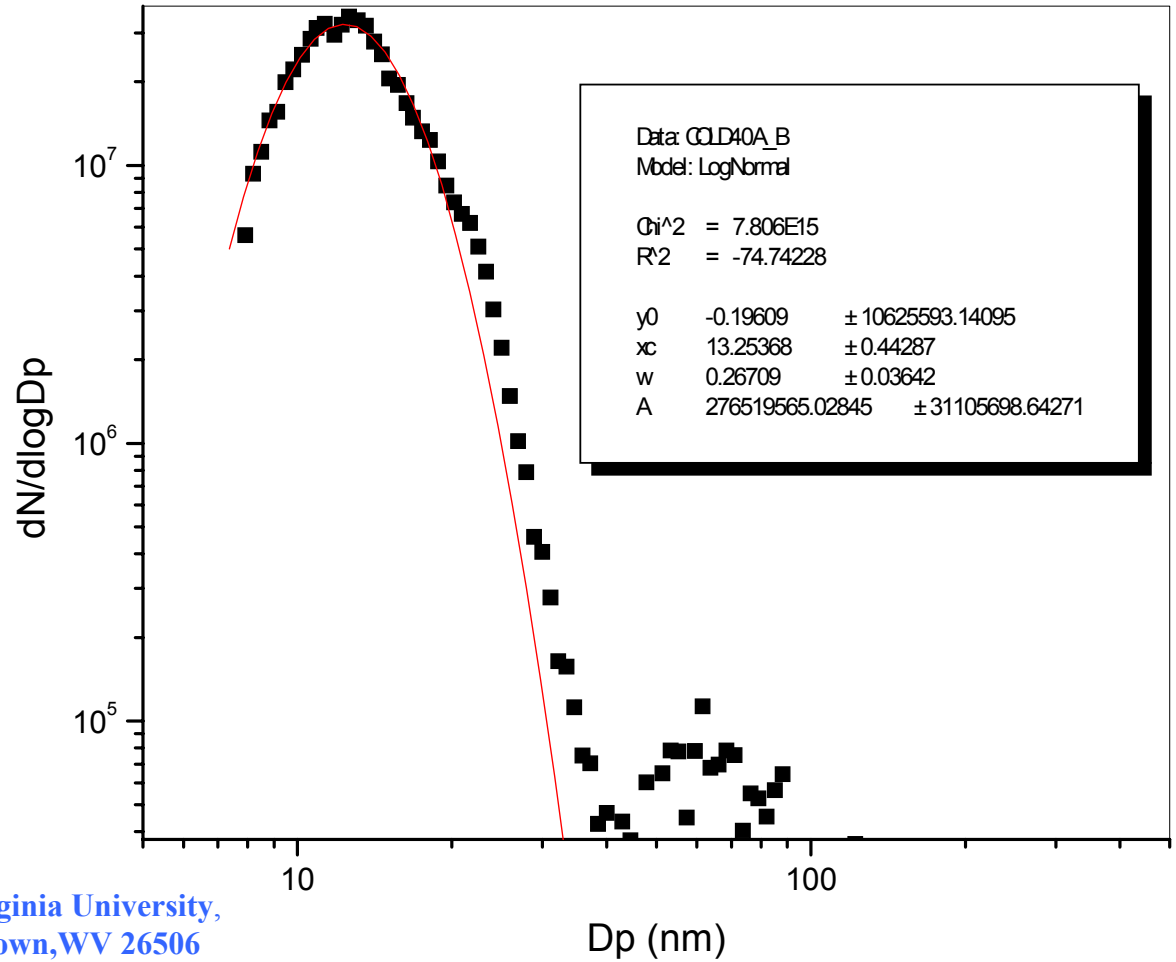

Ralph Grocery Tractor
Steady-State 40 mph Operation
ECD1+CRT
ECD+CRT
CARB
ECD1
dN/dlogDp
Dp (nm)
10
100


San Diego School Bus
Steady-State 40 mph Operation
(Post-Engine Warmup)
CARB-No Trap
ECD-No Trap
FT-DPX
ECD-DPX
dN/dlogDp
Dp (nm)
10
100
10^8
10^7
10^6
10^5


LA County MTA Transit Bus Diesel / CNG 1 / CNG 2
Steady-State 40 mph Operation
dN/dlogDp
10^7
10^6
10^5
10^4
10^3
10
100
Dp (nm)
CARB
ECD1+CRT
ECD1
CNG1
CNG2
ECD+CRT
(During Warm-Up)

COLD START AT 40 MPH
TRANSIT BUS
FUEL: ECD 1
EXHAUST AFTER-TREATMENT: JOHNSON-MATTHEY



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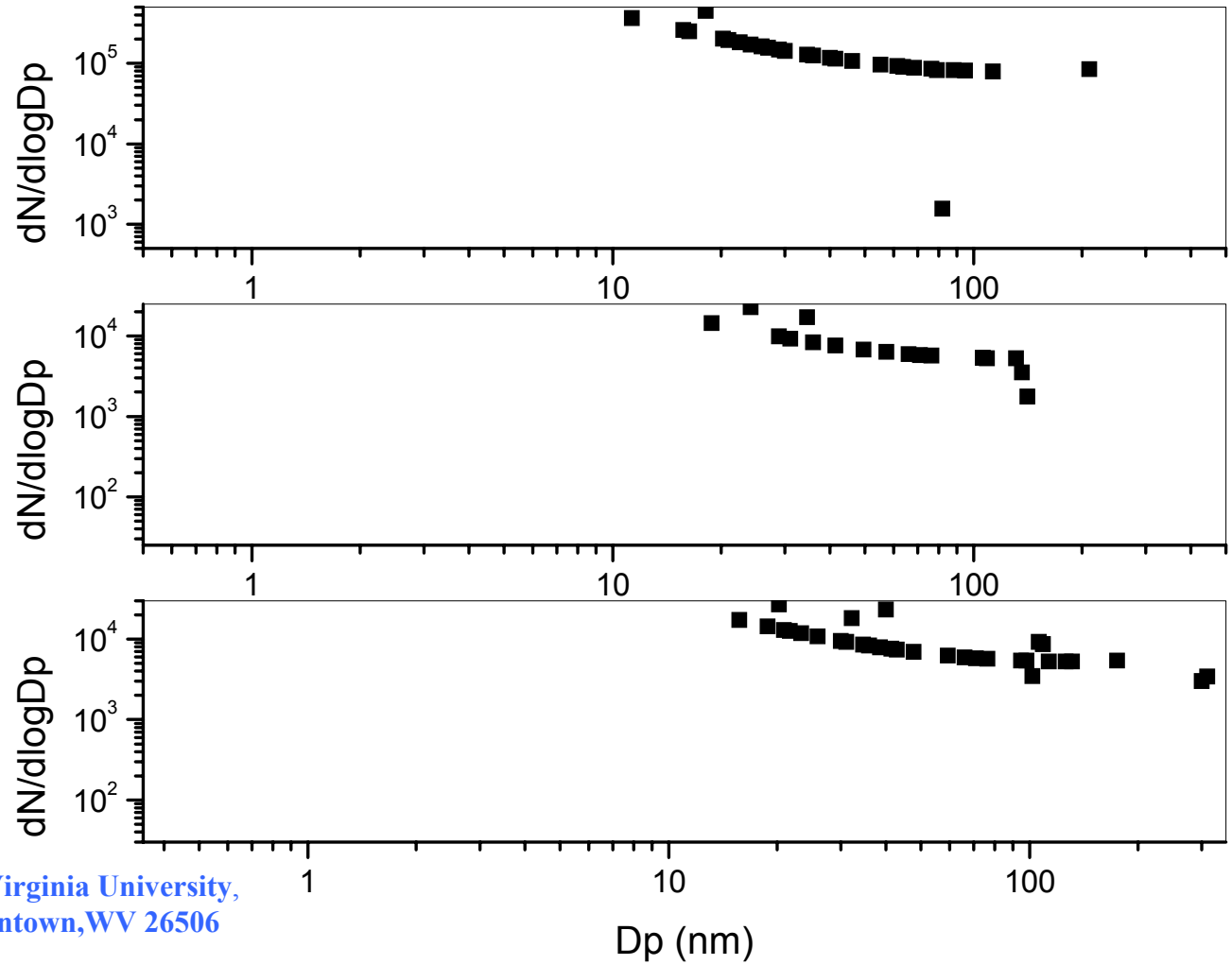
AFTERWARM-UP AT 40 MPH
TRANSIT BUS
FUEL: ECD1
EXHAUST AFTER-TREATMENT: JOHNSON-MATTHEY



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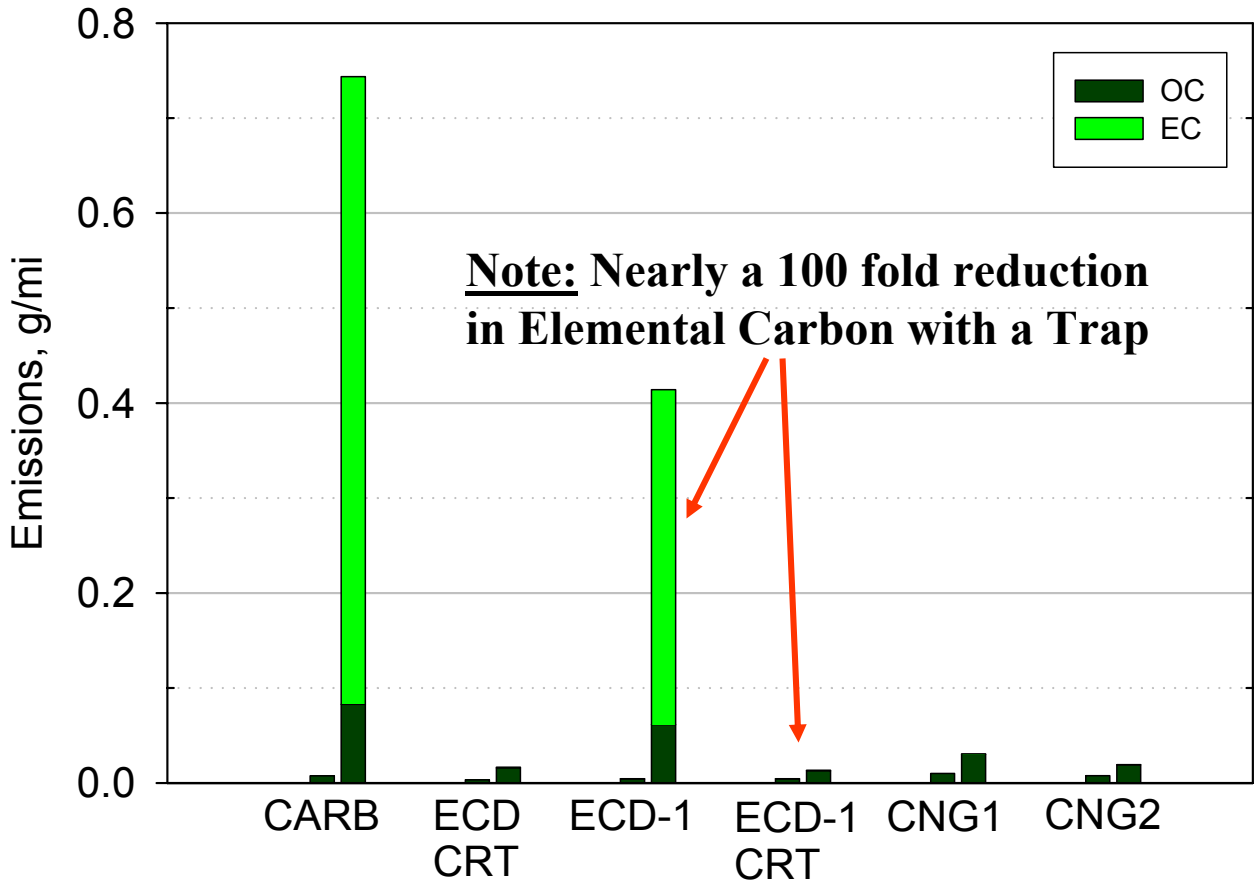
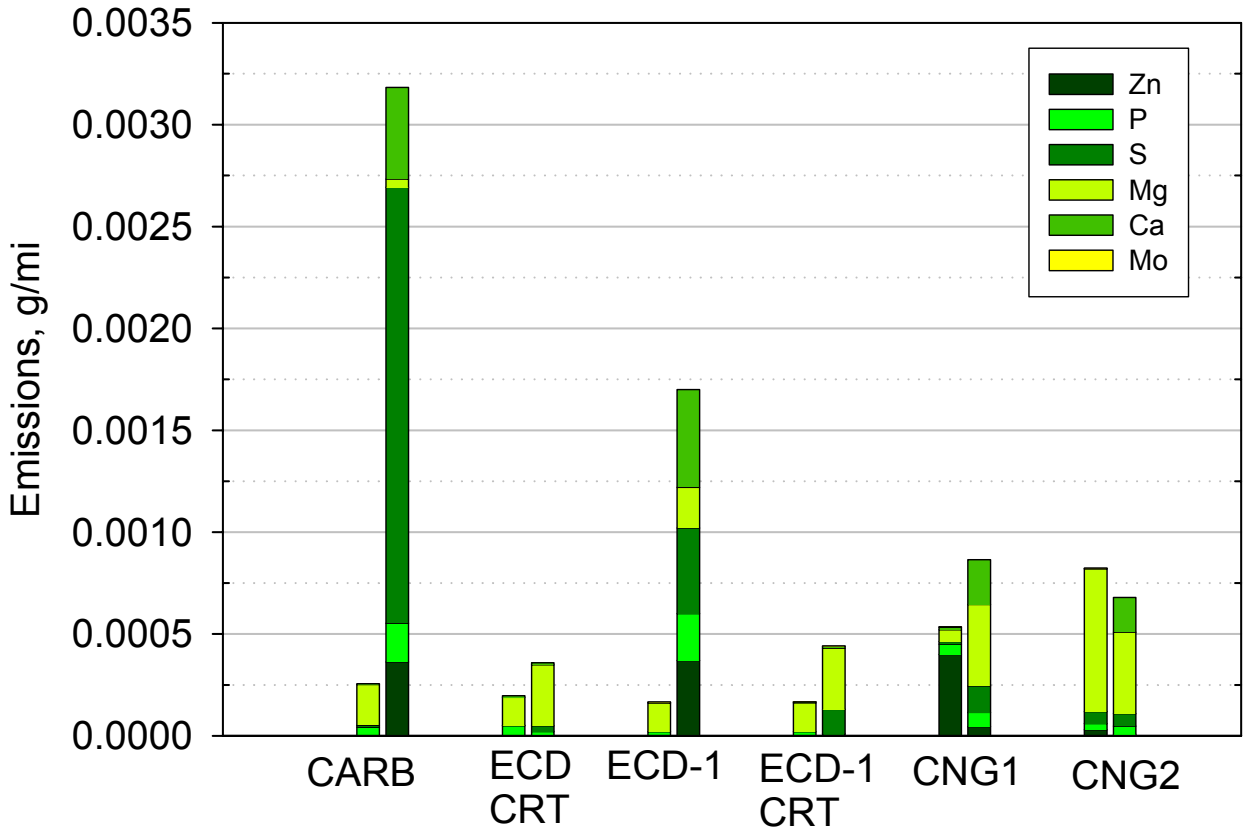
EC/OC



Left bar is tunnel bkgd
Right bar is sample
Bars are average of 3 replicate runs
Error bars are 1 standard deviation

Elemental Analysis:
Lubricant Oil Contribution



Left bar is tunnel bkgd
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Error bars are 1 standard deviation

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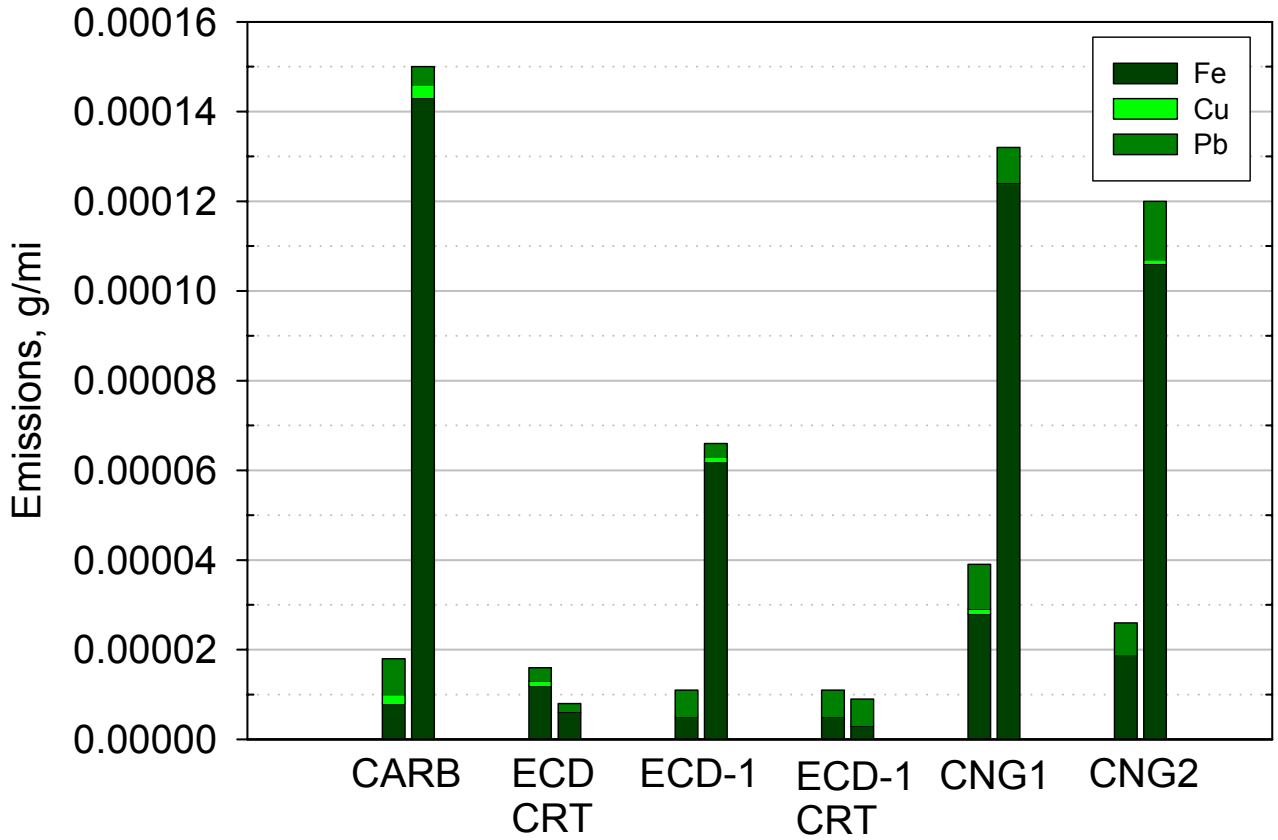
Engine Wear Contribution



Left bar is tunnel bkgd
Right bar is sample
Bars are average of 3 replicate runs
Error bars are 1 standard deviation

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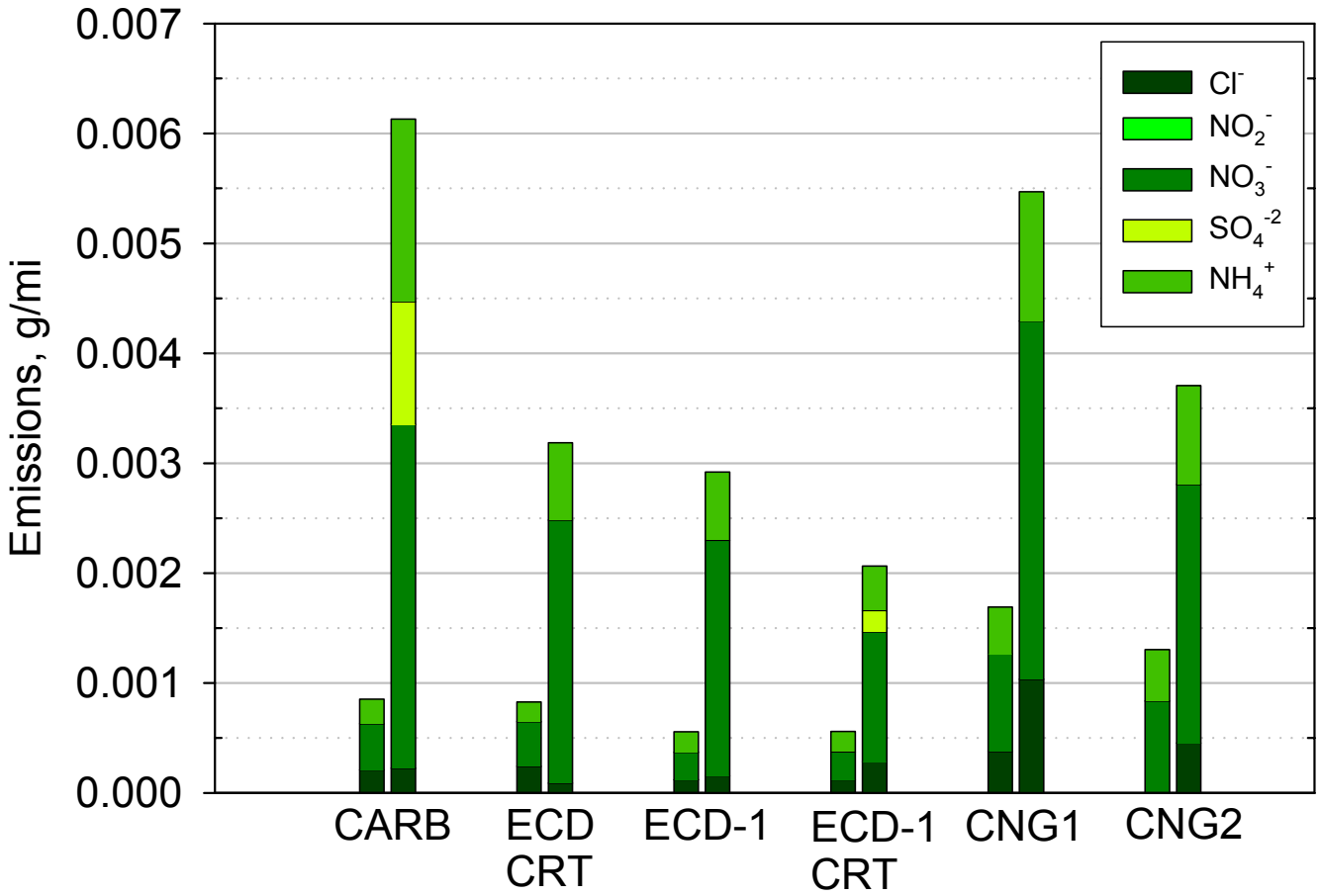
Inorganic Ionic Species



Left bar is tunnel bkgd
Right bar is sample
Bars are average of 3 replicate runs
Error bars are 1 standard deviation

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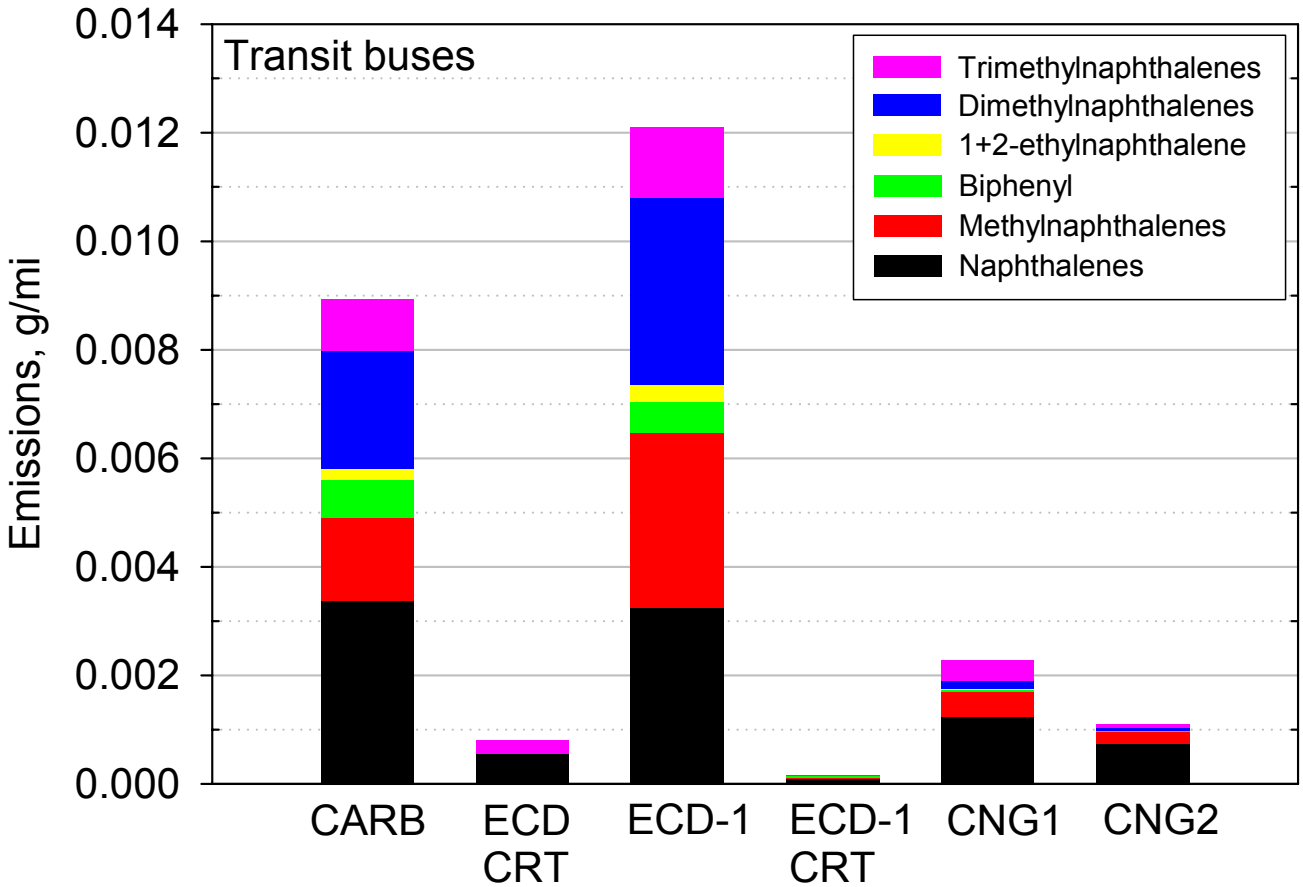
Summary

- Ionic species emissions were very low, regardless of fuel/filter/vehicle combination.
- Overall, the lowest EC/OC emissions were recorded with the DPF equipped vehicles and the CNG transit buses.
- Without the DPF, ~85% of the sum of the ionic species and EC/OC is elemental carbon.
- The organic carbon is ~90% of the sum of the ionic species and EC/OC for the CNG transit buses.

2-Ring PAH



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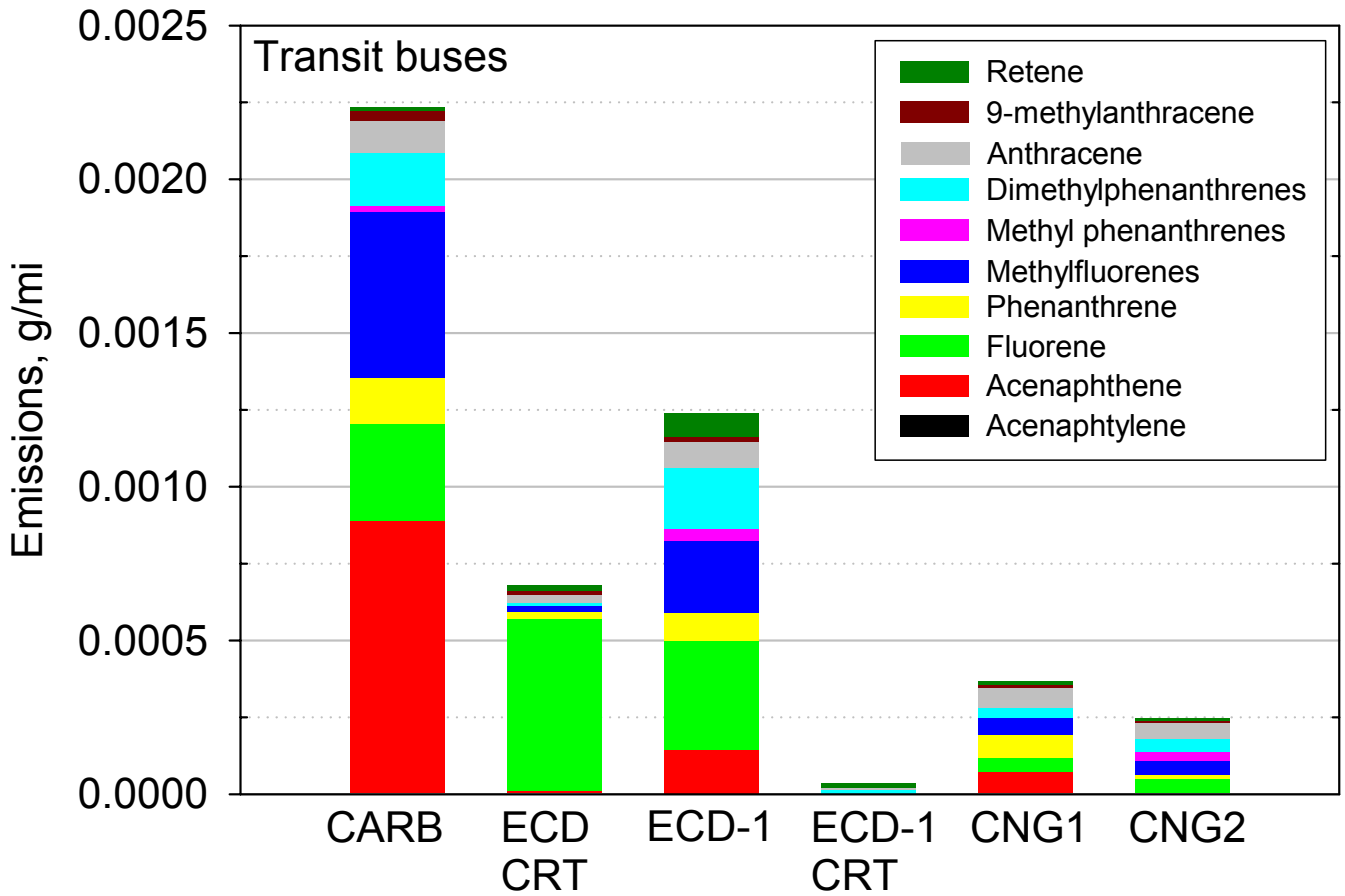
3-Ring PAH



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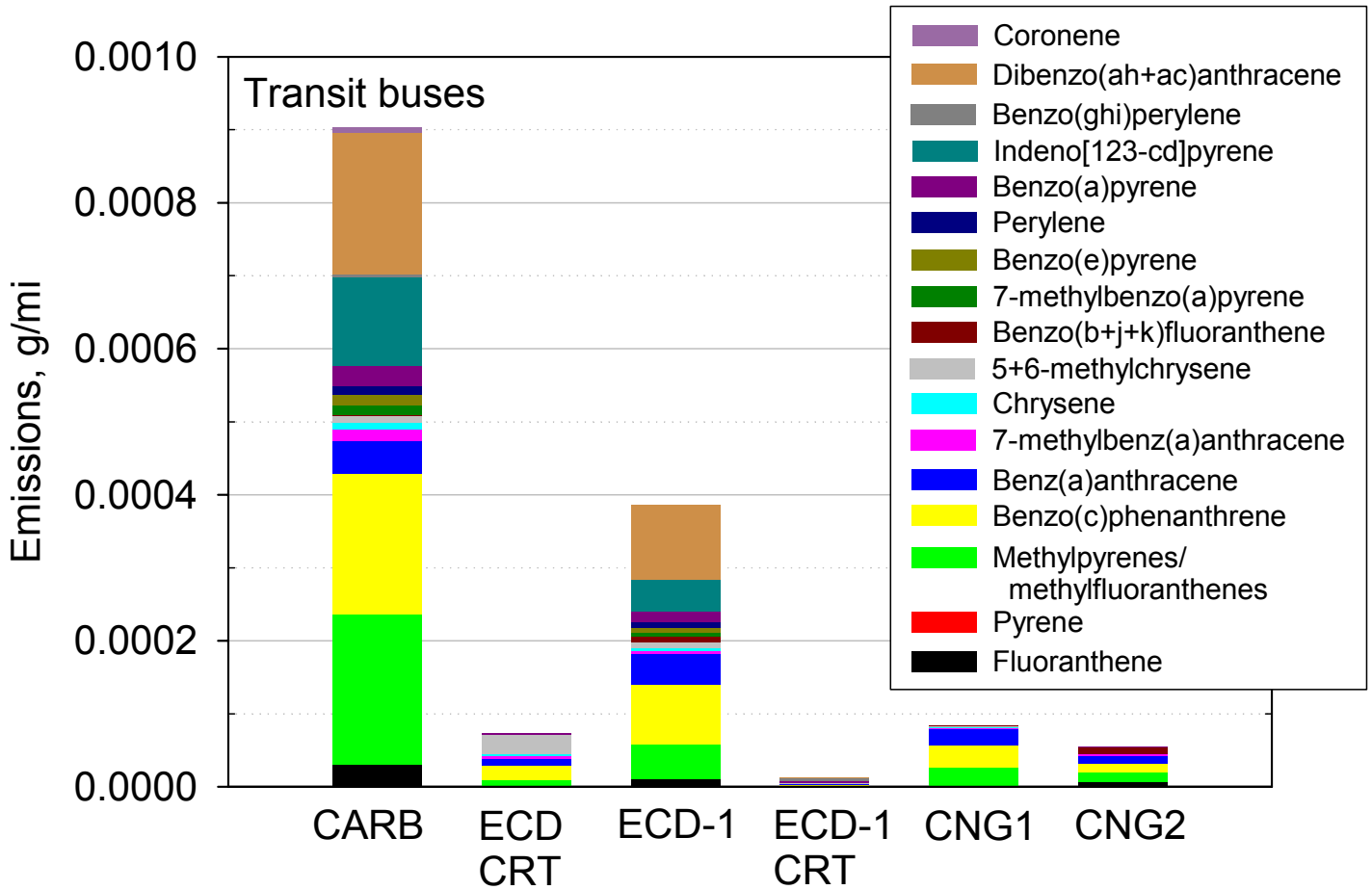
4-Ring PAH



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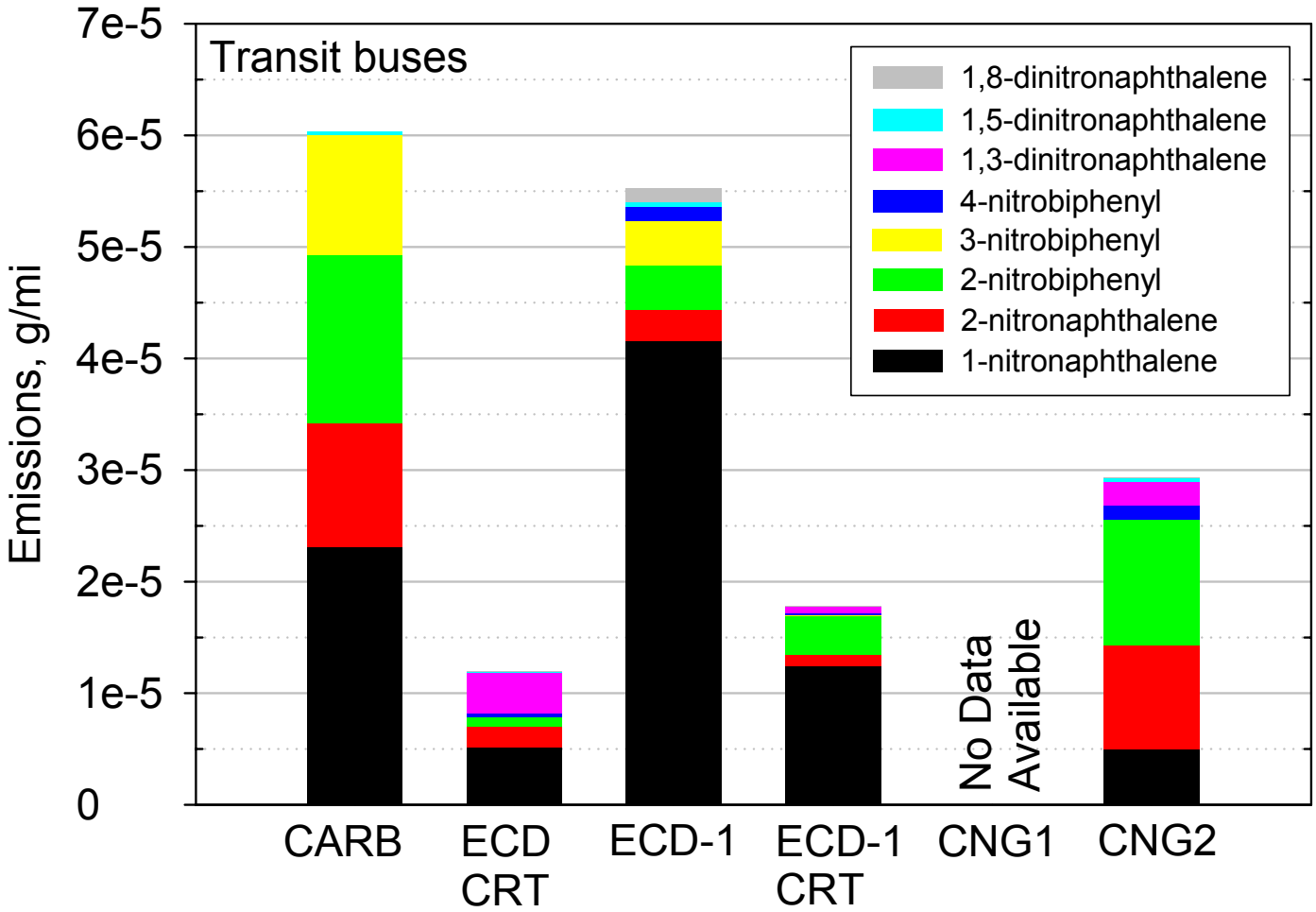
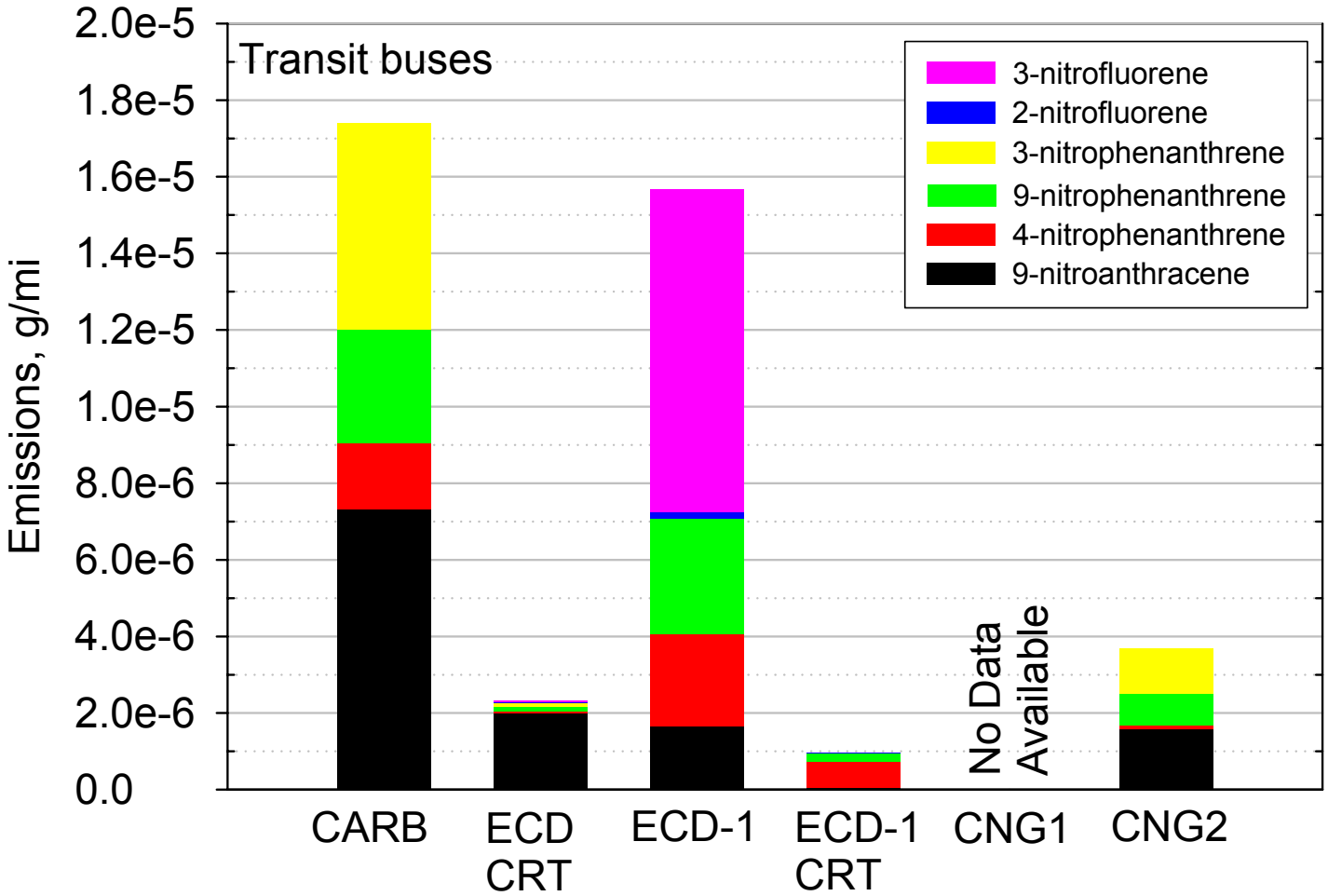
2-Ring n-PAH


Transit buses
Emissions, g/mi
7e-5
6e-5
5e-5
4e-5
3e-5
2e-5
1e-5
0
1,8-dinitronaphthalene
1,5-dinitronaphthalene
1,3-dinitronaphthalene
4-nitrobiphenyl
3-nitrobiphenyl
2-nitrobiphenyl
2-nitronaphthalene
1-nitronaphthalene
No Data Available
CARB
ECD CRT
ECD-1
ECD-1 CRT
CNG1
CNG2

3-Ring n-PAH



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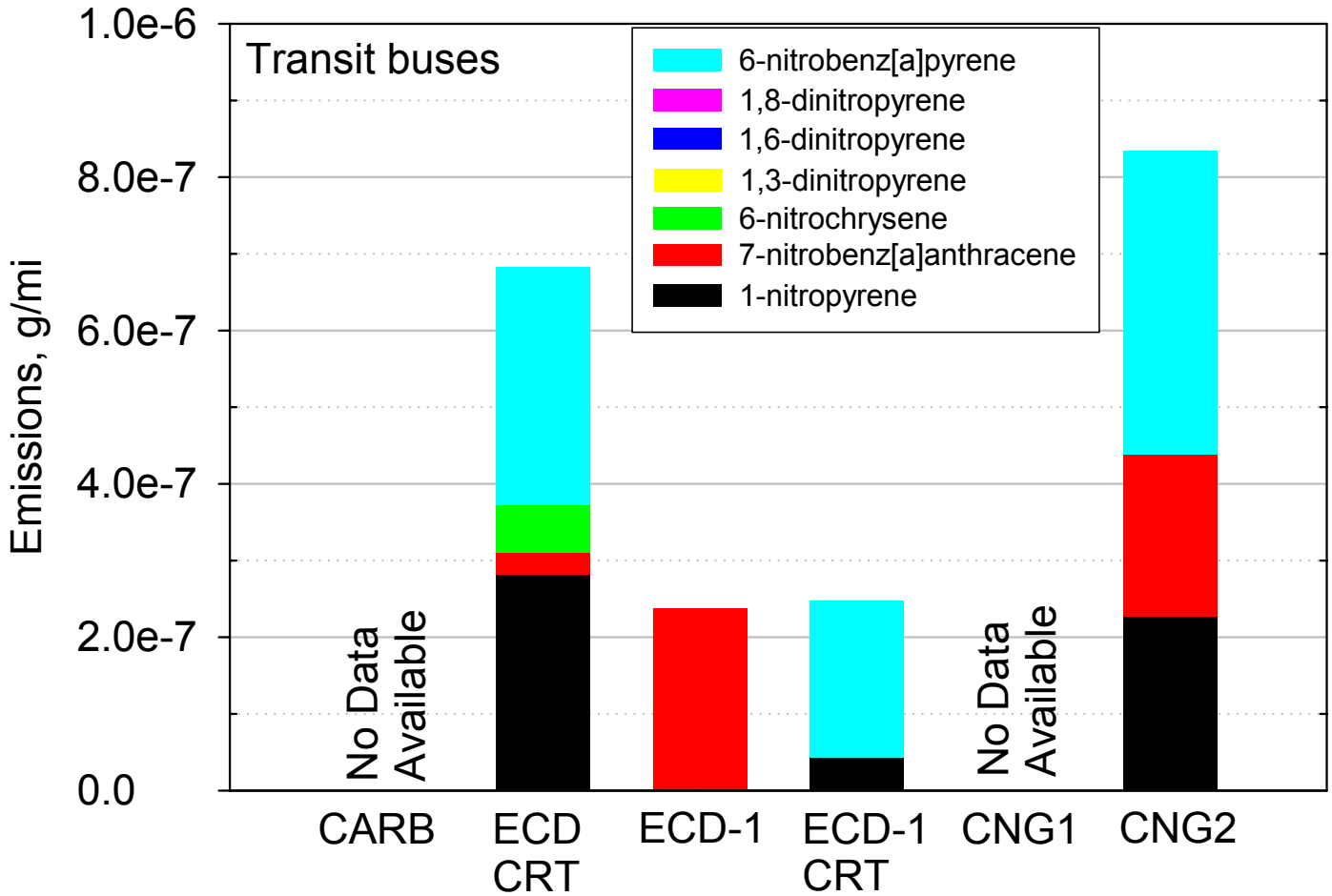
4-Ring n-PAH



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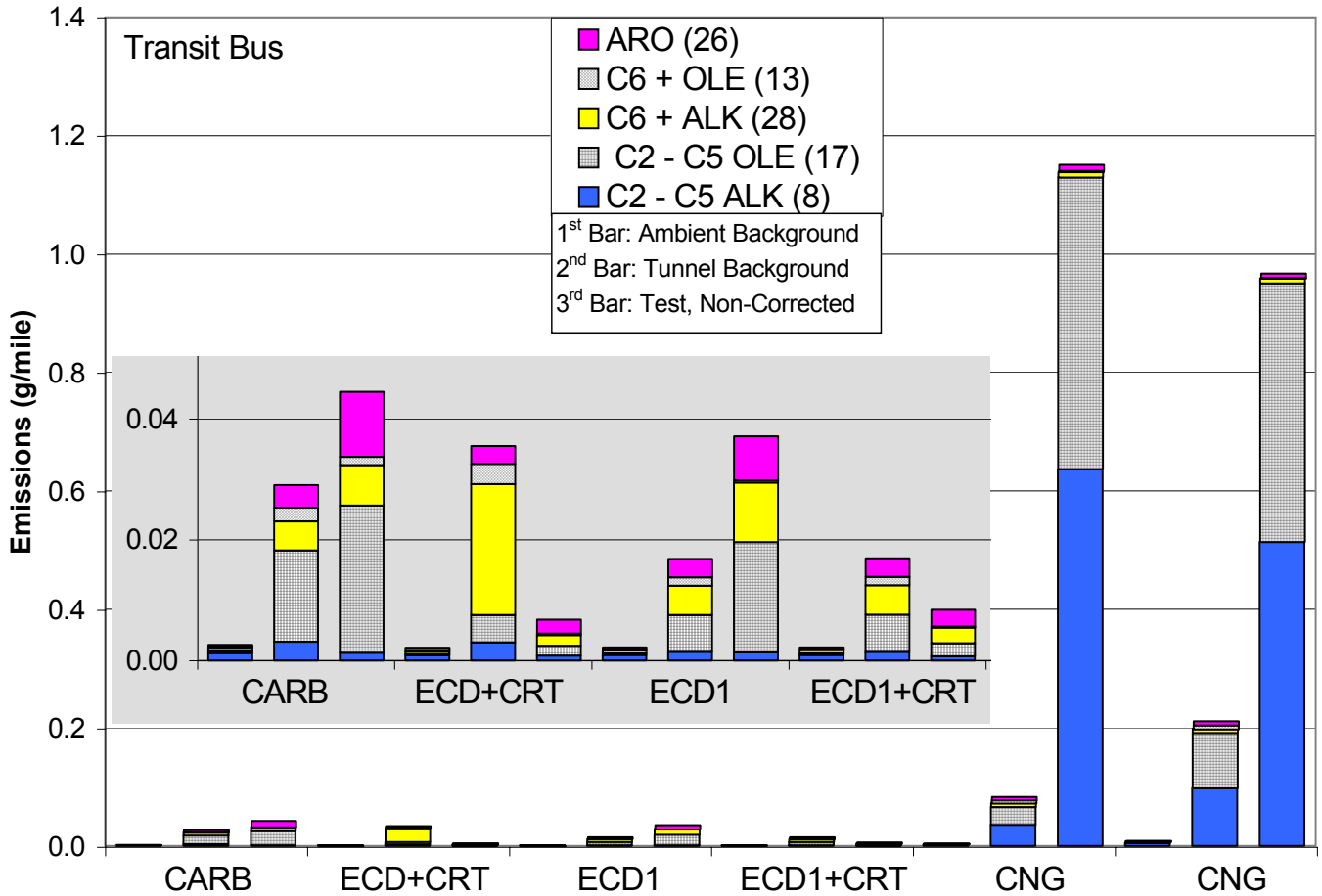
VOC's
(Grouped by Compound Classes)



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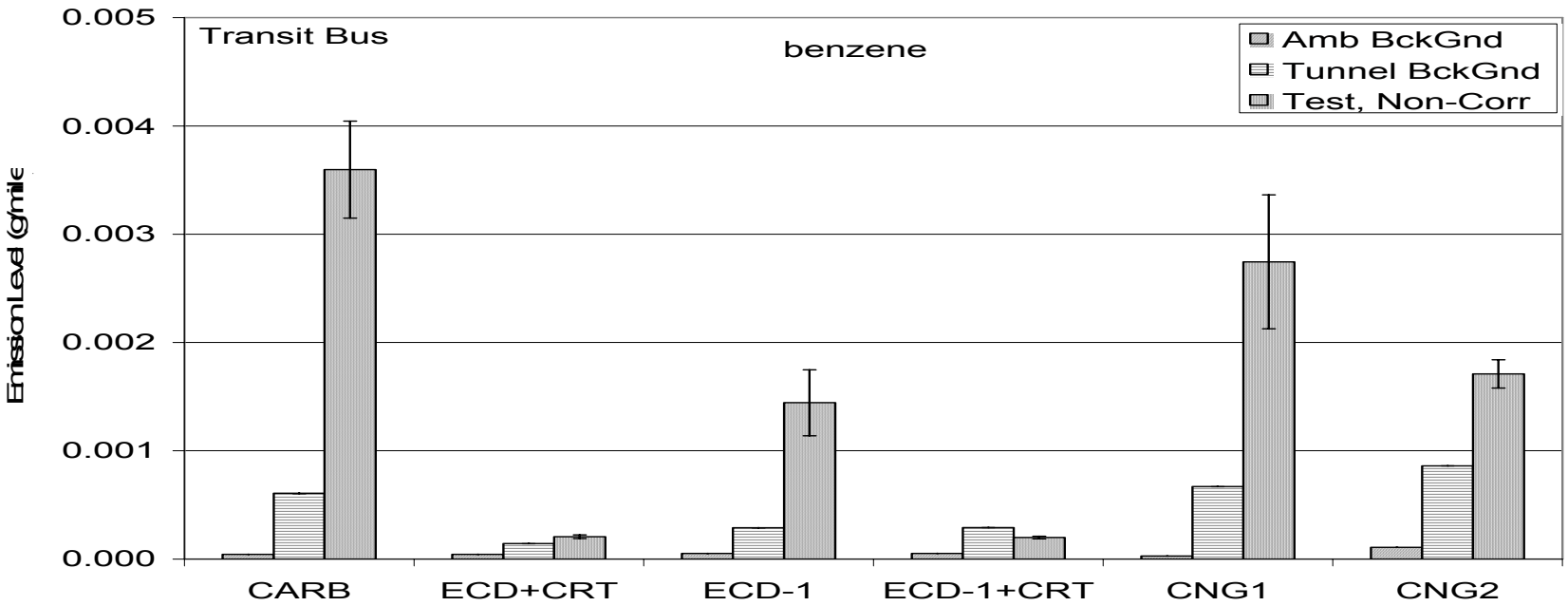
Benzene



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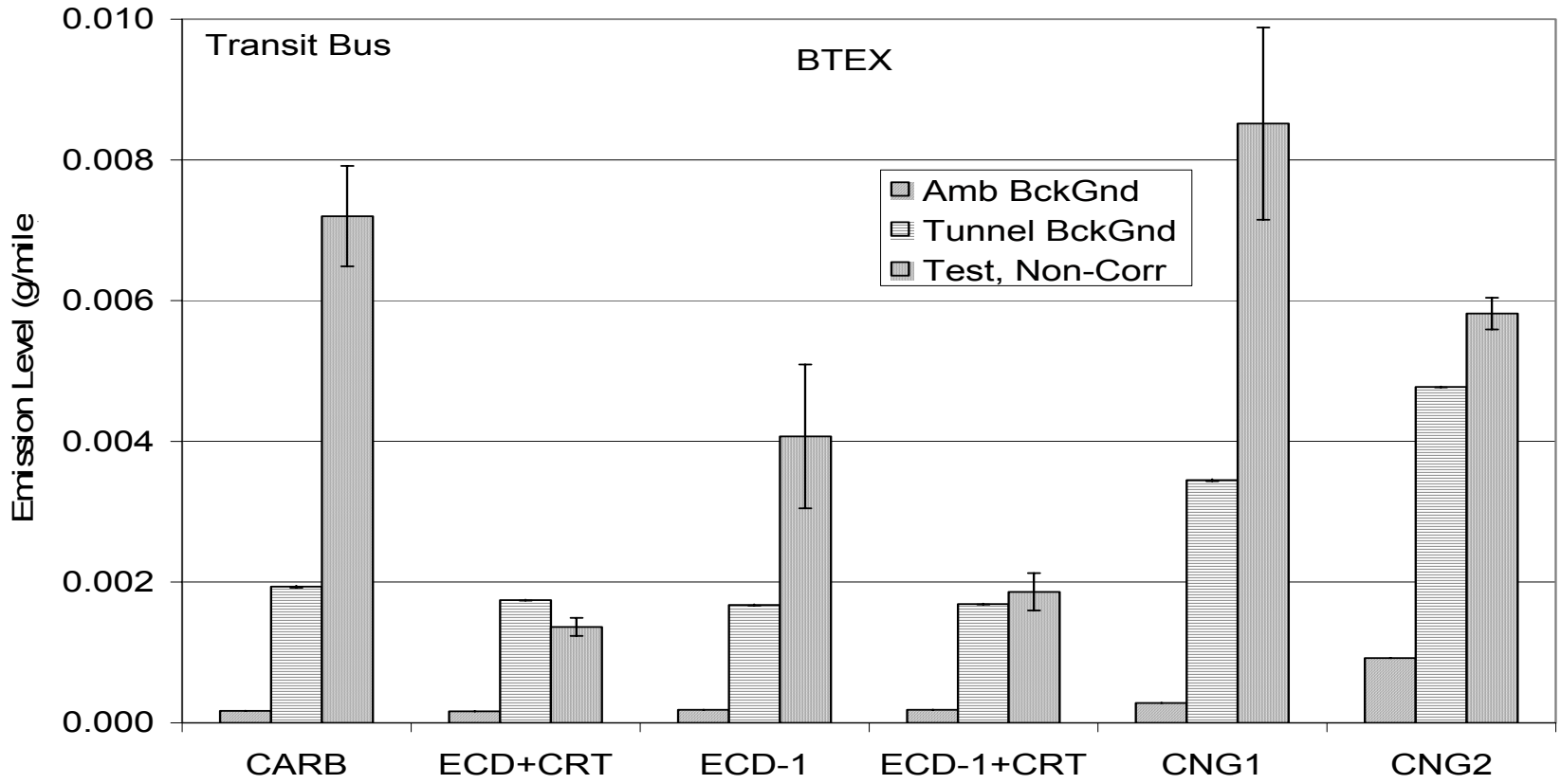
BTEX



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Carbonyl Compounds
(Air Toxics)

Formaldehyde

Acetone

Propionaldehyde

Methyl ethyl Ketone (MEK)

Butanal

Glyoxal

Tolual

Acetaldehyde

Acrolein

Croton

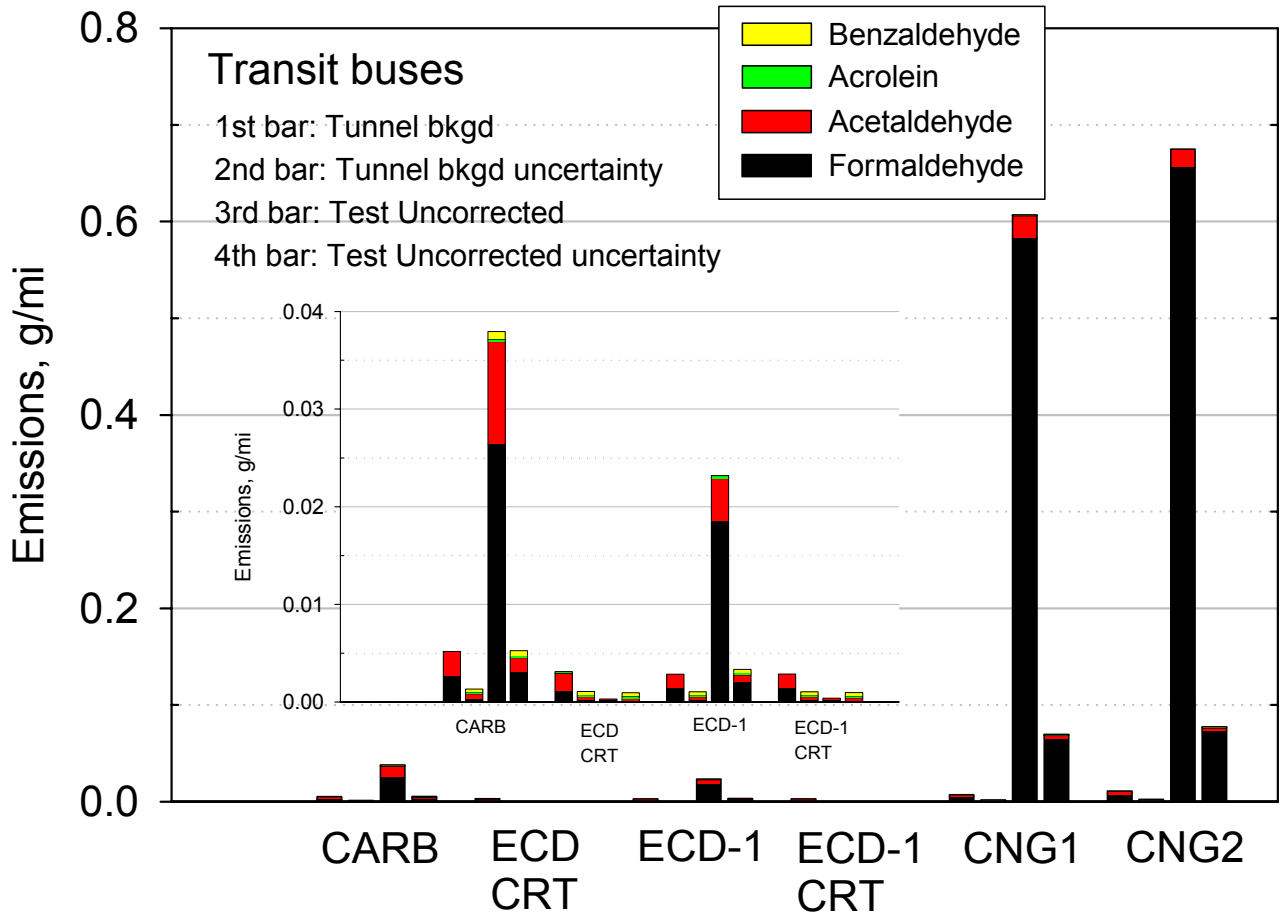
Methylacrolein

Benzaldehyde

Valal

Hexanal

Carbonyls



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Summary

- Controlling PM emissions to the 0.01 g/bhp-hr (2007 standards) is not a problem.
- The problem lies in accurately measuring the low levels of PM emissions (approx. 2 $\mu g/m^3$.
- Even measurement may not be a problem, but the current (outdated) definition of PM certainly is. Hence, the definition of PM needs to be modified.
- Also, the composition of PM from MY2007 engines clearly indicates that the definition of PM should be modified.
- Lube oil contribution to exhaust emissions is considerably more significant now than ever before.
- Natural gas engine designers need to focus more on cylinder materials, design of ring packs, valve stem seals, etc., to minimize oil consumption.
- Oil formulations need to be modified to counter the need for higher oil consumption in natural gas engines.