Un-Regulated Emissions from CRT-Equipped Transit Buses

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August 20-24, 2000

6th Diesel Engine Emissions Reduction Workshop
Hyatt Islandia Hotel
San Diego, CA

Environmental Conservation 30 YEARS
John P. Cahill
Commissioner

New York State “Clean Diesel” CRT Demonstration Team

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Project Objectives

- Demonstrate applicability of the CRT ™ to both new 4-stroke and older 2-stroke diesel engines
- Document the emissions reductions available using CRT ™ retrofits in conjunction with reduced sulfur diesel fuel
- Evaluate the durability of CRTs in rigorous New York City bus service
- Apply new measurement and monitoring technologies for PM and toxic emissions
- Compare diesel-CRT™ with CNG and diesel-electric hybrid buses

CRT Project Outline

I. Fleet Demonstration *(Feb 2000 - Jan 2001)*

- **An entire depot, approximately 130 buses, is being run on ultra low sulfur (30 ppm S) diesel fuel**
- **25 Series 50 buses (275 Hp 1999 model year) were retrofitted with CRTs**
- **Operate for 9-12 months in revenue service**
- **Check back pressure and exhaust temperature**

II. Emissions Testing *(April 2000; Jan 2001)*

- **2 Series 50 buses with CRT**
- **Check emissions with chassis dynamometer**
- **Baseline and durability testing after 9-12 months**

III. Test Configuration:

Configuration	OE Muffler*		OE Muffler*	CRT™	
Fuel	LSD (300 ppm S)		ULSD (30 ppm S)	ULSD (30 ppm S)	
Bus #6019	CBD+	NYBUS+	CBD	CBD	NYBUS
Bus #6065	CBD		CBD	CBD	

**** OE Muffler = oxidation catalyst***
+ Drive Cycle

CRT Project Emission Measurements

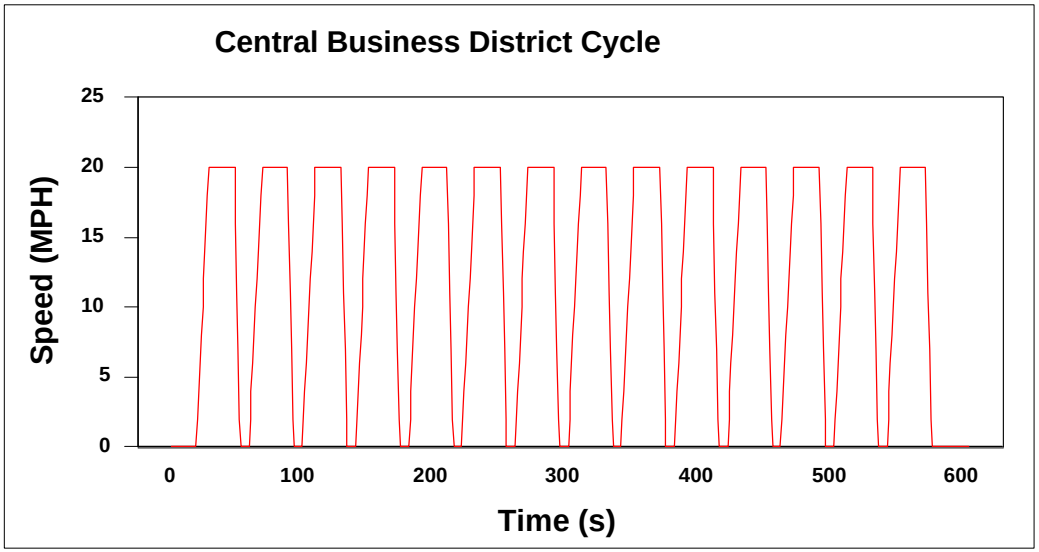
I. Regulated Emissions:

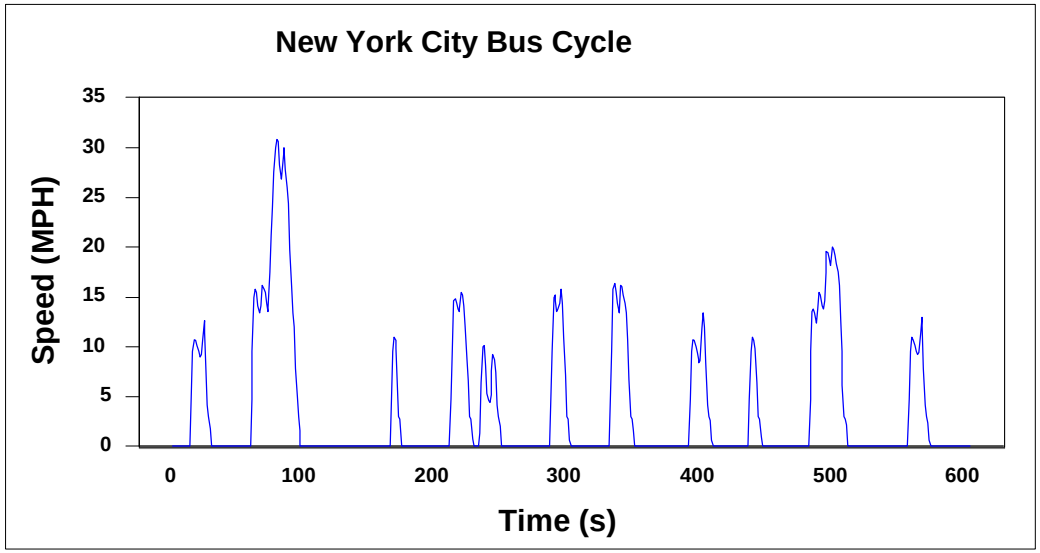
- **PM (Filter method; TEOM)**
- **THC (Heated FID)**
- **NOx (Chemiluminescence)**
- **CO, CO_2 (NDIR)**

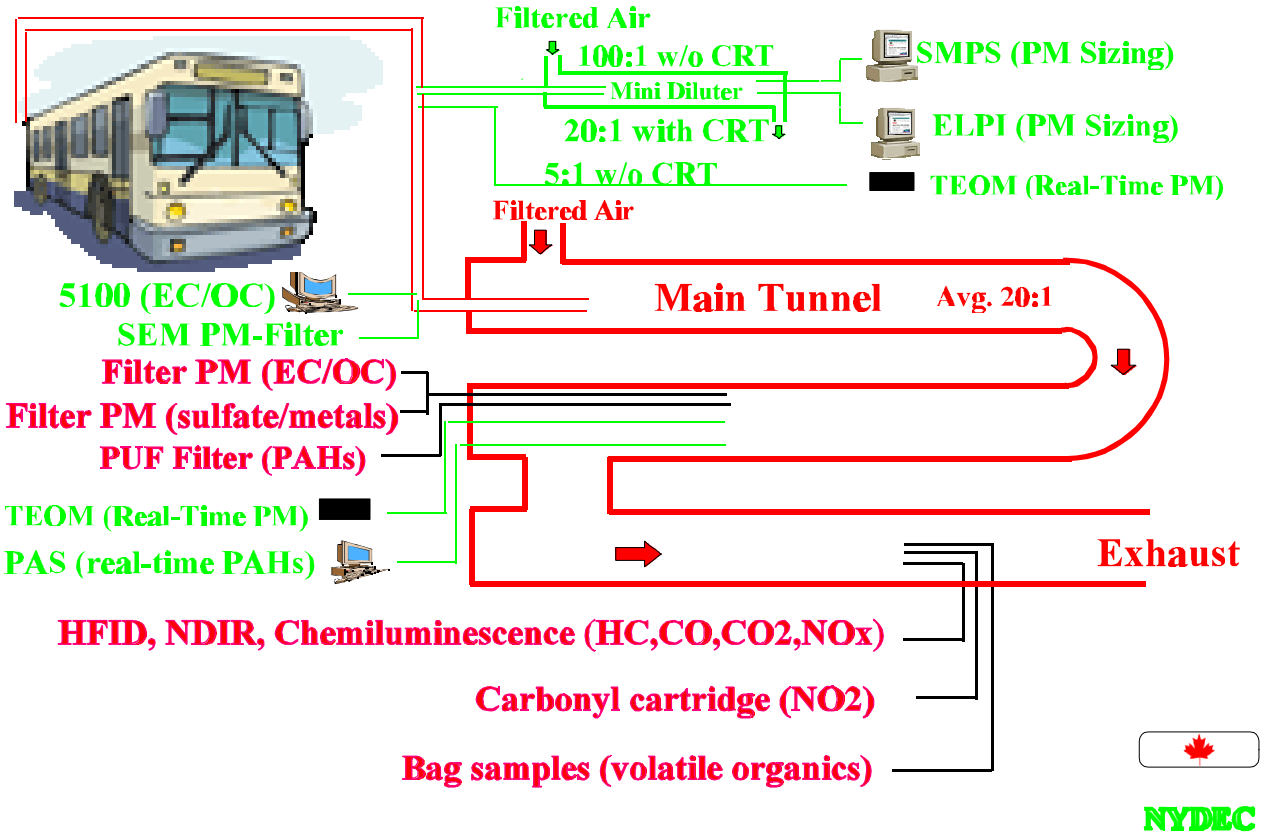
II. Unregulated Emissions:

- **Sulphate (filter collection, IC analysis)**
- **SO_2 (K_2 CO_3 coated filter collection, IC analysis)**
- **Carbonyls (DNPH cartridge collection, HPLC analysis)**
- **NO_2 (chemiluminescence, DNPH cartridge collection, HPLC analysis)**
- **PAHs and nitro-PAHs (quartz fiber filter w/ PUF filter collection, GC-MS analysis; photoelectric aerosol sensor (PAS))**
- **Elemental carbon and SOF (filter gravimetric; R&P diesel particulate analyzer)**
- **PM morphology (scanning electron microscopy (SEM))**
- **VOC (Tedlar bag collection, GC-MS analysis)**
- **PM number and size distributions (SMPS, ELPI)**

CRT™ Project Driving Cycles

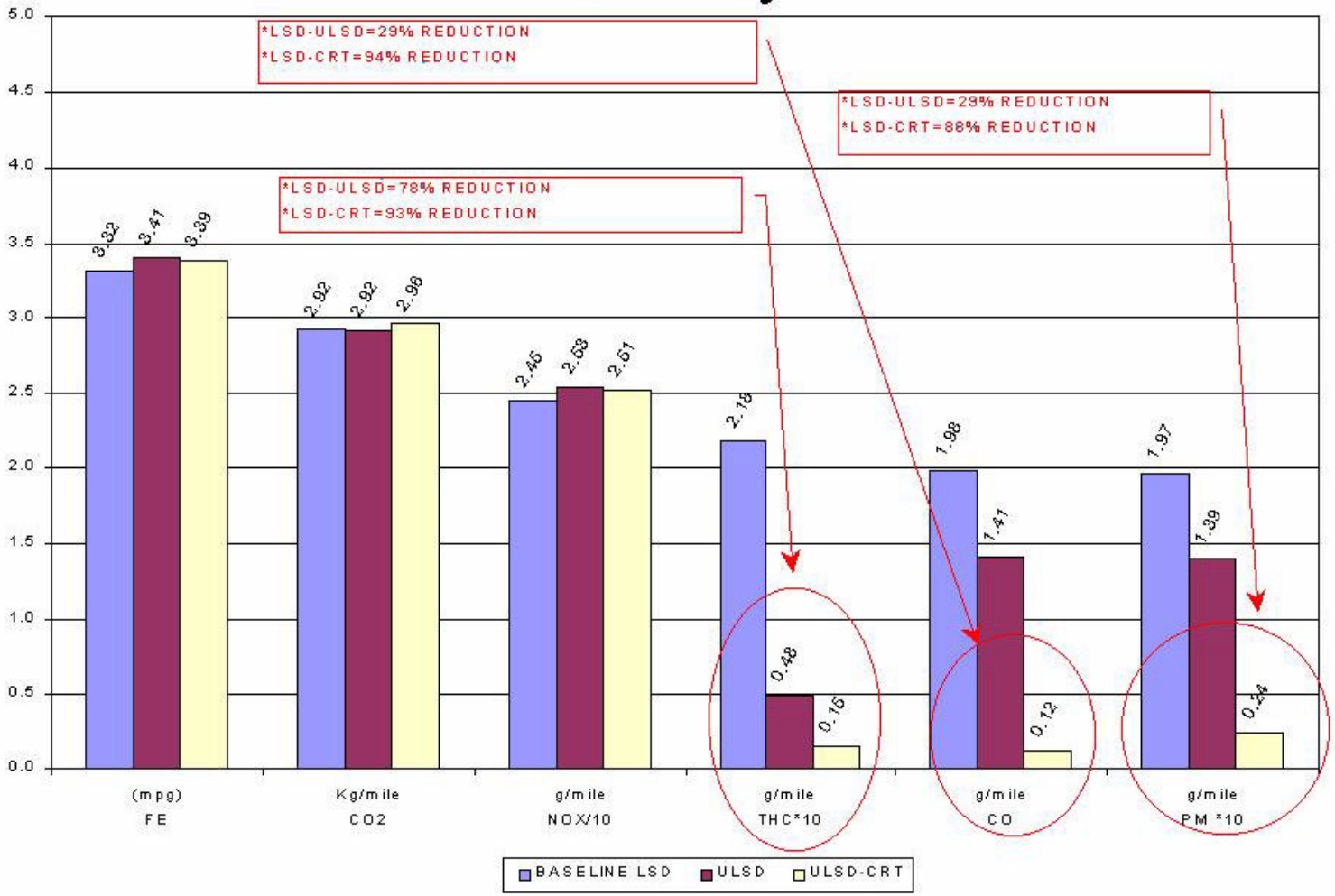


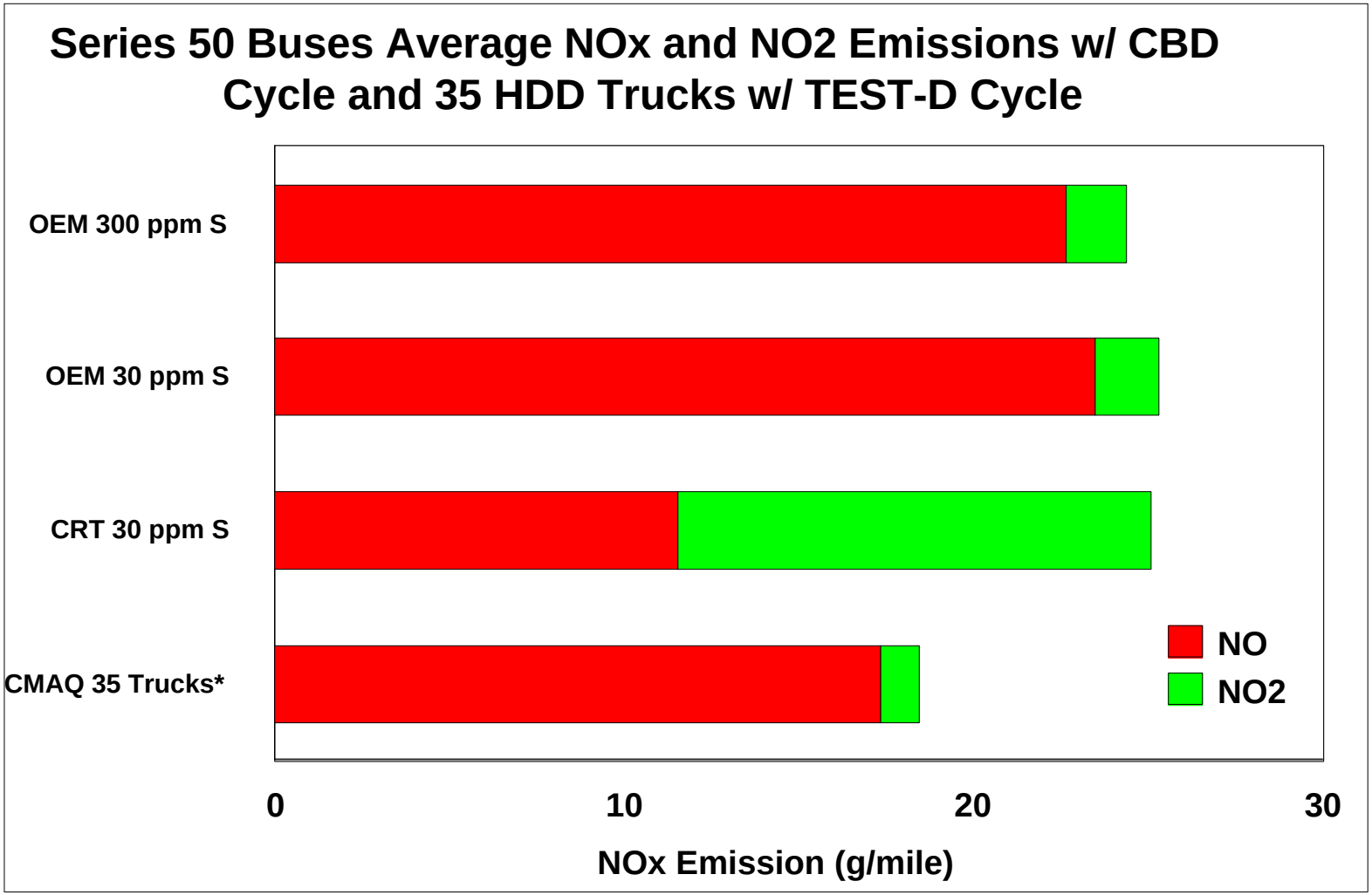




Sampling Diagram of CRT Testing Program

Average Series 50 Emissions Results
CBD Cycle

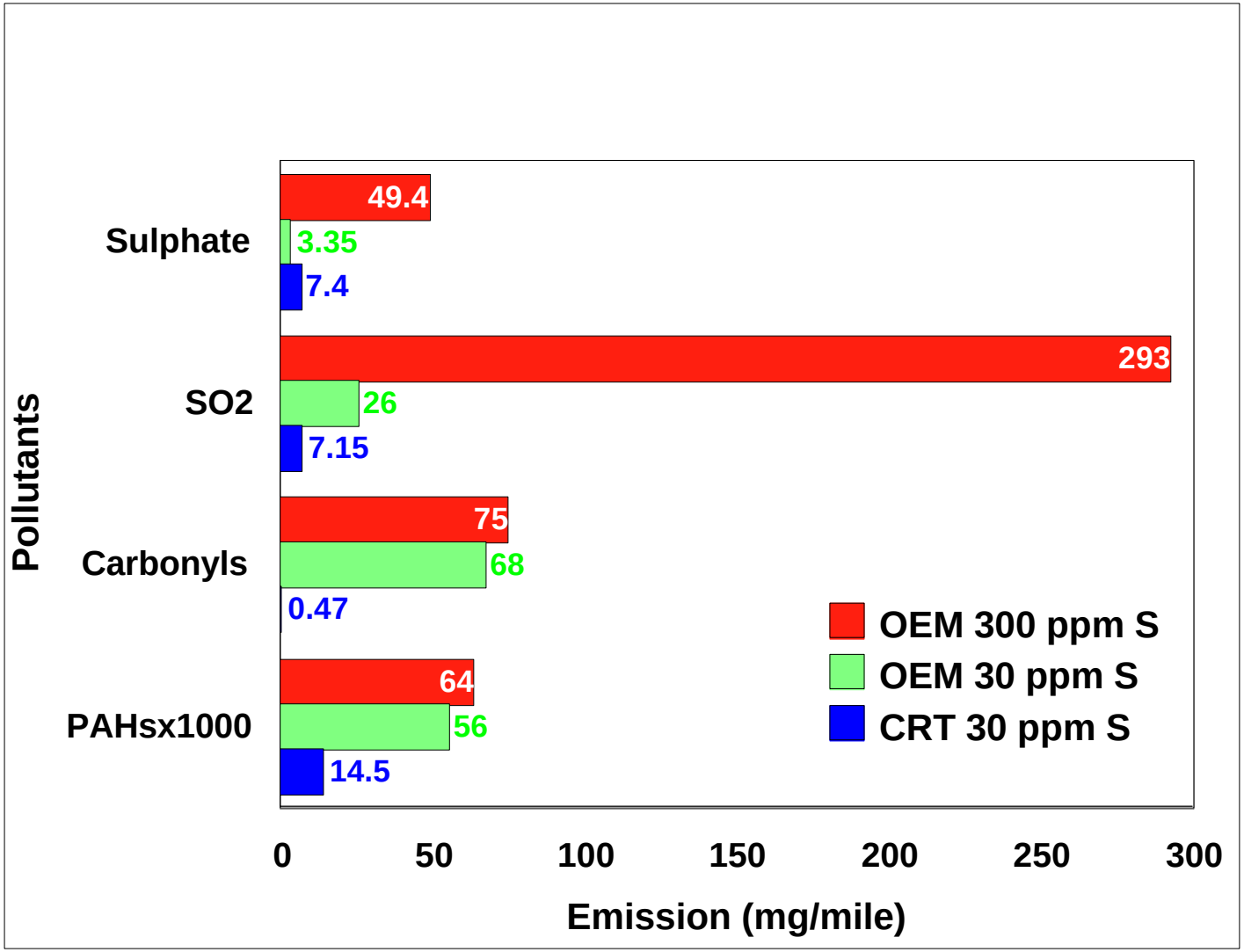




*

Emission tests were performed by West Virginia University in this HDD truck emission testing project funded through the federal Congestion Mitigation and Air Quality Improvement (CMAQ) program, with additional support from the EPA Office of Mobile Sources

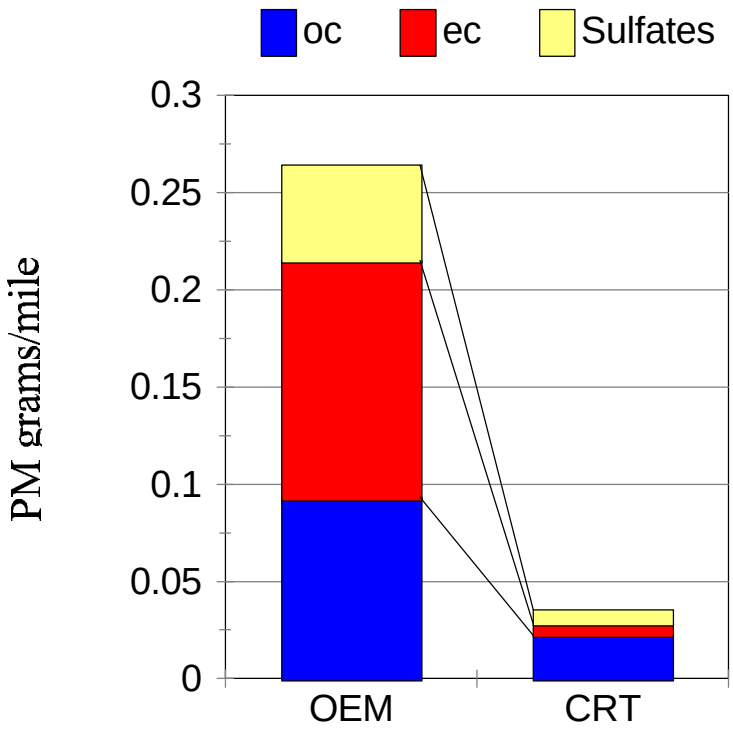
Unregulated Emissions from Two Series 50 Buses



Organic & Elemental Carbon Fractions

Two Series 50 Buses, CBD Cycle

- Multiple tests on 2 buses
- R&P's 5100 Carbon Analyzer
- Organic Carbon (oc)
- Elemental Carbon (ec)
- ec/oc split near detection limit



New York State Department of Environmental Conservation

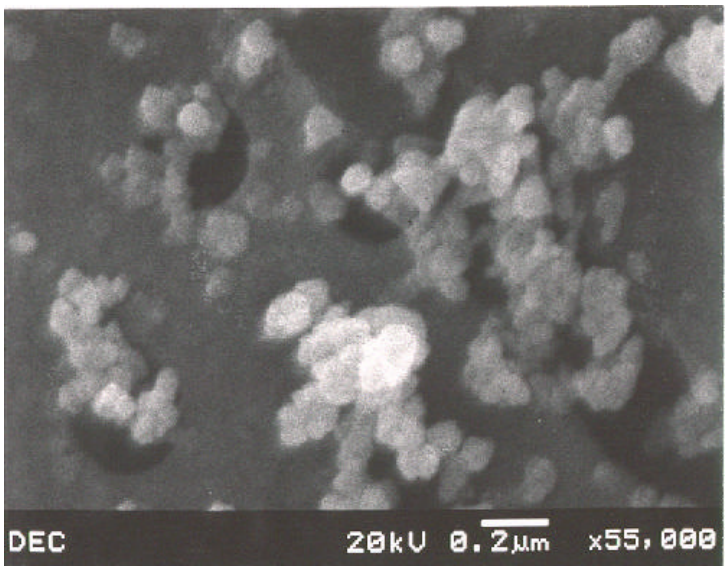
Division of Air Resources

Website: www.dec.state.ny.us

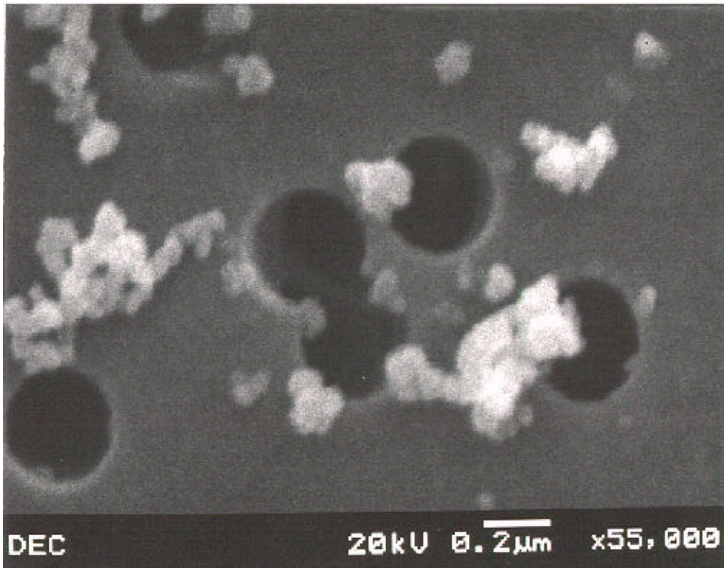
John P. Cahill
Commissioner

NYS DEC CRT STUDY

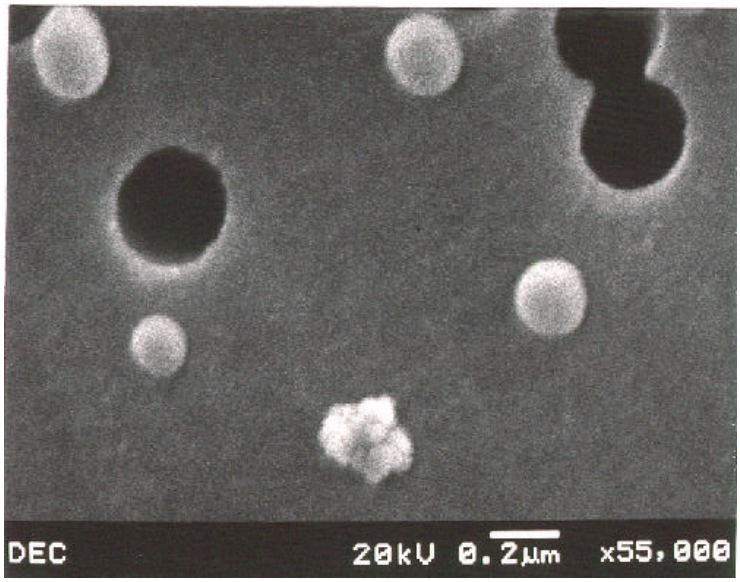
NYC Transit Bus #6019 Plate # C81056 High Magnification - 55,000x



Standard Fuel 300 PPM
CRT Not Installed



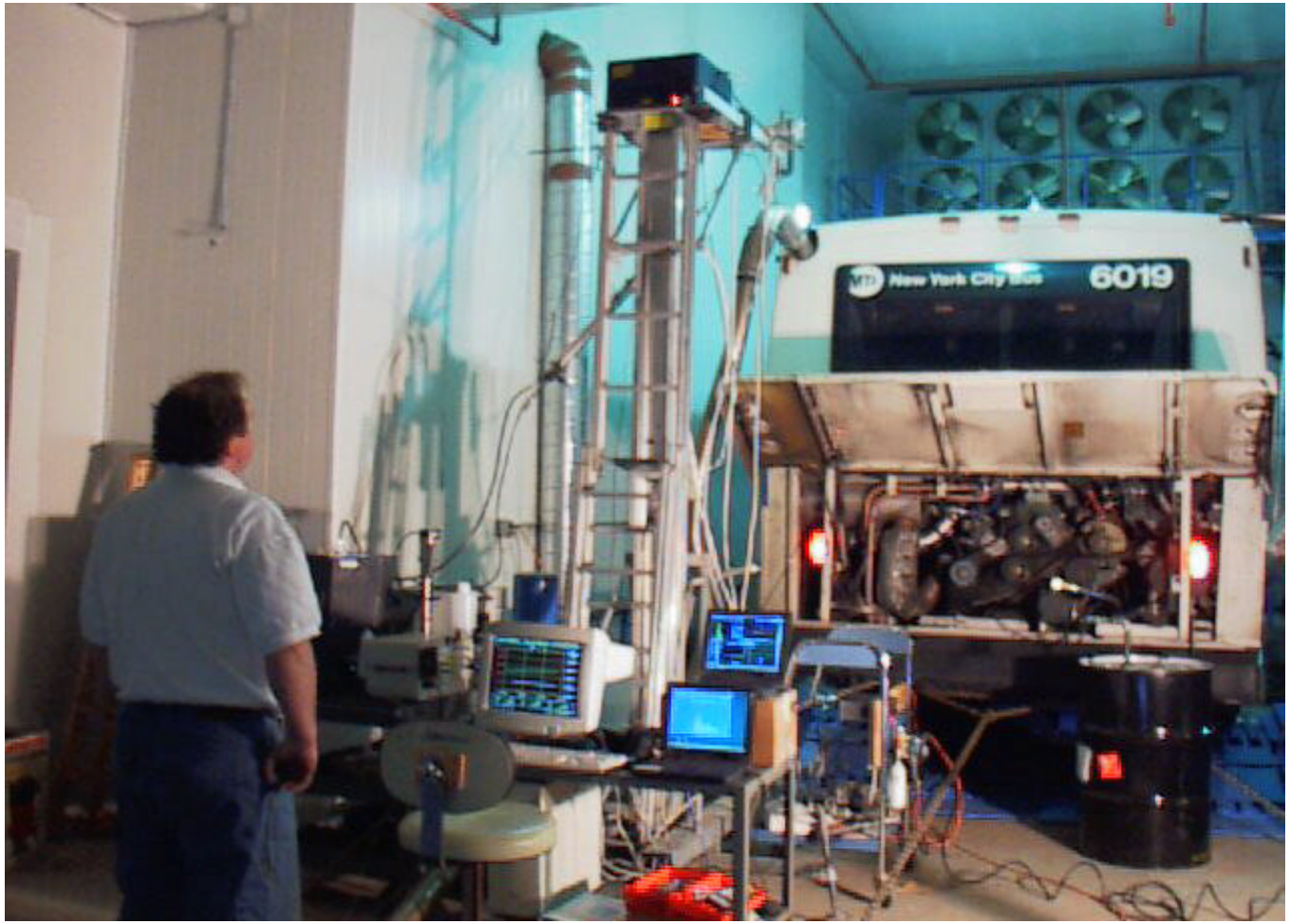
Low Sulfur Fuel 30 PPM
CRT Not Installed

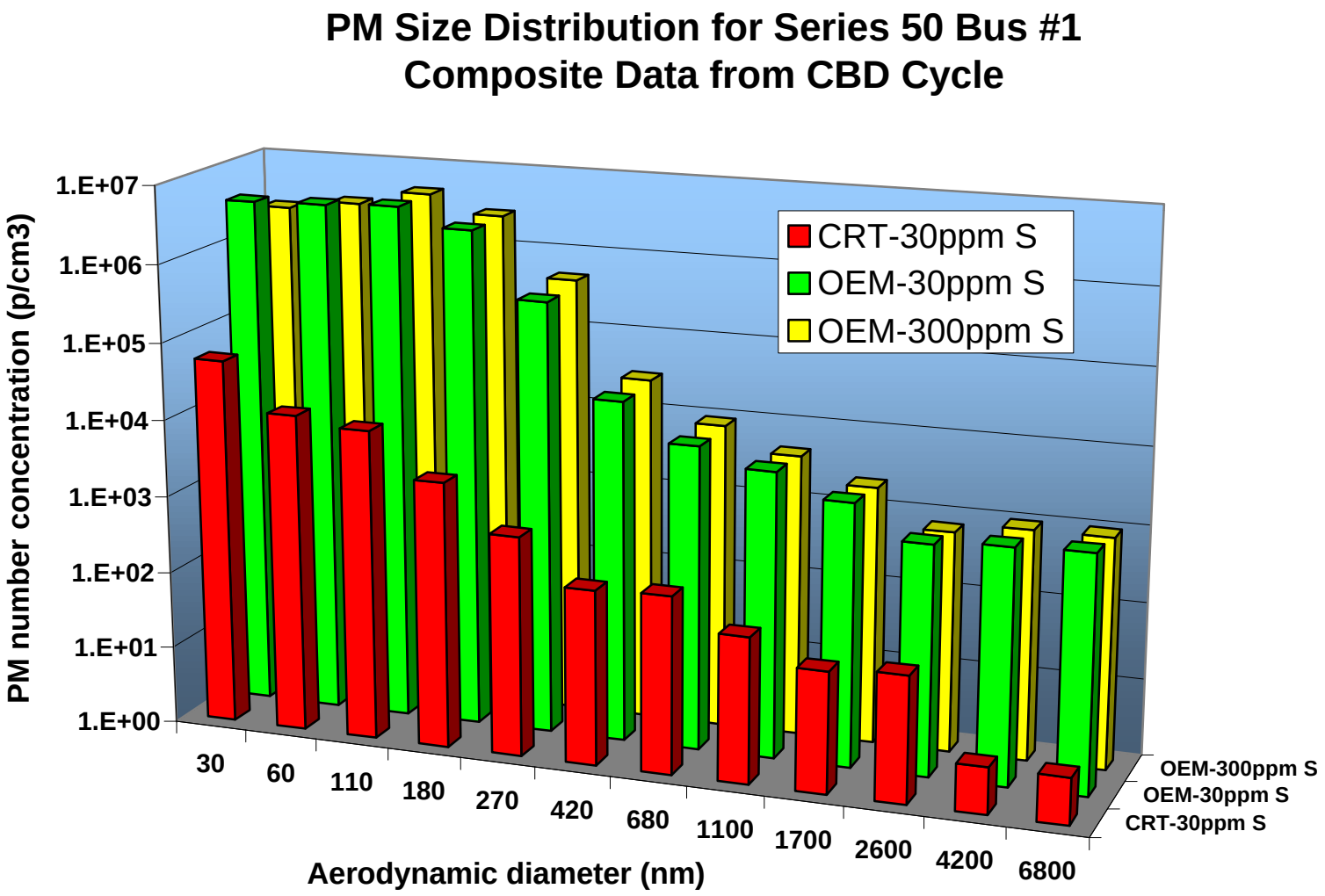


Low Sulfur Fuel 30 PPM
CRT Installed

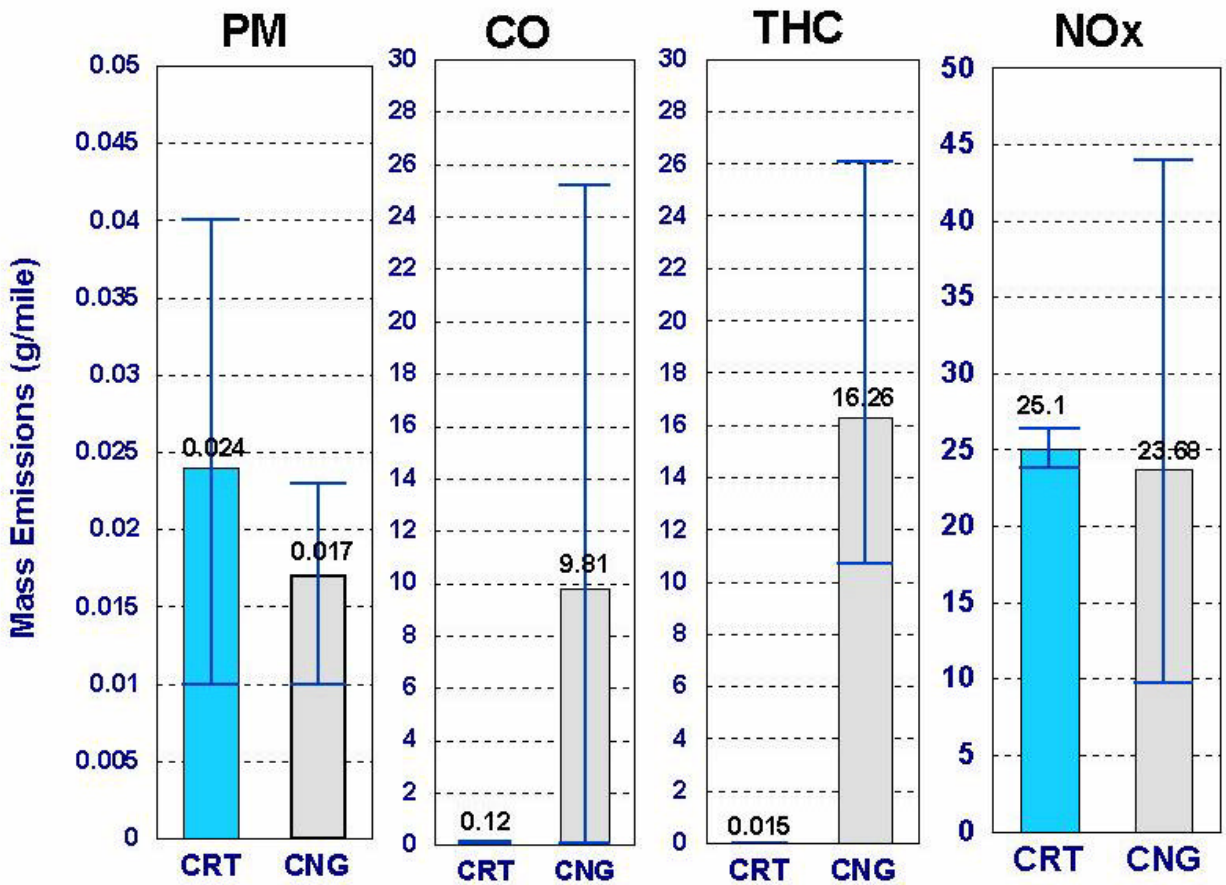
Samples were collected on a polycarbonate filter, pore size .4 microns. Black circles are the .4 micron holes in the filter.

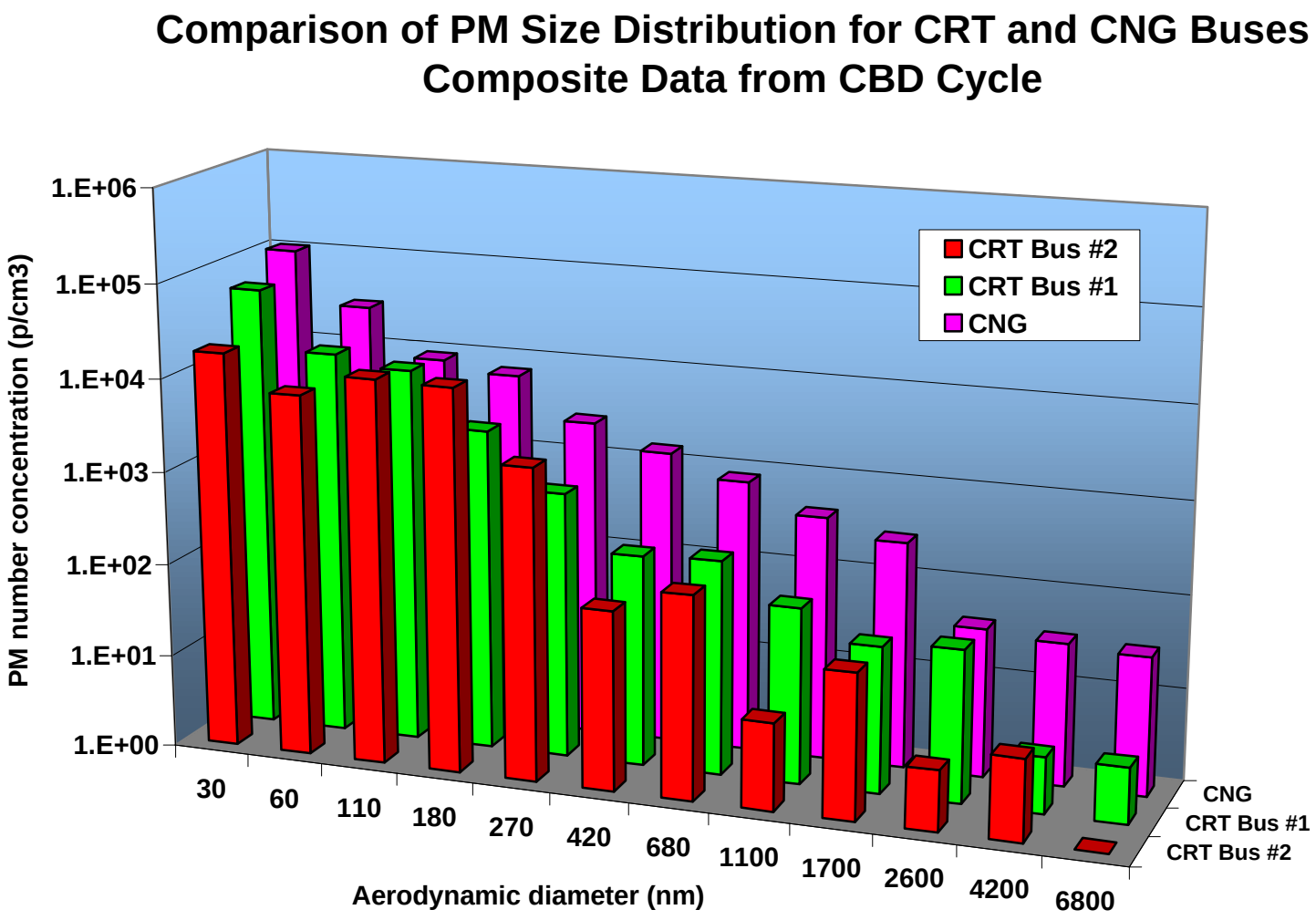
A picture of bus #6019 tested at Environmental Canada




PM Size Distribution for Series 50 Bus #1
Composite Data from CBD Cycle
PM number concentration (p/cm3)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
CRT-30ppm S
OEM-30ppm S
OEM-300ppm S
30
60
110
180
270
420
680
1100
1700
2600
4200
6800
Aerodynamic diameter (nm)
OEM-300ppm S
OEM-30ppm S
CRT-30ppm S

Emissions Test Results - CRT vs. CNG
CBD Cycle




Comparison of PM Size Distribution for CRT and CNG Buses
Composite Data from CBD Cycle
PM number concentration (p/cm3)
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
CRT Bus #2
CRT Bus #1
CNG
30
60
110
180
270
420
680
1100
1700
2600
4200
6800
Aerodynamic diameter (nm)
CNG
CRT Bus #1
CRT Bus #2

Conclusions

1. The JMI CRT Technology has been successfully demonstrated in revenue service on Series 50 engines operated with nominal 30 ppm sulfur fuel. Durability testing continues.

2. PM (gm/mi) emissions were reduced approximately 88% compared to base bus operated on 300 ppm sulfur fuel for two buses tested.

3. Total Carbonyl emissions (22 species analyzed) reduced from 75 mg/mi to less than 0.5 mg/mi under CRT operation.

4. Elemental and Organic carbon both reduced, further analysis pending.

5. Total NO_x emissions unchanged by CRT, but significant shift to NO_2

6. CRT PM size testing under transient CBD driving used rapid (100:1) dilution with filtered dry air gave 100x reductions over all size ranges (30-6800 nm) . Under steady-state operation, reductions were far greater.

7. SEM analysis reveals significant shape changes in remaining particles

Future Plan

- Evaluate the maintainability and durability of CRTs in rigorous New York City bus service
- Evaluate the applicability of the technology to older 2-stroke diesel engines
- More CNG bus testing
- Diesel-electric hybrid bus testing

NYCT Bus Operations

- Number of Depots: 18
- Employees: 12,159
- Bus Routes / Bus Stops: 234 / 14,000
- Ridership: 2.1 million weekday
- Revenue Miles: 99 million annually
- Diesel Fuel Used: 40 million US Gal. in 1999

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NYCT Bus Fleet

	2000	2006
Diesel Buses (2 -stroke)	1,658	0
Diesel Buses (4-stroke)	2,592	3,311*
CNG Buses	170	649
Hybrid Diesel Electric Buses	10	390
Total	**4,430**	**4,350***

** Total may change based on ridership trends and fleet mix*

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NYCT “Clean Fuel” Bus Commitment

- Program is technology neutral, and combines several different approaches
  - ➔ CNG Buses
  - ➔ Hybrid Buses
  - ➔ Clean Diesel Technologies
- Designed to give cost-effective emissions reductions as quickly as possible
- MTA 2000 - 2004 Capital Spending Plan includes $304 million for Clean Fuel Programs

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2000 - 2004 “Clean Fuel” Bus Actions

- Expand CNG Bus Operations
  - ➔ Purchase 300 buses and convert 2 depots to CNG
- Expand Hybrid Bus Programs
  - ➔ Purchase 250 hybrid buses
  - ➔ Develop hybrid articulated and coach buses
- Expand the Use of Clean Diesel technologies
  - ➔ Retire all 2-stroke diesel engines by 2003
  - ➔ Convert entire fleet to reduced sulfur fuel
  - ➔ Retrofit 3,500 buses with catalyzed exhaust filters

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Ultra Low Sulfur Diesel Fuel

- Base specification similar to #1 Diesel
  - ➔ Sulfur level of 30 ppm (350 - 500 ppm standard)
  - ➔ Lubricity enhancement
- Consistent with 2006 EPA Mandates
- As of October 2000, entire NYCT bus fleet will operate exclusively on ULSD
- Will displace approximately 40 million gallons standard #1 diesel
- Incremental cost: $0.12 per gallon

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Catalyzed Exhaust Filters

- Oxidation catalyst and wall-flow ceramic filter
  - ➔ Packaged to replicate OEM muffler dimensions
  - ➔ No moving parts
  - ➔ No external energy requirements
- In use in Europe for six years
- Commercially available in US from two manufacturers: Johnson Matthey and Englehard

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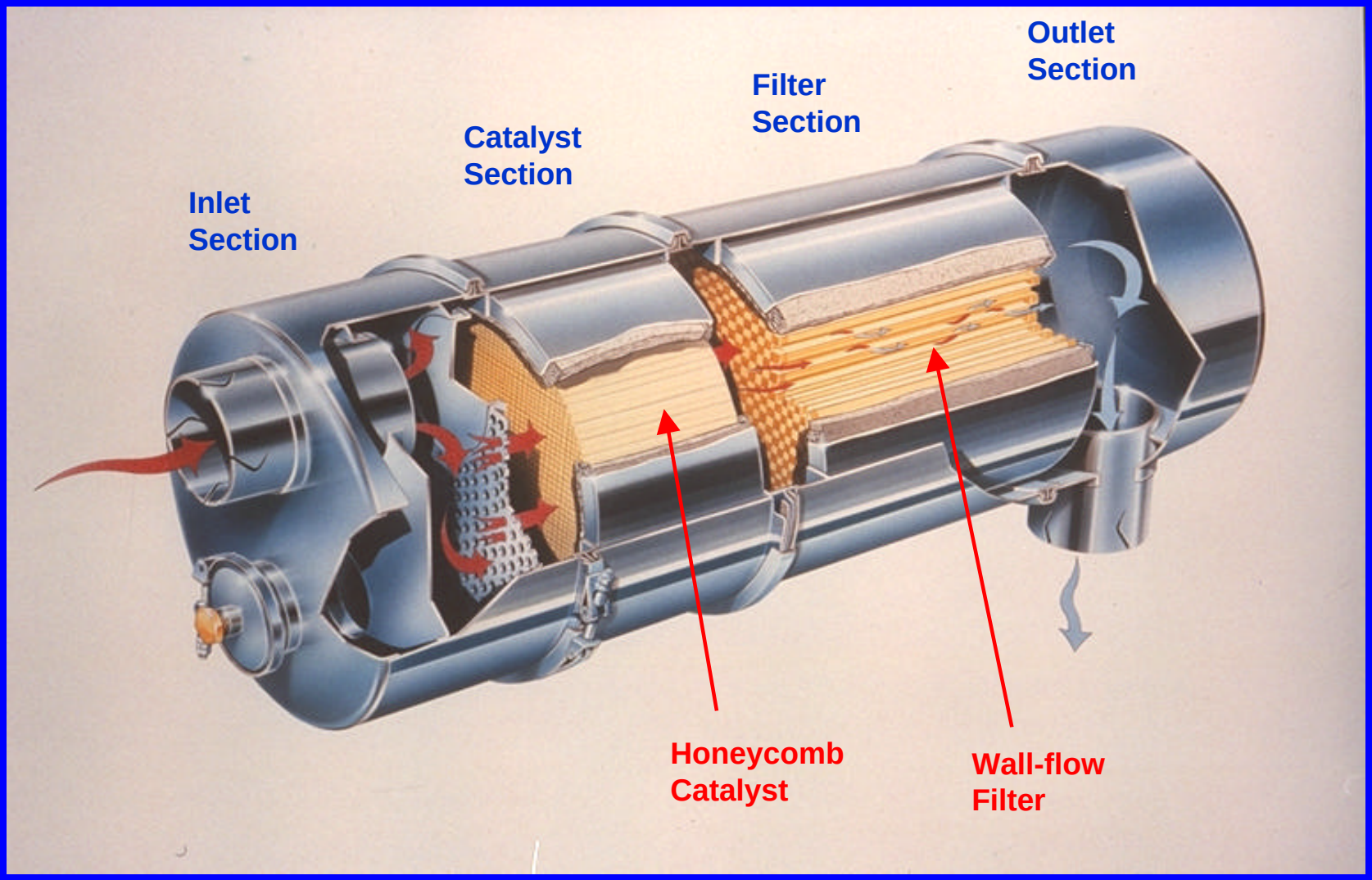
Johnson Matthey CRT ™



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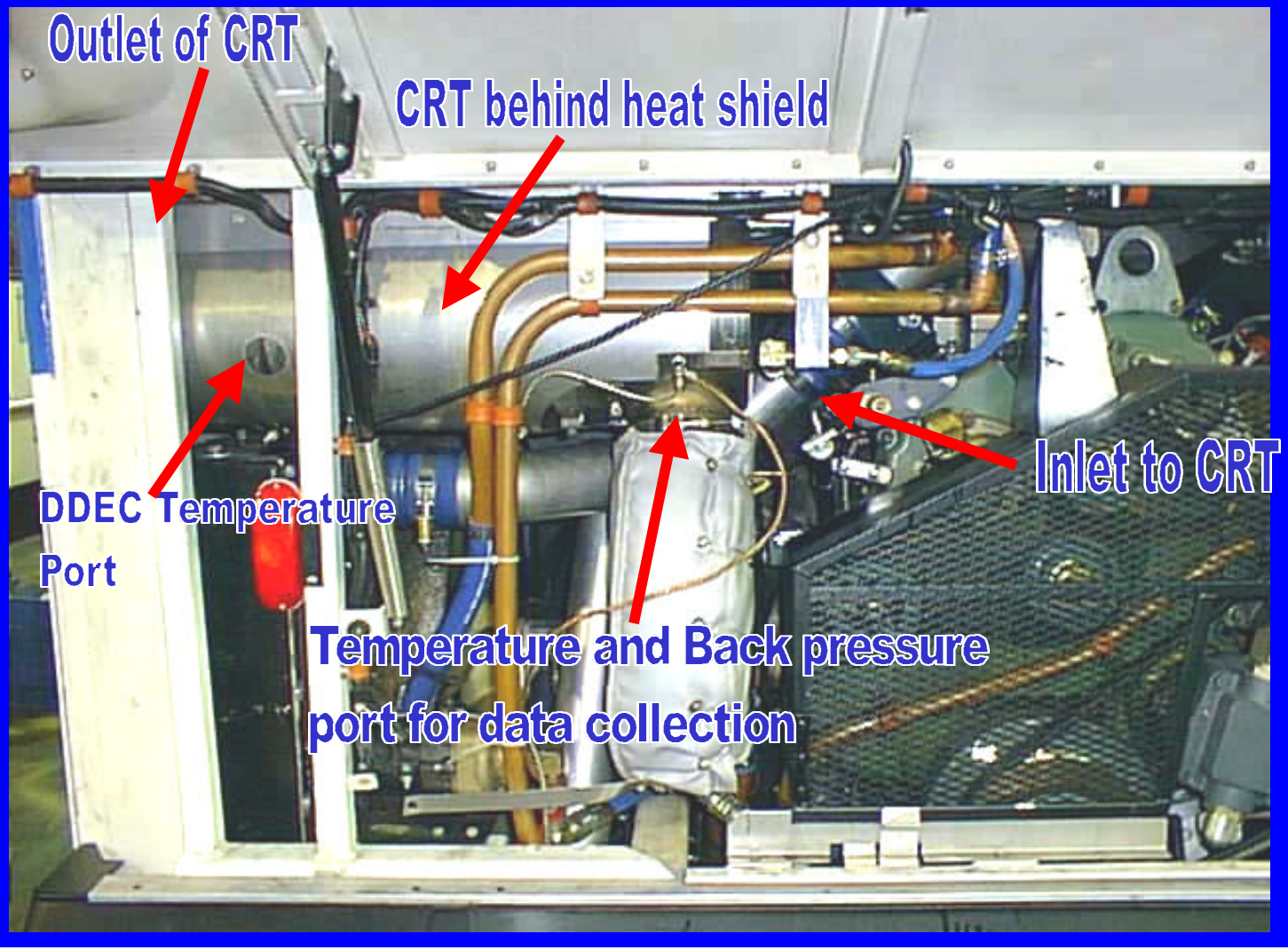
CRT Installation S50 Engine



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Catalyzed Filter Installation Plan

- NYCT will install catalyzed filters on every diesel bus in the fleet by the end of 2003
- Approximate Installation plan:

	2000	2001	2002	2003
Units	350	1,050	1,050	1,050

- Current Status:
  - ➔ 500 units ordered for retrofit; installations began 10/00
  - ➔ 170 units ordered w/ new buses; delivery began 10/00
- Cost: Approximately $6,000 per bus

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2-Stroke Diesel Retirement

- NYCT will retire all pre-1993 2-stroke diesel engines by the end of 2003
  - ➔ Approx 1,300 new buses delivered
  - ➔ 450 1990 - 1993 buses “re-powered” with new engines
- New engines will be up to 90% “cleaner”
- New buses will receive latest technology available, including catalyzed filters
- Re-powered buses will receive DDC Series 50 engines with EGR, plus catalyzed filters

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