Performance of Johnson Matthey CRT® Particle Filter System for Emission Control of Heavy-Duty Diesel Engines

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Diesel Emission Control Systems

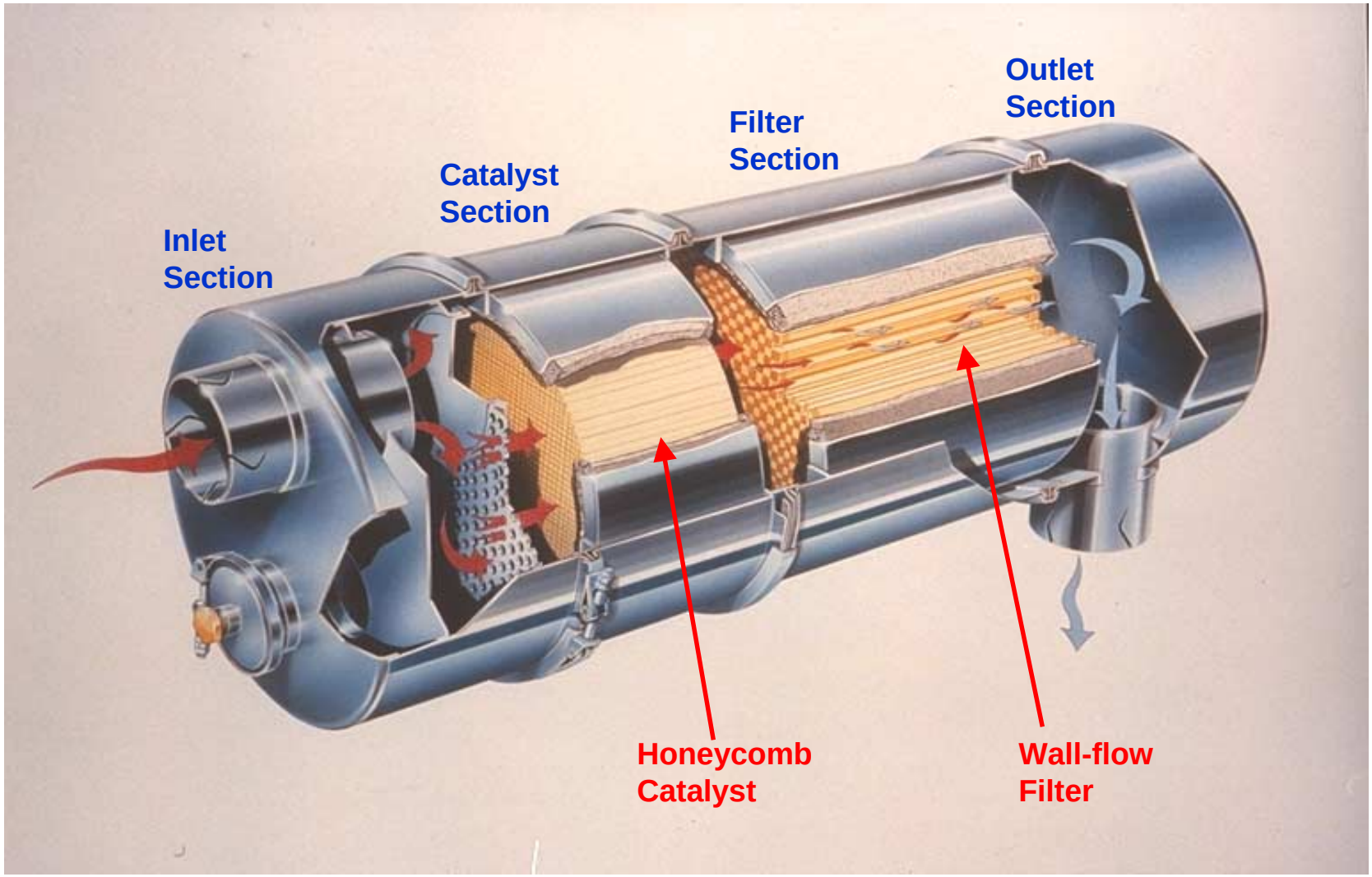
Outline

- CRT Particulate Filter - Introduction
- CRT Field Experiences - NY City Transit
- CRT Field Experiences - California
- New Developments & Applications
- Concluding Remarks

CRT® Particulate Filter

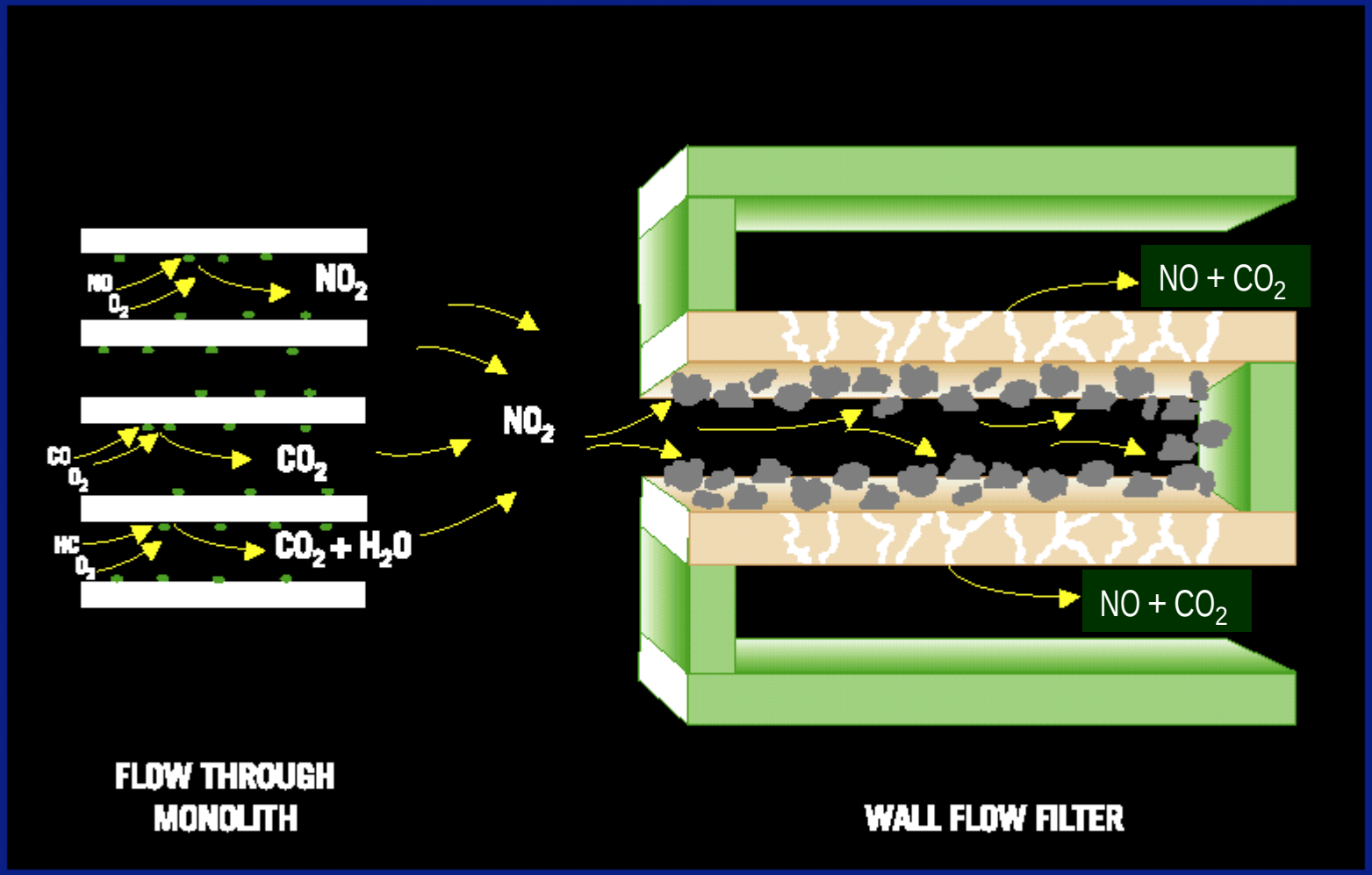
- Patented CO/HC/PM Emission Control System combining Oxidation Catalyst & Filter
- Engineered as a totally passive emission control system which requires no supplemental heat
- Uses NO_2 produced by a specially formulated catalyst to burn soot collected by the filter at typical operating temperatures of diesel engine exhaust
- Ultra Low Sulfur fuel for high efficiency and durability

CRT® Particulate Filter



Unique Patented Johnson Matthey System

NO_2 Reaction in a CRT™



JM Catalyst Technology

Typical CRT Particulate Filter

Factors Affecting CRT Application

- Exhaust temperature
- PM emissions
- NOx/PM ratio
- Fuel sulfur level

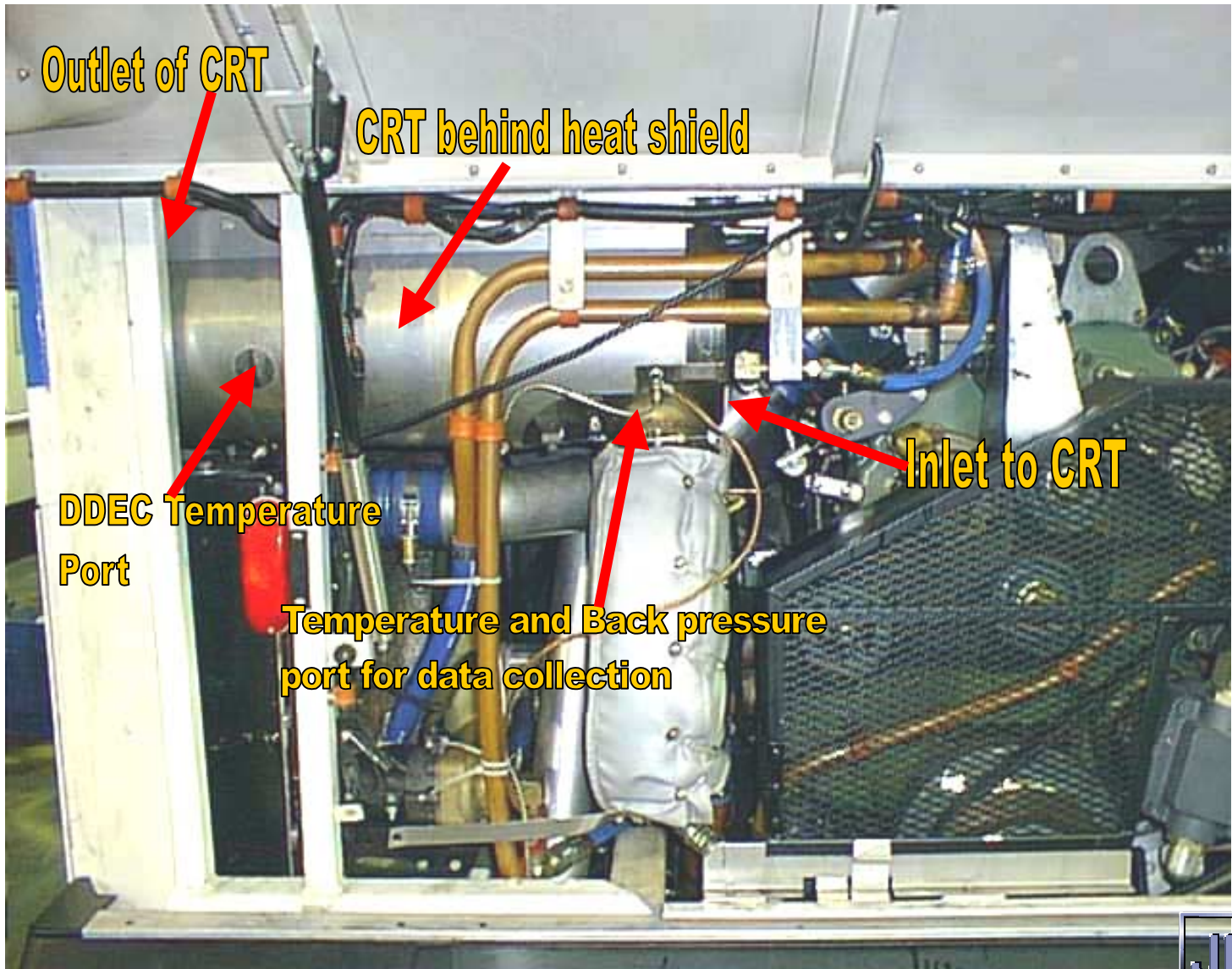
CRT Field Applications

- Europe
  - Over 18,000 units installed since 1994
- North America
  - About 1000 units installed since 1999
  - Over 1500 additional units to be installed by 6/2002
- Some North American Applications
    - MTA NY City transit buses
    - NY Sanitation trucks
    - Ralphs Grocery trucks
    - San Diego School buses
    - LA Unified School buses
    - LA City Sanitation trucks
    - LA MTA transit buses
    - Seattle transit buses
    - Seattle DOT trucks

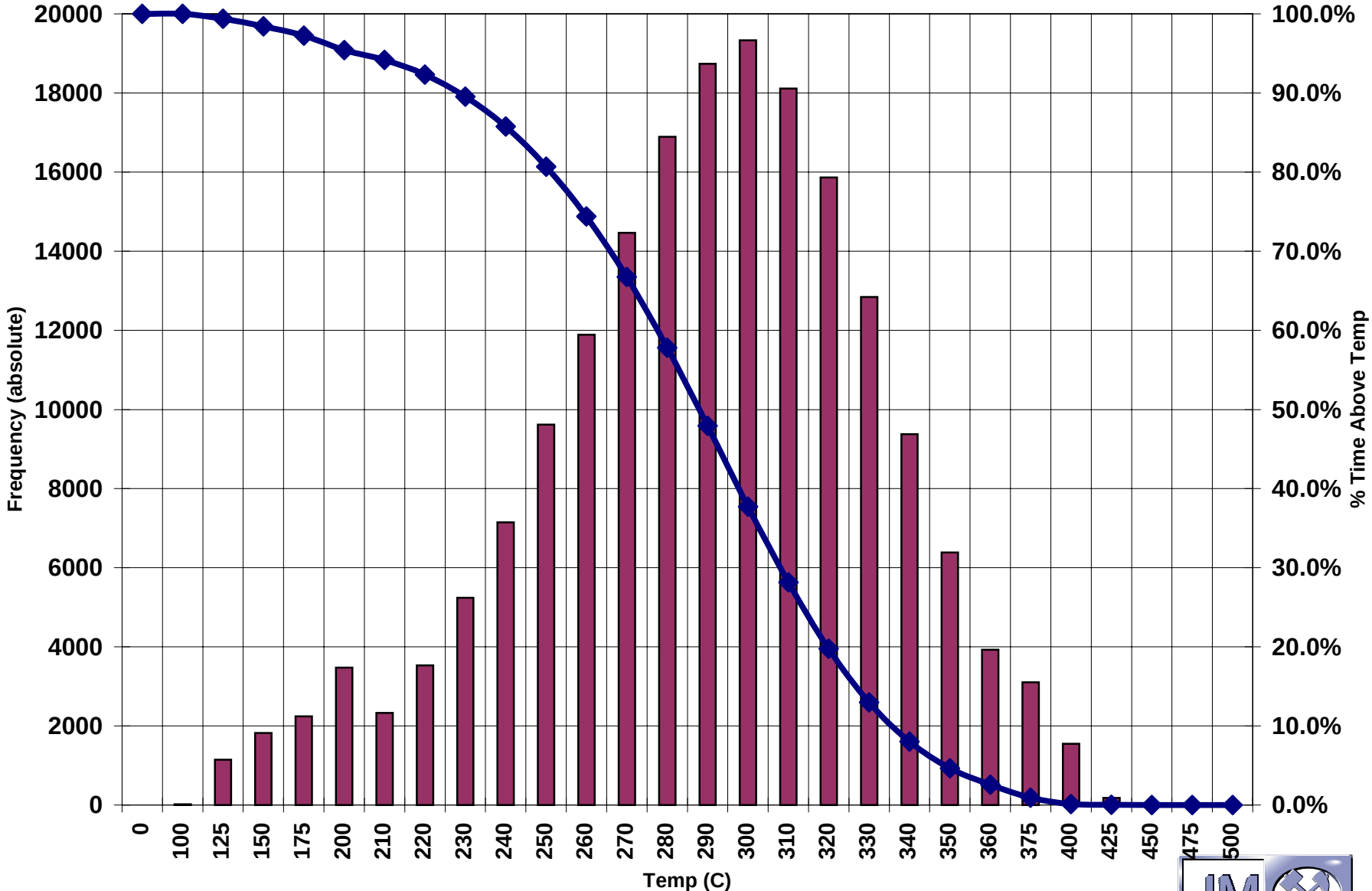
NY City Field Demonstration

- 25, 1999 Orion V with DDC Series 50 engines retrofitted with CRTs
- 41, 1999 Orion V with DDC Series 50 with OE muffler used as control vehicles
- The entire depot (140 buses) to operate on reduced sulfur fuel through the test period (9 months)
- 3 buses equipped with continuous data loggers to monitor back pressure & temperature; all others monitored monthly
- Monitor fuel economy, maintenance records & all operational information for test & control vehicles
- Carry out regulated & unregulated emissions testing on chassis dyno on selected buses at the start and after 9-12 months of operation

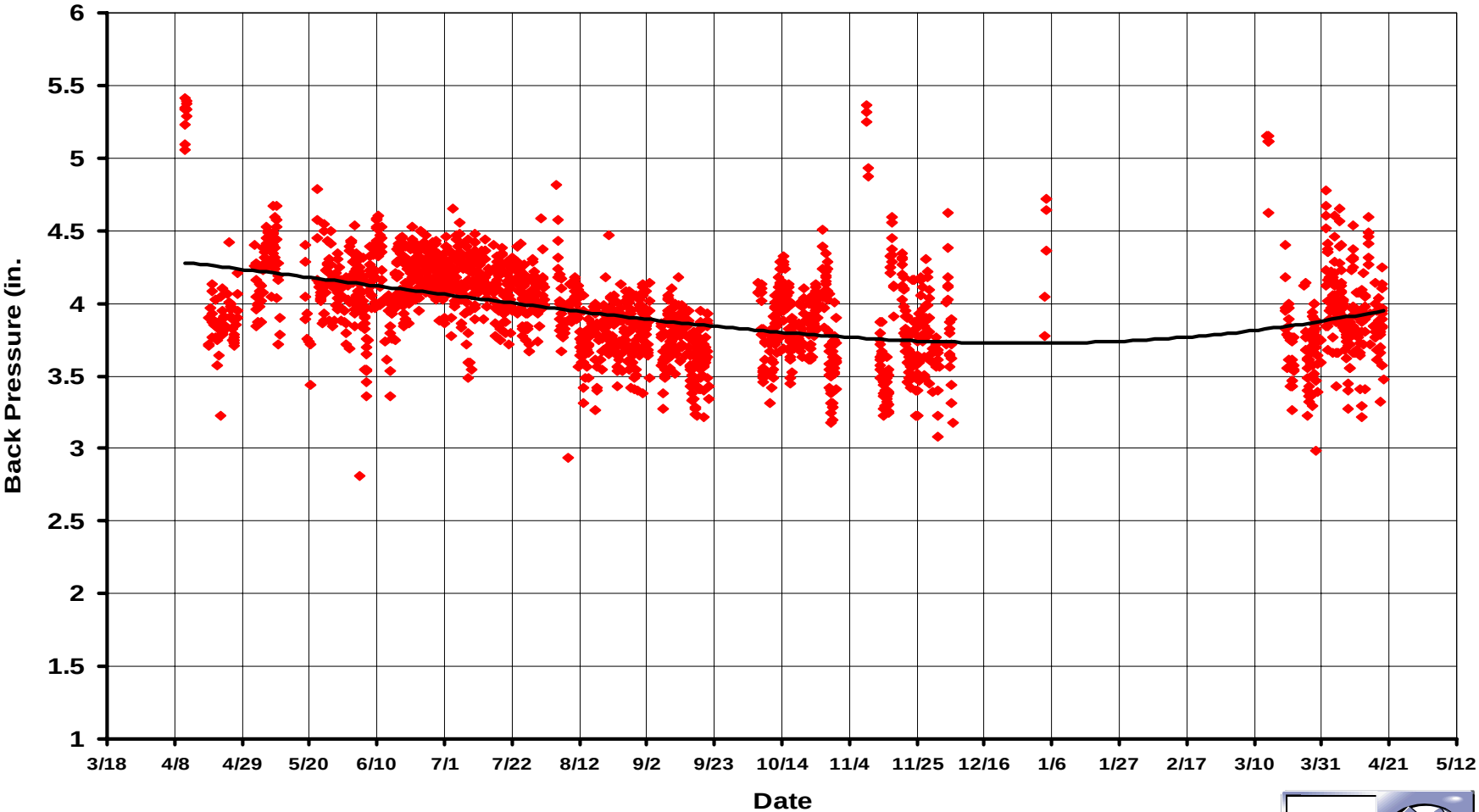
Series 50 DDEC Bus CRT installation



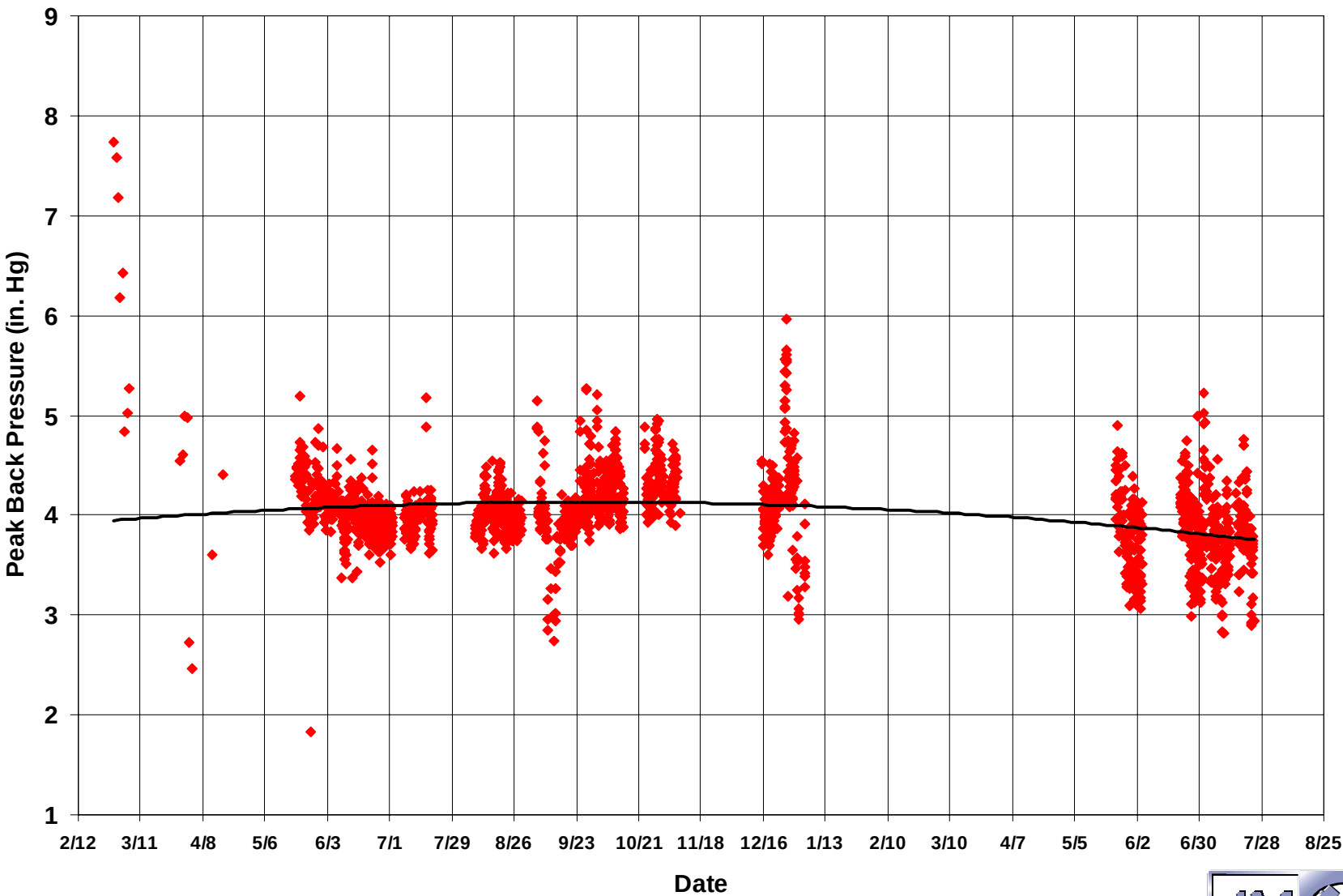
Temperature Histogram on Series 50 Bus



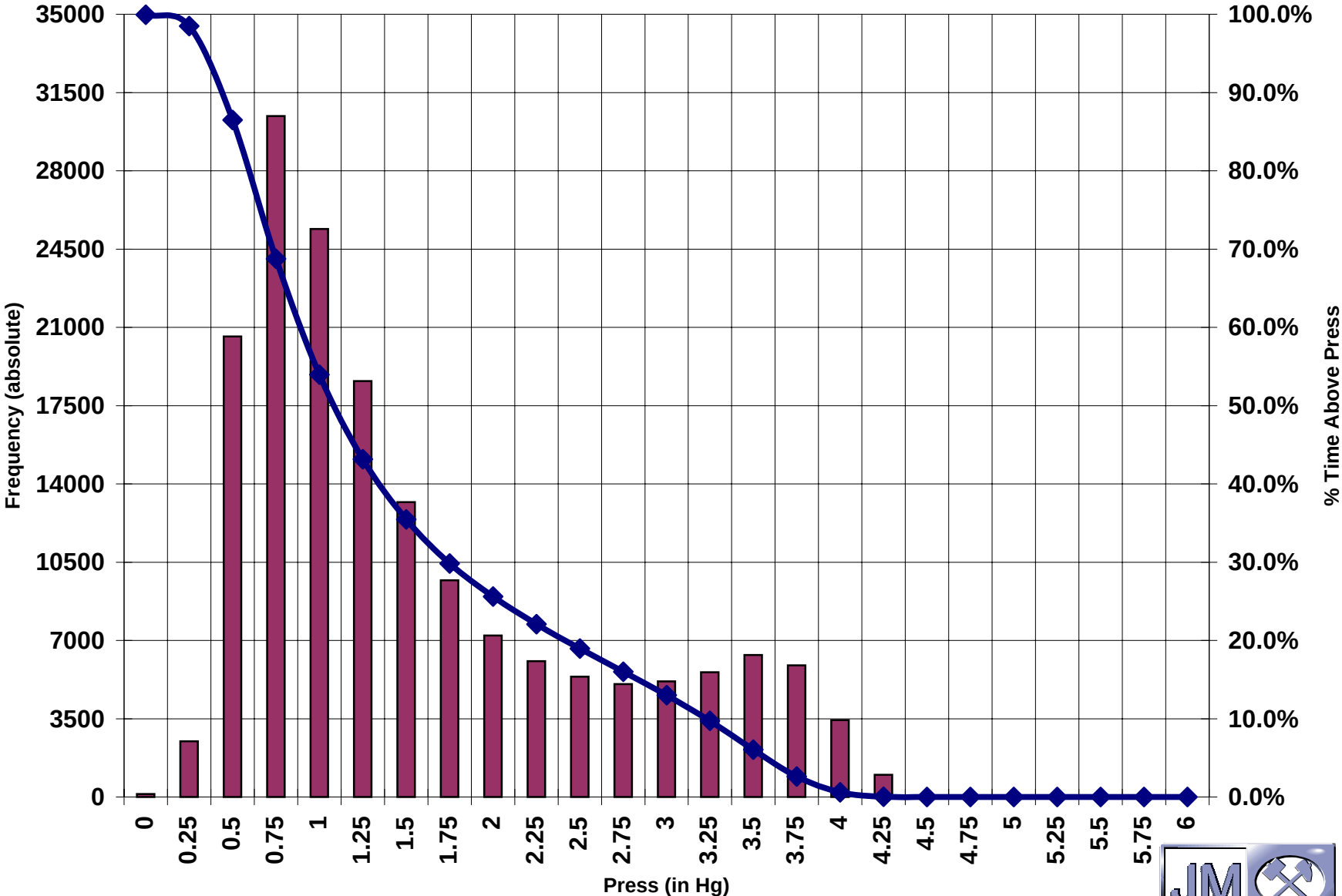
Peak Back pressure with CRT™ on Series 50 Bus; NY Road Test - Bus 6065



Peak Back pressure with CRT on Series 50 Bus; NY Road Test - Bus 6047



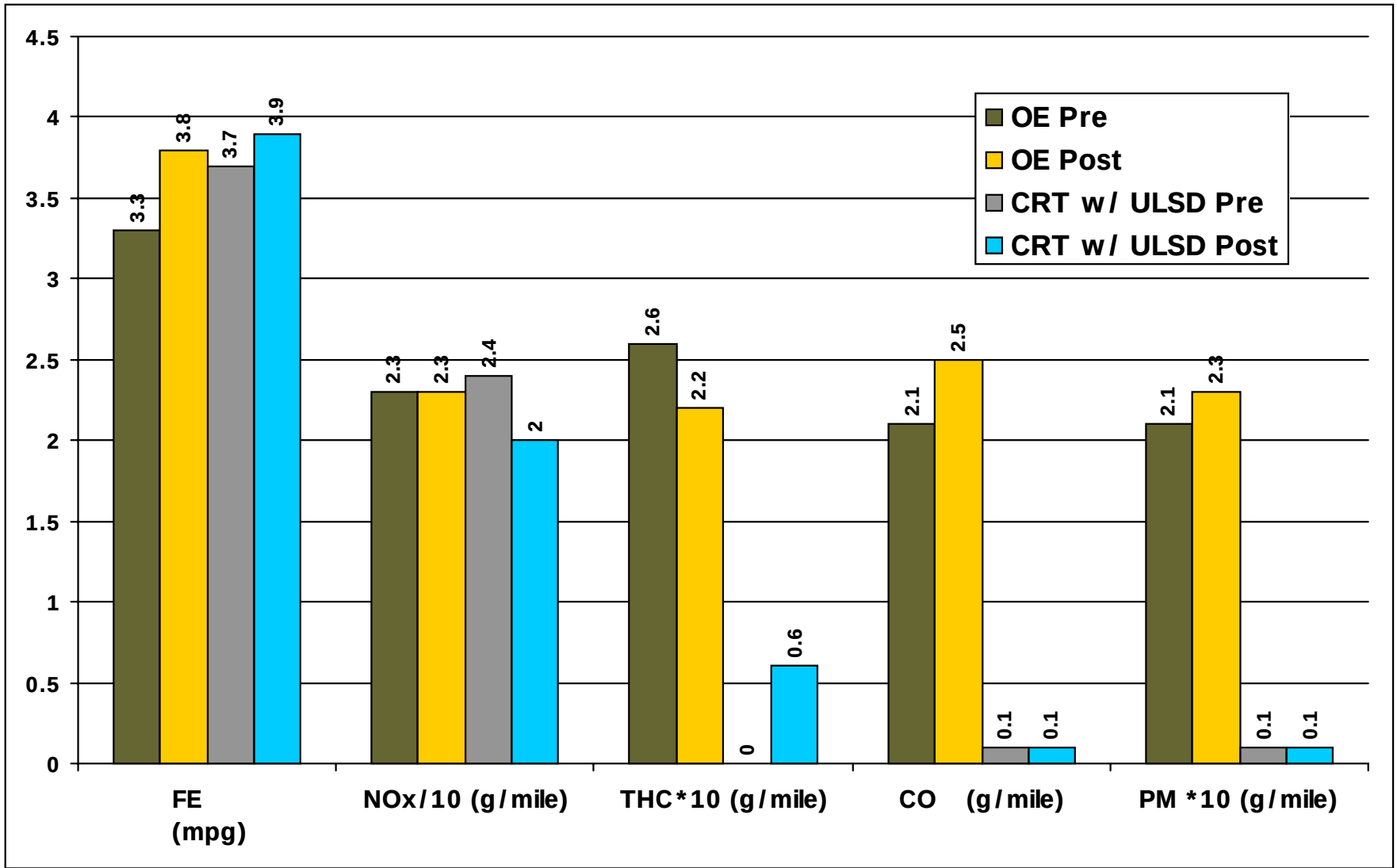
Pressure Histogram on Series 50 Bus with CRT at NYCT



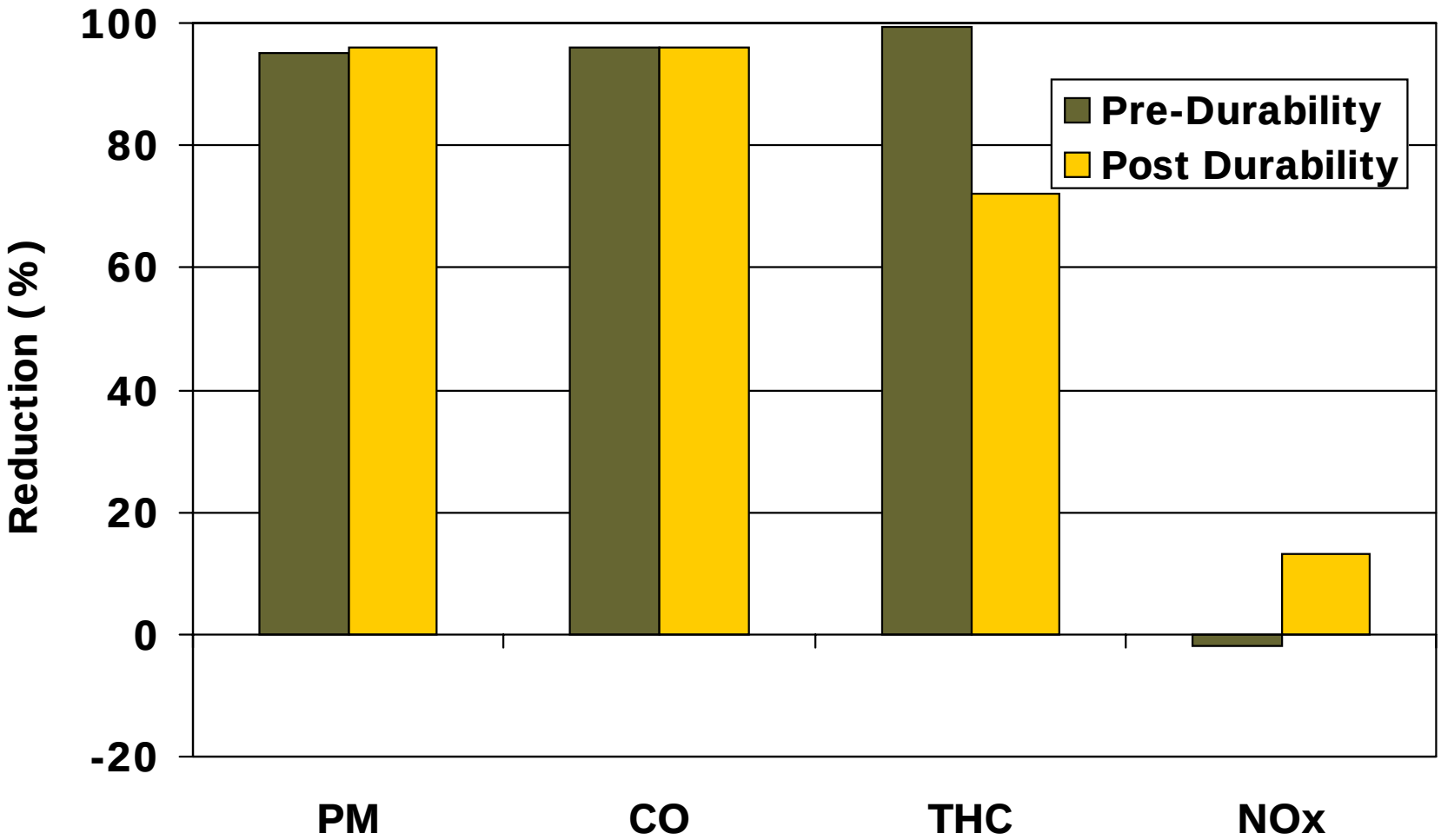
Emissions Testing

- 2 Series 50 buses tested at the beginning of the program
  - Each bus tested with OEM Catalyst/standard fuel (350 ppm S), with OEM Catalyst/ultra low sulfur fuel (30 ppm), and with CRT system/ultra low sulfur fuel (30 ppm)
- Test on chassis dynamometer using CBD and New York bus cycles
- Collect info on criteria pollutants (CO, HC, NOx, PM), plus particle size and toxicity
- Re-test both buses after 9 - 12 months of service with installed CRT filter system
- Comparison of CRT filter Data with recent CNG Test Data

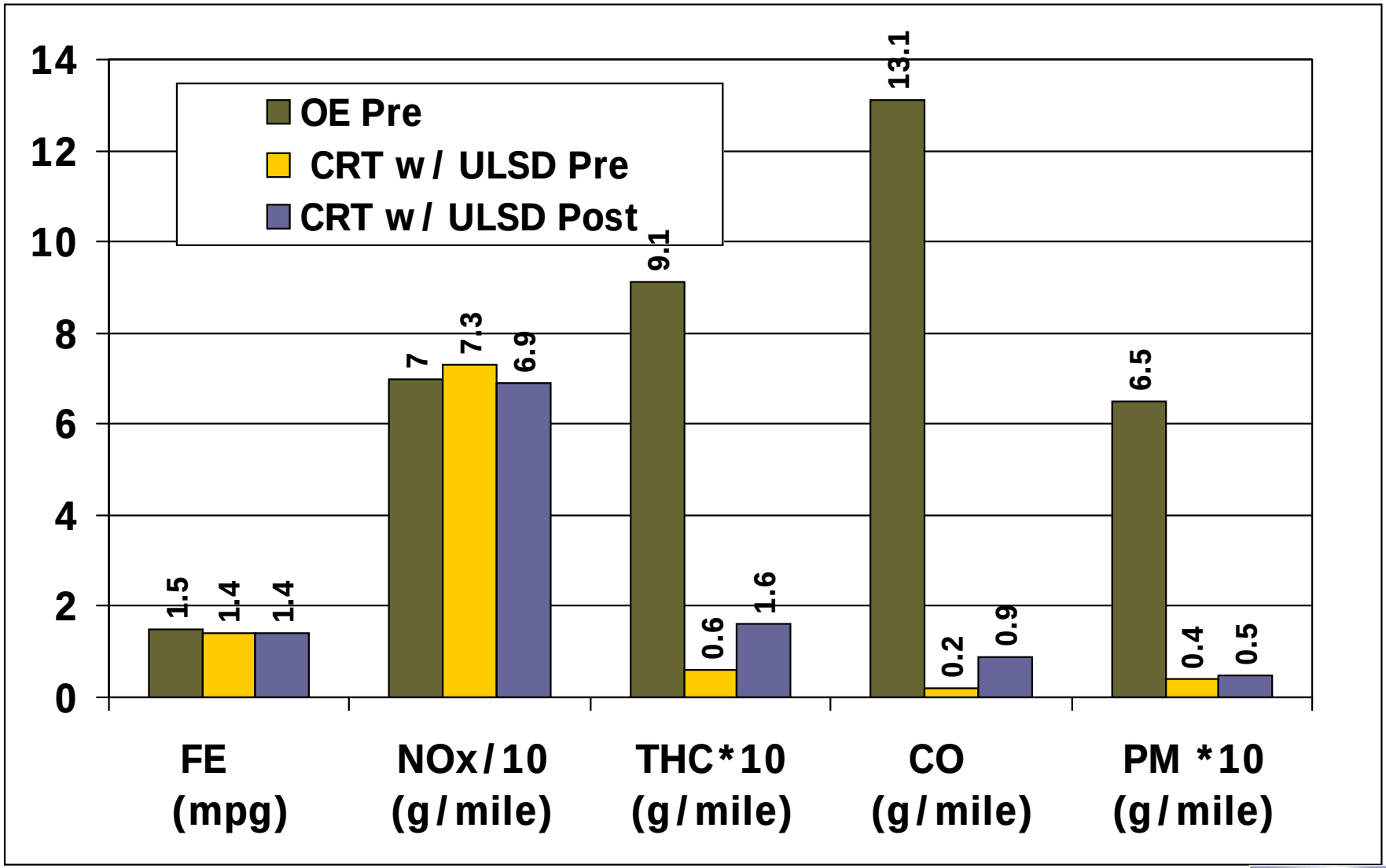
Series 50 Emissions Results of NY Bus 6065 under CBD Cycle



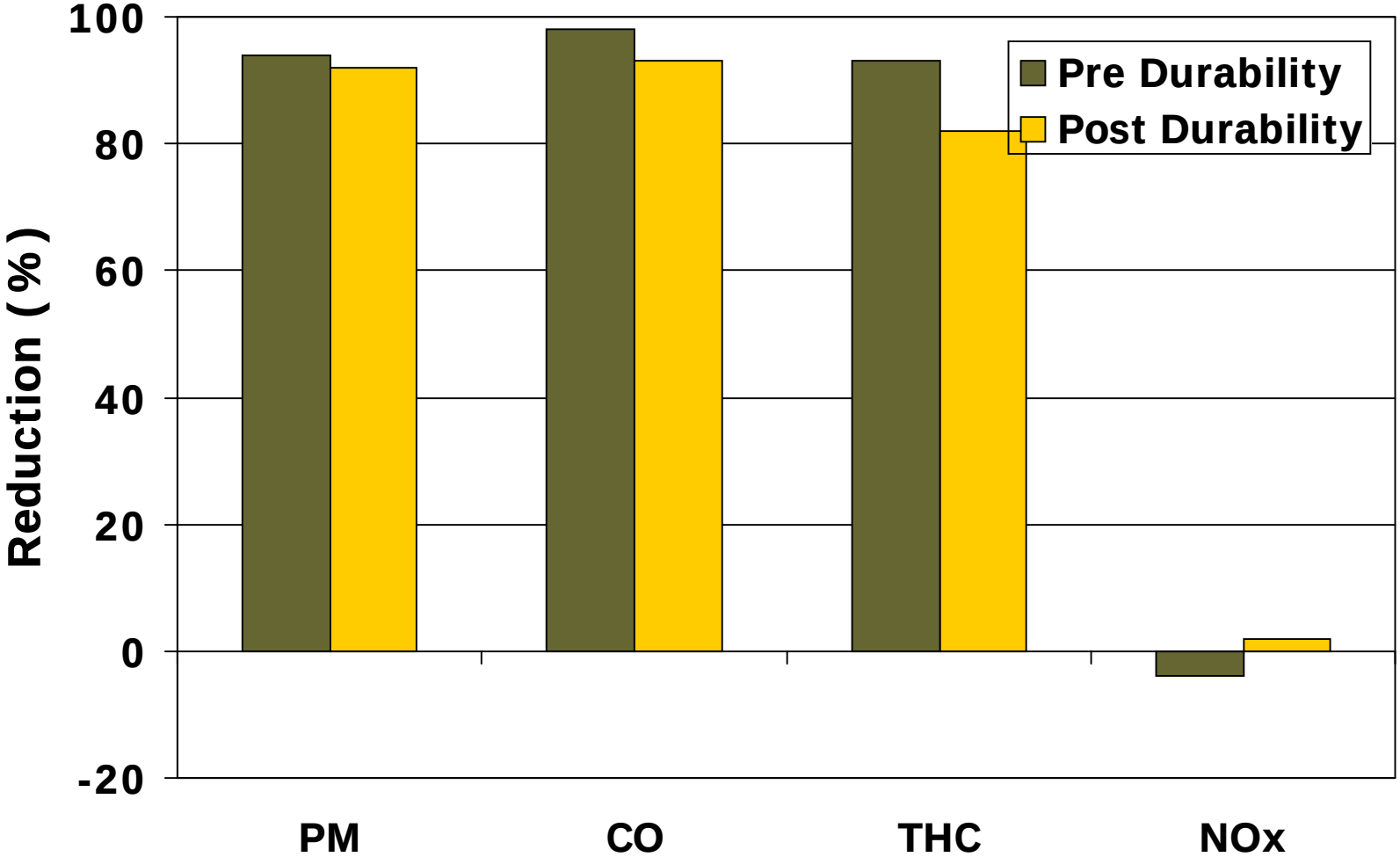
Emission Reductions Comparison for NY Bus 6065 under CBD Cycle



Series 50 Emissions Results of NY Bus 6019 under NYB Cycle



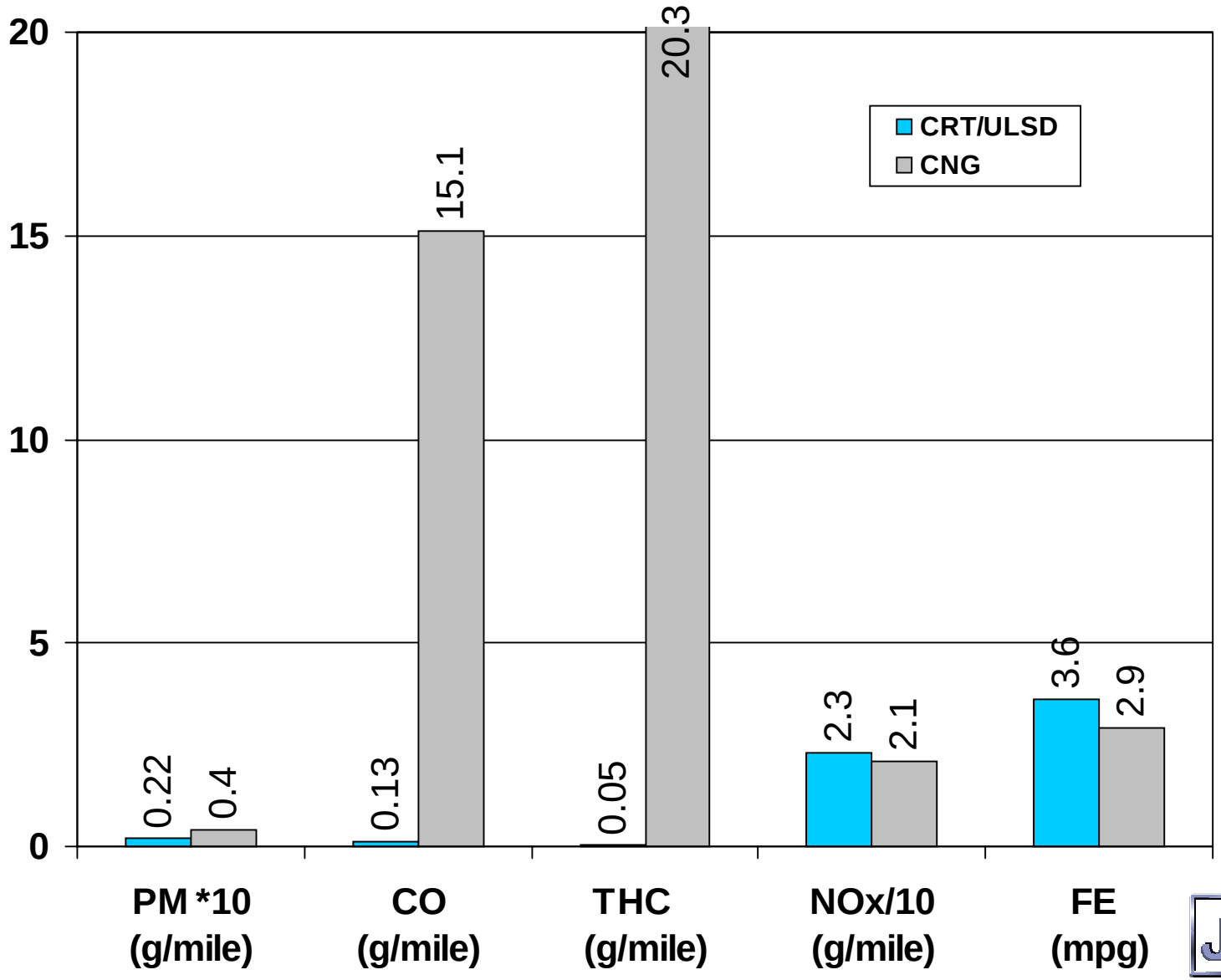
Emission Reductions Comparison for NY Bus 6019 under NYB Cycle



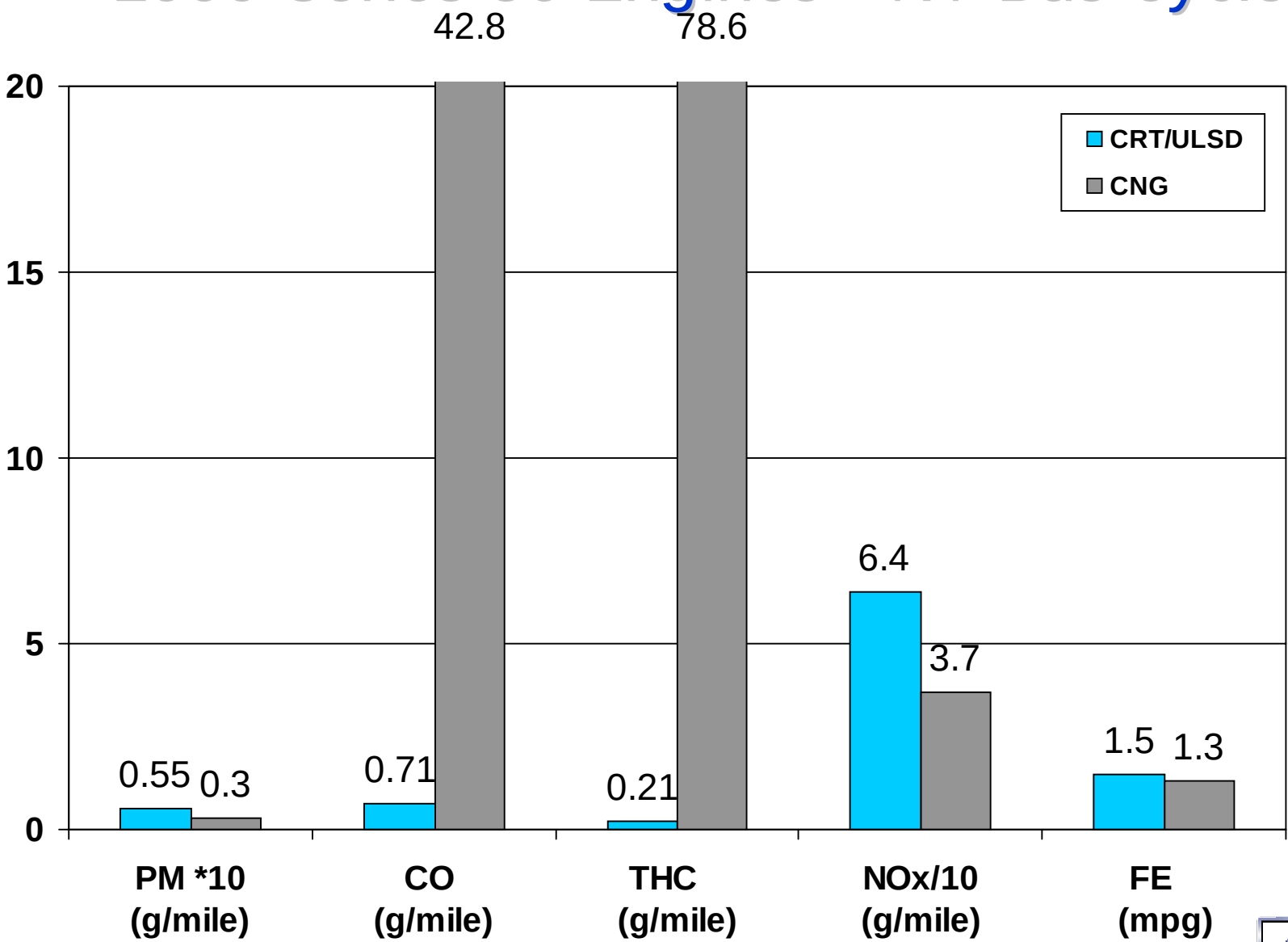
Emissions Comparison Clean Diesel vs. CNG

- Data on CNG emissions (3 buses) gathered from 2 test sites
  - NAVC Test Program (WVU)
  - NYCT Testing (Environment Canada)
- All CNG buses tested were equipped with OE Muffler
- All engines 1999 Series 50 - 275 hp
- CRT regulated emissions data collected after 9 - 12 months of durability testing on 2 buses
- CNG test data showed large variability in some emission components
- In addition to regulated emissions, data is included on unregulated emissions. This includes Carbonyls, PAH and VOC speciation. Many of these compounds such as Formaldehyde, Acetaldehyde, Acrolein and Propionaldehyde are considered very toxic and are listed in EPA's Hazardous Air Pollutants (Title II HAP) list.

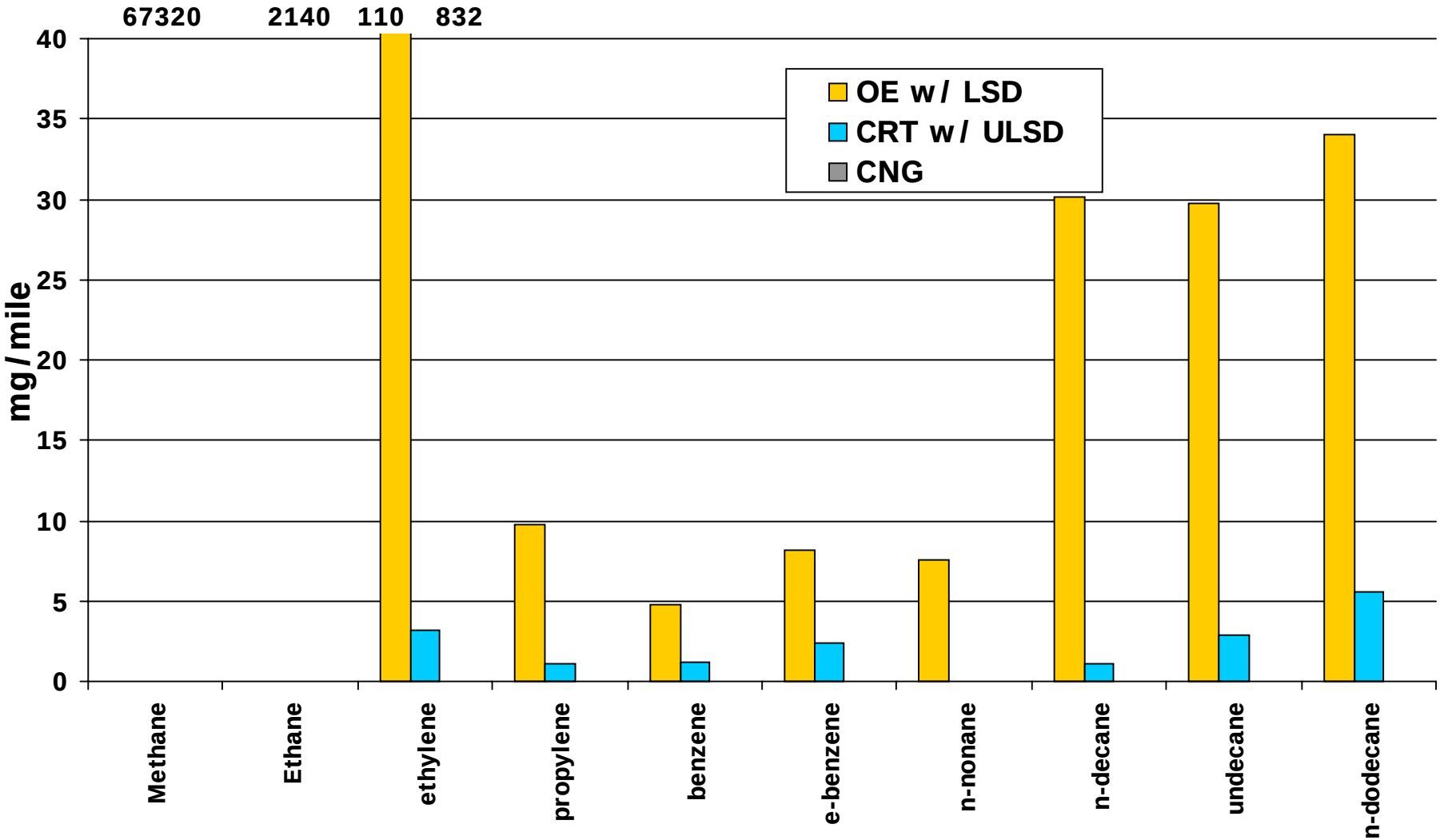
Average Emissions Test Results - CRT vs. CNG
1999 Series 50 Engines - CBD Cycle



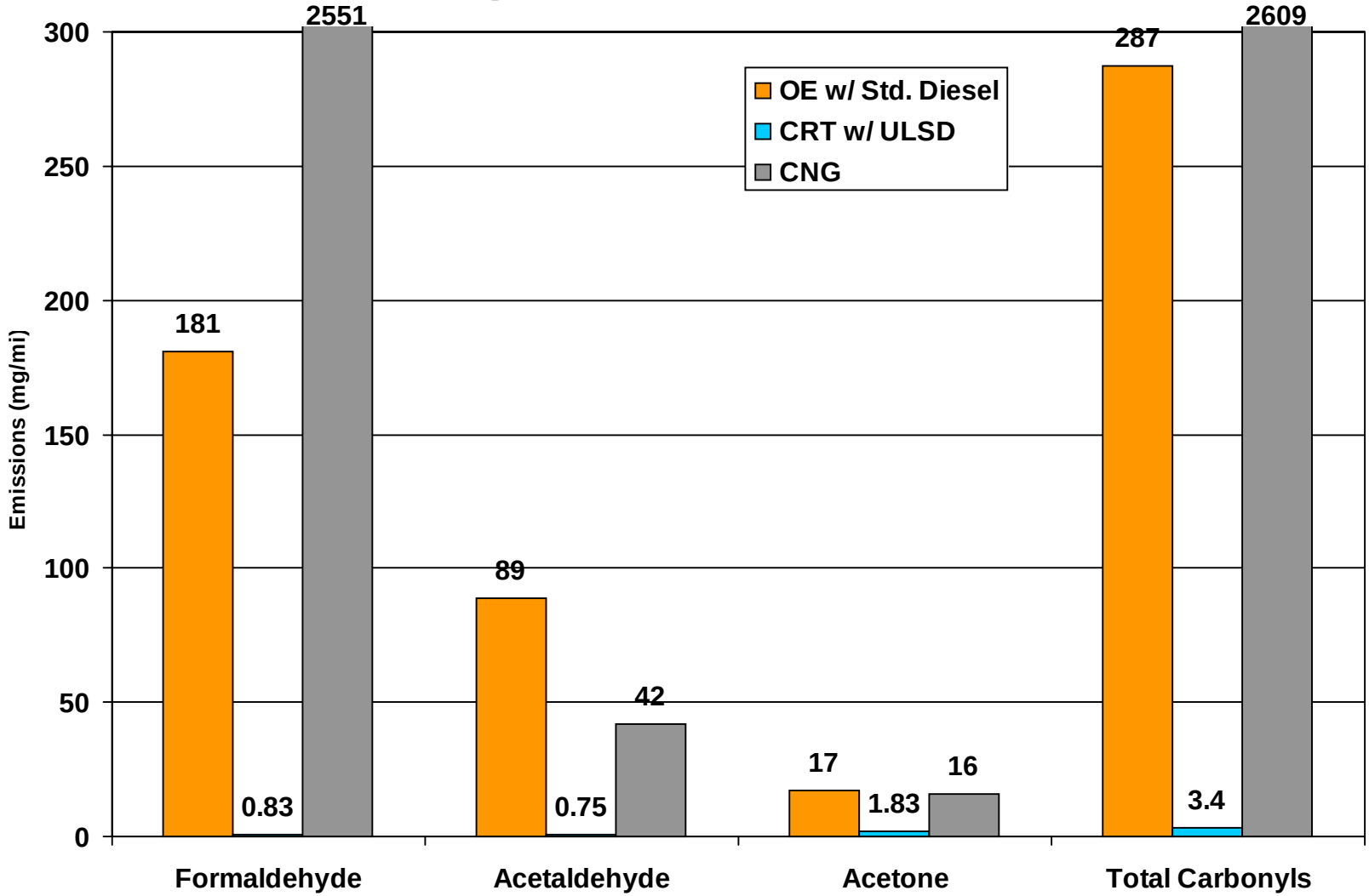
Average Emissions Test Results - CRT vs. CNG
1999 Series 50 Engines - NY Bus Cycle



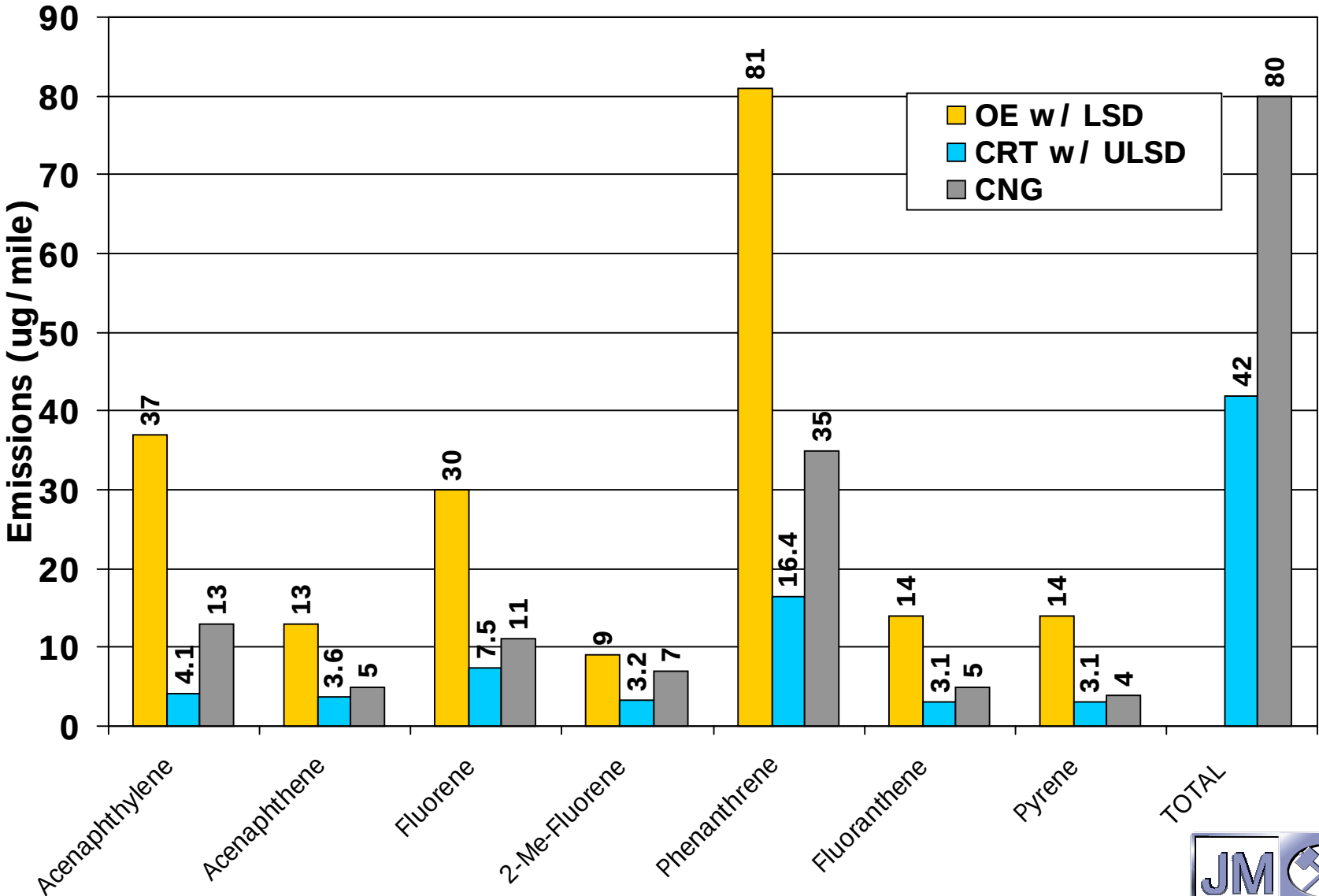
VOC Analysis Ser 50 Bus - NYB Cycle



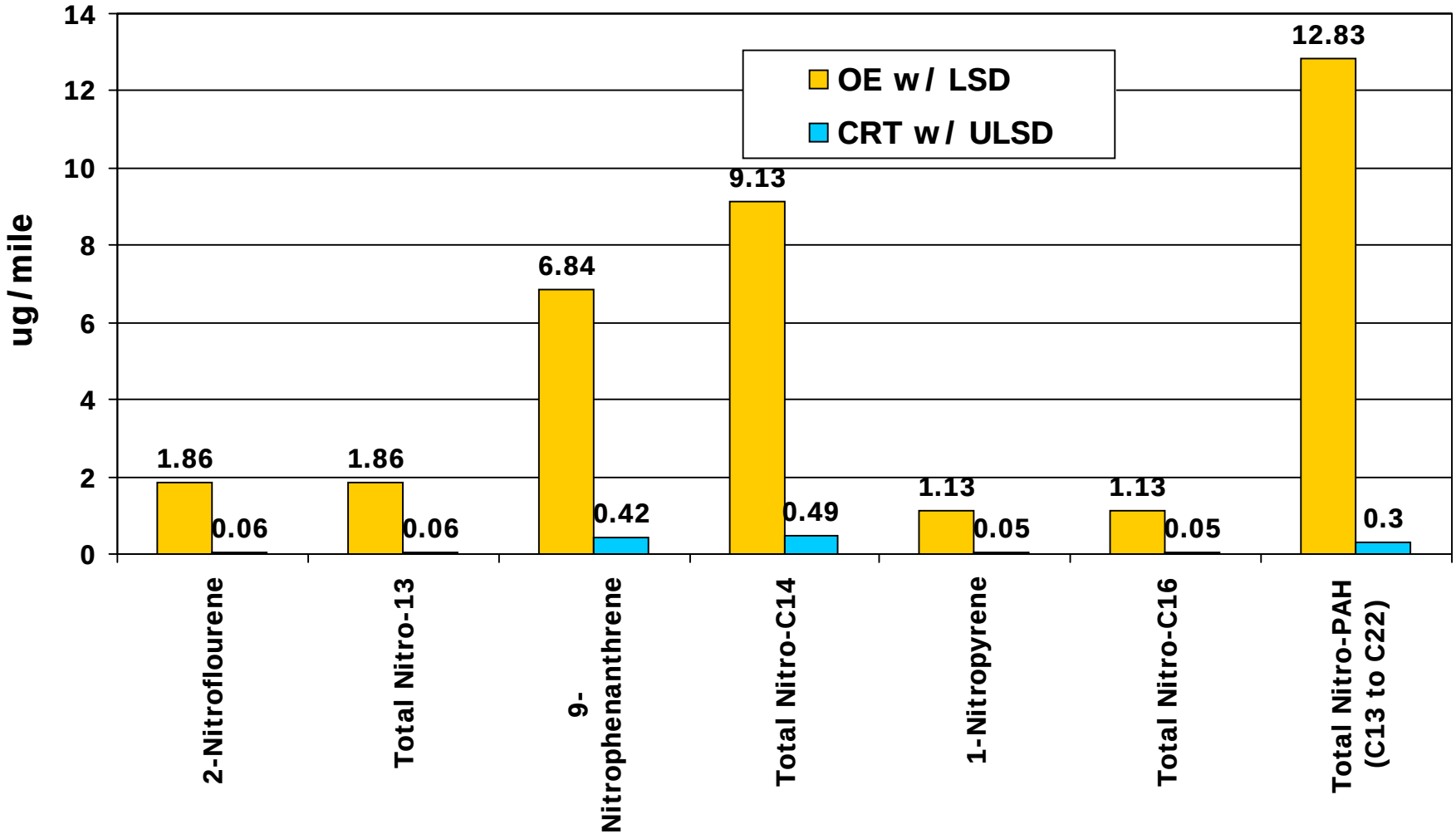
Carbonyl Destruction with CRT on Ser 50 under NY Bus Cycle



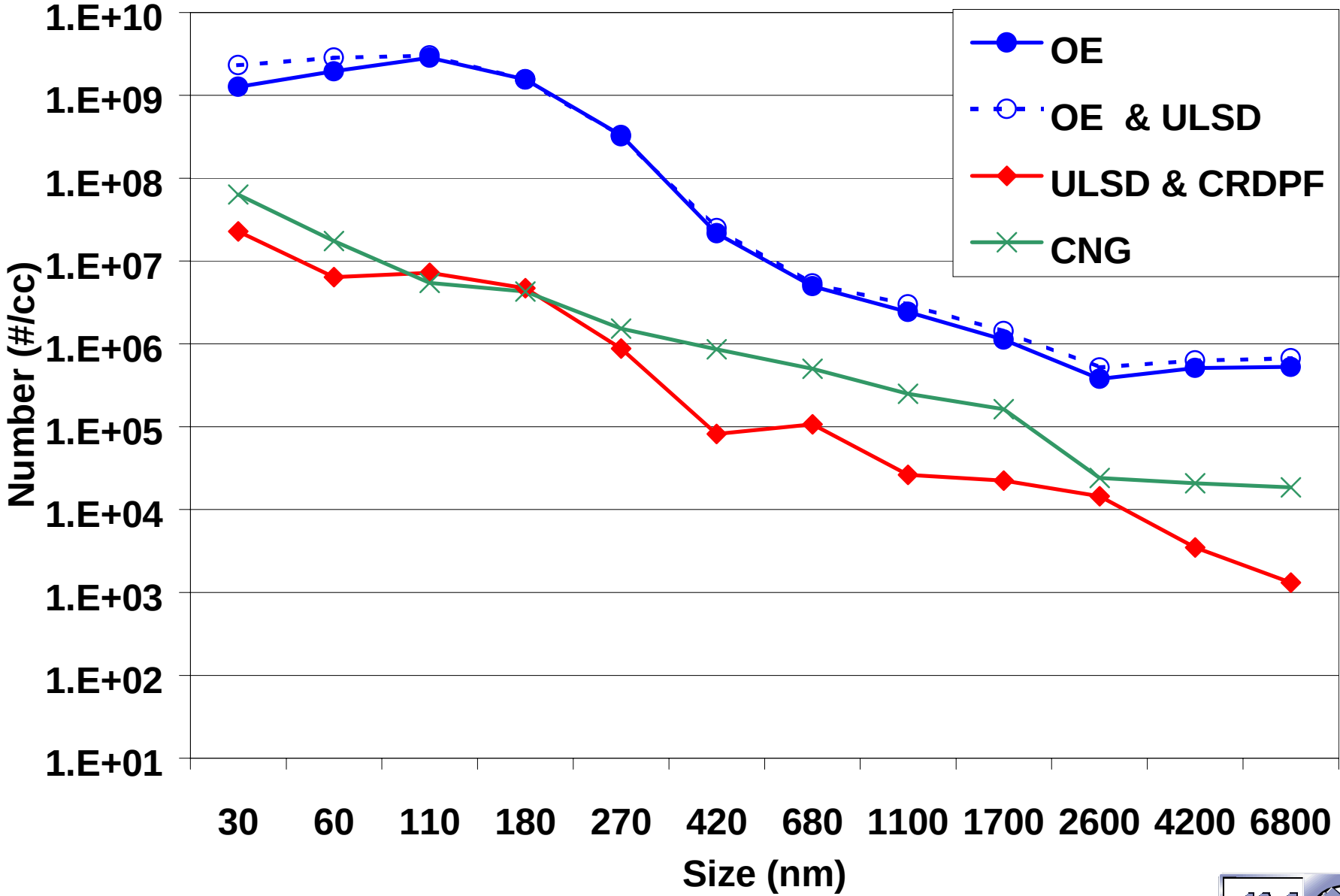
PAH Emissions Ser 50 Bus - NYB Cycle



Nitro-PAH Results Bus 6019 NYB Cycle



Particle Sizing Measurement of Ser 50 under CBD Cycle



Average Emissions Summary for CRT Equipped Series 50 Engine Bus

- Greater than 90% reductions in PM & CO after 9-12 months operation
- Greater than 75% reductions in THC after 9-12 months operation
- Greater that 99% reduction in Carbonyls
- Up to 80% Reduction in PAH
- Greater than 90% reduction of Nitro-PAH
- Greater than 99% Reduction in Particle counts in all size ranges

CRT Retrofitted Diesel compared to CNG

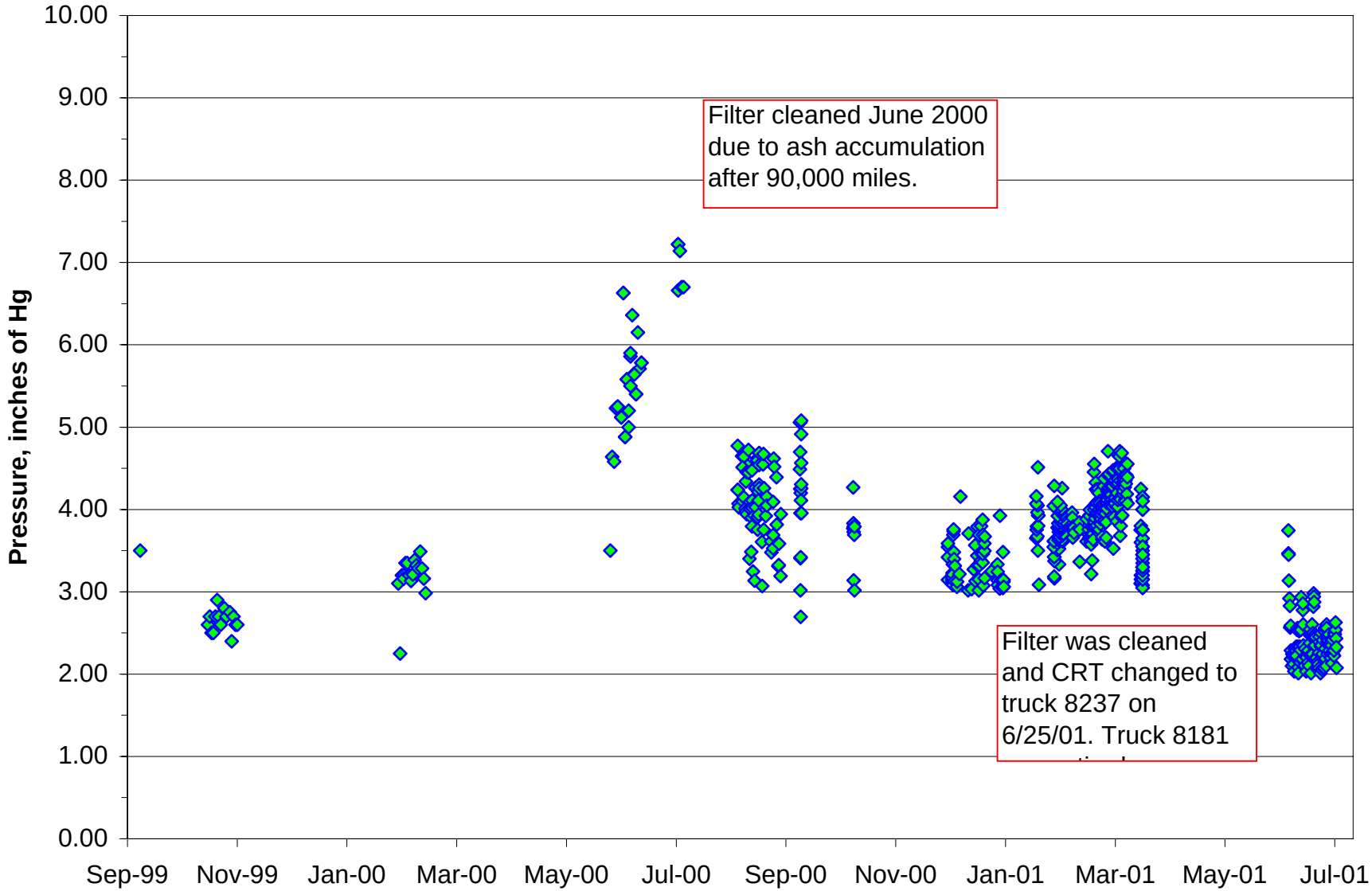
- PM emissions from CRT-equipped buses appear to be equivalent to those from CNG buses
  - Much wider range of values with CNG, especially on NY Bus cycle
- CO and HC emissions from CRT-equipped buses are much lower than those from CNG buses.
- NOx emissions are generally lower from CNG buses than from CRT-equipped buses, but show a wider range of variability
- Carbonyl emissions from CNG buses are much higher than from CRT-equipped buses. PAH emissions also higher.
- Improved particle sizing reduction with CRT over CNG
- Fuel economy is generally better with diesel than CNG on an equivalent basis

CRT™ Retrofit Demonstration Programs in California

- **ARCO EC Diesel Evaluation Program**
  - 7 different fleets with school bus, fuel truck, trash truck, grocery truck
- **LA MTA Transit Bus Retrofit**
  - Ser 50 non-EGR and 6V92 engine buses
- **SCAQMD School Bus Retrofit**
  - Cat 3115, NAV D 466, Cummins ISC & DDC 6V92 engines
- **Burrtec Trash Truck Retrofit**
  - CAT, Cummins and Volvo engines
- **Construction Equipment Retrofit - CIAQC**
  - CAT 3408 & 3412 engines in large earth moving vehicles, scraper
- **Locomotive Retrofit**
  - 3000 hp old GE engine used for power generation
- **Waste Management Trash Truck Retrofit**
  - Cummins L-10 and M11 engines

CRT on ARCO Fuel Truck - Cummins M11

On-Road Peak Back Pressure with CRT on ARCO Truck - Cummins M11; >200,000 miles with CRT



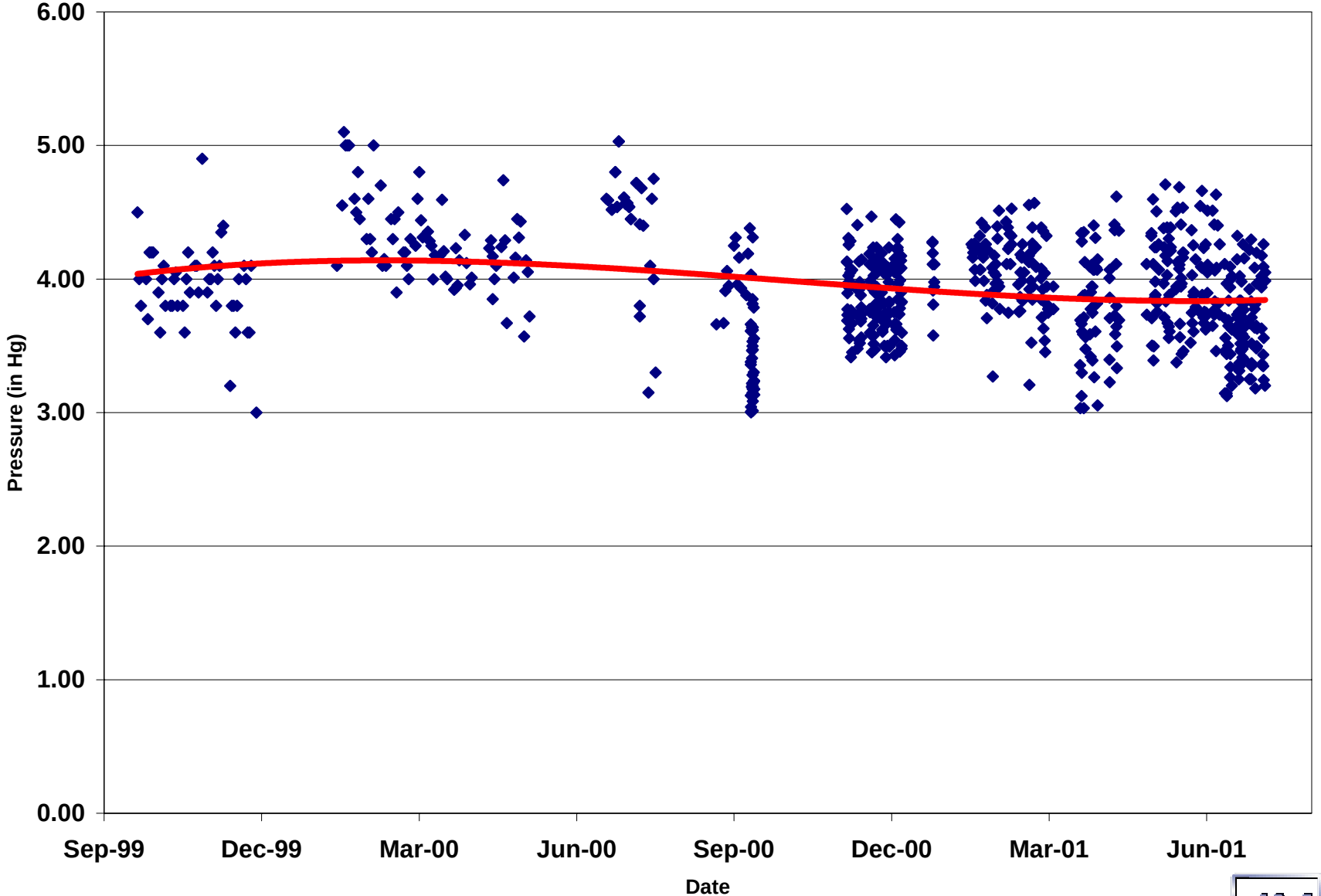
Ash Deposit in CRT Filter

Analysis of Ash Collected on CRT

	Mg	P	S	Ca	Zn
XRF Analysis (wt%)	3.5	7.4	14.3	15.6	14.3
XRD Analysis	CaSO4 Crystalline Phase				
TGA Analysis	6% wt loss in ramping up to 600 C				

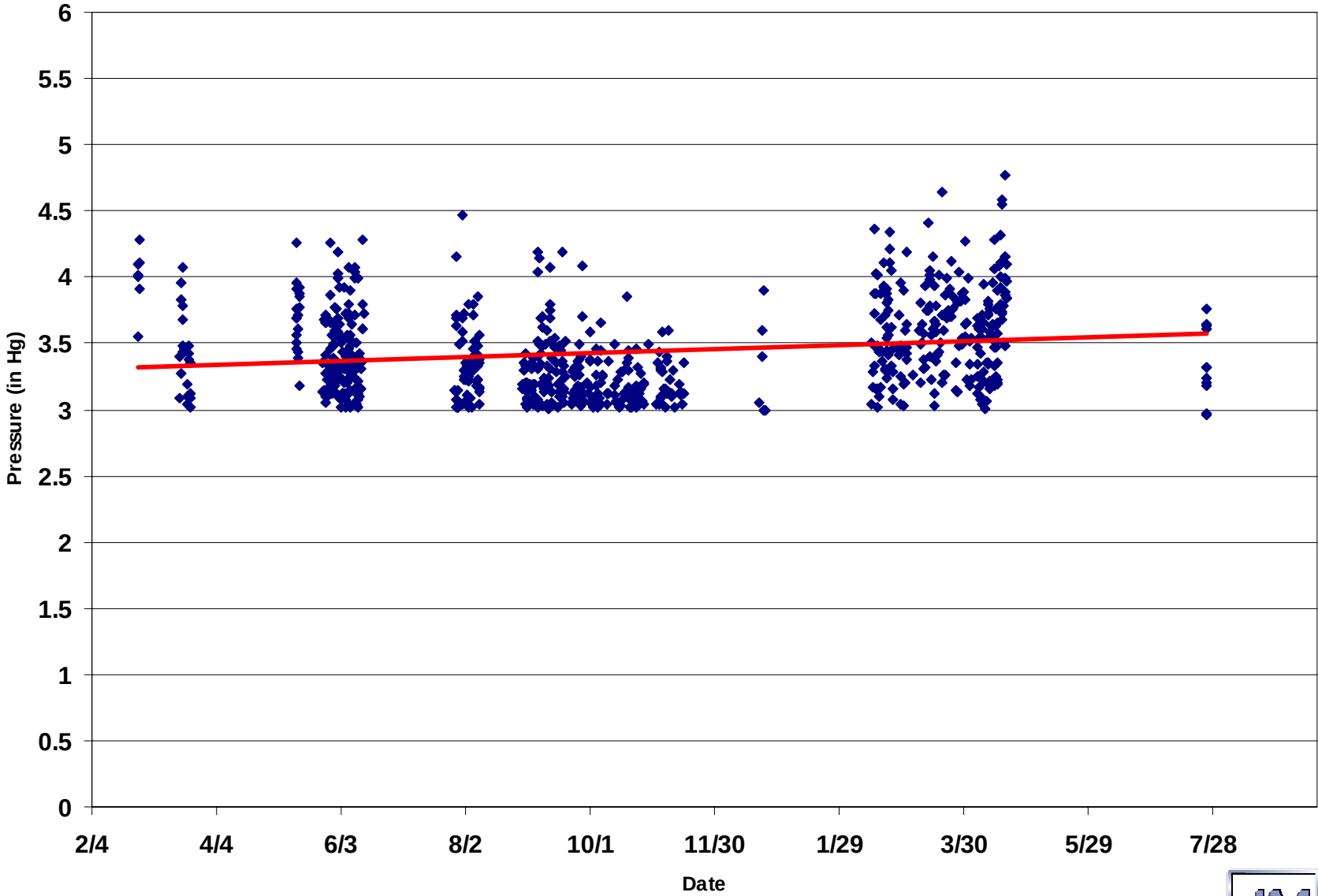
CRT on San Diego School Bus - Navistar 530 E

Peak Back Pressure with CRT on San Diego School Bus



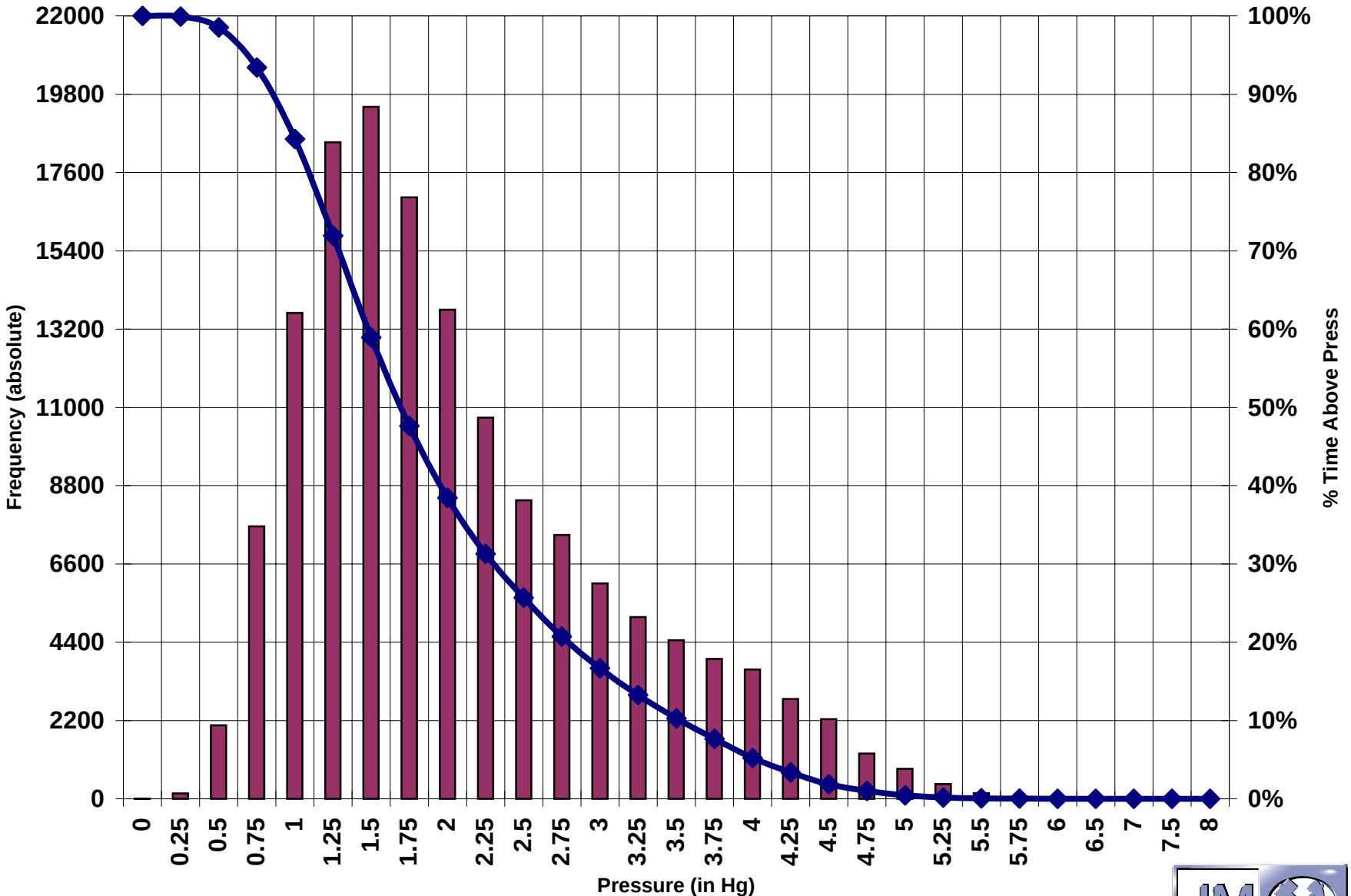
CRT on Ralphs Grocery Truck - Ser. 60

Peak Back Pressure with CRT™ on Ralphs Truck - 430 Hp DDC Ser 60 > 150,000 miles with CRT



LA Unified School Bus with Cat 3116

Pressure Histogram of Cat 3116 with CRT in LA School Bus



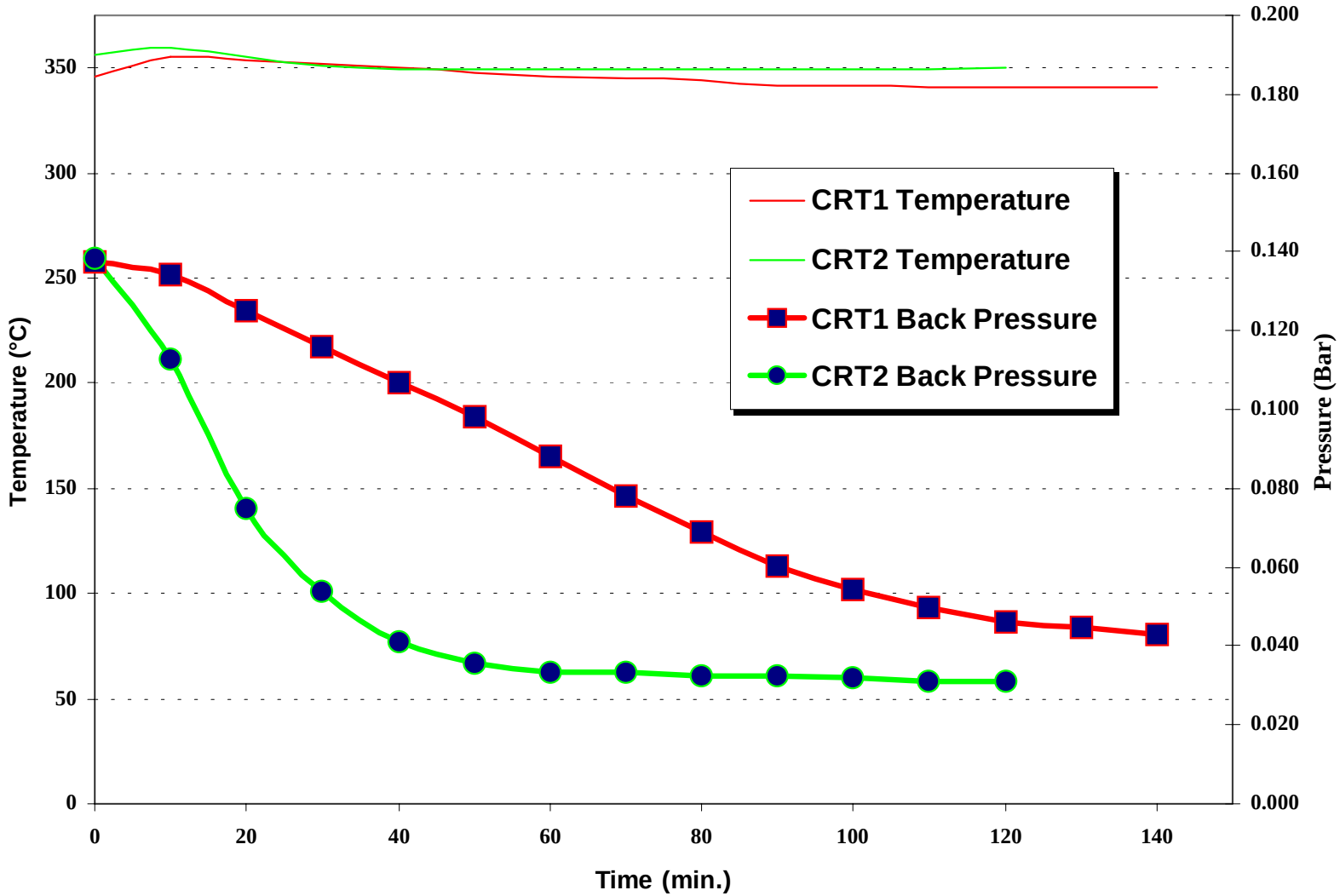
Future Development & Applications

- Improved CRT system
- NOx & particulate control

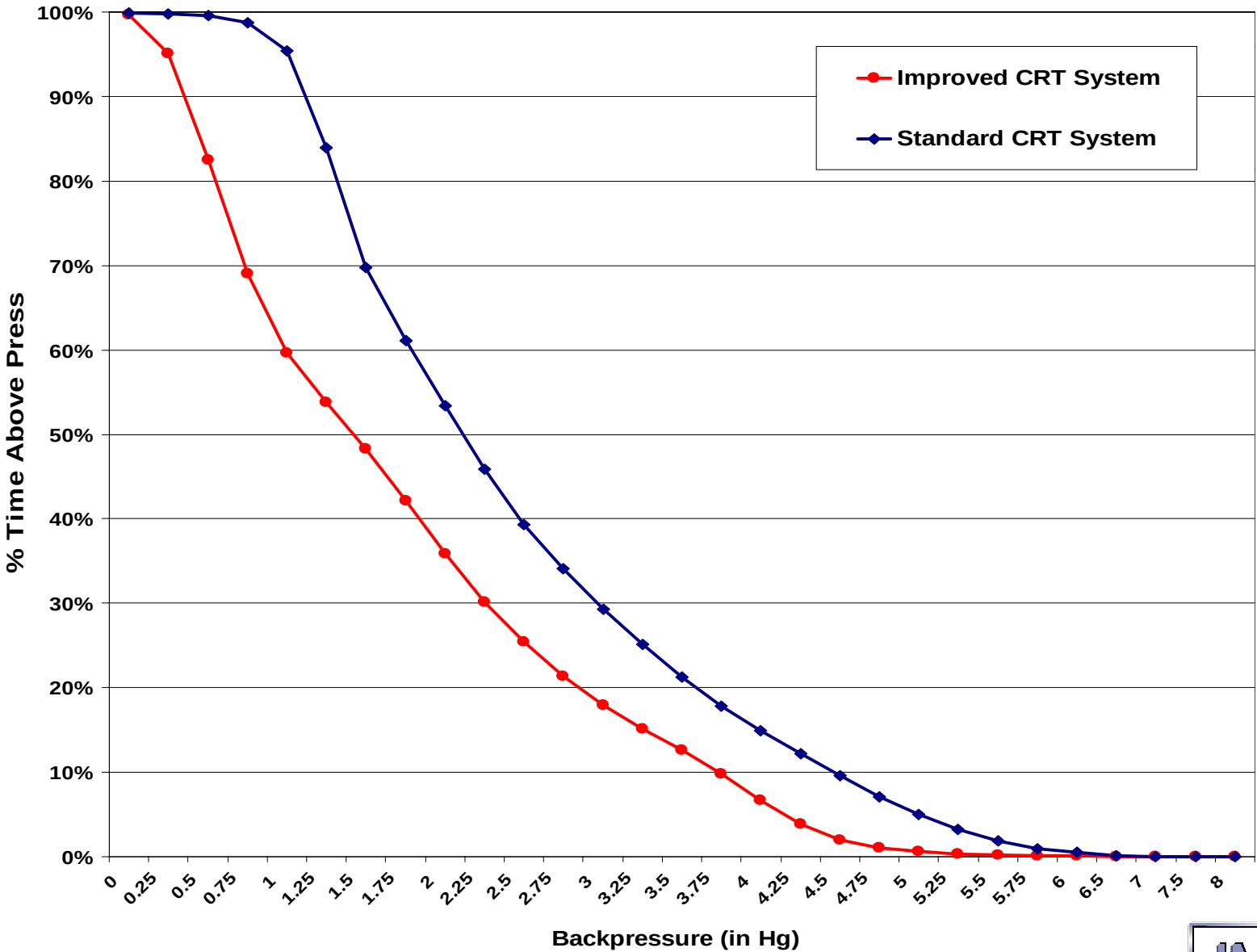
Improved CRT System

- Improved soot combustion
- Lower operating temperature
- Reduced back pressure

Regeneration Performance of Different CRT Systems at 350ºC



Back Pressure with Different CRT systems on DDC 6V92



Particulate & NOx Control

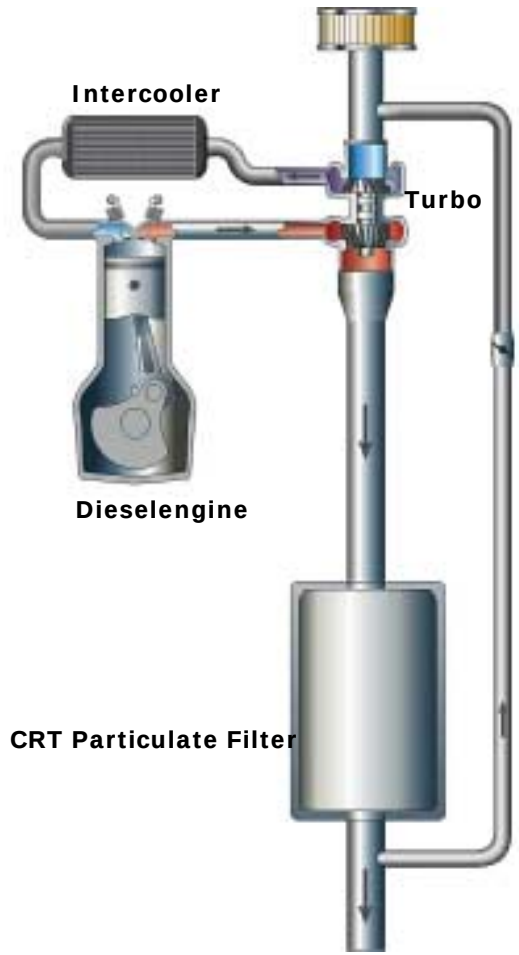
NOx/PM Control

- EGR with CRT
  - NOx reduction by EGR - up to 50%
  - PM reduction by CRT filter - up to 90%
- SCRT System
  - NOx reduction by SCR - up to 90%
  - PM reduction by CRT filter - up to 90%
- Lean NOx with CRT
  - NOx reduction by HC injection - up to 40 %
  - PM reduction by CRT filter - up to 90%

NOx Control by EGR

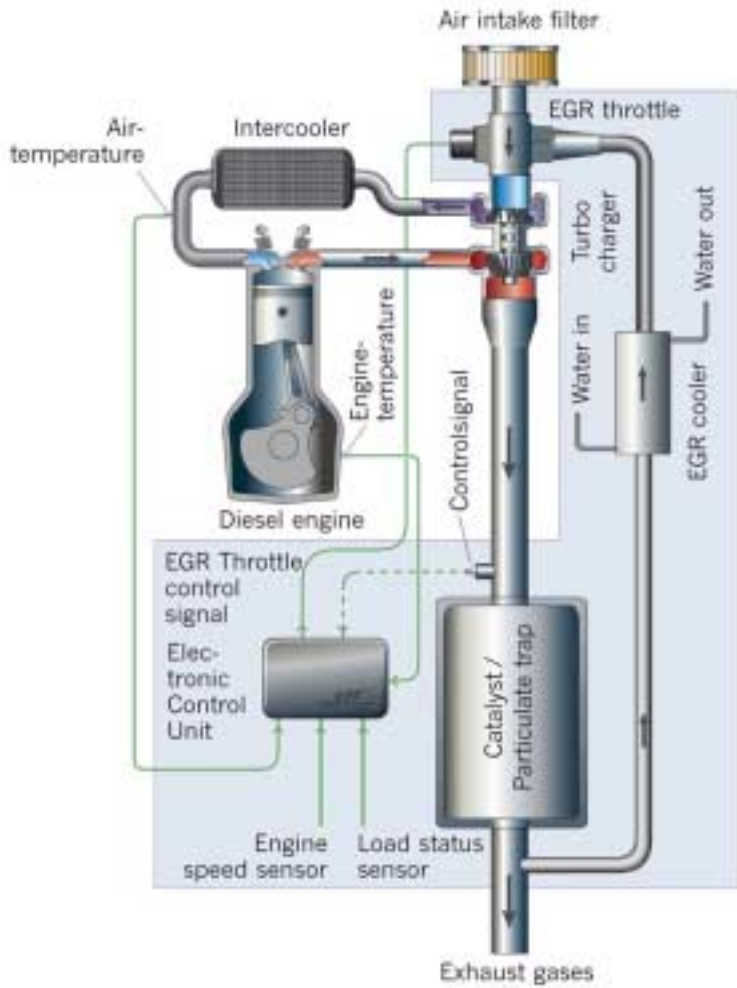
Low pressure EGR system

- Good controlability during transient conditions
- Suitable for retrofit
- Low cooling capacity
- Limited contamination of engine



EGR + CRT system

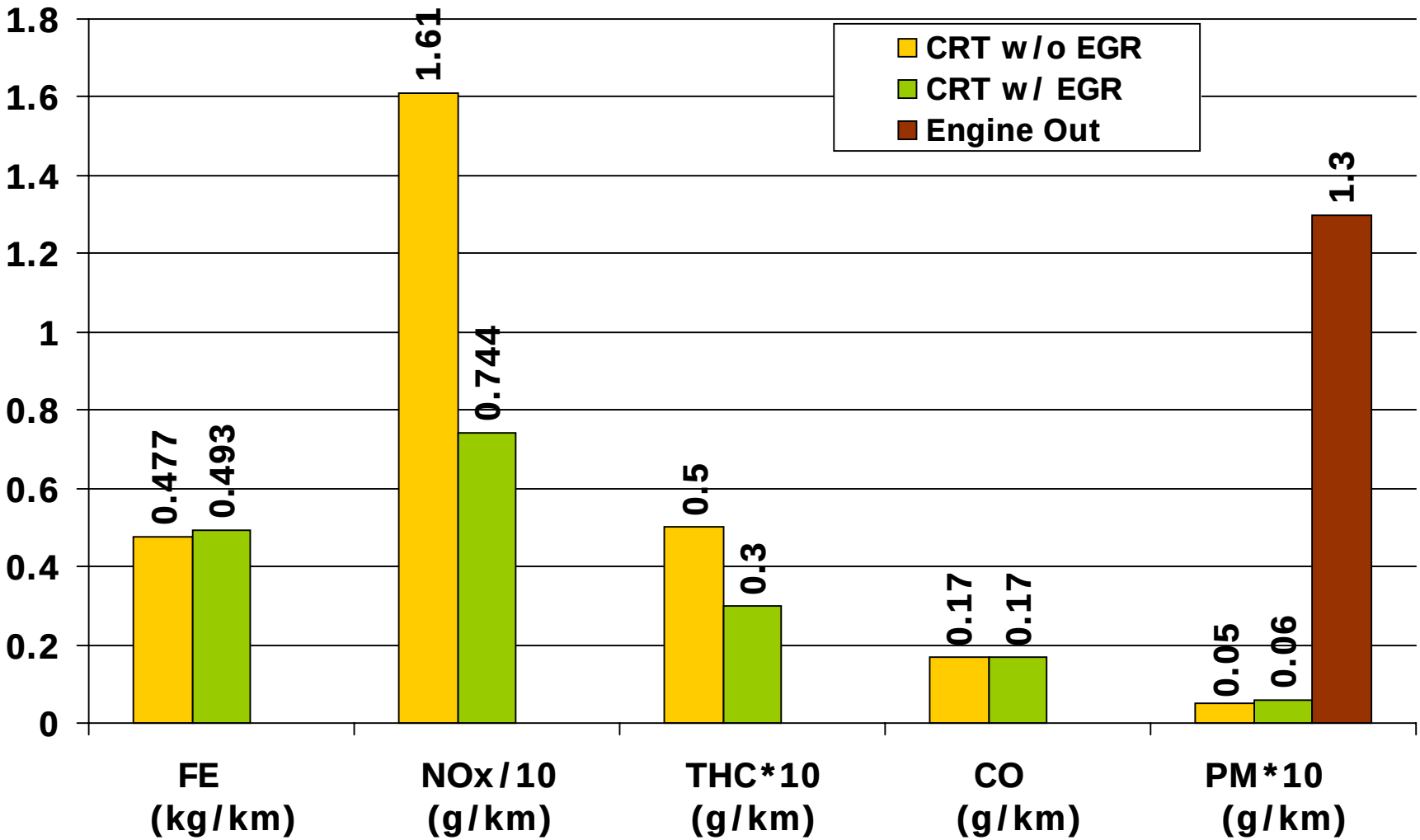
- **Low pressure EGR-system with CRT particulate filter**
- **Used for OEM and aftermarket installations**
- **For trucks, buses, and off-road machinery**
- **Reduction of legislated emissions**
  CO > 90 %
  HC > 90 %
  PM > 90 %
  NO_x > 40 %



EGR + CRT System Application

Emissions Results for EGR/CRT System

Volvo B10BLE Engine bus, Braunschweig Cycle on Chassis Dyno



Benefits of Johnson Matthey Emission Control as Clean Diesel Retrofit

- Meets current and future regulations, thereby allowing operators to use diesel engines and retain all its benefits
- Commercially available CRT filter reduces PM, THC and CO to levels equivalent or lower than alternative fuel vehicles
- CRT system provides substantial reduction in unregulated emissions including VOC, Carbonyl, PAH & NPAH
- CRT is approved for the EPA Voluntary Retrofit program & obtained California EO
- CARB reviewing Verification, expected in a month
- Retrofit NOx control achievable through low pressure EGR system

Acknowledgement:

- NY City Transit, NY DEC, Corning Inc., Equilon, Environment Canada & Rad Energy
- BP/ARCO, NREL, Ralphs Grocery, LA MTA, LA City Sanitation, San Diego Schools, WV University
- CARB, SCAQMD, LA Unified Schools, Hemet Schools

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