Johnson Matthey
Catalysts

NOx and PM Emissions Control on Heavy-duty Diesel Engines Using SCRT System

SCAQMD Off-road Emission reduction Technology Forum and Roundtable Discussion

May 1, 2007

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Johnson Matthey Catalysts

Emission Control Technologies

EMISSION CONTROL TECHNOLOGIES

Outline

- Introduction
- System Description
- Development Results
- Field Demonstrations
- Conclusions

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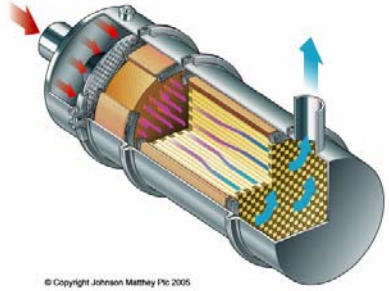
Johnson Matthey Catalyst
Areas of Expertise

- Catalyst technology: world-class facilities for research, development, analysis, modelling and testing of catalysts
- Manufacturing technology: 30 years of experience of supply to automotive OEM standards; 10 plants, all TS16949 certified.
- Systems technology: work to develop new aftertreatment systems, made available for integration into new engines and retrofitting.
- Applications expertise: have been applying retrofit aftertreatment in on-road and non-road for 15 years.



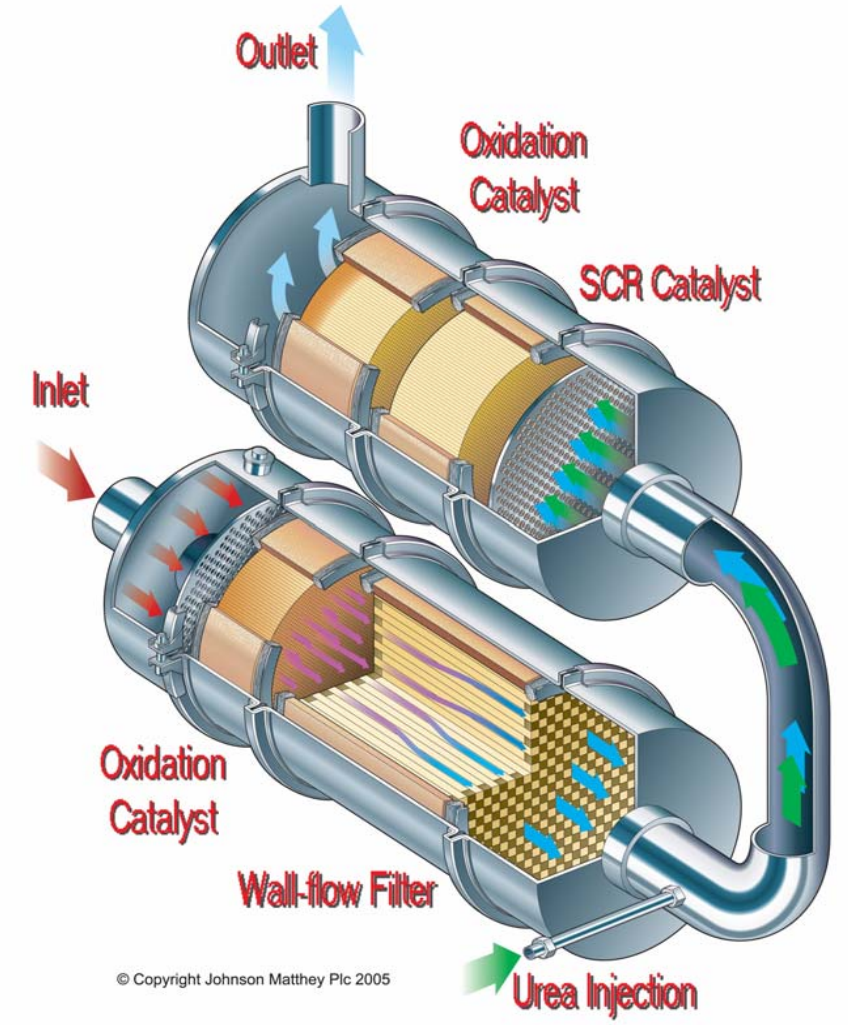
Introduction - SCRT® System
Combined NOx and PM Control

- **SCRT® = SCR + CRT®**
  - SCR= Selective Catalytic Reduction of NOx with urea
  - DPF= Johnson Matthey CRT® Diesel Particulate Filter

- Objective

Develop a retrofit SCR + DPF system for Heavy Duty Diesel applications that reduces PM, HC and CO emissions by > 90% and NOx emissions by 60 to 80%

- Use ULSD fuel



Selective Catalytic Reduction (SCR)

- Use ammonia (NH_3) to reduce NOx to N_2 under oxidizing conditions

$$4\ NO + 4\ NH_3 + O_2 \longrightarrow 4\ N_2 + 6\ H_2O$$

$$6\ NO_2 + 8\ NH_3 \longrightarrow 7\ N_2 + 12\ H_2O$$

- Ammonia can be derived from a number of sources (e.g. urea, ammonium carbamate, liquid ammonia etc)

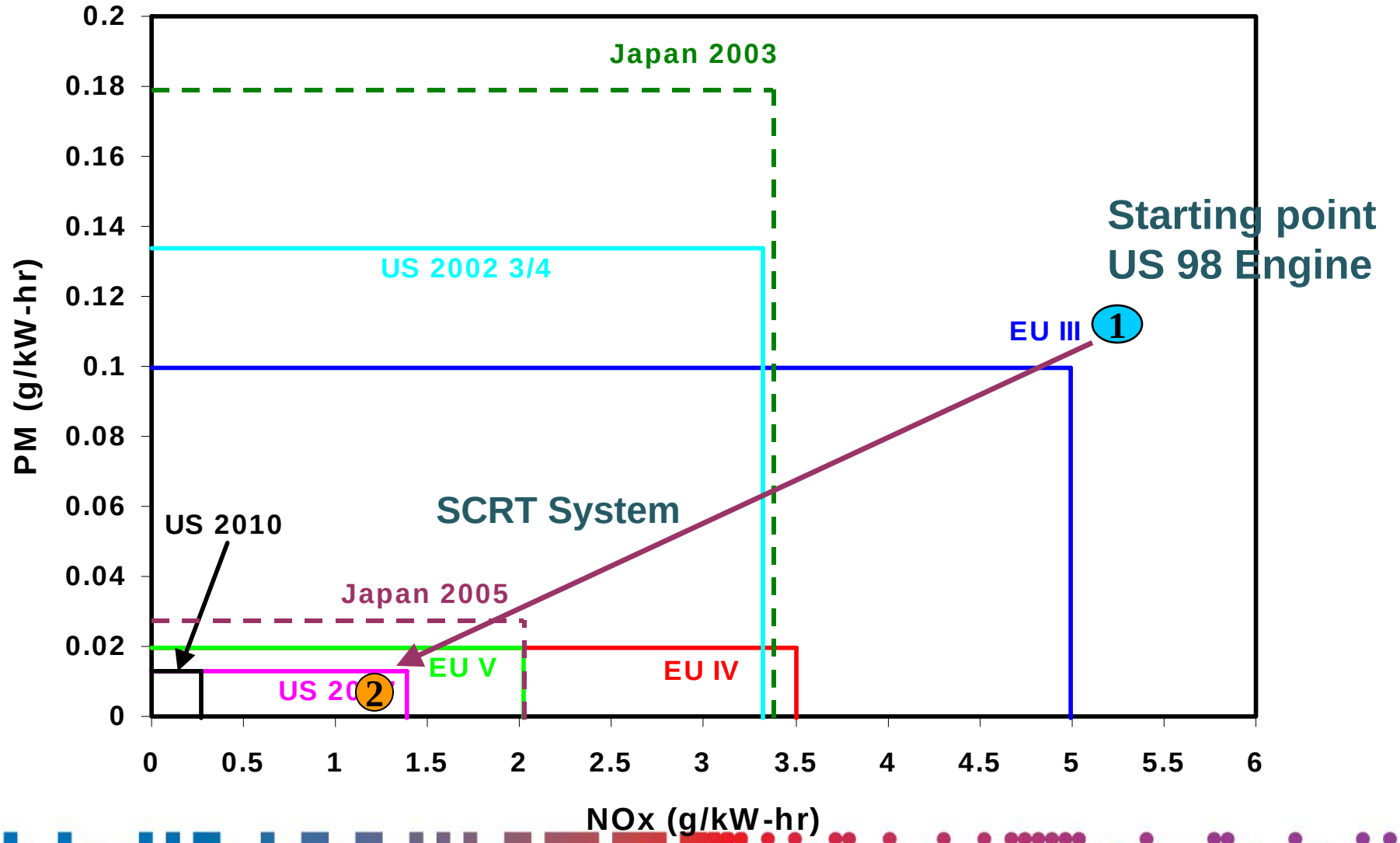
- NO_2 promotes SCR activity:

$$2NH_3 + NO + NO_2 \rightarrow 2N_2 + 3H_2O$$ VERY FAST REACTION

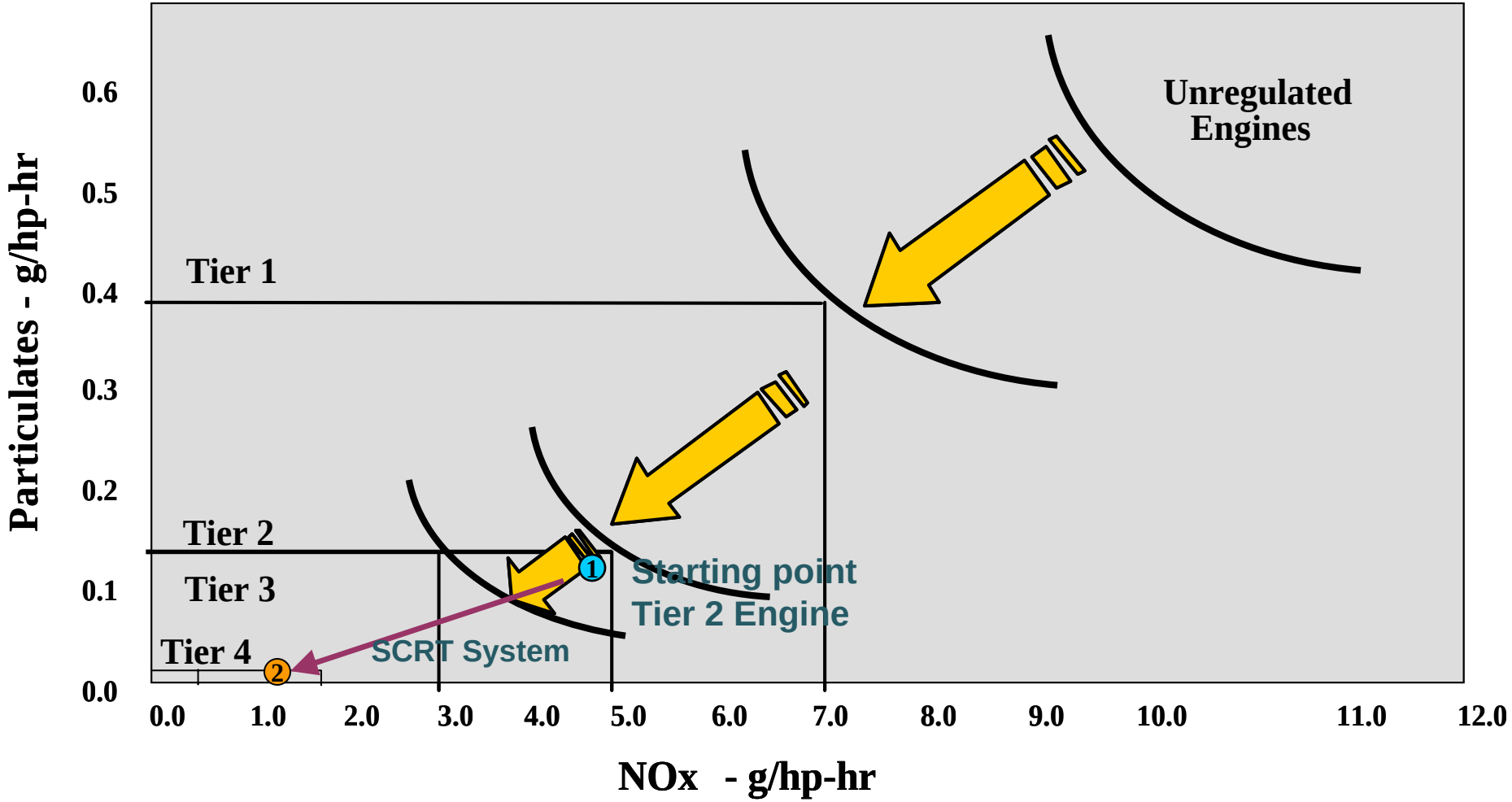
- Proven in stationary source applications for 30 yrs

- Has been introduced for Euro IV and Japan 05 vehicles

Capability of SCRT System
On-road Emissions



Capability of SCRT System
Off-road Emissions



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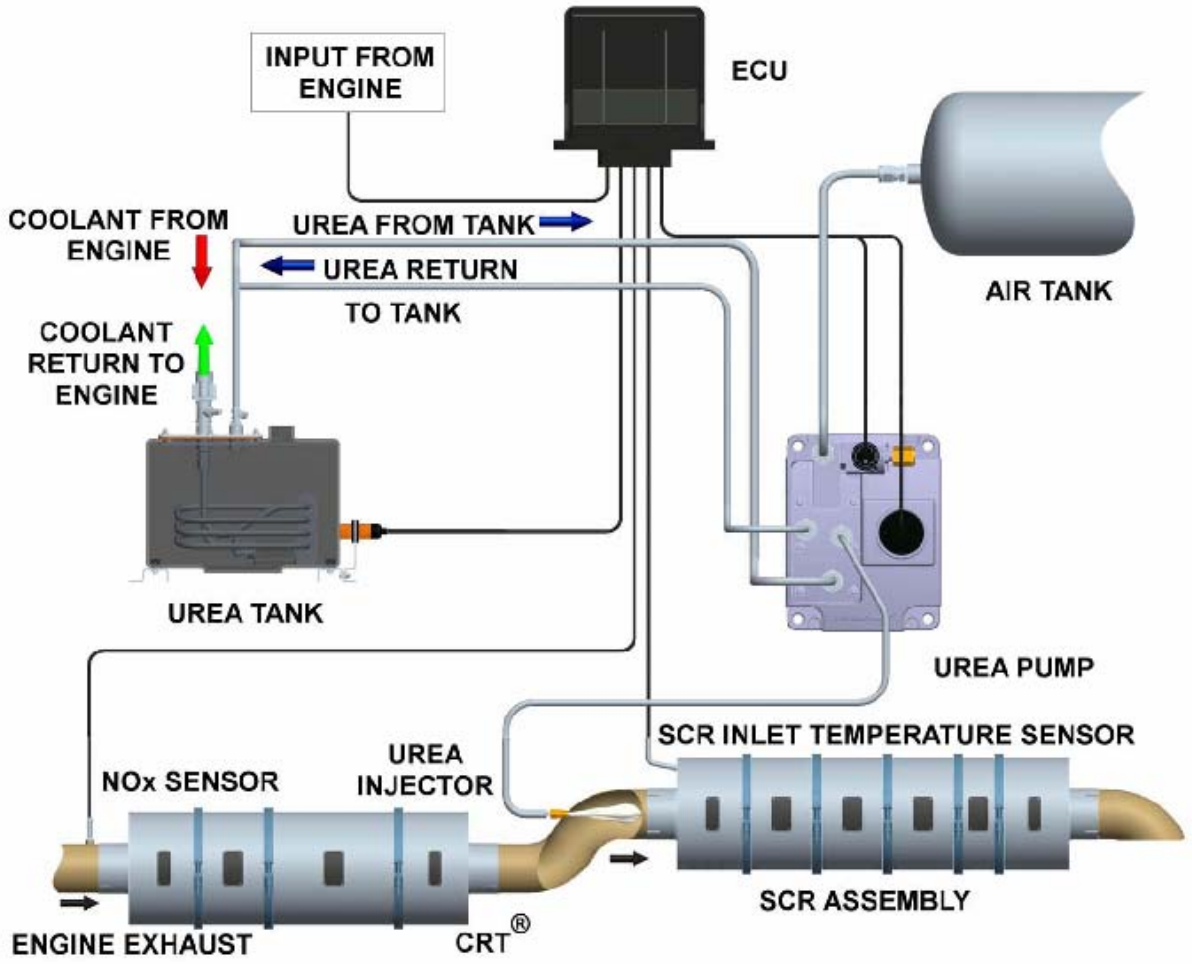
SCRT System Components

- CRT Diesel Particulate Filter

- SCR Catalyst system
  - SCR catalyst
  - NH_3 slip catalyst
  - NOx sensor(s)
  - Temperature sensors

- Urea delivery system
  - Urea tank
  - Urea Pump
  - Air regulator
  - Dosing Manifold
  - ECU & wiring harness
  - Nozzle
  - Sensors

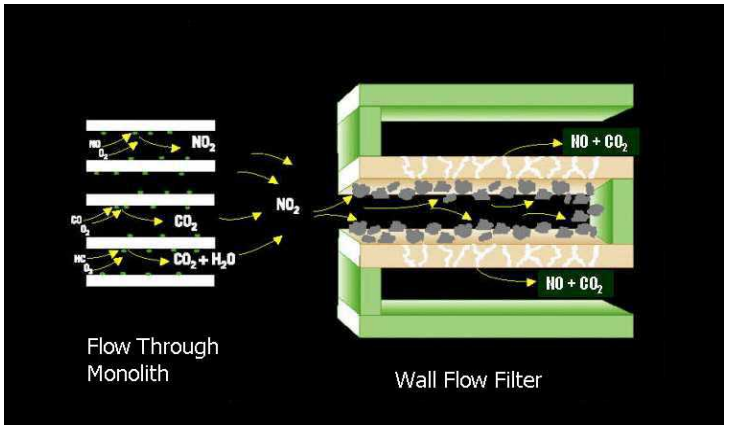
Retrofit SCRT System Diagram

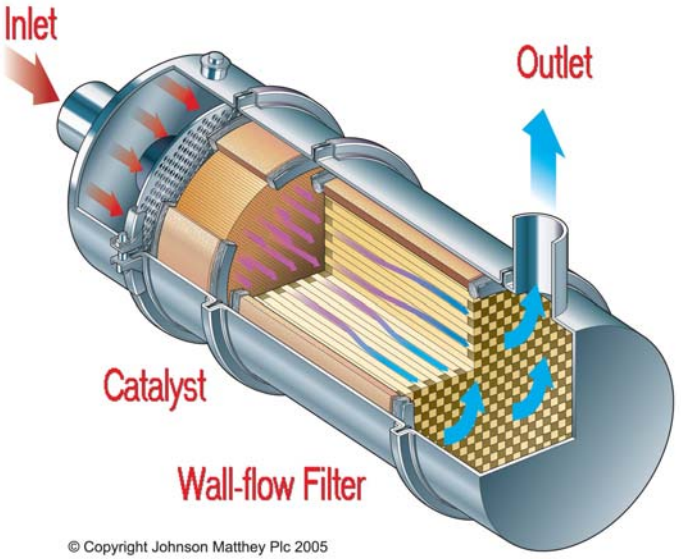


Johnson Matthey SCRT® Retrofit System

SCRT System Components
CRT Particulate Filter

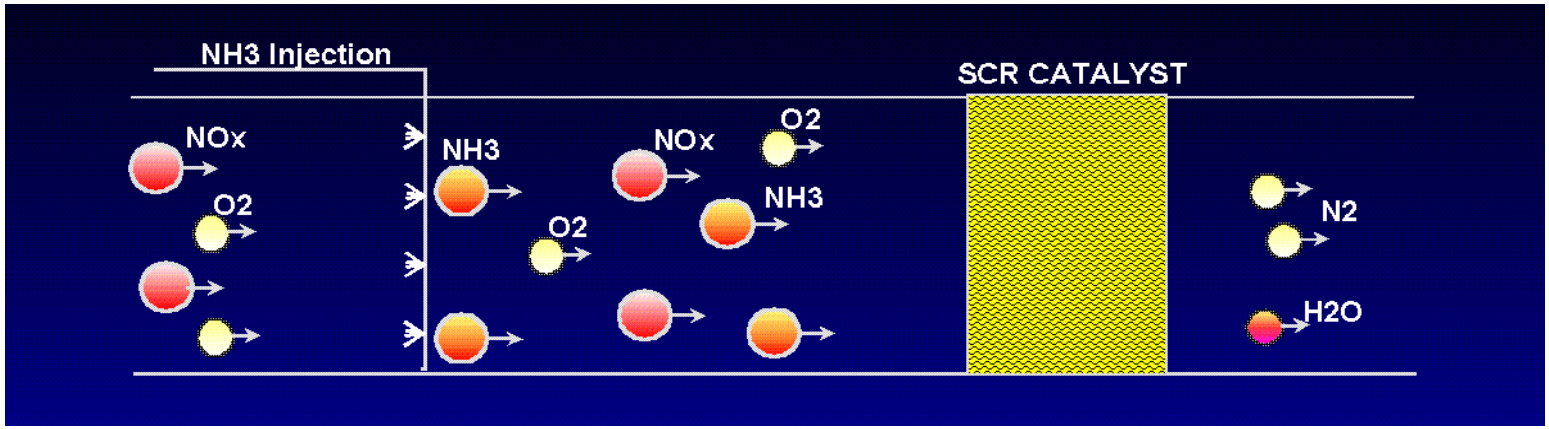
- CO/HC/PM Emission Control System combining Oxidation Catalyst & Filter
- Engineered as a totally passive emission control system
- Uses NO_2 produced by a specially formulated catalyst to burn soot collected by the filter at typical operating temperatures of diesel engine exhaust
- Requires the use of Ultra Low Sulfur fuel





SCRT System Components
SCR Catalyst

- High efficiency low temperature capable catalyst
- Proven durability
- In general, catalyst volume to engine volume 2:1



Primary Reactions:

- $4NO + 4NH_3 + O_2 = 4N_2 + 6H_2O$
- $6NO_2 + 8NH_3 = 7N_2 + 12H_2O$
- $NO + NO_2 + 2NH_3 = 2N_2 + 3H_2O$

SCRT System Components
Urea Injection System

Urea Dosing Pump

- Manufactured by Grundfos Pumps Corp.
- Compact
- Precise Air and Urea mixing
- Proven technology -Currently in series production for Euro IV applications
- High volume, relatively low cost
- 12 or 24 VDC power capability

Grundfos Pump

Urea Injection Controller

- Can handle up to 15 control inputs
- Analog, Digital and CAN input & outputs
- Can use either a look-up table (map) or algorithm for urea injection
- Capable of continuous logging of up to 8 system parameters
- Developed and tested to on-road automotive standards

Control ECU

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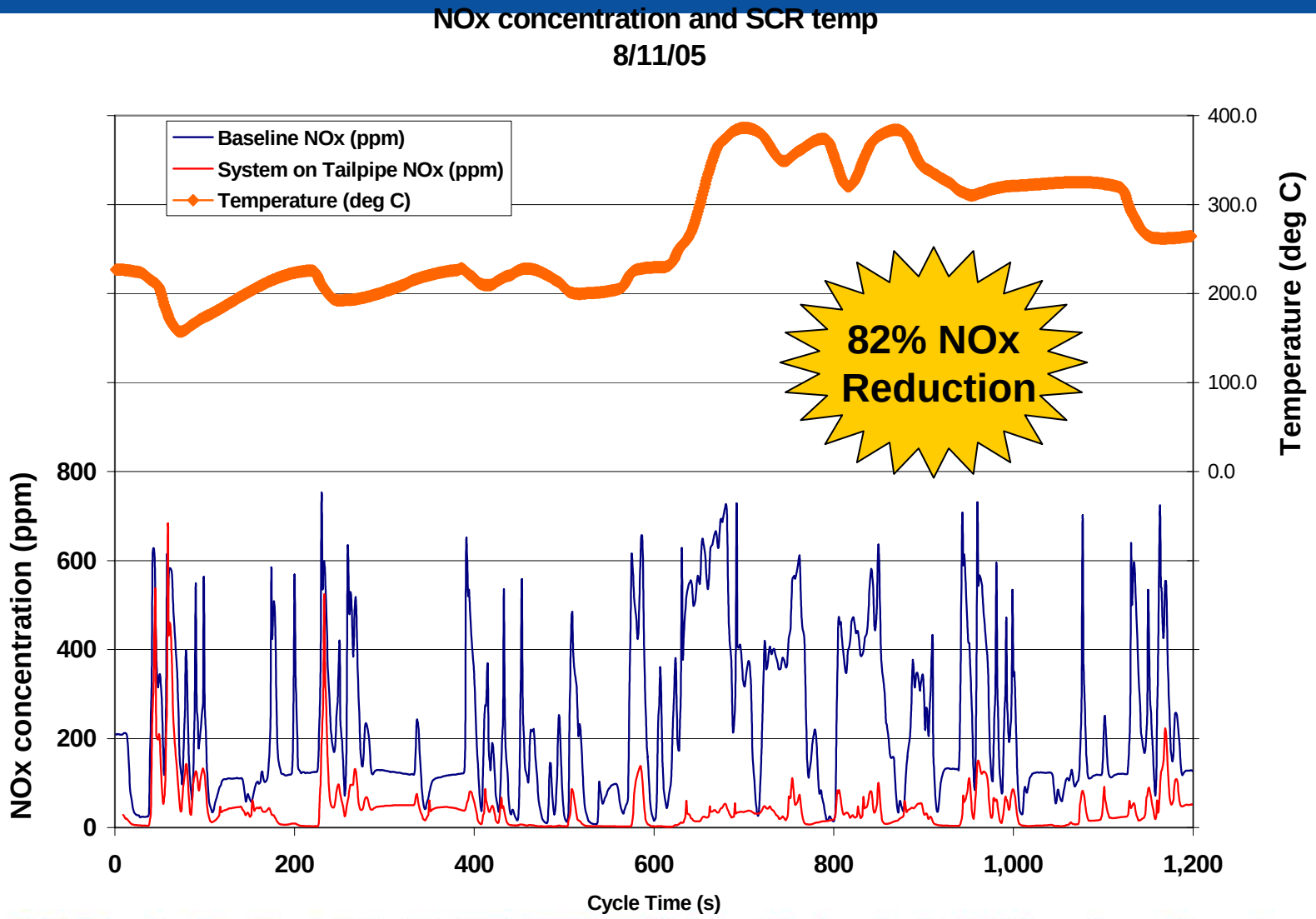
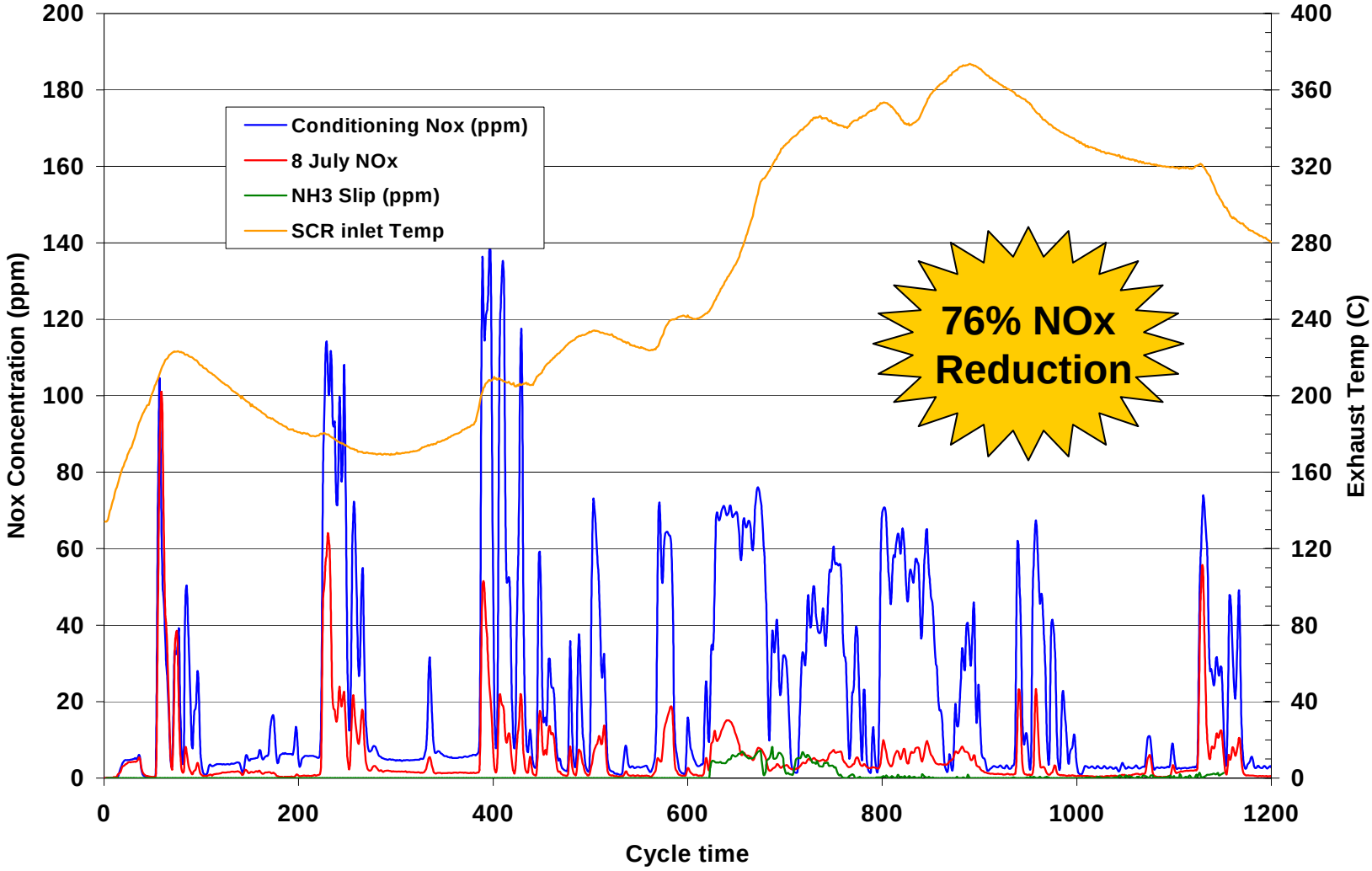
SCRT System Development
Cummins ISM Engine, FTP Cycle Test Results

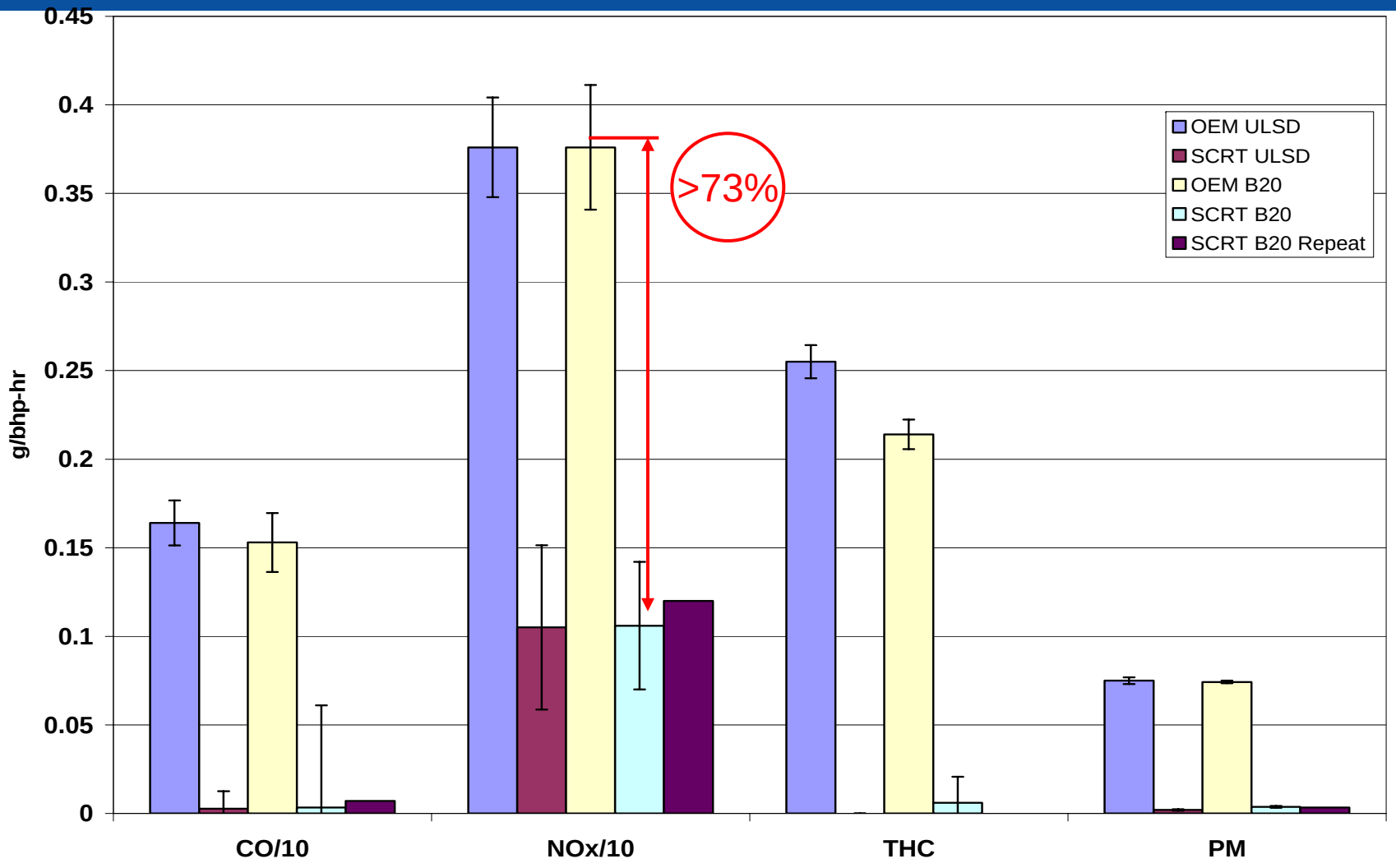


SCRT System Development
Caterpillar 3126 Engine, FTP Cycle Test Results



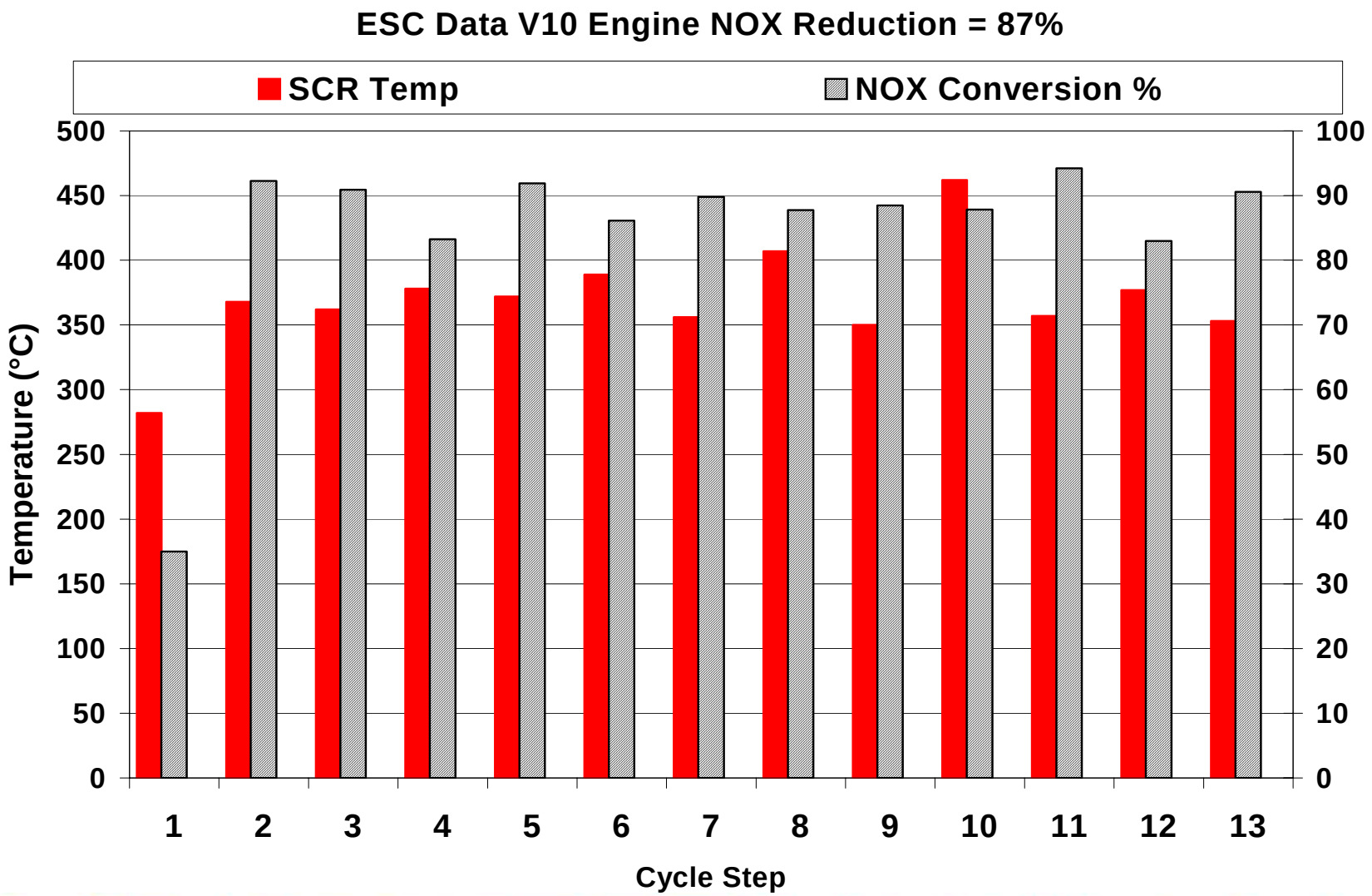
SCRT® System Testing With Biodiesel

FTP Hot Tests, CAT 3126, 250 hp, 1998



Ref: Environment Canada Testing

SCRT System Development
Volvo 10 L Engine, Test Cell Results – ESC Cycle



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SCRT System Field Trials

System being tested on different applications, worldwide

Ralphs Grocery Truck

LA County Sanitation Trash Truck

Long Beach Transit Bus

BP Fuel Delivery Truck

SCRT Field Trial – BP Fuel Delivery Truck

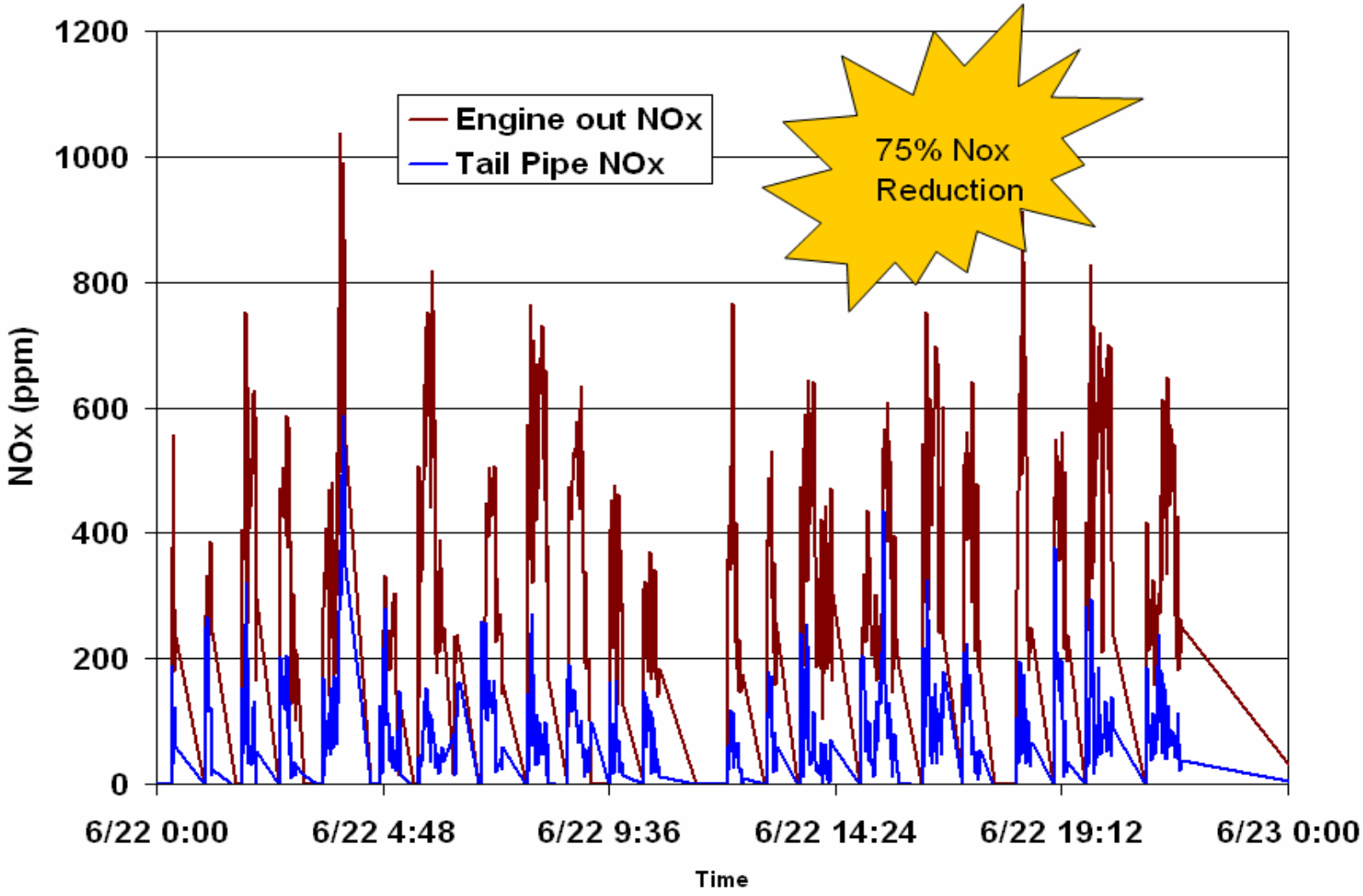
Engine Model	CRT Size		SCR Size	
	Cat (liter)	Filter (liter)	Cat (liter)	Slip (liter)
CUM ISM 10.8 L	8.5	17	25.5	4.2

CRT Module

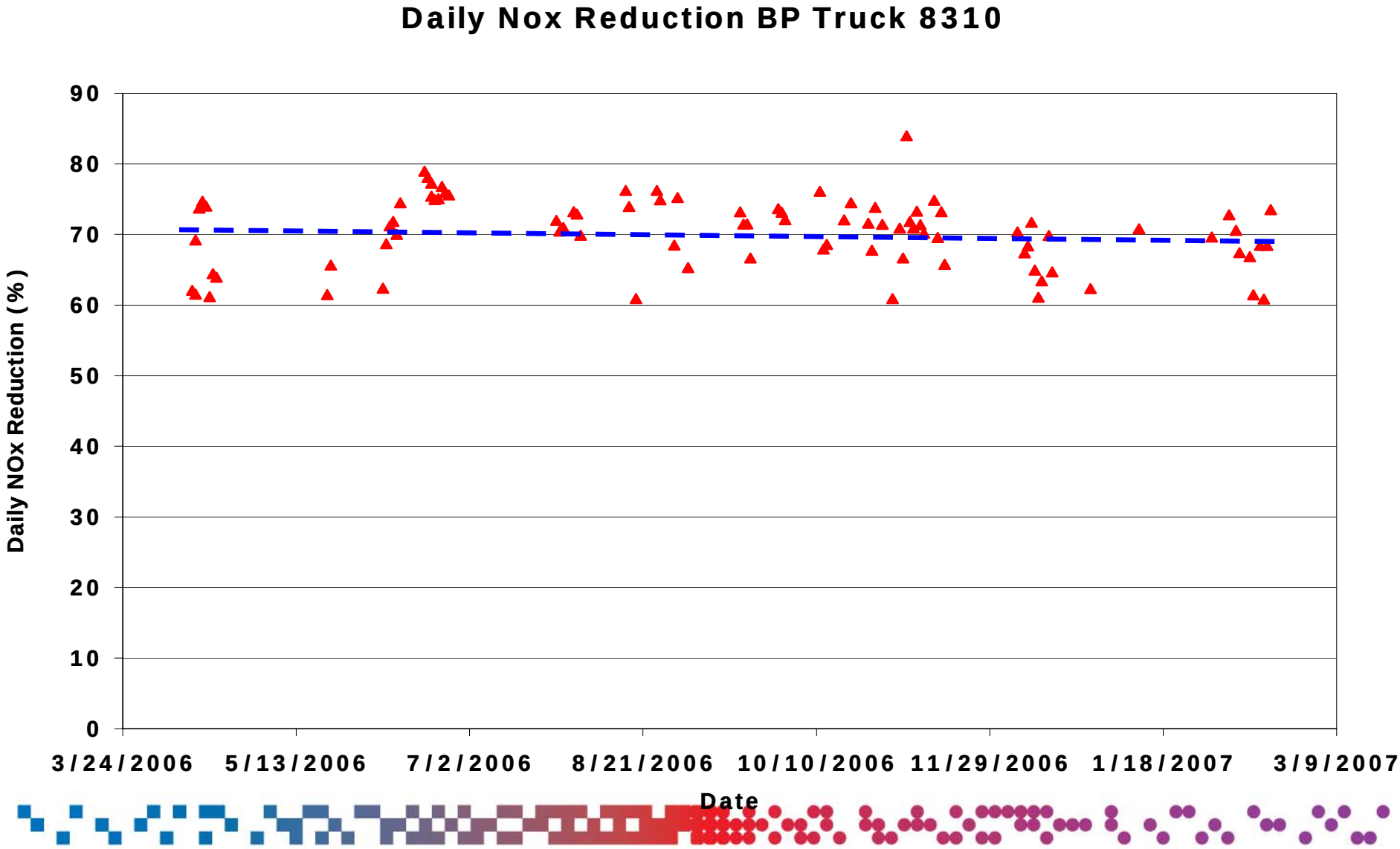
SCR Module

SCRT Field Data – On-Road NOx Reduction

BP Fuel Delivery Truck



SCRT System on BP Truck
Long Term NOx Reductions



SCRT Field Trial - Long Beach Transit Bus

4 Tail Pipe

3 SCR Module (vertically where CRT used to be)

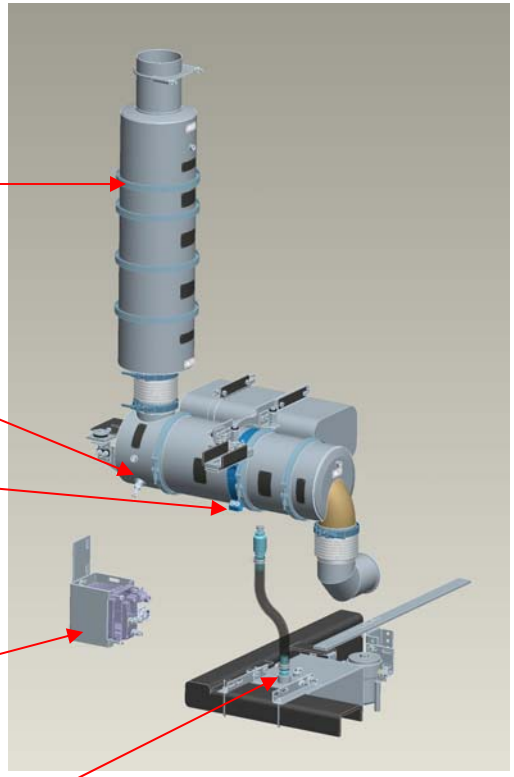
2 Inj Nozzle

1 CRT Module

5 Electronic Control Unit

6 Urea Pump

7 Urea Tank (Next to oil pan)

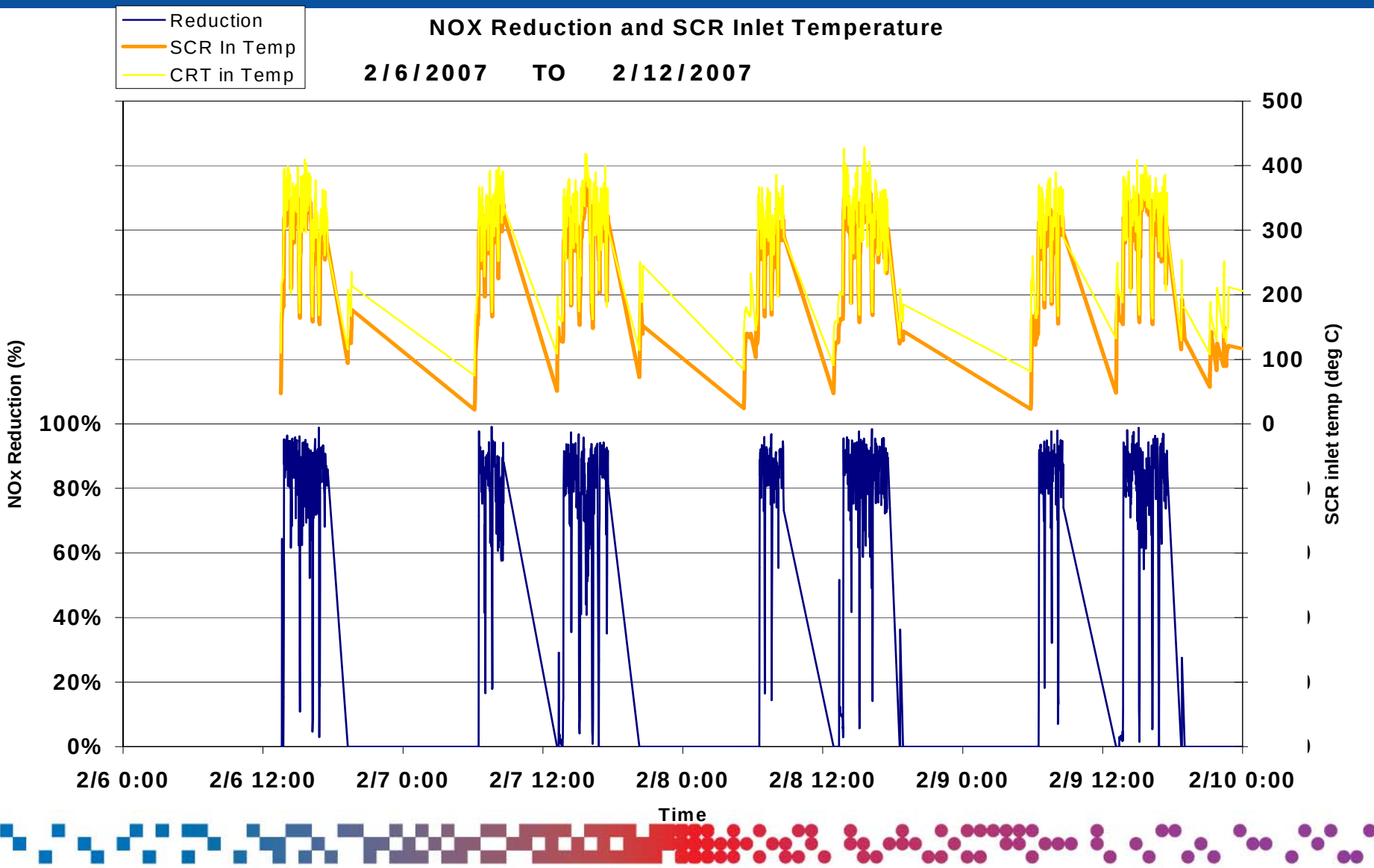


DDC S 50 Engine,

275 hp, 1998

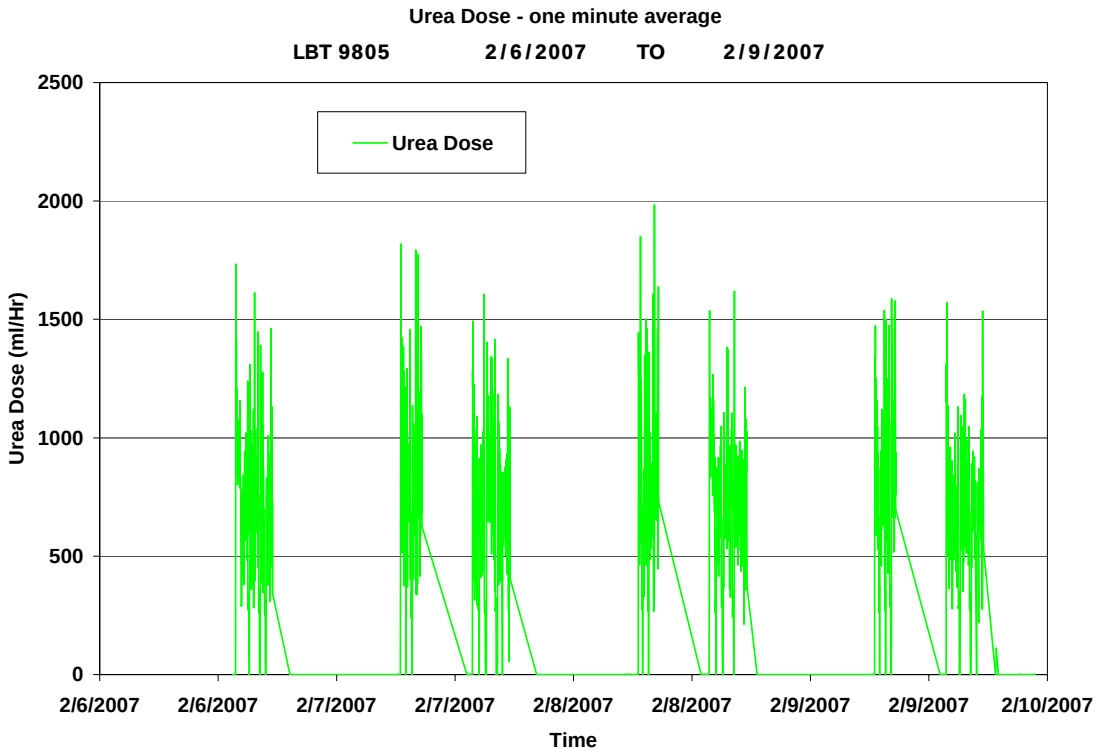
SCRT on Long Beach Transit Bus

Typical On-road NOx reduction data for 6 days



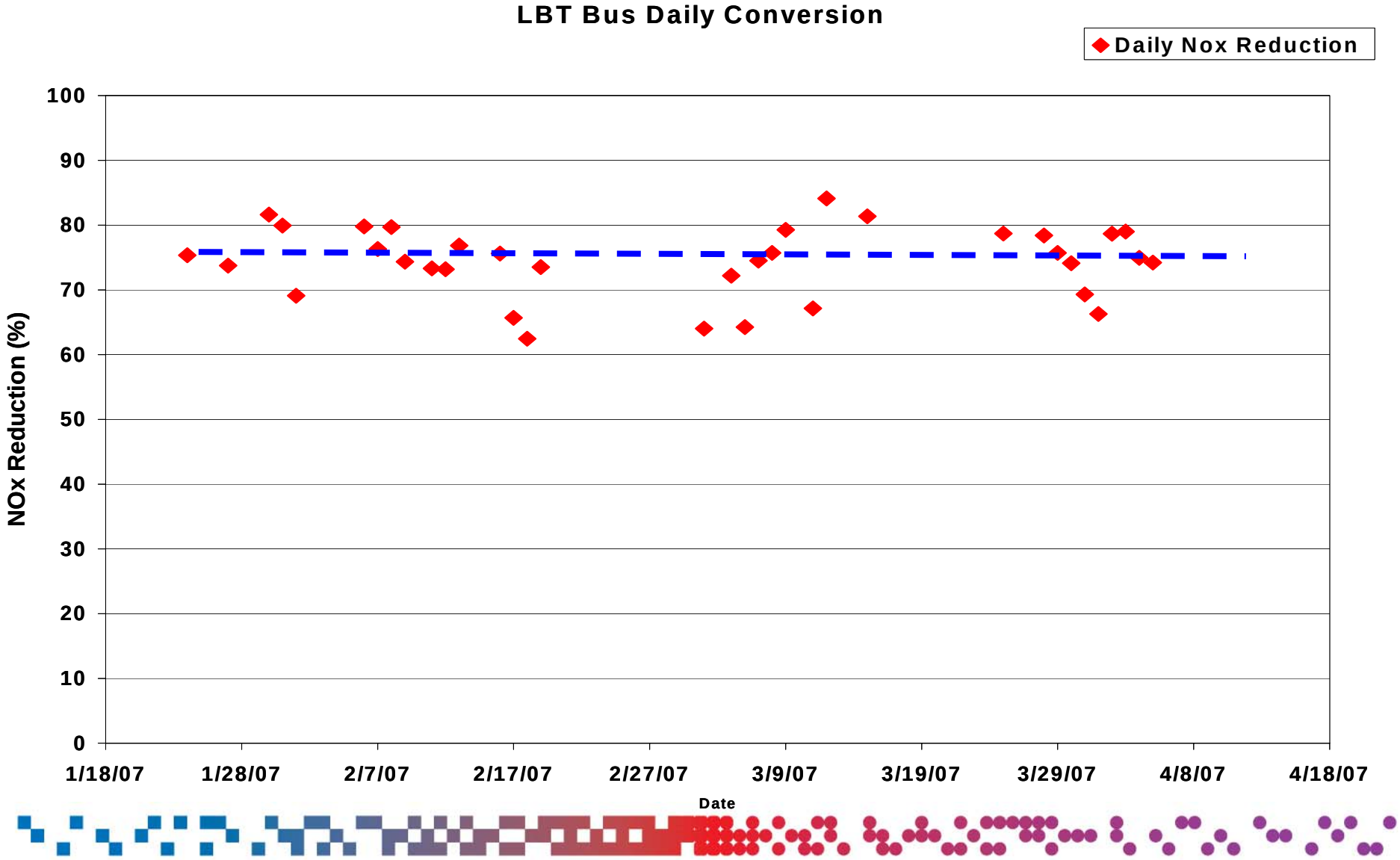
SCRT on Long Beach Transit Bus
Typical Urea Usage for NOx Reduction

- The average amount of urea injected every minute is recorded and added up for each day



Date	Urea used (ml)	Urea used (gal)
2/6/07	2510	0.66
2/7/07	4275	1.1
2/8/07	4321	1.1
2/9/07	3992	1.05

SCRT System on Long Beach Transit Bus
Long Term NOx Reductions

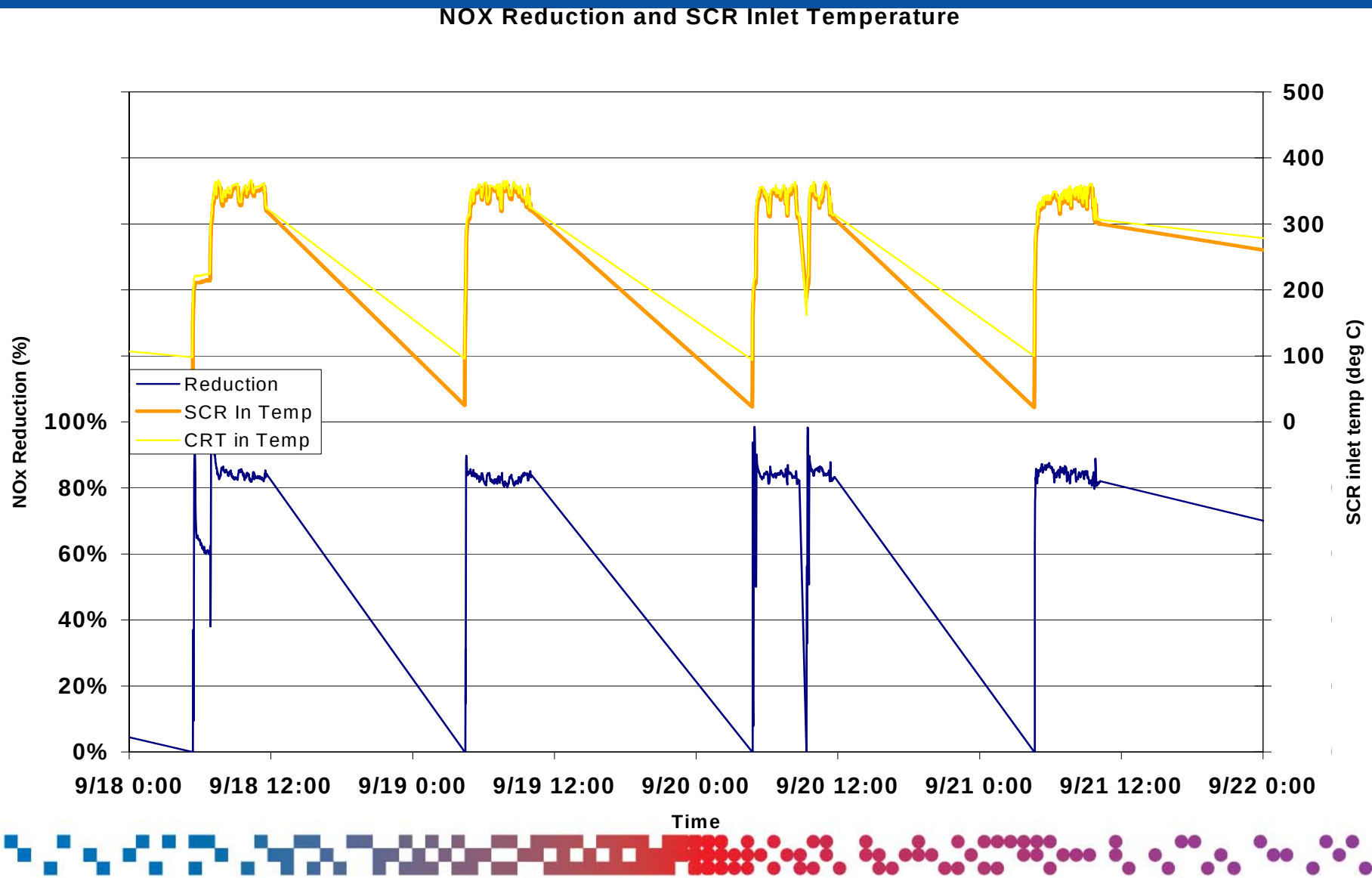


SCRT Field Trial – Non-road Application
Ingersoll Rand Air Compressor

- SCRT system was installed on a 2005 Ingersoll Rand P600WIR air compressor in Bronx, NY
- The engine is a 170HP John Deere 6IRF8TE (Tier 2)

SCRT Field Trial – Non-road Application
Ingersoll Rand Air Compressor

SCRT Field Trial - Croton Air Compressor
Typical NOx Reduction and Exhaust Temperature



Issues To Be Considered for Retrofit SCRT System Application in Off-road

- Mechanical Design
  - Limited space availability
  - Line of sight
- Mechanical durability
  - Filter & substrate material
  - Packaging
- Exhaust back pressure
  - Filter & DOC size
  - Substrate cell density
- Exhaust Temperature
  - In general warm
  - Good for CRT & SCR
- Engine out emissions
  - Tier 1 engines may have low NOx/PM
  - Issue with passive filter regen
- Urea & ULSD fuel availability

Conclusions

- Overall, the combination of Selective Catalytic Reduction and CRT can be a very effective emission control device for the reduction of NOx, PM, CO and HC emissions from existing diesel vehicles. NOx reduction of 60 - 85% is achievable with a retrofit system

- Engine and vehicle testing results showed high NOx reduction capabilities of the SCRT system. It produced 70-88% NOx reduction over FTP, ETC, ESC and other real world drive cycles. The presence of the CRT also enables this system to reduce CO, HC and PM by 85-95% .

- The tests also showed the critical nature of the SCR temperature in determining the overall NOx reduction. The average SCR temperature will have to be over 200 C in order to obtain high NOx conversions since effective urea hydrolysis cannot be achieved below this temperature

- Following introduction of on-road system (estimated. end 2007), JM will develop retrofit SCRT system for non-road applications

- Design issues will have to be carefully evaluated for off-road application

Acknowledgments

- Environment Canada, ERMD
- LA County Sanitation
- British Petroleum
- Ralph's Grocery
- Long Beach Transit
- Eastern Municipal Water District
- LA Dept of Power and Water
- Cummins Inc.
- Caterpillar Inc.
- Valley Power System
- SCAQMD
- SMAQMD
- TERP

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