The Development and On-Road Performance and Durability of the Four-Way Emission Control SCRT™ System

BJ Cooper, AC McDonald and AP Walker

Johnson Matthey plc

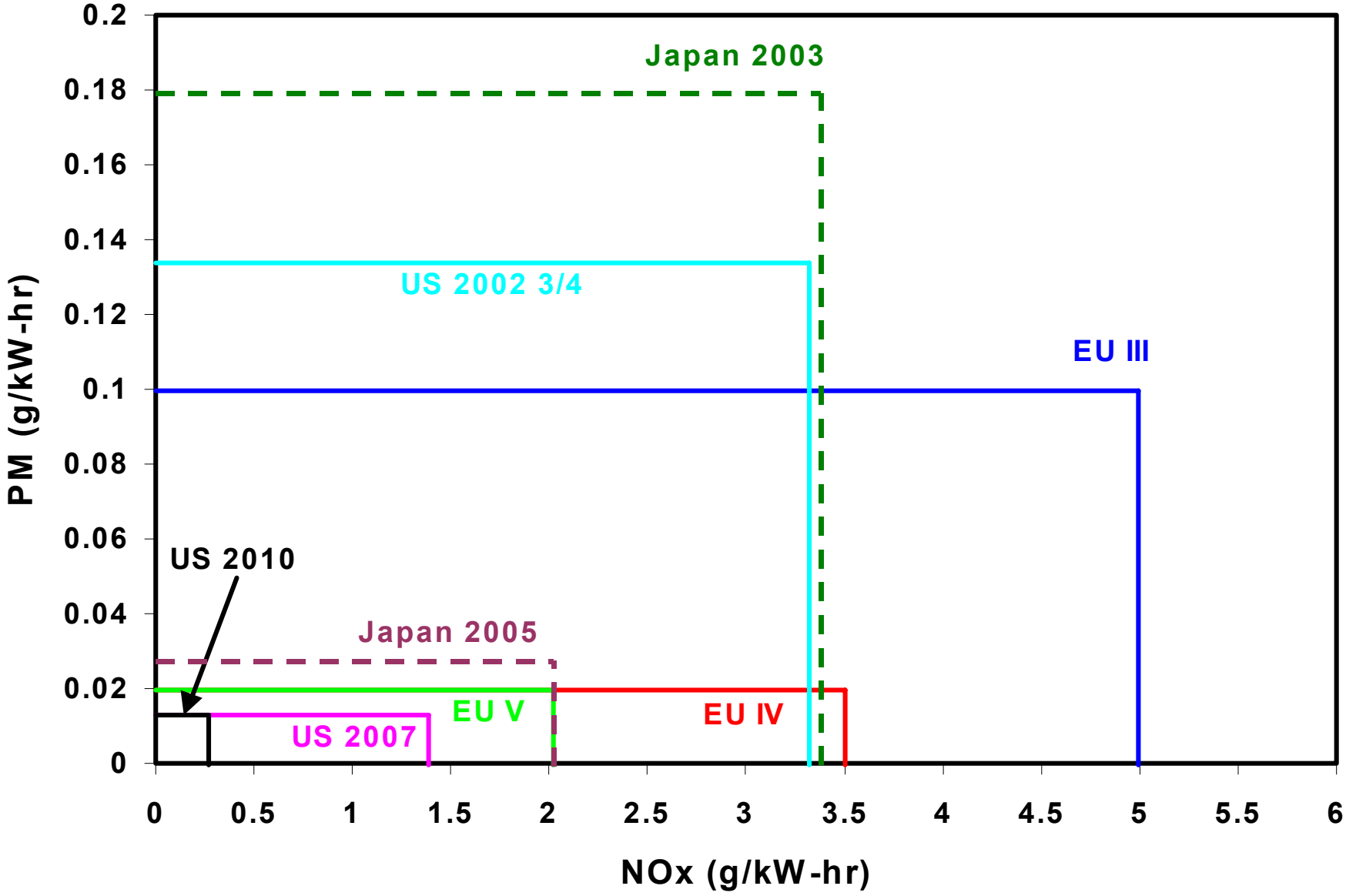
M Sanchez

Cummins Inc

Outline of the Presentation

- Introduction
- PM and NOx Control
- Combined Systems for PM and NOx Control
  - Engine bench studies
  - Field studies
- Conclusions

Global HDD Legislation



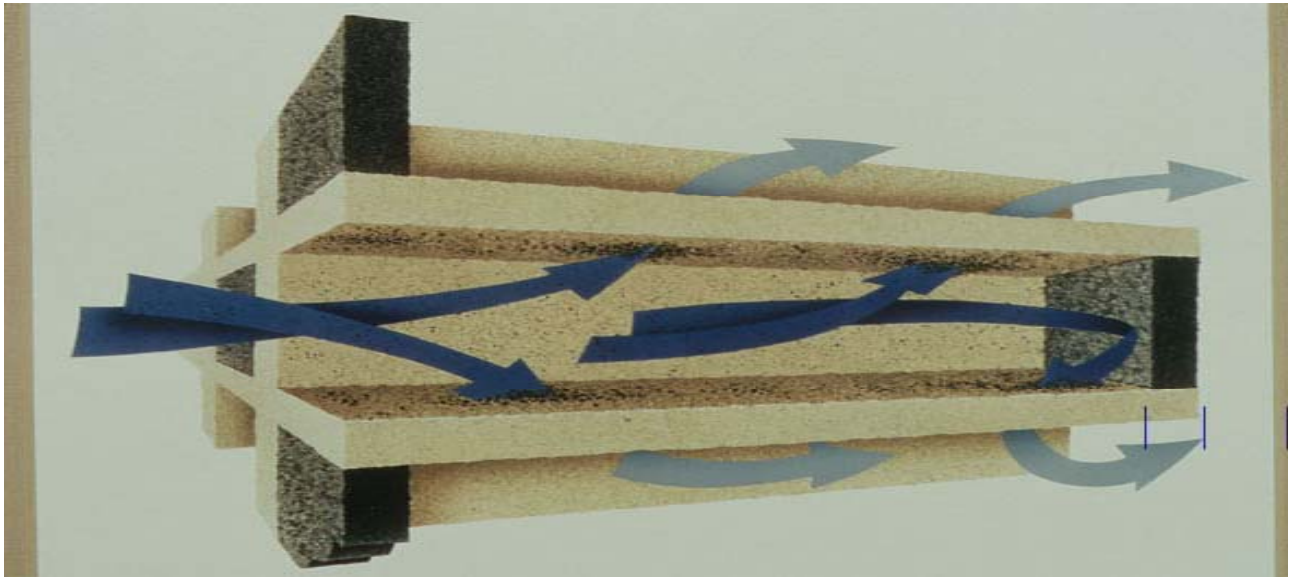
Introduction

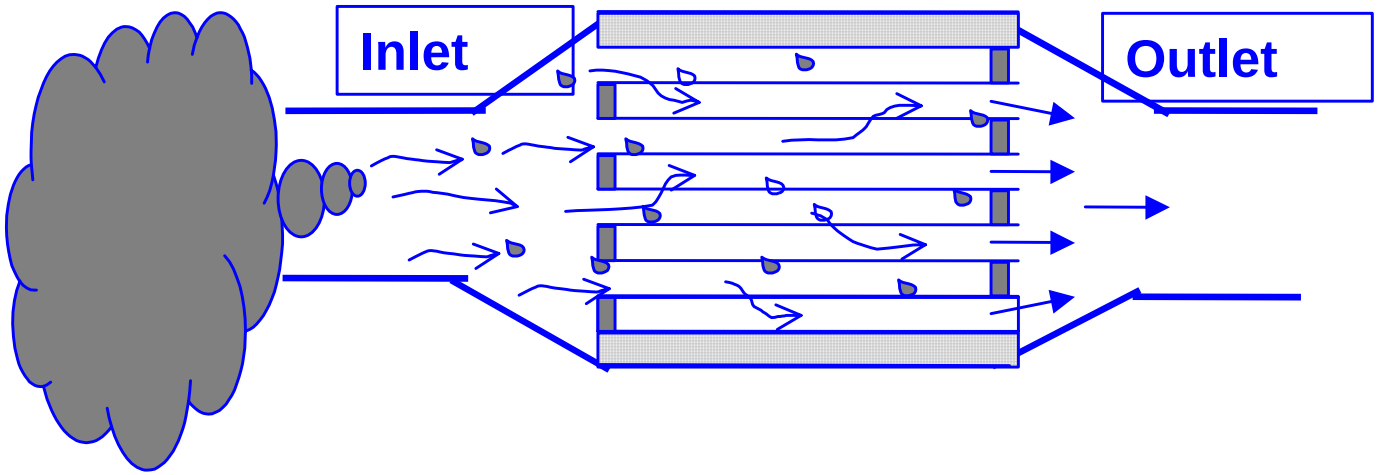
- HDD legislation is becoming progressively tighter
- Environmental considerations make large reductions in both NOx and PM highly desirable
- There is a need to develop four-way emission control systems
  - systems to control PM (and CO, HC) already exist
  - systems to control NOx already exist
  - need to put them together

Outline of the Presentation

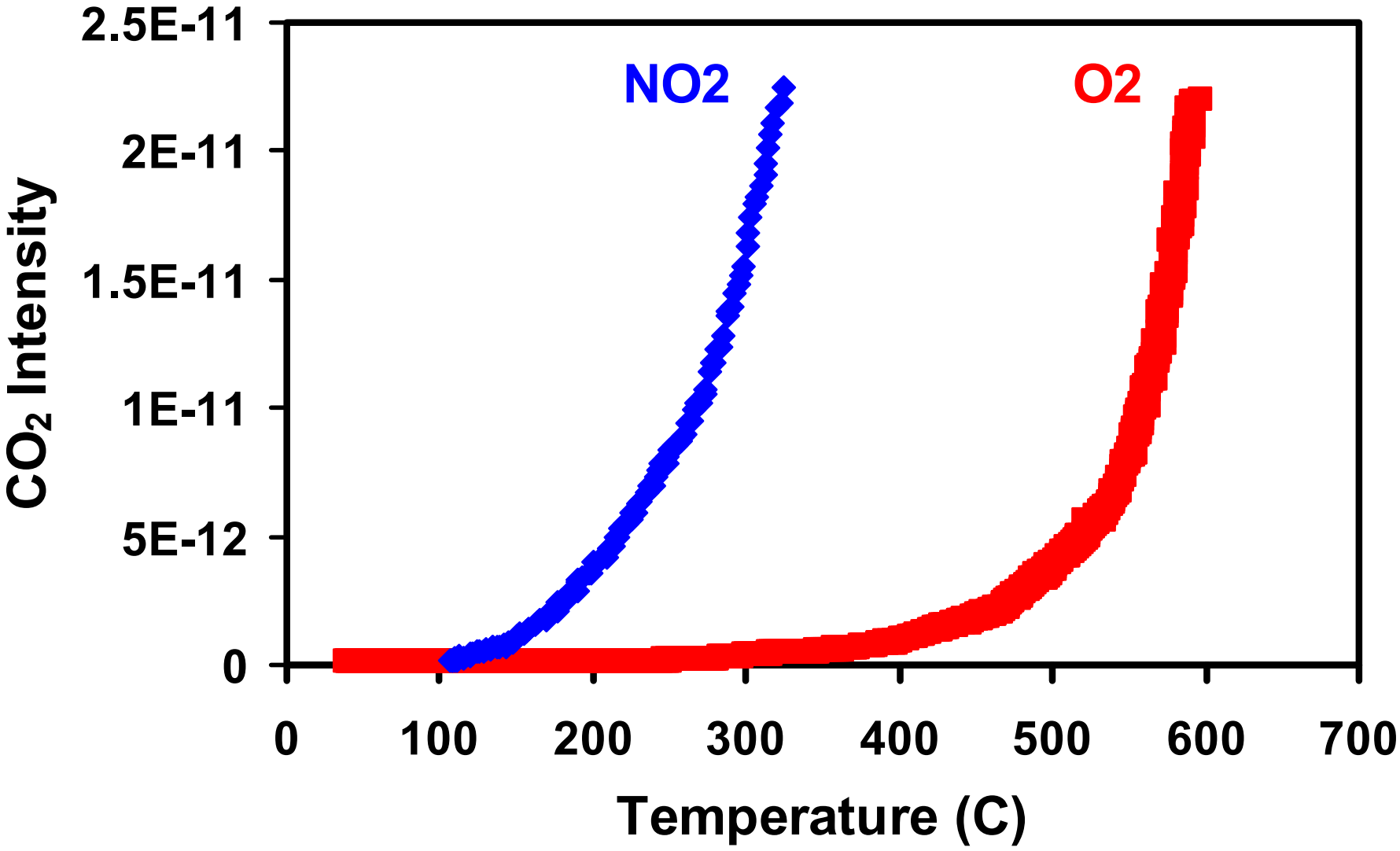
- Introduction
- PM and NOx Control
- Combined Systems for PM and NOx Control
  - Engine bench studies
  - Field studies
- Conclusions

Filtering the Particulates

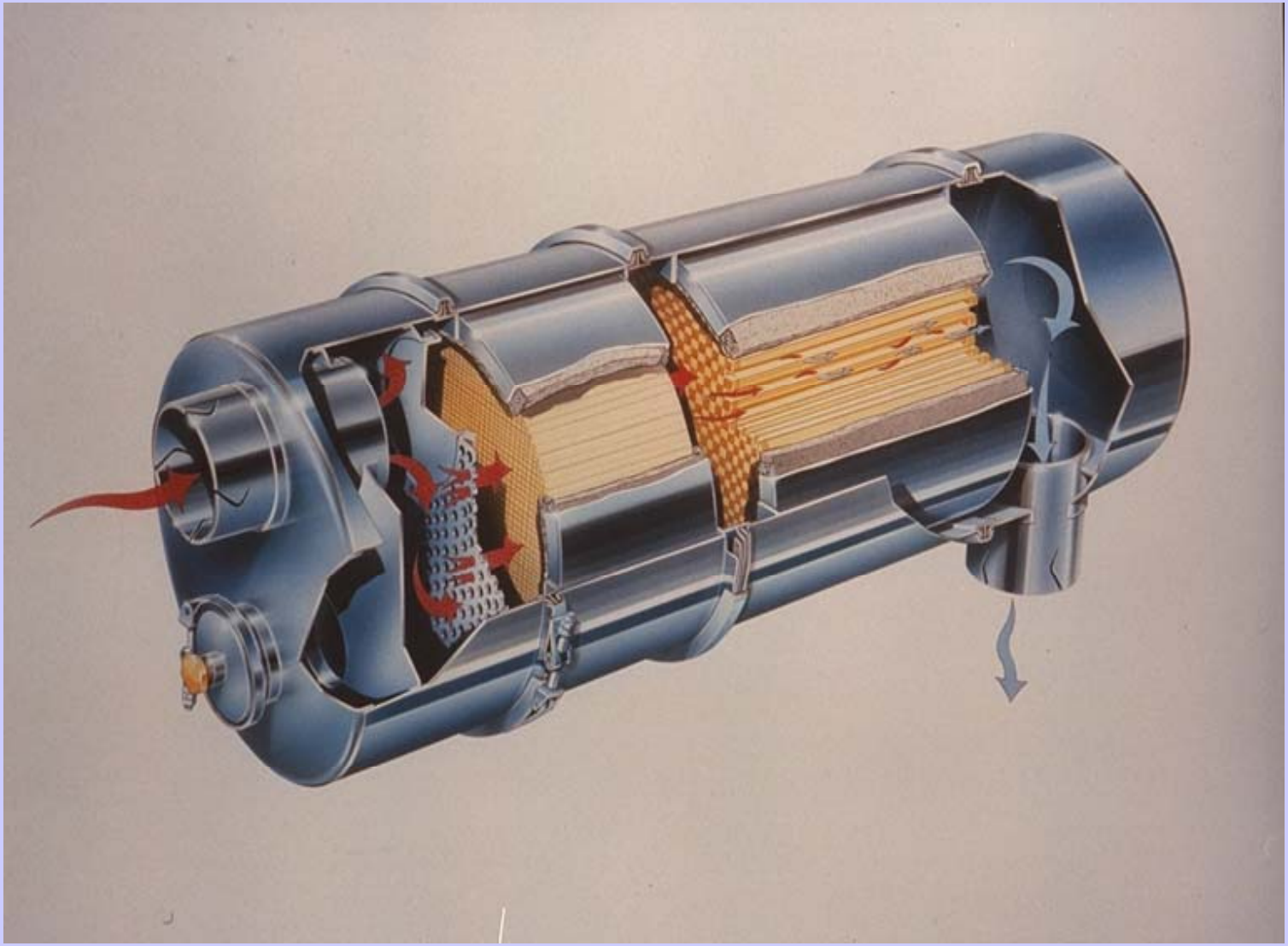




Combusting PM at Low Temperatures



The CRT® System



SCR Systems for NOx Control

- SCR is an established strategy to reduce NOx emissions:

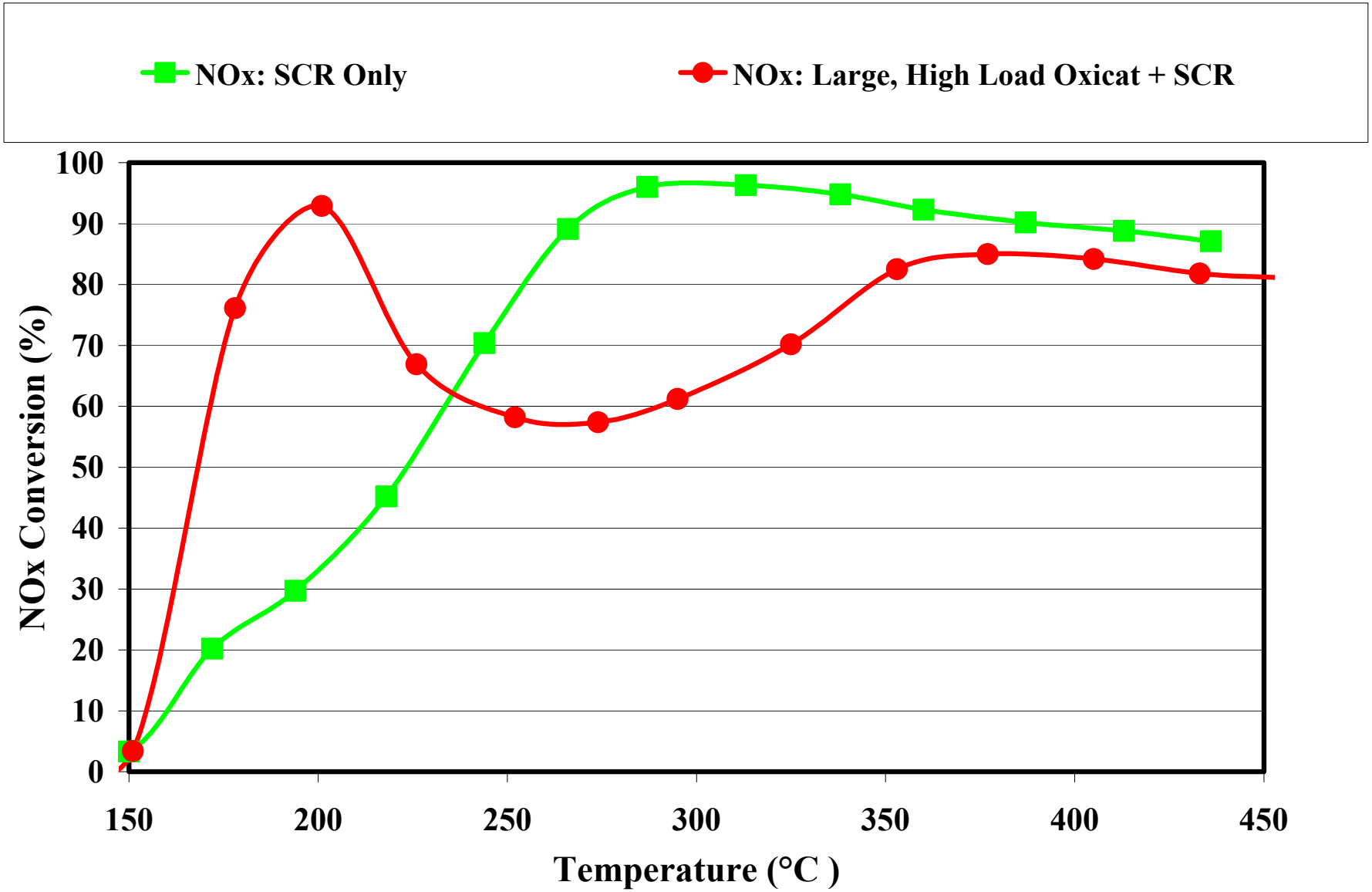
$$4\ NH_3 + 4\ NO + O_2 \longrightarrow 4\ N_2 + 6\ H_2O \quad (1)$$

$$2\ NH_3 + NO + NO_2 \longrightarrow 2\ N_2 + 3\ H_2O \quad (2)$$

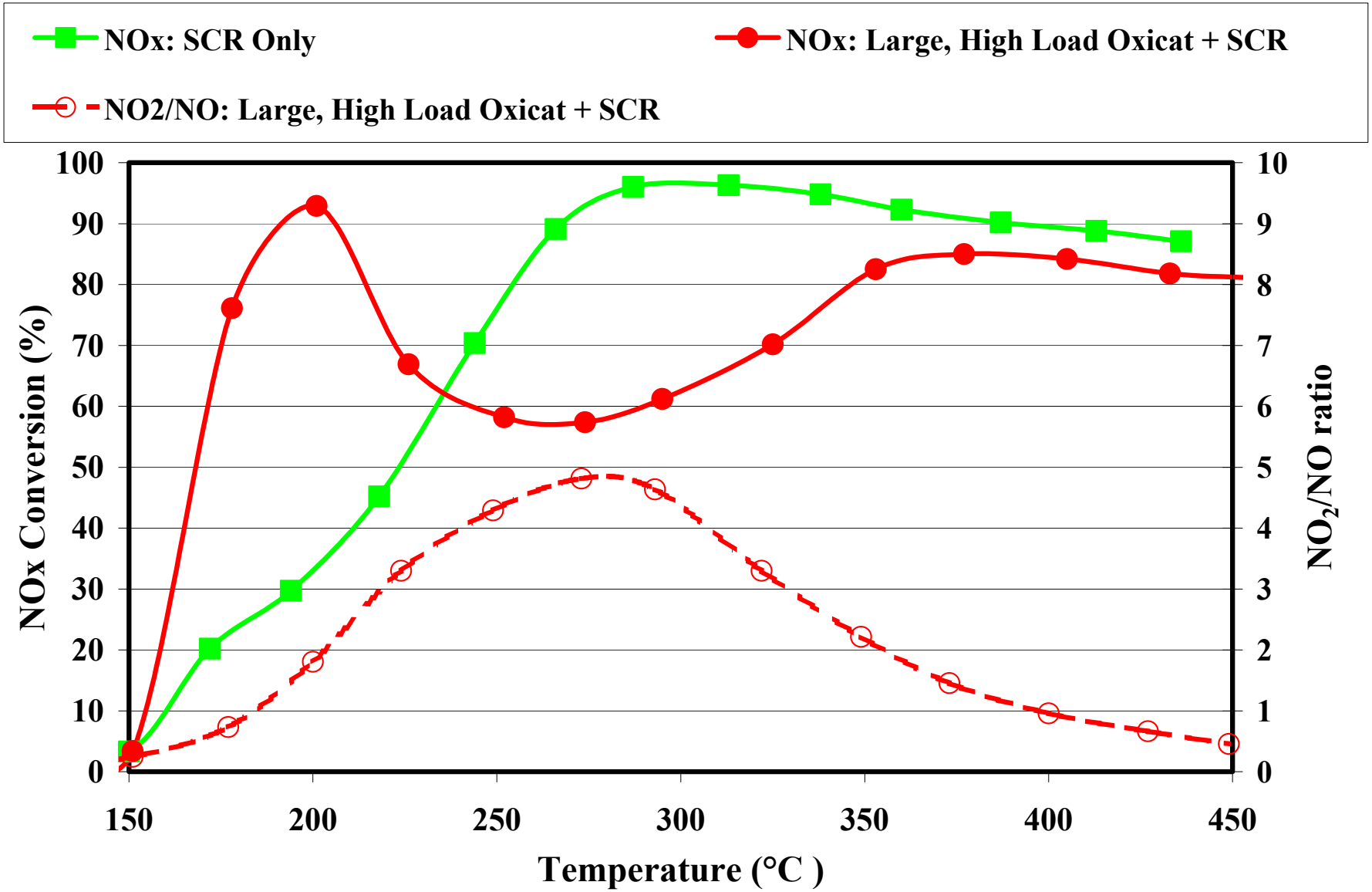
$$8\ NH_3 + 6\ NO_2 \longrightarrow 7\ N_2 + 12\ H_2O \quad (3)$$

- Reaction 1 is fast, Reaction 2 is very fast, Reaction 3 is very slow
  - low temperature SCR is strongly promoted by NO_2
  - but too much NO_2 can cause problems

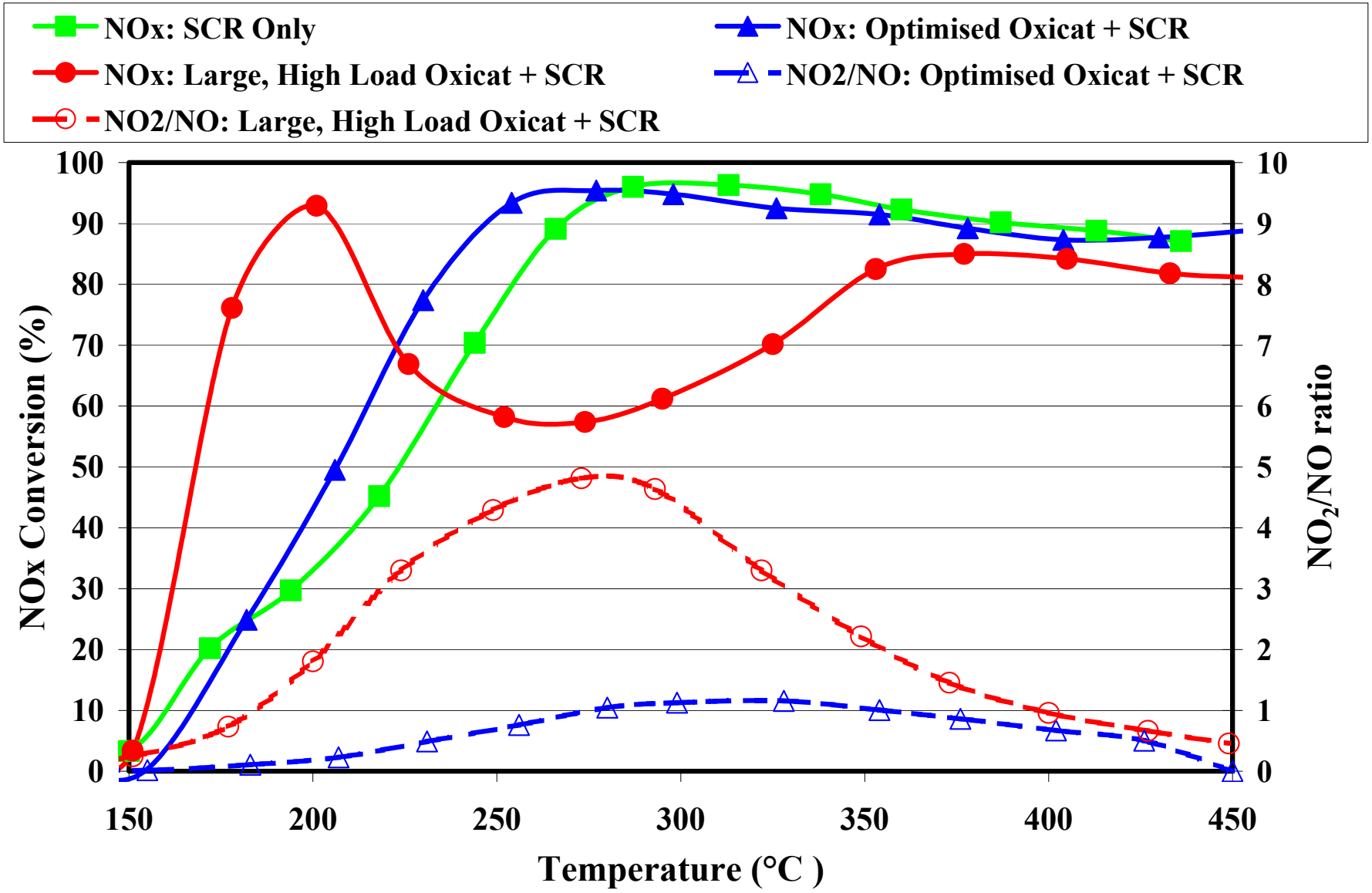
Impact of NO_2 on SCR Performance



Impact of NO_2 on SCR Performance



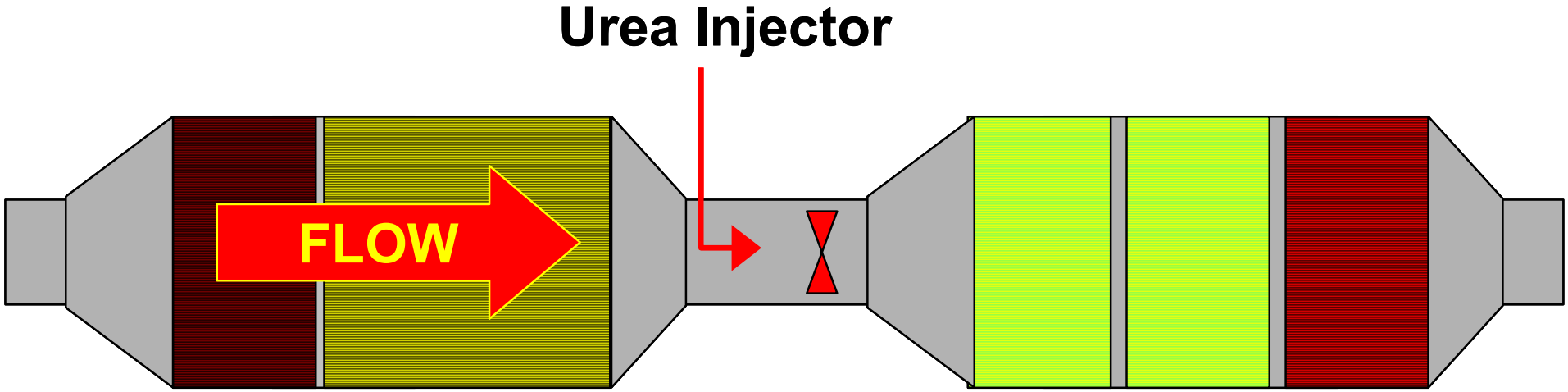
Impact of NO_2 on SCR Performance



Outline of the Presentation

- Introduction
- PM and NOx Control
- Combined Systems for PM and NOx Control
  - Engine bench studies
  - Field studies
- Conclusions

The In-Line SCRT System



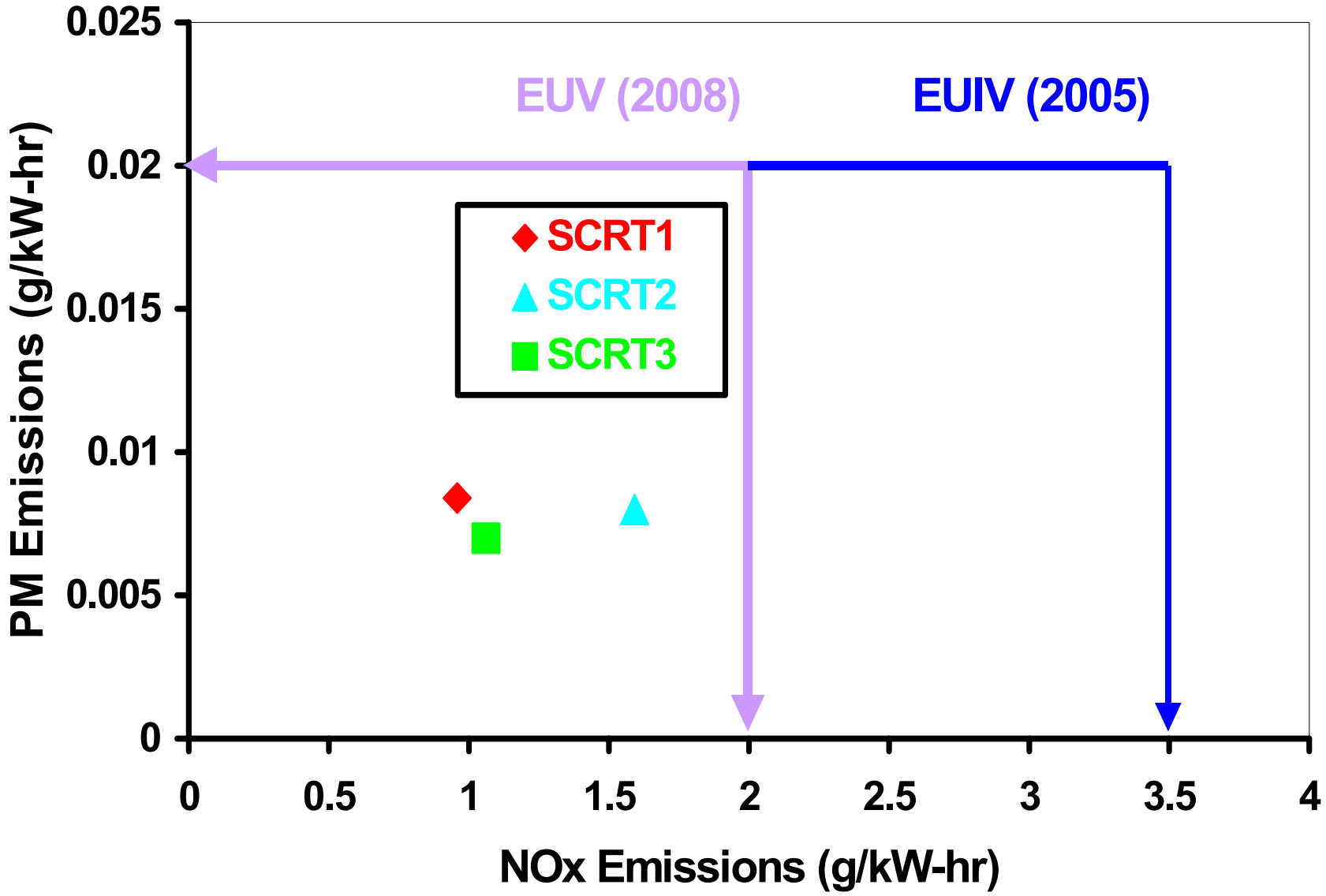
CRT® System

2 x SCR Catalysts +
1 x Pt Clean-up Catalyst

Catalyst Volume	= 34 l
Filter Volume	= 17 l
Total Volume	= 51 l

In-Line SCRT ESC Performance

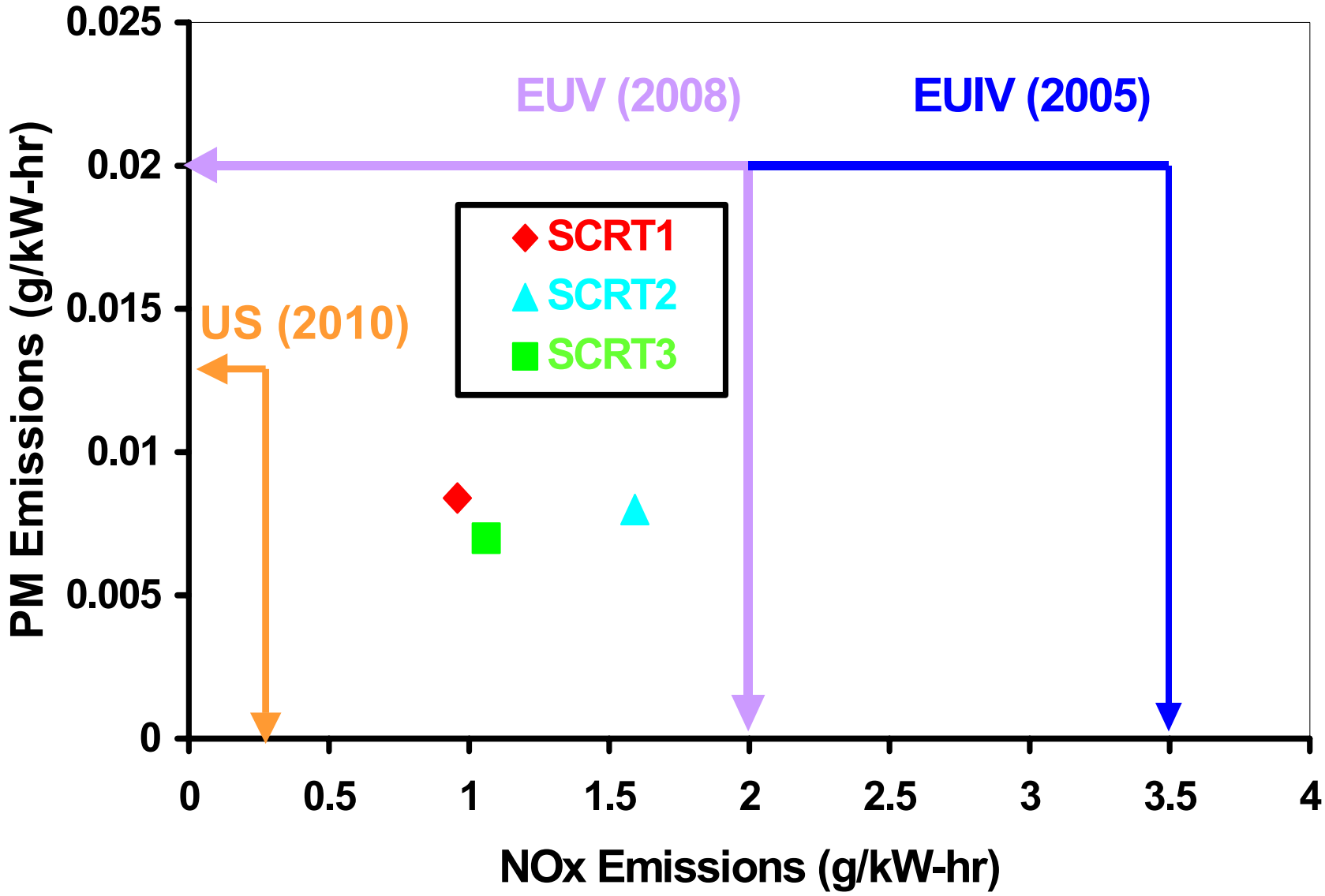
Engine-Out: PM = 0.163 g/kW-hr, NOx = 6.9 g/kW-hr



See SAE 2000-01-0188

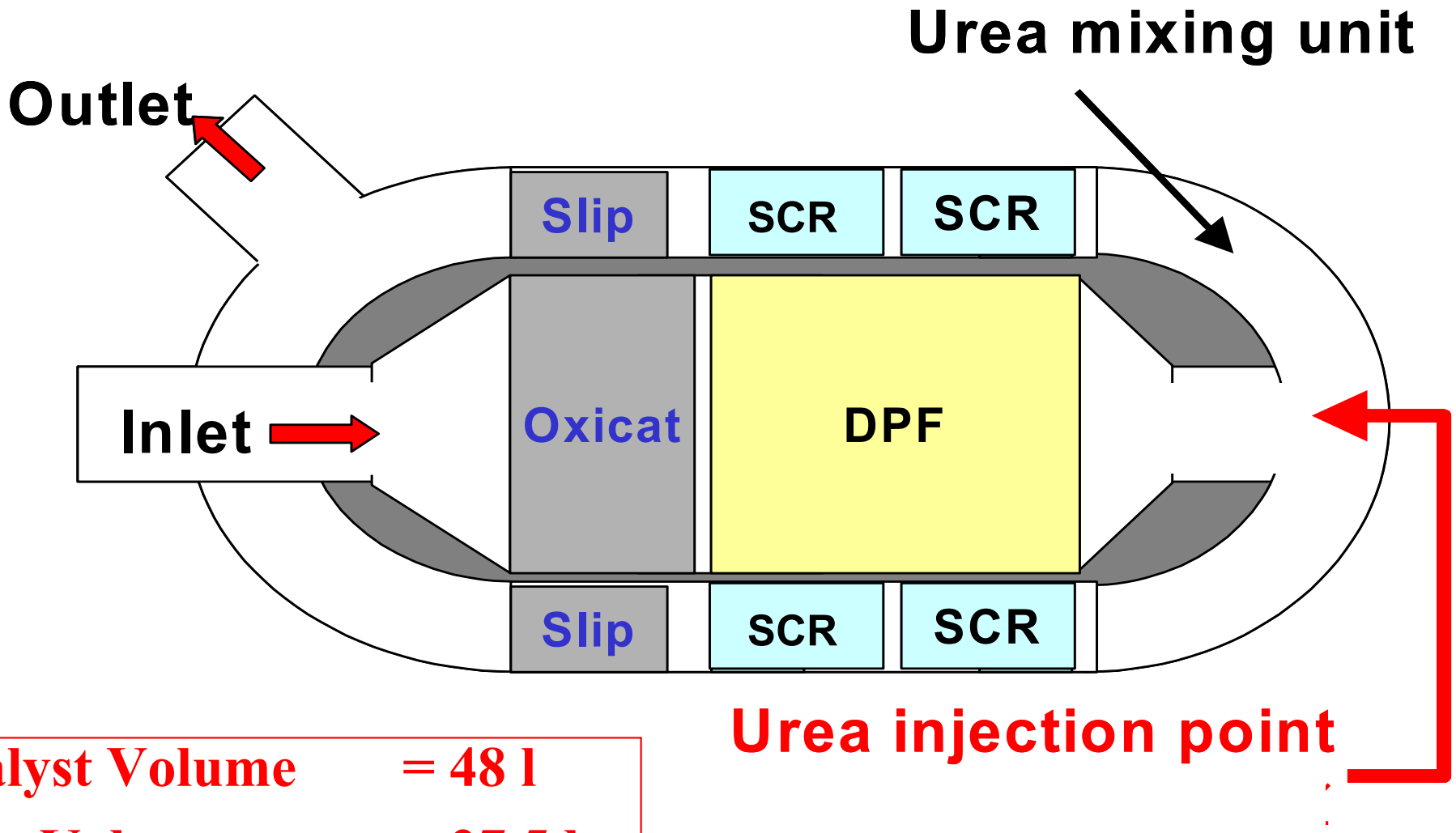
In-Line SCRT ESC Performance

Engine-Out: PM = 0.163 g/kW-hr, NOx = 6.9 g/kW-hr



See SAE 2000-01-0188

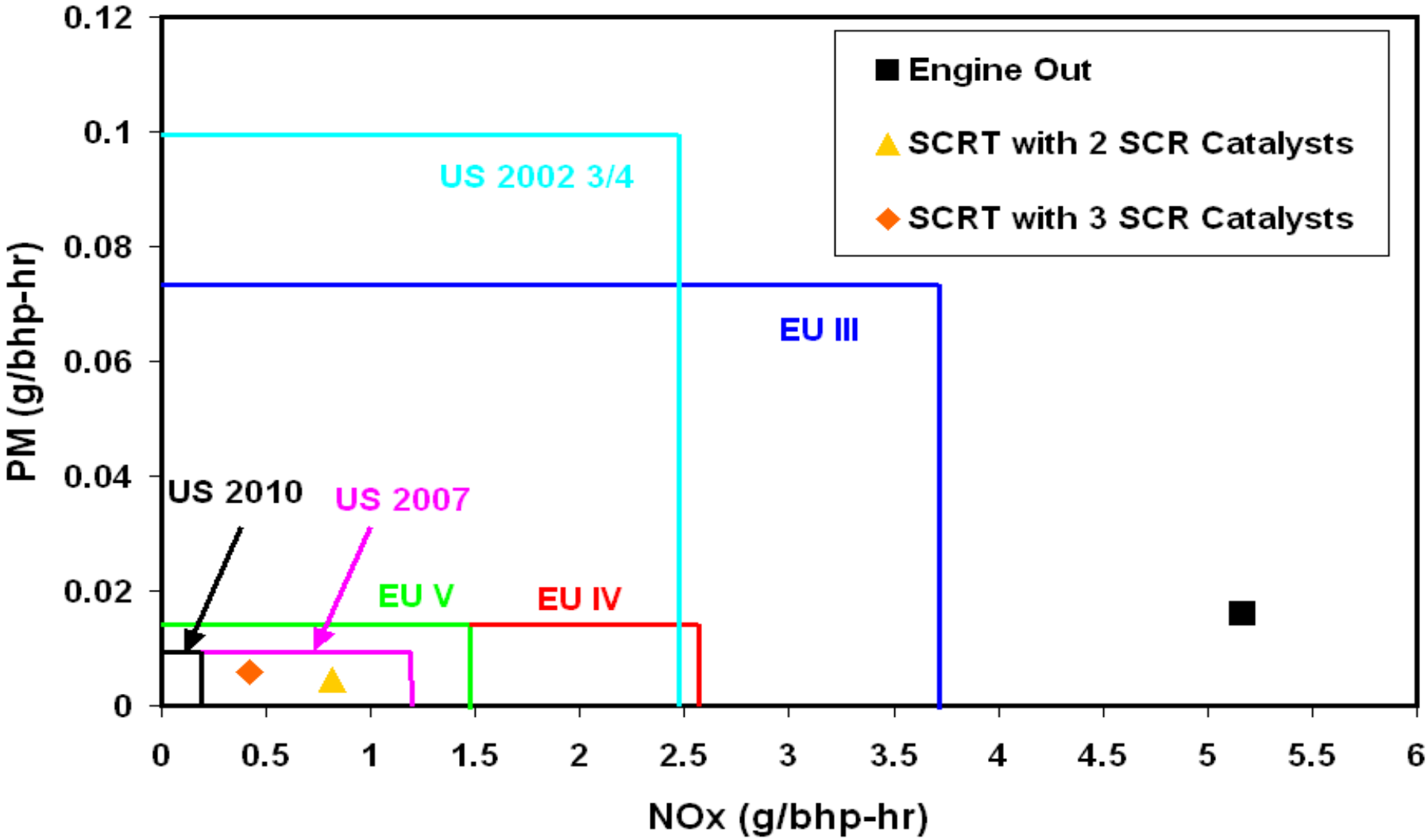
The Compact SCRT System



Catalyst Volume	= 48 l
Filter Volume	= 27.5 l
Total Volume	= 75.5 l

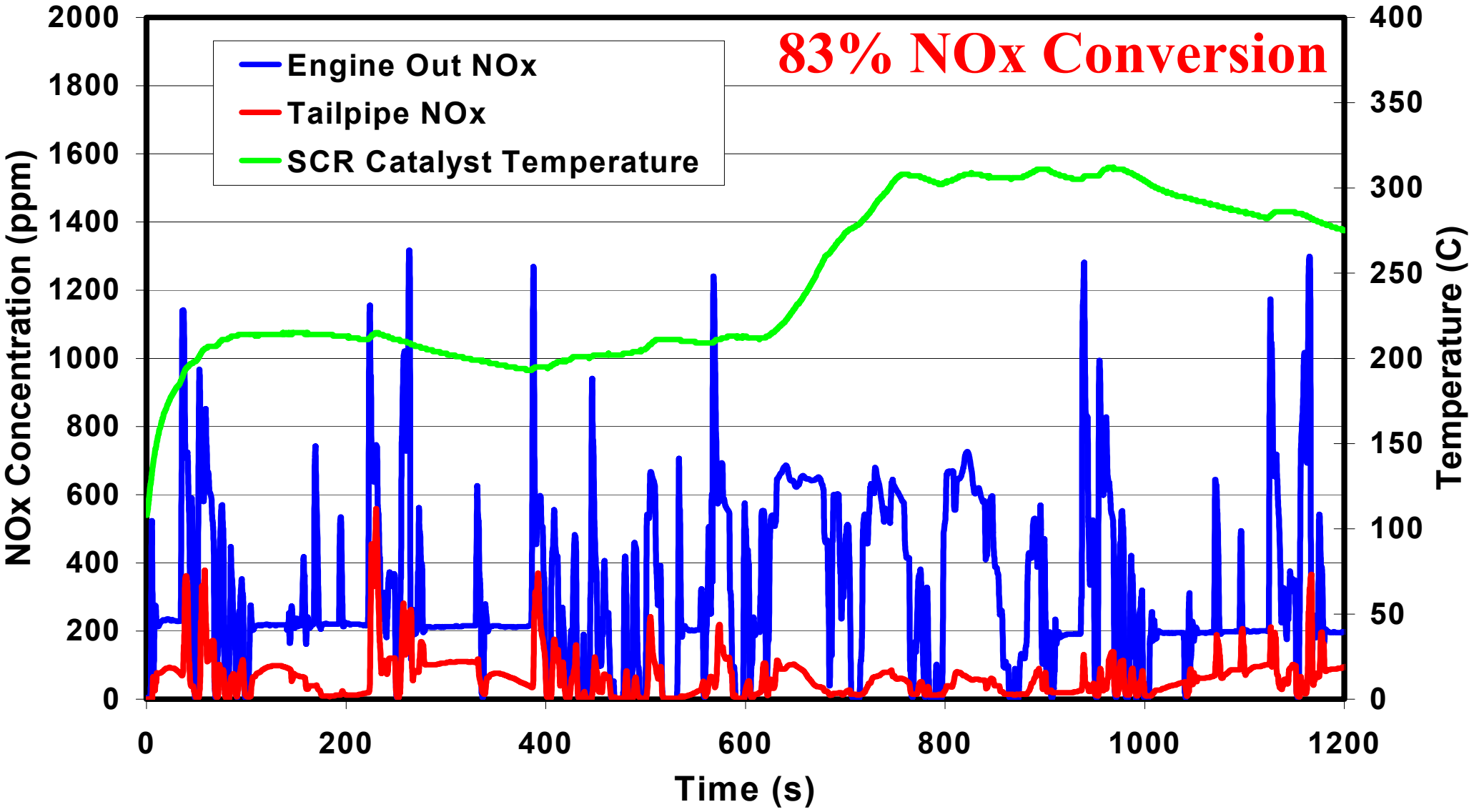
Compact SCRT ESC Performance

84-92% NOx Conversion



See SAE 2003-01-0778

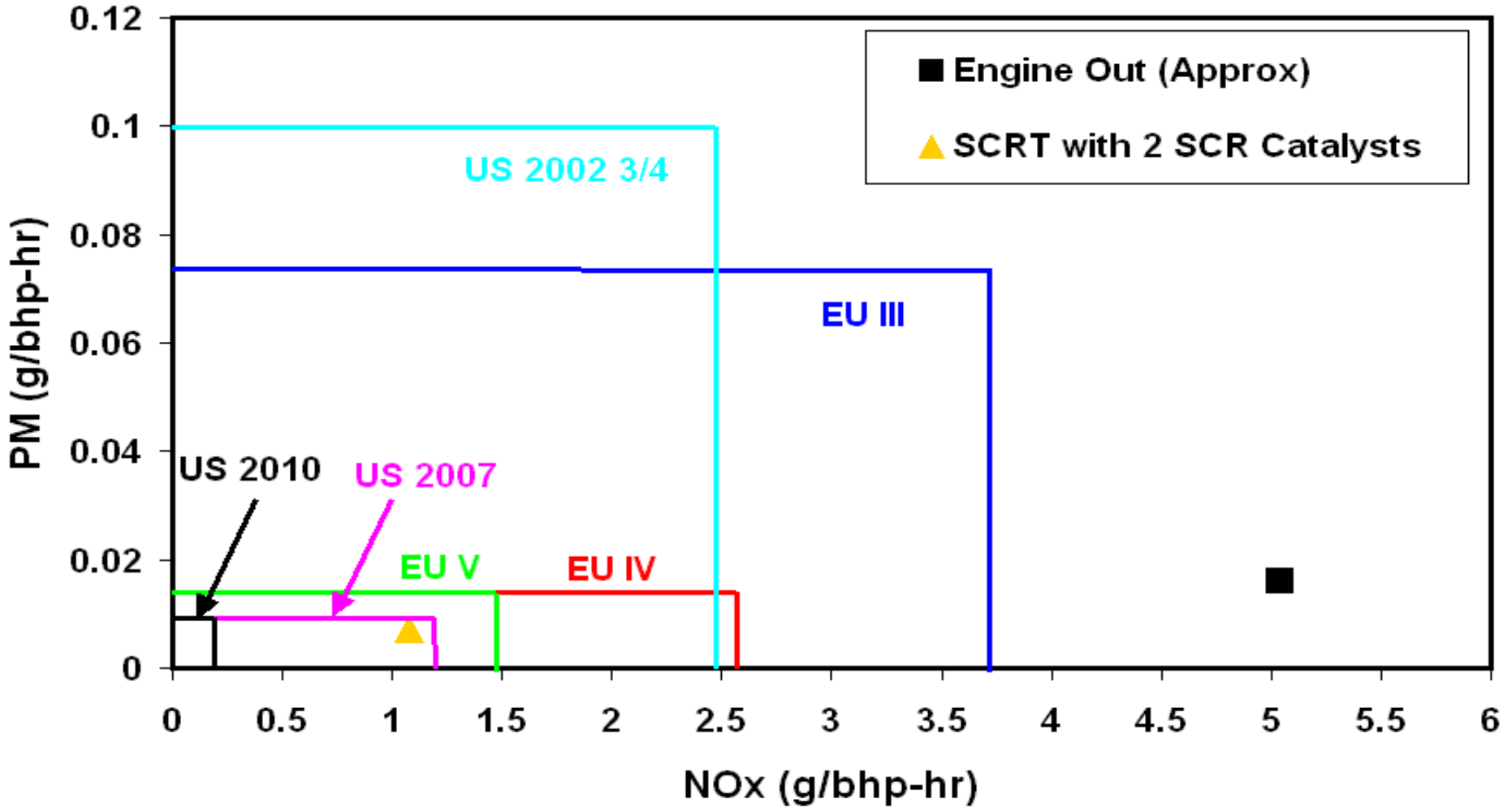
Compact SCRT: Hot Start FTP



See SAE 2003-01-0778

Compact SCRT FTP Performance

79% Weighted NOx Conversion



See SAE 2003-01-0778

Compact SCRT FTP Performance
(weighted; g/bhp-hr)

	HC	CO	NOx
Engine Out	0.199	0.899	5.040
Tailpipe	0.008	0.050	1.079
Conversion	96%	94%	79%
US 2007	0.140	15.500	1.200

(Previous data shows that PM level with DPF systems is around 0.007 g/bhp-hr, against the legislated level of 0.010 g/bhp-hr)

SCRT Systems

- Combined PM + NOx control systems can be designed to give excellent emission control
  - very high conversions of CO, HC, PM and NOx
    - Euro 5 and US 2007 compliance demonstrated
  - careful system design is essential
- Different system configurations can be used:
  - both In-line and Compact SCRT systems offer excellent performance
  - systems can be designed based on available packaging space

Outline of the Presentation

- Introduction
- PM and NOx Control
- Combined Systems for PM and NOx Control
  - Engine bench studies
  - Field studies
- Conclusions

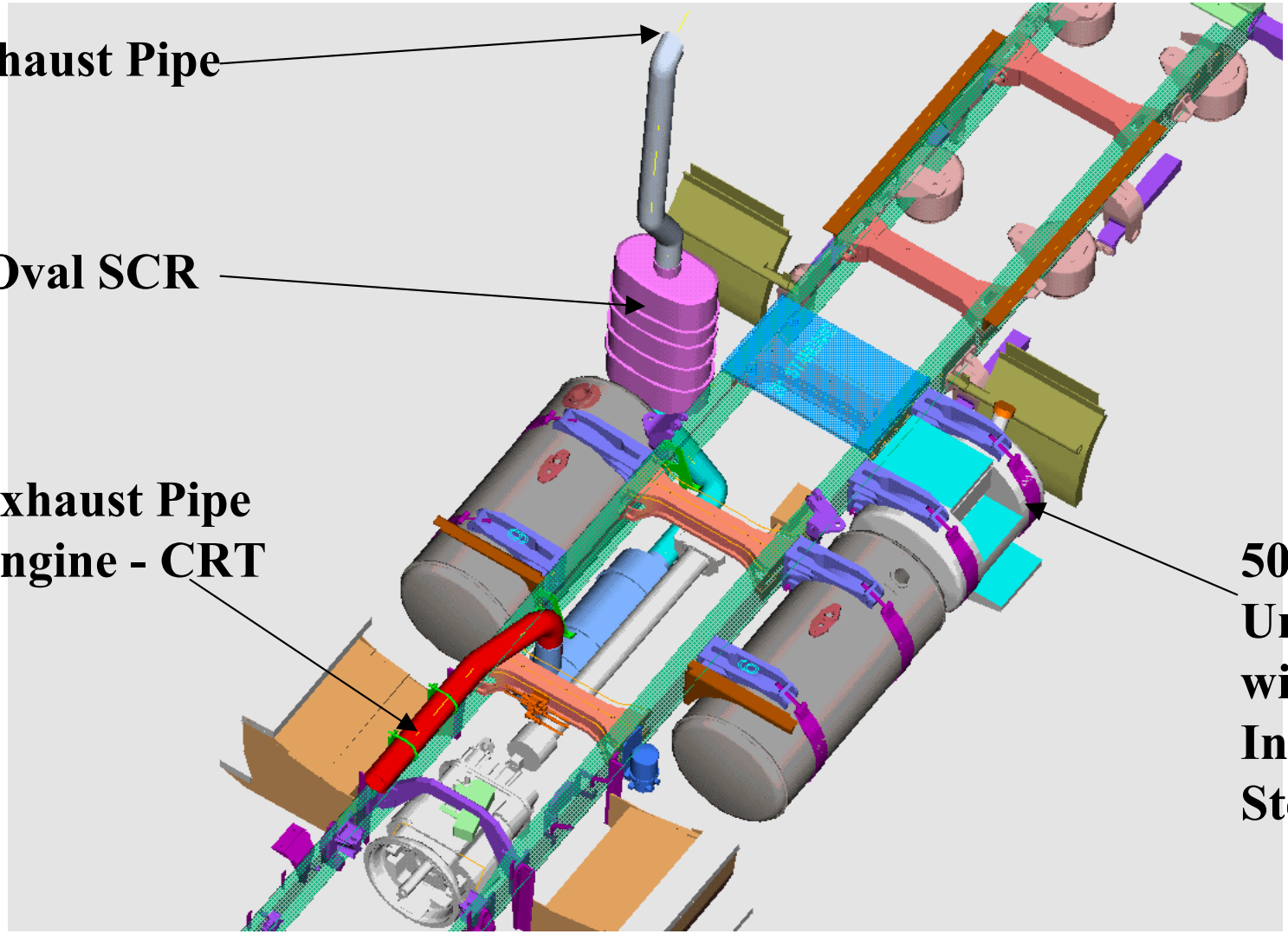
Field Study of the In-Line SCRT System

- Based upon the very promising engine bench data, a field trial was started

- The key system parameters were:
  - Class 8 truck, operating long-distance haulage
    - Cummins ISX 15 litre engine, 450 hp
  - Catalyst Volume = 48 l
  - Filter Volume = 27.5 l
  - Total Volume = 75.5 l

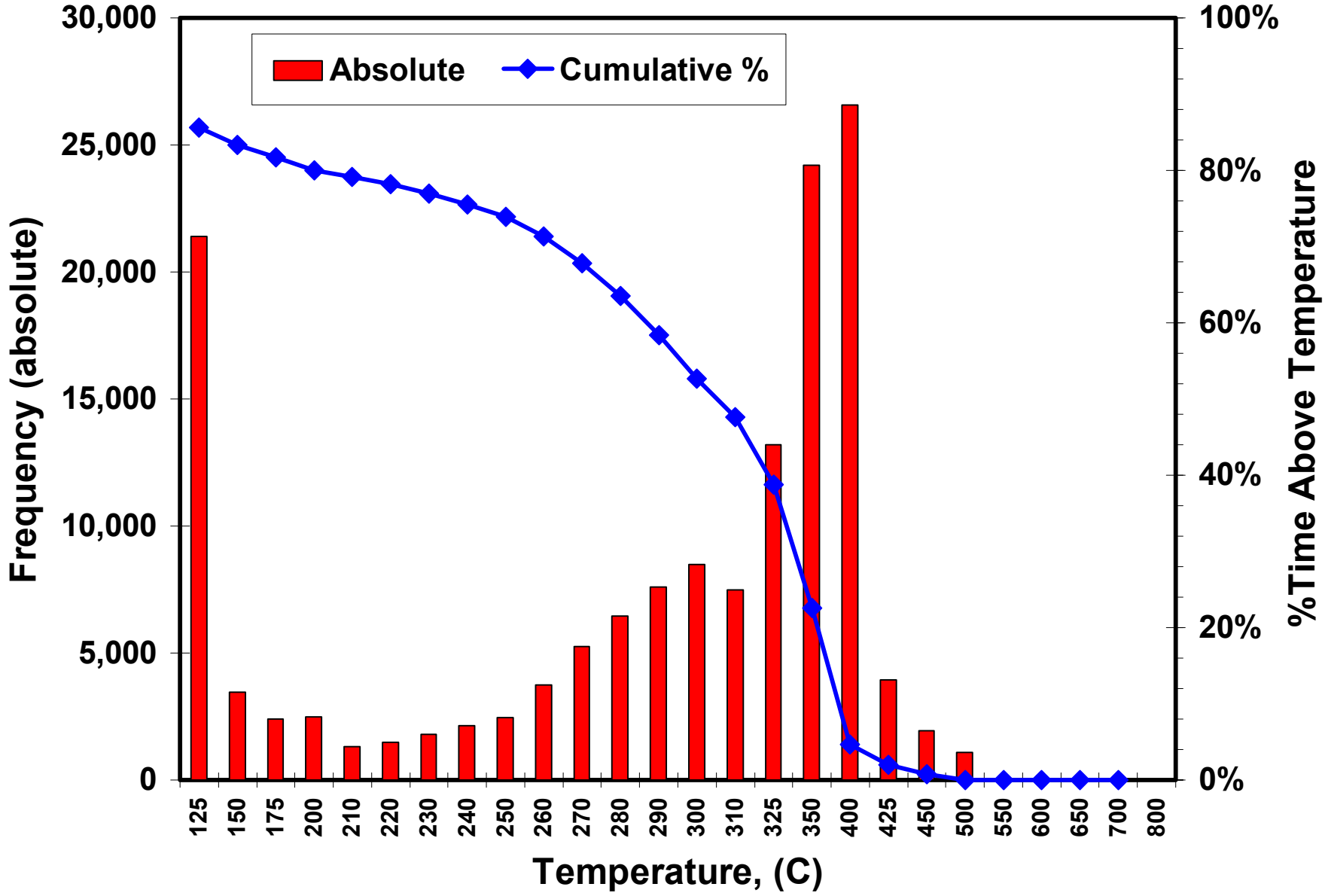
- Urea injected to give an ANR of 0.85

SCRT System Configuration

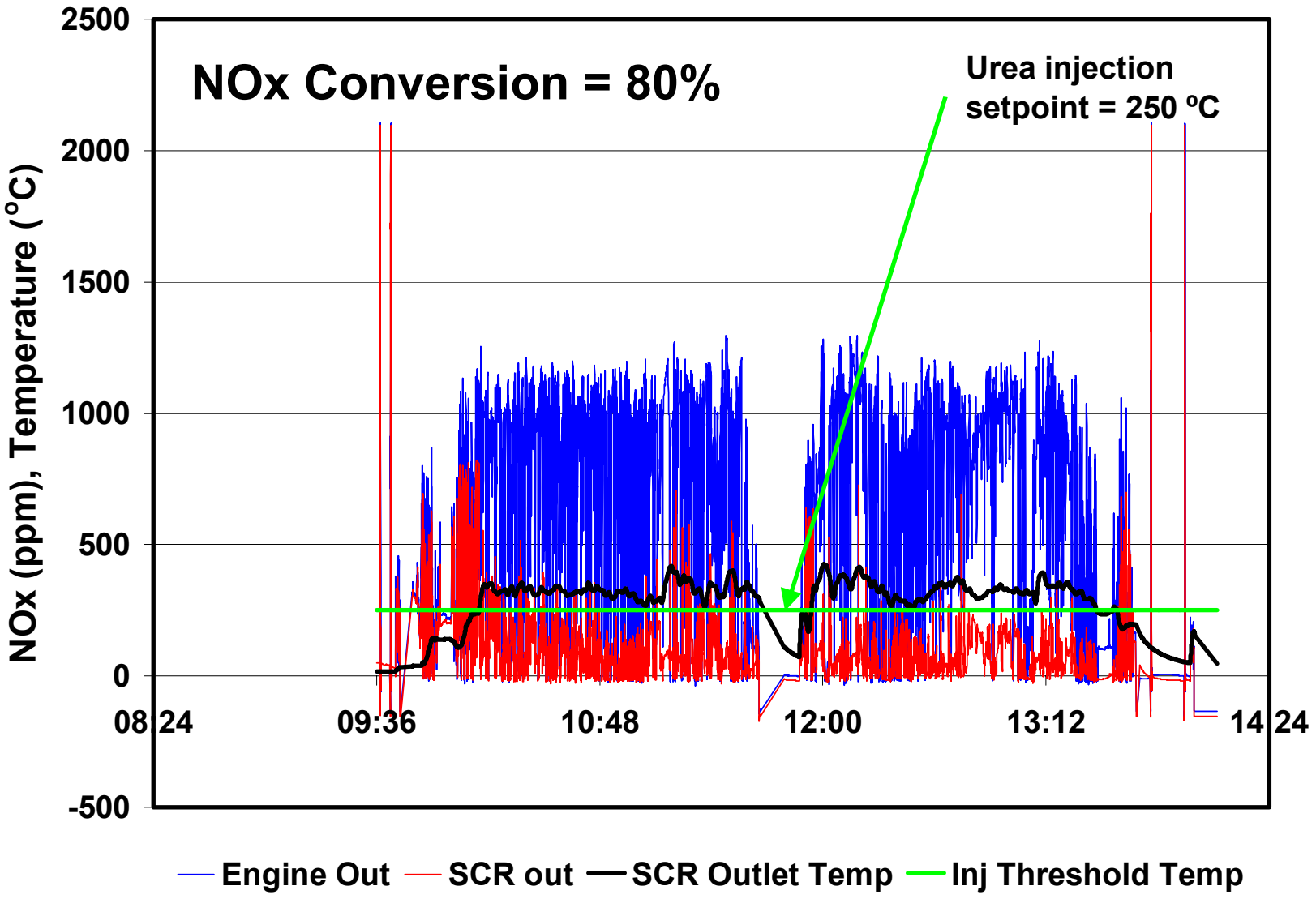


Truck with SCRT System Installed

SCR Outlet Temperature Histogram

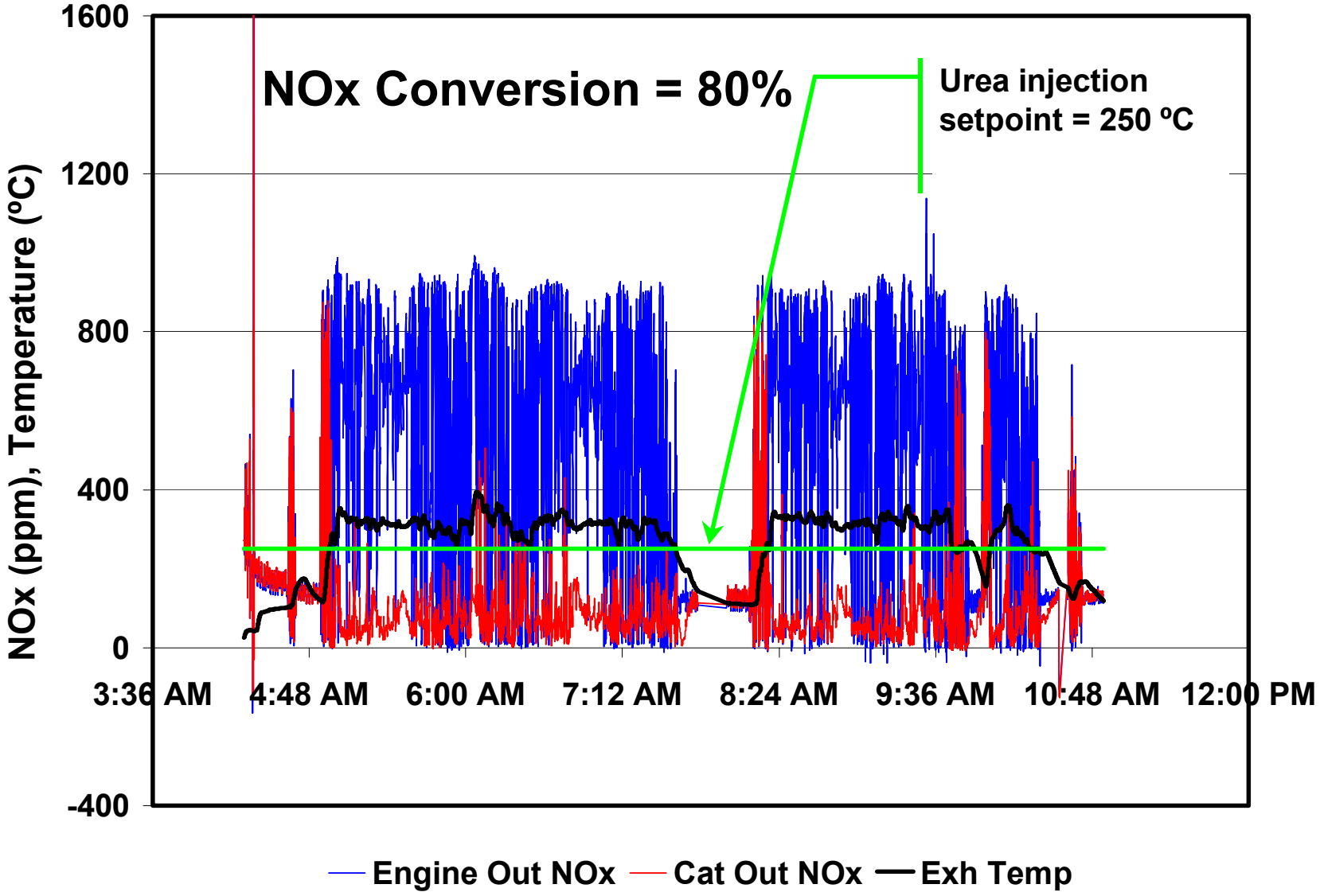


On-Road NOx Conversion: February



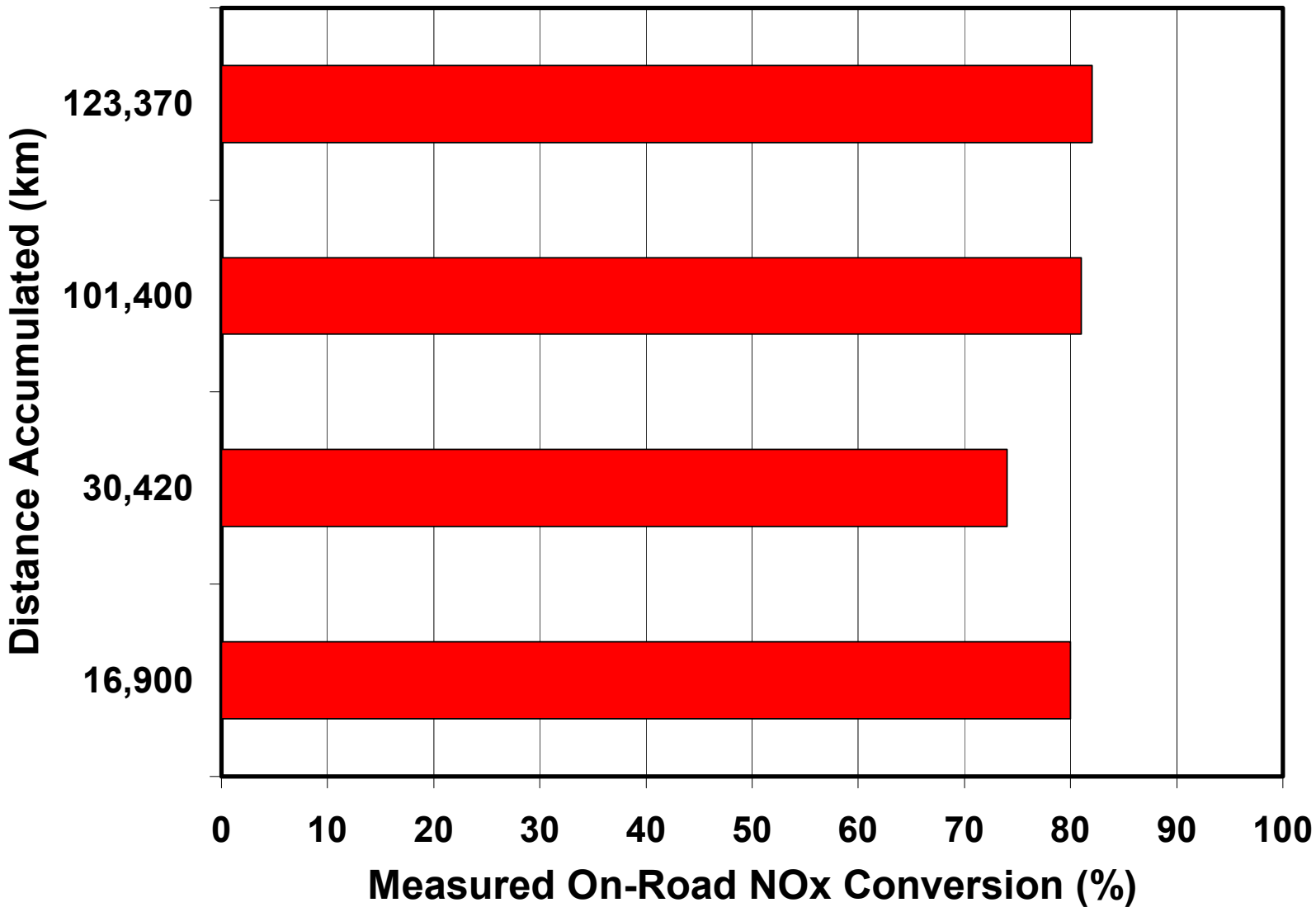
On-Road NOx Conversion: July

Standard Evaluation Trip of ~ 850 km; ANR = 0.85



On-Road System Durability

Standard Evaluation Trip of ~ 850 km; ANR = 0.85



SCRT Field Trial

- Excellent on-road system performance
  - CRT component worked without issues
  - SCR component gave very high NOx conversions
    - 82% NOx conversion with ANR = 0.85
    - SCR efficiency = 96%
- No change in NOx conversion efficiency over 125,000 km
  - excellent system durability demonstrated

Conclusions

- Systems to provide high PM and NOx control have been successfully developed
- These systems can be combined to provide four-way emission control systems
  - In-line and Compact configurations demonstrated
  - Euro 5 and US 2007 compliance achieved
- Excellent field performance and durability demonstrated in long-haul application