LNT + SCR Aftertreatment for Medium-Heavy Duty Applications: A Systems Approach

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2007 DOE DEER Conference

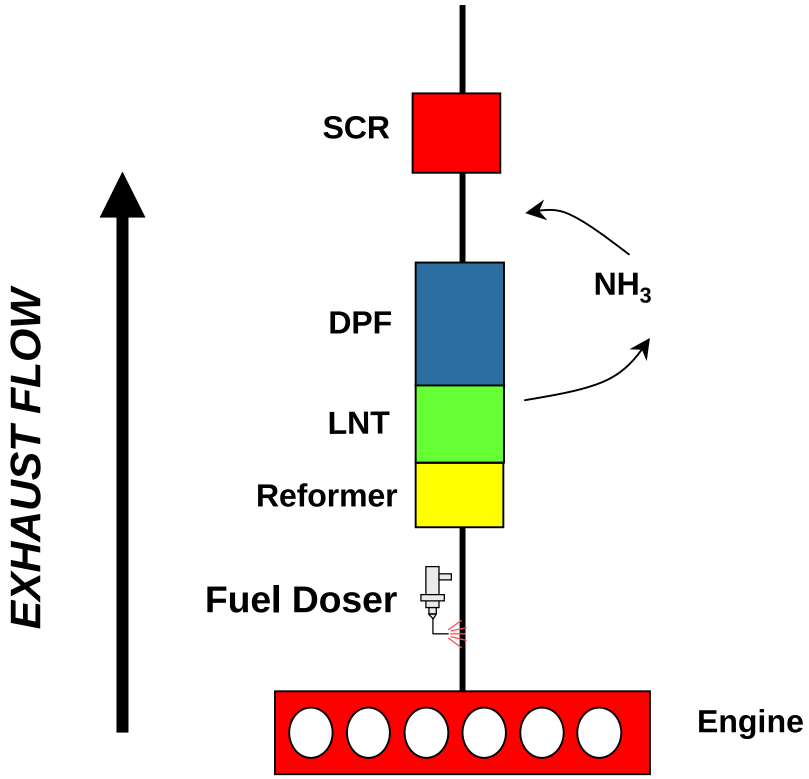
Poster Location: P-1

TOPIC AREAS

1. System Overview
2. System Optimization
3. Desulfation Testing
4. On-Road Vehicle Testing

System Overview

reformer + LNT + cDPF + SCR



System Function:

- Reformer Catalyst converts dosed HC into H2
- LNT regenerations produce NH3 pulse
- NH3 pulse enables downstream SCR Catalyst
- Integrated DPF for PM Control

Value Proposition:

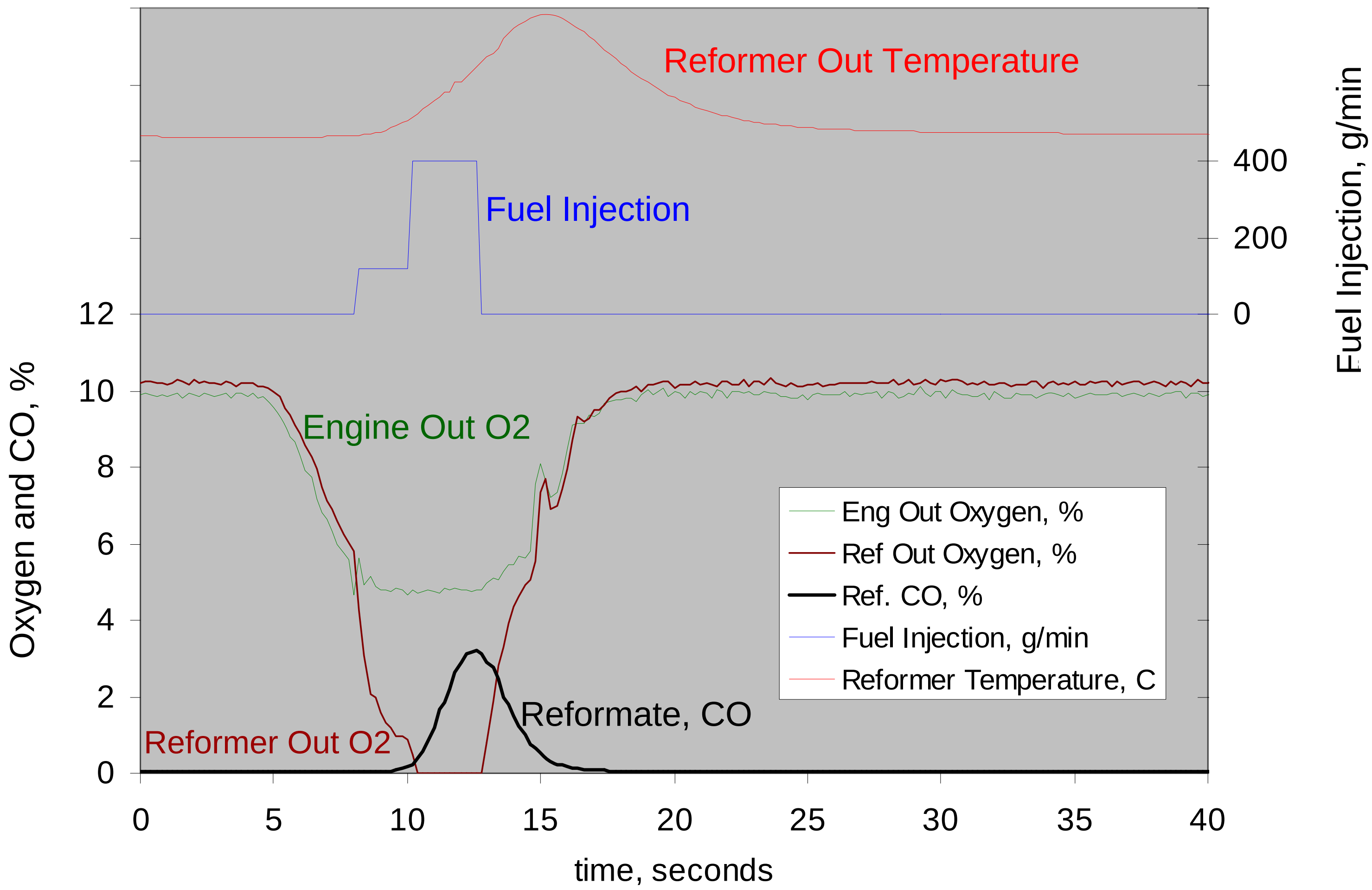
- Cost & Size Competitive to SCR
- No Urea Infrastructure Required

Key Challenges:

- LNT Durability through DeSulfation Cycles
- On-Board Transient Control

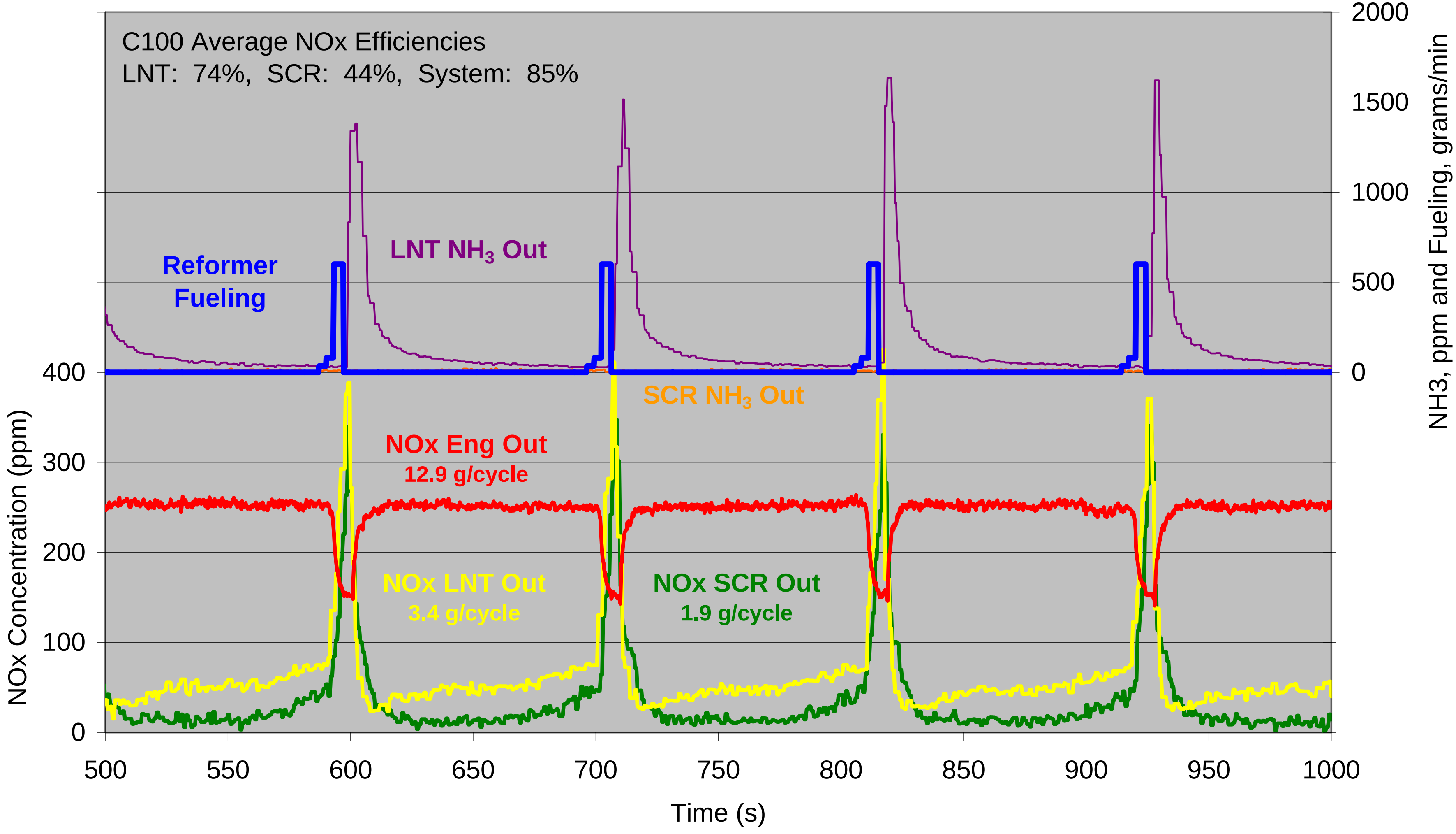
System Operation: Typical Regeneration Event

US'04 engine, steady-state engine condition



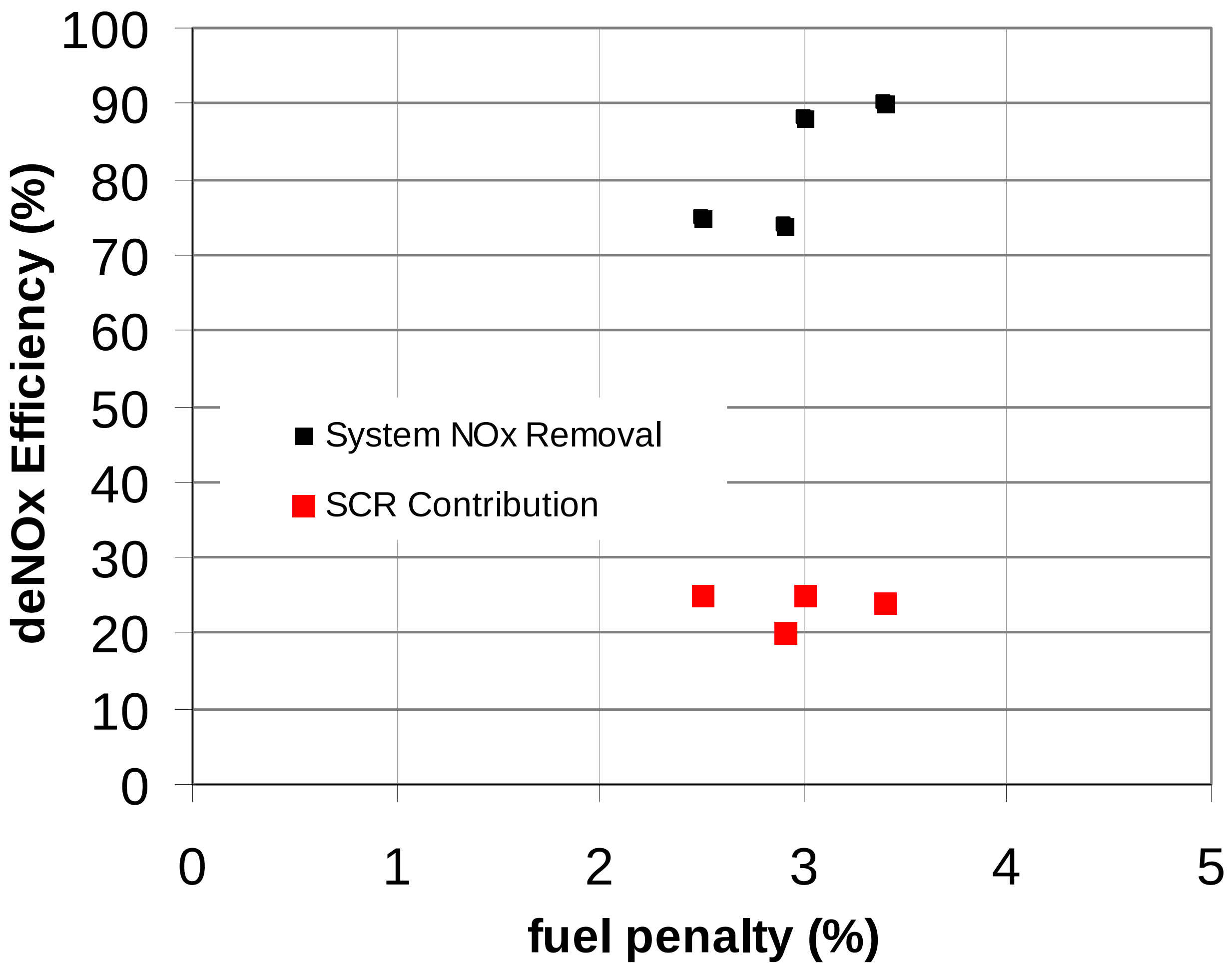
System Operation: Typical NOx Performance

14L engine, US'04 engine-out NOx, C100 engine condition

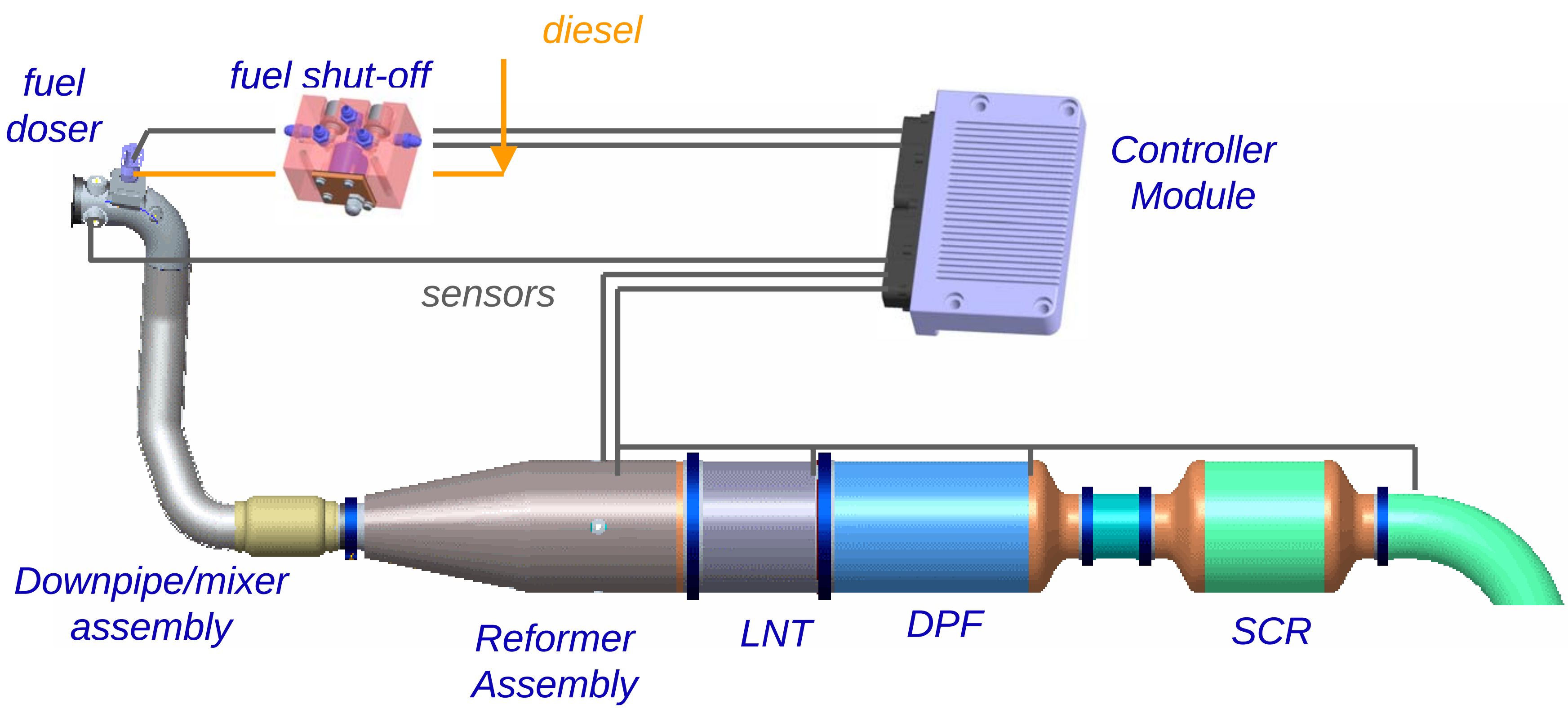


DeNOx Performance vs Fuel Efficiency

hydrothermally aged catalysts,
various engines & conditions



Aftertreatment System Layout
on-board prototype for testing, 1q 2008



System Overview: Summary

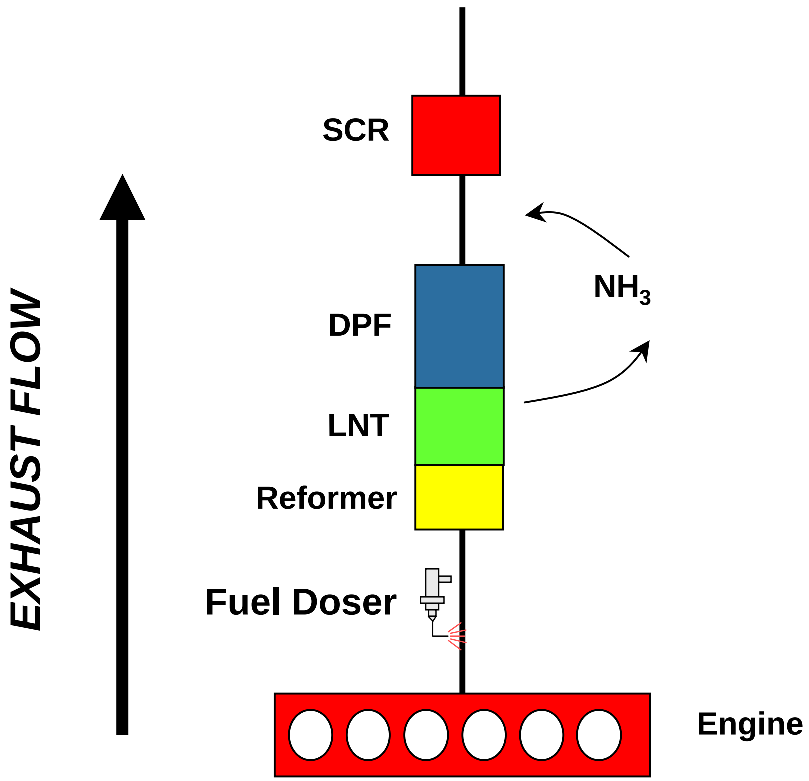
- Reformer, LNT, and SCR work in tandem to reduce NOx
  - Rich-pulse via doser hydrocarbons
  - LNT regeneration generates NH_3 for SCR

- Integrated DPF for PM control
  - Regeneration capability via lean-fueling reformer catalyst

- Competitive US2010 Performance Seems Achievable
  - Approximately 80% NOx Conversion
  - Approximately 3% fuel penalty

- Key Risks to be Considered:
  - LNT Desulfation / Durability
  - On-Board Transient Control

System Optimization

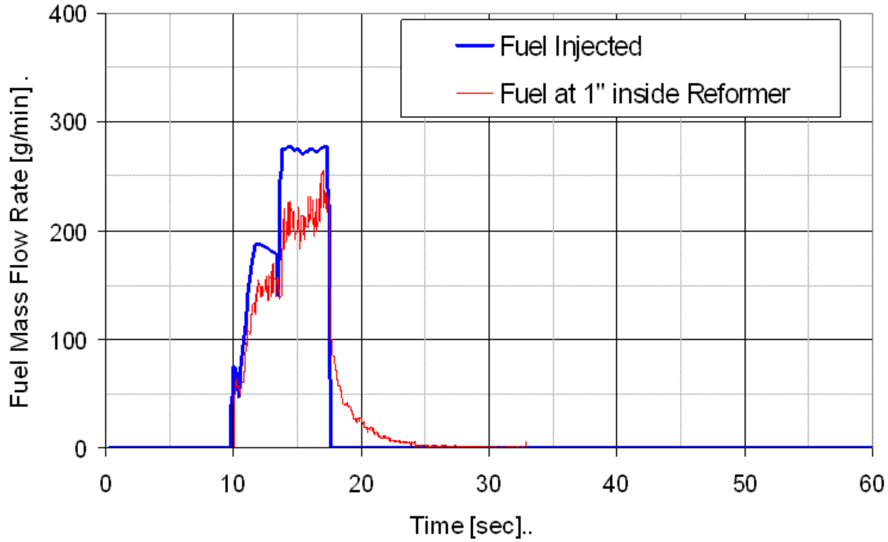


- System Modeling for Catalyst Sizing and Parameter Optimization
- CFD Optimization for spray dispersion & vaporization
- PGM Cost Reduction

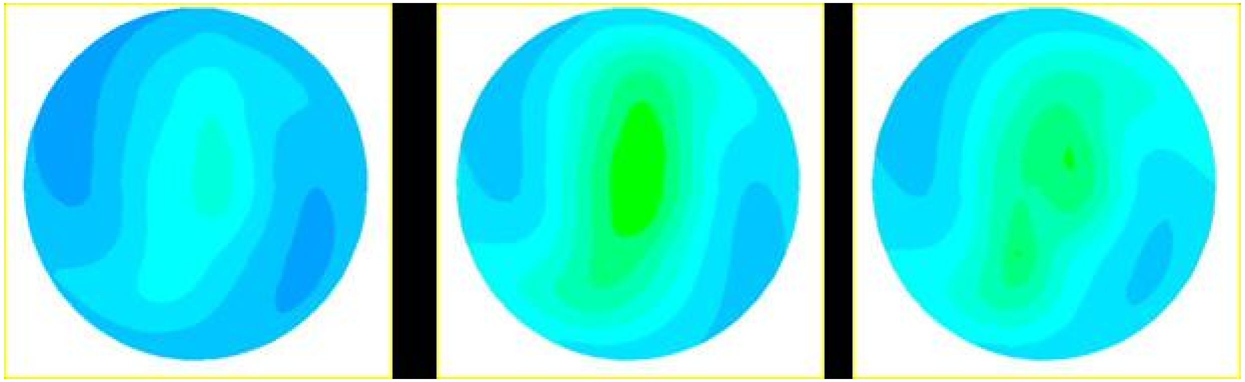
Original Mixing / Dosing System Performance

- •Straight pipe between doser and mixer
- •Large dosed droplets
- •'best guess' doser location and orientation
- •Large diameter downpipe

Major pulse-broadening effect…



…and poor distribution of hydrocarbons:



Optimized Mixing/Dosing System

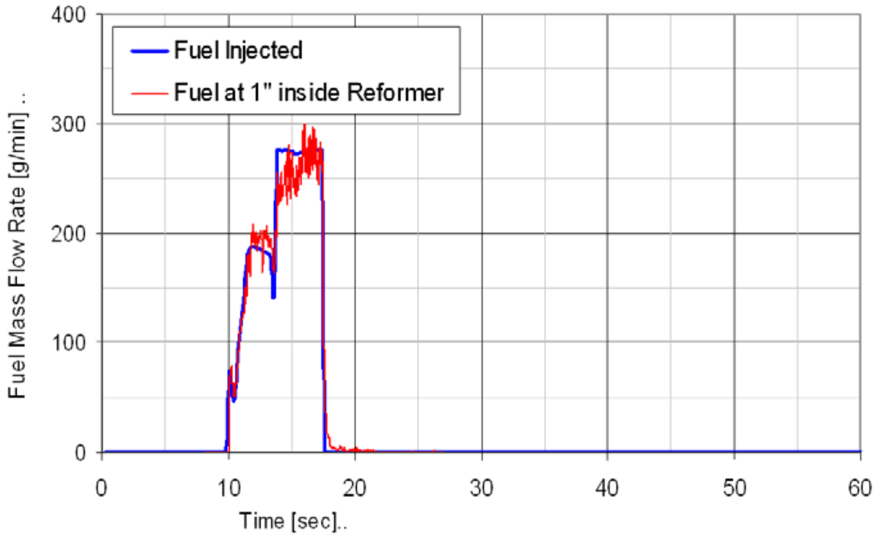
- Pipe bends between doser and reformer

- Small dosed droplets

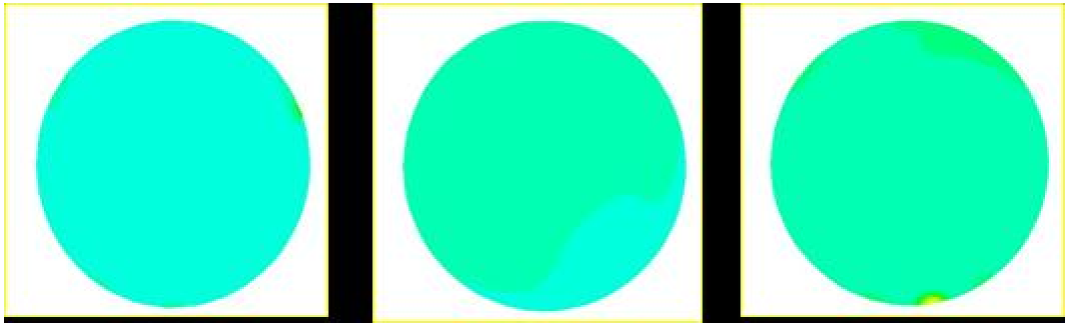
- Optimized doser location & orientation

- Small diameter downpipe

Pulse-broadening greatly reduced..



…and HC distribution much improved



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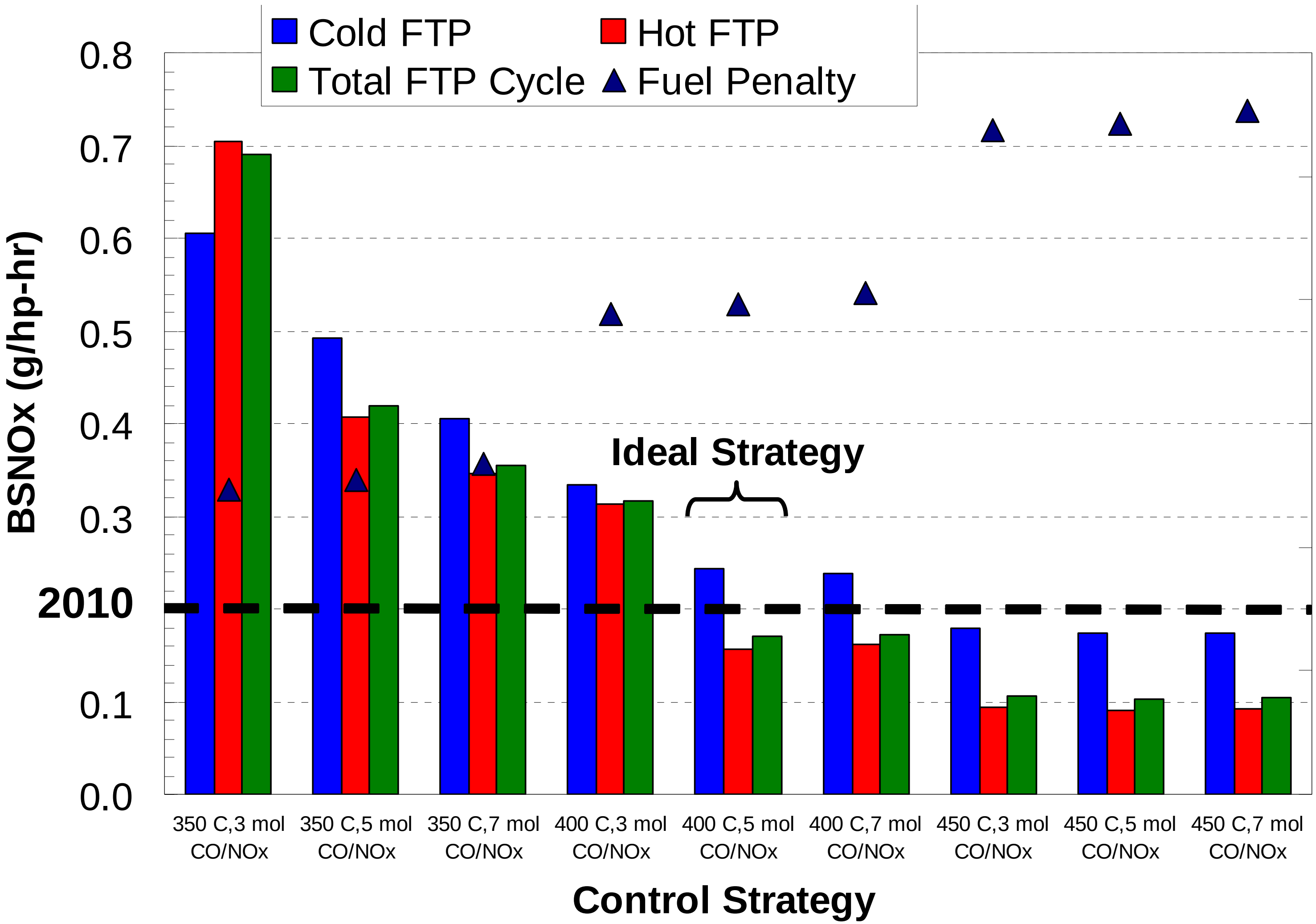
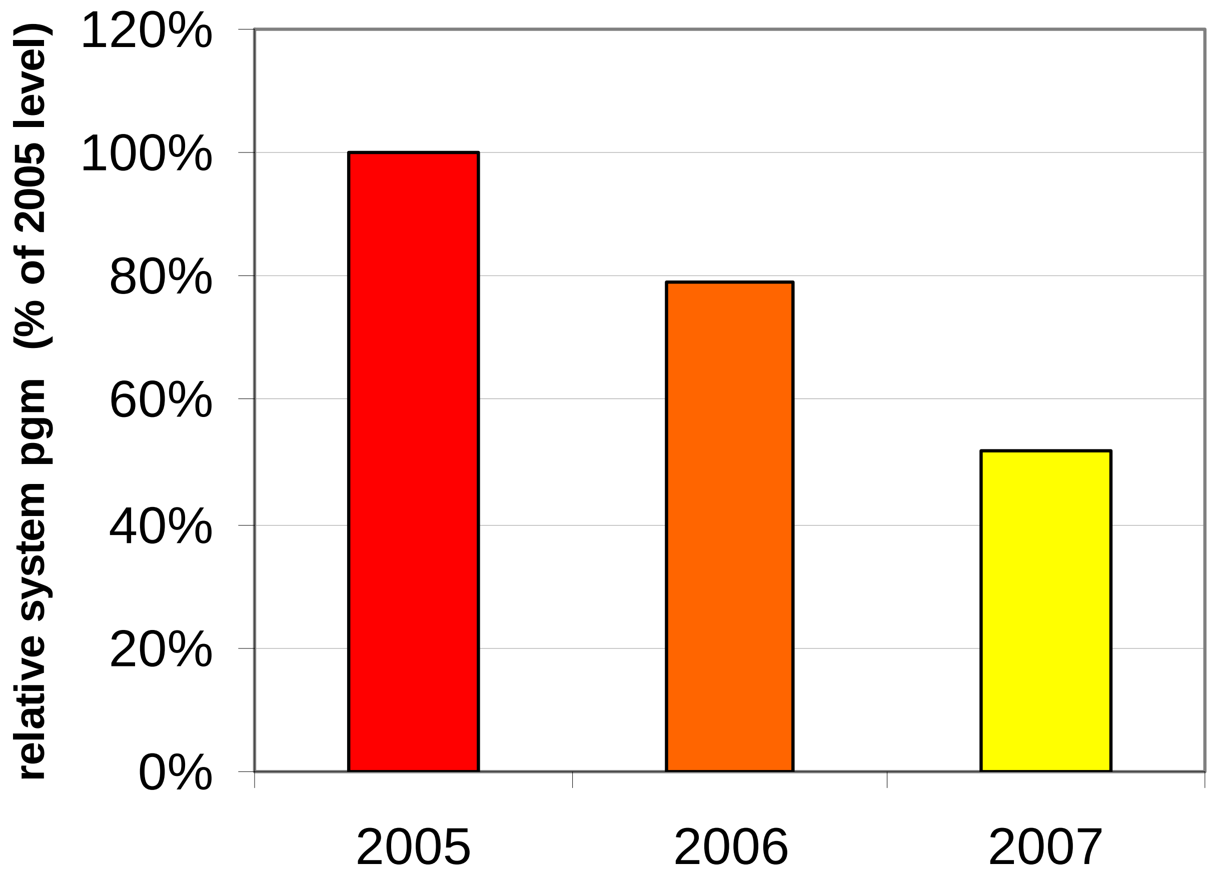
Optimization of Control Calibration via Simulation

warm-up temperatures, richness level, reductant to NOx ratio



Optimization Yields Major Improvements in Catalyst PGM Cost

relative PGM cost vs time



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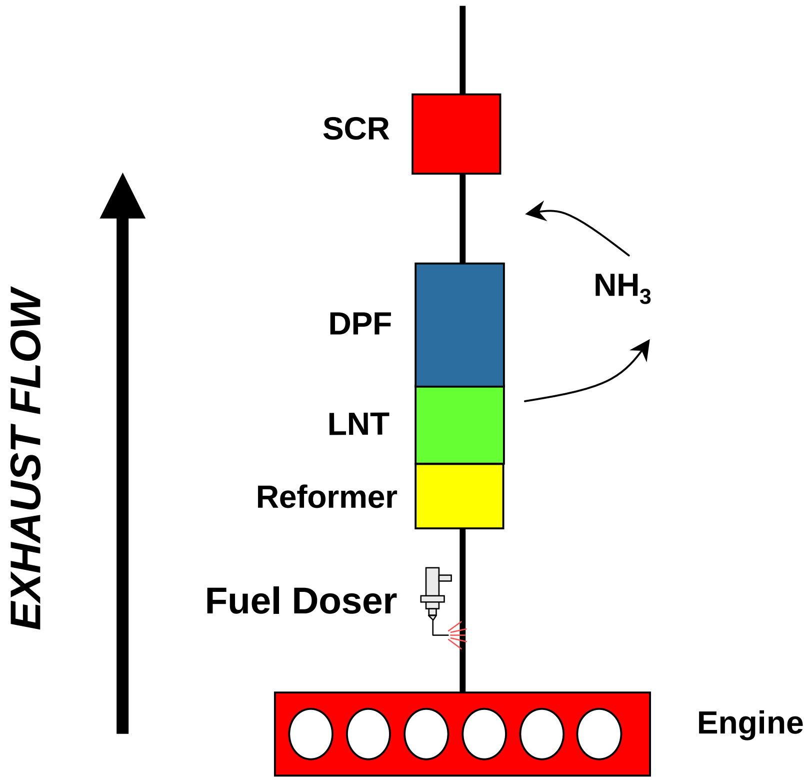
DeSulfation Testing: Overview



<u>Approach: Repeated Cycle On-Engine Aging:</u>

•Load LNT with sulfur from engine-fuel

•Remove sulfur with aftertreatment system control function (dosed fuel process)

•Repeat

<u>Two Tests Completed:</u>

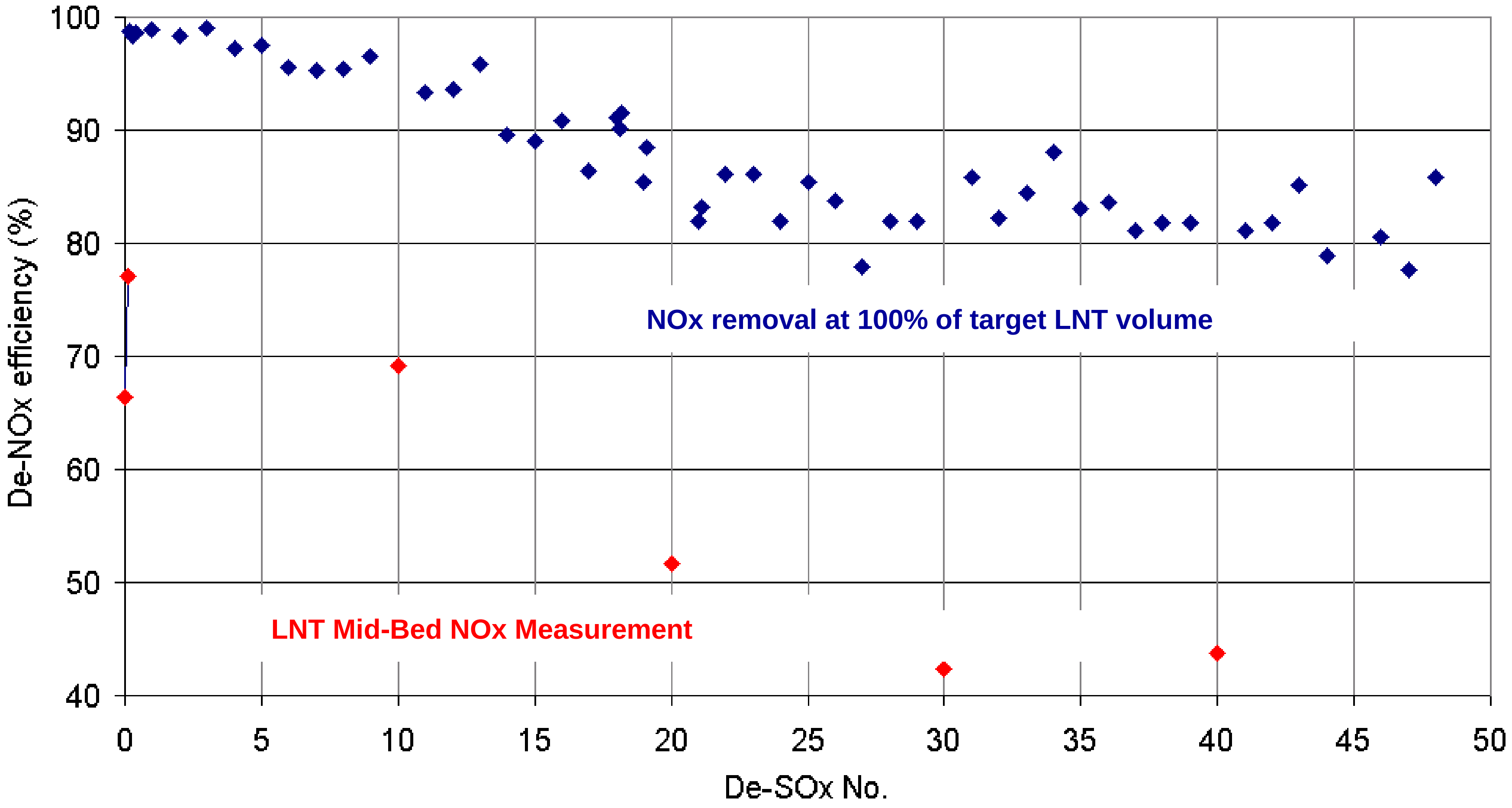
•*<u>TEST 1:</u>*

- •50-cycles (approx 50,000 miles)
- •completed 4q 2006
- •9L US'04 engine

•*<u>TEST 2:</u>*

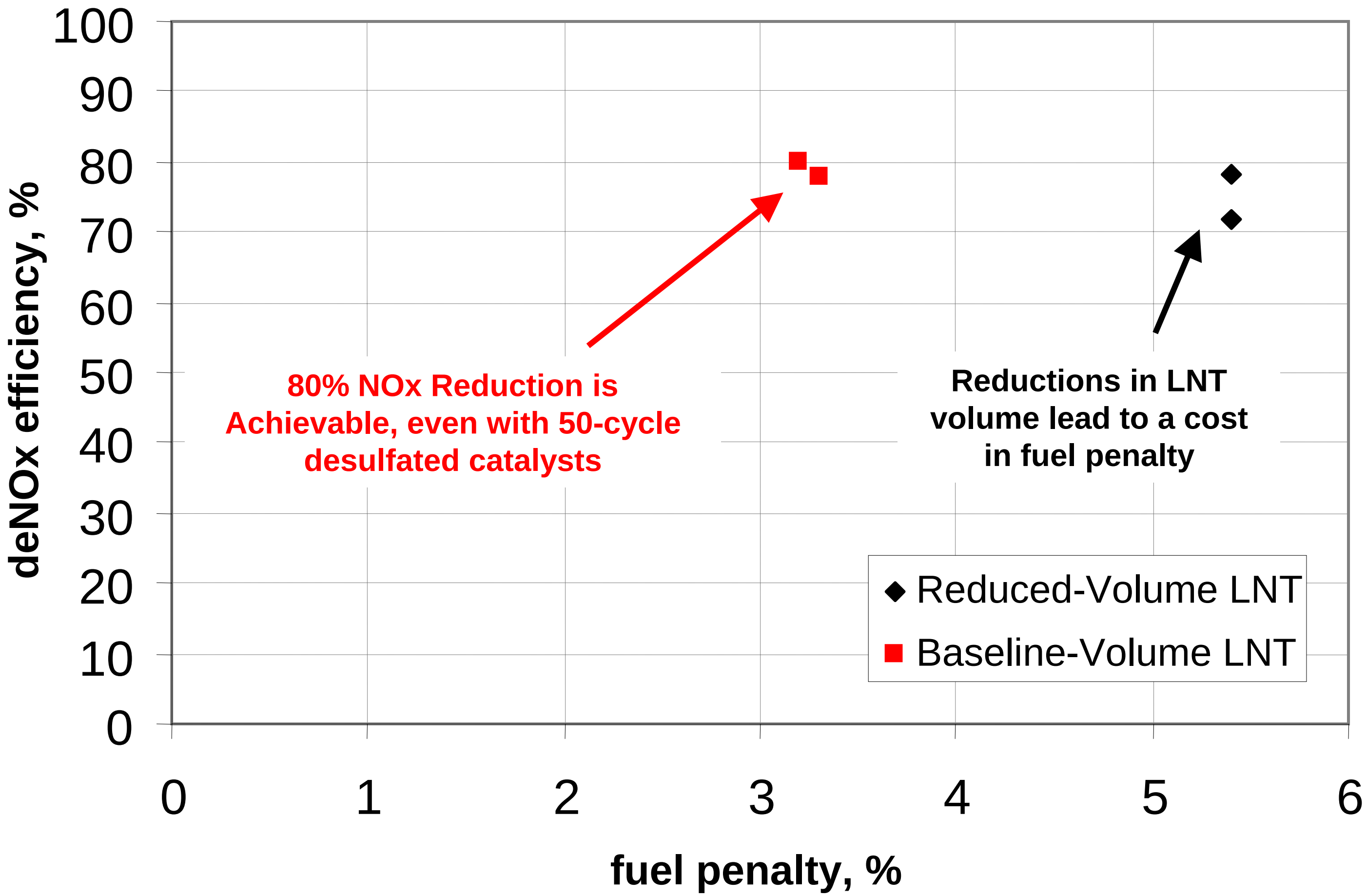
- •150 cycles (approx 150,000 miles)
- •Completed 2q 2007
- •7L US'07 engine

NOx Removal Efficiency After 50 DeSulfation Cycles
9L Engine, US'04 engine-out NOx
August 2006



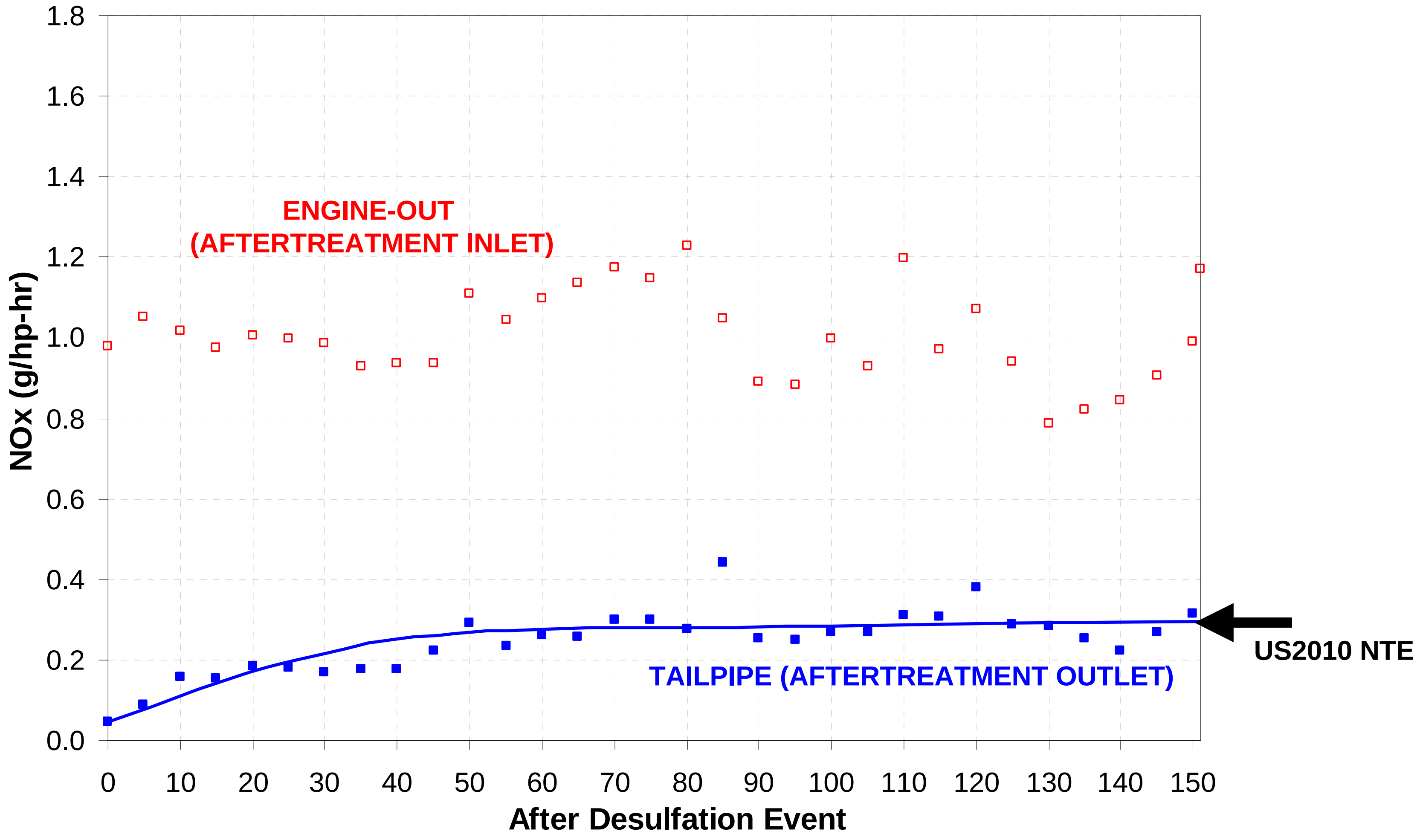
DeNOx Performance vs Fuel Efficiency

after 50-cycle desulfation-aging
December 2006



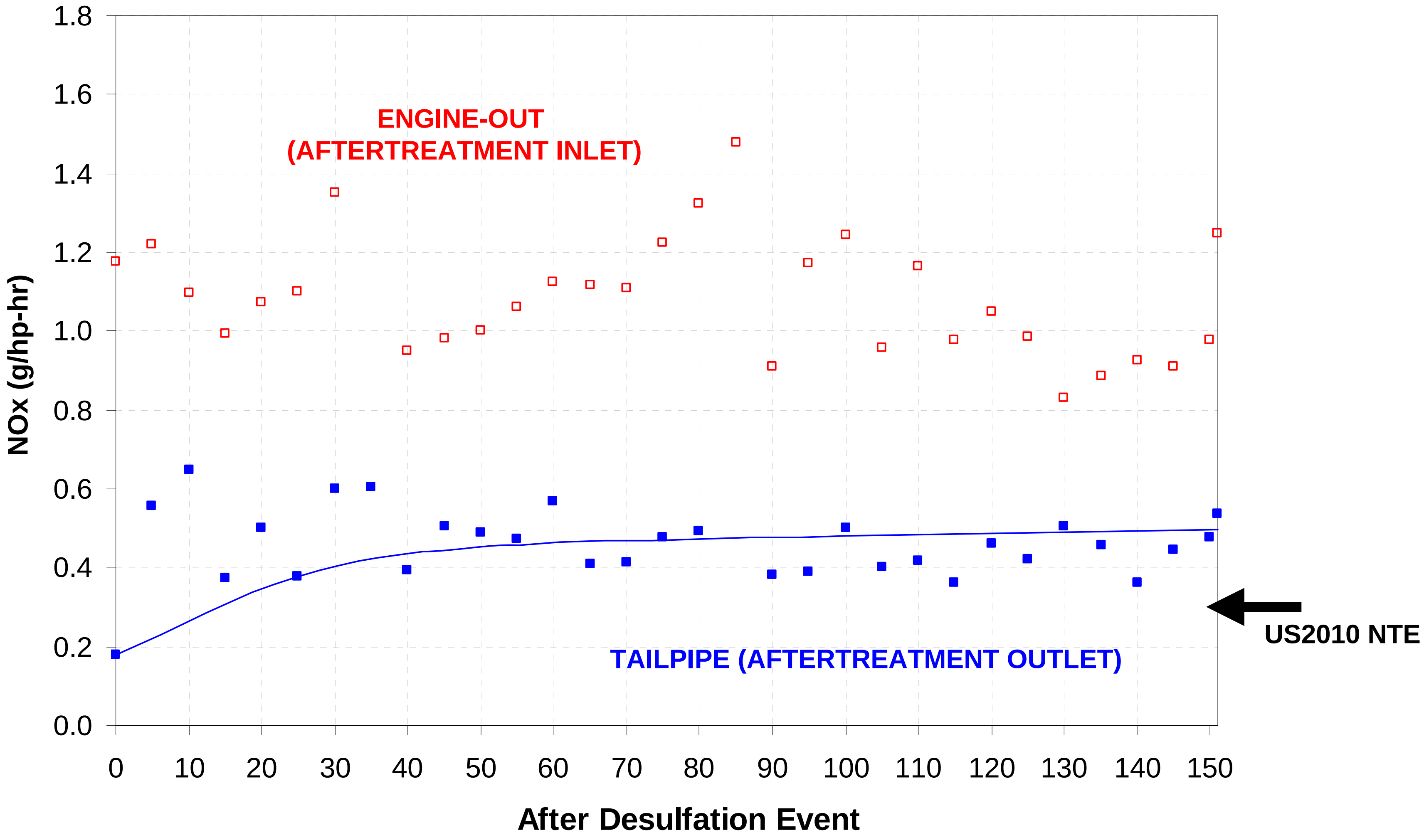
Brake Specific NOx After 150 DeSulfation Cycles

7L Engine, US'07 engine-out NOx, mid-load condition
June 2007



Brake Specific NOx After 150 DeSulfation Cycles

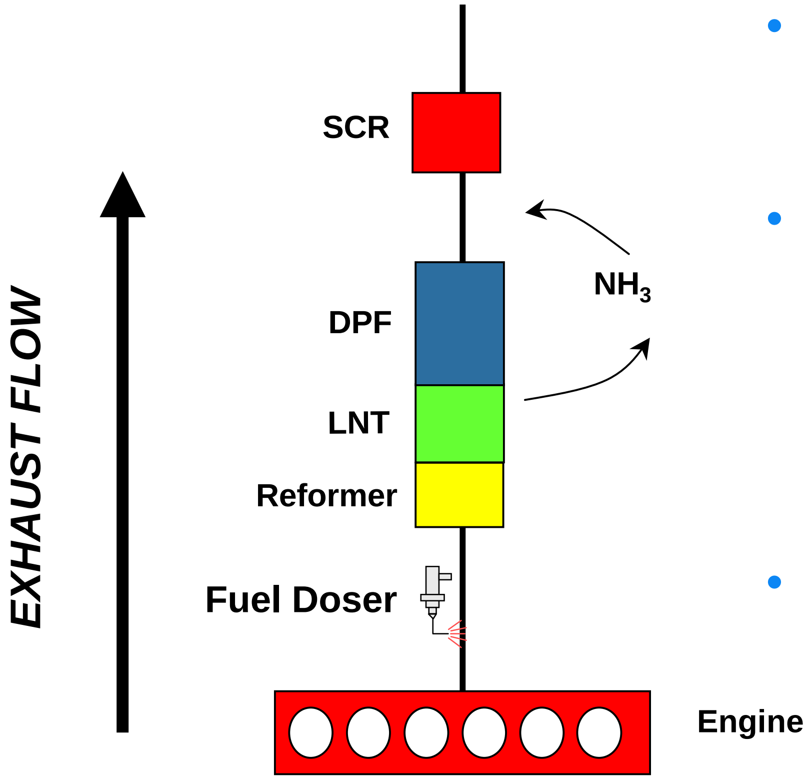
7L Engine, US'07 engine-out NOx, high-load condition
June 2007



DeSulfation Testing: Summary

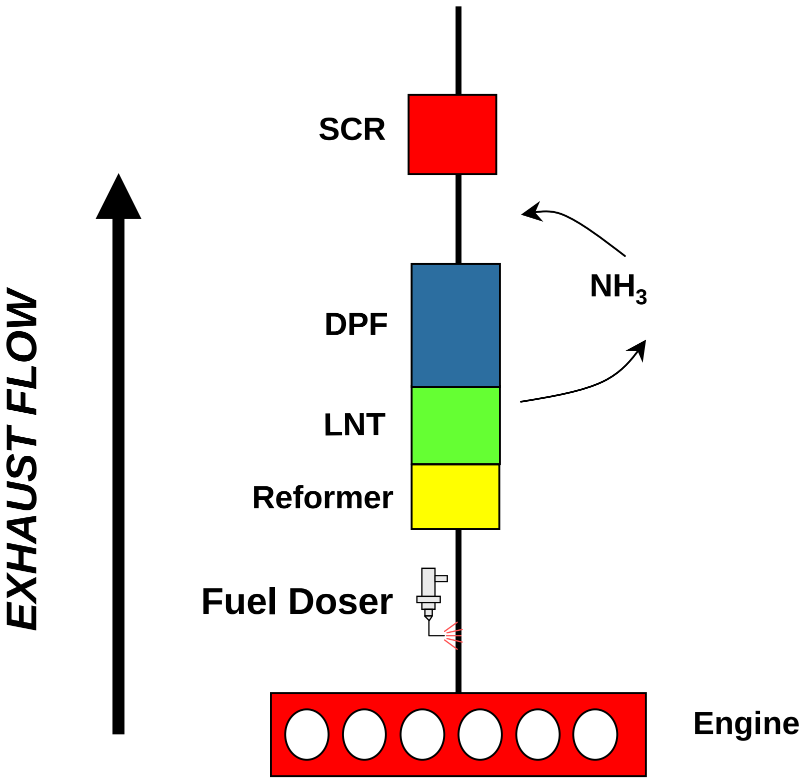
- 80% NOx reduction in 13-mode cycle after 50-cycle desulfation
- 2010 NTE condition met after 150 desulfation cycles
  - For mid-load condition
- 2010 NTE condition not met after 150 desulfation cycles
  - For high-load condition
  - Incremental progress is needed to meet US2010 NTE
- Basic ability proven in repeated-cycle testing
  - Incremental gain needed in test cell environment
  - On-board testing required to validate through transient cycles

On-Road Vehicle Testing: Overview (1 of 2)



- MD Truck with 7L, 270HP, US’07 Engine
  - Installed 5/2007; testing summer 2007
- Aftertreatment System with fully automated on-board transient control
  - de-NOx regeneration
  - DPF regeneration
  - De-Sulfation
- Objectives:
  - Determine on-board NOx performance in transient environment
  - Develop & validate on-board transient de-sulfation process

On-Road Vehicle Testing: Overview (2 of 2)



- Catalysts
  - Hydrothermally aged before installation
  - All NOx conversion shown after 20-30 desulfation events
  - Cordierite DPF technology
  - 15 ppm vehicle fuel (2007 'pump' fuel)
- Instrumentation
  - NOx sensors at engine-out and tailpipe
  - Various thermocouple and O_2 measurements

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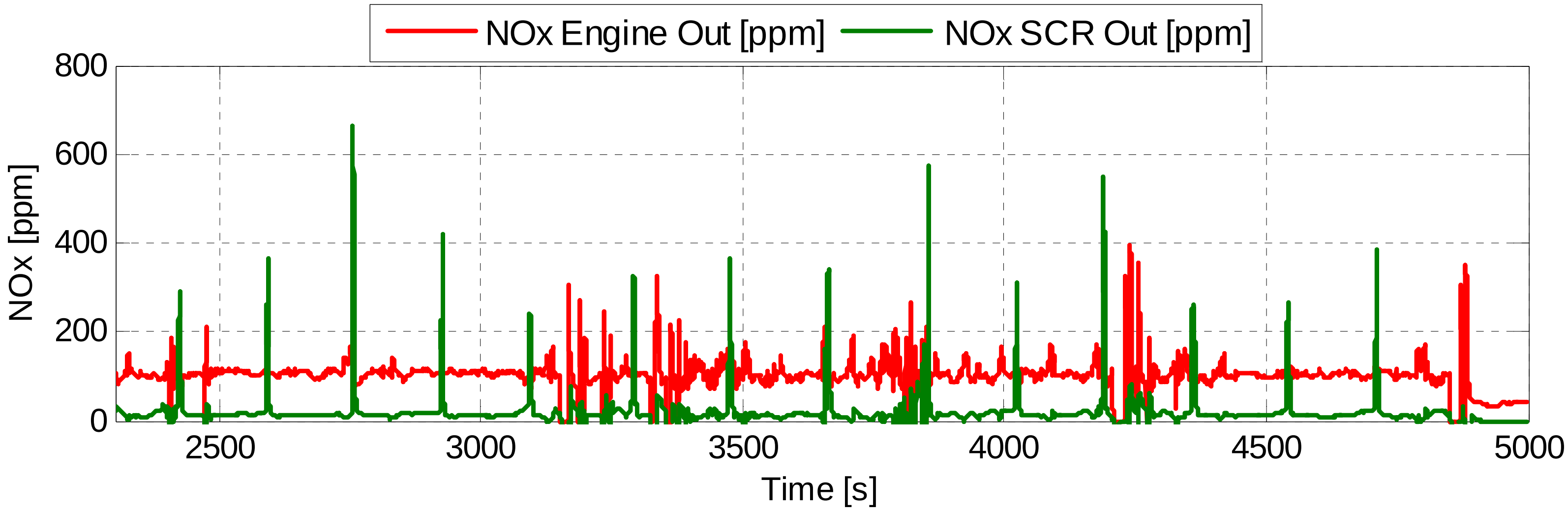
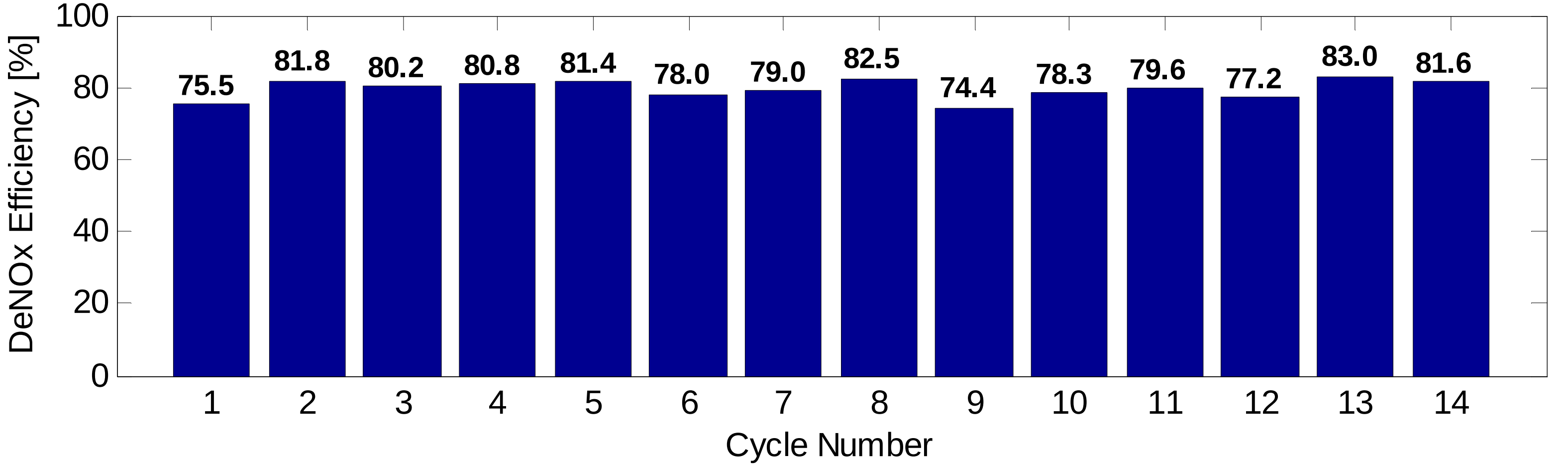
On-Road NOx Reduction Performance

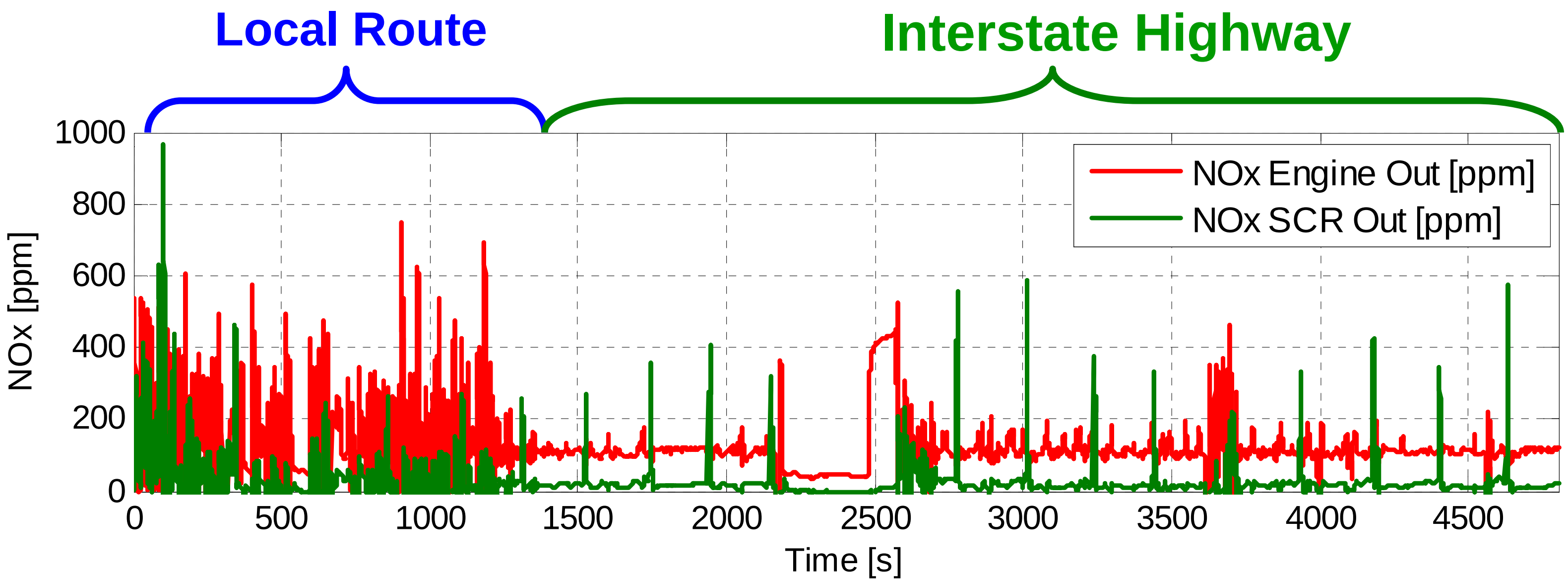
Interstate 94, June 2007

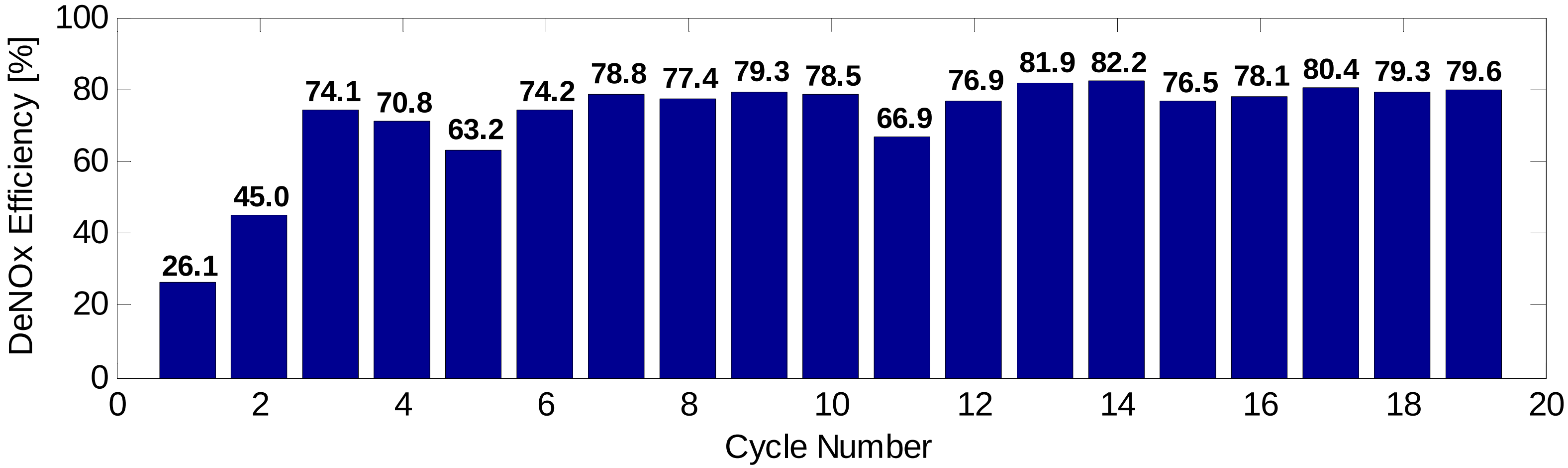




On-Road NOx Reduction Performance

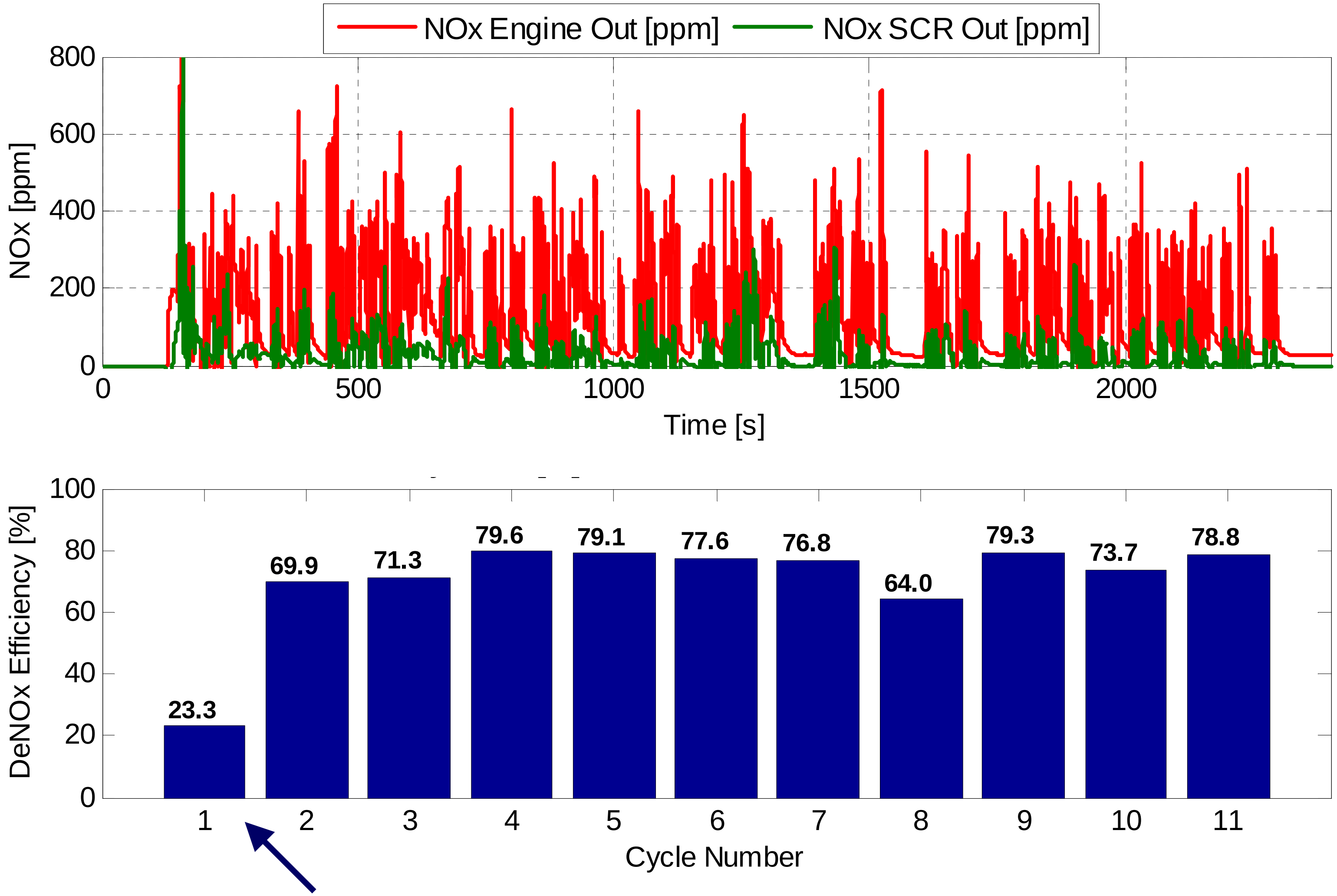
mixed-mode operation, June 2007





On-Road NOx Reduction Performance

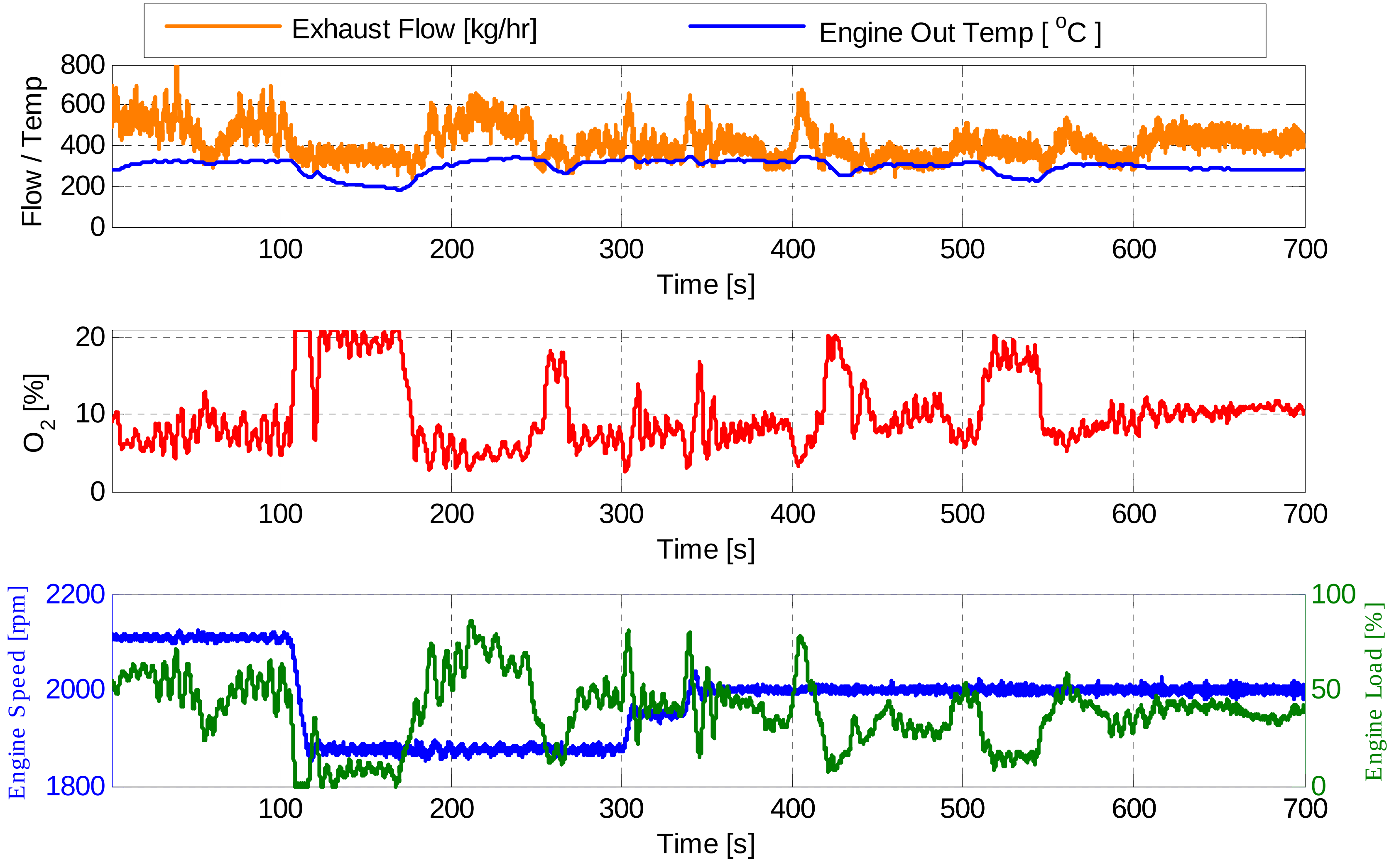
Urban Driving Route, June 2007



Cold-Start after cold soak limits initial performance

Conditions for Transient Desulfation

On-highway with engine speed & load variation



On-Board Transient Desulfation

Interstate 94 / Highway Driving Conditions

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On-Board Testing Summary

- 75 – 80% NOx reduction demonstrated across a variety of transient drive cycles
  - On-highway
  - Urban driving
  - Mixed mode
- On-Board desulfation process demonstrated in transient testing conditions
  - Good NOx performance after on-board desulfation
  - Basic ability to handle engine transients