12th Diesel Engine-Efficiency and Emissions Research Conference

Eaton Aftertreatment System (EAS) for On-Highway Diesel Engines

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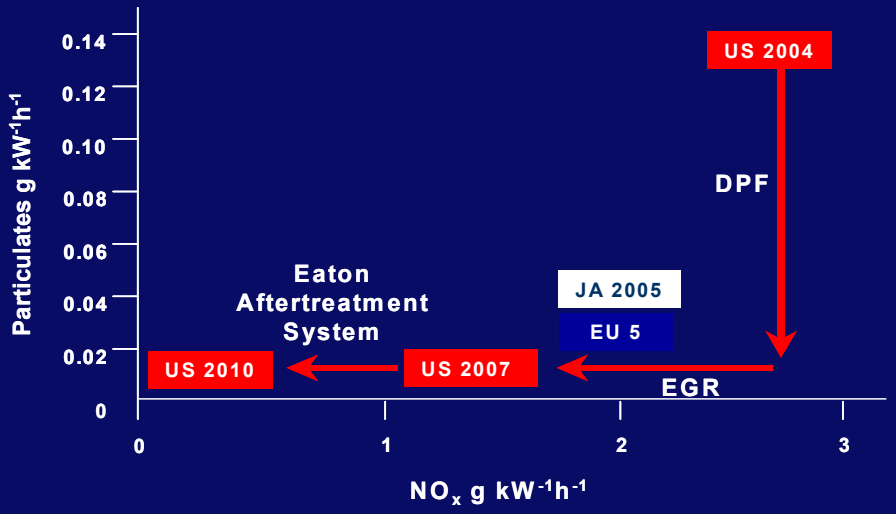
Agenda

- Challenges and Opportunities
- The Development of Eaton Aftertreatment System (EAS)
- Summary

Challenges of Stringent Diesel Engine Emissions Regulations

Evolution of ON-Highway Emissions Regulations



- Aftertreatment Systems Are Required to Meet 2010 Ultra-low NOx Requirements
- Most Probable Solutions:
  - Urea SCR Catalysts
  - NOx Adsorber (LNT) Catalysts

Challenges and Opportunities:

- SCR Catalysts Requires Urea Supply Infrastructure, which Is Unlikely to be Available for North America Market by 2009
- NOx Absorber (LNT) System has Higher Fuel Penalty and Durability Concerns
- A New Aftertreatment System Is Required

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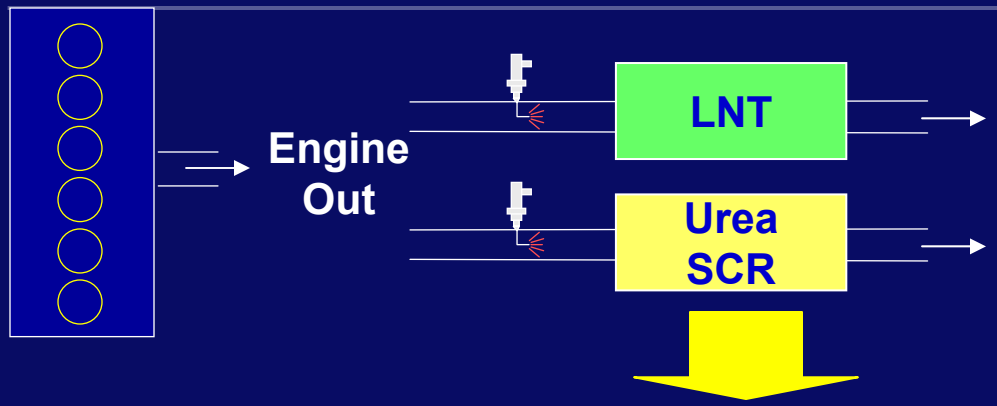
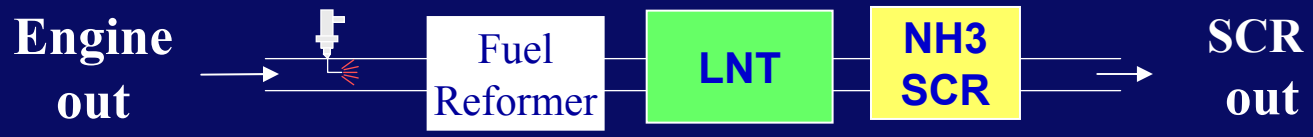
Eaton's Innovative Solution



- NH3 Generated during Fuel Rich Regeneration Process
- Urea Is Converted into NH3
- SCR Needs NH3, not Urea

Eaton Aftertreatment System (EAS)



Features:

- Fuel Reformer Converts HC to H2/CO During LNT Regeneration
- LNT Produces Ammonia During Regeneration
- SCR Catalyst Stores and Uses Ammonia for Further NOx Reduction
- Reduced Catalyst Volume and Cost
- Synergistic Use of LNT/SCR Catalysts
- Improved Durability

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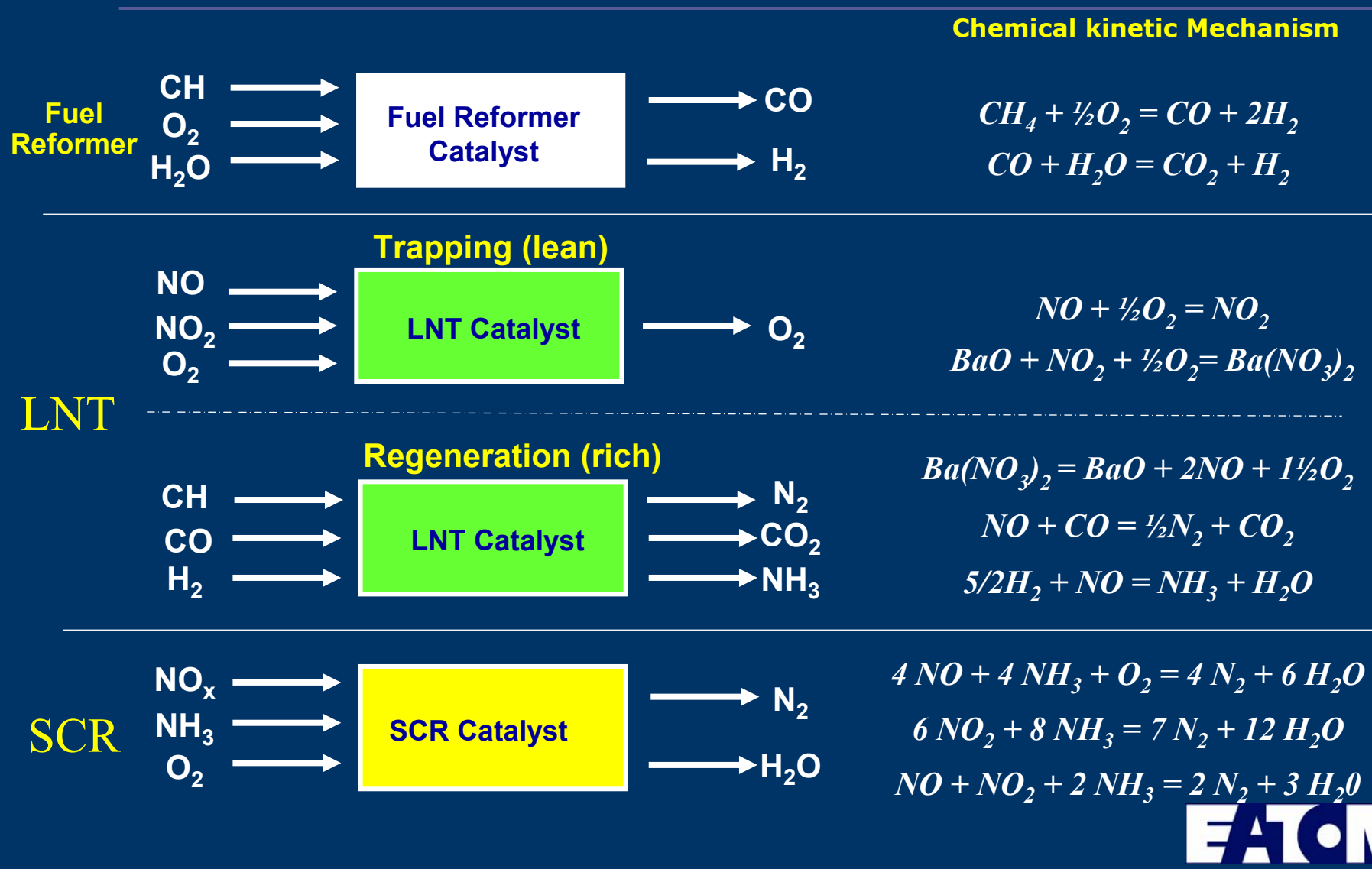
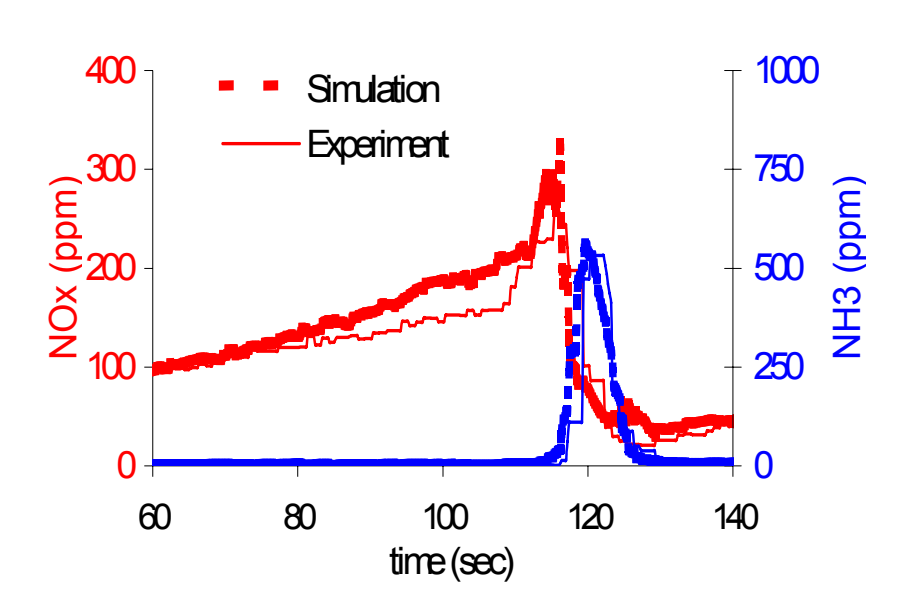
Chemical Kinetic Mechanism of Eaton Aftertreatment System

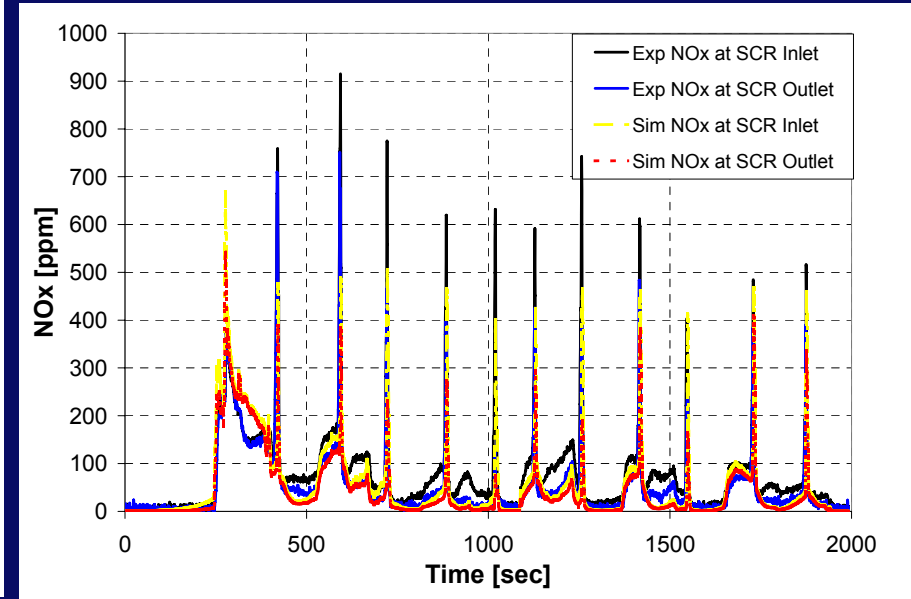


Developed Chemical Kinetic Models for System Simulation

Sample LNT Simulation



Sample SCR Simulation



Fully Transient Kinetic Models:

- Kinetic Mechanisms (21 reactions) Are the Result of Extensive Research
- Calibrated Kinetic Parameters With Engine Test Data
- Excellent Tool for Catalyst Development and System Simulation

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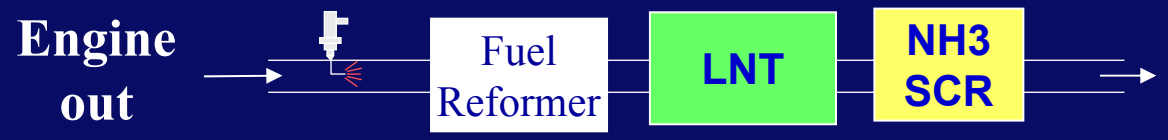
Two Fully Equipped Engine Dynamometers for Development

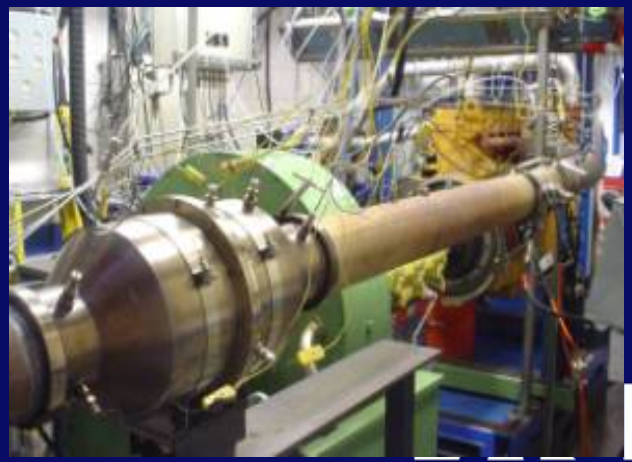


Performance Development

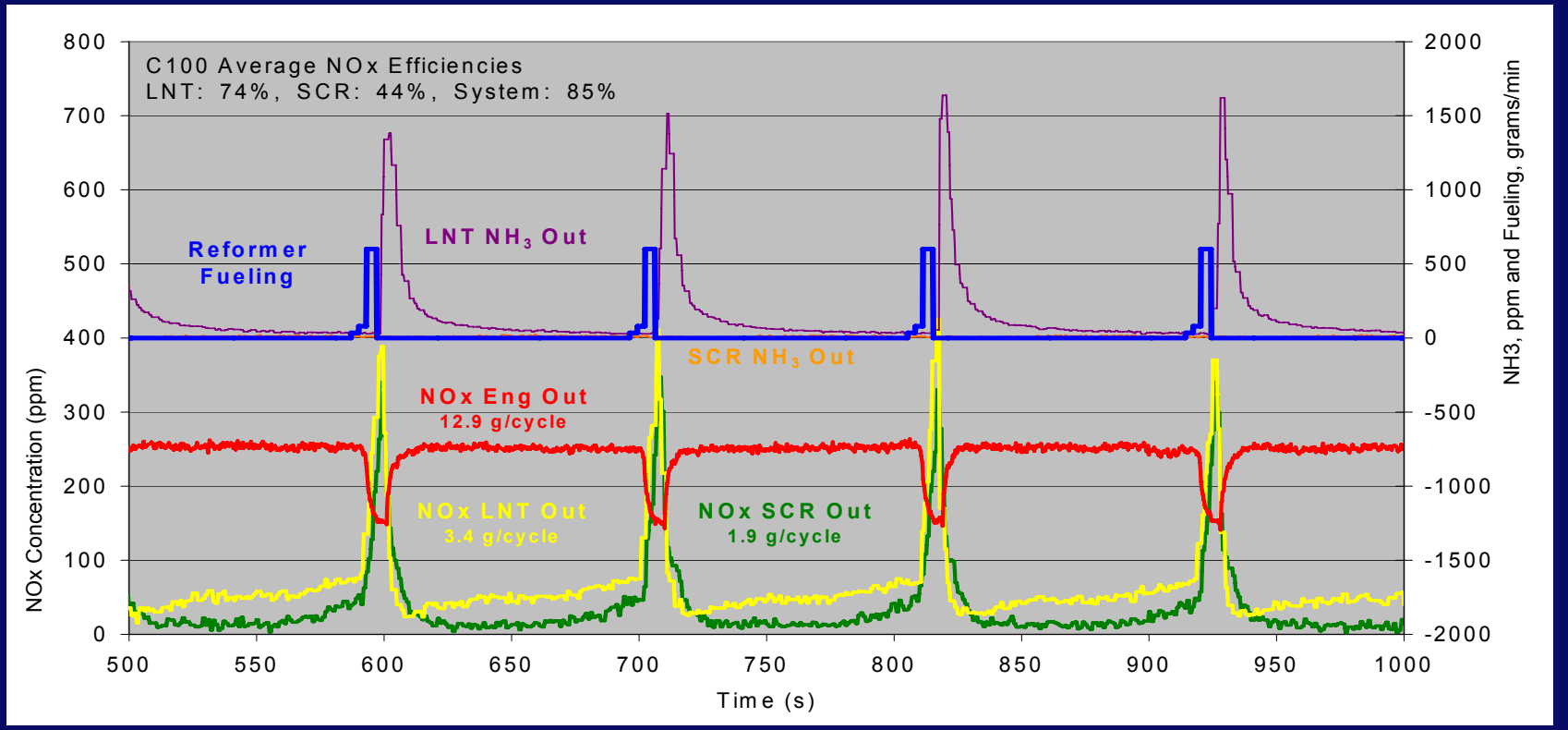
- DDC S60 14L Engine
  - 500 hp @ 2100 rpm
- Reformer +LNT +SCR
- Fuel Dosing System
- Emission Measurement Benches

Desulfation Development

- CAT C9 2004 ACERT Engine
  - 350 hp @ 2300 rpm
- Reformer+LNT+SCR
- Fuel Dosing System
- Emission Measurement Benches



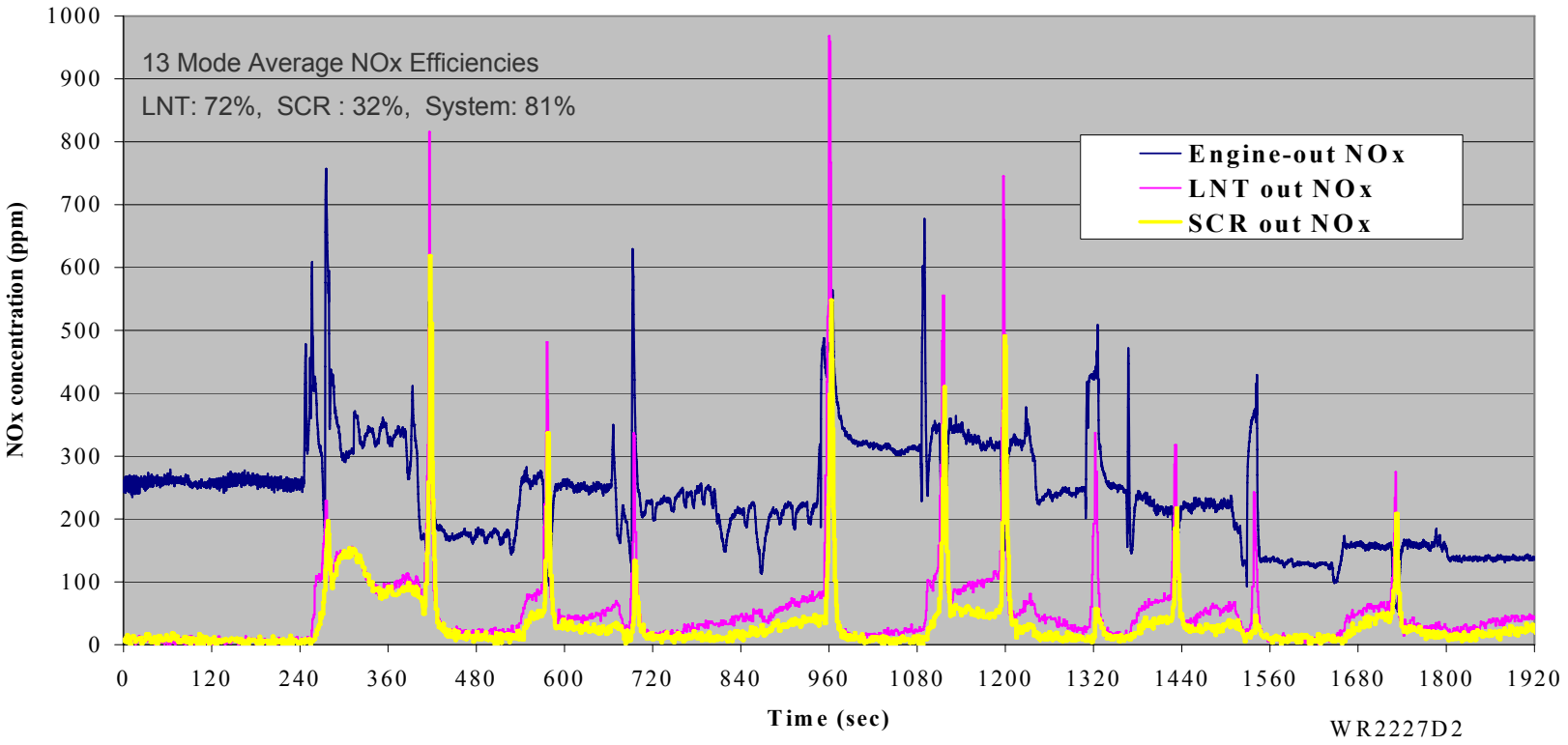
Excellent NOx Reduction Efficiency at Steady State Test Modes



Engine Dyno Steady-state C100 Mode:

- Demonstrated the Effectiveness of NOx Reductions in Both Total NOx Conversions and NOx Spikes (up to 50%) Reduction
- NH_3 Generated During LNT Regeneration and Can Be Stored in SCR Catalyst for NOx Reduction
- SCR Can Contribute up to 20% NOx Reduction Relative to Engine Out NOx

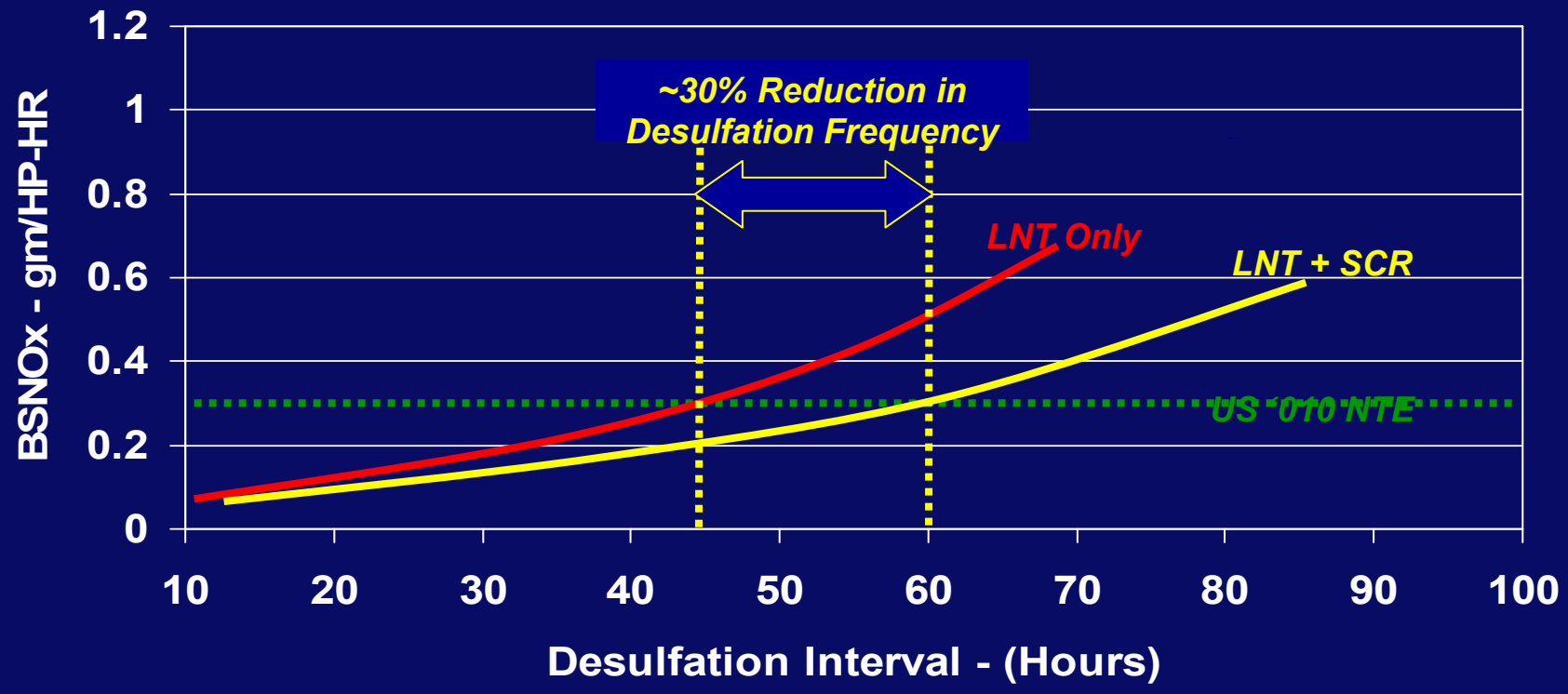
Demonstrated NOx Reductions With 13-mode Steady State Test



Engine Dyno 13 Mode Steady-state Tests:

- Over 80% NOx Efficiency, Less Than 4% Fuel Penalty for MY 2004 HD Diesel Engines, and Around 2% Fuel Penalty for 2007 Compliant Engines
- Significant Reduction in NOx Spikes
- Fuel Reformer Improves Catalyst Performance at Lower Temperature

Less Frequent Desulfation and Improved LNT Durability

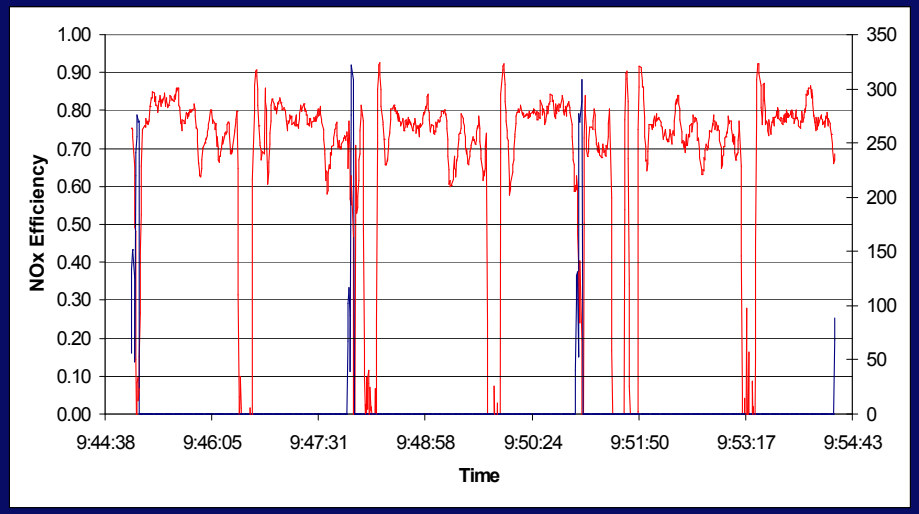


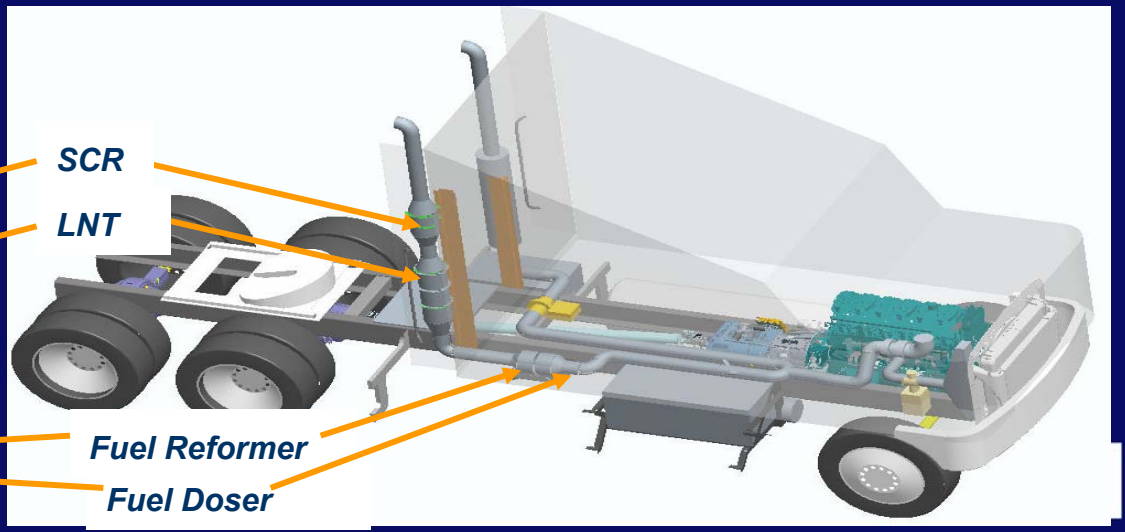
LNT Durability Improvement by Less Frequent Desulfation:

- SCR NOx Reduction Compensates for Loss in LNT Performance Due to Fuel Sulfur Poisoning.
- Less Frequent Desulfation is Required Comparing With LNT Only Systems
- Improved LNT Durability by Up to 30% Due to Less Frequent Desulfation

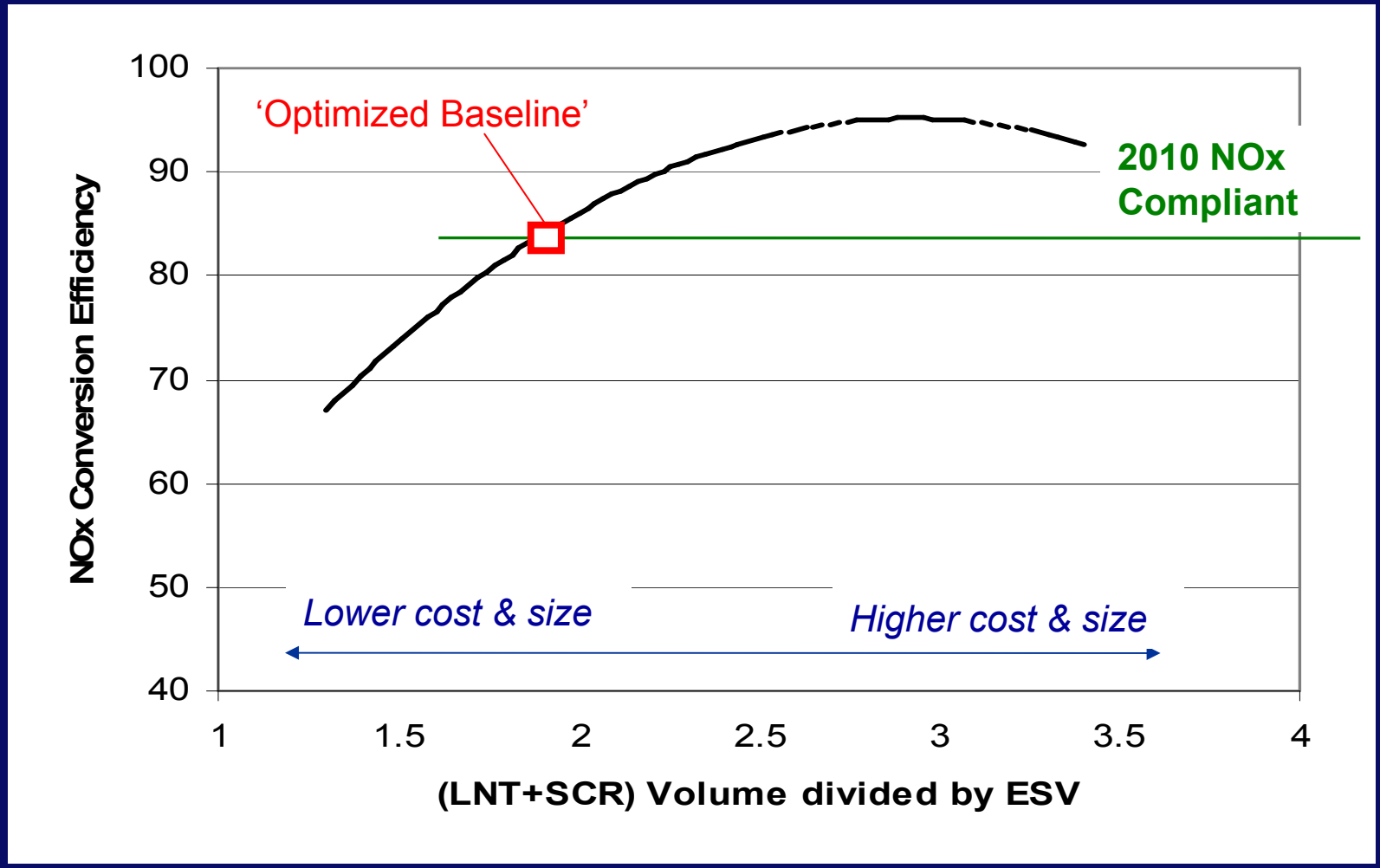
System Performance and Integration on Vehicle Road Test

- Freightliner Century Class Truck
- 2004 DDC S60 Engine
- Real-time NOx Conversions in Targeted Range
- Parameters Measured Include:
  - Exhaust NOx & O2 (6 positions)
  - Exhaust Flow Rate (2 positions)
  - Exhaust Temp & Pressure (6 positions)
  - Engine Parameters via J1587
  - Engine EGR and VNT Positions





Simulated System Size and Packaging with 2010 NOx Compliant Performance



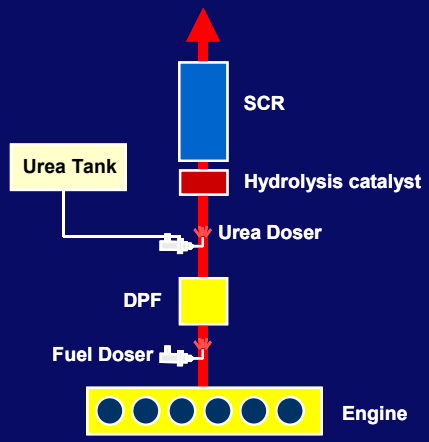
Based on system simulation w/ USEPA 2007 compliant engine

More Space-Efficient Than Urea Based SCR System

UREA SCR:

- SCR catalyst: 2.5x – 3.5x ESV
- Hydrolysis catalyst: 0.5 x ESV
- DOC: 0.5 x ESV
- DPF: 1.5 – 2.0x ESV
- TOTAL SYSTEM VOLUME: *5.0 – 6.5x ESV*
- *+ 4.0 – 6.0 x ESV urea tank volume*

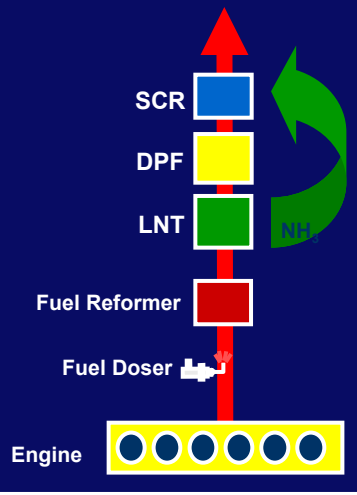
Typical Urea SCR System



Eaton Aftertreatment:

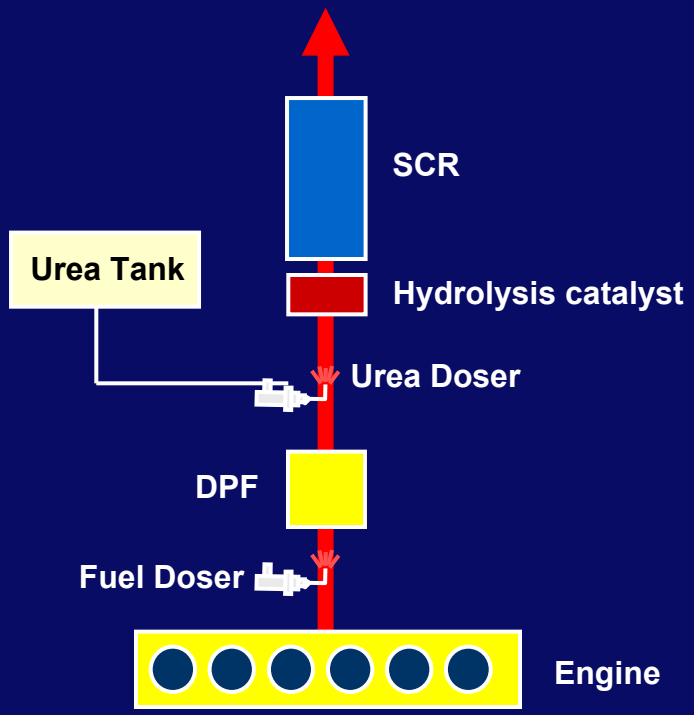
- LNT + SCR volume: 2x ESV *(engine swept volume)*
- Reformer catalyst: 0.5x ESV
- DPF: 1.5 – 2.0x ESV
- TOTAL SYSTEM VOLUME: *4.0 - 4.5 x ESV*

Eaton Aftertreatment System



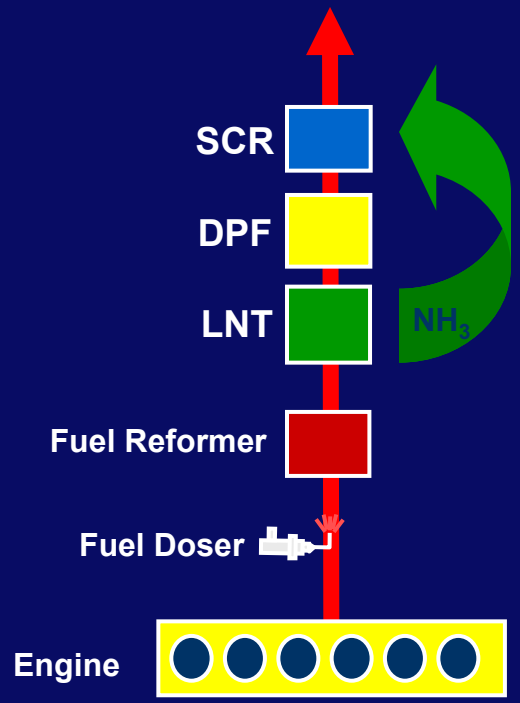
Good for the Environment and Superior Value for Our Customers

Typical Urea SCR System



- *Urea Infrastructure Investment Required*
- *Driver Intervention Required*
- *Tankage/Weight Penalty Required*
- *Penalty for "Failure to Fill" Required*
- *Dual Dosing Systems Likely*
- *Urea Price Volatility*

Eaton Aftertreatment System



- *No Urea Required*
- *Simple, Convenient in Operation*
- *Smaller Package Size*
- *No Weight Penalty*
- *Single Dosing System*

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Eaton Aftertreatment System Summary

- **A New Pathway to Utilize SCR Catalysts for NOx Reduction Without the Need of Urea Infrastructure**
- **An Innovative Method to Mitigate LNT Durability Concerns**
- **Demonstrated Technical Feasibility for Meeting 2010 Emissions Regulations**
  - Achieved Over 80% NOx Reduction Over 13-mode SET Test With Less Than 4% Fuel Penalty for MY 2004 HD Diesel Engines, and Around 2% Fuel Penalty for 2007 Compliant Engines
  - Developed and Validated Chemical Kinetic Models For System Modeling and Simulation
  - H2 Generated By Fuel Reformer Improves LNT Regeneration and Desulfation Performance
  - Developed Control Strategies for System Performance Optimization
  - Gained Experience in Desulfation, Package, Installation and System Integration
  - Demonstrated NOx Reductions and LNT Regeneration During On-road Driving Conditions

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Questions?

Acknowledgement: The author would like to thank Eaton Corporation for its permission to publish this work, and would like to acknowledge the supports of Eaton Aftertreatment Team.

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