APBF-DEC Heavy Duty NOx Adsorber/DPF Project: Heavy Duty Linehaul Platform Project Update

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Prepared by Mike May

Technical Specialist, Performance and Emissions

Chicago Technical Center, Ricardo Inc.

Project Sponsors

- - U.S. Department of Energy
- - National Renewable Energy Laboratory
- - Oak Ridge National Laboratory
- - American Chemistry Council
- - American Petroleum Institute
- - California Air Resources Board
- - Engine Manufacturers Association
- - Manufacturers of Emission Controls Association
- - South Coast Air Quality Management District

Objectives

- Design and build engine and emissions control system to permit regeneration and desulfurization under transient and steady state conditions.
- Demonstrate the emissions potential of advanced fuel, engines and emissions control systems over the Heavy Duty transient cycle and under steady state conditions. Target is to achieve the 2007-2010 Heavy Duty emissions standards of 0.2g/bhp.h NOx and 0.01g/bhp.h particulate matter (PM) over the transient test cycle.
- Evaluate effect of fuel sulfur level on engine and emissions control system performance, emissions and fuel economy and, in particular, effect on catalyst durability.

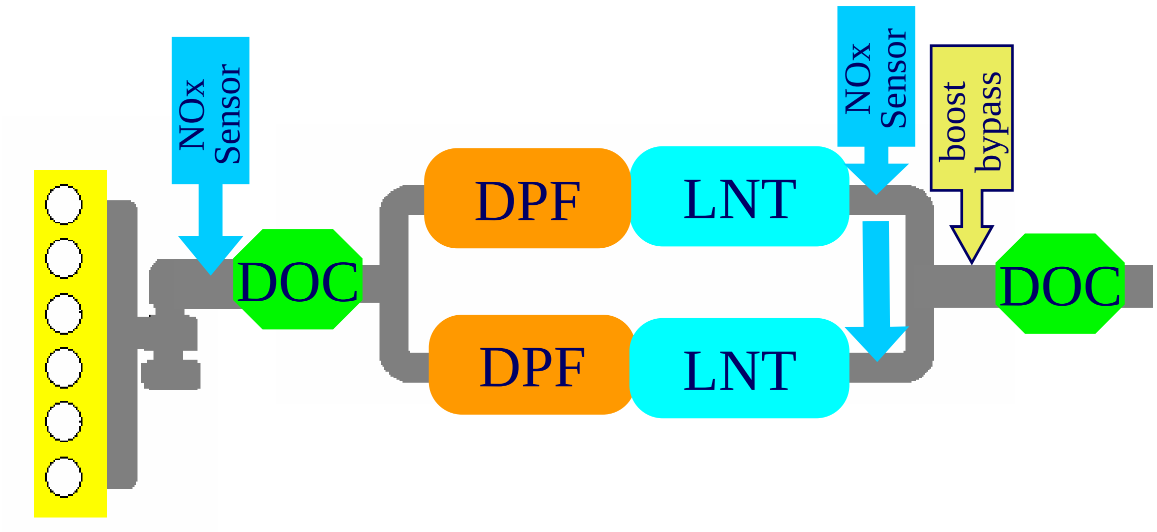
Program Approach

- Both single and dual NOx adsorber approaches were evaluated.
- Engine control and aftertreatment systems were built and developed:
  - Single adsorber system, engine lean/rich cycling to regenerate adsorber
  - Dual adsorber system, alternately adsorbs NOx in one adsorber while regenerating the other using fuel injected upstream of the catalyst
- Baseline engine engine out emissions were measured.
- Aging tests are being performed on the single adsorber.
- The catalyst system was aged for 300 hours on 15ppm sulfur fuel with performance evaluations every 50 hours.
  - Aging over 13-mode steady-state cycle
  - Performance evaluations consist of FTP cycles and ESC 13 mode tests.
- Total of 2000 hours aging on a 15ppm sulfur fuel will be run, with performance evaluations every 100 hours initially then 250 hours.
- New catalysts will then be installed and 300 hours aging on 8ppm sulfur fuel conducted with performance evaluations every 50 hours.

Engine

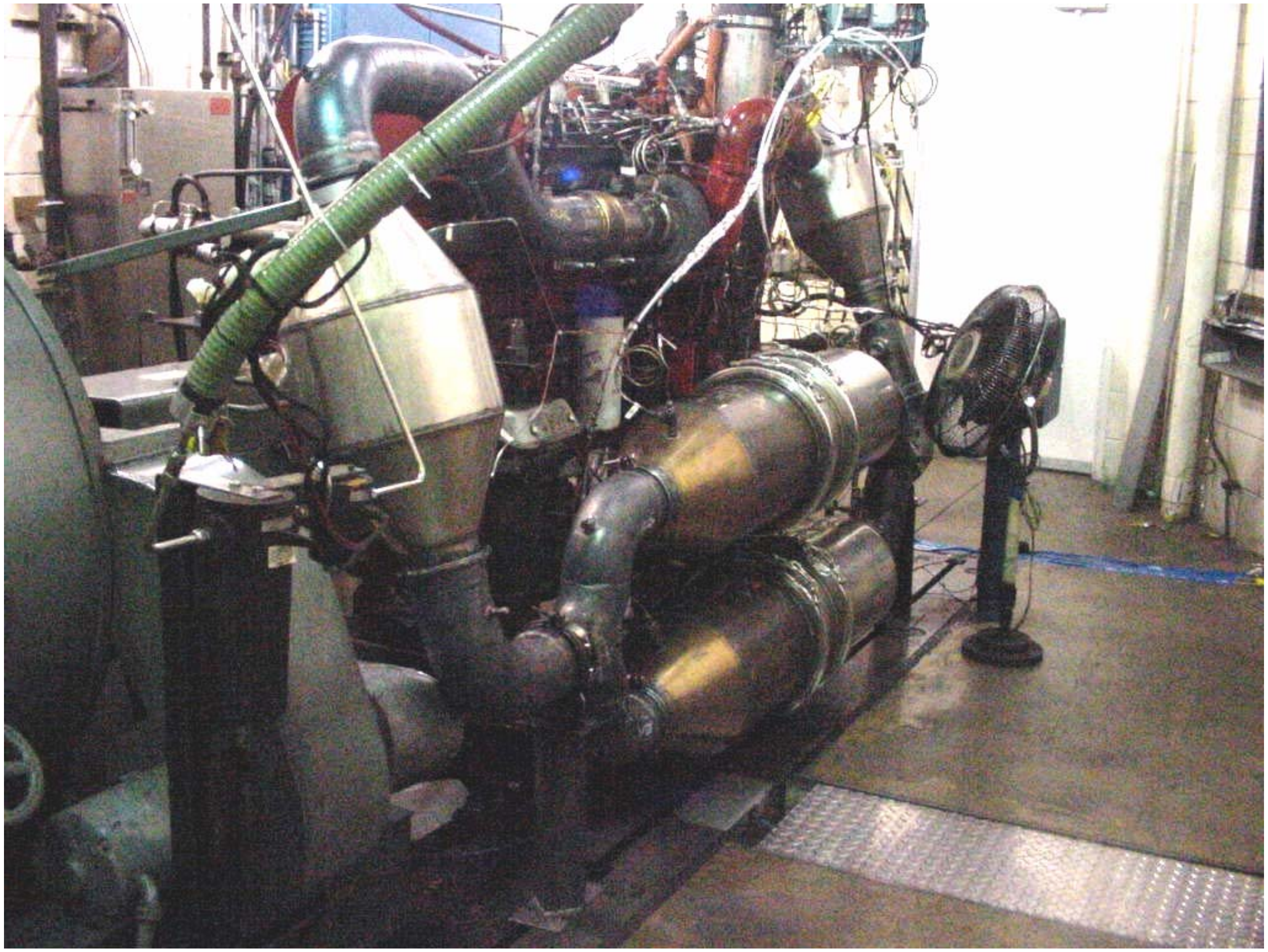
- Engine supplied by Cummins is an ISX, 15 liter, DOHC, 4 valves/cylinder, central unit injector
  - Rated at 475-500 hp, 1650 lb.ft torque
  - Fitted with EGR system, compliant with 2002/2004 standards
- Cummins is also supplying engineering support to interface to the control system

Aftertreatment System Layout

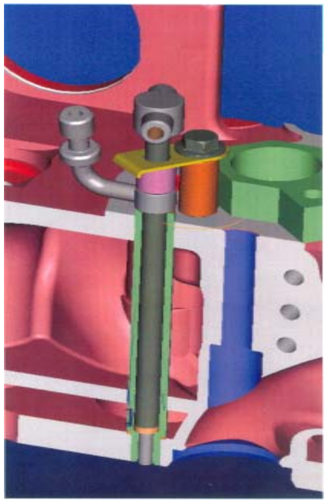


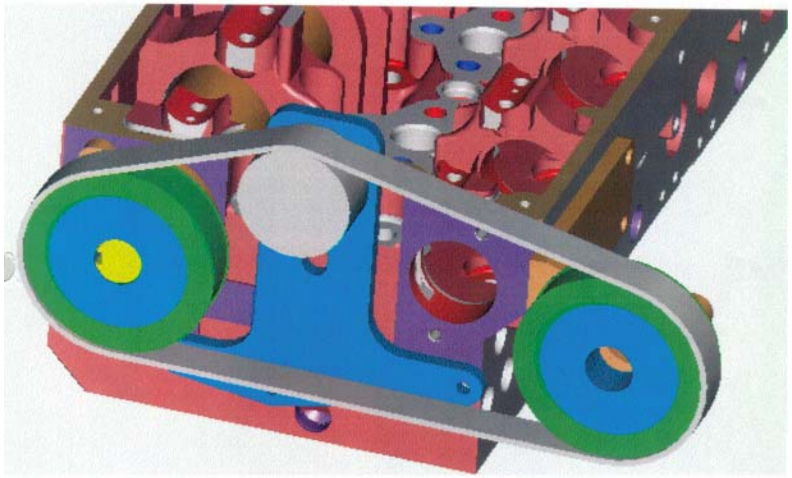
- "Single" NOx adsorber system uses dual DPF/ LNT to reduce back pressure, exhaust flows through both DPF/LNT units at all times
- Total catalyst and DPF volume 118 liters, 7.9x engine swept volume, scope for volume reduction by:
  - reducing engine out NOx to reduce LNT volume required
  - increasing tolerance of engine to back pressure
  - tradeoff of regeneration frequency with fuel consumption penalty
  - depending on aging results
- In-pipe injectors used for full load regeneration and desulfation

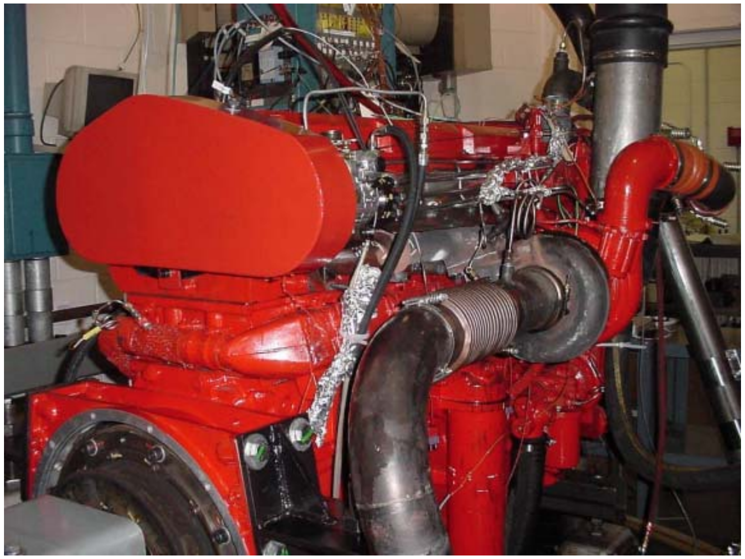
NOx Adsorber / DPF System



Secondary Fuel System

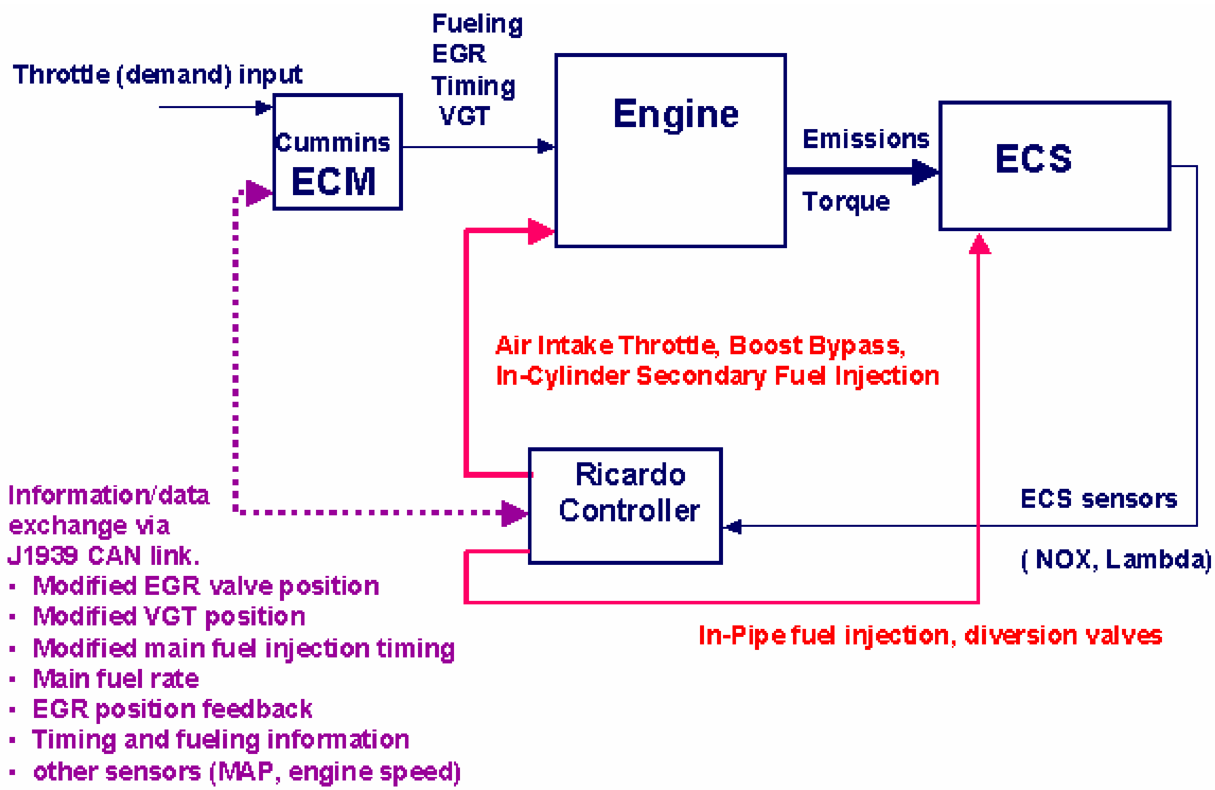






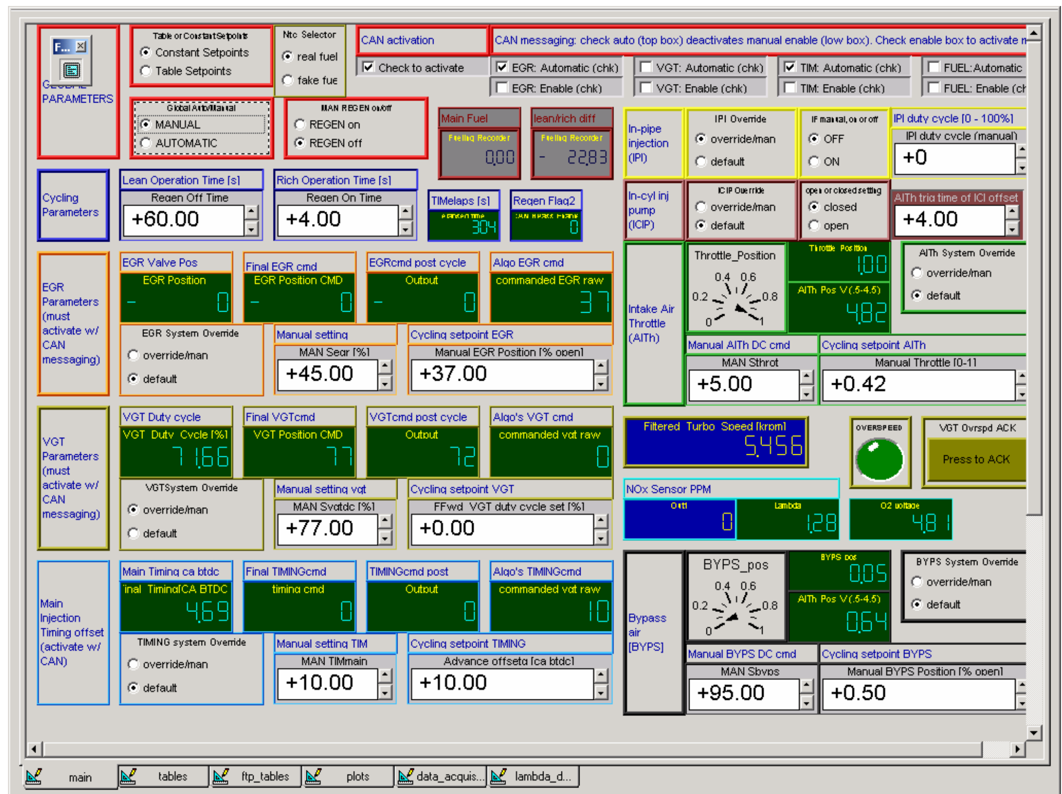
Control System

- System requirements:
  - Control engine during rich operation, Cummins ECM controls engine during lean operation
  - Govern/oversee regeneration process, ensuring flexibility during system development
  - Control the ECS hardware, enabling both steady state and transient testing



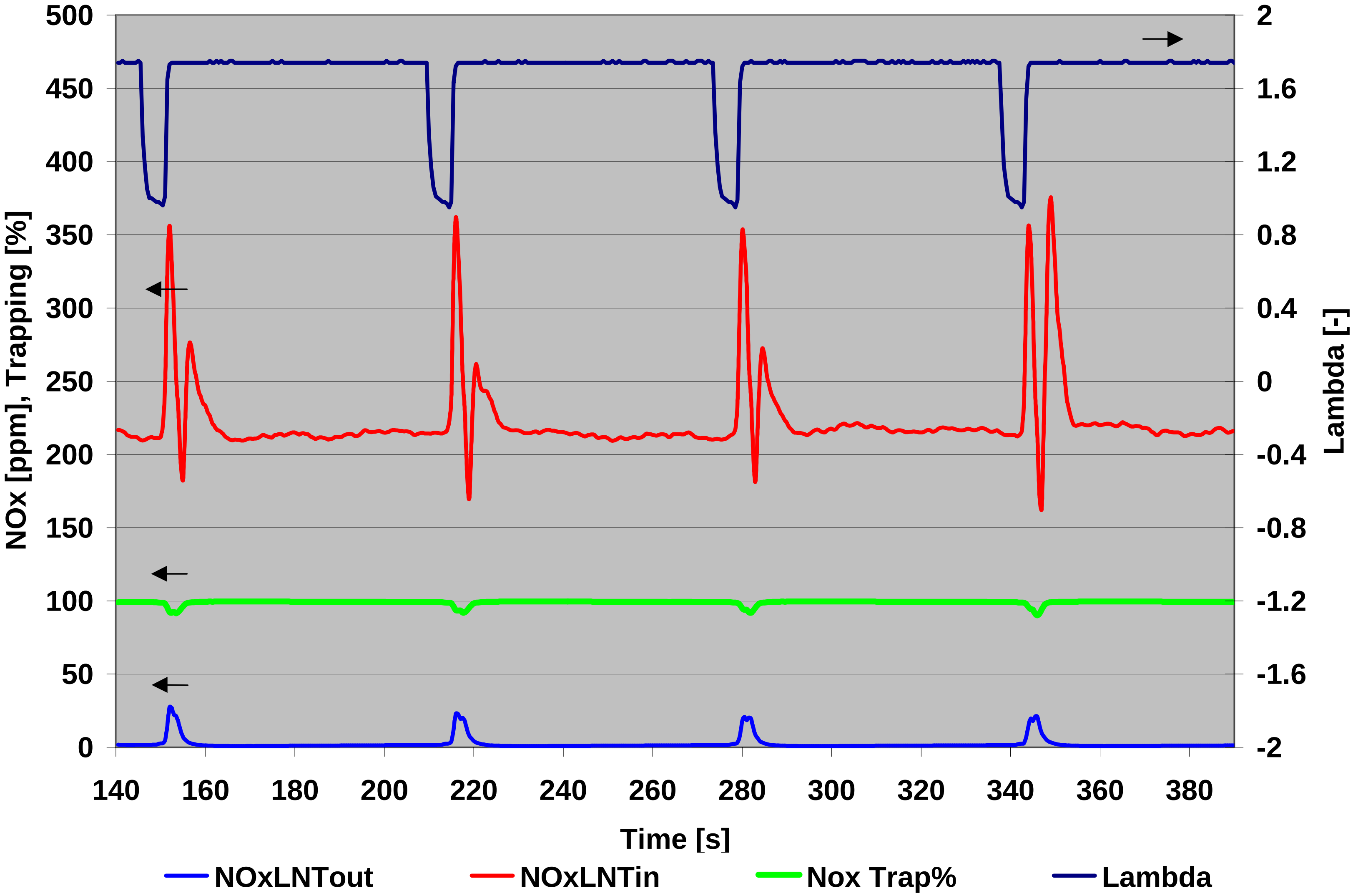
Control System

- Hardware and user interface for lean/rich cycling assessment.



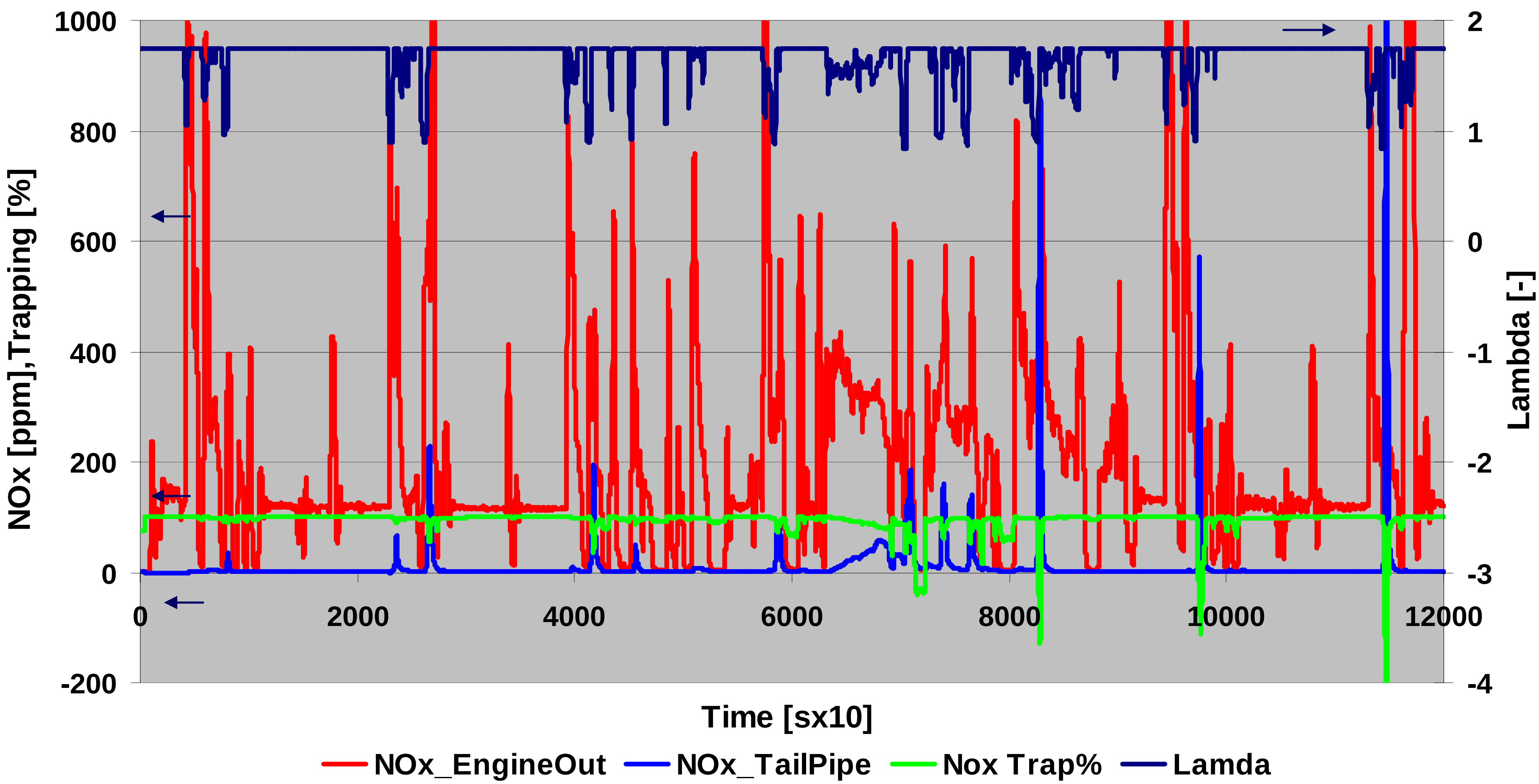
Steady State Engine Operation

- Lean/rich cycling at 1800 rpm, 800 Nm

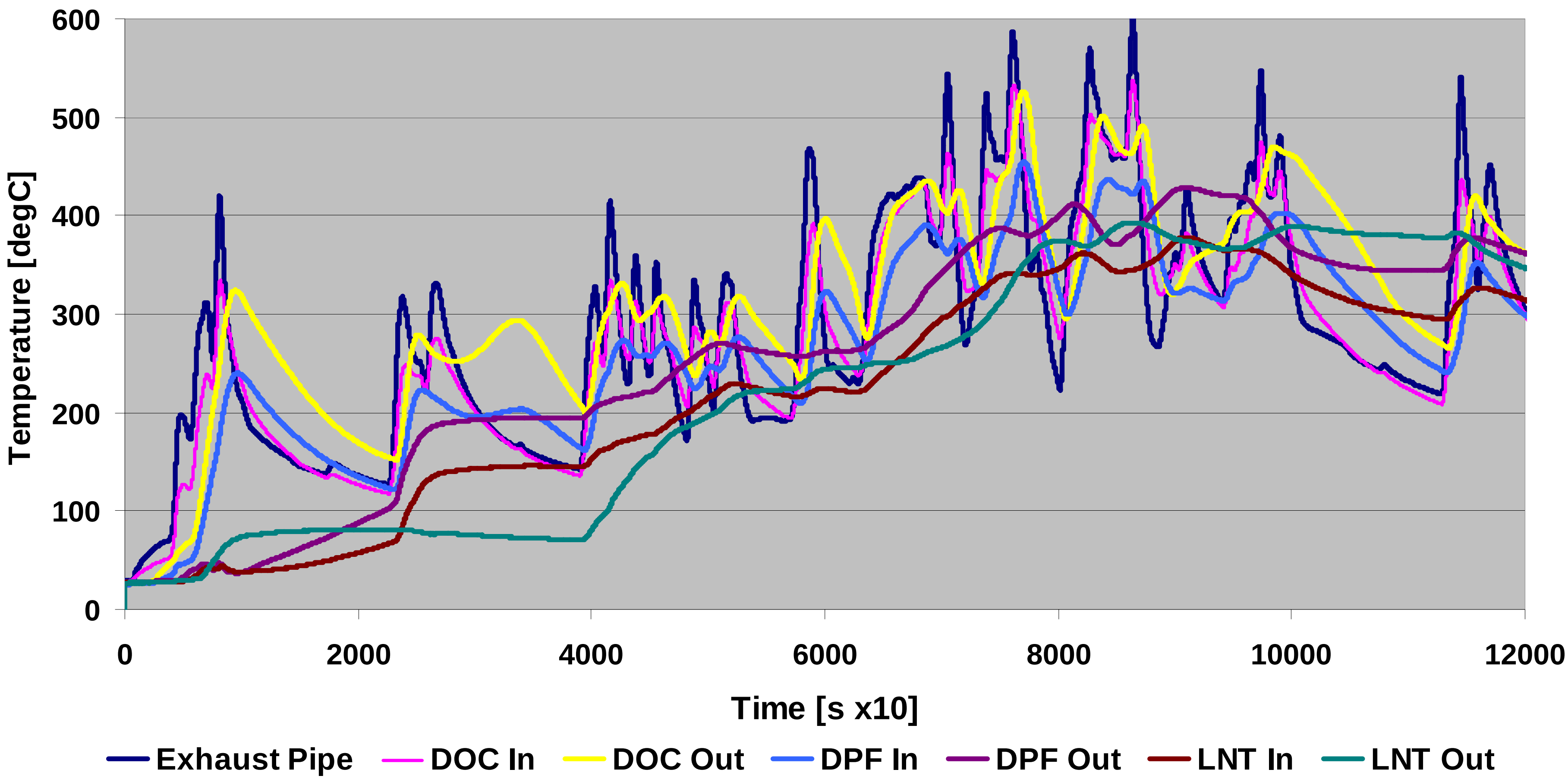


Hot Start Transient FTP Cycle
- Aged Adsorbers, Partially Sulfated

- Overall NOx absorber efficiency around 94%

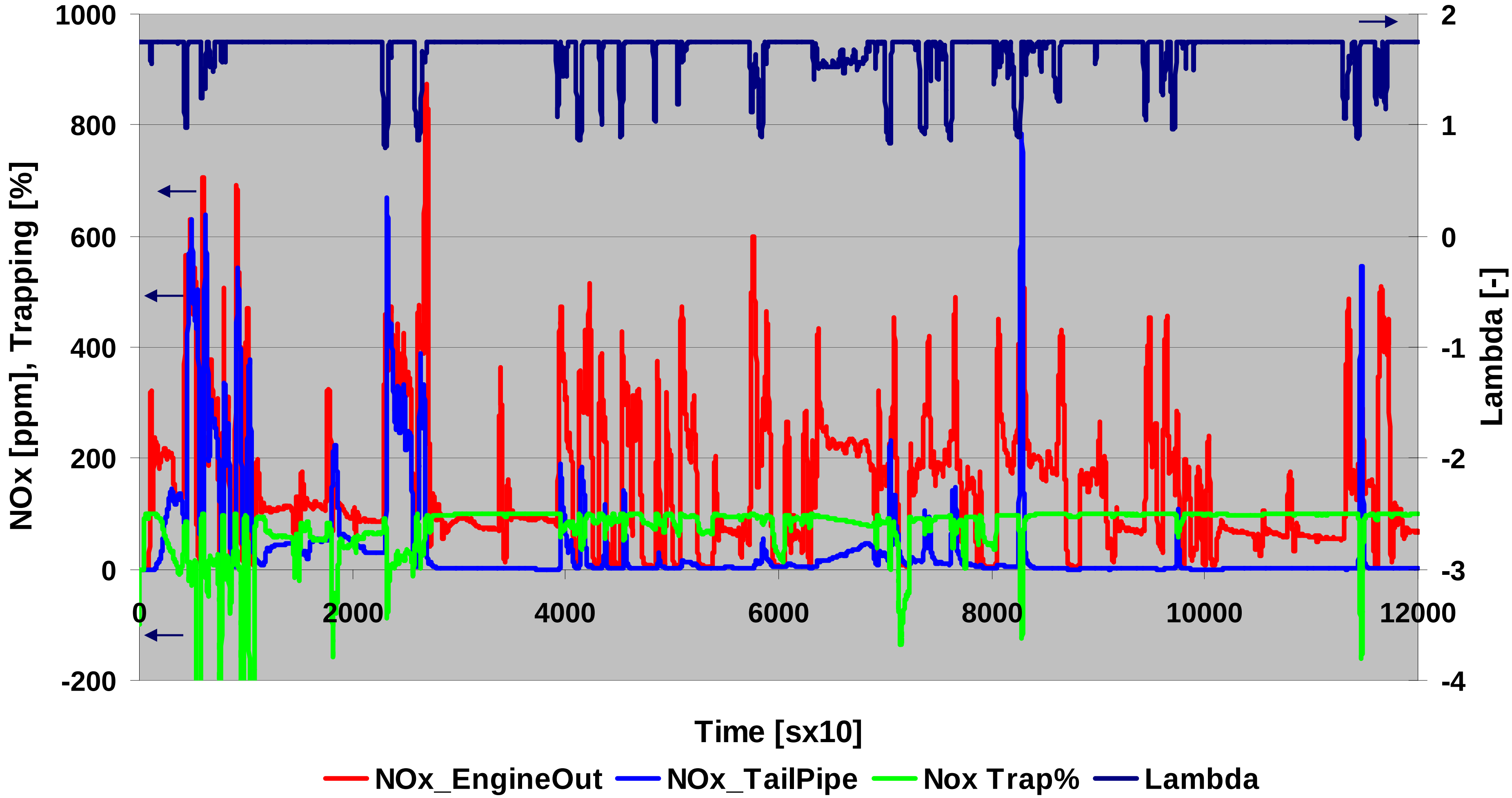


Cold Start FTP Cycle – Exhaust Temperatures

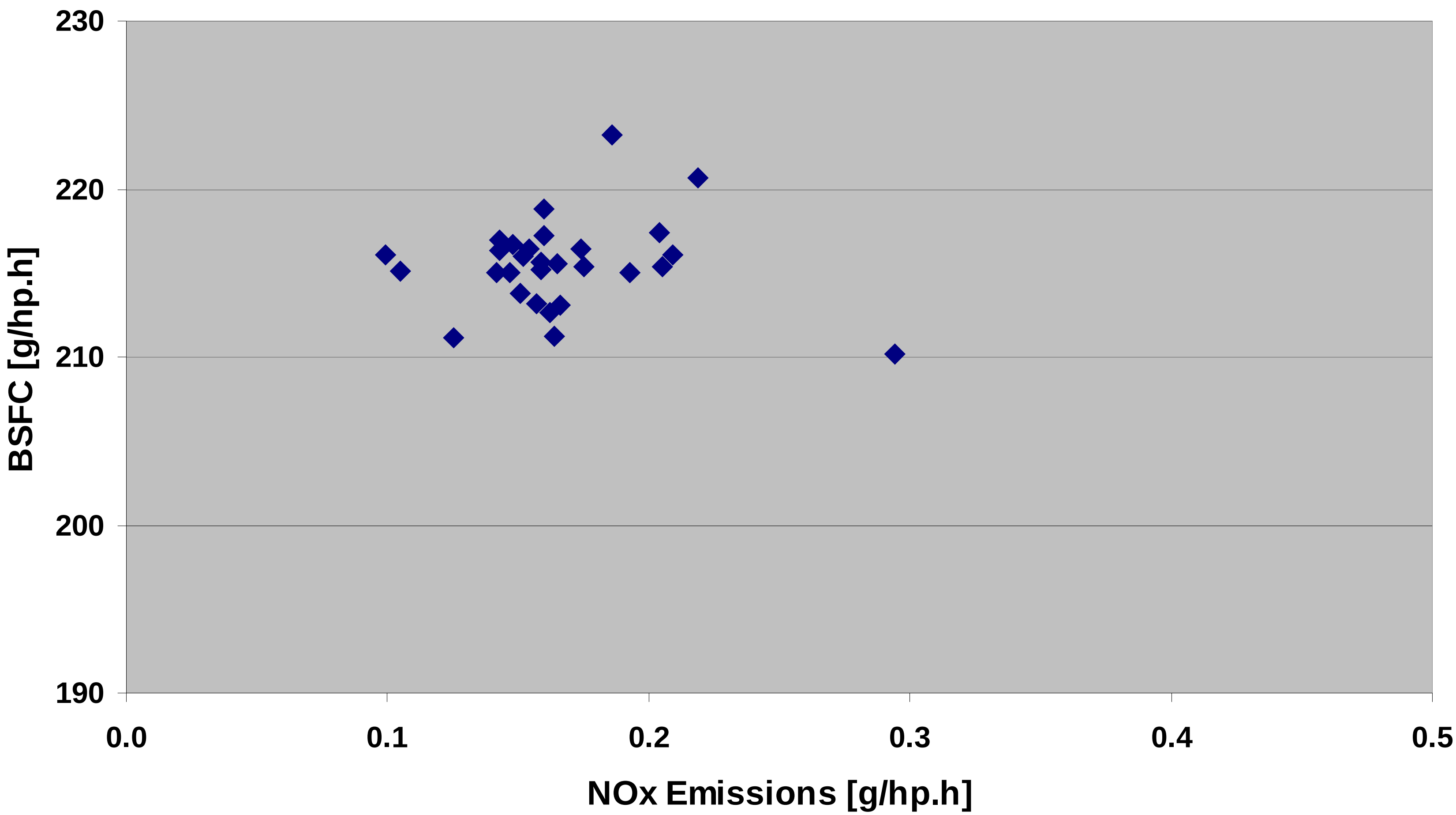


Cold Start Transient FTP Cycle
- Aged Adsorbers, Partially Sulfated

- Overall NOx absorber efficiency around 80%



Transient FTP Cycle Results – Aged Adsorbers, Partially Sulfated

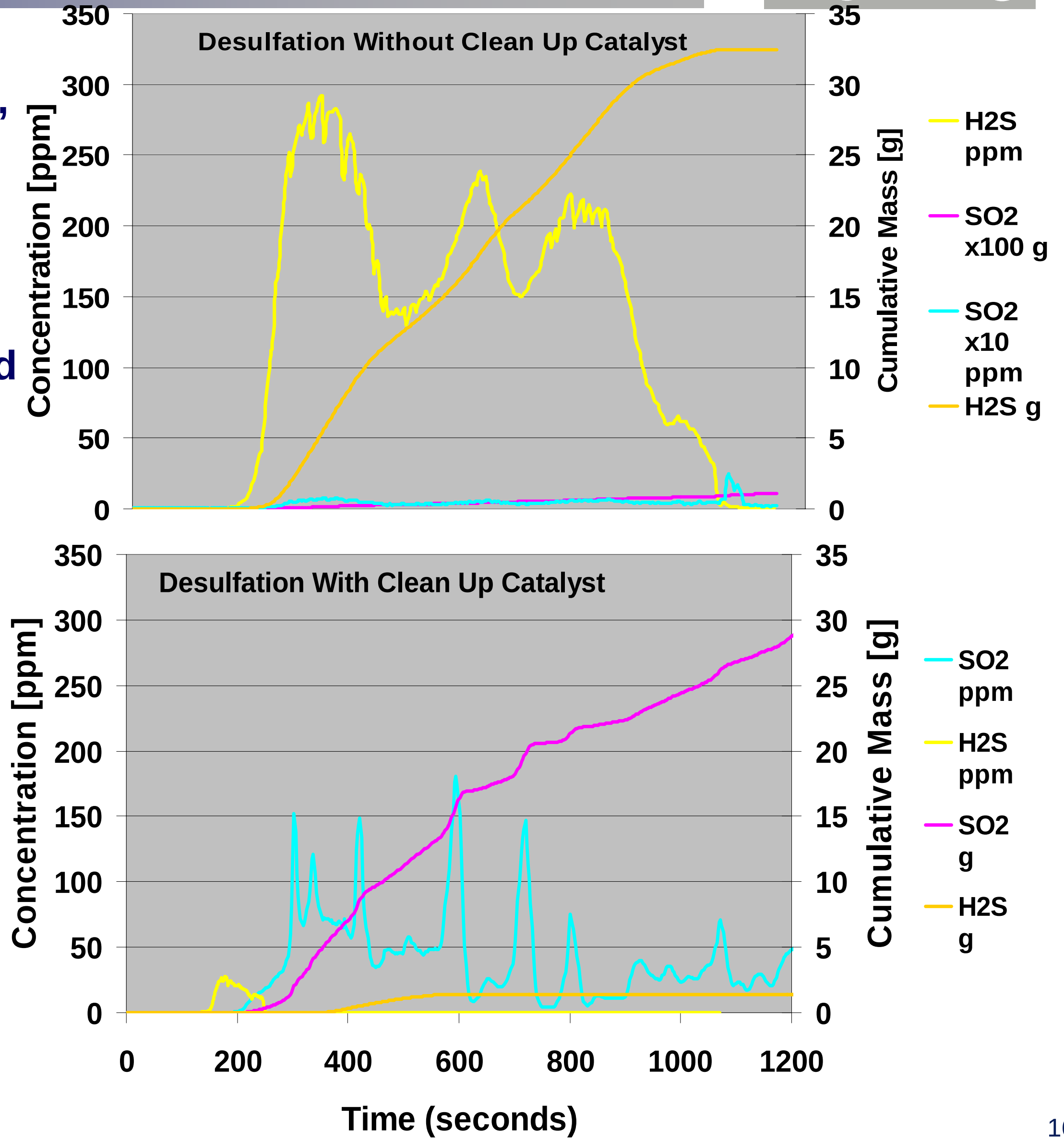


- Baseline emissions with high back pressure: NOx 2.2 g/hp.h, BSFC 199 g/hp.h

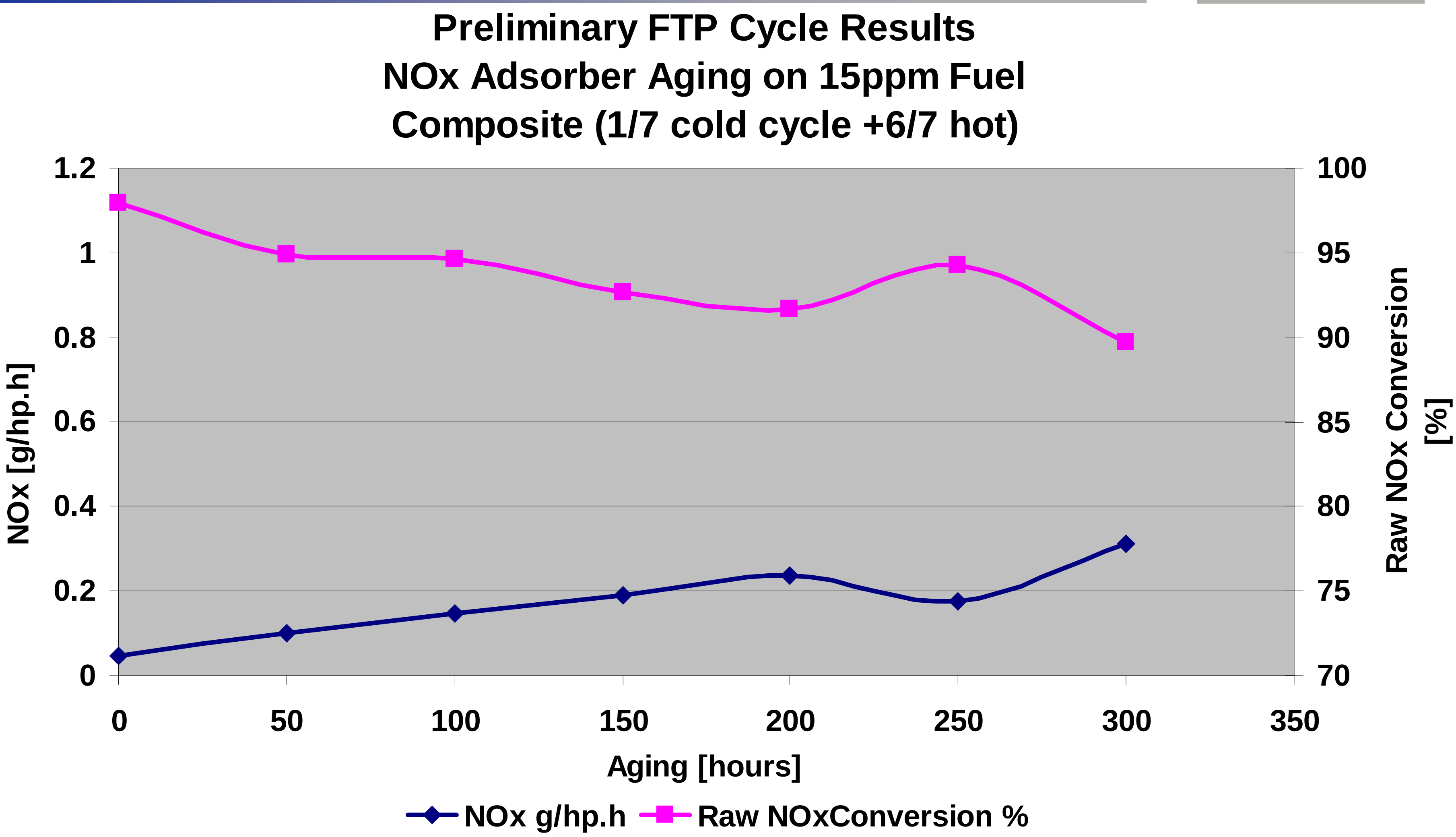
Desulfation

- Desulfation run by engine throttling at 1100 RPM, 1100 Nm, close to an air fuel ratio of λ=1
- Secondary fuel injection upstream of the DPF to achieve target λ of 0.85 to 0.95
- 700°C LNT bed temperature used as max temperature limit
- Sulfur evolution monitored by mass spectrometer. Most sulfur emitted from NOx adsorber as H_2S
- Clean up DOC very effective at conversion of H_2S to SO_2

Note: Traces are for different tests, sulfur loading is not the same, but data demonstrates the conversion of H_2S



Preliminary Aging Results To Date



- Partial Desulfation at 250 hours

Concluding Remarks

- This program has demonstrated that NOx adsorbers are capable of high NOx conversion efficiency (>90%),with a fuel consumption penalty of around 7% (excluding back pressure).
- Cold start FTP NOx conversion up to 80% is achieved, aided by in-cylinder secondary injection to heat the catalysts.
- The aging phase of this program is currently underway and this will provide valuable data on the effect of fuel sulfur and desulfation on catalyst performance.
- Issues such as:
  - Effect of lean rich cycling on engine durability, driveability
  - Aftertreatment system cost, packaging on vehicle
  - Full useful life emission control system durability (435,000 miles)

  are not currently part of this program but will need to be addressed before the feasibility of NOx adsorbers can be determined.

Concluding Remarks

- Further development is required to reduce the fuel consumption penalty and the HC slip (mainly composed of methane). A significant improvement is expected with the additional control capabilities a common rail fuel system would provide.
- The elevated temperatures experienced in the ESC and NTE portions of the Heavy Duty certification will present a significant challenge to maintaining high adsorber efficiency. Additional testing needs to be done to ensure compliance with all portions of the certification test.
- Desulfation of the NOx adsorber in this program is conducted under steady state engine operating conditions. Sophisticated control will be required to enable desulfation at a wide range of engine conditions suitable for normal vehicle operation.