APBF-DEC Heavy-Duty NOx Adsorber/DPF Project - Initial Results for Single NOx Adsorber

Joint Meeting

of Research Programs Sponsored by

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Program 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 aftertreatment and engine control system to permit regeneration and desulfurization under transient and steady state conditions.
- Evaluate effects of changes in base engine parameters, in-cylinder post injection and EGR for regeneration and improved efficiency of the NOx trap.
- Demonstrate emissions potential of engine and aftertreatment system over Heavy Duty transient cycle and under steady state conditions. Target is to achieve the proposed 2007 Heavy Duty emissions standards of 0.2g/bhp.h NOx and 0.01g/bhp.h particulates over the transient test cycle.

Objectives

- Evaluate effect of fuel sulfur level on engine and aftertreatment system performance, emissions and fuel economy and, in particular, effect on catalyst durability.
- Evaluate effect of other fuel properties on regeneration, desulfurization, emissions and fuel economy.
- Provide data, reports and recommendations to support EPA technology review planned for fall of 2003.
- In meeting these objectives consideration will be given to designing and implementing a practical system, with catalyst volumes consistent with space available on a vehicle, and limiting the fuel consumption penalty to a level that could be acceptable within the industry.

Program Approach

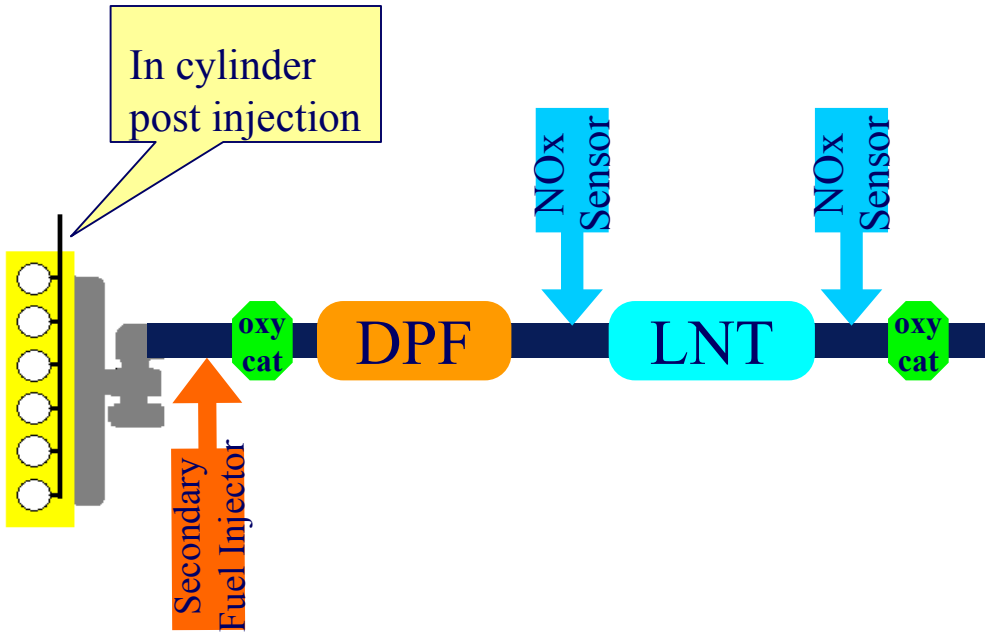
- Both single (System A) and dual LNT (System B) approaches will be evaluated.
- Engine control and aftertreatment systems are being built and developed.
- Baseline engine tests will be conducted.
- Both catalysts systems A&B will be tested initially up to 300 hours aging on 8 & 15ppm sulfur fuel with performance evaluations every 50 hours.
- Evaluations will consist of FTP cycles and OICA 13 mode tests.
- Either System A or B will then be selected and a further 1200 hours aging run on a single fuel with performance evaluations every 100 hours.

Scope of Presentation

- Update on current status of :
  - Emissions controls system design
  - Engine and secondary fuel systems
  - Control system
  - Initial single NOx adsorber (LNT) results

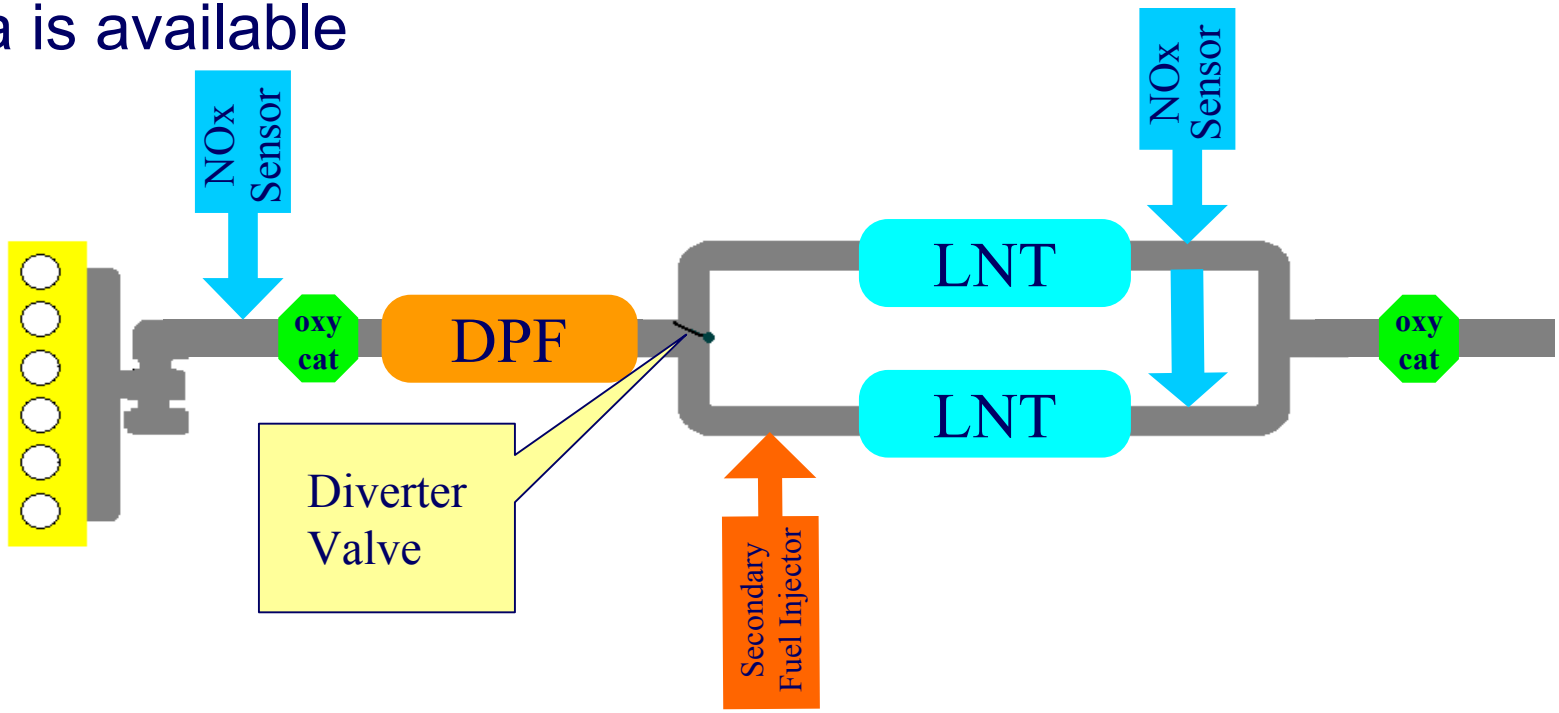
Single LNT System

- Engine is required to cycle lean / rich to regenerate LNT using combination of throttling, increased EGR, in-cylinder and in-pipe post injection
- Total catalyst and DPF brick volume being tested is 91 liters, volume reductions possible by optimization



Dual LNT System

- Engine not be required to cycle lean / rich to regenerate LNT. Rich conditions achieved by injection of fuel into bypassed LNT.
- Catalyst and DPF brick volume to be evaluated once test data is available



Main Areas for ECS Modeling Work

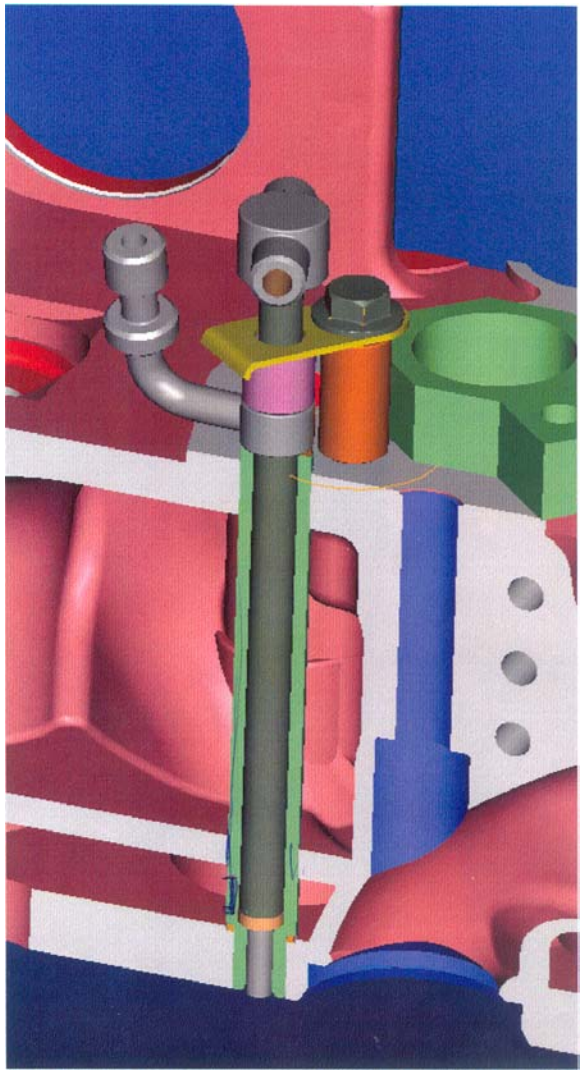
- Catalyst systems supplied by MECA are being modeled to:
  - simulate exhaust temperatures throughout aftertreatment system, LNT fill and DPF loading under transient and steady state conditions, sulfate effects
  - examine tradeoffs of sizing, activity, configuration and positioning in exhaust on NOx reduction efficiency and fuel consumption
  - input to strategies for control and testing for:
    - LNT regeneration under rich conditions
    - LNT desulfation under hot and rich conditions
    - DPF regeneration type - active/passive (O_2/NO_2)
  - support re-tuning during catalyst aging

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

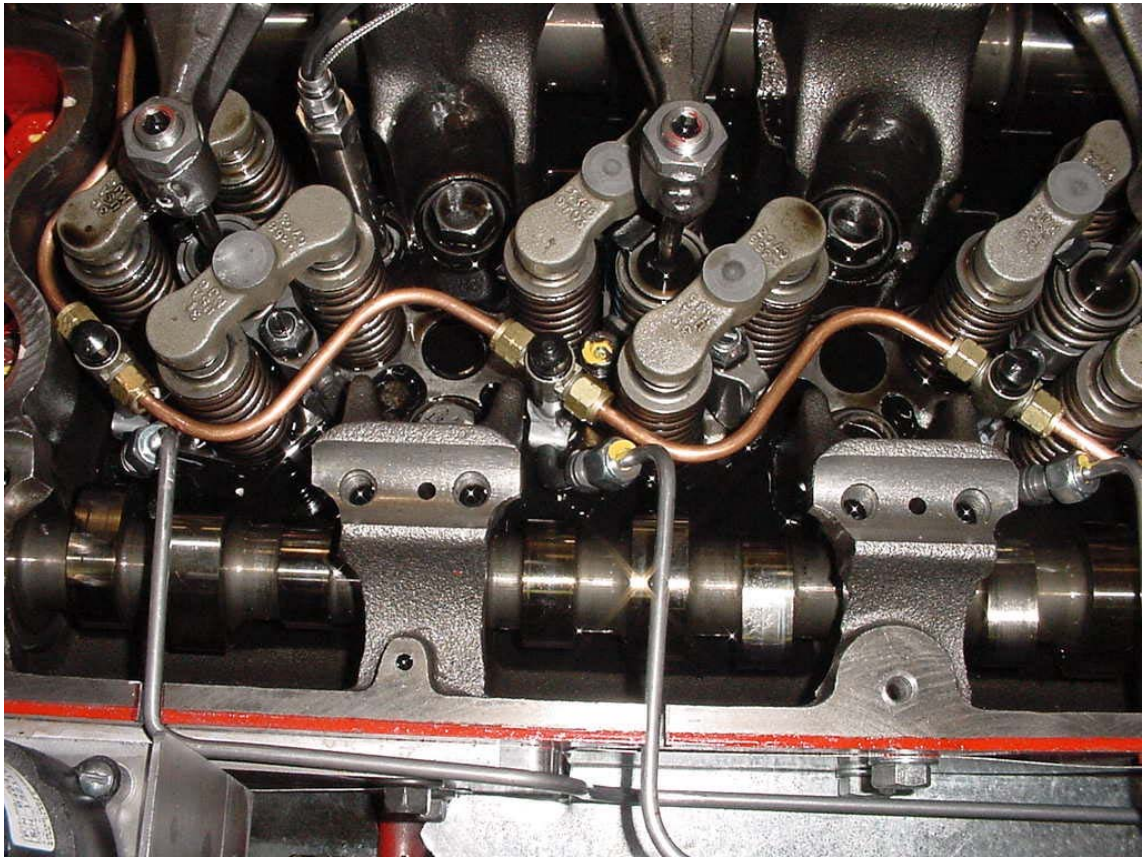
Secondary Fuel System

- Injector location



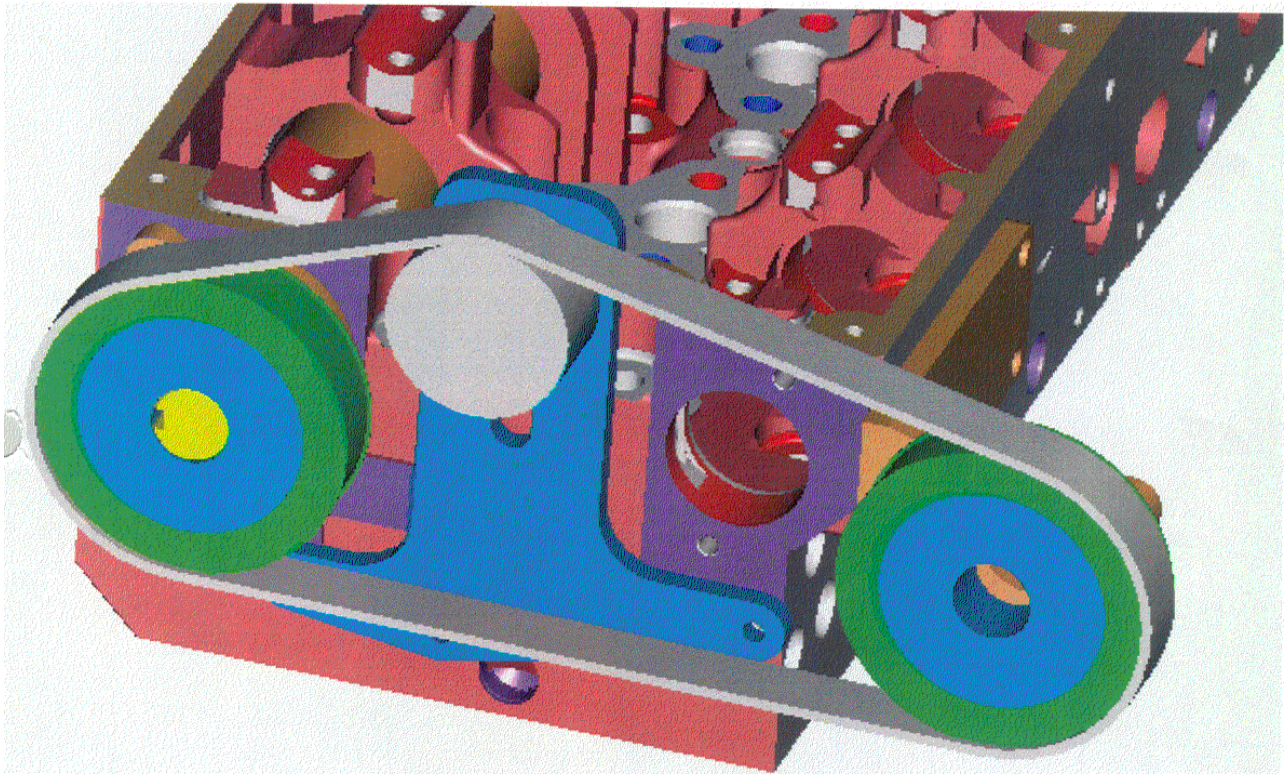
Secondary Fuel System

- Secondary injection hp and spill line arrangement



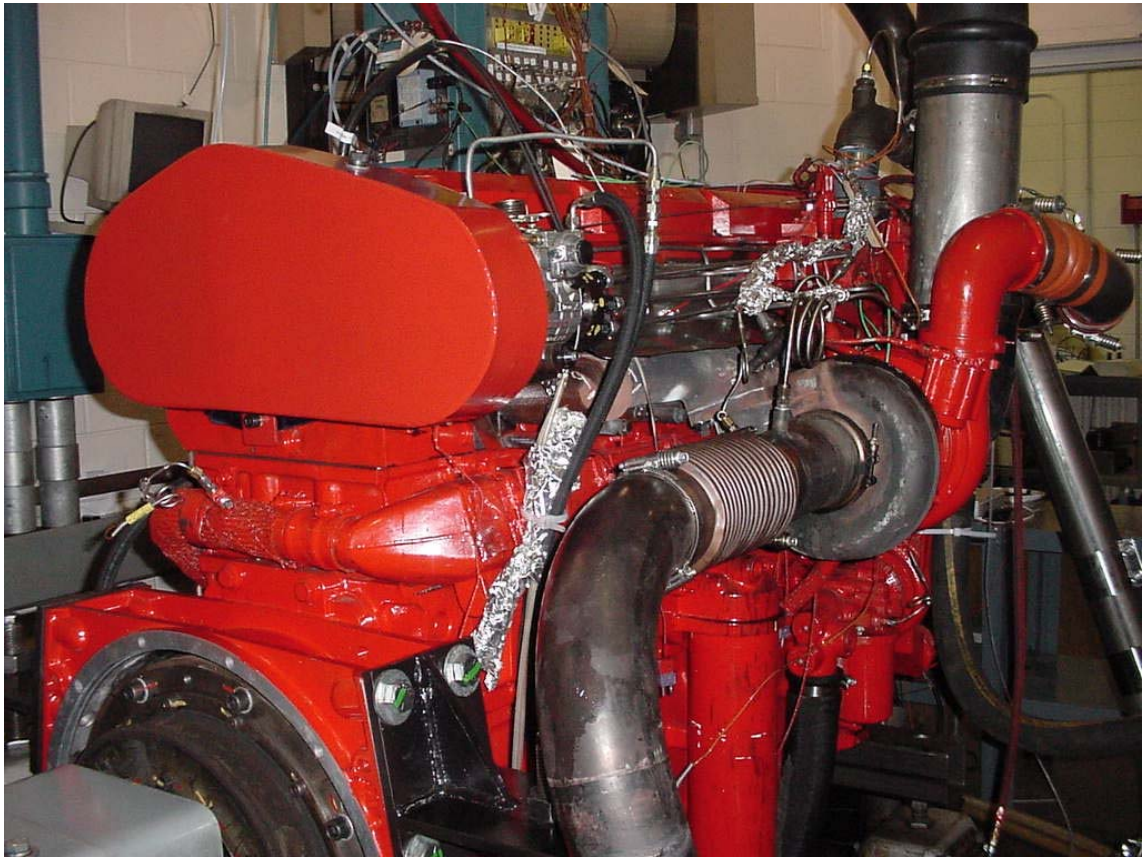
Secondary Fuel System

- Secondary pump drive



Secondary Fuel System

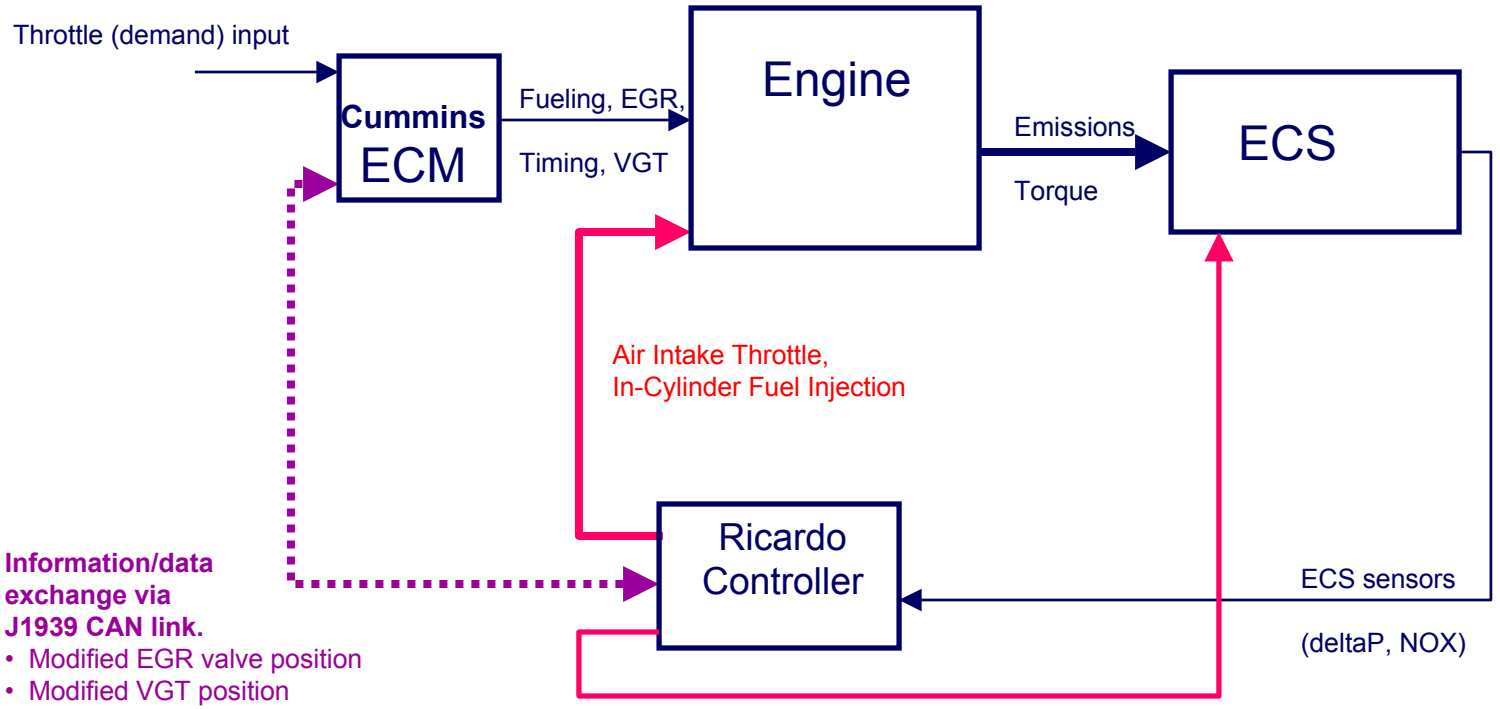
- View of engine in test cell



Controls

- Single LNT configuration
  - Cummins ECM controls “lean” or normal operation
  - Ricardo system determines need for regeneration or desulfation (timed, NOx sensors, simple models of LNT’s NOx conversion efficiency)
  - Ricardo system determines new actuator setpoints for “rich” operation:
    - Exchange EGR, VGT, injection timing via CAN
    - Open and closed loop control of throttle and secondary injectors
  - Smooth exchange between controllers during “lean to rich” and “rich to lean” transitions

Controls

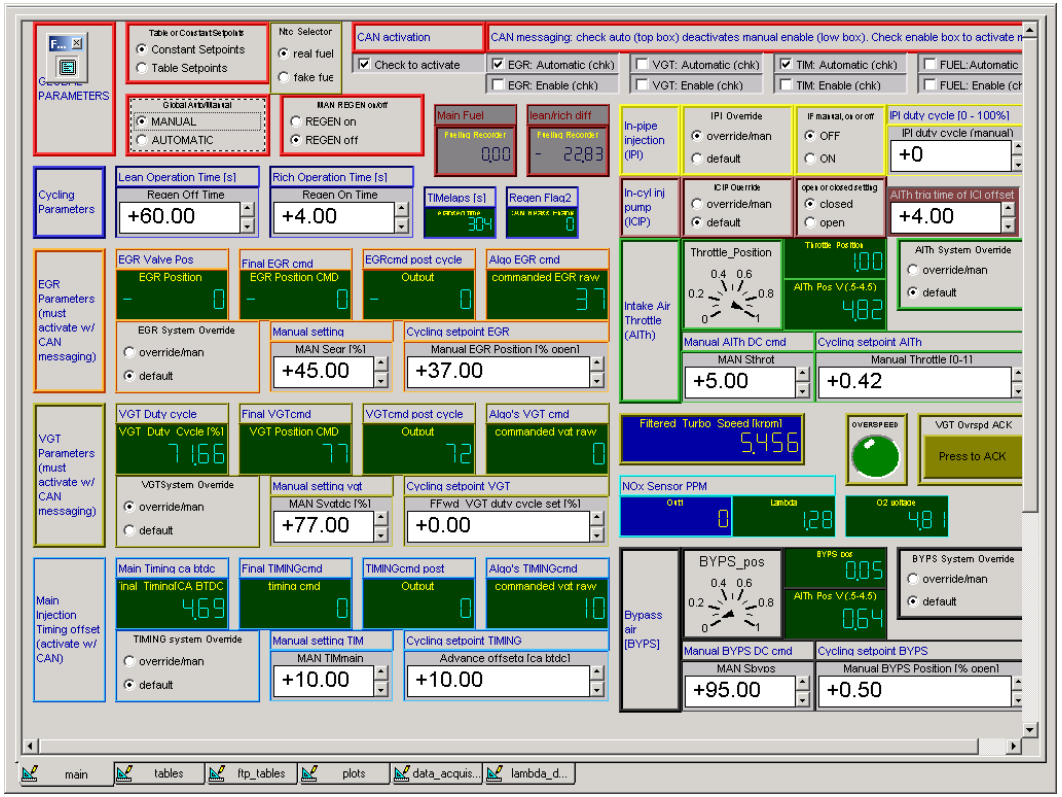


Information/data exchange via J1939 CAN link.

- Modified EGR valve position
- Modified VGT position
- Modified main fuel injection timing
- Main fuel rate
- EGR position feedback
- Timing and fueling information
- other sensors (MAP, engine speed)

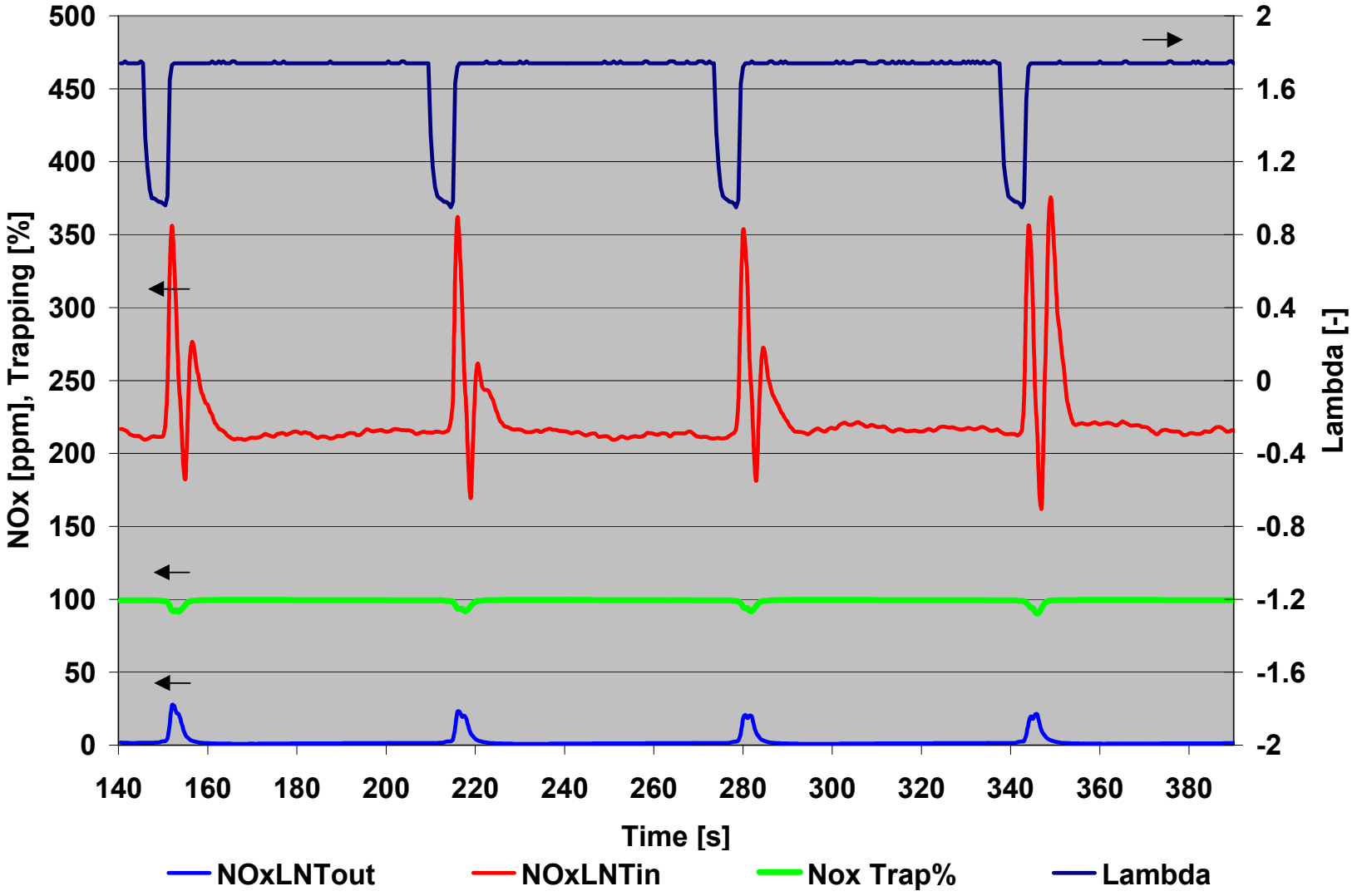
Controls

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



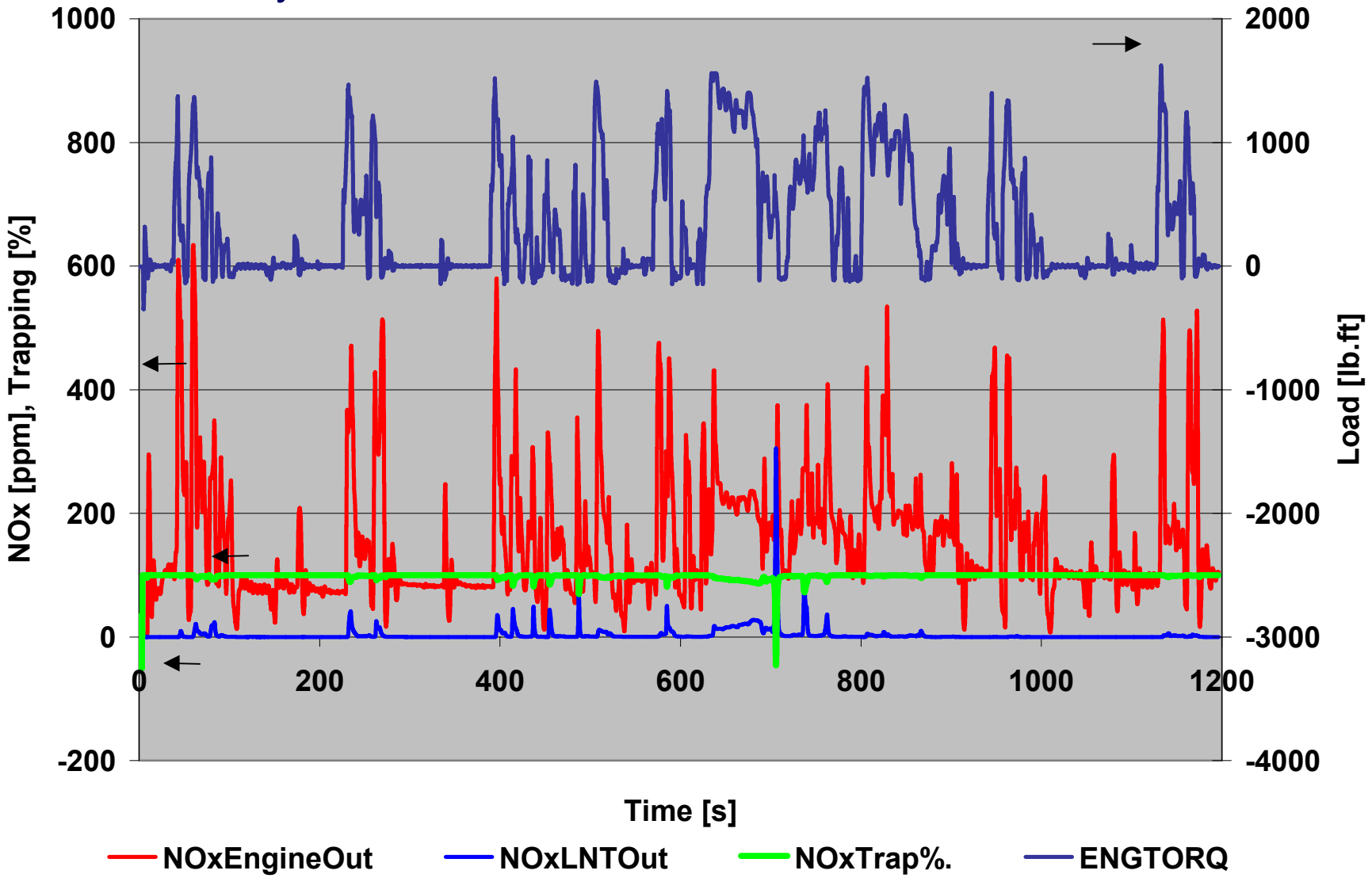
Preliminary Results-Single NOx Adsorber

- Lean/rich cycling at 1800 rpm, 800 Nm



Preliminary Results-Single NOx Adsorber

- Hot start FTP cycle trace



Preliminary Results-Single NOx Adsorber

- Preliminary FTP Cycle Results without downstream clean up catalyst

Test #	Type	NOx g/hp.h	HC g/hp.h	CO g/hp.h
1303	Hot	0.108	1.350	0.984
1304	Hot	0.095	1.230	0.941
1305	Hot	0.085	1.240	0.987
1306	Hot	0.184	1.361	1.612
1307	Hot	0.109	1.230	1.009
1308	Hot	0.097	1.237	1.046
1309	Hot	0.097	1.240	0.996
1310	Hot	0.098	1.237	1.061
1330	Hot	0.158	1.330	1.454
1331	Hot	0.119	1.331	1.118
Average	Hot	0.115	1.279	1.121

	Type	NOx g/hp.h	HC g/hp.h	CO g/hp.h	PM g/hp.h
1329	Cold	0.609	1.920	2.261	0.0033
1330	Hot	0.158	1.330	1.454	0.0025
Composite	Wtd 1329+1330	0.222	1.414	1.569	0.0026
2007 / 2010 Limits		0.2	0.14		0.01

- Development aims to address:
  - Optimization of rich regeneration strategy to minimize HC slip and fuel consumption penalty
  - Clean up catalyst needs to be evaluated
  - Cold cycle strategy optimization for improved light off
- Unregulated emissions will be evaluated during the test program

Concluding Remarks

- Initial results show >85% NOx adsorber efficiency under steady state operating conditions. Peak efficiencies up to 98% at optimum conditions, light -medium engine load, exhaust temperature around 350 degC
- Transient FTP cycle NOx adsorber regeneration strategies are under development. Initial results show excellent NOx conversion efficiency and FTP cycle NOx approaching 2007 targets.
- HC emissions are currently very high and optimization of the rich regeneration strategy and aftertreatment system is required to minimize HC slip and the fuel consumption penalty.
- The NOx adsorber has so far run 59 hours on 0.6 ppm sulfur fuel without desulfation with no discernable deterioration in trapping efficiency

Concluding Remarks

- Rich regeneration under full engine load has not been achieved yet and development effort is planned following initial catalysts evaluations. This is expected to include in-pipe post injection.
- Lean / rich cycling of the engine places additional demands on the engine, turbocharger and EGR system. The effect on engine durability will need to be fully evaluated before the feasibility of such a system in production can be determined - this is outside the scope of the current program.