Emissions Control for Lean Gasoline Engines

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2010 U.S. DOE Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

June 7-10, 2010

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U.S. Department of Energy

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Overview

- **Timeline**
  - **Project start date: Oct. 2009**
  - **Project end date: not set**
  - **% Complete: Ongoing**
  - *Note: this project is a recent adaptation from a previously funded project that focused on Lean NOx Trap catalysts for diesel engines*

- **Barriers**
  - **Cost-effective emission control for lean gasoline engine vehicles**

- **Budget**
  - **FY2010: $200k**

- **Collaborations/Interactions**
  - **DOE Vehicle Technologies Program**
  - **Cross-Cut Lean Exhaust Emissions Reduction Simulations (CLEERS)**
  - **General Motors**
    - Loan of Euro spec Lean GDI BMW vehicle

Objectives / Relevance

- **Objective:** Address technical challenges of enabling market penetration of lean gasoline engine vehicles by studying emission control approaches to achieve emission regulation compliance

- **Relevance:** U.S. passenger car fleet is dominated by gasoline-fueled vehicles. Enabling introduction of more efficient lean gasoline engines can provide significant reductions in passenger car fuel consumption (thereby lowering petroleum use and reducing greenhouse gases).

Milestones

- **Characterization of exhaust from the LNT system of a lean gasoline engine vehicle including reductants produced for LNT regeneration and reporting of information to the CLEERS community. (September 30, 2010)**

Approach

- Study emission control devices on multi-cylinder lean gasoline engine on engine dynamometer; potential emission control devices include:
  - Lean NOx Trap (LNT) catalyst
  - Selective Catalytic Reduction (SCR) catalyst
    - Urea-based
    - Hydrocarbon-based
  - Three-way catalyst (TWC) [likely as part of system]
  - Oxidation catalyst [or oxidative function of catalysts]
  - Hydrocarbon trap catalysts [or cold start specific technologies]
  - Combinations of catalysts (e.g. LNT+SCR)
- Complement engine-based studies with bench flow reactor studies and other catalyst characterization tools
- Communicate results to stakeholders with CLEERS being a primary conduit for information exchange

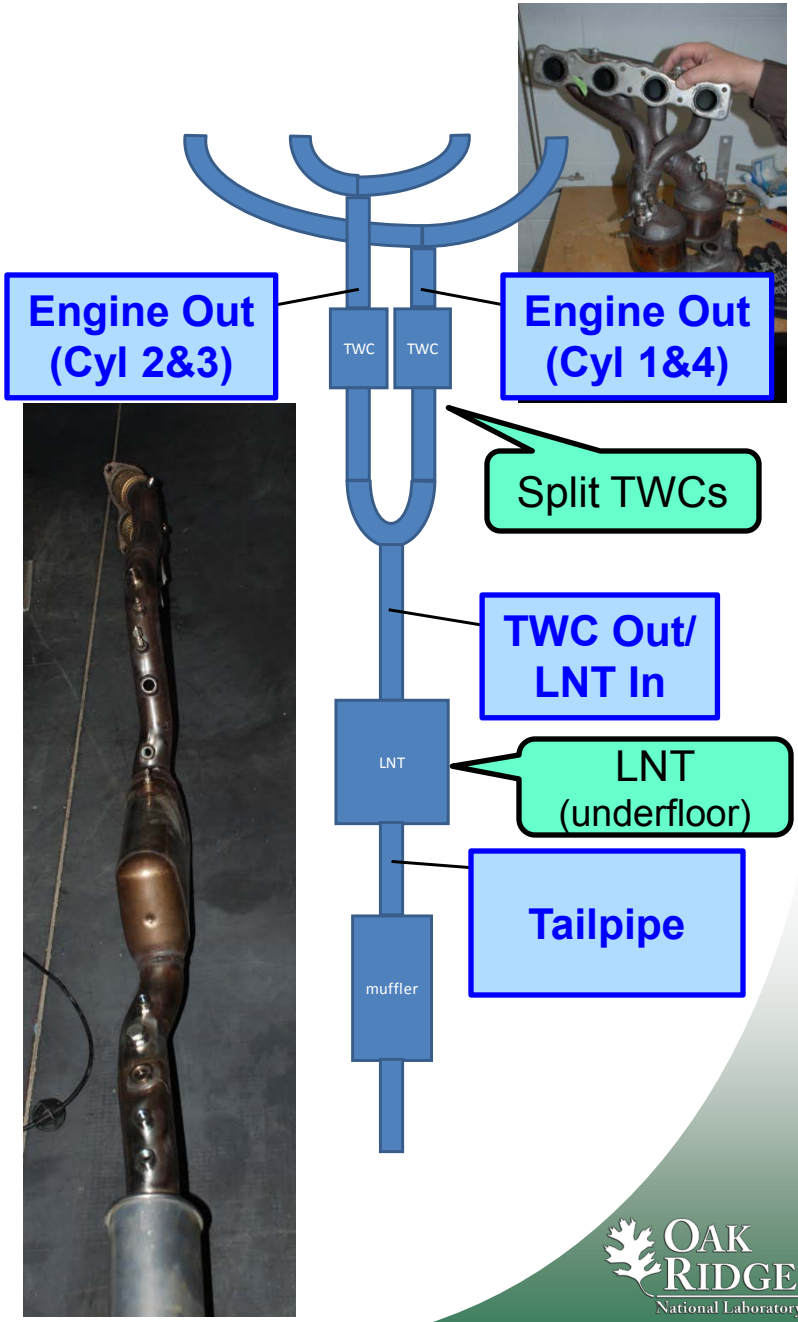
Technical Accomplishments and Progress

Beginnings of project are focused on gaining information on lean gasoline engine emissions with end goal of engine dynamometer experimental platform

- **Chassis-dynamometer experiments performed to characterize exhaust from MY2008 BMW 120i vehicle which uses TWC + LNT technology for European emissions compliance**
  - **Leveraging with Vehicle Systems program**
- **Bench flow reactor studies of CLEERS LNT (a lean gasoline catalyst) under lean gasoline engine exhaust conditions [ongoing]**
- **Acquire a modern lean gasoline engine vehicle suitable for engine dynamometer studies [in progress]**
  - **Targeting same BMW engine with associated LNT exhaust system**
  - **Plan to develop Drivven control system for full control of engine operation**

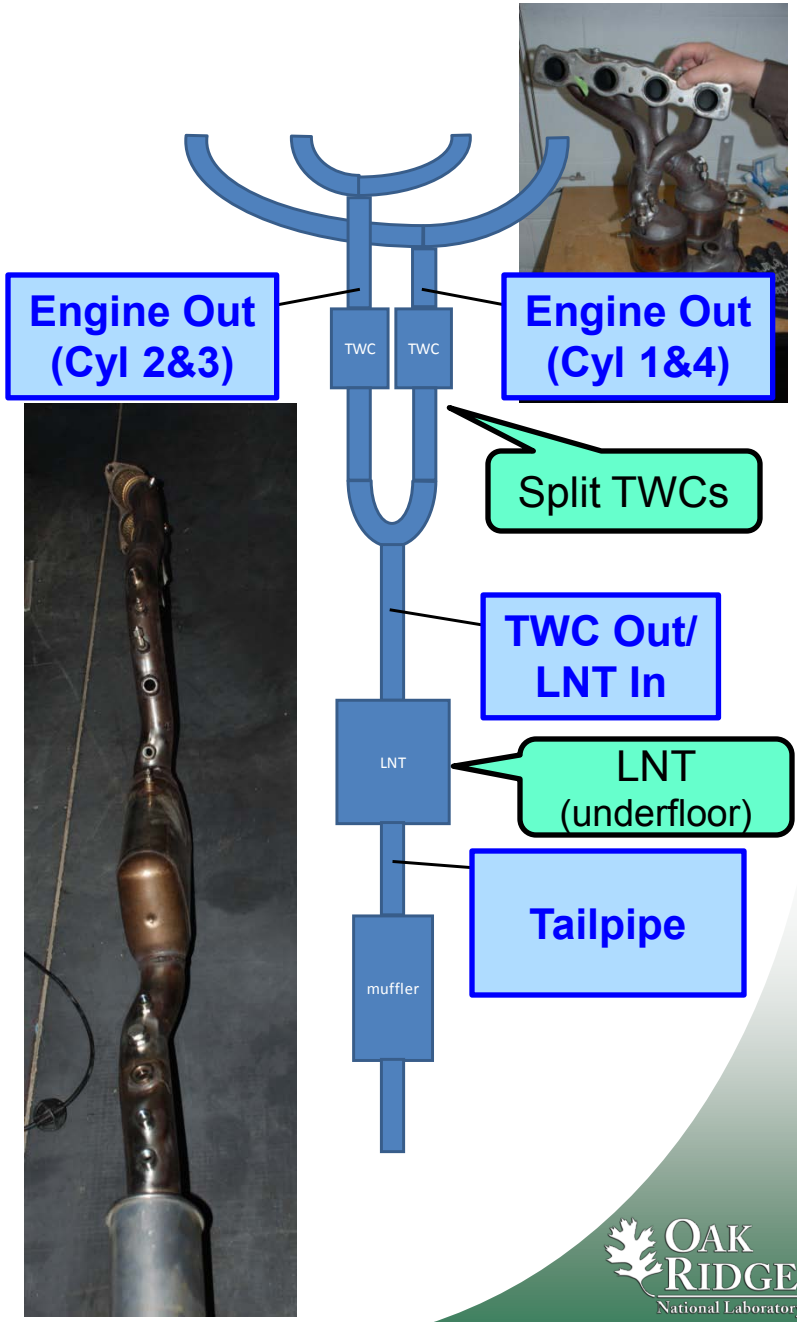
Accomplishments – Chassis-Dynamometer Study

- Engine specs (N43B20)
  - 2.0l 4-cylinder
  - Lean burn combustion
  - 200bar direct Injection
  - 170 hp (130 kW) at 6,700 rpm,
  - 210 Nm (155 ft.lbf) at 4,250 rpm
  - 12:1 compression ratio
  - Dual VVT and EGR
- Exhaust
  - Split TWCs
  - LNT



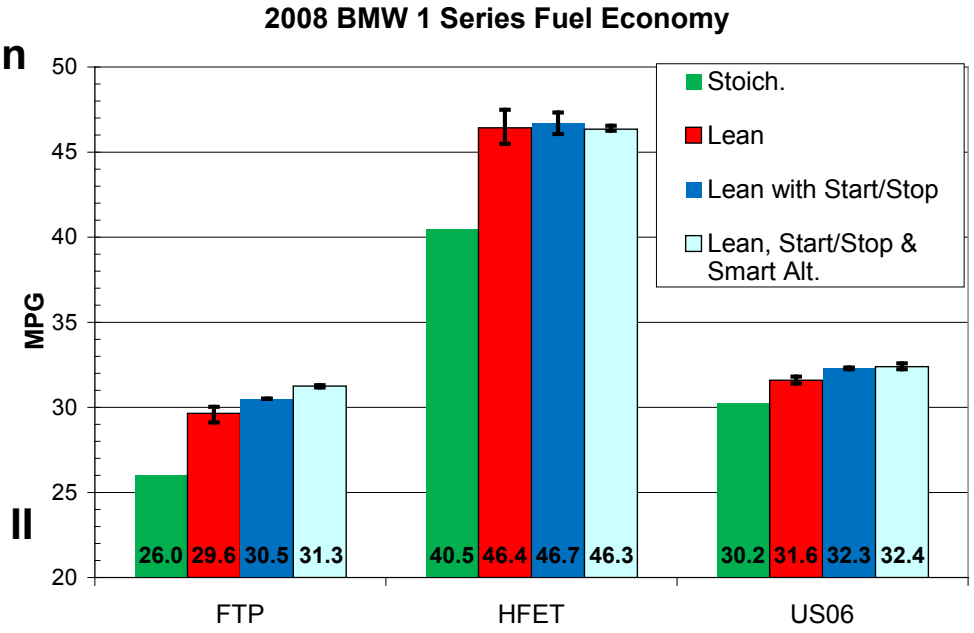
Accomplishments – Experimental Focus

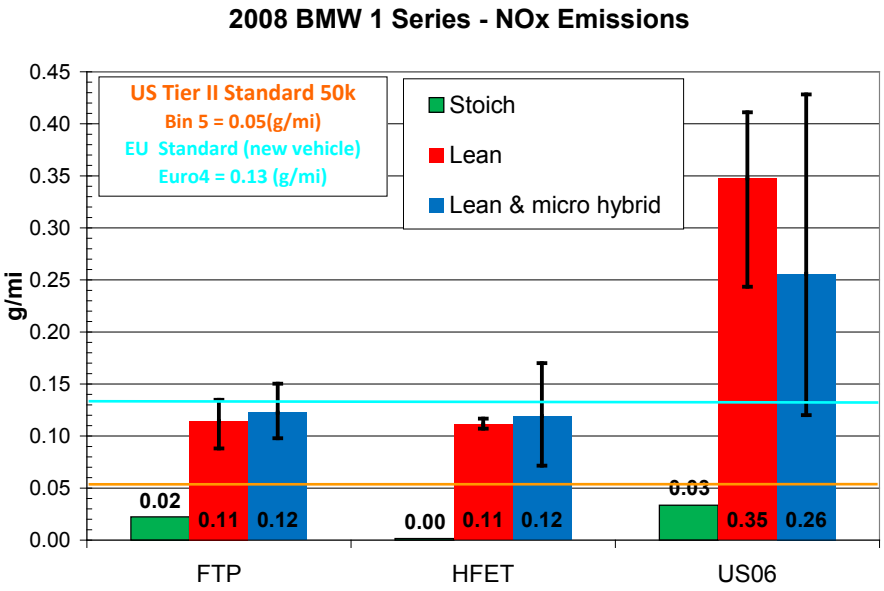
- **Emissions and Reductant Species (this project)**
  - UEGOs for both exhaust manifold legs
  - General emissions analyzers at engine out and tailpipe positions
  - Reductant focused emissions analysis at LNT inlet position
    - FTIR (NO, NO_2, N_2O, NH_3, HCs, CO, etc)
    - SpaciMS (H_2, O_2)
    - *Note: some measurement at other positions with these tools*
- **Vehicle Systems Program project**
  - Overall efficiency and emissions
    - Transient drive cycles
    - Steady-state conditions
  - Mapping of engine for database
  - Start-stop feature
  - Mild hybridization (Intelligent alternator)
  - See "Light-Duty Lean GDI Vehicle Technology Benchmark" (presentation VSS17) for more information



Accomplishments: Drive Cycle Results

- **Fuel Economy Benefit of Lean Operation = 4-14% depending on drive cycle**
  - **FTP: 13% better fuel economy with lean operation**
  - **HFET: 14% better fuel economy with lean operation**
  - **US06: 4% better fuel economy with lean operation**
- **Tailpipe NOx emissions exceed US Tier II Bin 5 Standard**





	Stoich	Lean	Lean with Start/Stop	Lean with Start/Stop And Inteligent Alt.
Fuel Consumption [MPG]	26.02	29.52	30.50	31.25
Improvement [%]	0	13.5	17.2	20.1

Lean engine improves fuel economy but fails to meet US emission standards

Accomplishments: Conditions for data collection

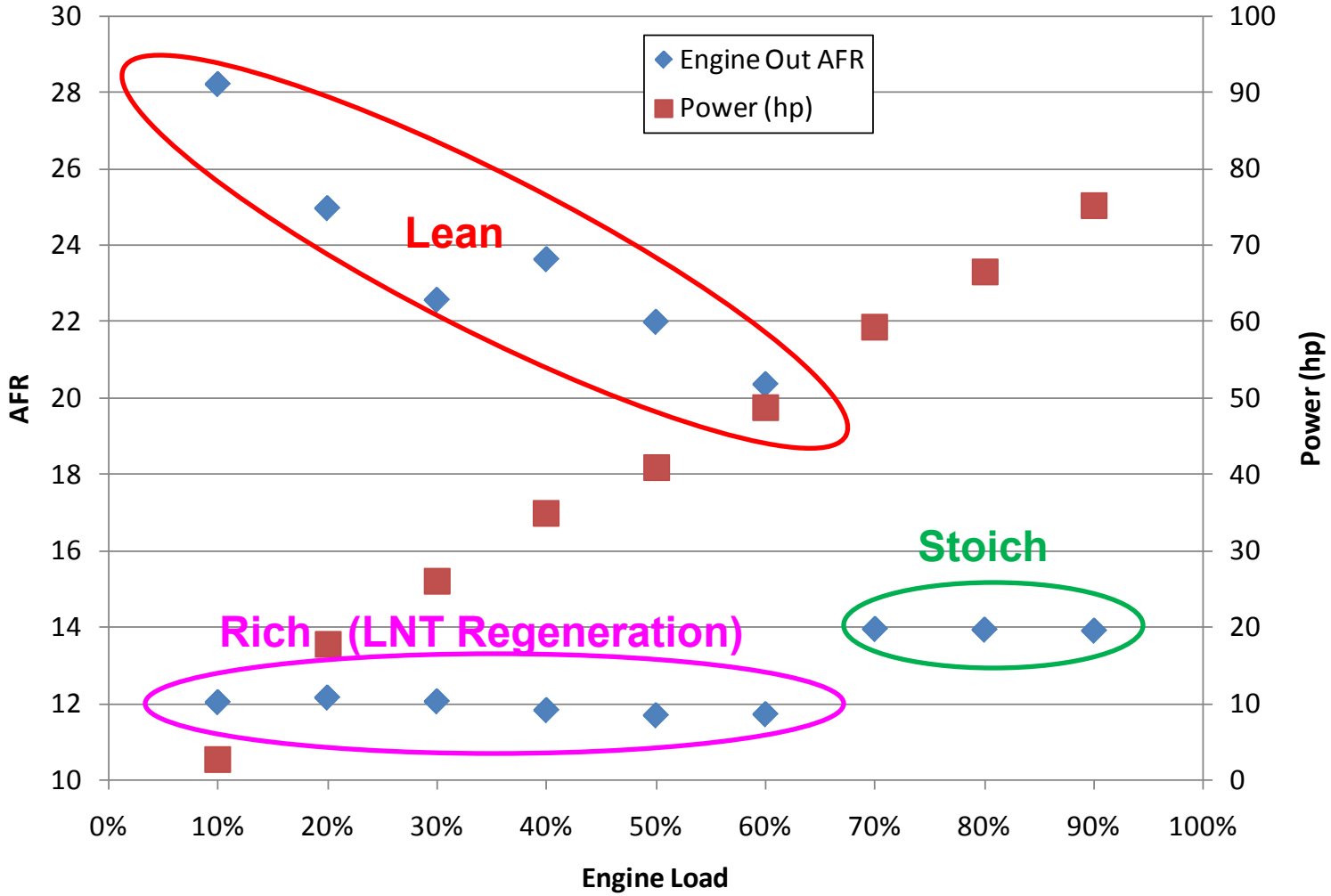
- **Transient drive cycles:**
  - **FTP, HFET, US06**
- **Matrix of driving conditions examined for mapping purposes**
  - **Vehicle speed =**
    - **1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 6000, 7000 RPM**
  - **Load =**
    - **10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%**
- **Will focus on 3500 RPM load sweep data for today's review**

Large amount of data acquired; analysis ongoing

Accomplishments: AFR as function of load (3500 rpm)

- Lean operation up to 60% load
  - (leaner at lower loads)
- Rich LNT regeneration at similar AFR

Lean operation at lower loads; stoich for high loads

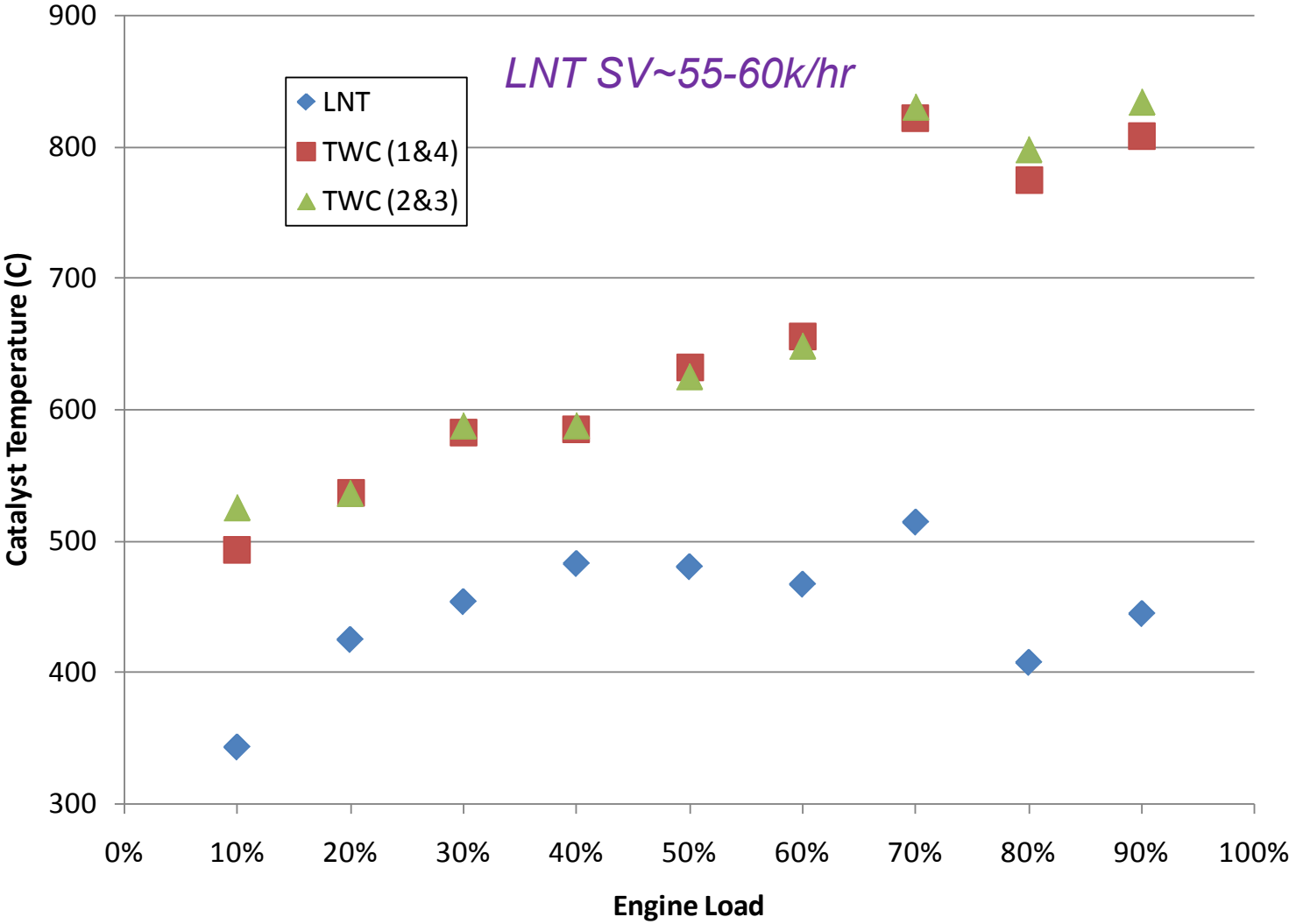


Note: order of load sweep=60%,50%,70%,40%,80%,30%,90%,20%,10%
(Steady-state operation)

Accomplishments: Catalyst temperatures

- LNT temperatures generally between 300 and 500ºC
- TWC temperatures generally between 500 and 820ºC

Temperature Range = 300-500ºC

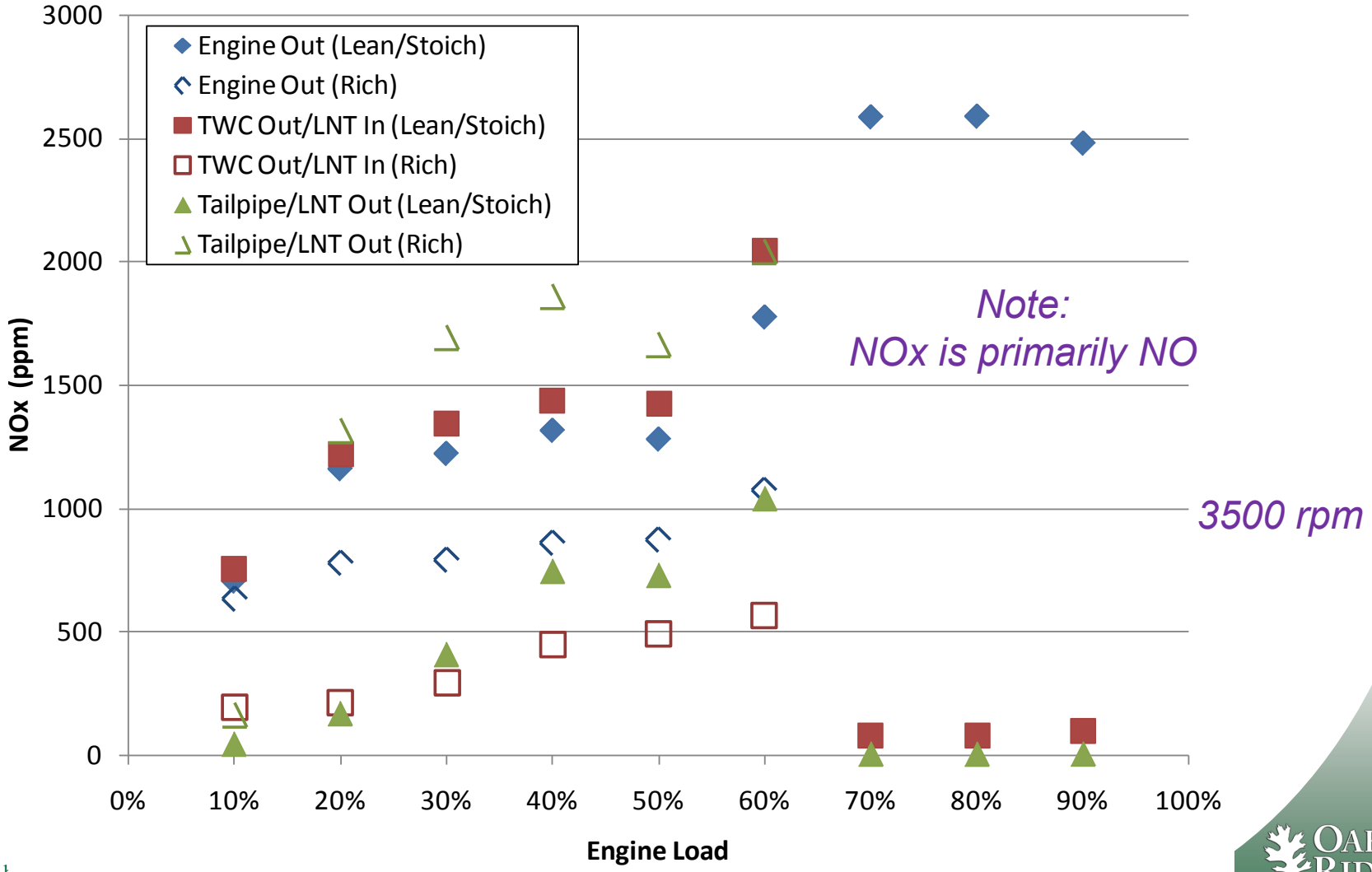


3500 rpm

Accomplishments: NOx Concentration

- LNT adds TWC-function at stoich conditions
- Challenging high concentration of NOx for LNT
- LNT out NOx significant (lean and rich)

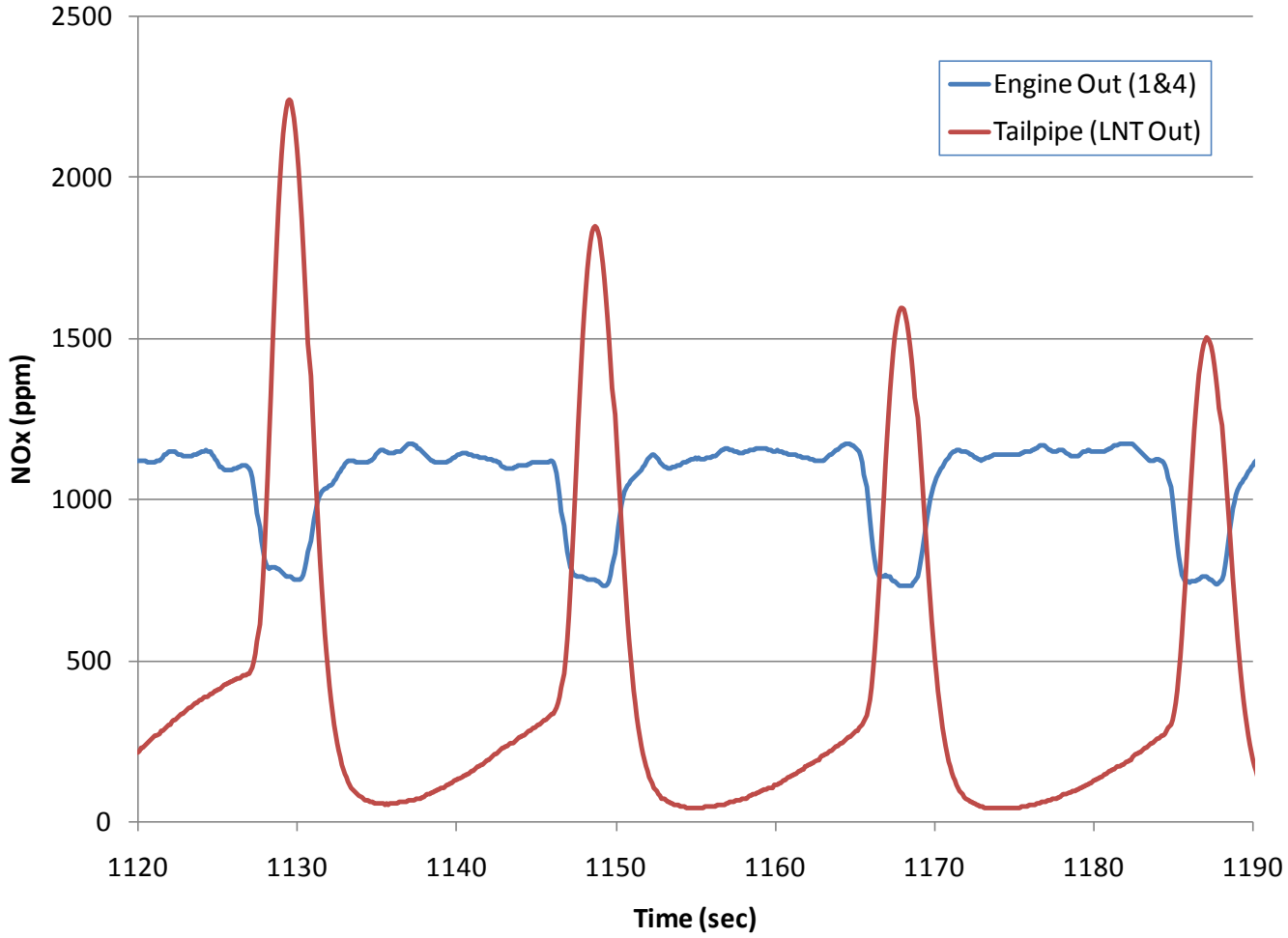
Very high NOx concentration (vs. diesels)



Accomplishments: NOx concentration at 20% load

- Significant NOx breakthrough occurs even during short cycle
- Large NOx emissions during rich operation for regeneration

NOx profiles show significant NOx breakthrough and desorption during regeneration

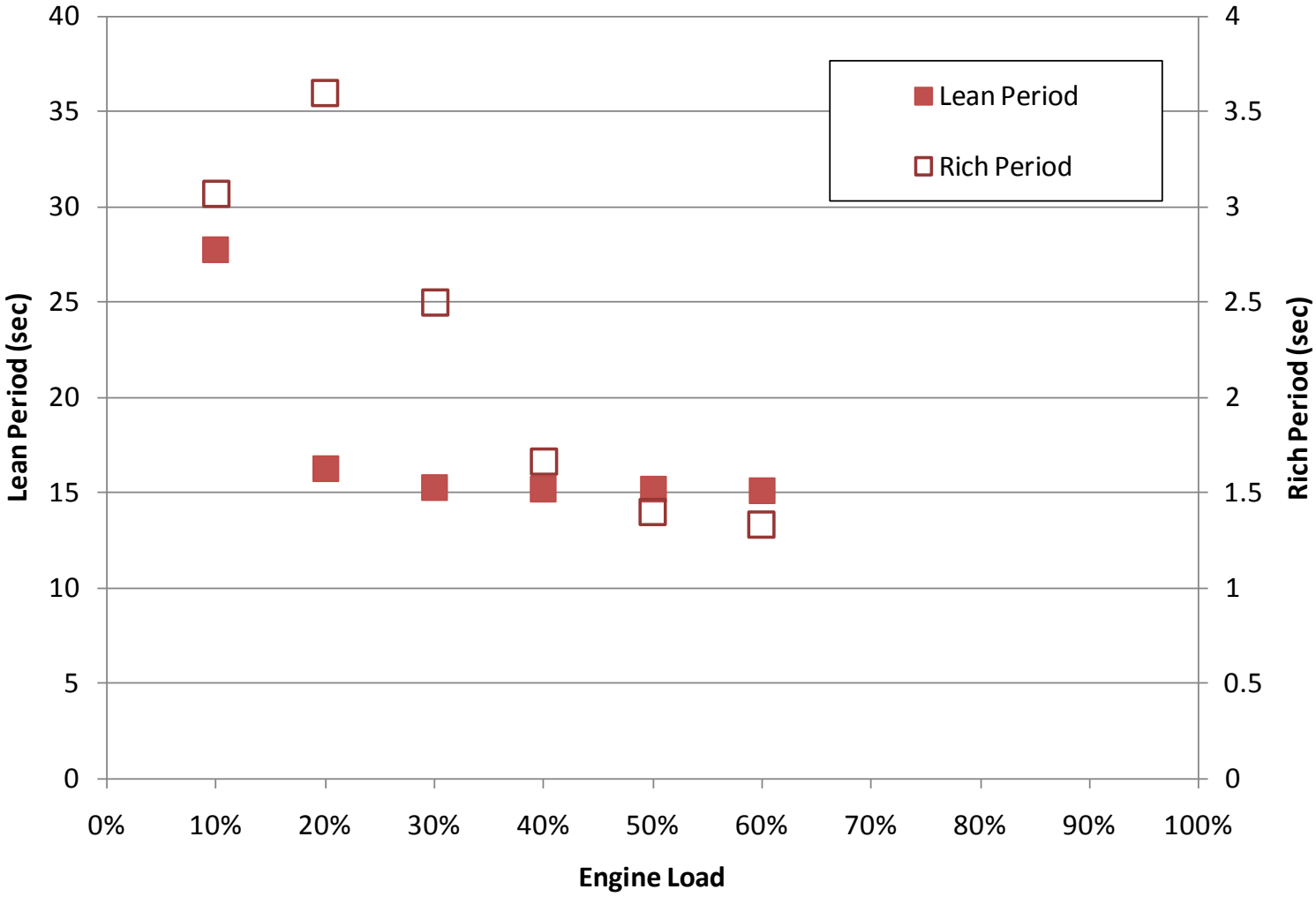


3500 rpm

Accomplishments: Lean-Rich cycle period

- Short lean period due to filling of LNT (15 sec limit?)
- Rich period varies with load (temp?)

Short time for lean operation due to high NOx levels

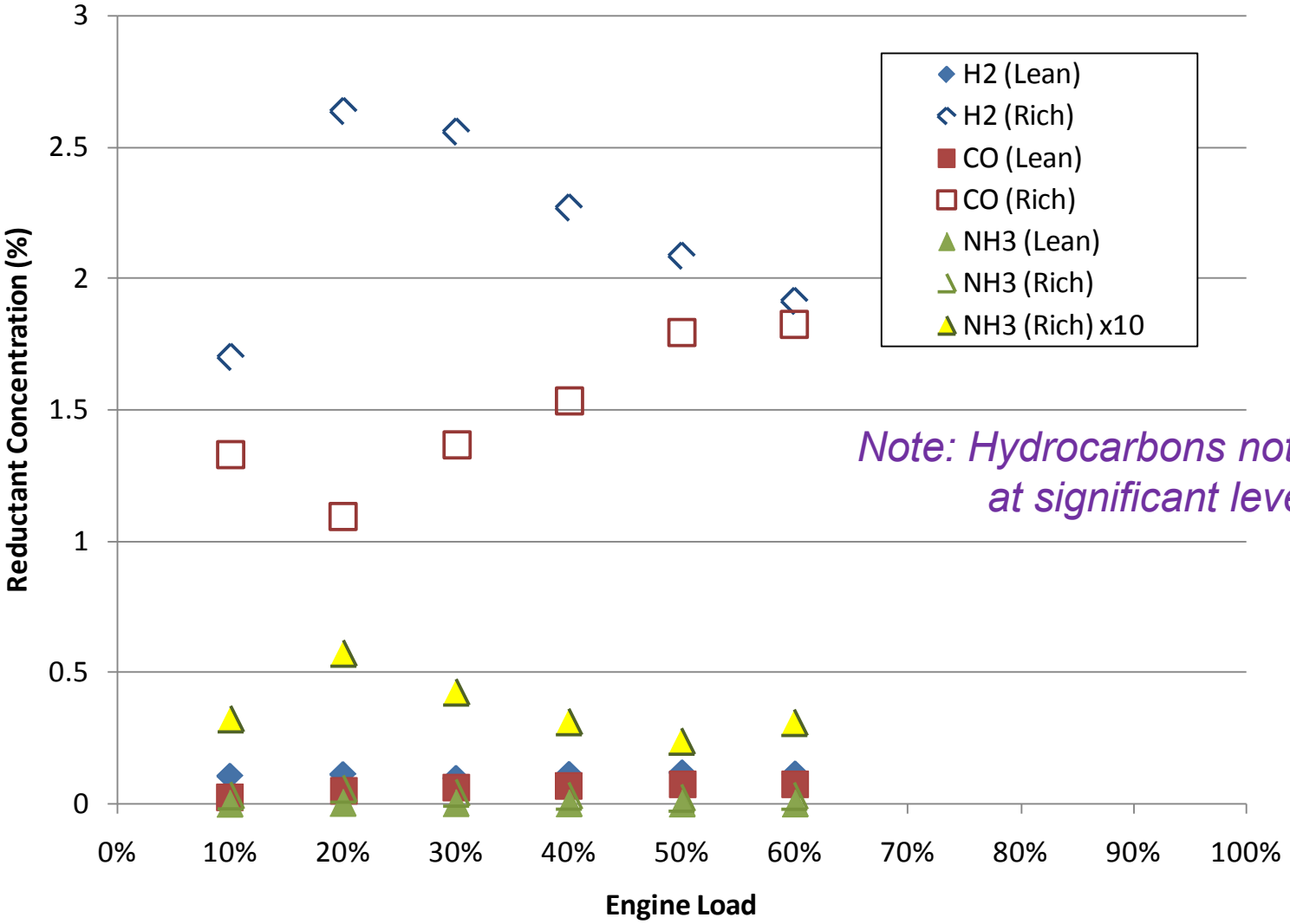


3500 rpm

Accomplishments: Reductant Chemistry

- H_2 present at higher levels than CO during rich period
  - Water-gas-shift over TWC
- NH_3 detected at small levels can perform some reduction on LNT

Primary reductants are H_2, CO, NH_3



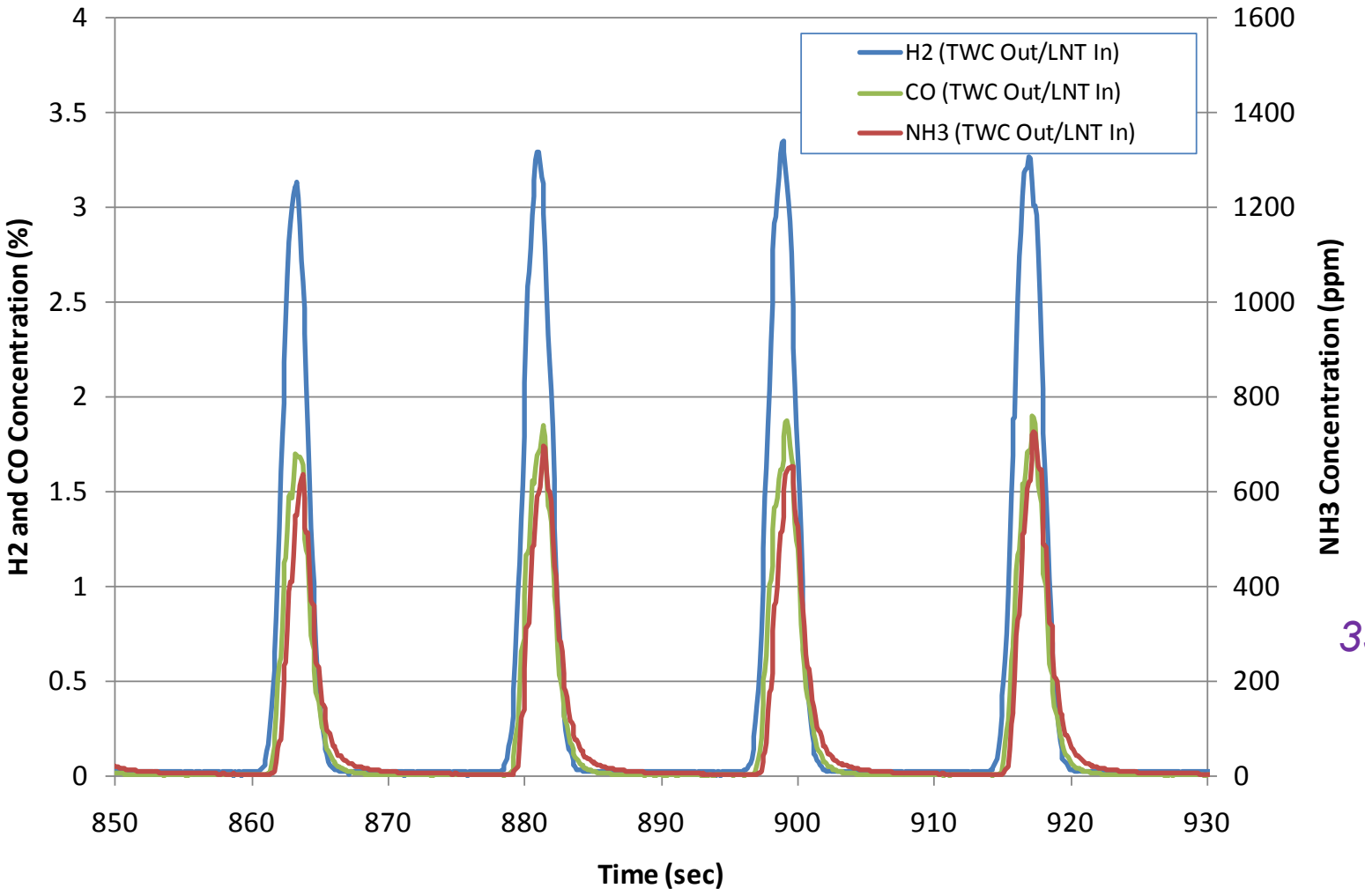
Note: Hydrocarbons not detected at significant levels

3500 rpm

Accomplishments: Reductants at 30% load

- Sharp peaks of reductants from rich operation
- H_2, CO, and NH_3 are main reductants

Temporal profiles for reductants are similar

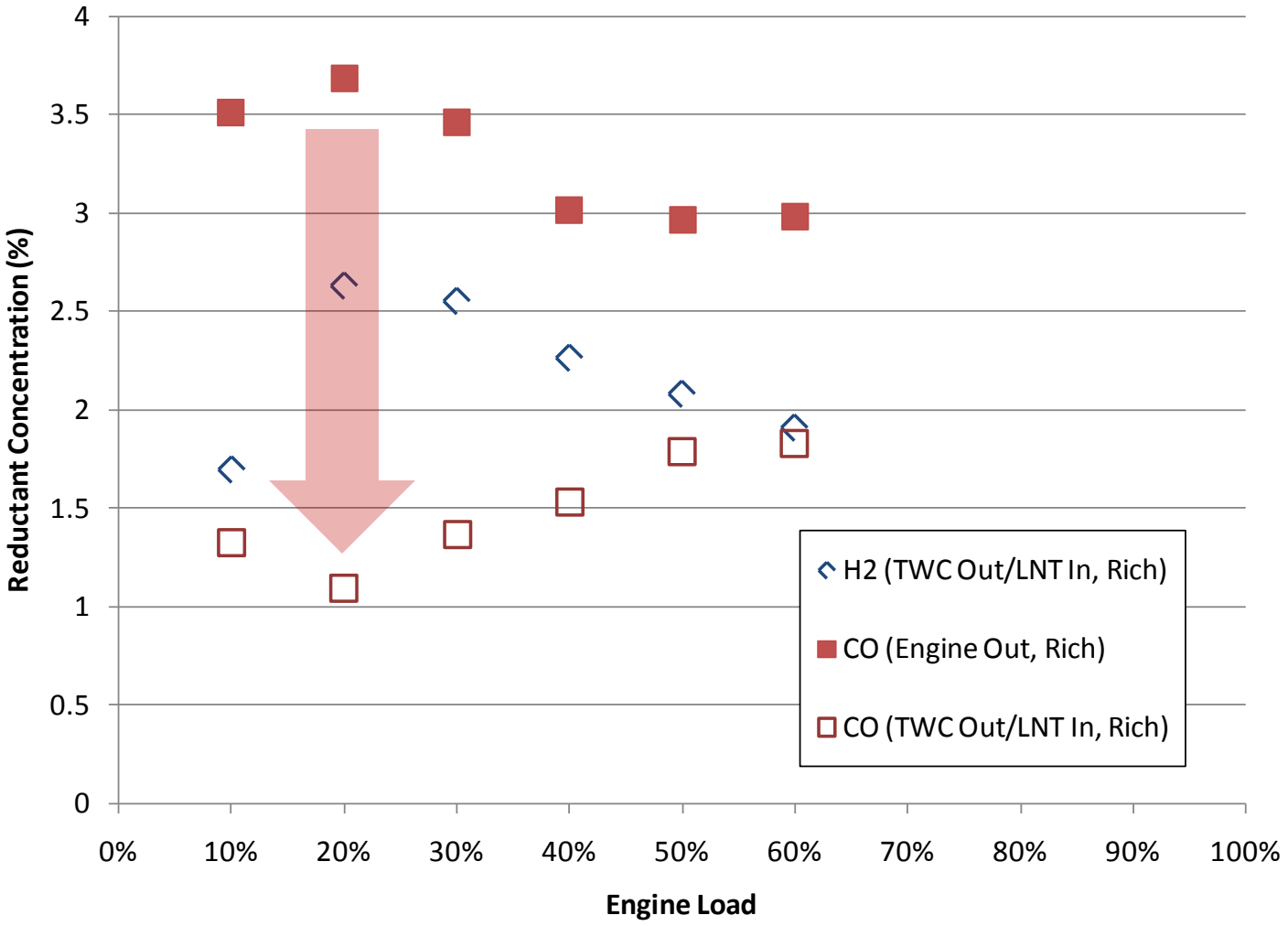


3500 rpm

Accomplishments: Reductant Chemistry- TWC Effects

- CO concentration drops over TWC during rich operation
  - Water-gas-shift over TWC
- More analysis to come

Evidence of Water-gas-shift over TWC

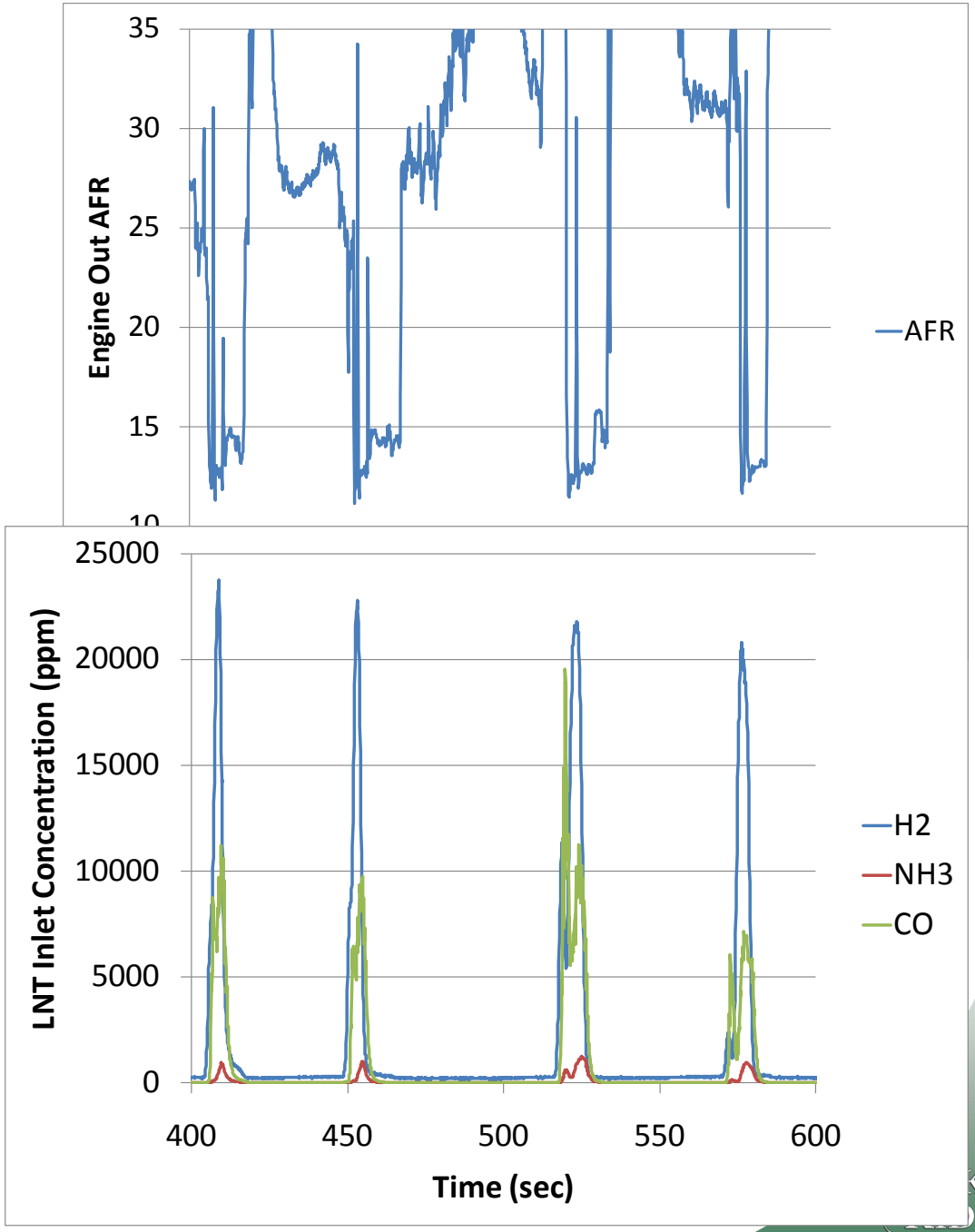


3500 rpm

Accomplishments: Drive Cycle Data

- Reductant species at LNT inlet positions during transient drive cycle (LA4)
- (4) regeneration events shown
- LNT regeneration at AFR of ~13
- H_2, CO, and NH_3 present at LNT inlet
  - H_2:CO ratio higher than observed in diesel case
  - Significant NH_3 observed (product of TWC)

Transient regenerations appear similar to steady-state observations… more analysis coming



Collaboration

- Collaboration with Vehicle Systems program (internal project) which will support PSAT program
- Intend to work in CLEERS structure to share results and identify research needs
- General Motors (loan of Euro spec Lean GDI BMW vehicle)
- Catalyst manufacturers
  - Open to study of new formulations

Future Work

- **Remainder of FY2010**
  - **Continue analysis of results from BMW 120i chassis-dynamometer experiments**
    - **Supply information to CLEERS via website database**
  - **Continue bench flow reactor capacity examination of CLEERS LNT**
  - **Acquire and setup lean gasoline engine with controls**
- **FY2011 and beyond**
  - **Characterization of reductant production for LNT regeneration at various operating conditions (controlled AFR, etc)**
  - **Examine LNT+SCR approach for NOx control**
    - **Carry forward from experience gained on diesel-based project**

Summary

- Project focus is emission control for lean gasoline engines
  - Potential for significant reduction in petroleum use in U.S. passenger vehicle fleet
- Chassis-dynamometer based experiments on European lean gasoline engine vehicle with LNT technology for NOx control
  - Analysis ongoing; results to be shared in CLEERS
- Acquisition of lean gasoline engine for engine-dynamometer experiments underway

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