Light-Duty Lean GDI Vehicle Technology Benchmark

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Overview

- **Timeline**
  - Project start date: Oct. 2009
  - Project end date: Sept. 2010
  - 50% complete
- **Barriers**
  - Fundamental knowledge of engine combustion
  - Emission control
  - Hybrid technology
- **Budget**
  - Total project funding: $300k
  - DOE funding: $300k
  - New project, no FY09 funding
  - FY10 funding: $300k
- **Collaborations/Interactions**
  - DOE-ORNL emissions, after-treatment and health effects projects
  - **General Motors** (Loan of Euro spec Lean GDI BMW vehicle)
  - Idaho National Laboratory (testing support)
  - Argonne National Laboratory (integration of engine data into PSAT, Autonomie)

Objectives / Relevance

- Benchmark performance and emissions of engine featuring new technologies:
  - Engine combustion (Lean direct injection)
  - Emission control (LNT for gasoline engine)
  - Engine technology (Stop-start, smart alternator)

- Improve knowledge and understanding of those new technologies:
  - Quantify benefits and drawbacks
  - Advise on future work related to those technologies

- Make information publicly available for vehicle simulations of advanced powertrains and after-treatment systems

Milestones

- **Milestone #1 - July 31, 2010 :**
  - **Acquire and characterize modern lean GDI vehicle on chassis dynamometer**

- **Milestone #2 - September 30, 2010 :**
  - **Finalize performance/emissions maps and make available with simulation example to Vehicle Systems team**

Approach

- **Acquire a modern lean GDI vehicle with lean NO_x emission controls system from Europe (vehicle has to be representative of the most advanced technologies on the market)**
- **Instrument vehicle and perform chassis dynamometer experiments to characterize performance, emissions, and after-treatment system for**
  - **US drive cycles: UDDS, HFET, and US06**
  - **Steady-state experiments to establish performance/emissions maps for future vehicle simulations.**
- **Investigate modern production micro-hybrid performance attributes, such as engine start-stop and smart alternator control**
- **Make use of vehicle chassis dynamometer data to develop, substantiate, and exercise vehicle simulation with conventional and advanced powertrains**

Accomplishments – Vehicle Procurement

- **MY2008 BMW 1-series 120i (E81)**

- **Vehicle on loan from GM**
  - **Received early February 2010**
  - **Benchmarking until end of April**

- **Engine specs (N43B20)**
  - **2.0l 4-cylinder**
  - **Lean burn combustion**
  - **200 bar direct injection**
  - **130 kW (170 hp) at 6,700 rpm,**
  - **210 Nm (155 ft-lb) at 4,250 rpm**
  - **12:1 compression ratio**
  - **Dual VVT**
  - **EGR**

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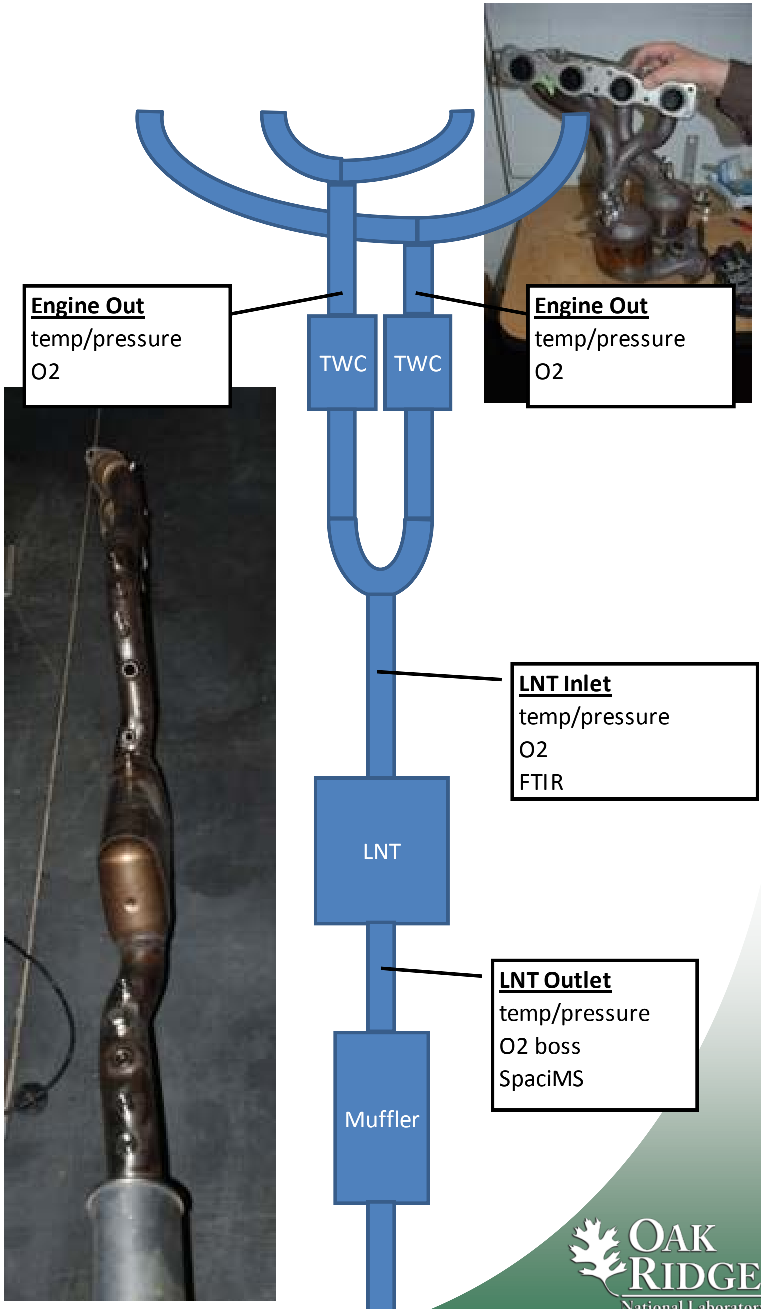
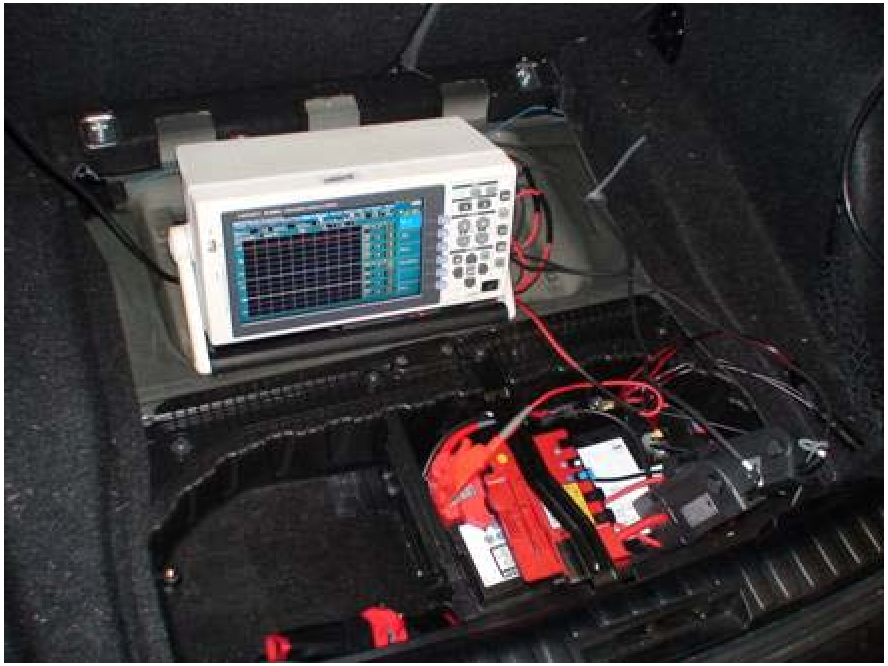
Accomplishments – Engine and After-treatment Instrumentation

- **Exhaust system instrumentation at 4 locations:**
  - NO_x, HC, CO, CO_2, O_2 gas analyzers
  - FTIR for nitrogen oxide speciation, ammonia and hydrocarbon speciation
  - Spatially resolved capillary inlet mass spectrometer for temporal H_2 and O_2 measurements (for LNT regeneration characterization)
  - Particulate matter measurements.
- **Vehicle and engine instrumentation**
  - OBD link
  - Analog channels (AFR, temperature and pressure)



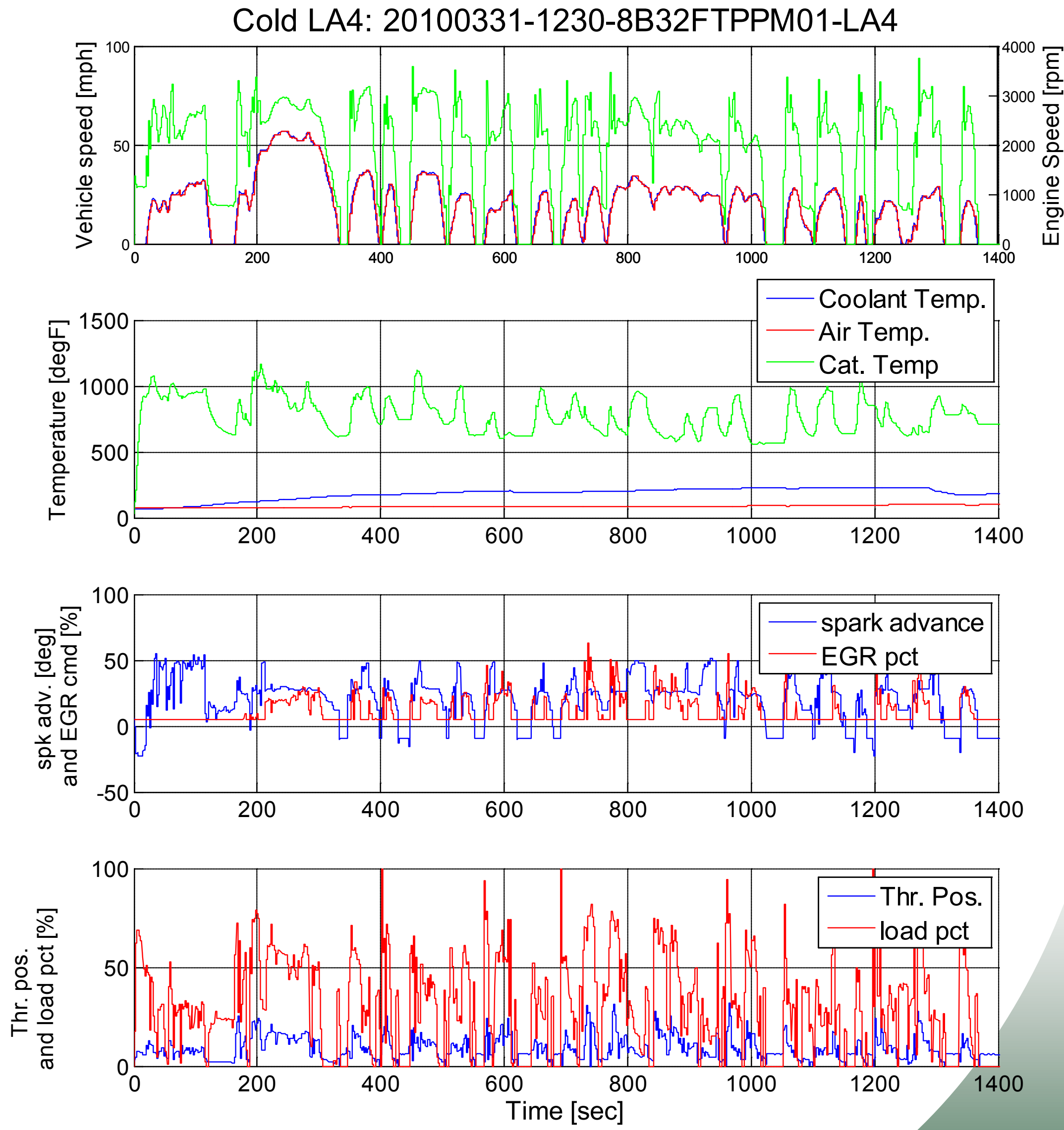
Accomplishments – Hybrid Features Instrumentation

- **Instrumentation**
  - Power analyzer procurement: Hioki 3390
    - High voltage and current Instrumentation
    - Hioki analyzers used by other national laboratories
  - Integration with chassis roll main data logger
- **Start-stop**
  - Engine is stopped when the vehicle is stopped and when certain criteria are met
  - Starter current monitoring (Hioki)
  - Engine operating condition (OBD link)
- **Intelligent alternator**
  - Battery is never fully charged so that it can accept energy. During accelerations, the alternator is not excited to reduce the load on the engine. During coast downs, the alternator recharges the battery utilizing kinetic energy from the powertrain
  - Alternator current and load current monitoring (Hioki)
  - Engine operating condition (OBD link)



Accomplishments – Drive Cycle Testing

- **US drive cycles:**
  - **FTP**
  - **HFET**
  - **US06**
- **Three iterations to guarantee repeatability**
- **Characterization:**
  - **Emissions**
    - **Engine out**
    - **Tailpipe**
    - **LNT reductant chemistry**
  - **Fuel economy**
  - **Engine operation**



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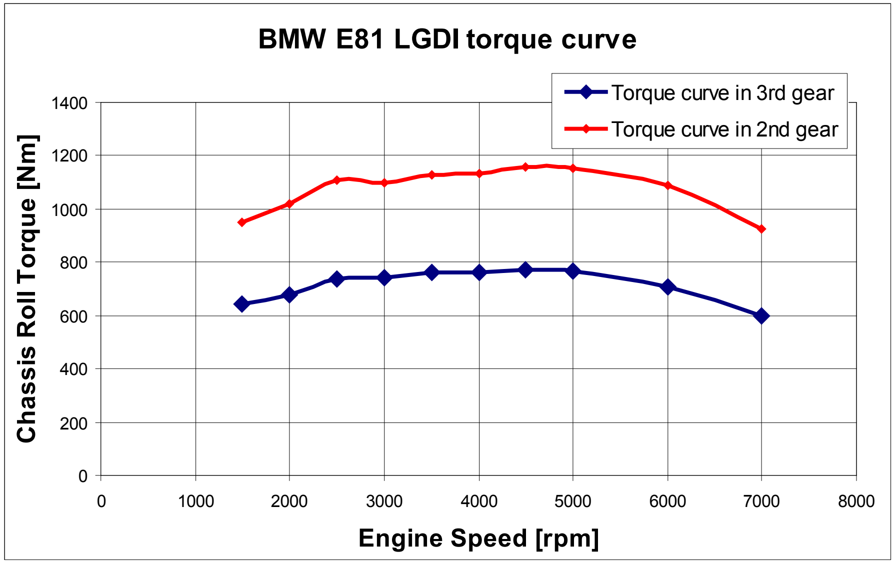
Accomplishments – Steady State Testing

- Complete speed and load engine mapping
- Three iterations to guarantee repeatability
- Characterization:
  - Emissions
  - Fuel economy
  - Engine operation



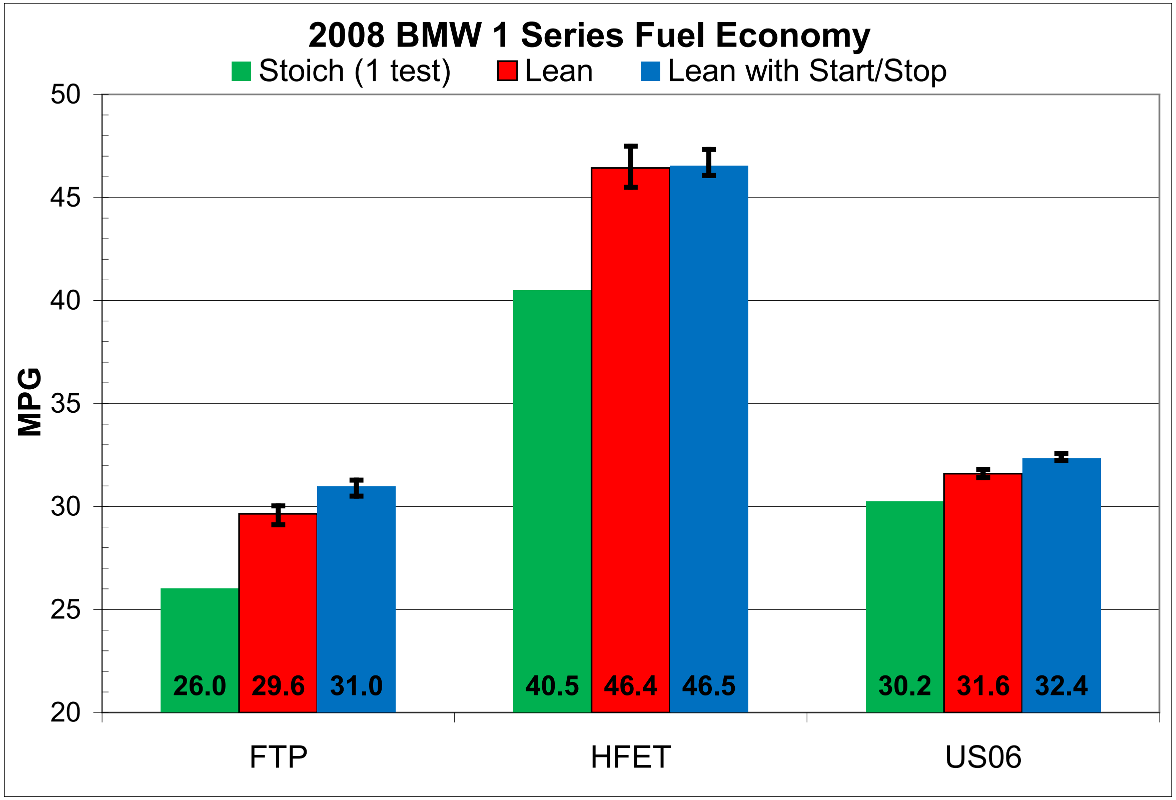
Master Axle Torque (MAP1)

2nd gear

%Load \ RPM	1500	2000	2500	3000	3500	4000	4500	5000	6000	7000
100	950	1020	1106	1097	1129	1132	1158	1153	1088	925
90	855	918	996	987	1016	1019	1042	1038	979	832
80	760	816	885	878	903	906	926	923	870	740
70	665	714	774	768	790	793	810	807	762	647
60	570	612	664	658	677	679	695	692	653	555
50	475	510	553	548	565	566	579	577	544	462
40	380	408	443	439	452	453	463	461	435	370
30	285	306	332	329	339	340	347	346	326	277
20	190	204	221	219	226	226	232	231	218	185
10	95	102	111	110	113	113	116	115	109	92
0	0	0	0	0	0	0	0	0	0	0

Accomplishments – Fuel Economy Preliminary Results

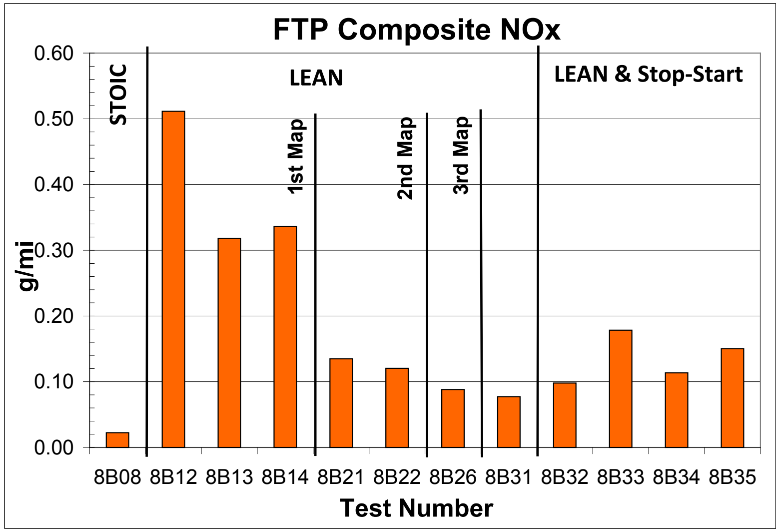
- **Three different operating conditions were tested:**
  - **Stoichiometric**
  - **Lean**
  - **Lean with Stop-start**

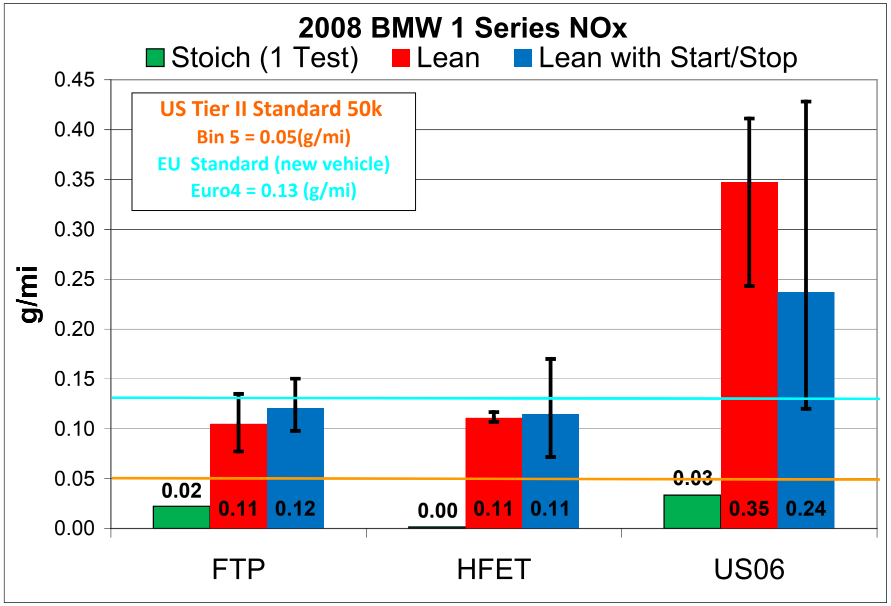


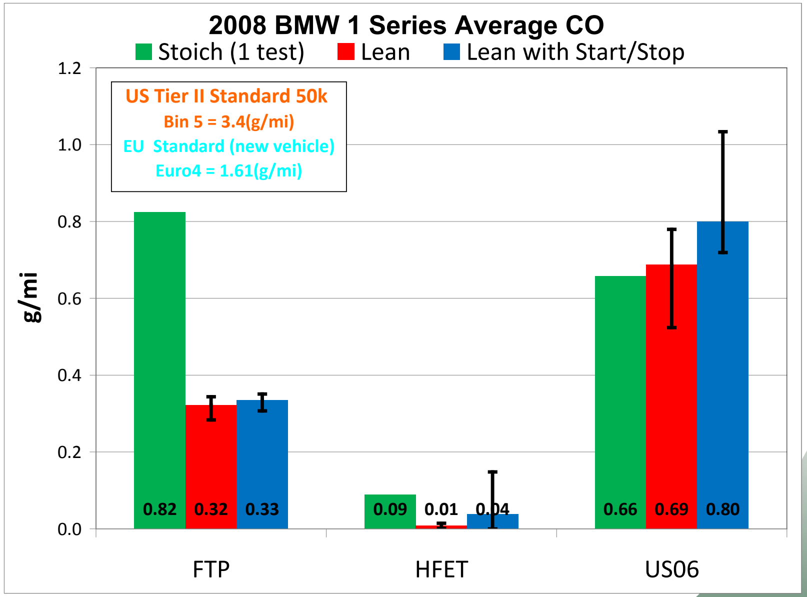
range bars indicate maximum and minimum of multiple tests

Accomplishments – Engine Emissions Preliminary Results

- Emissions were greatly affected by the first mapping exercise
  - High speed and load conditions presumed to have helped clean the LNT
  - Extra low sulfur fuel (<2ppm) used from test 8B12
  - LNT might have been contaminated with earlier higher sulfur level fuel (UTG96, ~26-27ppm sulfur at ORNL and unknown fuel at GM)
- Similar trends on NO_x, CO and PM

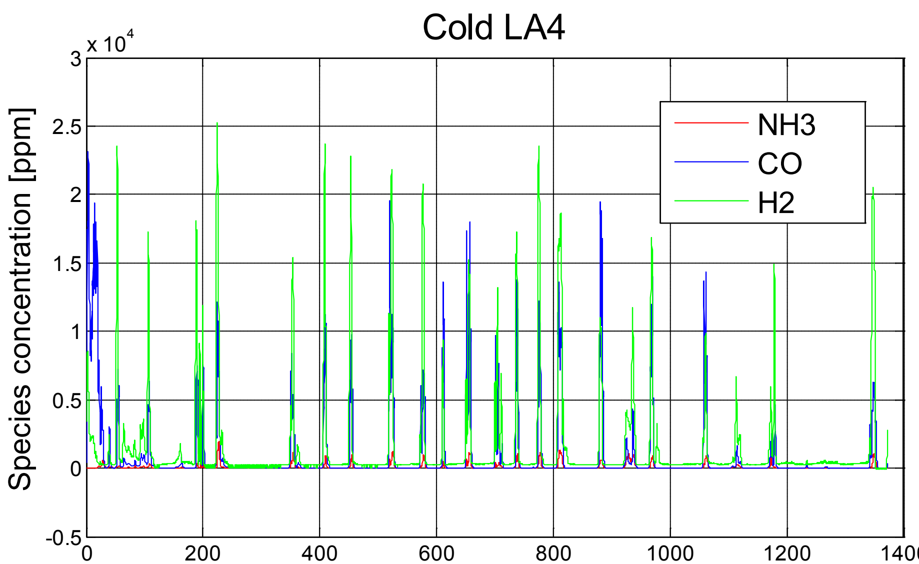


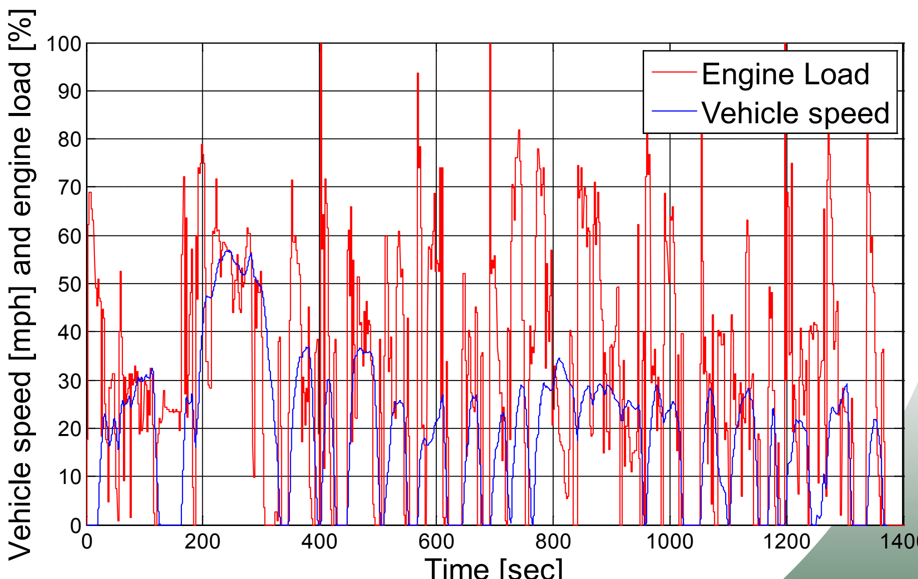




Accomplishments – LNT Characterization (On-going)

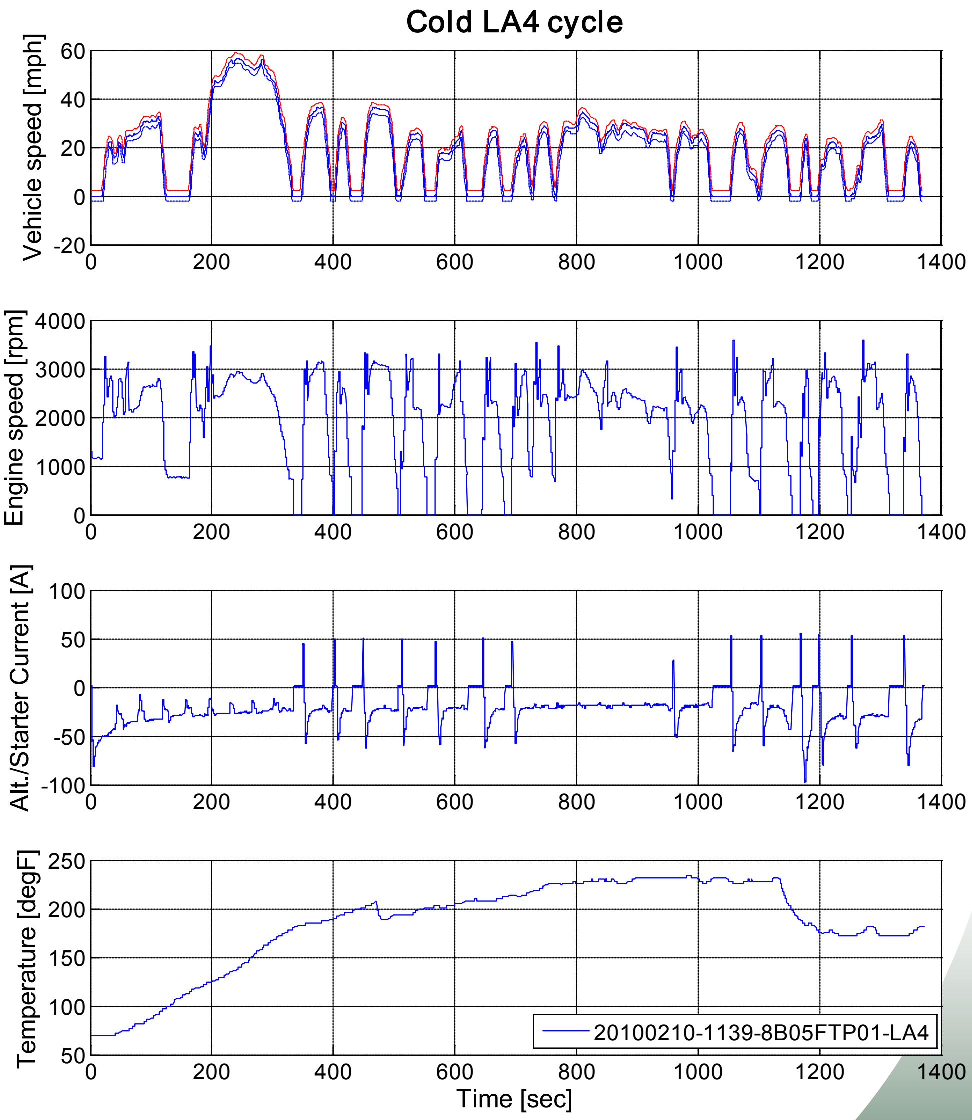
- **Operation of LNT characterized by measurement of exhaust species with FTIR, SpaciMS, and bench analyzers**
- **Reductant species observed at inlet to LNT include H_2, CO, and NH_3**
  - **H_2:CO is much higher than previously observed in diesel engine studies**
  - **NH_3 is present due to formation by upstream Three-Way Catalyst**
- **More analysis in "Lean Gasoline Emission Control" (ACE031) project presentation**
  - **Final results to be shared with CLEERS community**

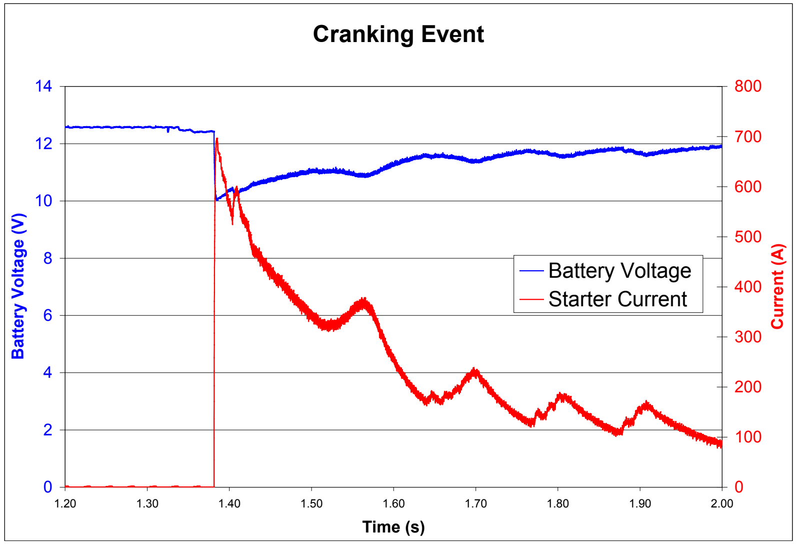




Accomplishments – Start-Stop Characterization (On-going)

- **Present when:**
  - **Vehicle stopped**
  - **Clutch not engaged**
  - **Neutral gear**
  - **Warm engine**
  - **Suitable battery charge**
  - **Other secondary conditions**
- **Fuel economy and emissions effect characterization**

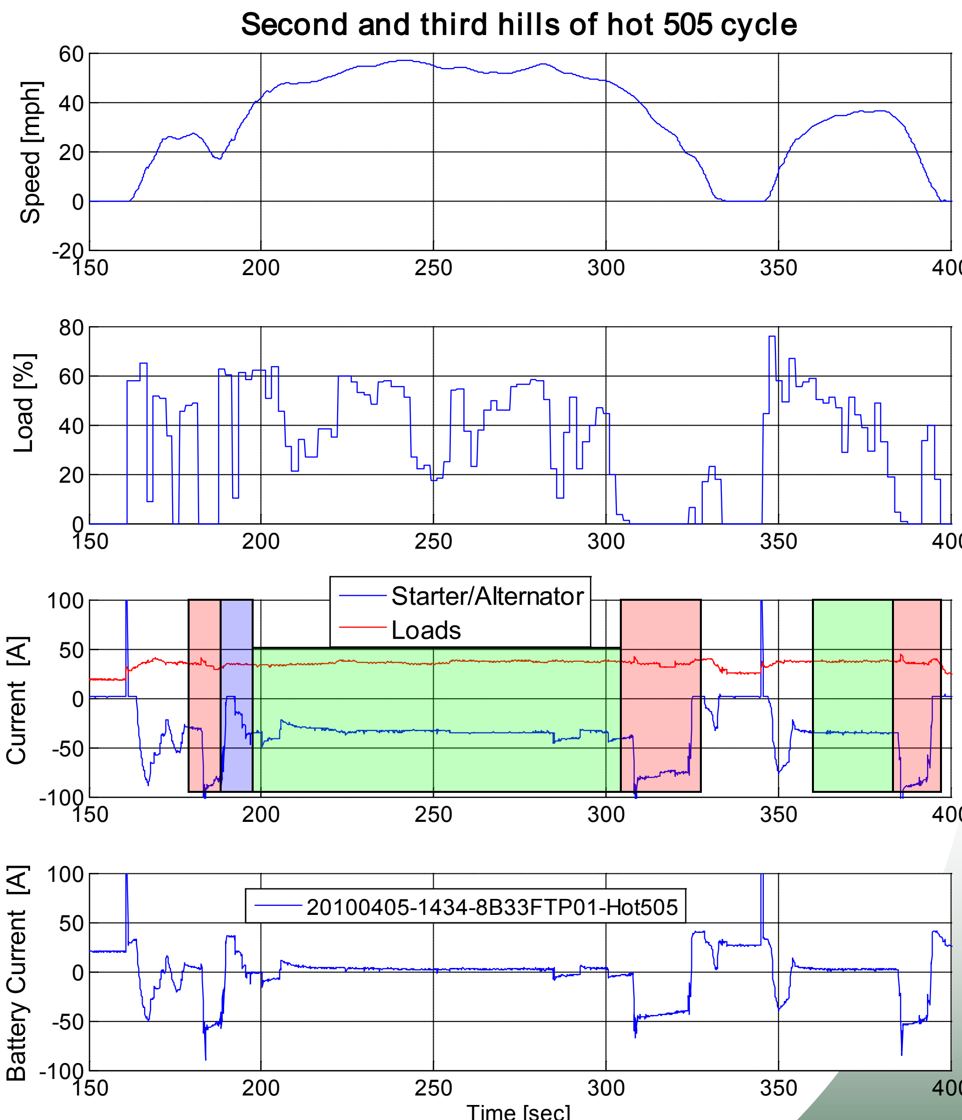




Accomplishments –Intelligent Alternator Characterization (On-going)

- **Principle:**
  - **Battery is never fully charged so that it can absorb energy**
  - **During accelerations, the alternator is not excited to reduce the load on the engine**
  - **During coast downs, the alternator recharges the battery**

- **Observations**
  - **Increased alternator load during some coast downs**
  - **Rare alternator load reduction during accelerations**
  - **Excellent load adaptation: alternator load matches electrical loads out of battery**

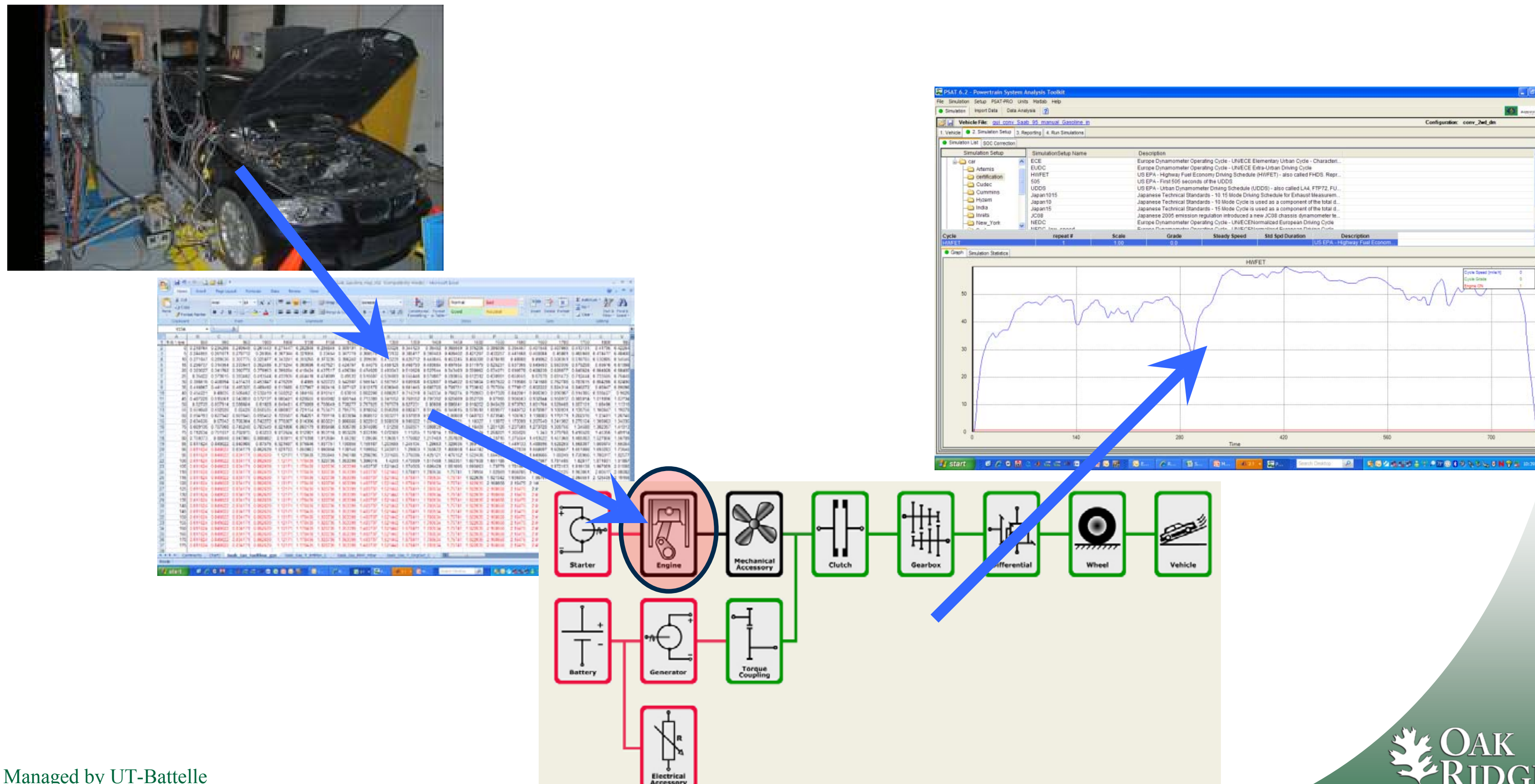


Collaboration

- **VSATT- Data is available for use by Vehicle Systems Analysis technical team and others in simulating advanced powertrains (project VSS008 will use data collected here)**
- **Lean NO_x aftertreatment data will be used in support of the CLEERS modeling activity**
- **ORNL Advanced Combustion Engines programs**
  - **Use of the steady-state engine maps and controller information measured during the chassis experiments to commission an engine setup with a micro-processor based control system.**
  - **Use engine dynamometer setup to explore expanded lean operation and produce more advanced engine maps which will be used for future advanced powertrain simulations.**
- **Idaho National Laboratory: advanced powertrain/vehicle testing support**

Future Work – FY10

- Complete data collection
- Publish project findings
- Process data into useable format for simulation environment (PSAT/Autonomie)



Proposed Future Work

- Use experimental data to evaluate the potential of lean GDI engine operation and after-treatment systems with advanced (hybrid) powertrains
- Combine vehicle benchmark data with engine dynamometer experiments to develop and validate emissions control models for use with lean GDI advanced powertrain vehicle simulations
- Focus on ethanol blends and potential opportunities presented by ethanol for lean combustion and emission control

Summary

- **Relevance**
  - Benchmark performance and emissions of advanced lean GDI vehicle
  - Technology not sold in the US
  - Understand barriers to widespread use of this technology in US market
- **Approach**
  - Vehicle on loan from GM
  - Comprehensive instrumentation and Vehicle testing
  - Characterization over transient cycles and steady conditions
  - Data processing
- **Technical Accomplishments**
  - Vehicle acquired
  - Instrumentation completed
  - Characterization carried out in 8 weeks
- **Future work**
  - Publish benchmarking data
  - Format data for simulation purposes
  - Use data for other projects (advanced hybrid powertrain simulation, engine dynamometer experiment, ethanol lean burn …)

Acknowledgements and Contacts

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- ***Lee Slezak, Office of Vehicle Technologies***

ORNL Advanced Vehicle Systems Program Manager:

- ***David E. Smith***

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