High Efficiency Clean Combustion for Heavy-Duty Engine

Houshun Zhang, Yury Kalish, Marc Allain, Guangsheng Zhu, and Zhiping Han

August 6, 2008

Outline

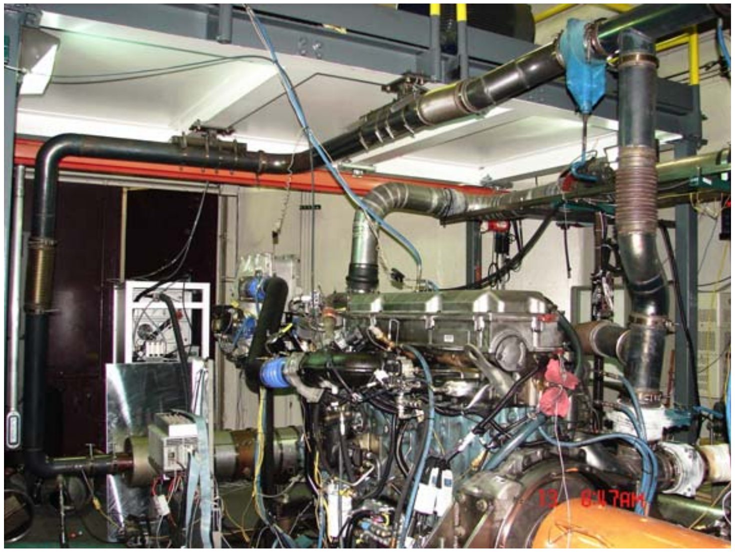
- Program Overview
- Technical Details
  - Advanced Fuel Injection System
  - Combustion Optimization
  - Advanced Next Generation Control
- Summary

Program Objectives

- Explore advancements in engine combustion systems using high-efficiency clean combustion (HECC) techniques to minimize cylinder-out emissions while optimizing engine fuel economy

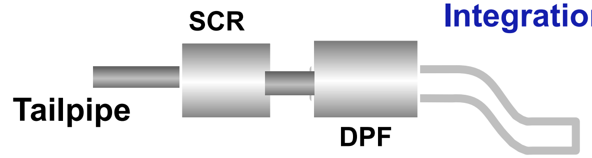
- Maximize thermal efficiency with integrated engine and DPF+SCR aftertreamtent system while meeting 2010 emission regulations

- Emphasis on Enabling Sub-system Technologies
  - Advanced combustion system technologies
  - Flexible, precise fuel injection
  - Air and EGR system technologies
  - Advanced multiple input multiple output control technologies



DETROIT DIESEL

System Development Approach



Integration of aftertreatment systems

Evaluation on truck operation for overall technology assessment and refinement

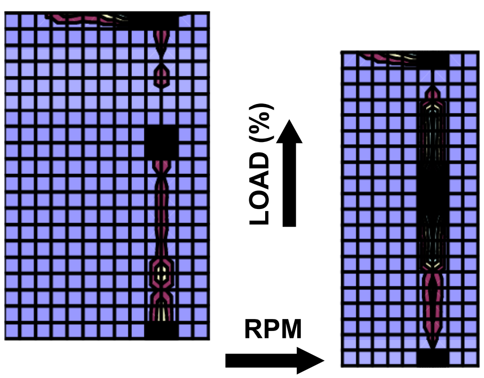
Steady State and Transient Dynamometer Testing

Focus on integrated engine and DPF+SCR system,

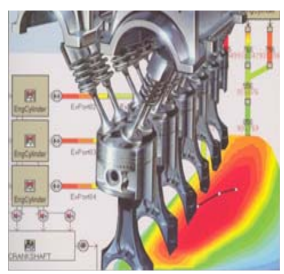
maximizing thermal efficiency

while meeting 2010 emissions

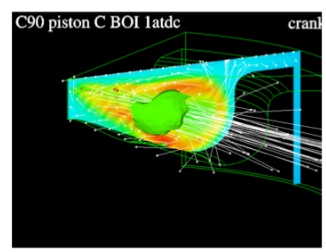
Selecting road-load operating conditions

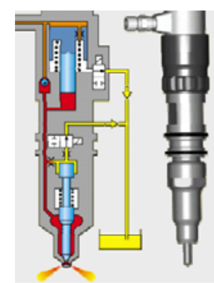


Example Operating Conditions Over Truck Routes



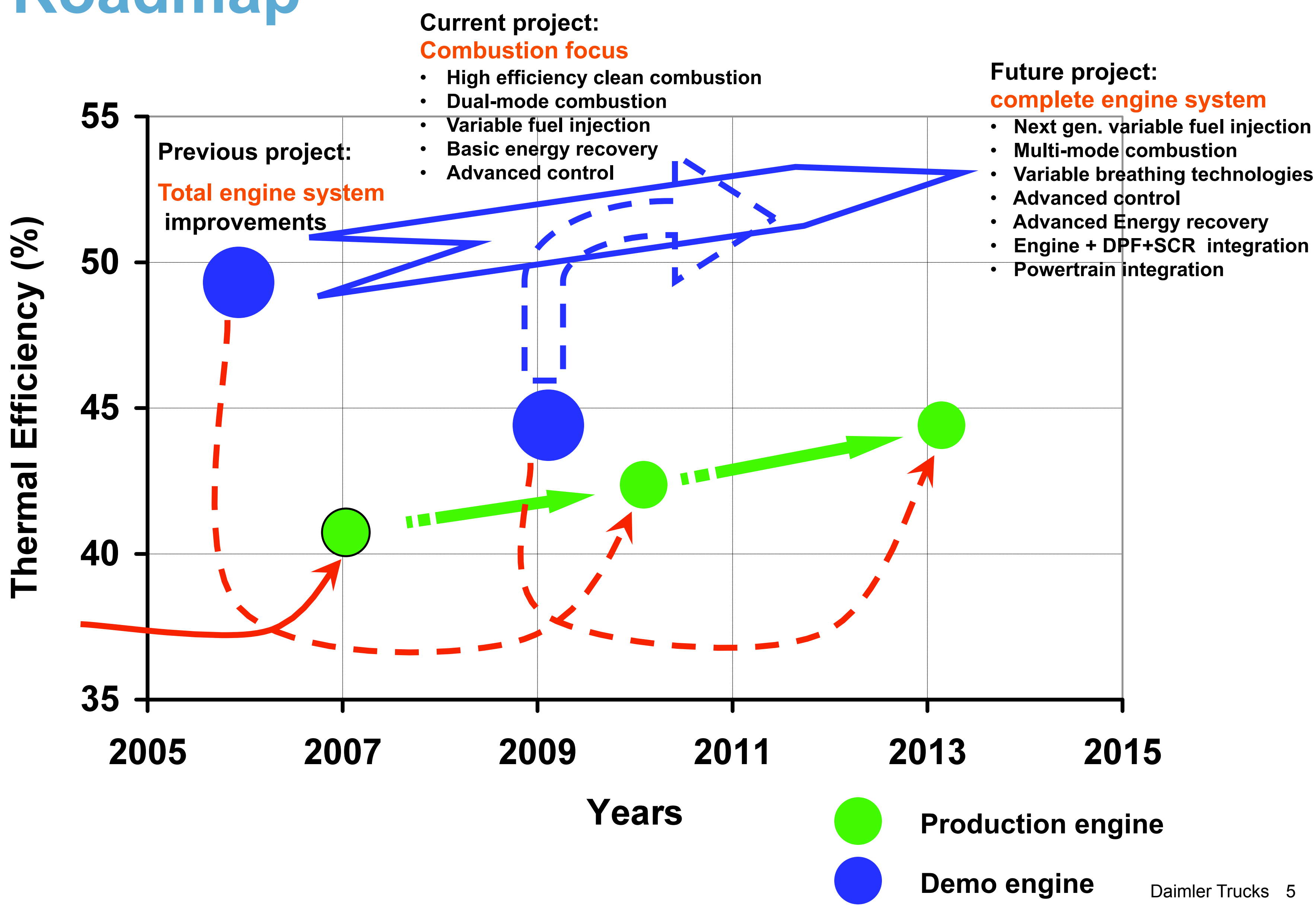
Integrated Analytical Simulation Tools





Component Optimization

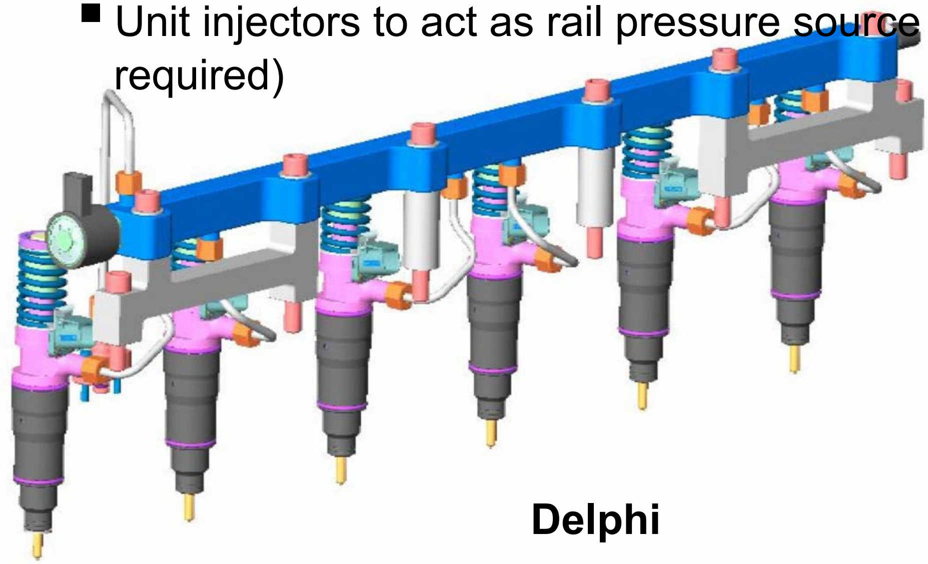
Thermal Efficiency Roadmap



DETROIT DIESEL

Advanced Fuel Injection System

- Advanced fuel injection with full flexibility of injection events was procured and being evaluated.
  - System combines unit injectors and an accumulator rail
  - Medium pressure rail (up to 1000 bar) to provide early / late injection events
  - Unit injector to provide high pressure short duration main injection
  - Combined rail / unit injector operation for boot shape and close pilot / post injections
  - Unit injectors to act as rail pressure source (no rail pump required)



Delphi

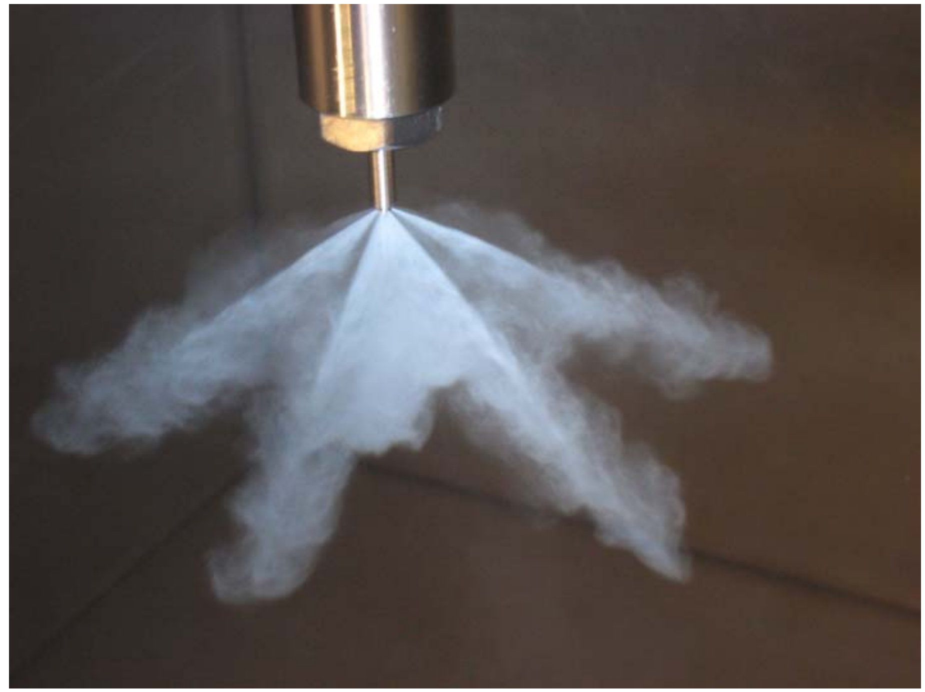
Variable Nozzle Technology

- Introduced variable fuel injection technology into the program with high potential to significantly enhance high efficiency clean combustion.
- Great potentials have been demonstrated analytically throughout different speeds and loads
  - Significant fuel economy improvement, ranging from 5% to 12%
  - Substantial NOx and soot emission reductions, ranging from 50% to 90%
- Variable nozzles have been procured, and assembled with advanced fuel injection system.
- Flow bench tests are underway, and the engine tests will follow soon.

DETROIT DIESEL

Micro-Variable Circular Orifice (MVCO)

First phase injection with conical spray and narrow spray angle produced by MVCO Nozzle

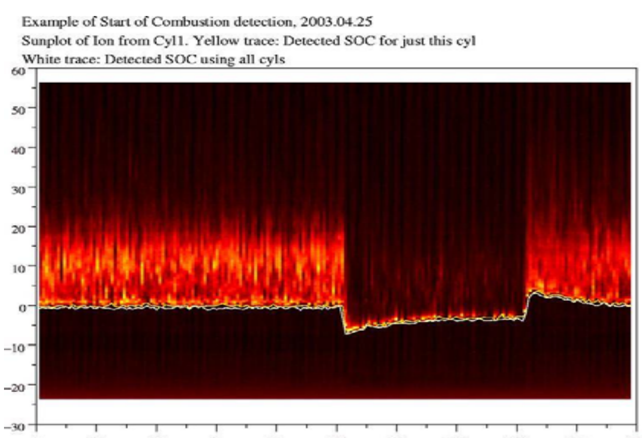


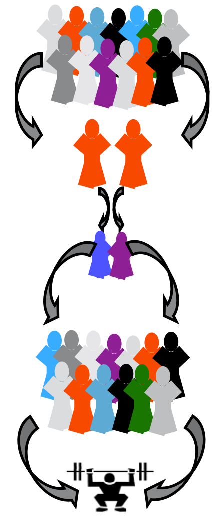
Second phase injection with multi-jet spray and wide spray angle produced by MVCO Nozzle

QLC QuantLogic Corp.

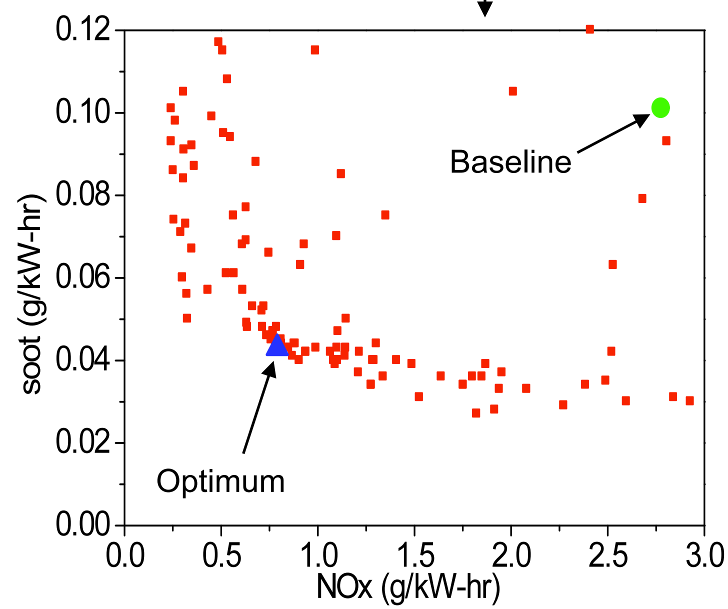
Advanced Combustion Development

- Genetic combustion optimization
  - Fuel injection and piston bowl optimization
- New combustion concept exploration
  - Multi-mode combustion with advanced fuel injection system and variable nozzle technology
- Real time combustion control
  - In-cylinder pressure sensor
  - ionization sensors





Automated selection of engine operating parameters for optimal emissions reduction



Specific Combustion Optimization on PCCI

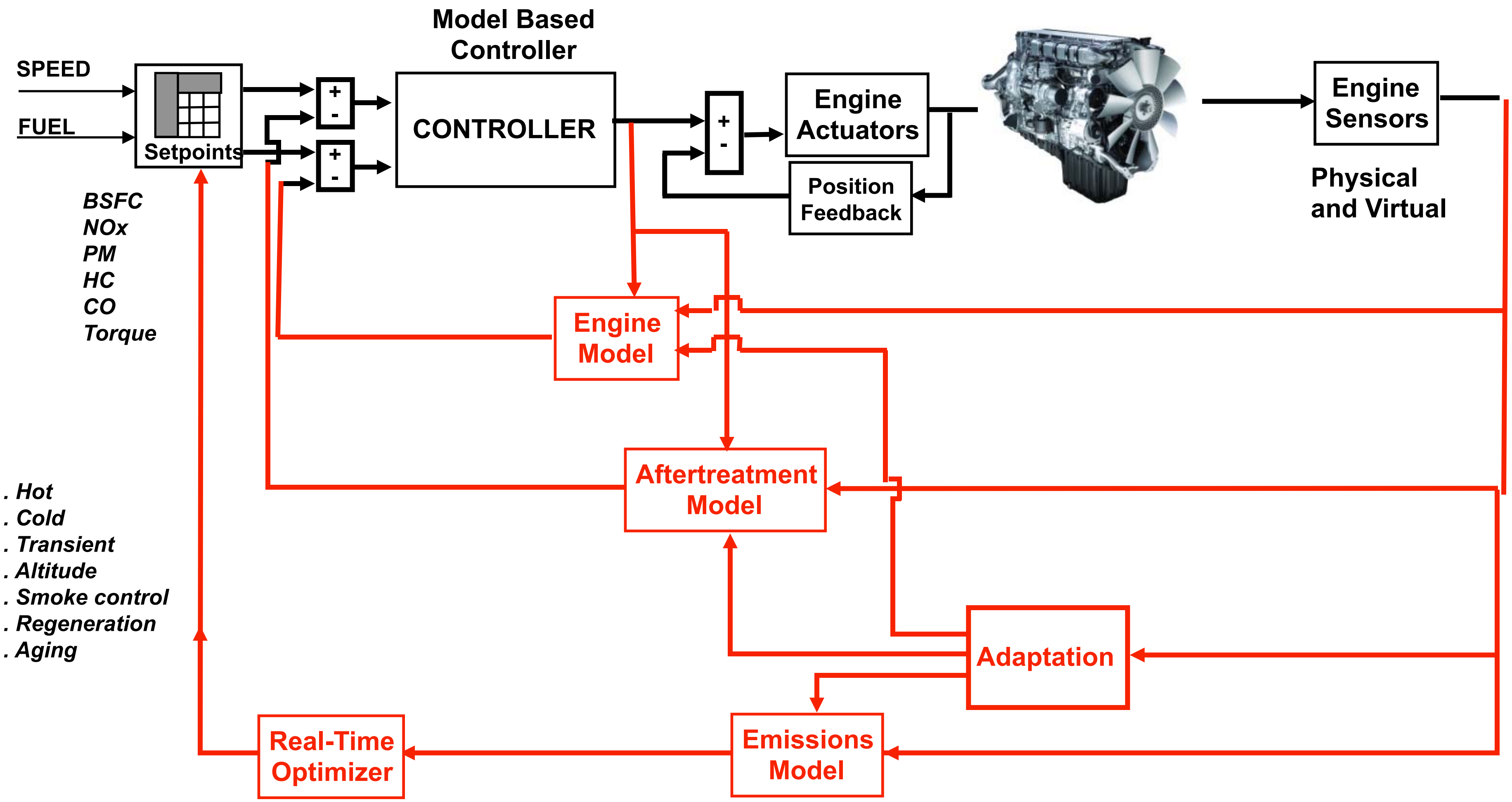
The objective is to achieve similar soot and NOx emissions to that of the baseline case but with a ~10% fuel consumption improvement

run	Soot	NOx	gisfc	Fuel economy improvement
	g/kgf	g/kgf	g/kW-hr	%
base	0.23	3.24	233.3	-
1	0.12	5.27	201.1	13.8
2	0.41	7.76	223.0	4.4
-----	-----	-----	-----	-----
11	0.33	1.98	212.9	8.7
12	**0.19**	**3.72**	**208.1**	**10.8**

10.8% fuel economy improvement was obtained while maintaining the same emission level as baseline.

Engine testing is just under way and preliminary results show 5.03% BSFC improvement. More tests will be reported soon.

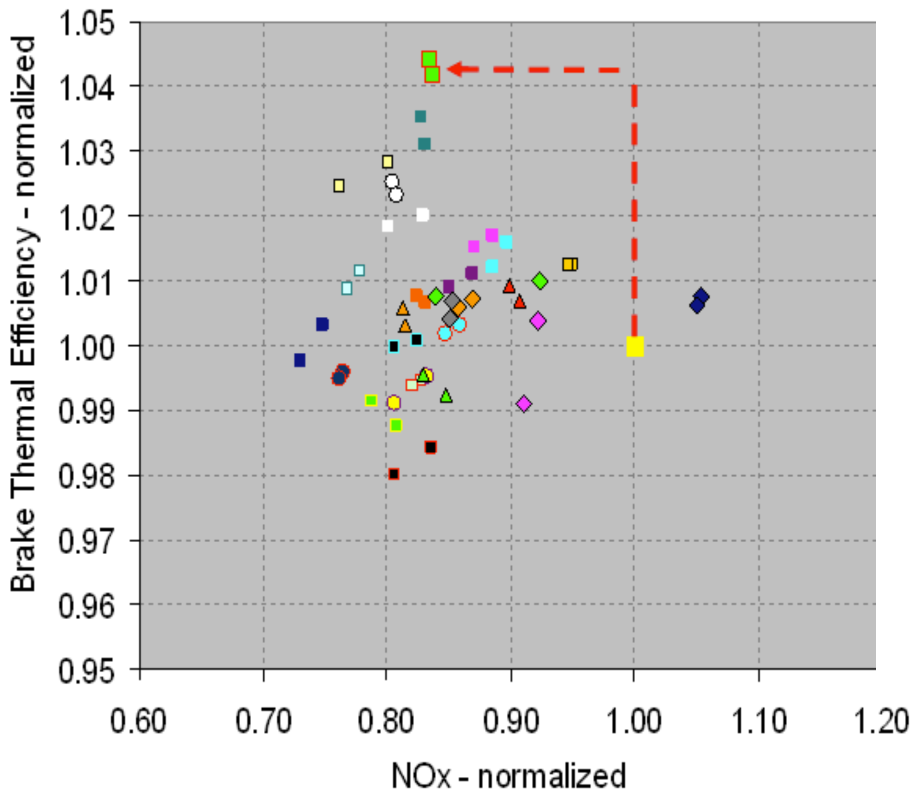
Next Generation Model-Based Controller



Application of Transient Calibration Optimization to FTP Cycle

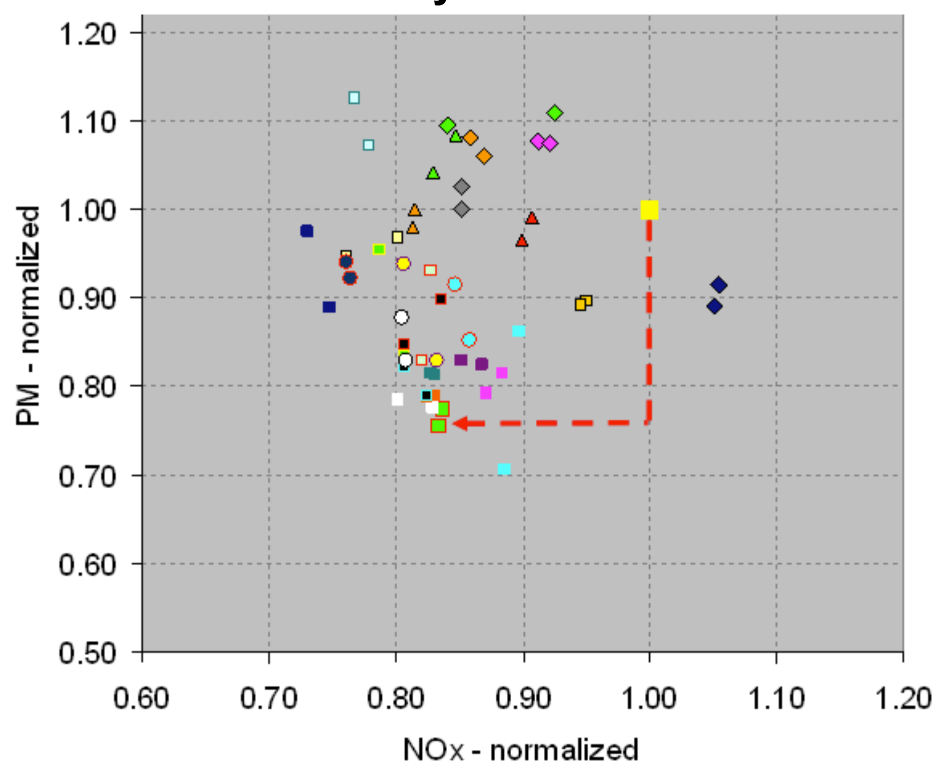
4% Thermal Efficiency Improvement

With Next Generation Model Based Controller



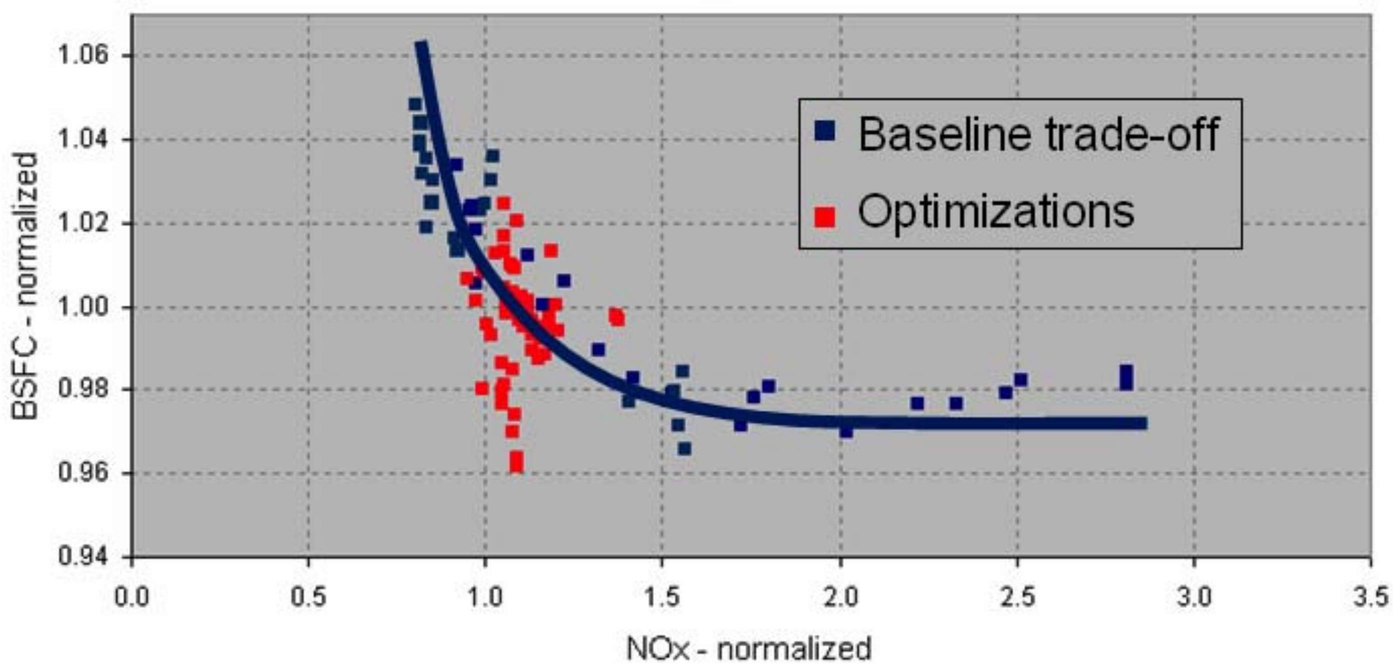
Each point marker designates one calibration FTP set point

And 15% NOx and 25% PM Reduction Simultaneously



Transient Calibration Optimization (FTP Tests)

Next Generation Model Based Controller breaks traditional BSFC -NOx Trade-off Curve toward more Fuel Economy Improvement



Barriers/Challenges

- Technical challenges with variable nozzle technology are enormous
  - Needle lift control
  - High sensitivity to needle position – design may not be robust to tolerances
  - Very high precision required in manufacture
- Combustion mode transition
  - Need robust controls methodologies
- Next generation model based control
  - Computational power and speed in engine control unit
  - Model integration complexity with real time engine, aftertreatment, and emission model that must be adaptive, robust, and precision

DETROIT DIESEL

Summary

- Program is progressing well and aggressively. It is toward meeting the program objective with 10% thermal efficiency improvement by 2009.

- Identified key enabling technologies with high potential returns
  - Advanced fuel injection system coupled with variable fuel injection nozzle
  - Genetic combustion system optimization
  - Transient control optimization

- Significant benefits with advanced fuel injection system and variable nozzle technology have been demonstrated. A new combustion strategy covering the entire operating range is emerging.

DETROIT DIESEL

Acknowledgements

- Department of Energy Headquarters
  - Gurpreet Singh
  - Roland Gravel

- National Energy Technology Laboratory
  - Carl Maronde
  - Jeffrey Kooser