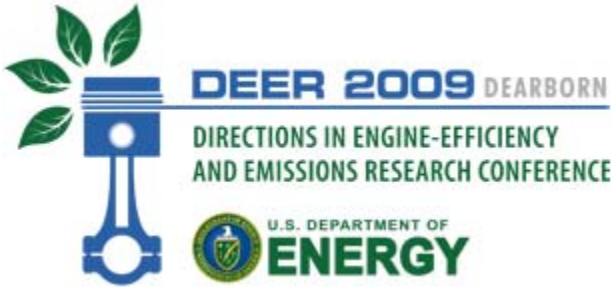
DETROIT DIESEL

High Efficiency Clean Combustion for Heavy-Duty Engine

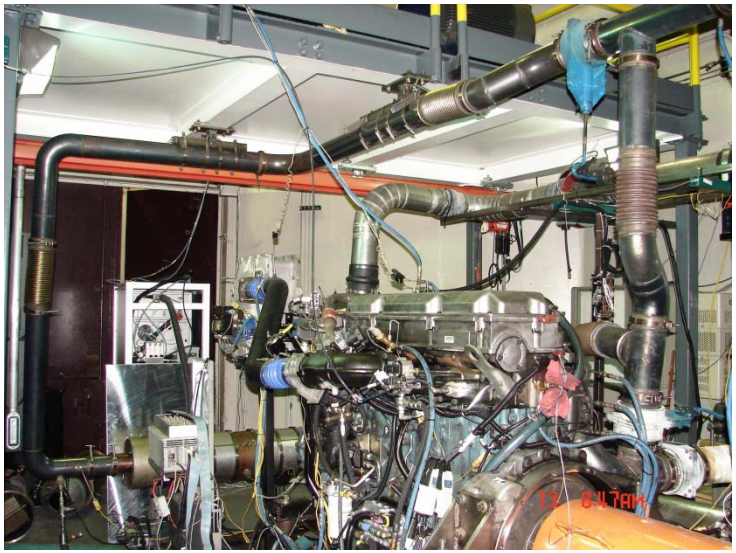
Houshun Zhang, Yury Kalish, Marc Allain, and Guangsheng Zhu



Objective

- Explore advancements in engine combustion systems using high-efficiency clean combustion (HECC) techniques to minimize engine-out emissions while optimizing fuel economy
- Emphasis on enabling sub-system technologies
  - Advanced fuel injection system
  - Innovative combustion system optimization
  - Air/EGR system optimization
  - Next generation control logic
  - Real time combustion control

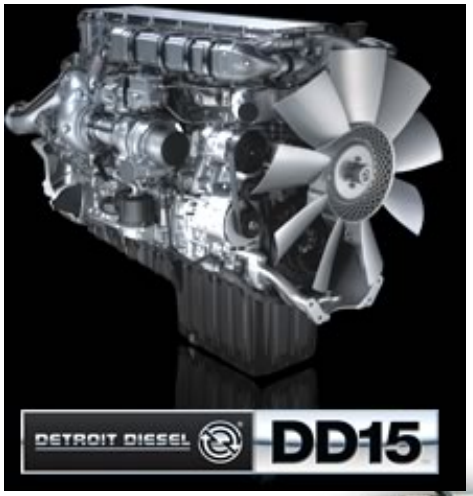
Multi-cylinder Test-bed



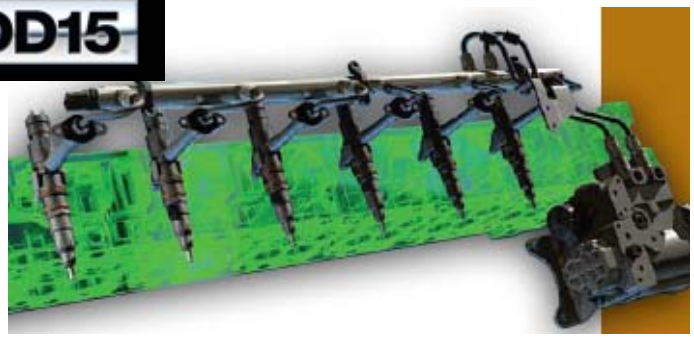
Advanced Fuel Injection System

- Demonstrate potential of advanced injection system for achieving high efficiency clean combustion (HECC) mode operation for engine conditions consistent with heavy-duty drive cycles
- Characterize emissions/efficiency for multiple high efficiency clean combustion strategies

Delphi E3 injection system



Bosch's ACRS fuel injection system



Combustion Optimization

- Optimization covers a wide range of injection timing, phasing, EGR rate, and boost
- Analytically demonstrated potential for 10.8% fuel economy improvement at a single low load and low speed point while maintaining the same emission level as baseline

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
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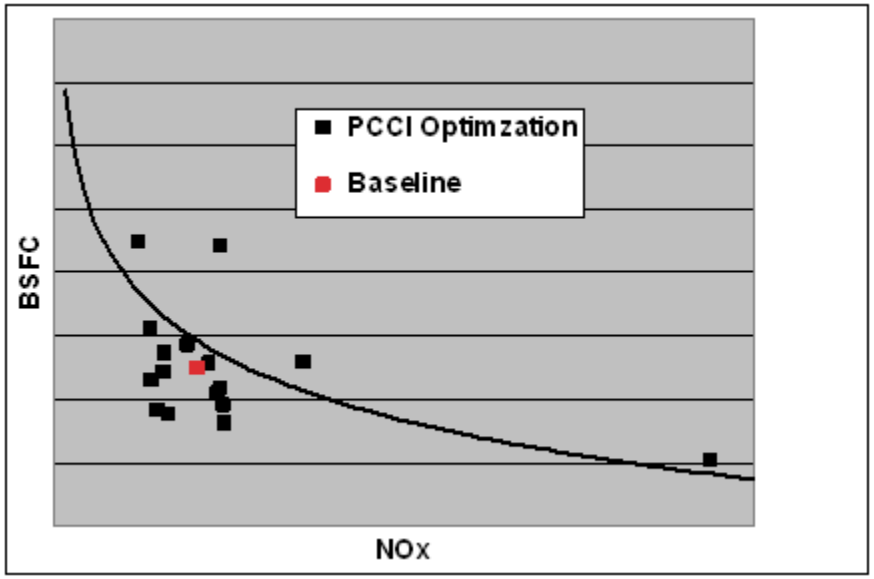
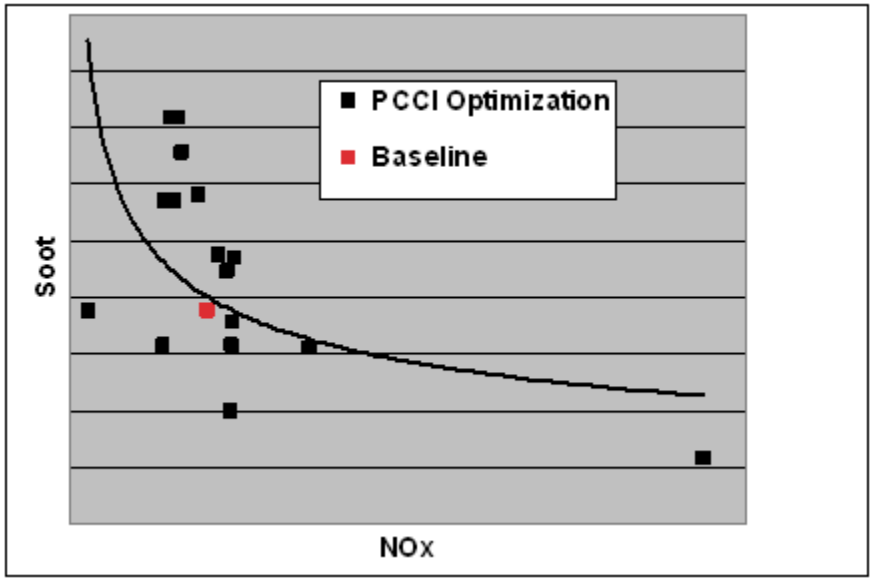
11	0.33	1.98	212.9	8.7
12	**0.19**	**3.72**	**208.1**	**10.8**

PCCI Testing with Help of Combustion Analyses

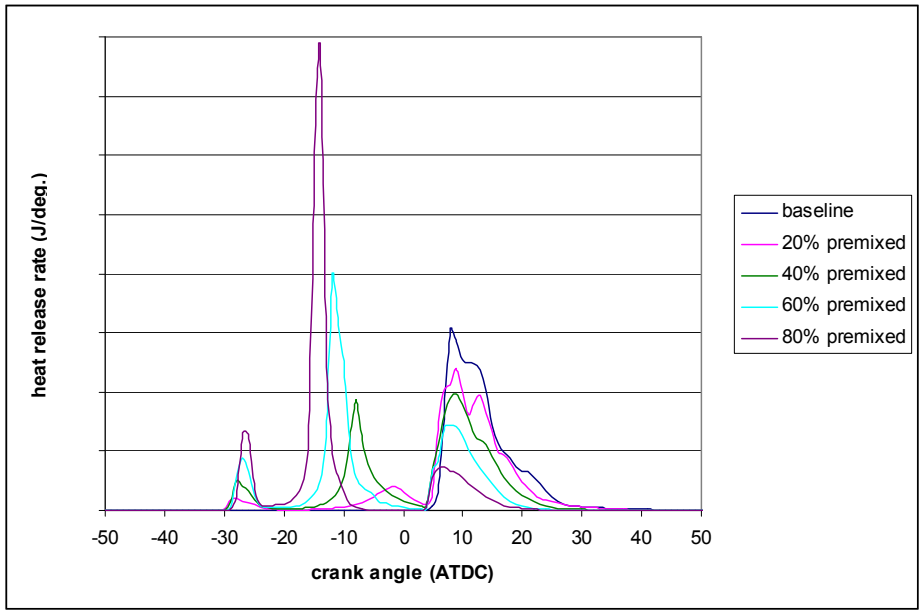
- Flexible fuel injection system allows to follow up analytical set points on injection timing, fueling, phasing, and multiple injection events
- Preliminary engine tests demonstrate 5% thermal efficiency benefits while maintaining about the same or lower emissions (NOx and PM)





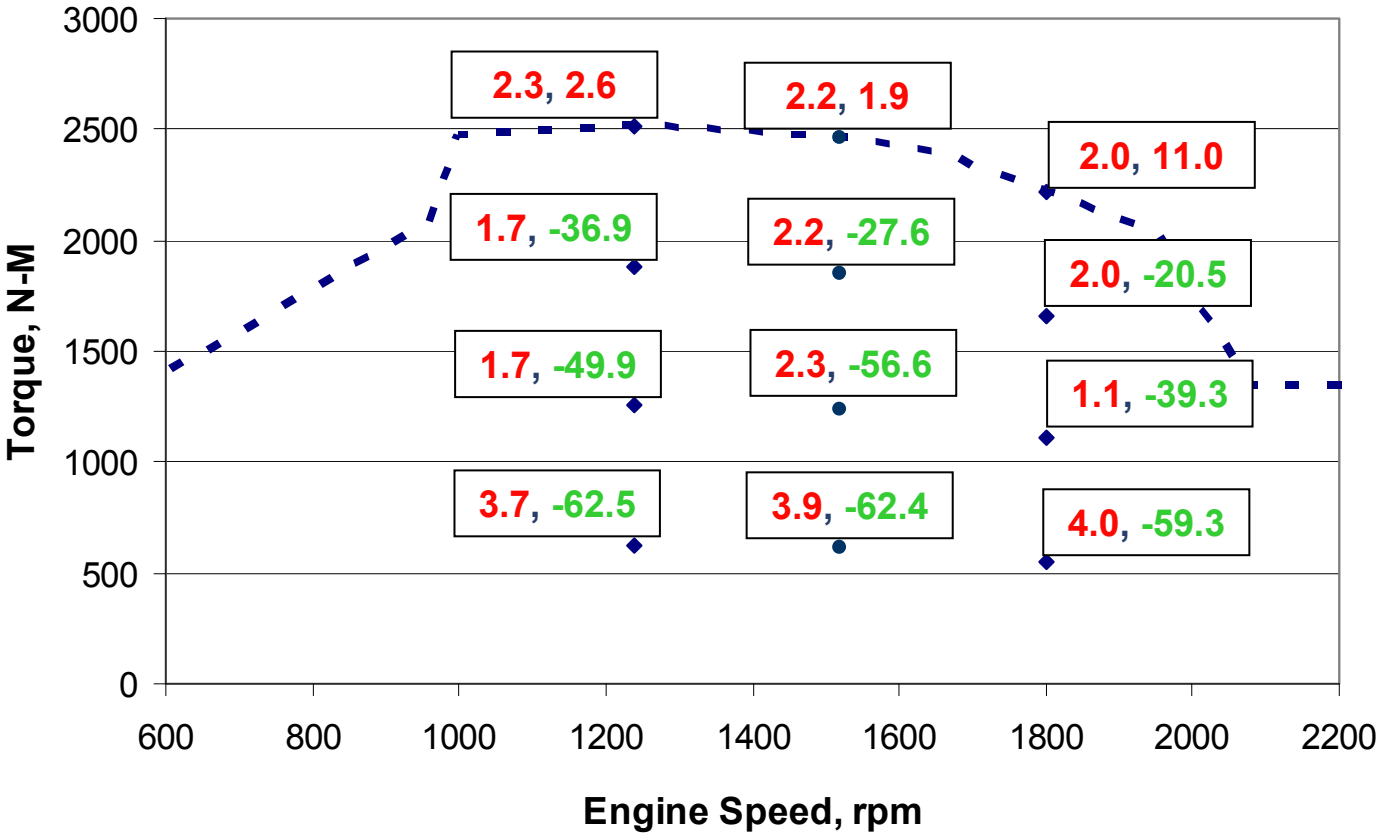
Multi-Mode Combustion

- Investigation of multi-mode combustion concept based on University of Wisconsin's extensive research and development
- Each mode is controlled by its own advanced flexible fuel injection system, operated based on individual combustion mode requirements, such as spray angle, timing, phasing, fueling split in order to achieve optimal combustion efficiency
- The combustion analysis using KIVA on a production engine is being conducted
- Comprehensive CAD feasibility study is being conducted



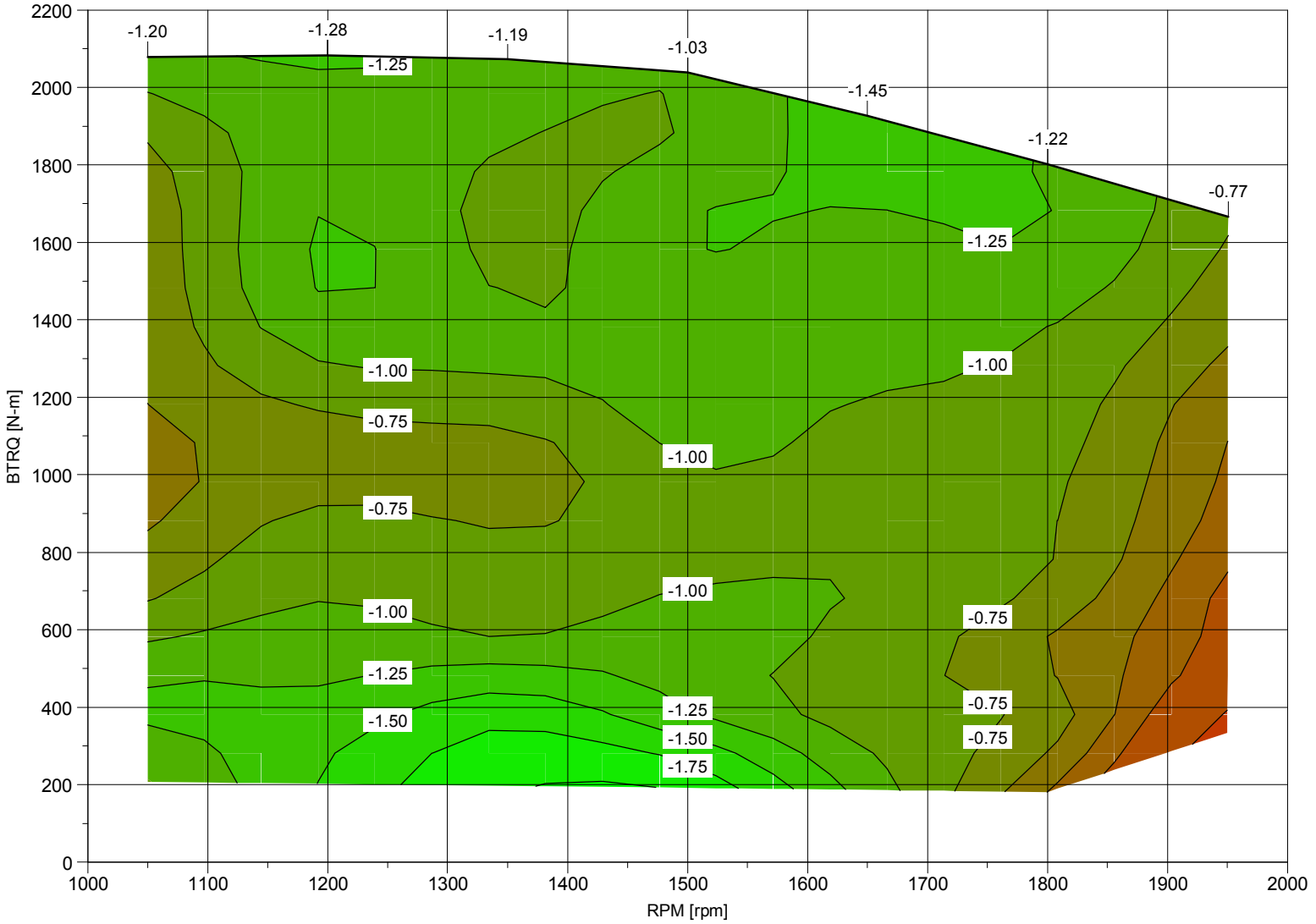
Piston Optimization

- (%BSFC, %Smoke) – Positive numbers indicate increase
- Significant reduction in smoke is seen, although there is penalty in BSFC

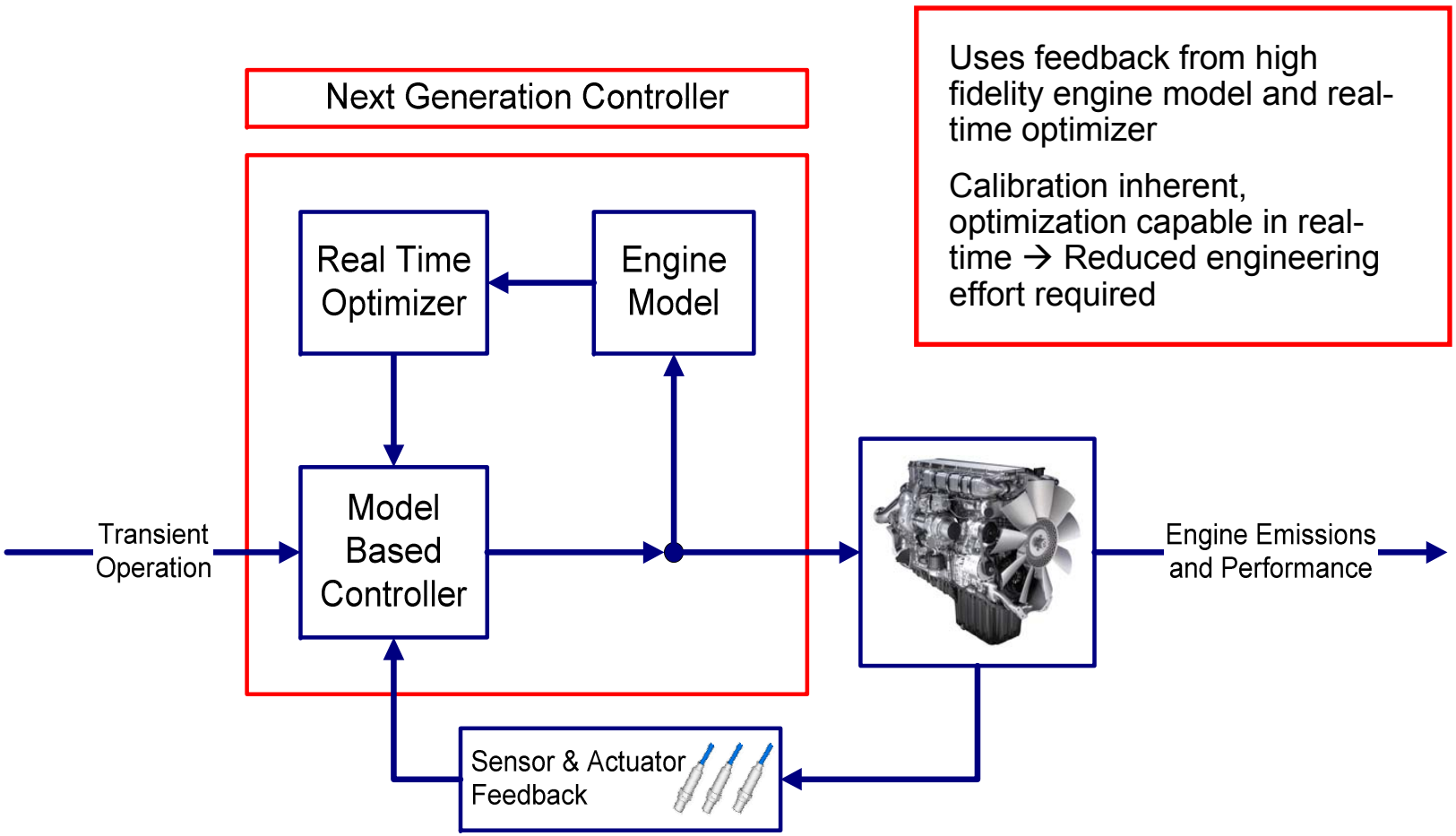


Turbocharger Optimization

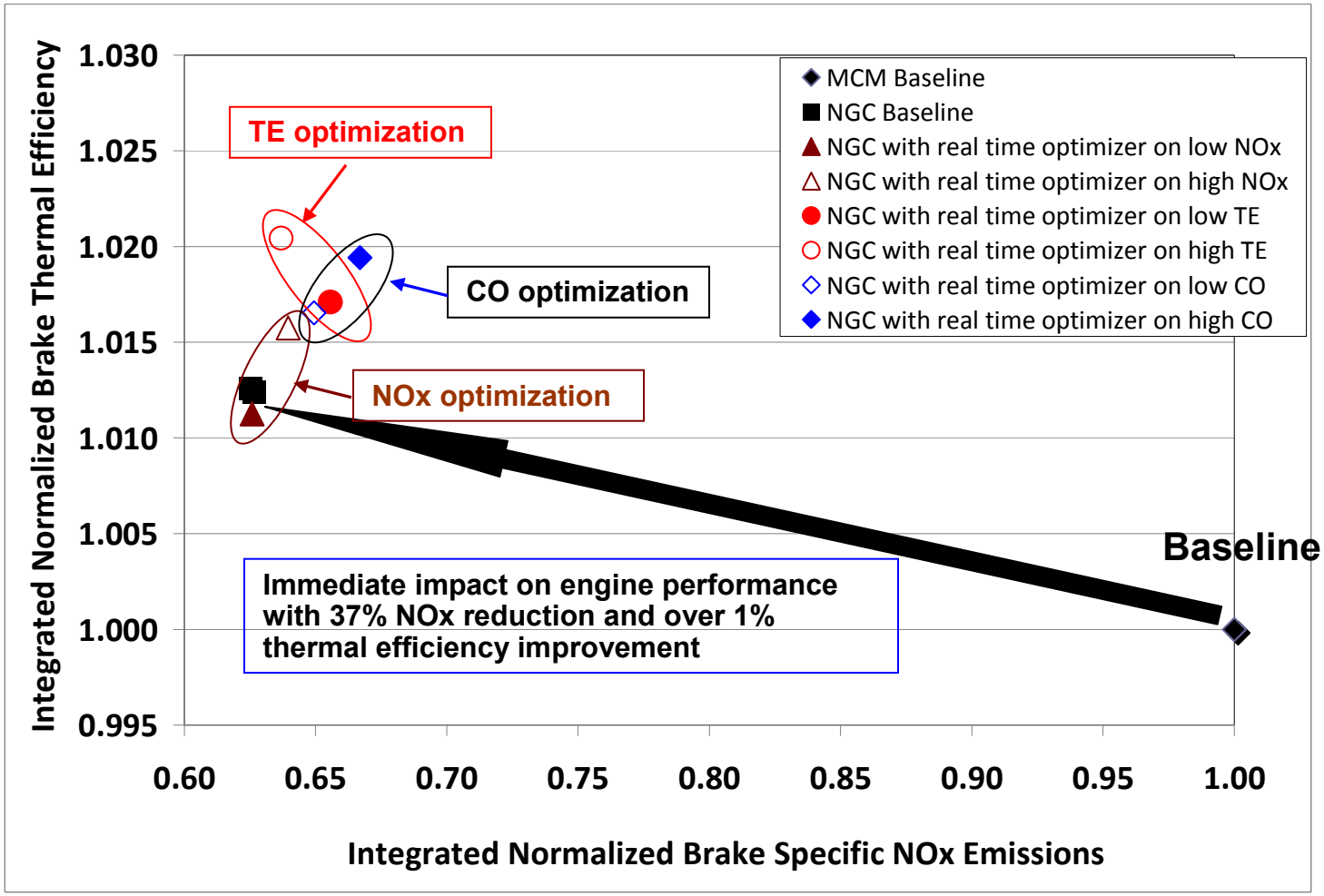
(1%-1.5% improvement in BSFC)



Next Generation Controller (NGC)

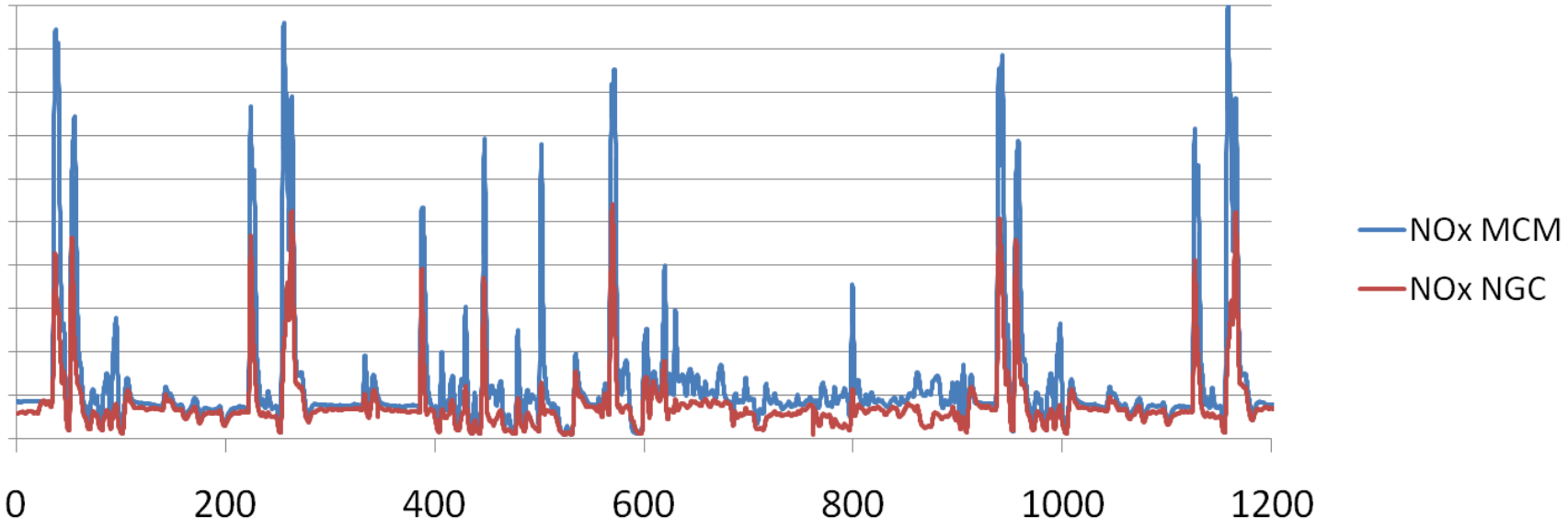


Controller Optimization on Transient Cycle A



Comparison of FTP NOx Emissions for Baseline Control and NGC

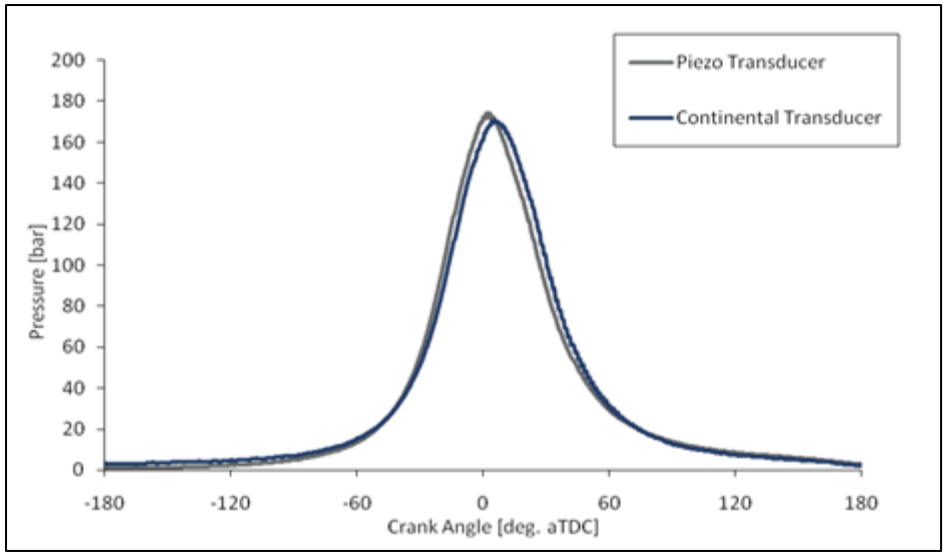
- NGC shows significant reductions in NOx over the FTP cycle
- PM maintains similar level

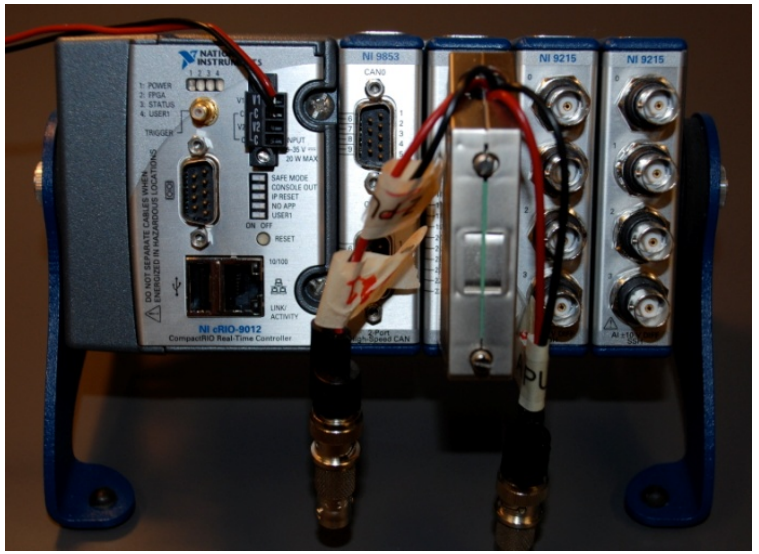


MCM – Motor Control Module

Real Time Combustion Control

- Sensors have been demonstrated to match results from lab standard piezo transducers
- Ion sensing hardware is on hand, waiting to be installed for evaluation
- Signal processing hardware and software being developed
  - 100 kHz simultaneous sampling analog inputs
  - Digital I/O for triggering
  - High speed CAN communication with MCM
  - Custom-developed LabVIEW code





Summary

- Experimentally demonstrated 5% thermal efficiency improvement with guidance of advanced combustion analysis
- Significant progress was made in next generation control development with substantial benefits in both thermal efficiency and emissions
- Air system enhancements have been proven capable of providing additional efficiency benefits

Acknowledgements

- Department of Energy Headquarters
  - Gurpreet Singh
  - Roland Gravel

- National Energy Technology Laboratory
  - Carl Maronde
  - Jeffrey Kooser