Heavy-Duty Engine Combustion Optimization for High Thermal Efficiency Targeting EPA 2010 Emissions

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August 13, 2007

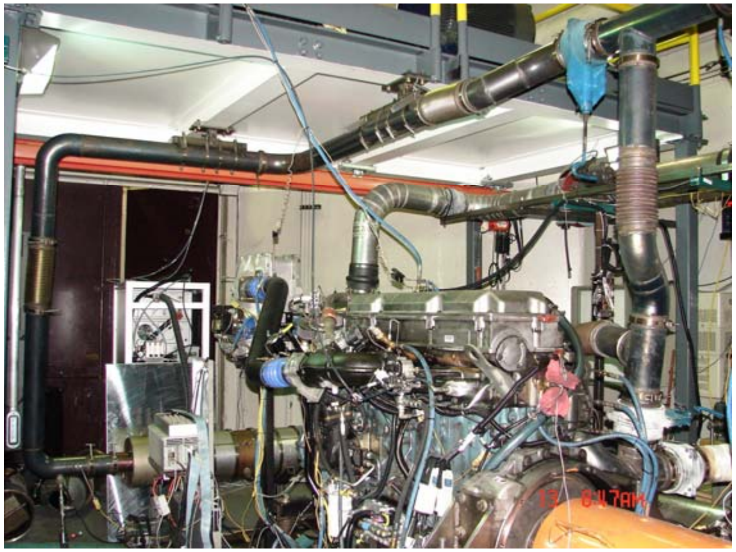
Outline

- Project Overview
- Technical Details
  - Fuel Injection System
  - Combustion
  - Controls
- Future Work
- Challenges
- Conclusions

Program Objectives

- Explore Advancements in Engine Combustion Systems Using High-Efficiency Clean Combustion (HECC) Techniques to Minimize Cylinder-out Emissions

Multi-cylinder Test-bed



- 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

Program Development Approach:

Potential for Real Contribution to Energy Savings a Key Assessment Criteria

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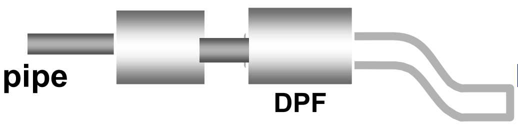
Selecting road-load operating conditions

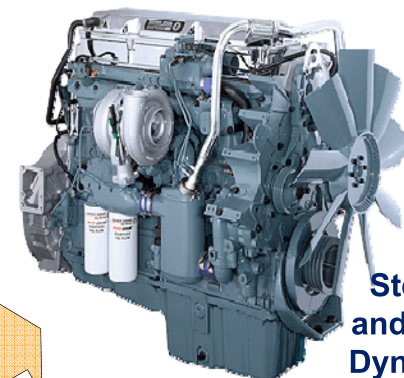


Evaluation on truck operation for overall technology assessment and refinement

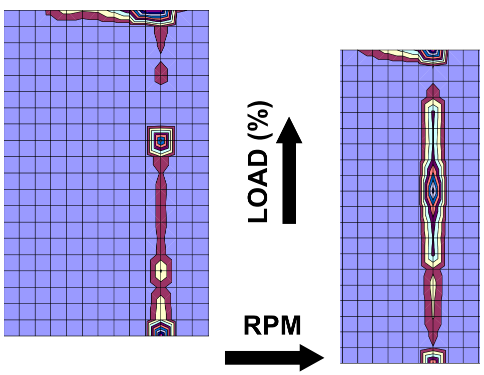
Integration of aftertreatment systems

Thermal Efficiency

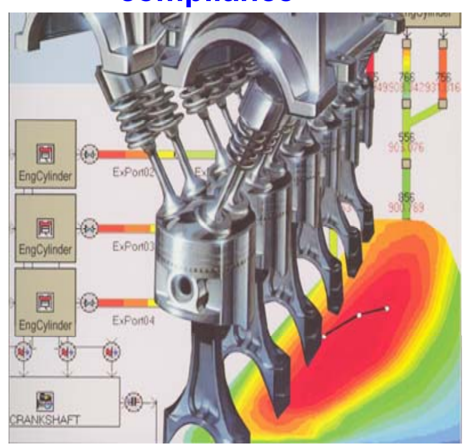
Emission compliance



Steady State and Transient Dynamometer Testing



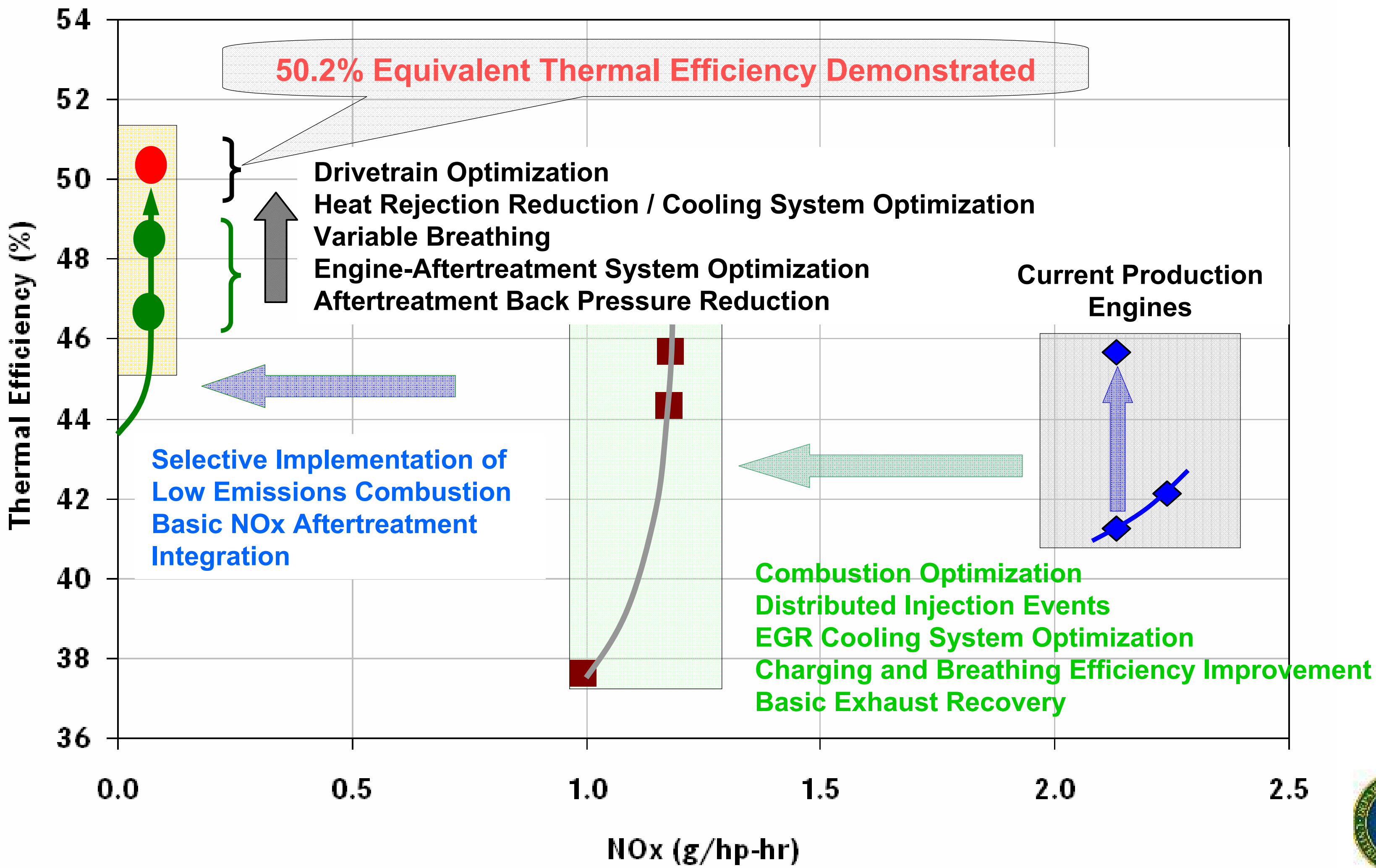
Example Operating Conditions Over Truck Routes



Integrated Analytical Simulation Tools

Experimental validation and down-selection of advanced engine technologies

Thermal Efficiency Roadmap And Accomplishments - Foundation for the Current Work



Key Enabling Technologies Implementations for the Current Effort

- Most Significant Key Enabling Technologies for Achieving Program Objective Were Initiated and Are Being Effectively Implemented

  - Variable Fuel Injector Nozzle Coupled with The Most Advanced Fuel Injection System

  - Combustion System Optimizations

  - Transient Control Optimization

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Micro-Variable Circular Orifice (MVCO)

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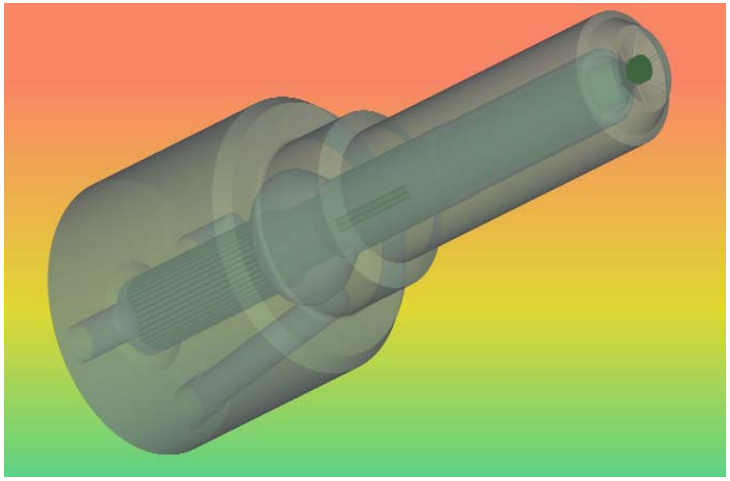
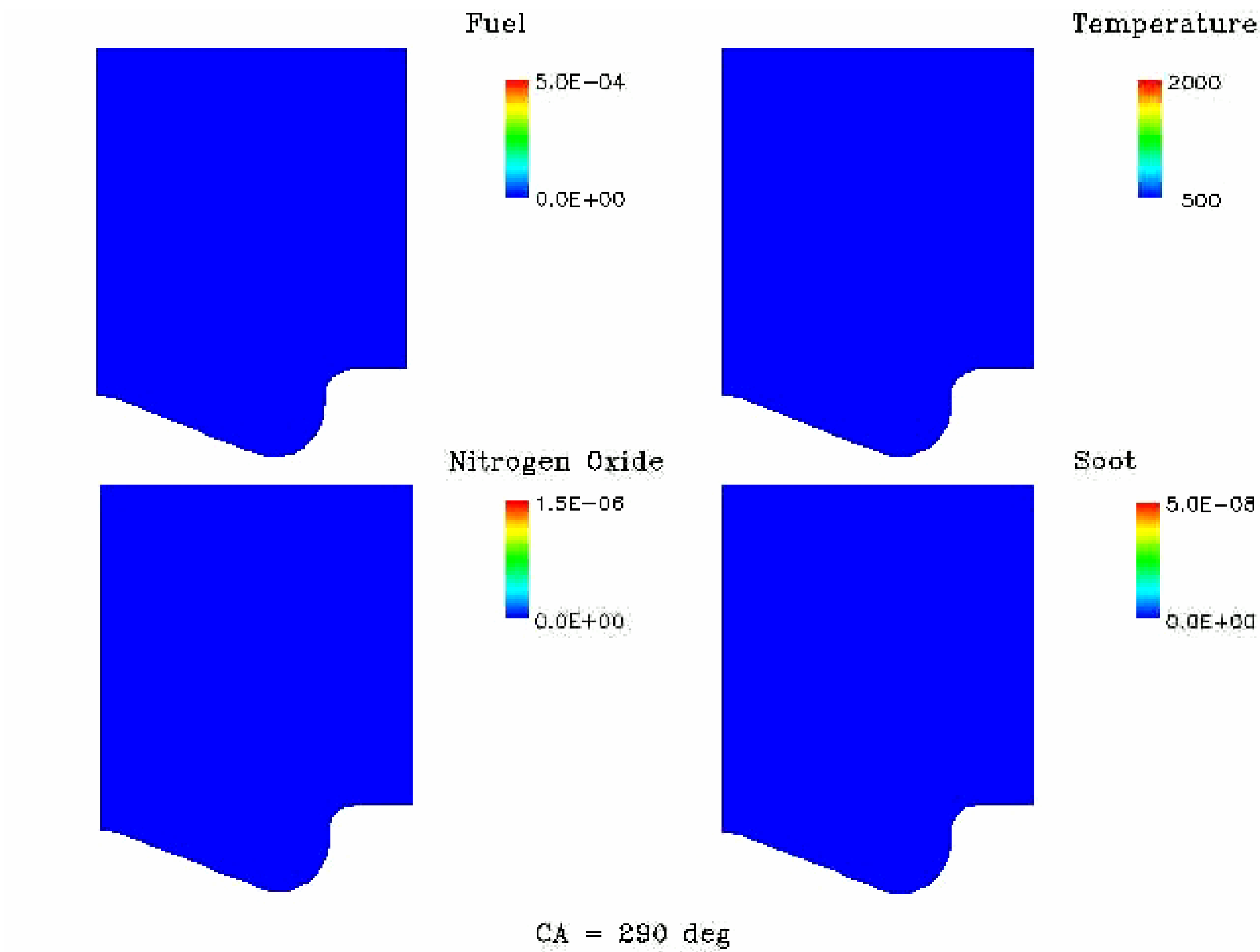
- Introduced variable fuel injection technology into the program with high potential to significantly enhance high efficiency clean combustion.



- The moving needle and nozzle body generate a micro-variable circular orifice (MVCO), which is equivalent to a 6 - 50 variable micro-hole nozzle.

- It can generate a conical spray only or mixed-mode conical-multi-jet spray patterns to meet the needs of different engine operating conditions.

Dual-mode PCCI Combustion Concept (A25)
- New combustion and injection strategy is emerging



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Performance And Emissions Improvement with MVCO Technology

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Case	BSFC [g/kW·hr]	NOx [g/hp·hr]	Soot [mg/m3]	CO [g/hp·hr]	HC [g/hp·hr]
Baseline	222	1.592	0.767	0.47	0.071
MVCO (Dual Injection Mode)	195.2	0.07	0.349	0.473	0.189
Improvement	12%	96%	54%	-1%	-166%

A25 CASE:

- 12% BSFC Improvement
- Significant reductions in both NOx (96%) and soot (54%)
- Only small increase in CO, and HC is not quite significant as opposed to other HCCI/LTC technologies

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Innovative System Optimization Methodology Emerging

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Traditional Approach

Technology Building Blocks

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Individual Component Optimization

↓

System Optimization

↓

"Optimal" Emissions and/or Fuel Economy

New Approach

Best Emissions and/or Best Fuel Economy Targets/Objectives

↓

Genetic Optimization Scheme

Hardware

Piston bowl, compression ratio,

swirl ratio

Injection System

Number of holes, spray angle, hydraulic flow rate, tip protrusion, multiple injection

Calibration

Injection timing. injection pressure,

EGR rate,

injection scheme

"Best"

- New Approach Is Able to Significantly Shorten Development Cycle in Achieving Program Objectives by Combining Sophisticated Genetic Optimization Scheme with a Well Planned Design of Experiment,

1st Generation of Design Recommendations

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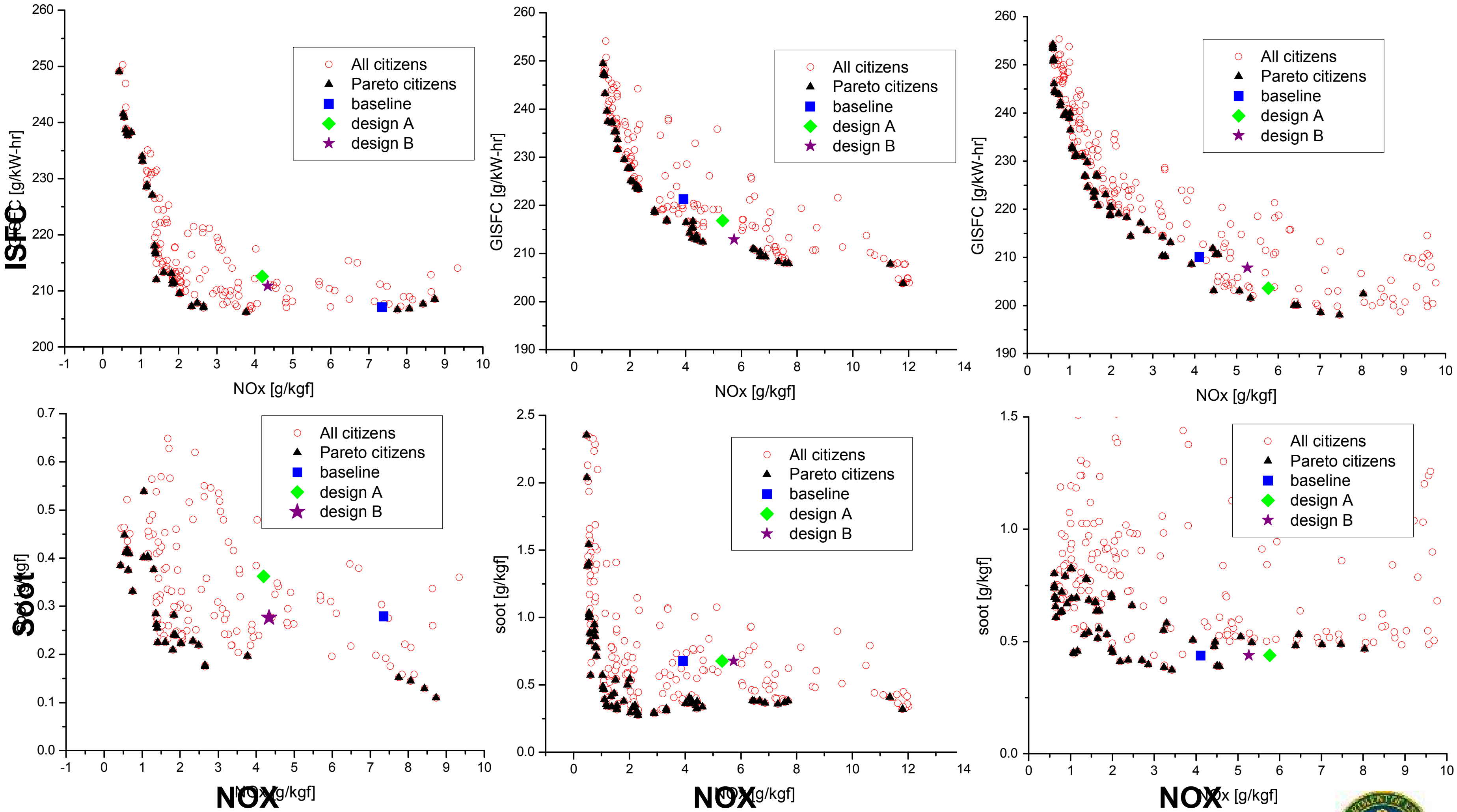
A25 B50 A100



Transient Calibration Optimization Program

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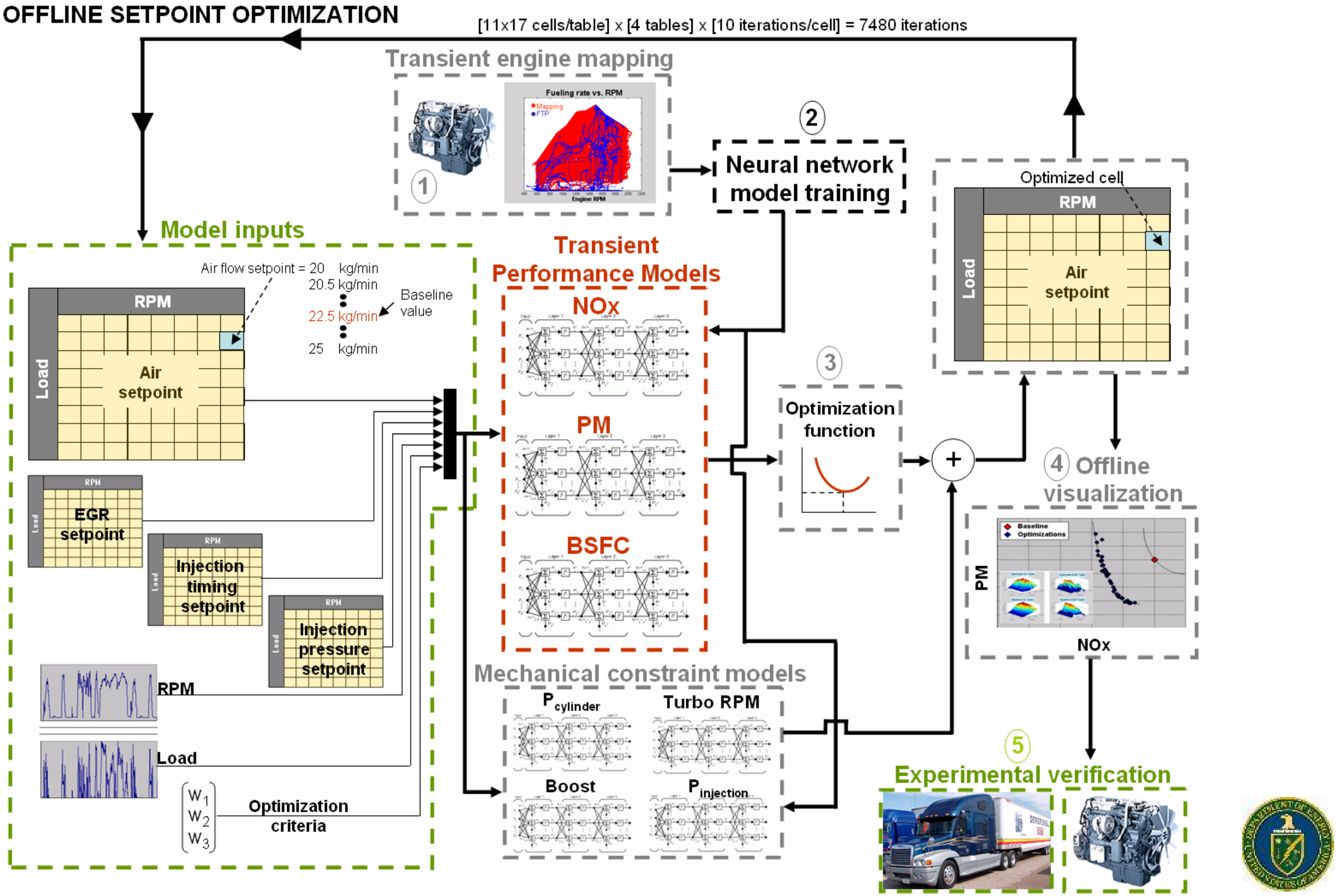

Trade-off of BSFC and NOx Emissions Using Integrated Control Development

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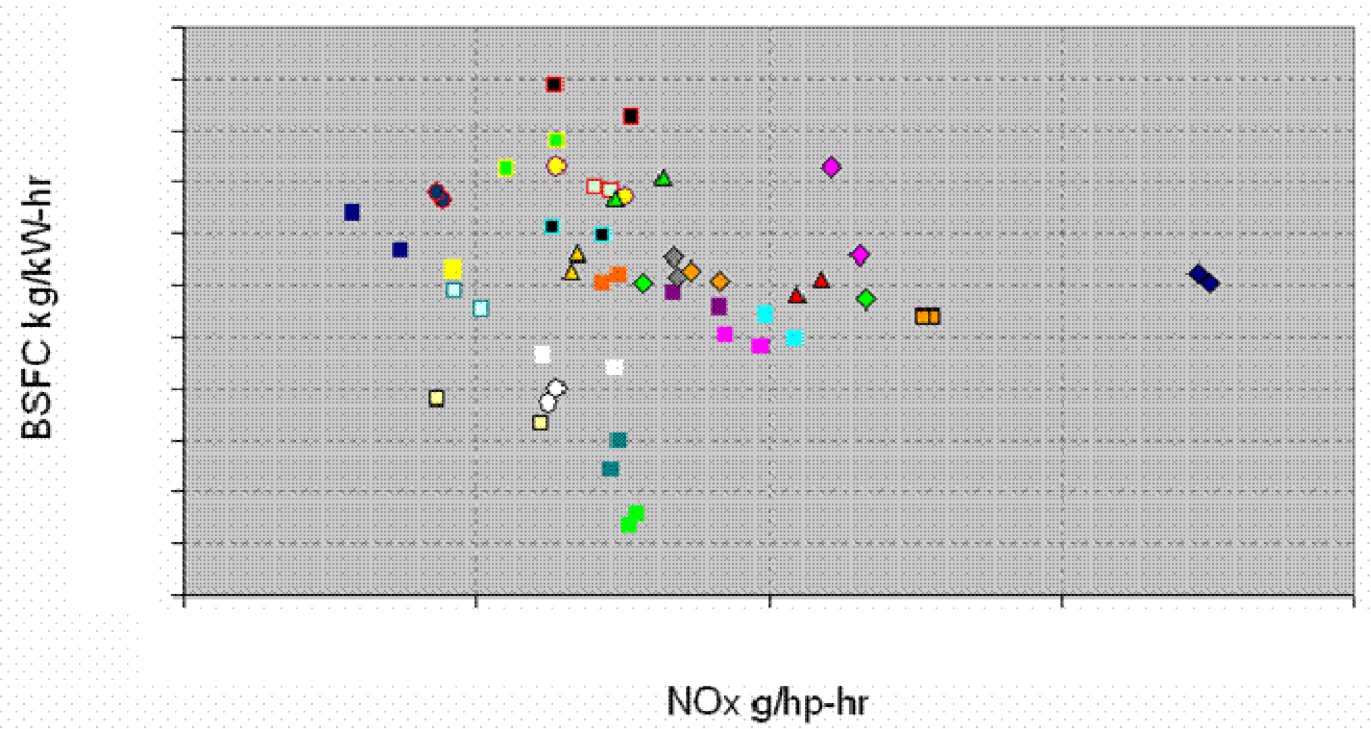

Each point marker designates one calibration FTP set point

- Conduct Large Scale Of Offline Control Optimizations over A Hundred Set Points
- Validate Selective Calibration Set Points in Test Cells Based on The Best Possible Offline Optimization Results
- Derive Clear-cut Trade-off Between Key Parameters (NOx, PM, And BSFC)
- Obtain Significant Time and Resource Saving from Traditional Experiments

Future Work

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- Variable Injection Nozzle Technology
- Advanced Next Generation Fuel Injection System
- Steady-state Advanced Combustion Development
- Transient Combustion and Control Development
- Integrated System Controls Development

Challenges

- Significant Development Still Required for Viable Strategies
  - Advanced Fuel Injection System Integration with Variable Nozzle Injector
  - Combustion Mode Transition
  - Application of HCCI to High Loads While Limiting Hydrocarbon Spike and High Fuel Economy Penalty
  - Sensors, Controls and Calibration Techniques
  - Minimization of System Variability for Reduced NOx Margin
  - Tailoring Engine-out Chemical and Thermal Boundary Conditions for The Optimized Performance of Integrated Engine and Aftertreatment System

Summary

- Significant Benefits in Both Fuel Economy And Emissions Are Obtained by Implementing Key Enabling Technologies
  - Variable Fuel Injection Nozzle Coupled with Advanced Fuel Injection System
  - Genetic Combustion System Optimization
  - Transient Control Optimization

- Integrated Engineering Methodologies Enabled by Analytical Tools are Critical to Develop and Validate the Technical Roadmap to Achieve Thermal Efficiency and Reduce Emissions Goals

Acknowledgements

- Department of Energy Headquarters
  - Gurpreet Singh
  - Roland Gravel
- National Energy Technology Laboratory
  - Carl Maronde
  - Jeffrey Kooser