Technology Development for Light Duty High Efficient Diesel Engines

Donald Stanton
Research & Technology

August 5, 2009

Cummins®

Project Goals and Objectives

Goal

Improve the efficiency of diesel engines for light duty applications through technical advances in system optimization and critical subsystem component integration.'

Objectives

- Improve light duty vehicle (5000 lb test weight) fuel efficiency over the FTP city drive cycle by 10.5% over today's state-of-the-art diesel engine.
- Develop & design an advanced combustion system that synergistically meets Tier 2, Bin 5 NOx and PM emissions standards while demonstrating the efficiency improvements.
- Maintain power density comparable to that of current conventional engines for the applicable vehicle class.
- Evaluate different fuel components and ensure combustion system compatibility with commercially available biofuels.

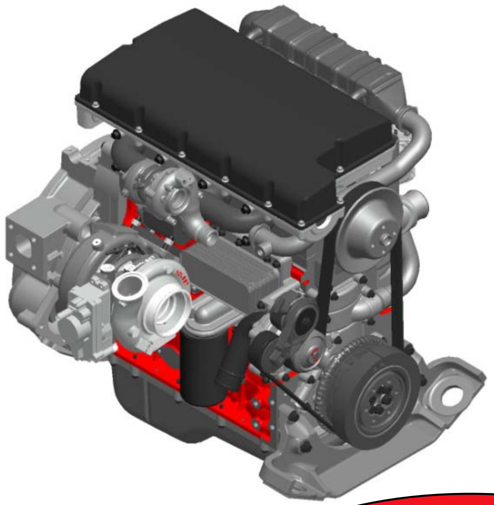
Light Duty Technology Roadmap

Fuel System
- Precision Injection
-High Injection Pressure
-Piezo

Variable Valve Actuation

Advanced Combustion
-Enhanced Early PCCI
-Lifted Flame Combustion

Variable Intake Swirl



Controls
-Closed loop combustion
- Charge air manager

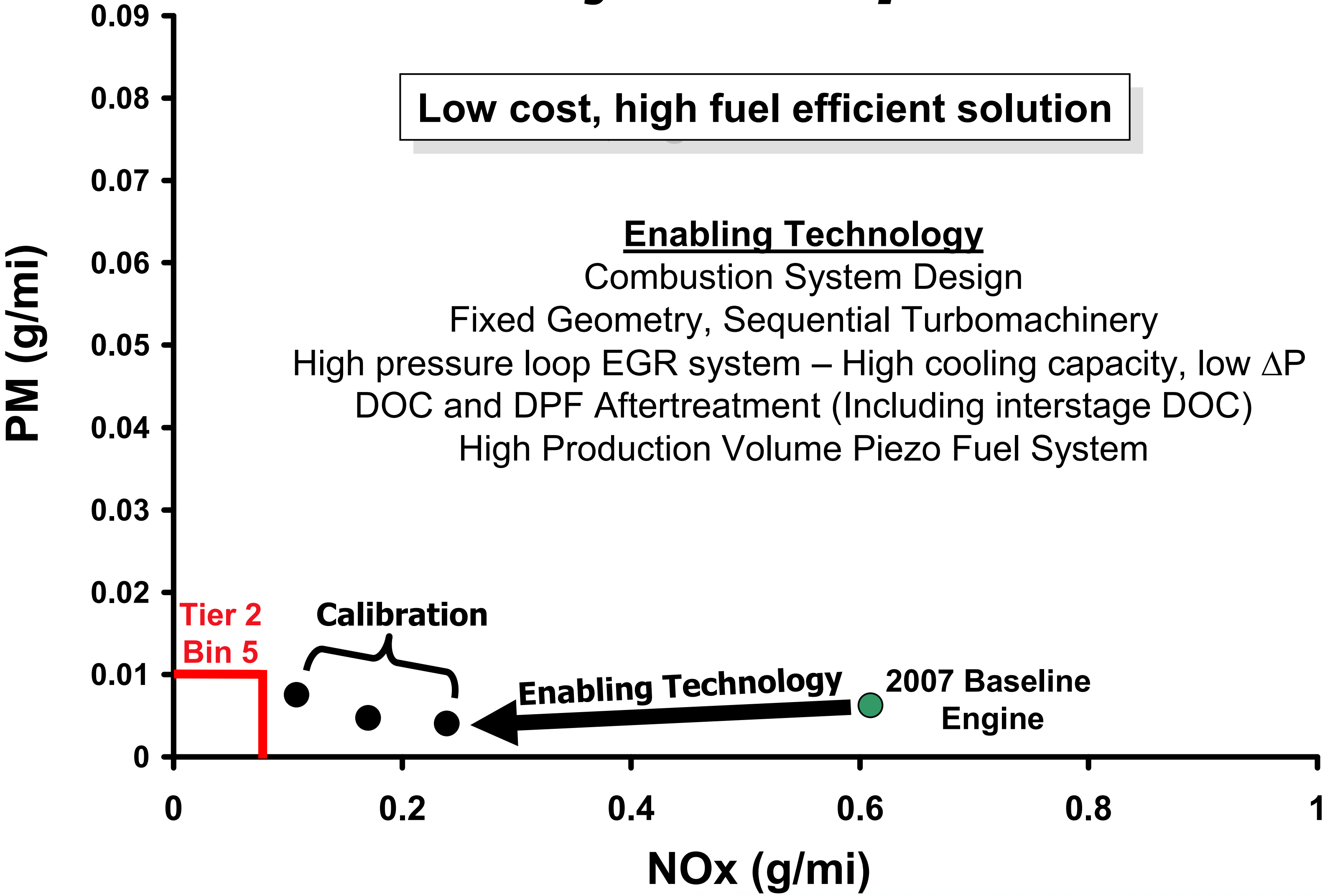
Aftertreatment
- Low Temperature SCR
- Low ΔP
- Low Soot Loading
- Partial Filter
-IDOC

EGR Loop
- Lower Pressure Drop
-Alternative Cooling
-2-loop Cooling
-HP/LP

Turbo
-Two Stage
-HP Stage VGT

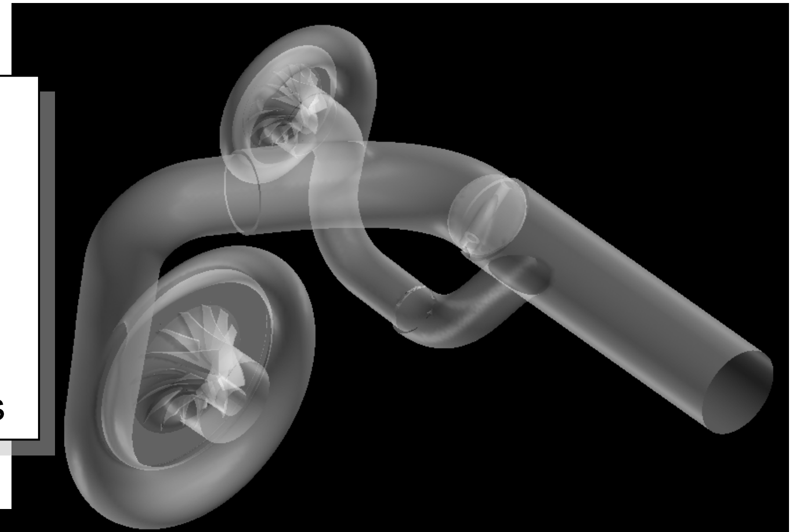
Friction/Parasitics
-Variable displacement pumps
-Piston
-Bearings
-Lube oil

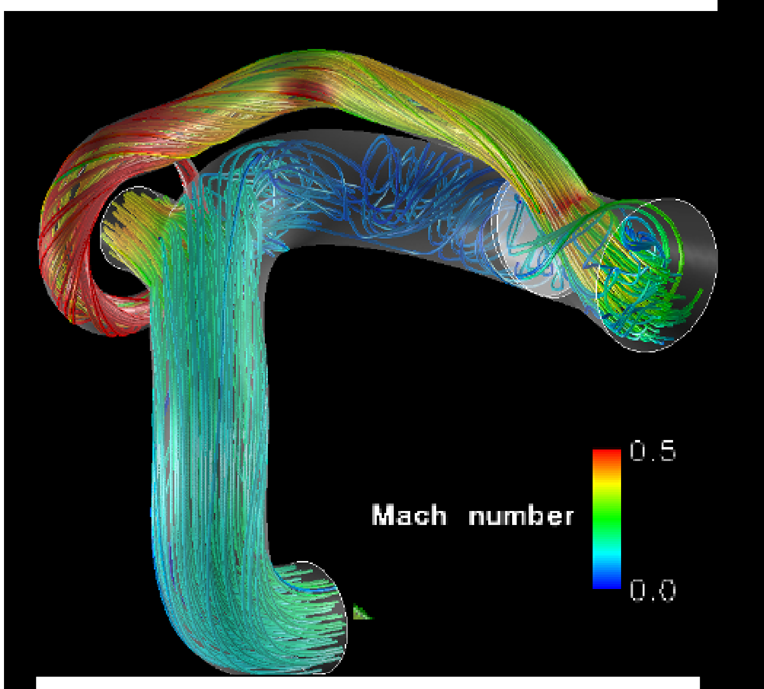
Current Status of Emissions and Efficiency Accomplishments



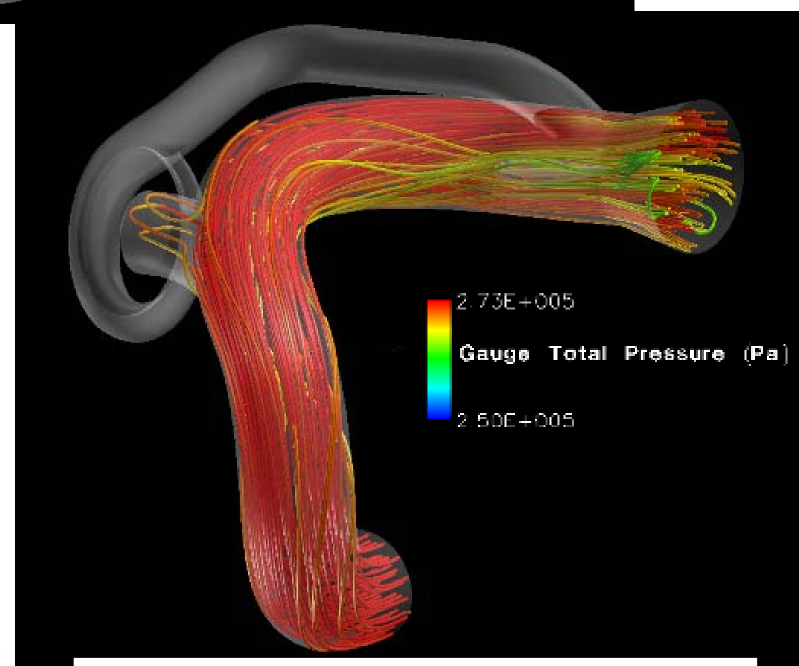
Sequential Turbomachinery Analysis

Optimization of the compact 2-stage, sequential turbo done with CFD
- Provide sufficient power density
- Minimize ΔP
- Deliver target A/F and EGR rates determined from single cylinder engine testing and GT-Power analysis



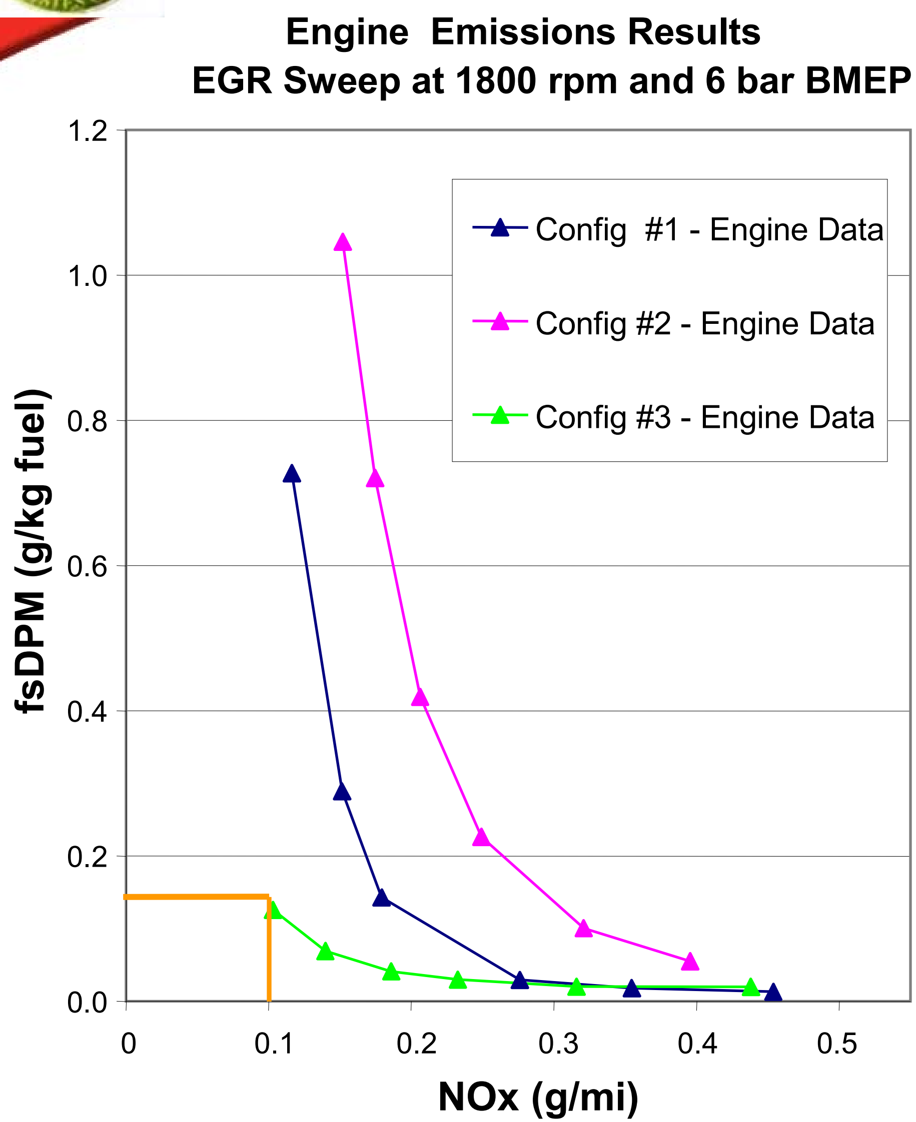


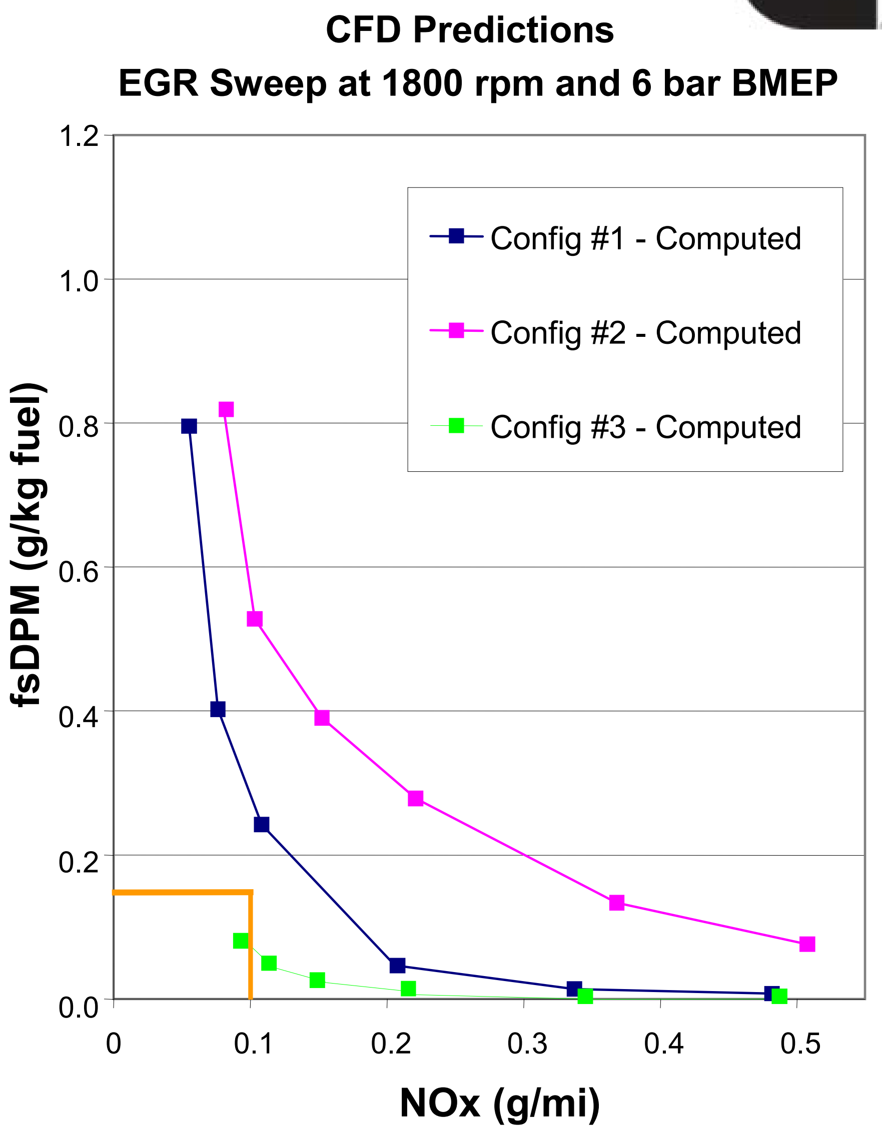
Compressor bypass valve closed



Compressor bypass valve opened

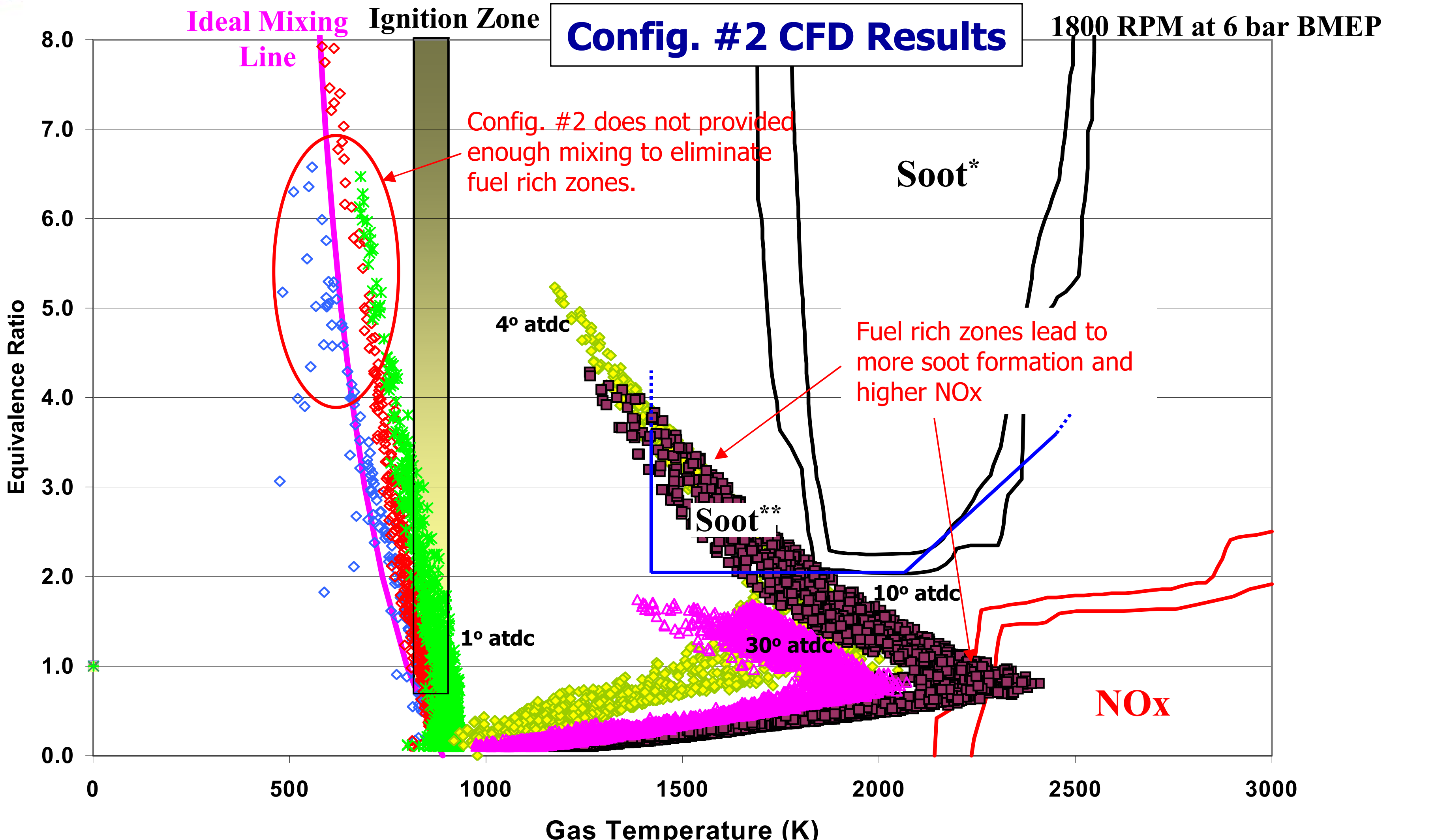
Combustion System Design for LTC





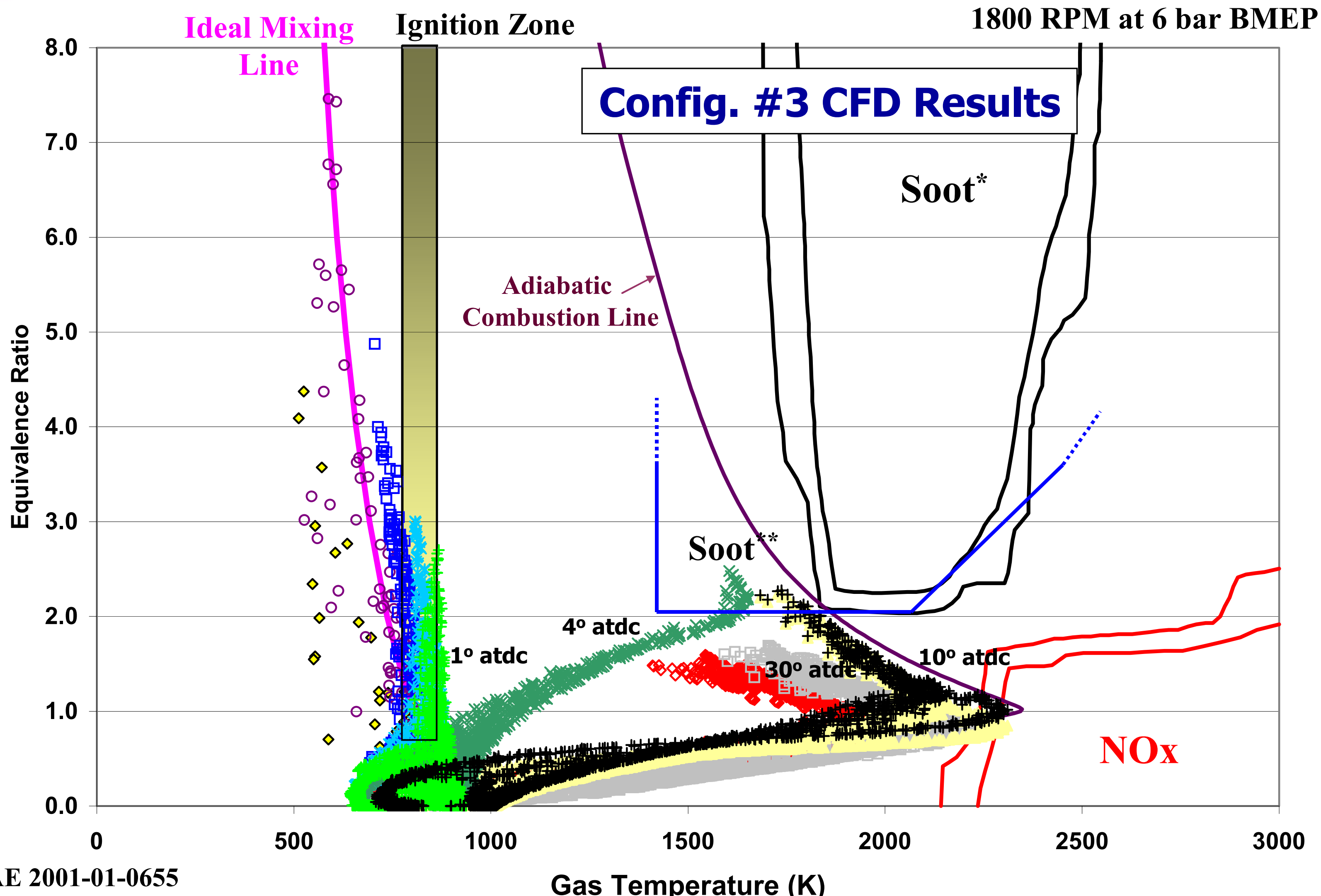
Note: Each configuration represents a unique piston bowl, injector nozzle, and intake swirl combination

Evolution of the Combustion Process for Combustion System Configuration #2



*SAE 2001-01-0655
**SAE 880423

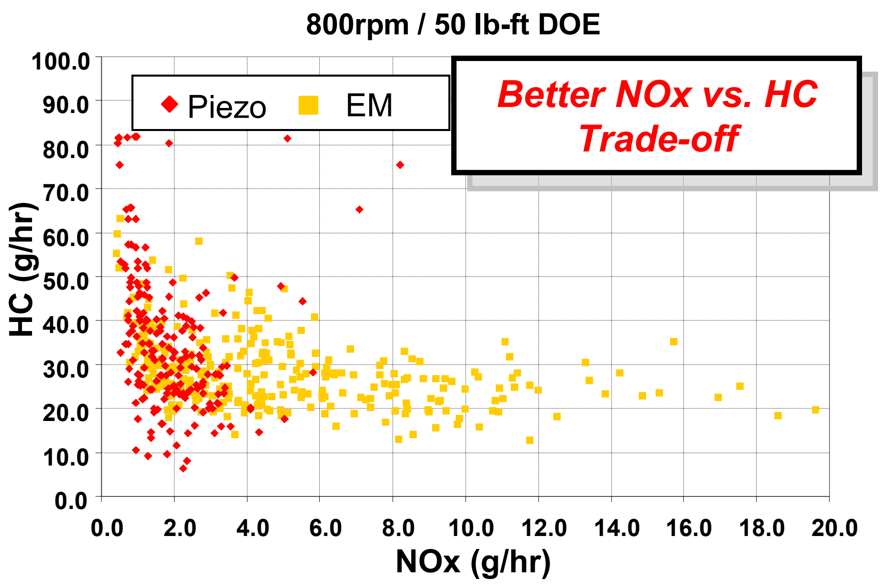
Evolution of the Combustion Process for Combustion System Configuration #3

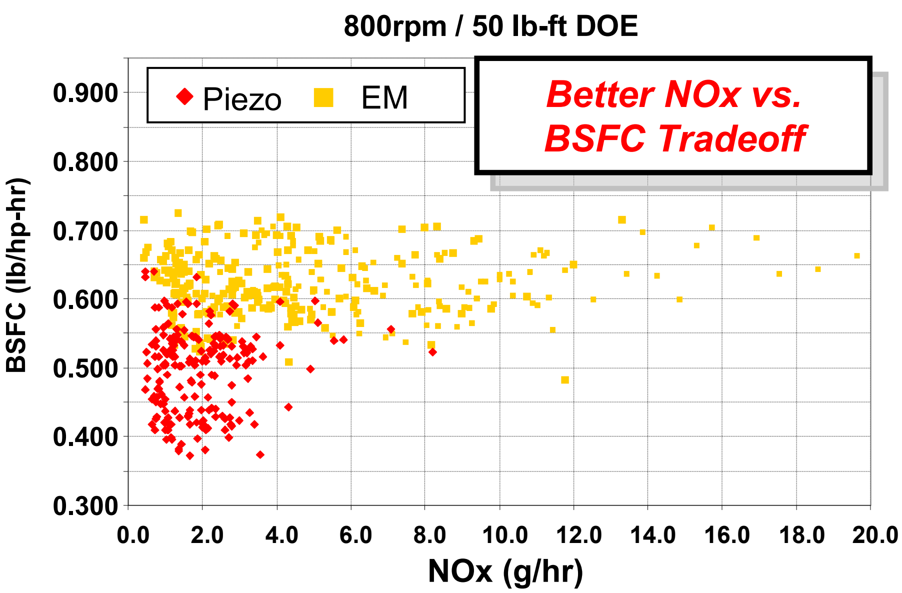


*SAE 2001-01-0655

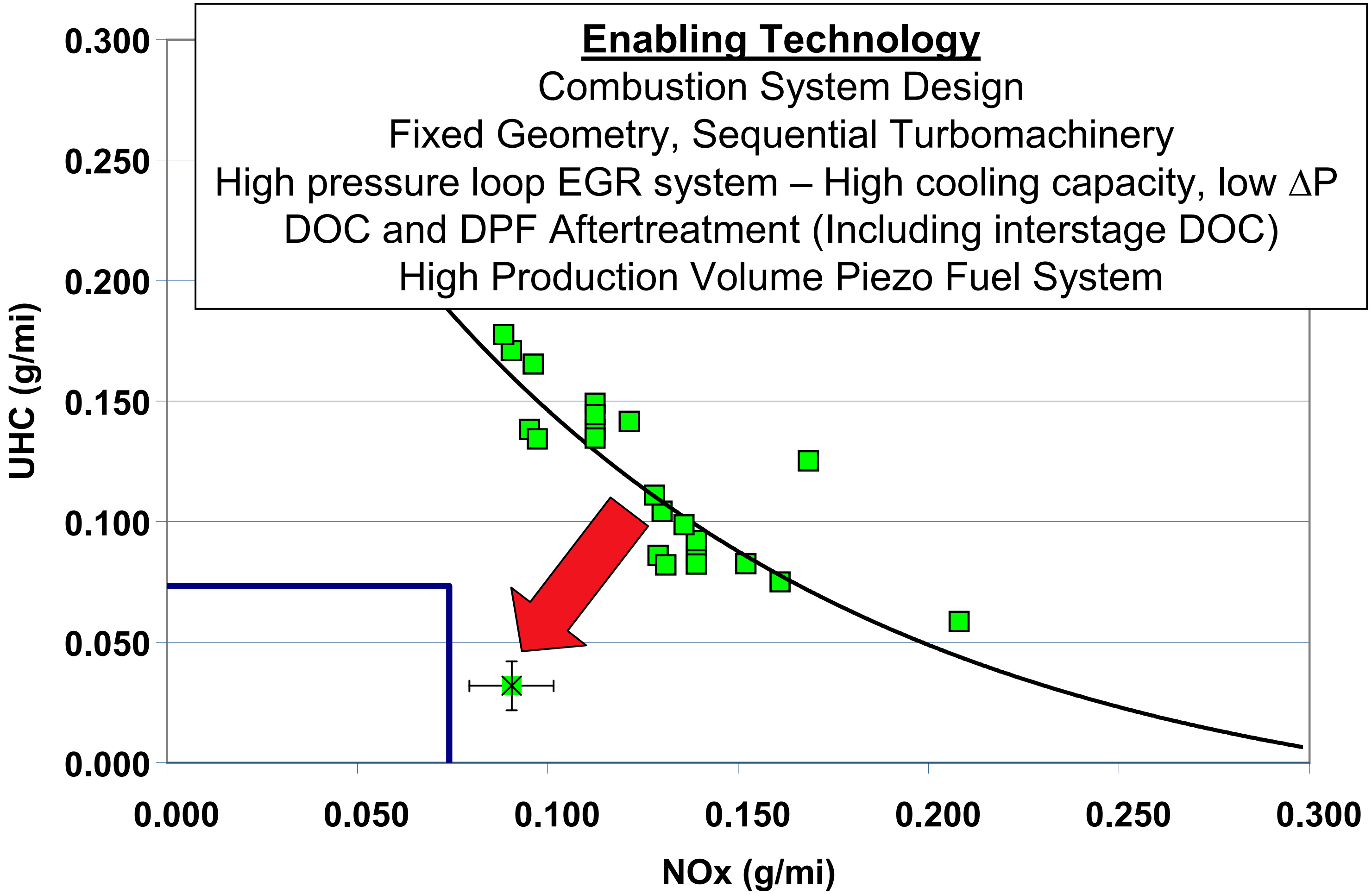
**SAE 880423

Fuel System Performance Comparison for Light Duty Operation



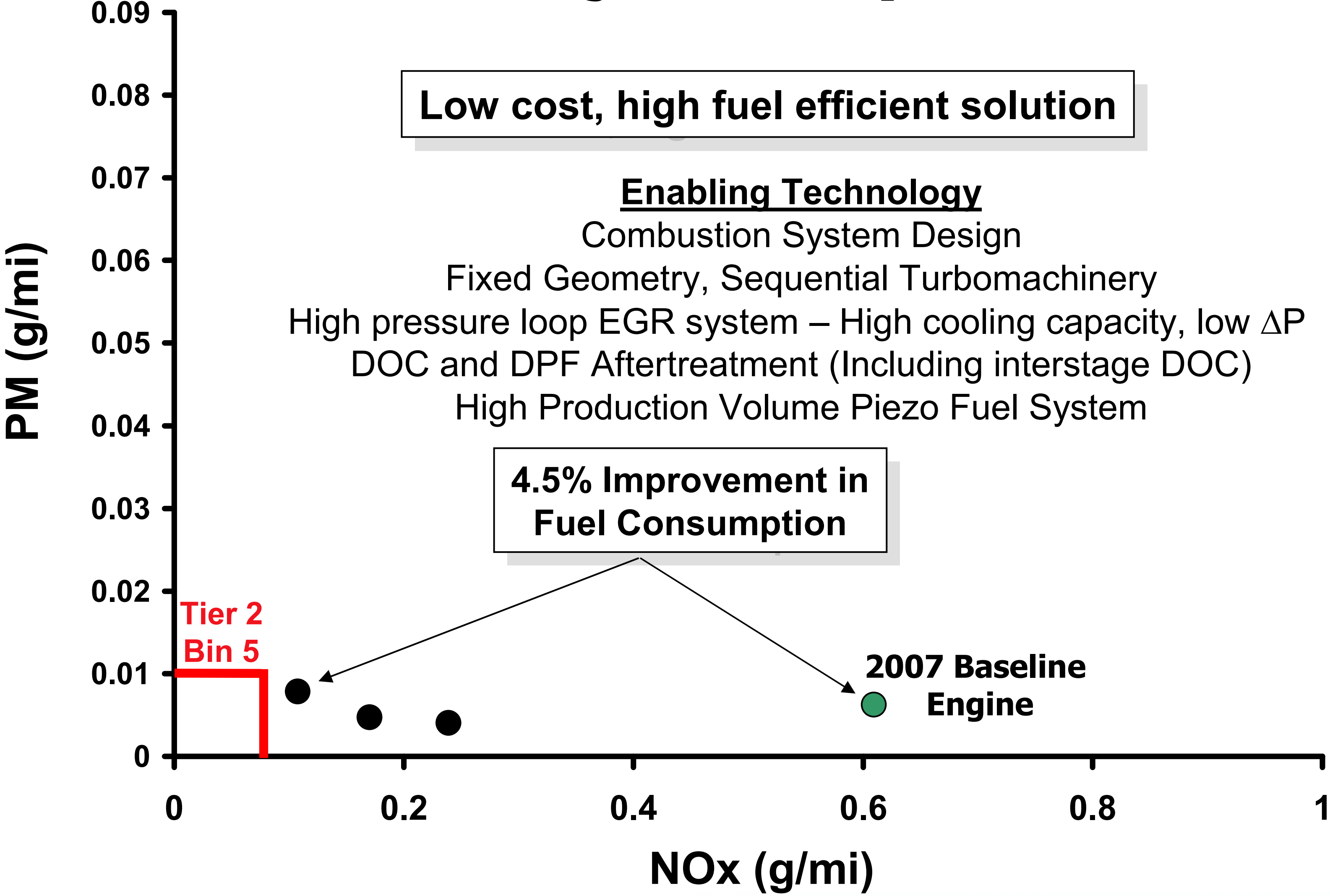


Impact of Interstage DOC on Emissions

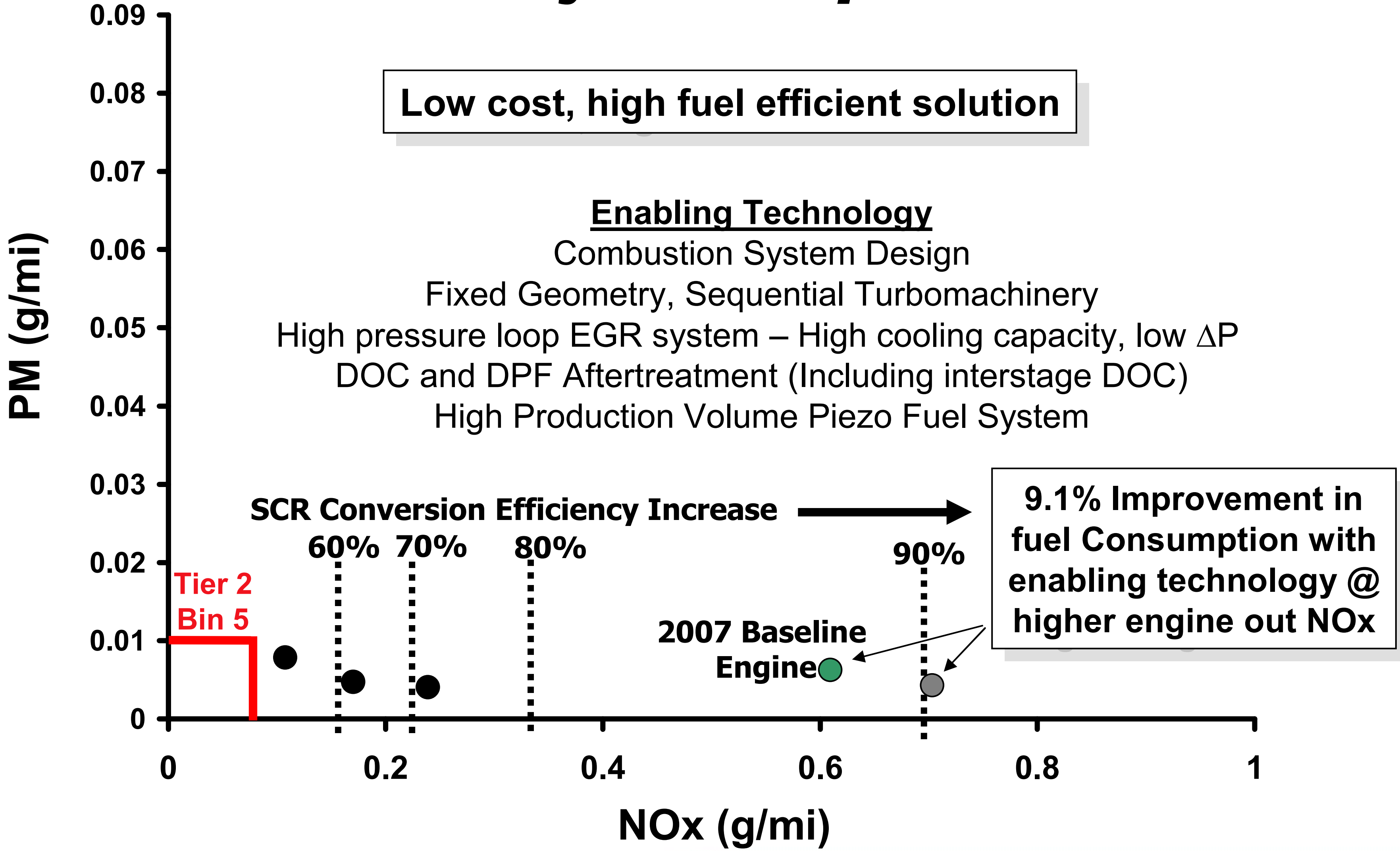


Without NOx AT

Current Status of Emissions and Efficiency Accomplishments



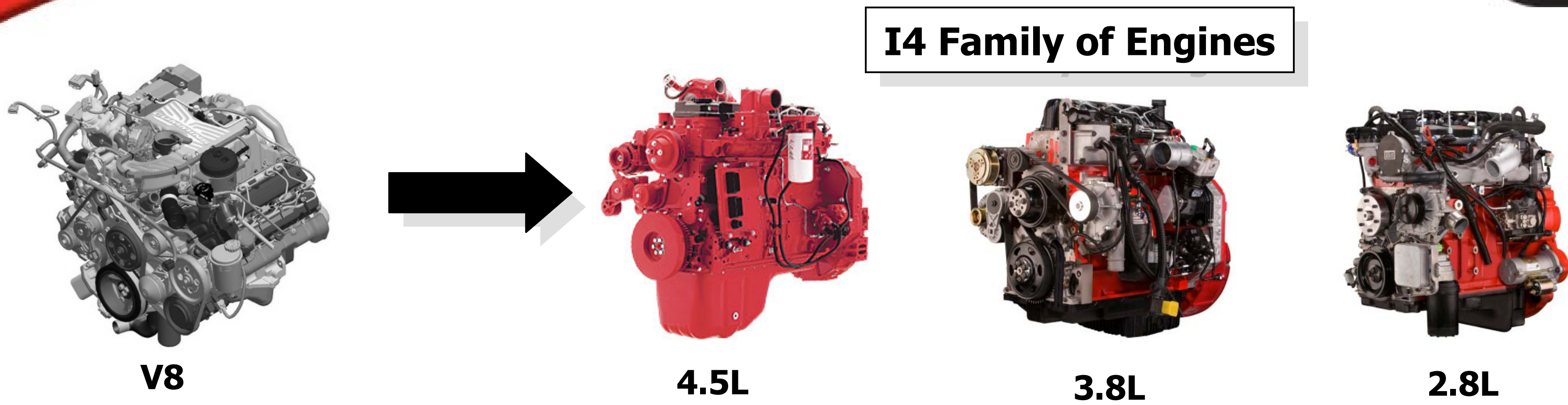
Current Status of Emissions and Efficiency Accomplishments



Conclusions

- Seeking cost competitive solutions
  - Minimize EGR system complexity
  - Utilizing 2-stage sequential turbo that is comparable in price to a VGT
  - High production volume piezo fuel system
- More work needed to meet Tier 2 Bin 5 (SFTP1 and SFTP2) emissions without NOx aftertreatment (best calibration is 0.8 g/mi NOx)
  - Achieved 4.5% fuel efficiency improvement against 10% target
- SCR NOx aftertreatment solution can provide a 9.1% fuel efficiency improvement while meeting Tier 2 Bin 5 emissions (SFTP1 and SFTP2)
  - Focus to cost reduce aftertreatment architecture

Commercial Viability



- LDECC technologies scale across all Cummins light duty diesel engines
- Key component technologies and subsystems are being developed by Cummins Component Business units (aftertreatment, turbomachinery, electronics, etc.) that are intended for production

Fuels Collaboration

Purdue University, ORNL, and BP

Fuels Collaboration Key Questions

1. What fuel properties are conducive to promoting fuel efficiency and emissions improvements?

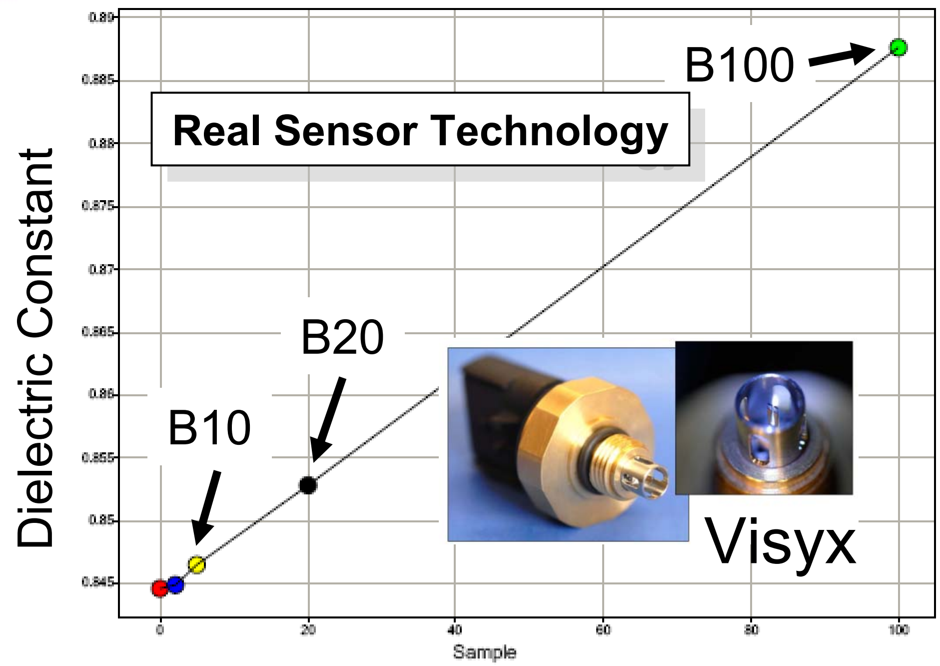
2. Are the LDECC engine technologies compatible with biodiesel?

LDECC Engine Efficiency with Biodiesel

- Drive cycle optimization with a variety of biodiesel blends is on-going
- Difficult to maintain fuel efficiency at desired emissions levels with biodiesel given the lower energy content of the biofuel
- Seeking cost effective ways to sense that biofuels are employed along with sensing variation in biodiesel blend percentage
  - Virtual and real sensor evaluation
  - Study includes variations in biofuel feedstock
  - If nothing is done, fuel efficiency will degrade by 1% to 6% for B20
- Seeking cost effective ways to develop engine control strategies for variation in biodiesel blends
  - Can not develop unique engine calibrations for biodiesel blends

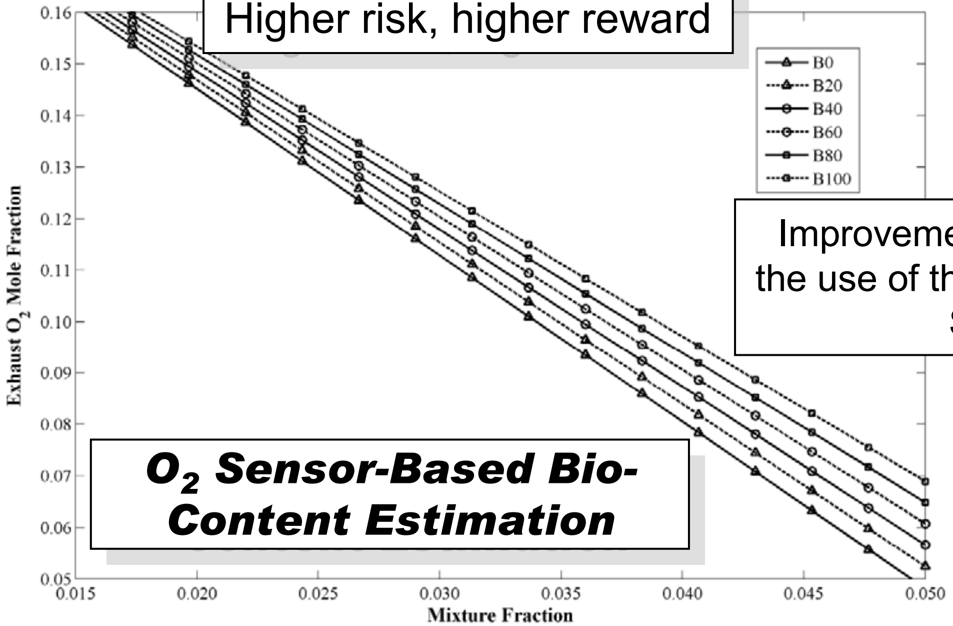
Biofuel Sensing

Real Sensor Technology



Virtual Sensor Technology

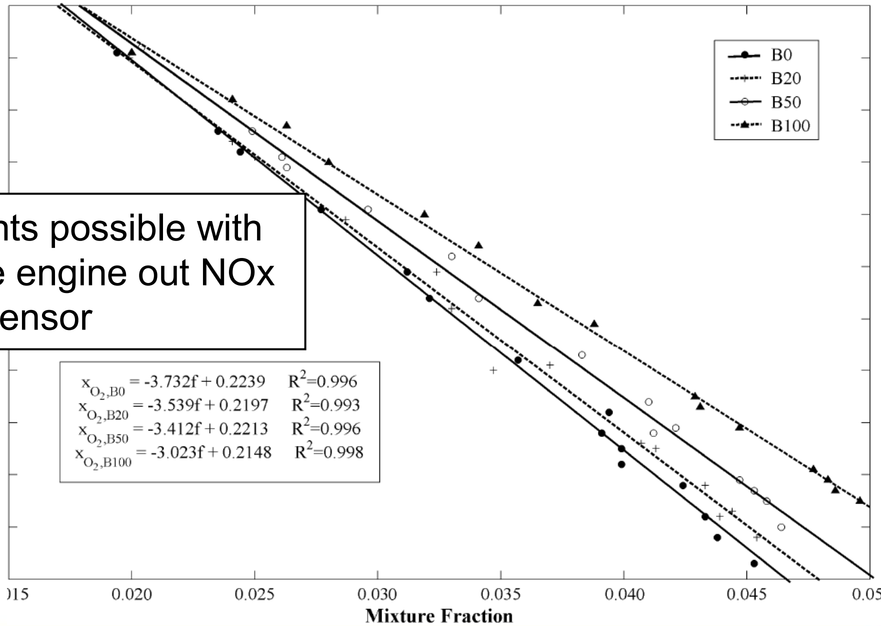
Higher risk, higher reward



O_2 Sensor-Based Bio-Content Estimation

Model Prediction

Improvements possible with the use of the engine out NOx Sensor



Experimental results

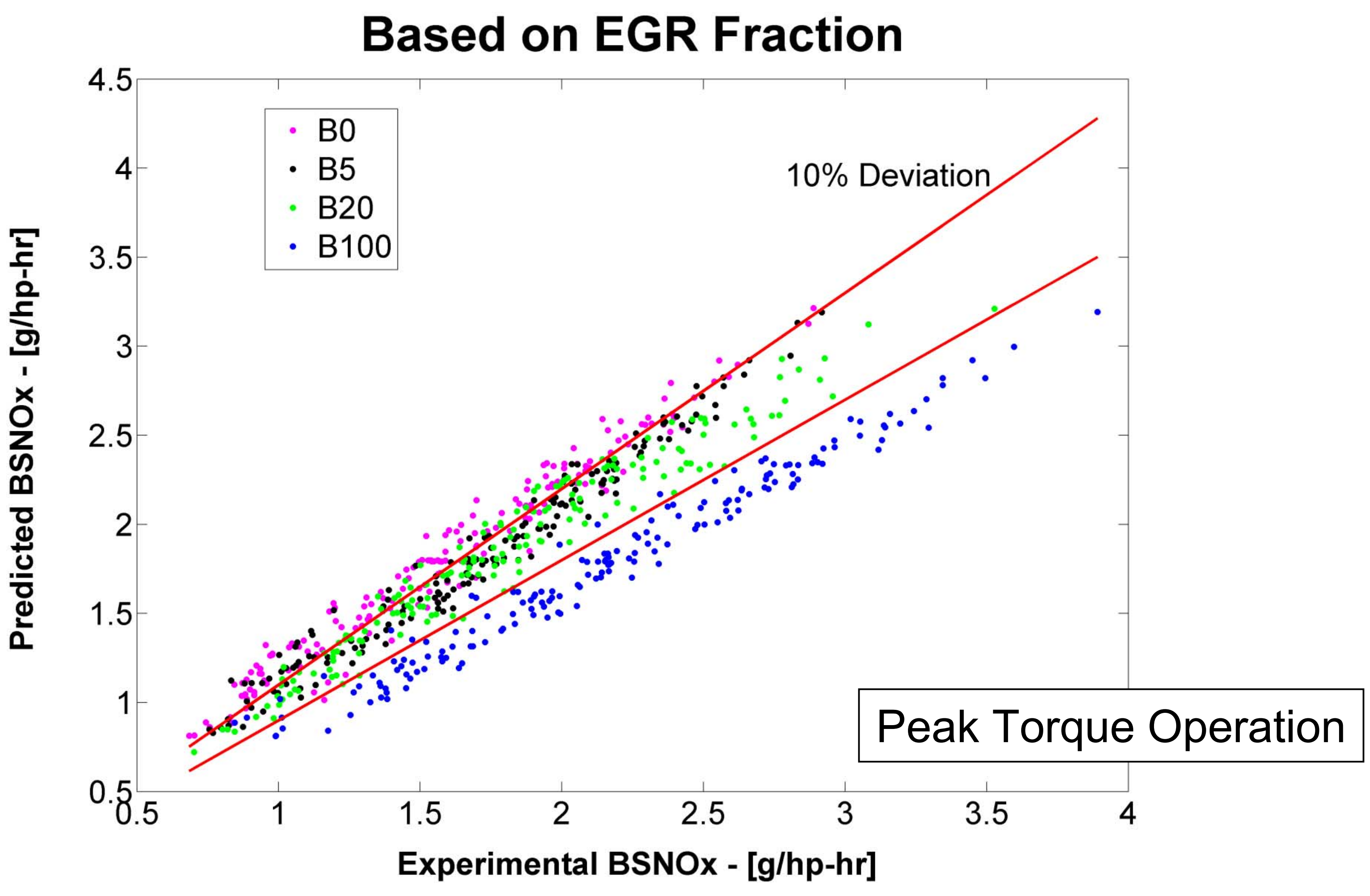
Engine Control Strategy with Biodiesel

- Objective is to use the engine + AT calibration developed using ULSD certification fuel to optimize fuel efficiency at the target emissions and desired performance
- Most cost effective solution for the market segment

Transform Controls Variables

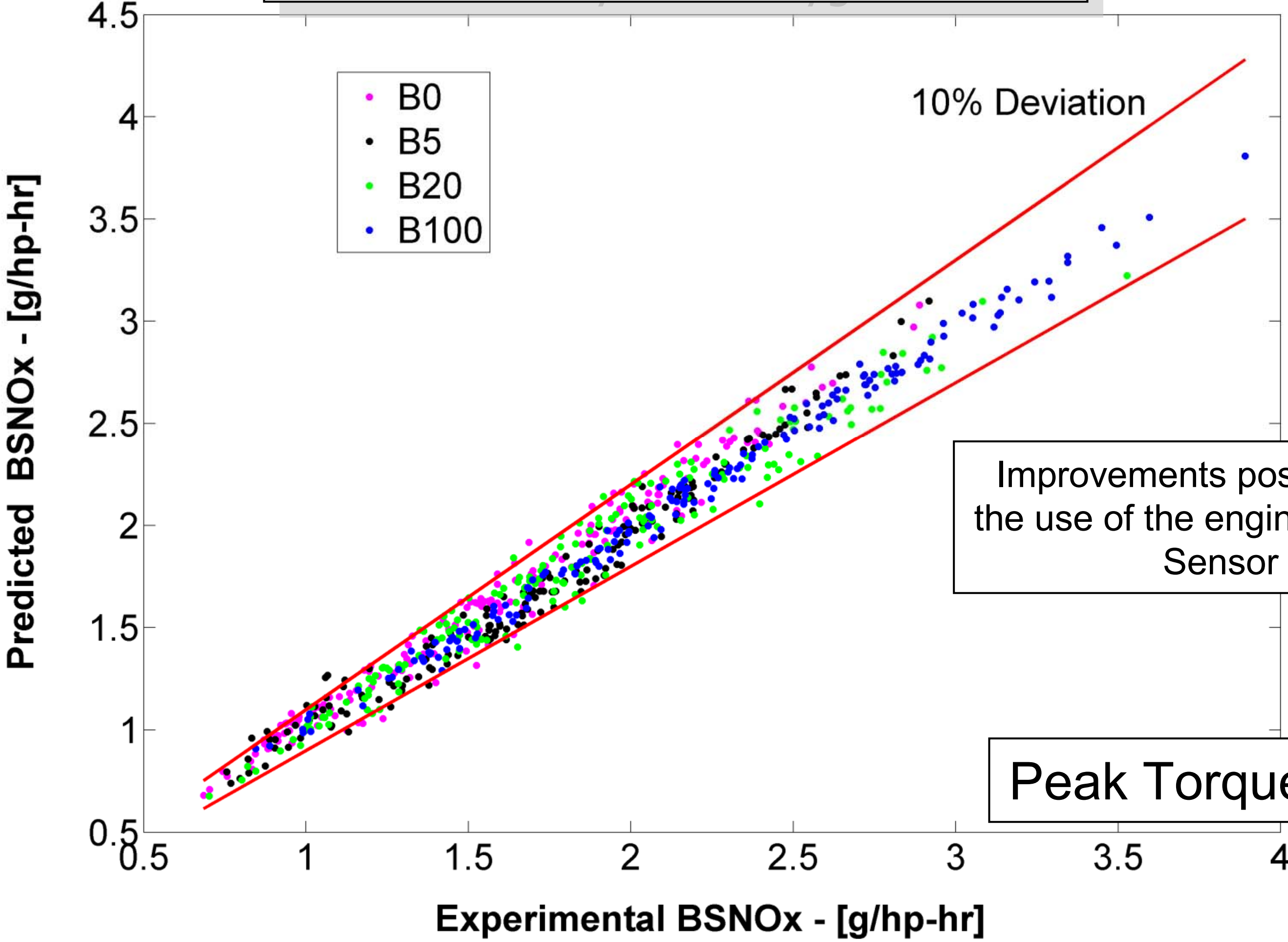
AFR EGR Fract. Rail Press. Main SOI	→	Charge Flow In-Cylinder Oxygen Fract. Rail Press. Main SOI

Engine Control Strategy with Biodiesel



Engine Control Strategy with Biodiesel

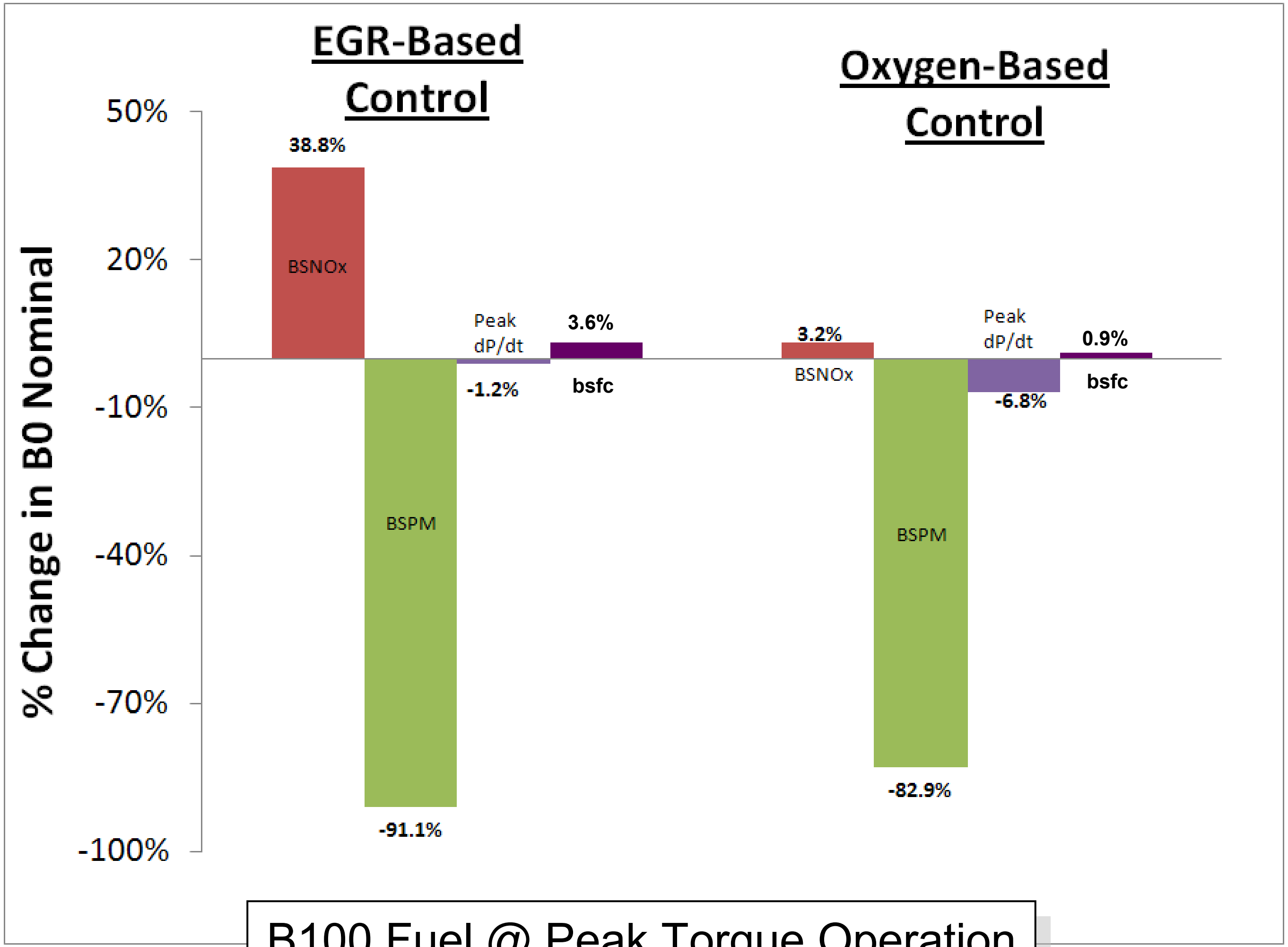
Based on In-Cylinder Oxygen Fraction



Improvements possible with the use of the engine out NOx Sensor

Peak Torque Operation

Engine Control Strategy with Biodiesel



B100 Fuel @ Peak Torque Operation