**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**

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

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

- **Turbo**
  - Two Stage
  - HP Stage VGT

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

- **Controls**
  - Closed loop combustion
  - Charge air manager

- **Advanced Combustion**
  - Lifted Flame Combustion
Current Status of Emissions and Efficiency Accomplishments

*Low cost, high fuel efficient solution*

**Enabling Technology**
Combustion System Design
Fixed Geometry, Sequential Turbomachinery
High pressure loop EGR system – High cooling capacity, low \( \Delta P \)
DOC and DPF Aftertreatment (Including interstage DOC)
High Production Volume Piezo Fuel System

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-tier 2 bin 5 calibration

2007 baseline engine
Optimization of the compact 2-stage, sequential turbo done with CFD
- Provide sufficient power density
- Minimize $\Delta P$
- Deliver target A/F and EGR rates determined from single cylinder engine testing and GT-Power analysis
Combustion System Design for LTC

Engine Emissions Results
EGR Sweep at 1800 rpm and 6 bar BMEP

- Config #1 - Engine Data
- Config #2 - Engine Data
- Config #3 - Engine Data

CFD Predictions
EGR Sweep at 1800 rpm and 6 bar BMEP

- Config #1 - Computed
- Config #2 - Computed
- Config #3 - Computed

Note: Each configuration represents a unique piston bowl, injector nozzle, and intake swirl combination.
Config. #2 CFD Results

1800 RPM at 6 bar BMEP

Config. #2 does not provide enough mixing to eliminate fuel rich zones.

Fuel rich zones lead to more soot formation and higher NOx.

Soot*

Soot**

NOx

*SAE 2001-01-0655

**SAE 880423
Evolution of the Combustion Process for Combustion System Configuration #3

1800 RPM at 6 bar BMEP

Config. #3 CFD Results

Soot*

NOx

Evolution of the Combustion Process for Combustion System Configuration #3

*SAE 2001-01-0655

**SAE 880423
Fuel System Performance Comparison for Light Duty Operation

800rpm / 50 lb-ft DOE

Better NOx vs. HC Trade-off

800rpm / 50 lb-ft DOE

Better NOx vs. BSFC Trade-off
Impact of Interstage DOC on Emissions

Enabling Technology
Combustion System Design
Fixed Geometry, Sequential Turbomachinery
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High Production Volume Piezo Fuel System

Without NOx AT
Current Status of Emissions and Efficiency Accomplishments

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- High Production Volume Piezo Fuel System

4.5% Improvement in Fuel Consumption

Tier 2 Bin 5

2007 Baseline Engine
Current Status of Emissions and Efficiency Accomplishments

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High Production Volume Piezo Fuel System

SCR Conversion Efficiency Increase
60% 70% 80% 90%

9.1% Improvement in fuel Consumption with enabling technology @ higher engine out NOx

Low cost, high fuel efficient solution
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

**O₂ Sensor-Based Bio-Content Estimation**

**Virtual Sensor Technology**

Higher risk, higher reward

Improvements possible with the use of the engine out NOx Sensor

1. Model Prediction

2. Experimental results

Real Sensor Technology

Virtual Sensor Technology

Visyx
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

Based on EGR Fraction

- B0
- B5
- B20
- B100

10% Deviation

Peak Torque Operation
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

- BSNOx: -91.1%
- bsfc: -6.8%
- BSPM: -82.9%
- Peak dP/dt: 3.6%
- Peak df/dt: 3.2%

B100 Fuel @ Peak Torque Operation