Heavy Truck Clean Diesel (HTCD) Program Heavy Duty HCCI Development Activities

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Team Leader: Gurpreet Singh Prgm Mgr: Roland Gravel Tech Mgr: Carl Maronde

Caterpillar Pl's: Kevin Duffy, Andrew Kieser, Eric Fluga Prgm Mgr: David Milam

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# 2010 Emissions/Efficiency Challenge



By 2010 NOx levels must be below 0.2 g/hp\*hr

These levels are unlikely with traditional diesel combustion and at best incur large BSFC and particulate penalties

How do we meet 2010 NOx levels AND improve engine efficiency?

## **Combustion Methods**



# **HCCI** Development at Caterpillar



# Flexible Injection System



#### Mixed Mode Injector



# Fuel/Engine Systems Approach





#### <u>CAT</u>

Hardware Engine Testing Systems Integration

### Combustion Modeling

Fluid Dynamics

#### <u>ExxonMobil</u>

#### Fuel

Advanced Characterization

Refining Process Technology

Chemical Kinetics

Systems Modeling





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" "B" "C" "D" "E"

C2C\*O

C2•C\*O

с•ссоон с\*сс

HOOCCCHO + OH. C\*CC.

# Joint Program Objectives

### HCCI Combustion

 Evaluate suitability of a range of fuels to facilitate HCCI combustion with goal of identifying preferred HCCI fuels in an optimized engine system

### Multi-dimensional Diesel Combustion Modeling

 Model diesel HCCI combustion using chemical kinetic mechanisms and multi-dimensional CFD

#### Initial Testing Shows No Benefit for Increased Cetane

- Initial testing on effect of cetane #, aromatic content
- In general, fuel property changes can impact cylinder pressure rise rates, combustion phasing and HC/CO emissions
- Increasing cetane # produced undesirable advance in combustion phasing
- Fuels effects dependent on HCCI injection, combustion approach
  - Details to be presented at IFP Conference in Sept, 2004.



## Climbing the BMEP Ladder



### Top of the BMEP Ladder



# Test Background

3401 single cylinder engine	
Low CR piston	
Multi-hole nozzle	
Conventional #2 Diesel fuel	
No catalyst used, CO/HC levels are engine-out	
Variables: Injection timing, Boost/backpressure (eff. turbo efficiency), manifold temp, etc.	

Displacement	2.44L
Bore/Stroke	137.2 / 165.1 mm
Connecting Rod Length	261.6 mm
Valves per cylinder	4
Injection System	Intensified Hydraulic
Swirl Ratio	~0.4
Inlet Valve Open, Close	320.3, 568.7 deg
Exhaust Valve Open, Close	119.5, 380.0 deg

## Full Load Diesel HCCI Operation



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## 1200 rpm, Load Sweep



### **Compression Ratio Effect**



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# Single Cylinder HCCI Emissions Data



# HC/CO Emissions Data

15.5 g/hphr CO standard for onhighway in 2010. Off-road levels for Tier 4 in the 3-4 g/hphr range.Oxidation catalysts at 90%efficiency should achieve these levels with sufficient temperature.





BMEP (kPa)

0.14 g/hphr HC standard for 2010. Light loads very challenging. Higher loads will still require 80%+ HC conversion (temp is sufficient).

# Low Temperature Oxidation Catalysts



# Many Challenges Remain

- Multi-cylinder engine implementation
- Controlling combustion phasing (best sensor?), ECM processor capability, transients
- Light load HC/CO cleanup
- Structural reliability with higher PCP and rise rates
- Noise/vibration
- Etc.

# Summary and Conclusions

- Fundamental recipe for HCCI operation with diesel fuel now developed
- Significant progress made on expanding operating range for HD HCCI engine
- Full load HCCI extremely challenging
- Flexible fuel systems can enable mixed mode operation
- Fuels effects can have impact on performance/emissions
- Much work still needed to determine production feasibility of HCCI as a 2010 emissions strategy
- Advanced technology Diesel engines should continue to have long term viability as a prime power source for on and off-highway markets