Stoichiometric Compression Ignition (SCI) Engine Concept

DOE Contract DE-FC26-05NT42416

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Outline

- History
- Objectives
- Overall Concept
- Major Issues
- Comparison to Other Concepts
- Status of Development
- Further Work
- Acknowledgements

Operation of Diesel Engines at Stoichiometric

Starting

Full load at low speeds

Military Investigations in 1989 – 1991 for increased power

Full time Stoichiometric Compression Ignition for emission control on DDC Series 60 prototype engine in November, 1981

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Program Objectives

- Heavy-duty vehicle engine of reasonable size and cost
- Engine meeting 2010 on-highway emission standards
- Superior fuel economy and life cycle cost
- Applicability to off-highway vehicles

SCI Concept

- Operate compression ignition engine at stoichiometric and use three-way catalyst for control of NOx, HC, and CO
- Use continuously-regenerating diesel particulate filter for PM control
- Obtain superior fuel efficiency because of rapid combustion near TDC and efficient air system with reduced exhaust aftertreatment losses

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Major SCI Issues

- Smoke and PM at $\phi = 1.00$
- NOx level and three-way catalyst efficiency
- High exhaust temperature
- Control to maintain stoichiometry, especially during rapid load changes
- Transient response

Comparison of Alternative Combustion Concepts

- **Massive EGR – high percentages of EGR at relatively rich A/F ratio to reduce NOx**
- **Extreme EGR – very high EGR to give true Low Temperature Combustion (LTC) with low NOx and PM**
- **HCCI – homogeneous charge ignites and produces very little NOx and PM (requires EGR for higher loads)**
- **PPCI – some homogeneous charge ignites near TDC, while remainder of fuel is injected relatively late to minimize NOx**
- **SCI – conventional diesel combustion at near optimum timing with $\phi = 1$**

Full Load Estimates of Low Emission Concepts

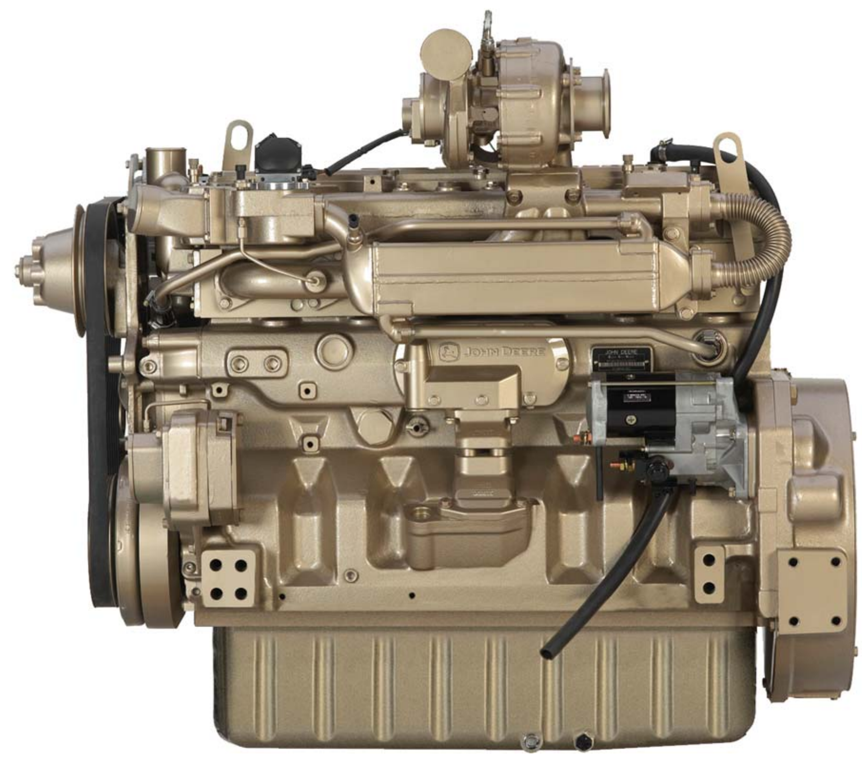
Combustion System	% EGR	ϕ	Major Issues
Massive EGR	40 - 50	0.8	power & PM
Extreme EGR	60 - 70	0.9	power & efficiency
HCCI	45 - 55	0.9	power & control
PPCI	40 - 50	0.8	control and PM
SCI	0 - 20	1.0	control, NOx & PM

Advantages of SCI Concept

- Little or no EGR
- High power capability with moderate cylinder pressure
- Low air and exhaust flows
- Low turbocharger boost requirements
- Rapid combustion near TDC for good fuel economy
- Easy starting and reliable combustion
- Relatively simple and reliable exhaust aftertreatment

Base Engine – John Deere 6090

9L six-cylinder
242 kW @ 2100 rpm
1530 N-m @ 1575 rpm
118.4 x 136 mm bore x stroke
Four-valve head with pushrods
Vertical central common rail injector
Single-piece steel piston
Variable geometry turbocharger
Air-to-air intercooled
HPL cooled EGR
John Deere ECU
Off-highway Tier 3 compliant



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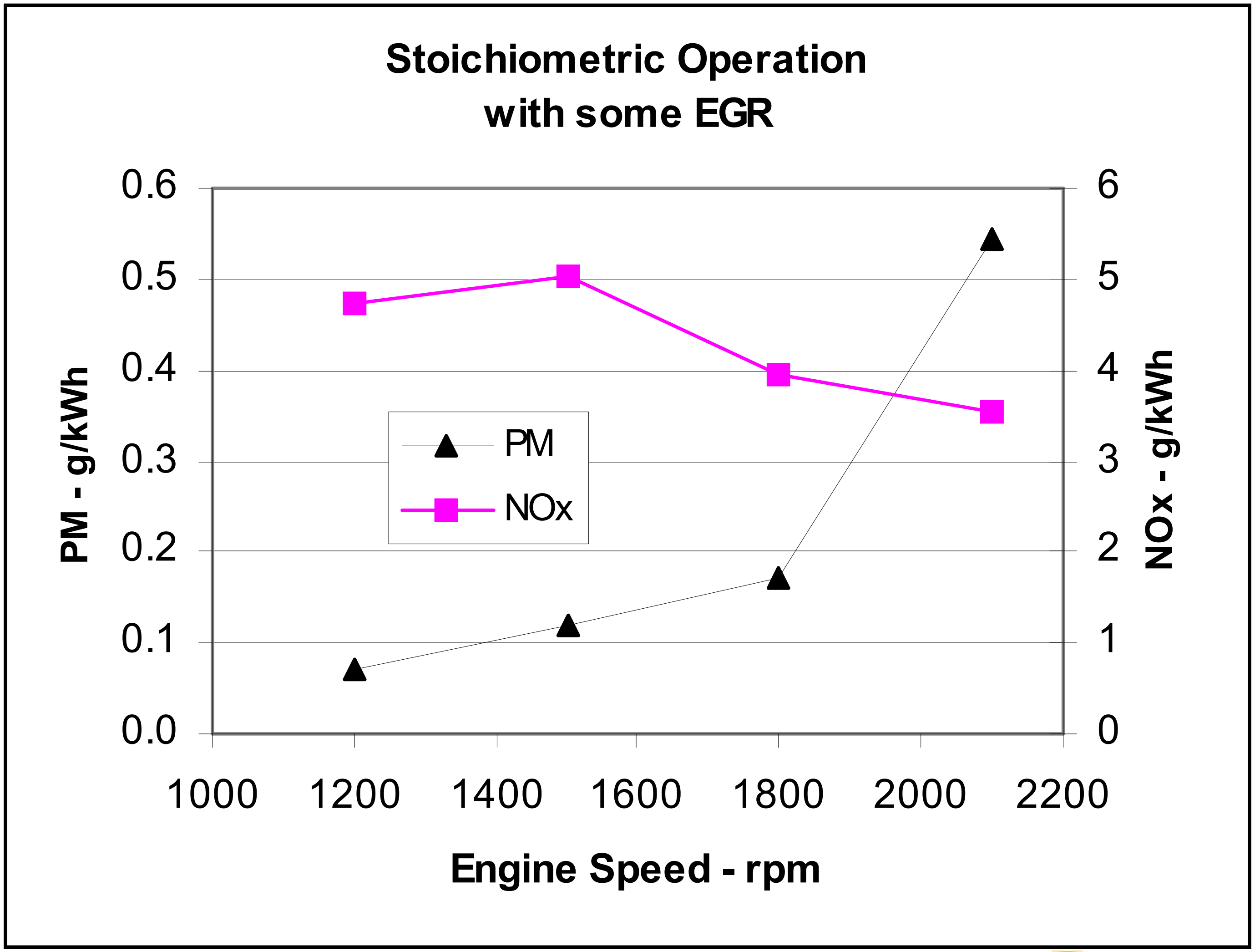
Development Status

- Operated at stoichiometric at half and full load
- Smoke and PM – need improvement
- NOx – unclear
- BSFC - promising

Promising Early Results at Half Load



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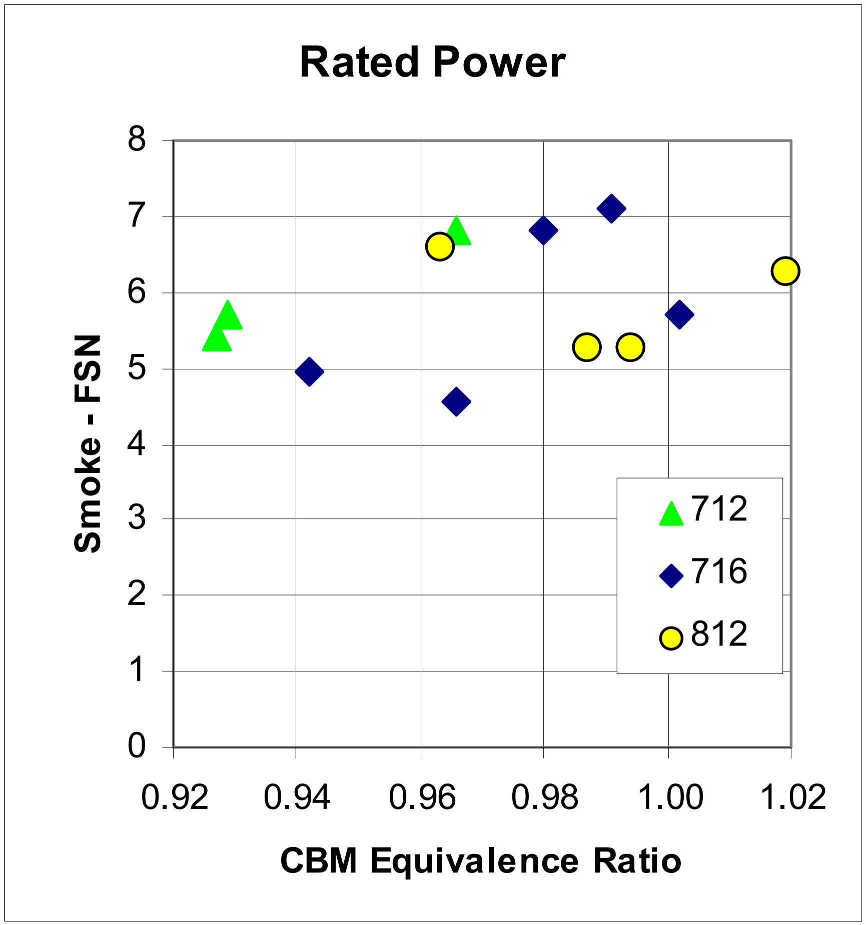
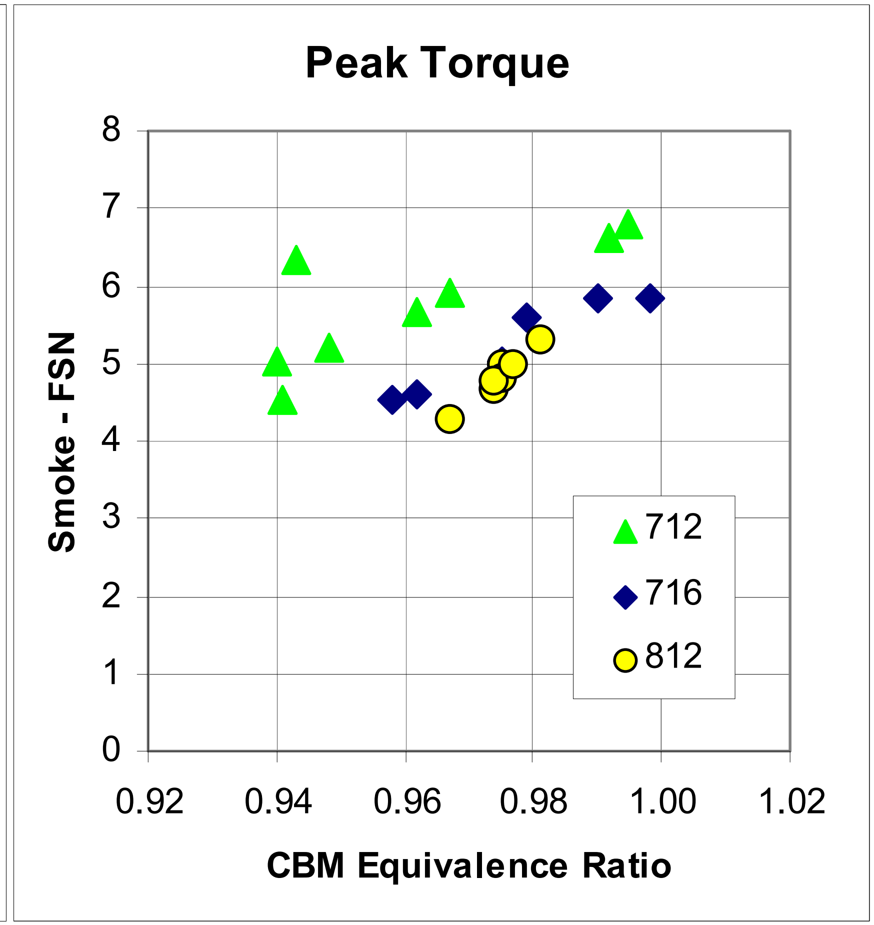
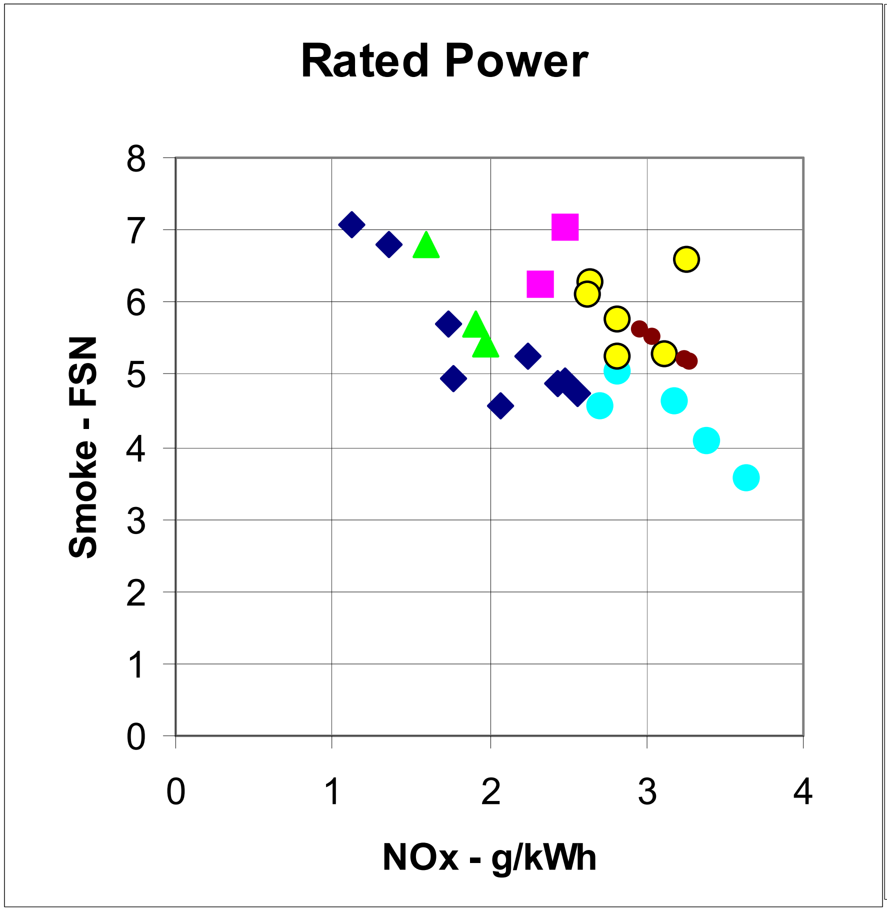
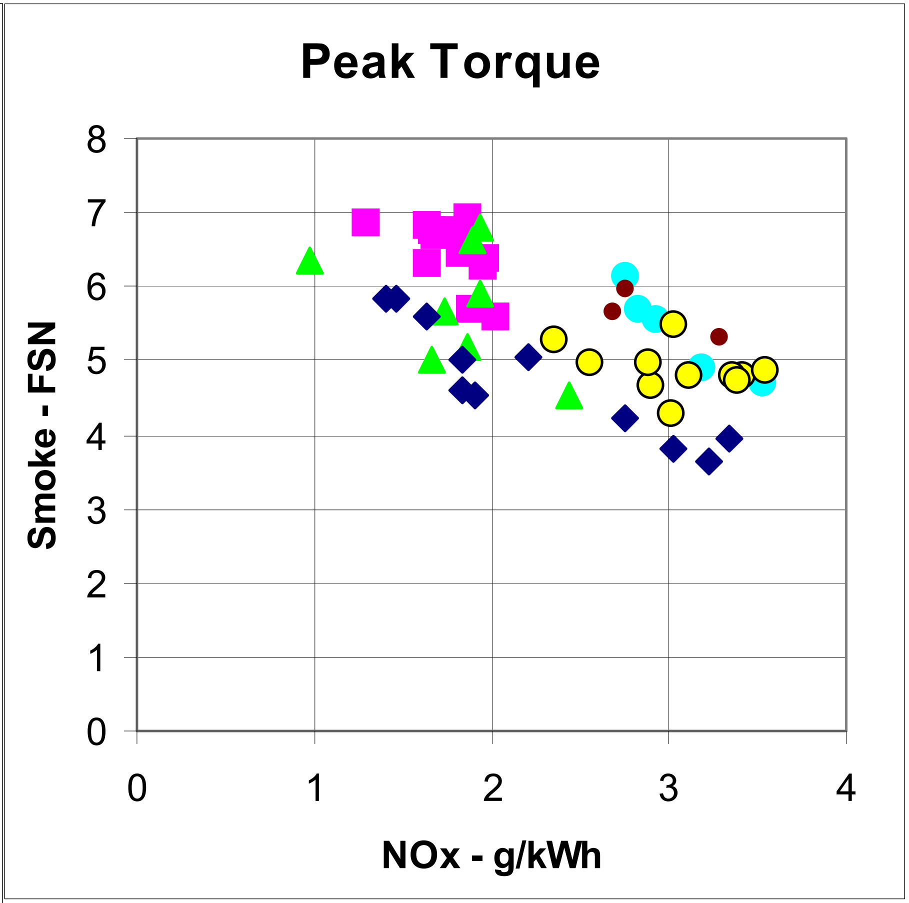
Full Load Smoke Results (~ 20% EGR)





Full Load NOx Results (~ 20% EGR)





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Methods to Reduce Smoke and PM

- Combustion system optimization
- Higher injection pressure
- Multiple injection strategy
- Less EGR – **no EGR**
- Higher H/C ratio in fuel
- Oxygenated fuel

BSFC Estimates from Simulation

- Simulation was baselined using production engine
- Heat release changed to curve calculated from cylinder pressure data at stoichiometric conditions
- With exhaust aftertreatment and using standard restrictions and efficiencies calculated 41% brake thermal efficiency at rated power and 42% at peak torque
- Air system restrictions and efficiencies are being reviewed for improvement based on the reduced flows and pressure ratios
- Camshaft is being optimized for the operating conditions
- Combustion is being improved by better mixing

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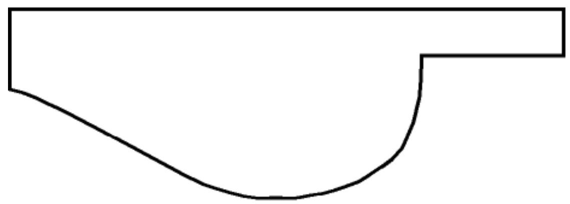
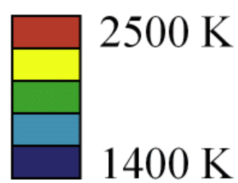
CFD to Improve Combustion System

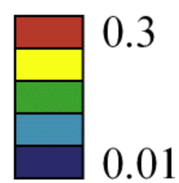
Temperature – -15°





Studying Injection, Piston Bowl, and Mixing

Mixture Fraction – -15°



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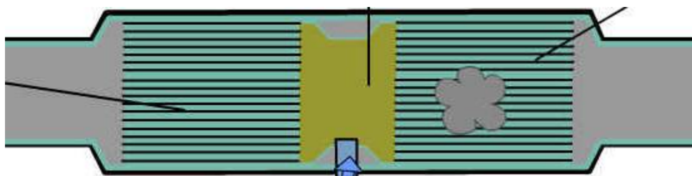
Likely SCI Engine Configuration

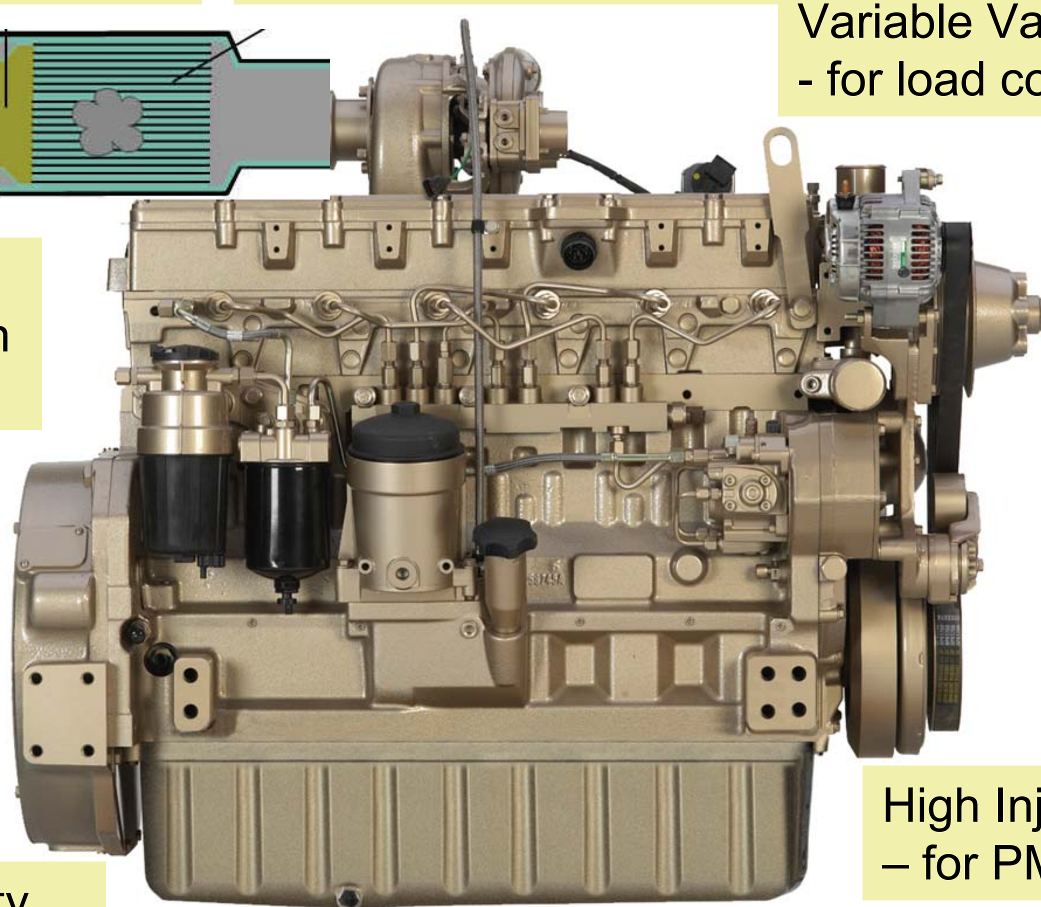
Three-way Catalyst – for NOx control

Low Boost Variable Geometry Turbocharger

Variable Valve Actuation - for load control



Diesel Particulate Filter with air injection – for PM control



High Injection Pressure – for PM control

No EGR – for simplicity, cost, low heat rejection

Next Development Activities

- Demonstrate acceptable engine-out smoke and PM
- Refine fuel consumption estimates
- Develop F/A ratio control for three-way catalyst
- Install VVA system for load control in conjunction with VTG
- Consider higher power for better brake efficiency (thermal loading issues)

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Acknowledgements

- John Fairbanks - DOE Technology Development Manager
- Ralph Nine - DOE Project Manager
- Ricardo Inc. for air system simulations using WAVE
- Prof. John Abraham (Purdue University) for CFD of combustion system
- Sturman Industries for advanced injection system

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