Low Temperature Combustion Demonstrator for High Efficiency Clean Combustion

William de Ojeda
Phil Zoldak, Raúl Espinoza, Chunyi Xia, Dan Cornelius, Raj Kumar
Navistar, Inc

Advanced Combustion Technologies

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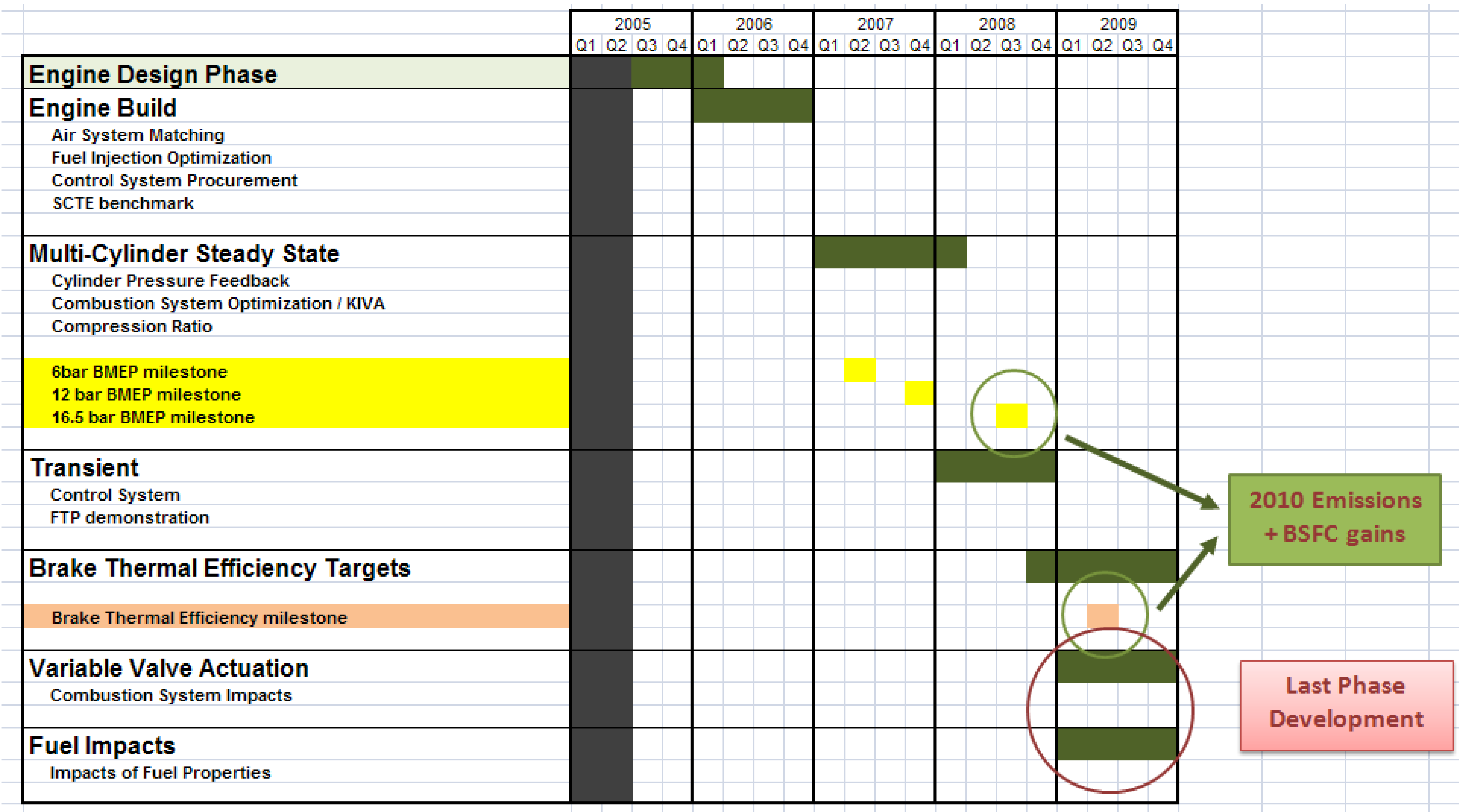
Goals and Objectives

- **Demonstrate the application of low temperature combustion:**
  - Yield 2010 NOx and DPF tolerant soot in-cylinder emissions
  - Study is carried out on a production platform (Navistar 6.4L)
  - Use today's Diesel fuel
  - Target min load 12.6bar, up to 16.5bar
  - Improve engine thermal efficiency
- **Develop technology capable for production implementation:**
  - Cylinder pressure diagnostics
  - ECU and sensing technologies
  - Fuel and air system

Project Timeline



Technologies Leveraged

Base engine development

Combustion Efficiency	Enablers
Combustion Phasing Combustion Duration	Injection strategy (PCCI) High Inj Pressure Controls
Cylinder Heat Rejection	
High Boost / Lean	Efficient Turbocharging
Optimum Compression Ratio	CR and VVA

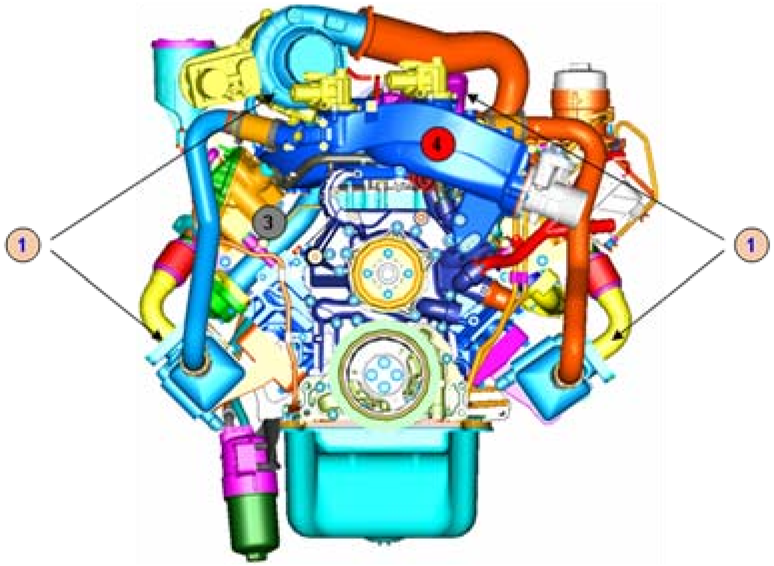
Parasitic Losses

Bottoming Cycles

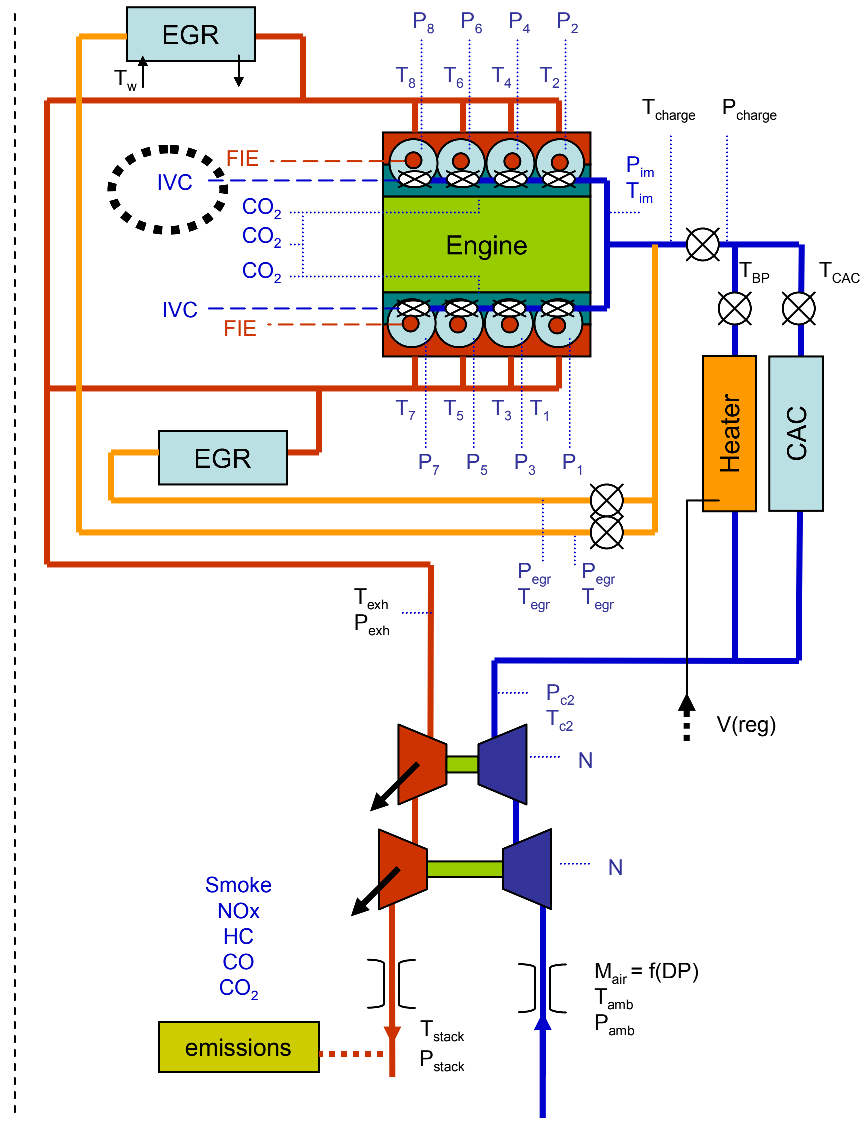
Rankine Cycle
Turbo Compounding

Aftertreatment Management

Engine Setup



	Base engine	V8 Test Engine	SCTE
Displac. Bore Stroke	6.4L 98.5mm 105mm	6.4L 98.5mm 105mm	0.75L 95mm 105mm
FIE	DI Common Rail	DI Common Rail	DI Common Rail
CR	16	12-16.5	15-16.5
Turbo Charger	Single Stage VNT	Dual Stage VNT	Surge tank
EGR system	HP loop Single Cooler	HP loop Dual Cooler	Cooled
IVC EVO	-133 BTDC 132 ATDC	variable 132 ATDC	-133 BTDC 132 ATDC

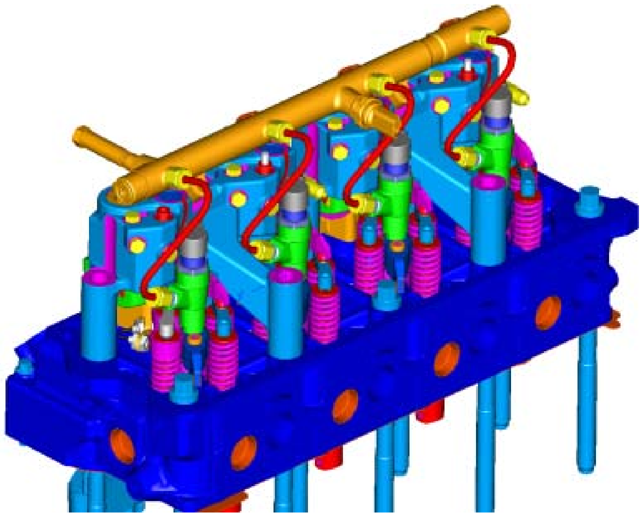


New Engine Configuration

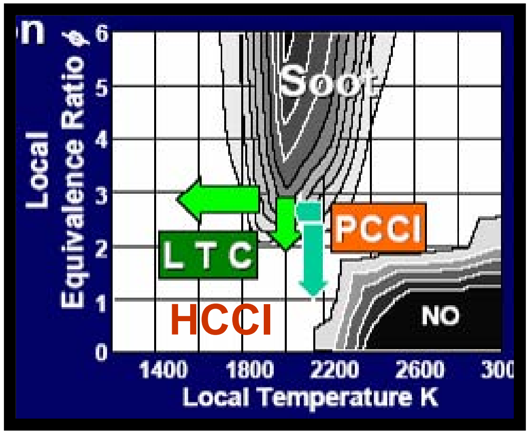
Variable Valve Actuation

VVA system Assembly*:*

Adjust intake valve closing on each cylinder.
Adjustments on each combustion cycle.



Combustion Approach

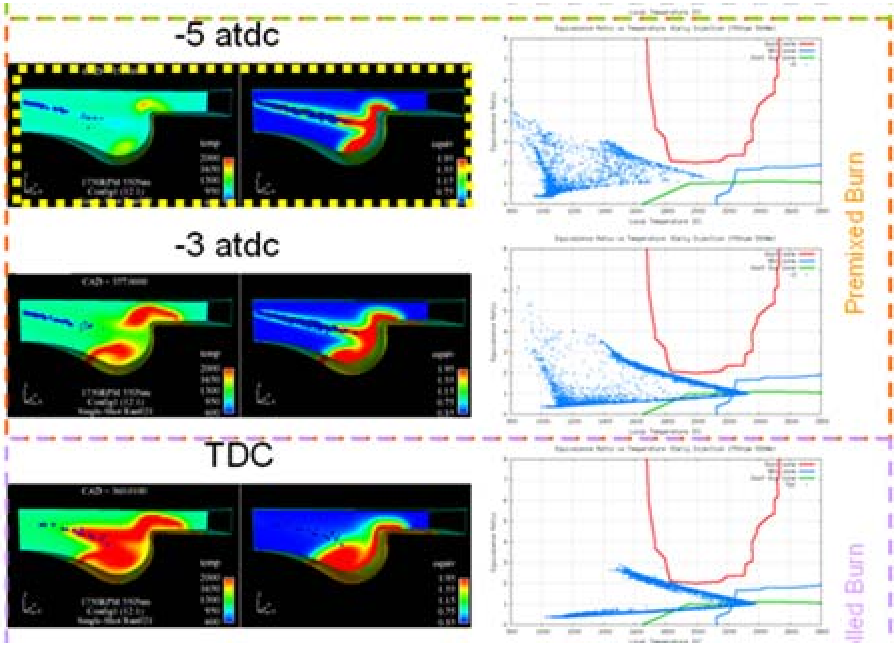


[Herzog et. al 1992]
[Akihama et. al 2001]

<u>HCCI</u>: Lean, Homogenous (Φ ~ 0.2)
Temp controlled ignition

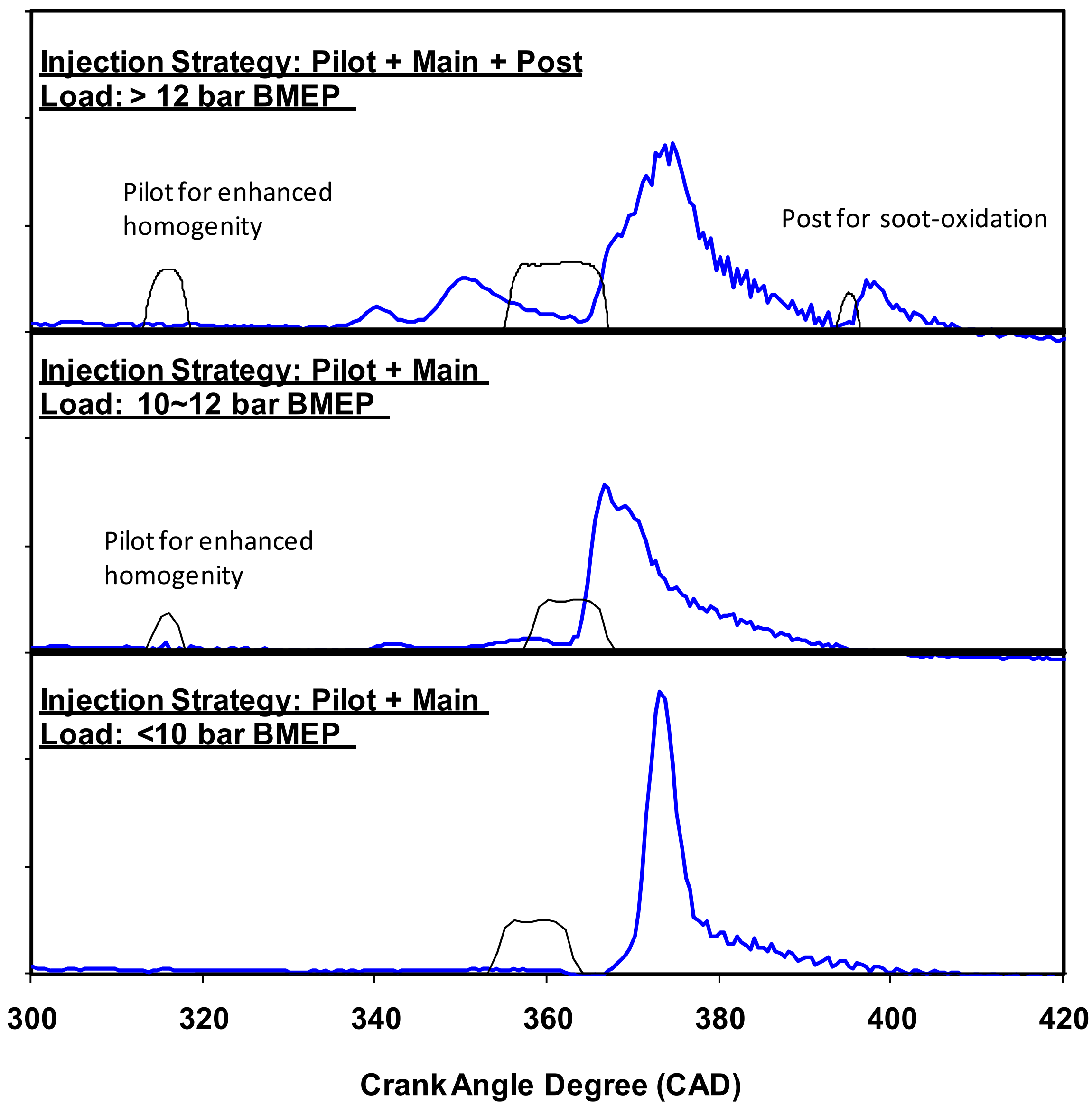
<u>LTC</u>: Similar to Conventional
Diesel Diffusion (Φ ~ 1 -1.2)
Very-high EGR (~60%)

<u>PCCI</u>: Improved mixture
Increased ignition delay
Higher injection pressures
Ignition timing closer to TDC
Less dependent on very-high EGR
Further bowl – injector matching

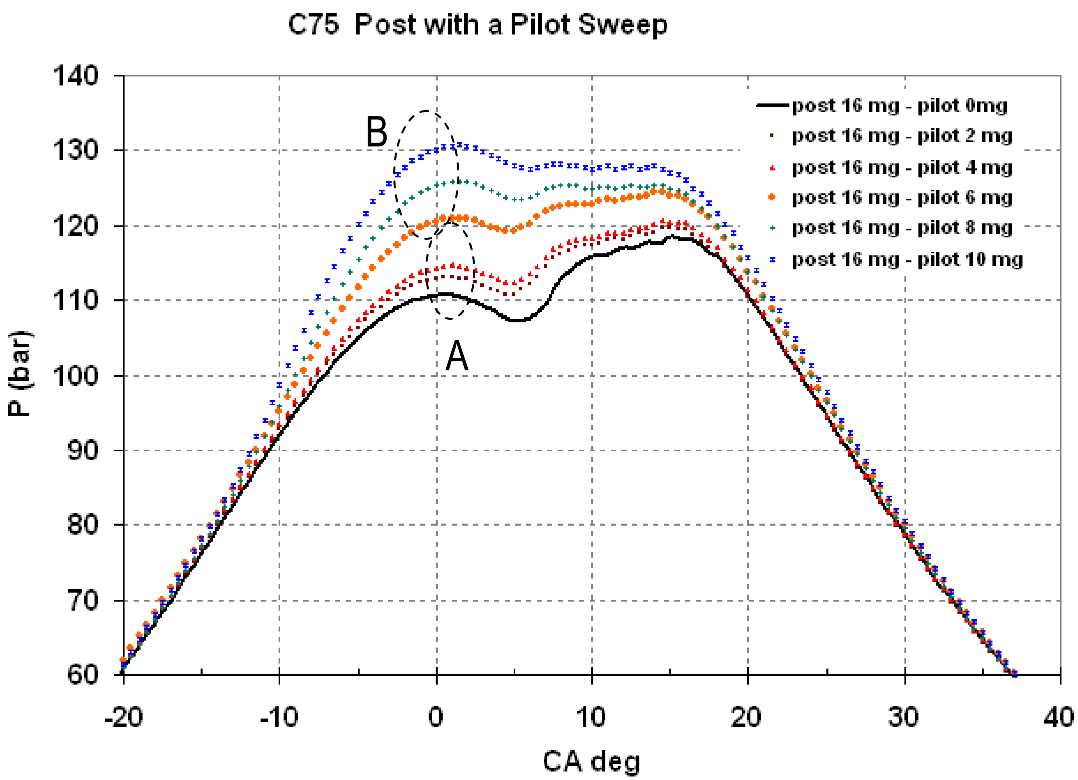


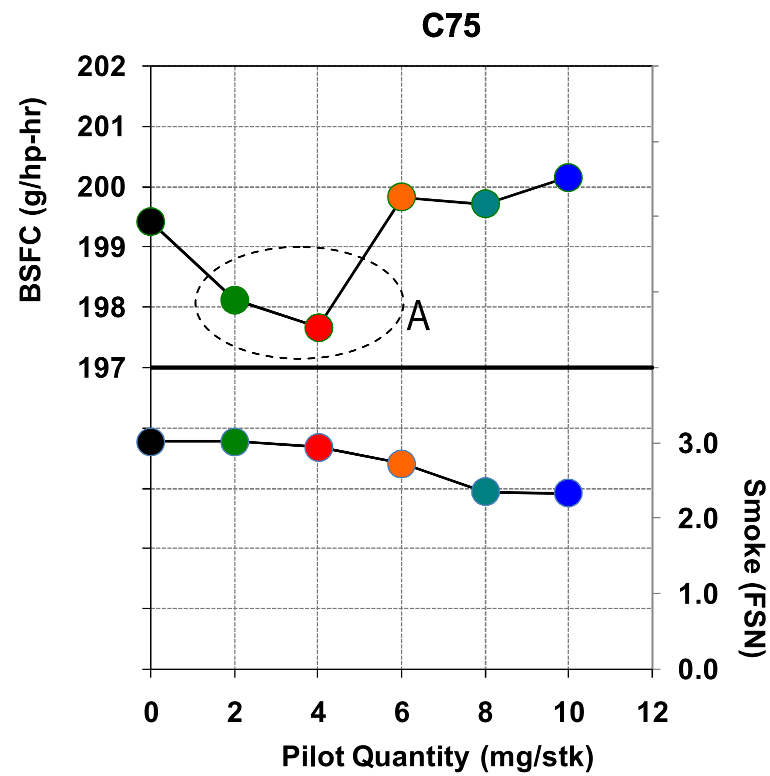
Examples of Early PCCI - SAE 2008-01-0057

Injection Strategies



PCCI Effects (test data)





A BSFC improvement of 1-2% can be identified by PCCI or fuel pilot and harvested with accurate cylinder pressure control.

B Excess pilot deteriorates performance due to premature combustion.

PCCI Effects (simulation)

1750 rpm – 10.7 bar BMEP

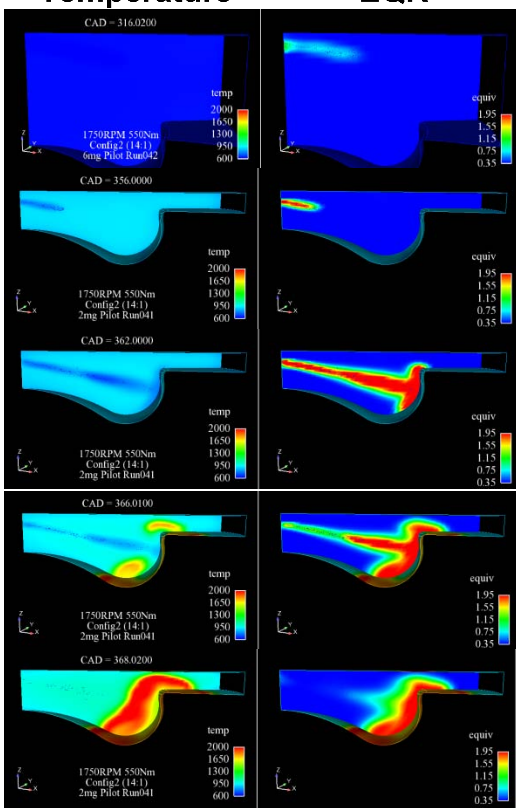
2 mg pilot | **14 mg pilot**

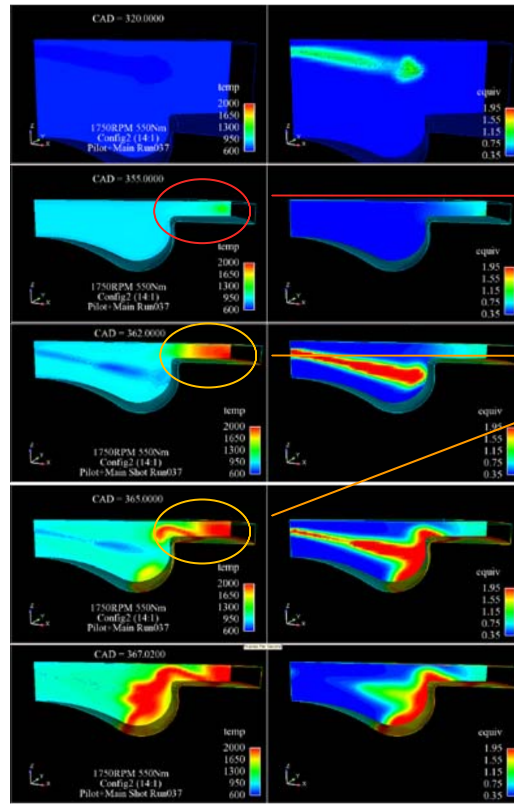
Temperature **EQR** | **Temperature** **EQR**

Pilot injection

Main Injection

Diffusive Combustion



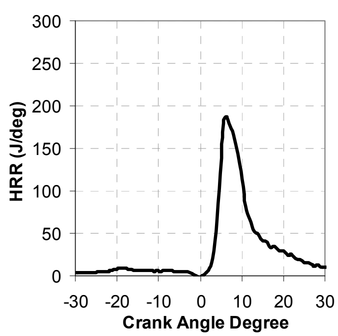


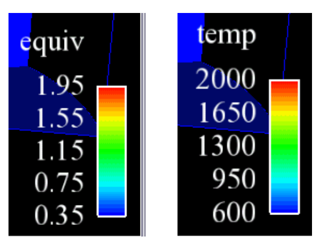
Pilot injection

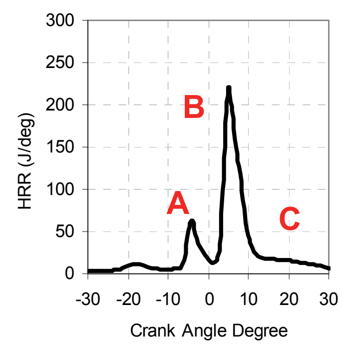
Pilot combustion
355-360º **A**

Main injection

Pilot "ignition source" contributes to
* faster burn of the main injection 360º-365º **B**
* reduces diffusion burn 370º-390º **C**

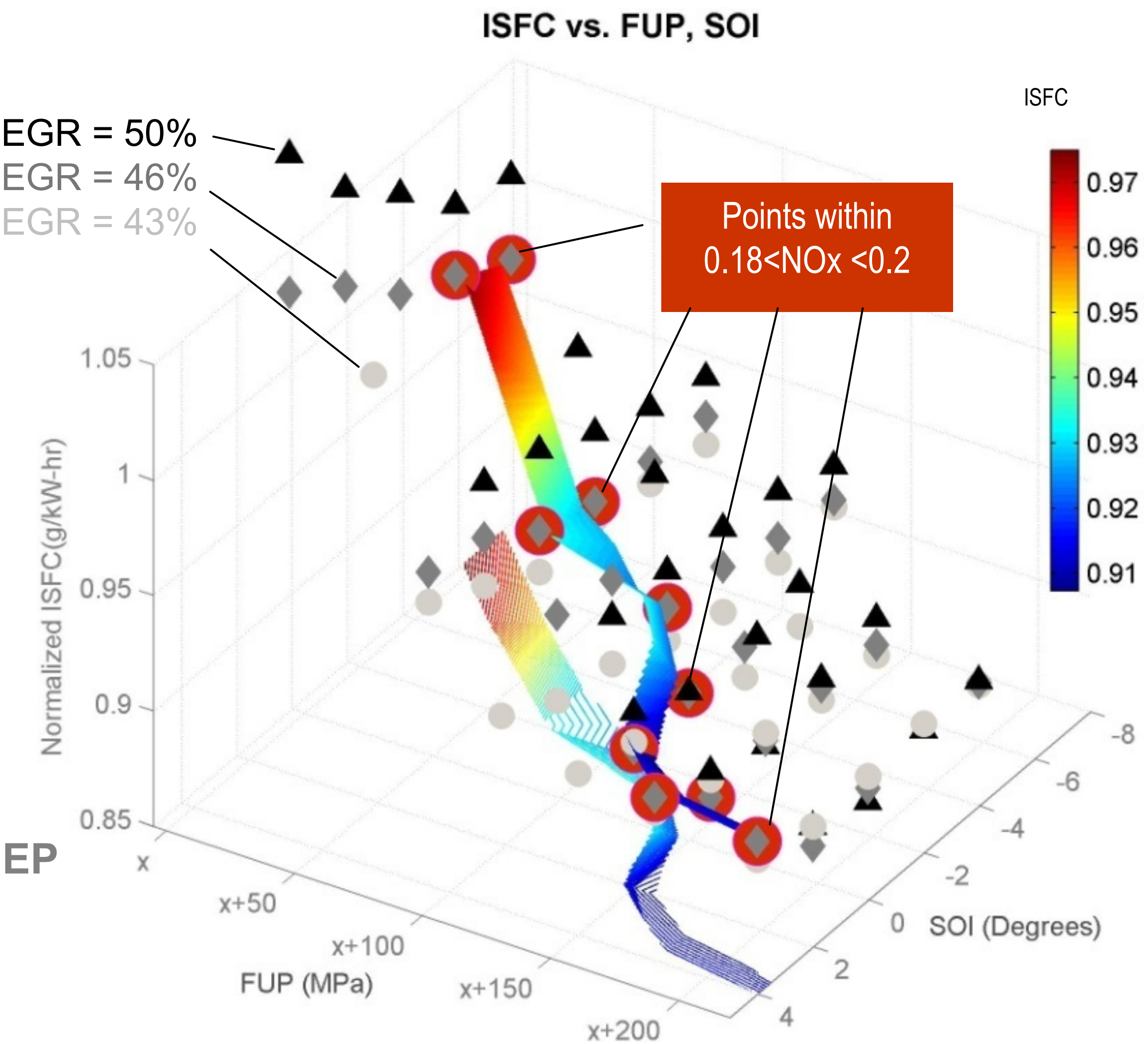






Injection Pressure Effects (simulation)

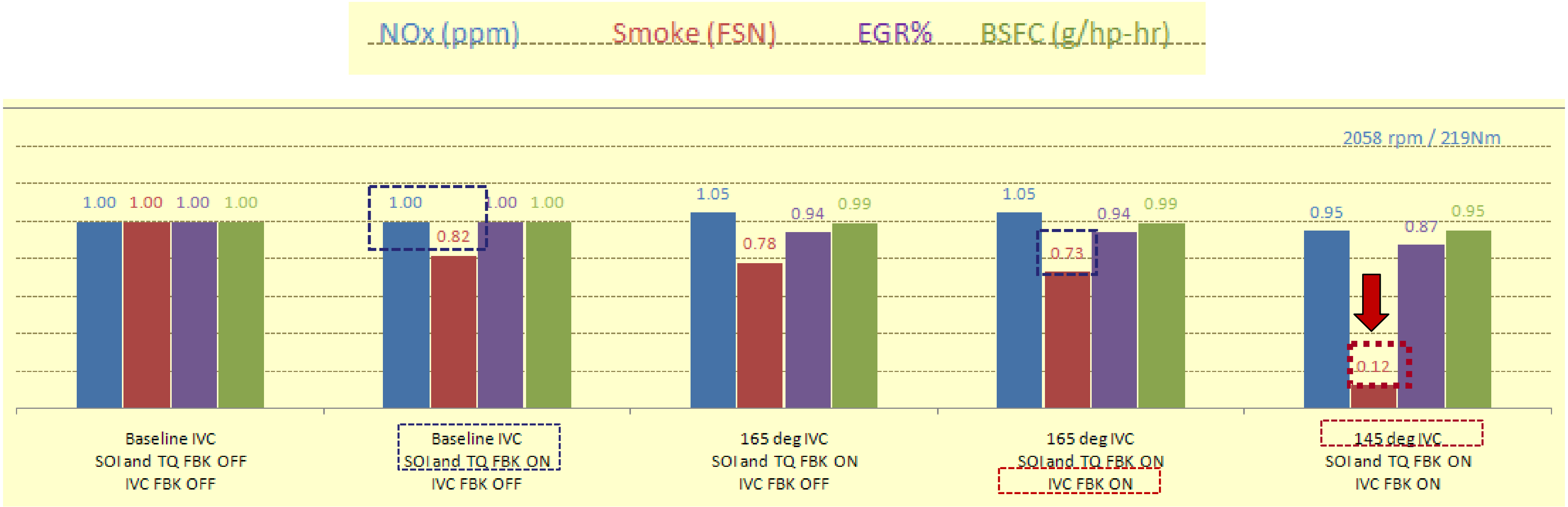
Higher injection pressure can yield better thermal efficiency (5-7%)
Improvements are coupled with soot reduction



1750 rpm – 10.7 bar BMEP

Efficiency path at
0.2gNOx emissions

Variable Valve Actuation

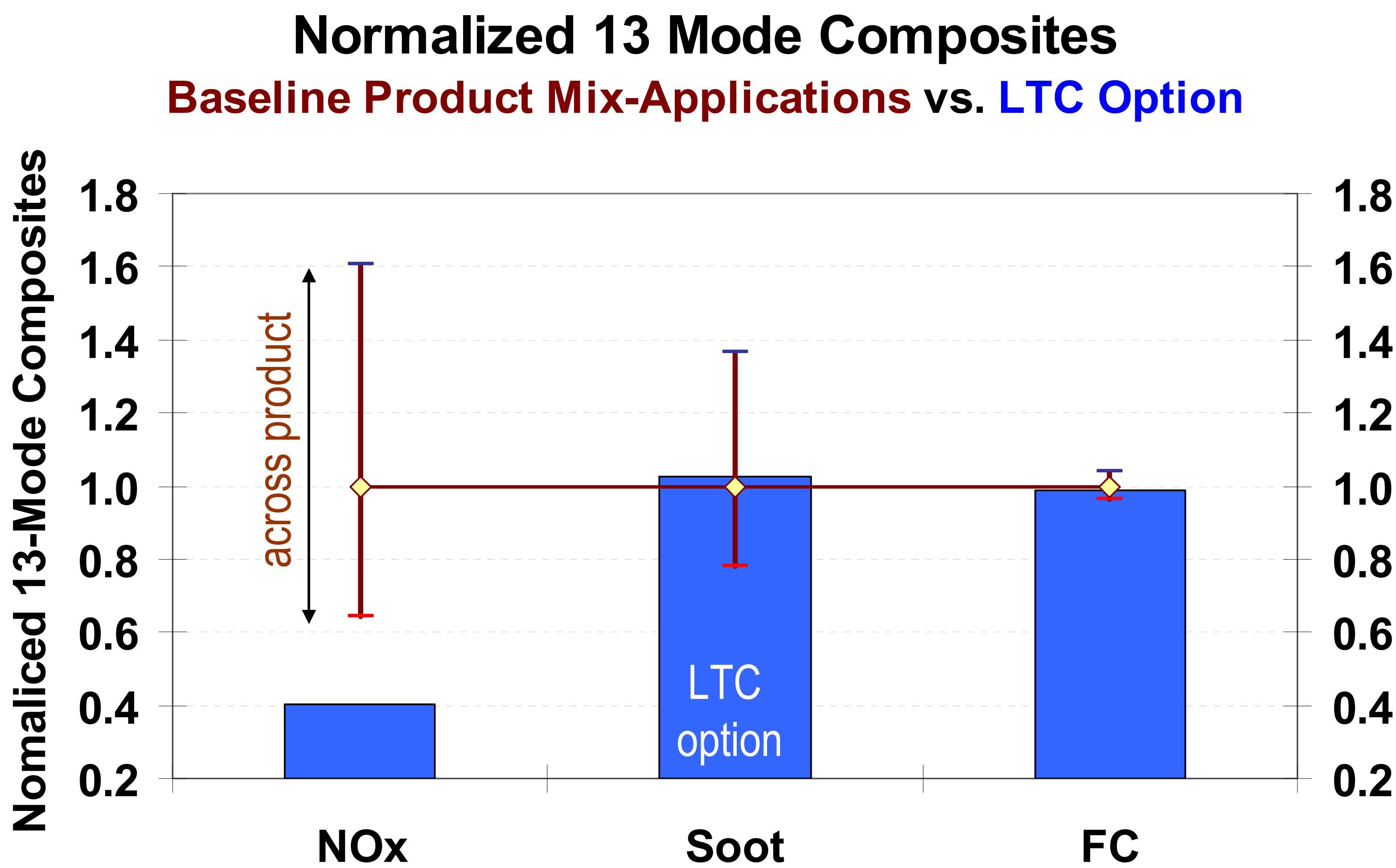


Cylinder-to-Cylinder
Fuel "trim"

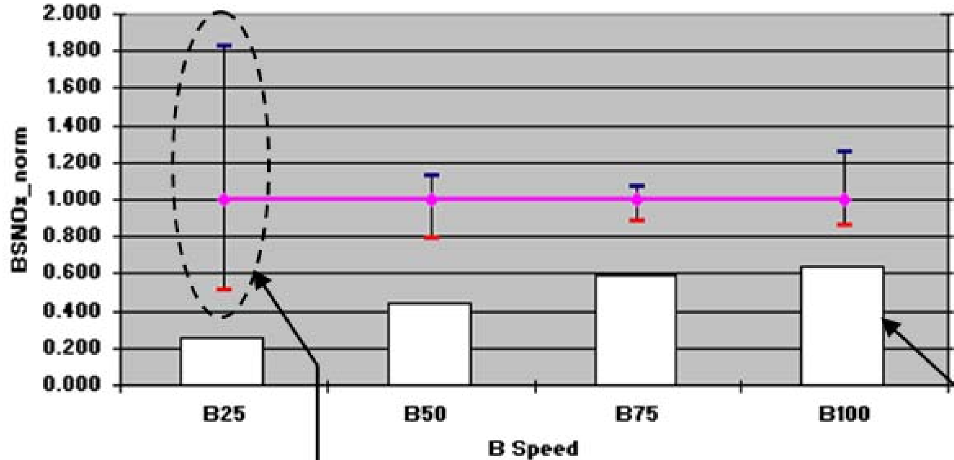
Cylinder-to-Cylinder
IVC "trim"

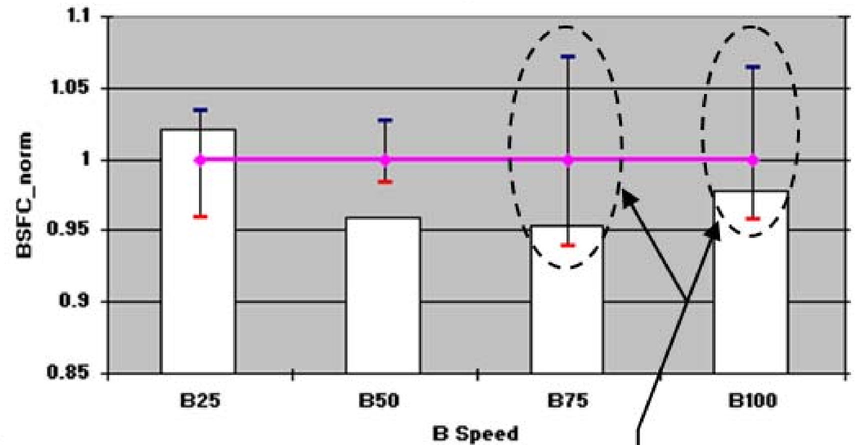
IVC adjustment

Emissions and Performance



LTC Thermal Efficiency





Conventional Diesel Approach

Multiple calibrations with NOx optimized to

0.5 – 1.2 gNOx engine out

Max – Average – Min shown

LTC

NOx optimized to below 0.2 gNOx engine out

BSFC gains can be 5-10% better

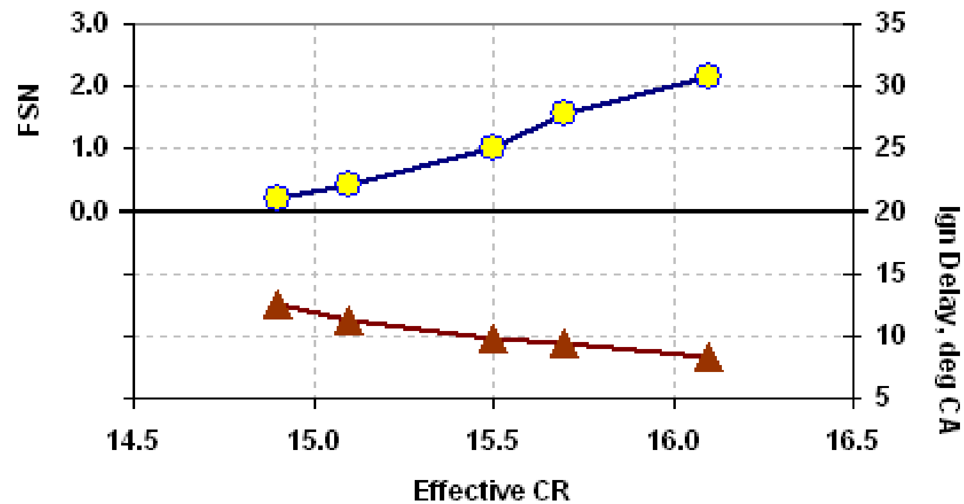
Variable Valve Actuation

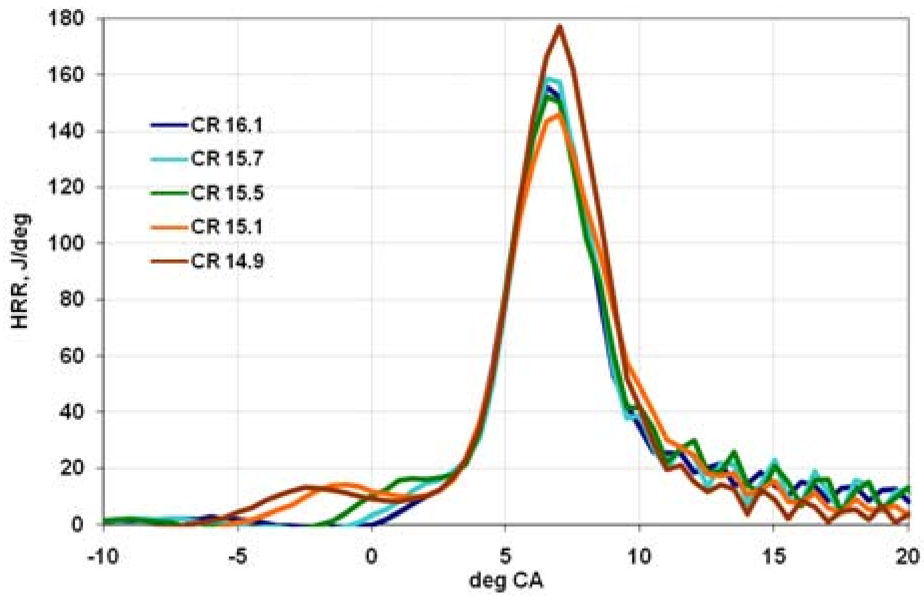
1671 rpm and 4.2 bar BMEP

All data at NOx < 0.2g/bhp-hr

Early intake valve closing:

- Reduces ECR
- Enhancing LTC ~ longer τ_{id}
- Better BSFC ~ lower EGR
- Soot reduction of over 90%

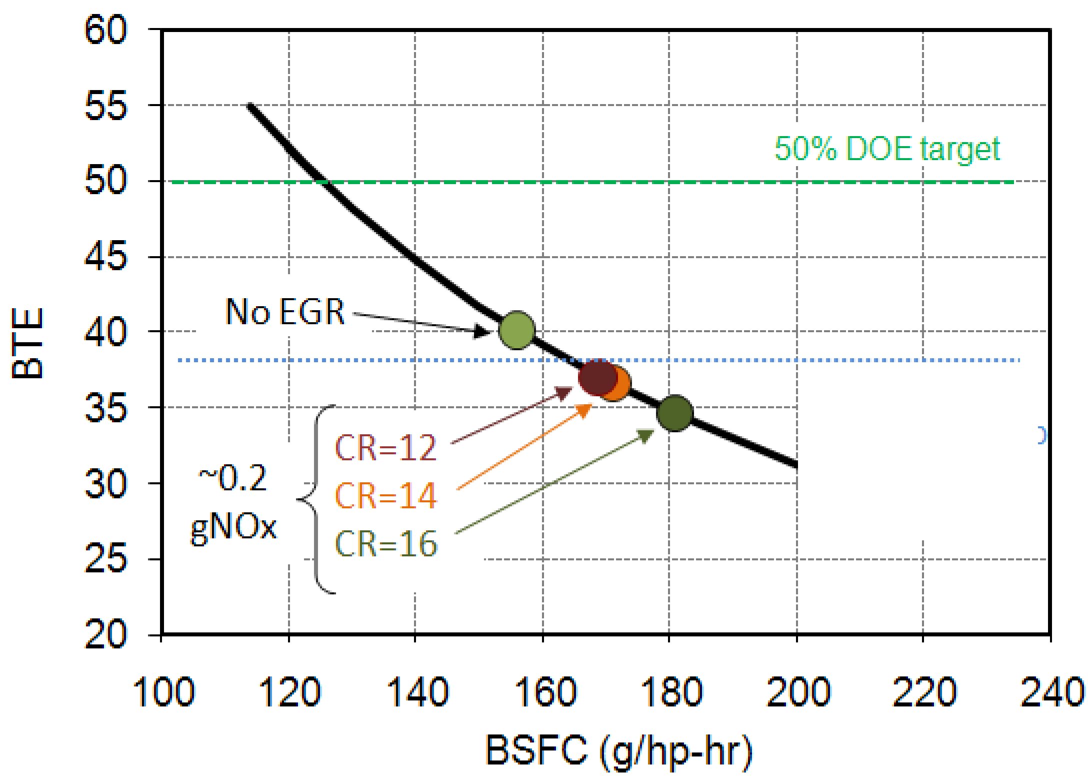




Compression Ratio

Compression Ratio may be optimized:

- Favor optimum combustion phasing
- Other issues will limit low compression ratios

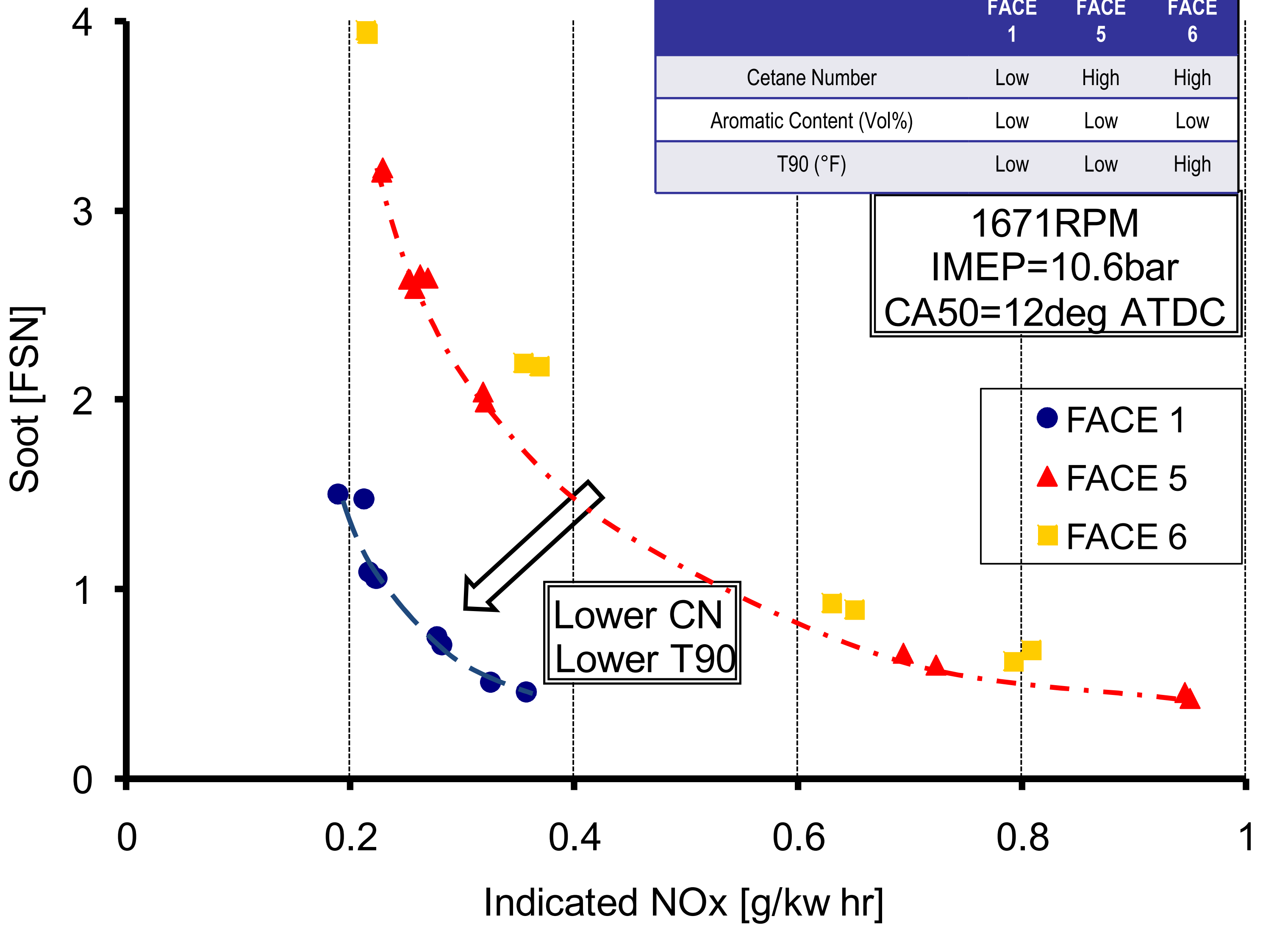


Fuel Properties

- Fuel properties affect ignition delay
- Fuels for PCCI reduce
  - -Reliance on post/pilot injection for soot reduction
  - -Late CA50 for prolonging ignition delay

Improved BTE

	FACE 1	FACE 5	FACE 6
Cetane Number	Low	High	High
Aromatic Content (Vol%)	Low	Low	Low
T90 (°F)	Low	Low	High



Summary

Applied low temperature combustion to the Navistar 6.4L V8 engine:

Operating range:

LTC with 0.2g NOx/bhp-hr operation attained at the rated 16.5 BMEP.
Soot contained to DPF capable regeneration (similar to base engine).

Fuel Economy:

LTC – CR showed improvements of up to 5%.
LTC – PCCI demonstrated 1-2% BSFC.

VVA enhances the application of LTC like chemistry:

Longer ignition delays
Excellent soot management

Acknowledgements

Project Partners

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MAHLE

Jacobs Vehicle Systems™

Continental

Thomas
Driven by magnetics

Combustion Diagnostics

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