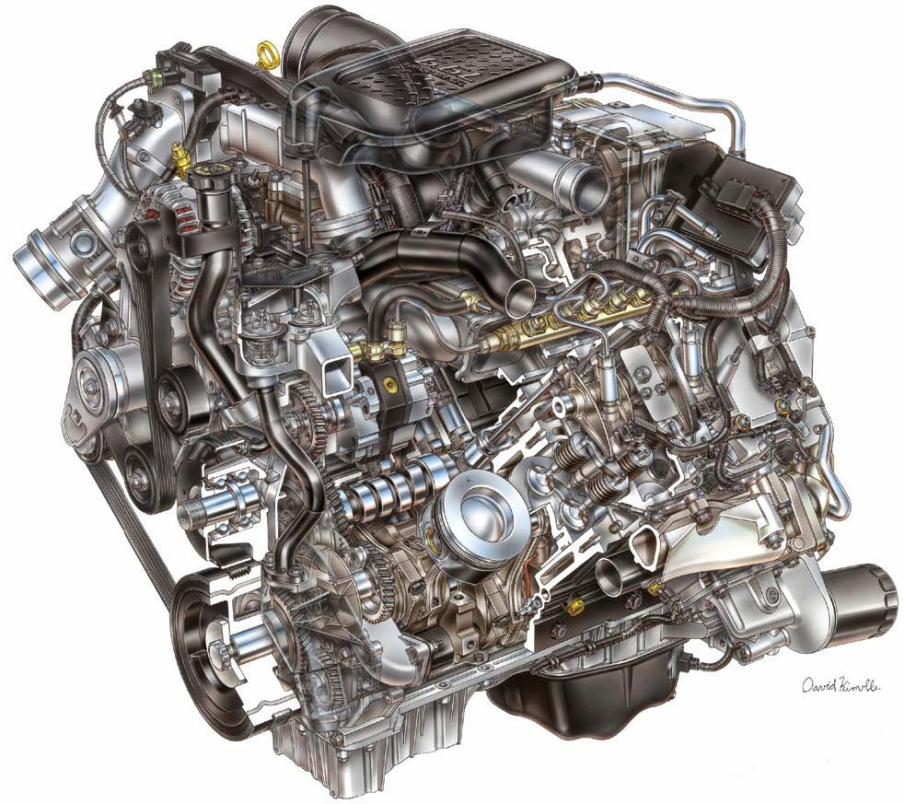
Bringing the Low NOx Diesel
Under Control

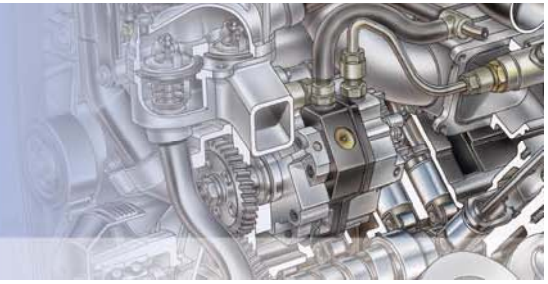


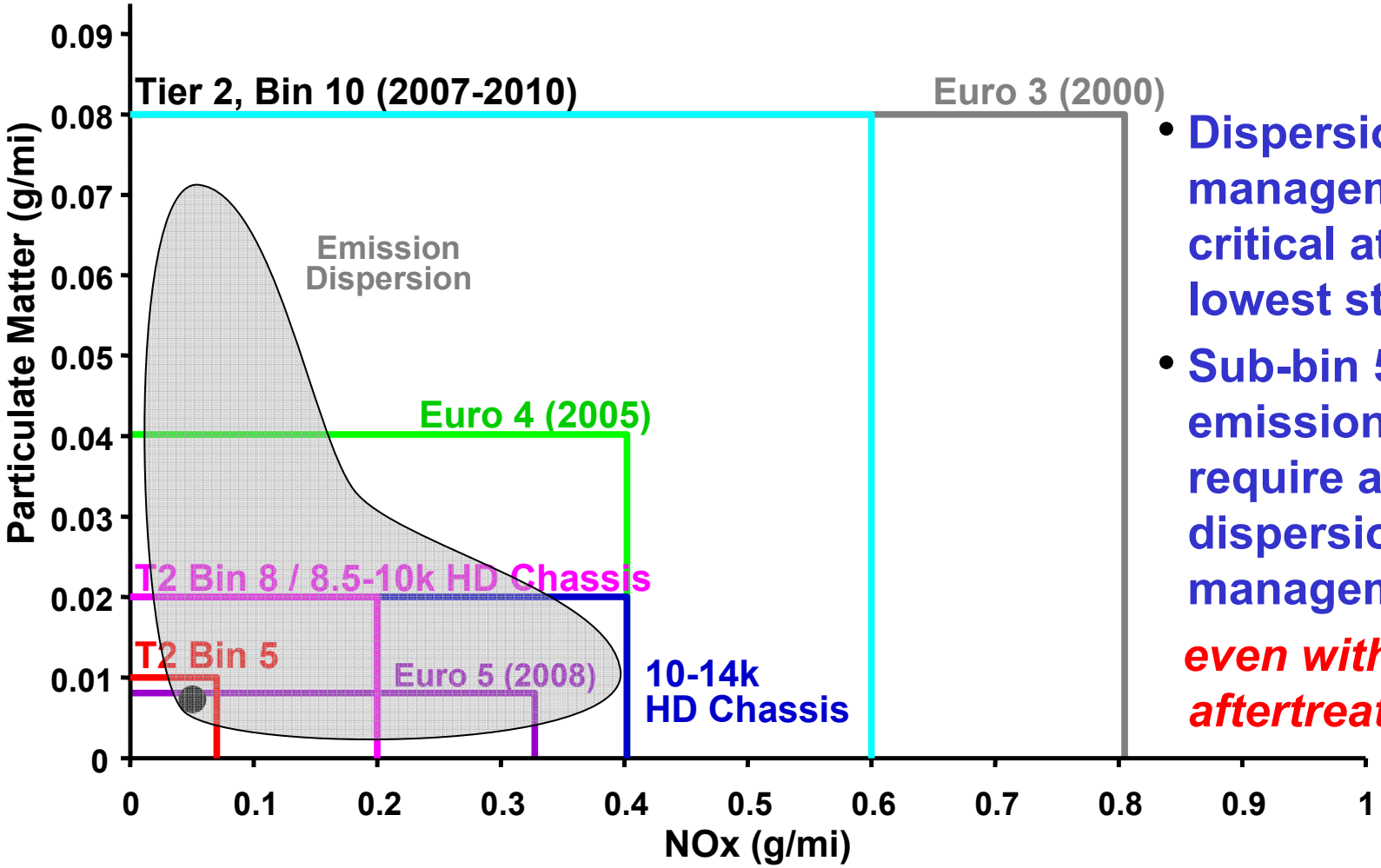
John Pinson

August 22, 2006

DEER Conference, Detroit

Dispersion management is the greatest challenge facing the low-NOx diesel



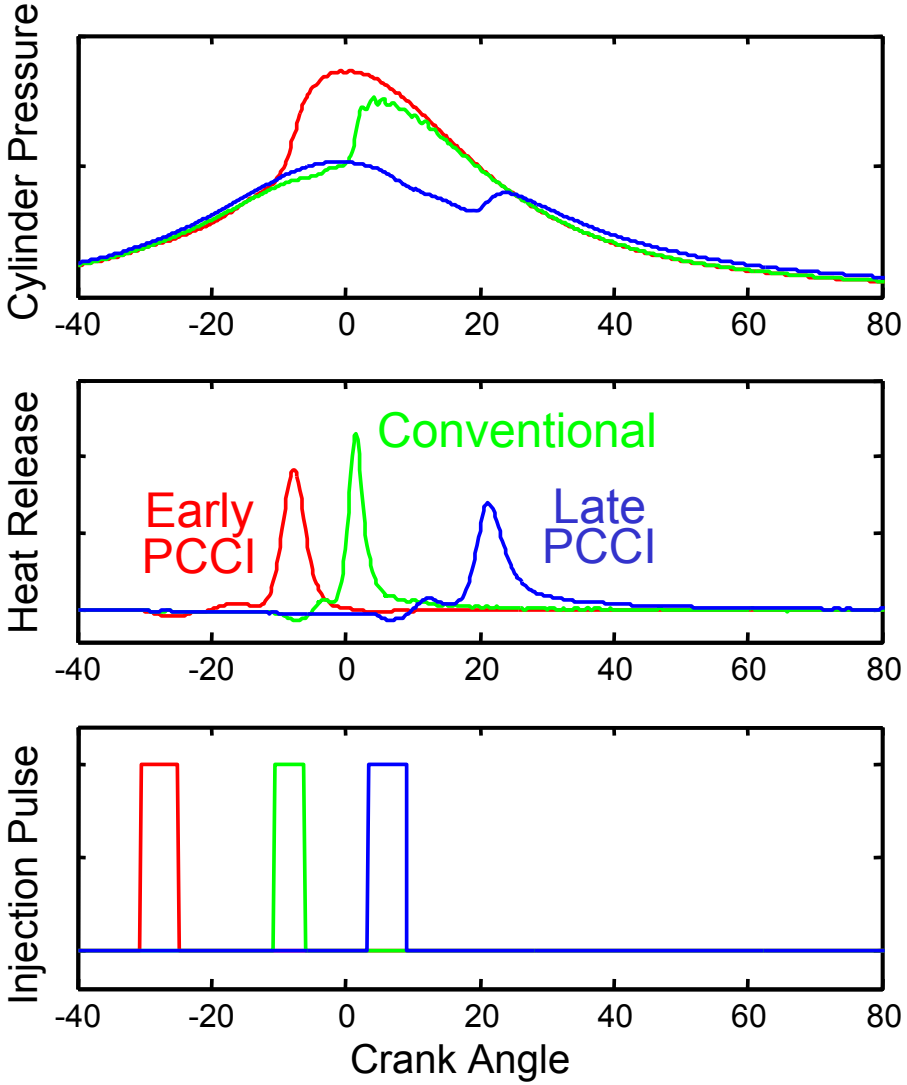


- **Dispersion management is critical at the lowest standards**
- **Sub-bin 5 emissions may require active dispersion management -**

even with effective aftertreatment

Roadmap to Low-NOx Combustion

Premixed Charge Compression Ignition (PCCI)



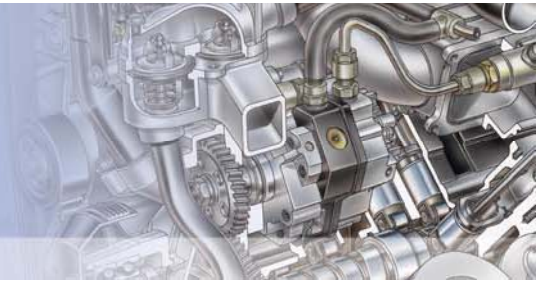
- Reduce charge temperature with cooled EGR and reduced compression ratio
- Enhance premixing through injection strategy
  - Early PCCI for light loads
  - Late PCCI for heavier loads

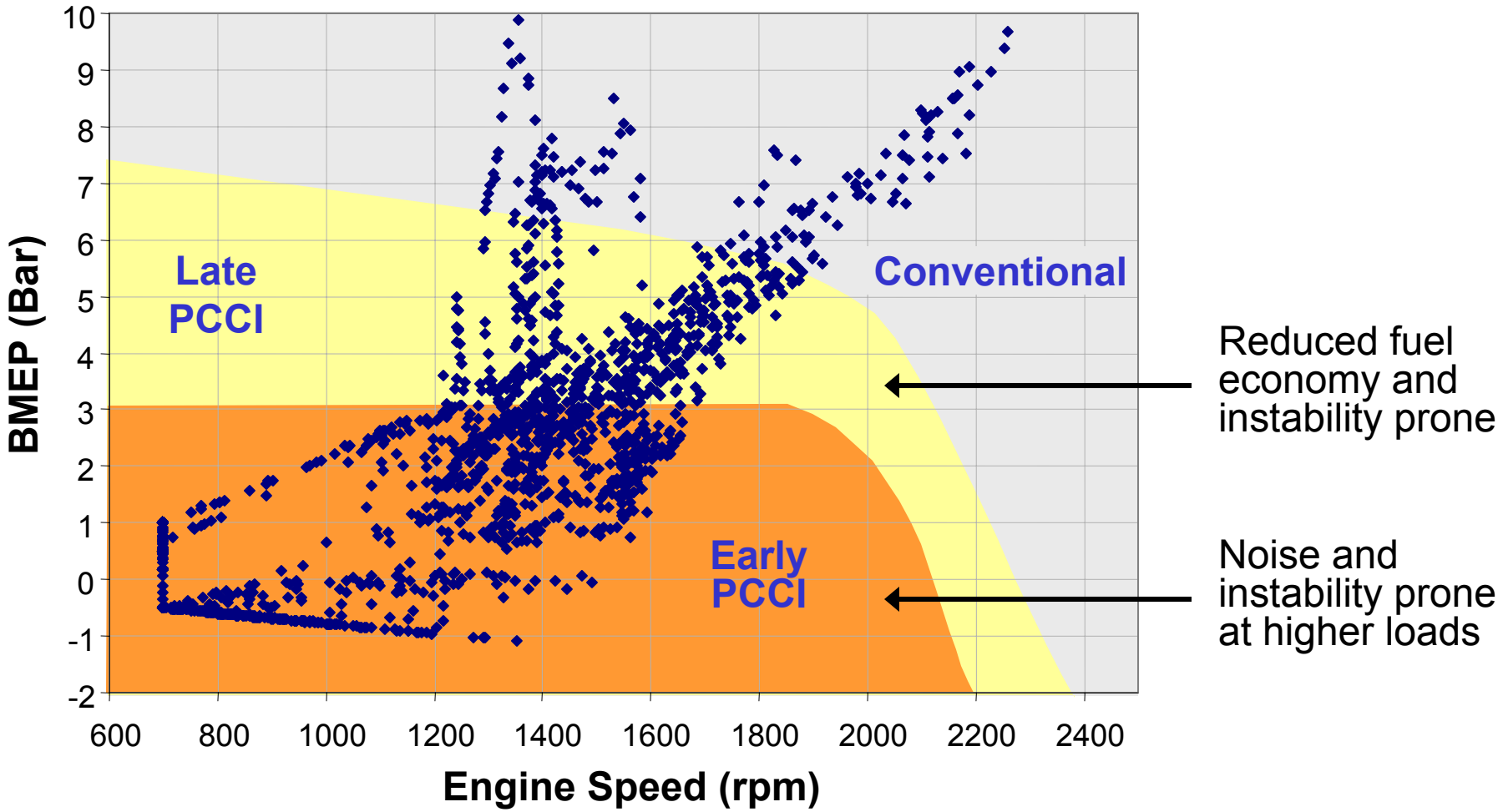
Issue

- Minimum achievable NOx levels are limited by the combustion quality and robustness

Extreme cases for illustration

Combustion Mode Map over FTP for Chassis Certification HD Truck (8500 lb)

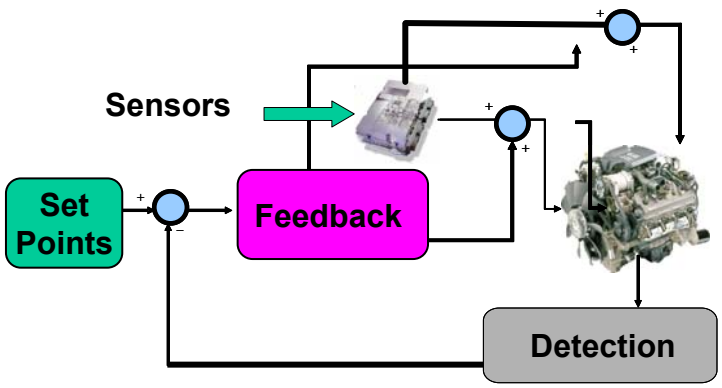


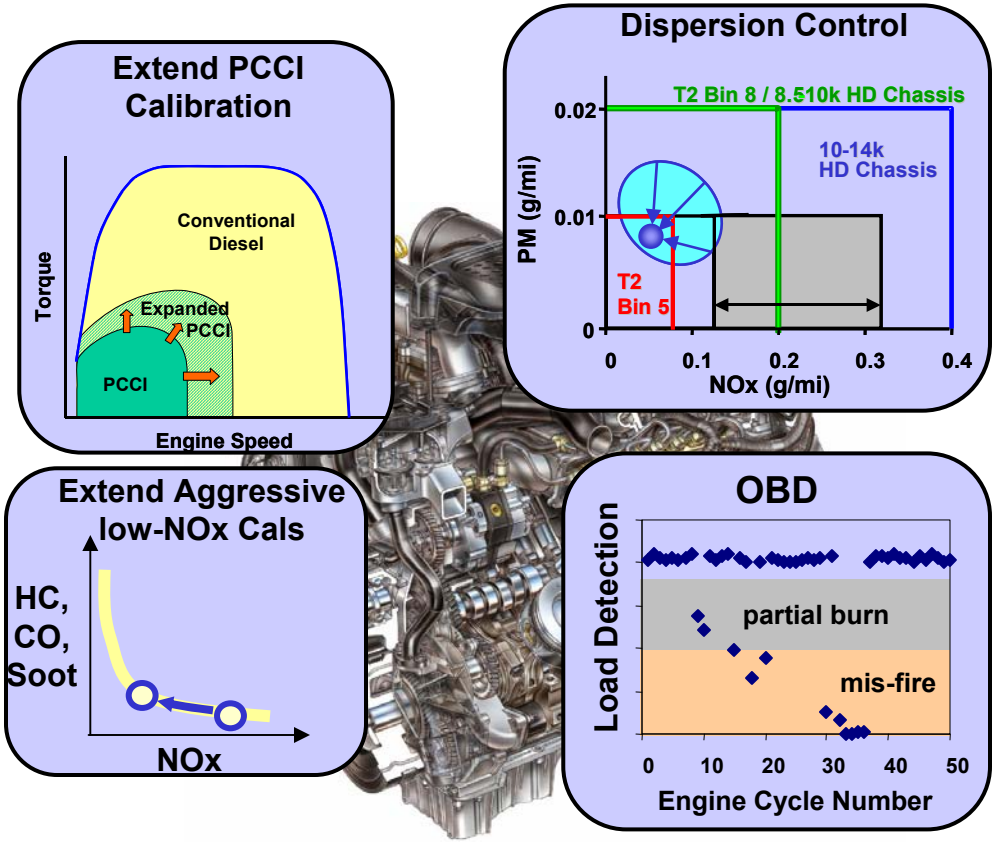


Combustion Feedback Control – The Promise

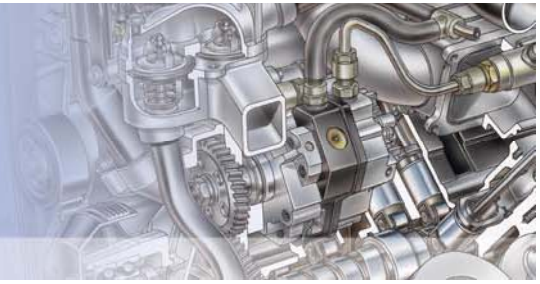
- Aggressive low-NOx calibration
- Extended PCCI calibrations
- Compensate for ageing and variation
- Early & accurate problem detection

Combustion Feedback Control





Major Sources of Dispersion



Major players:

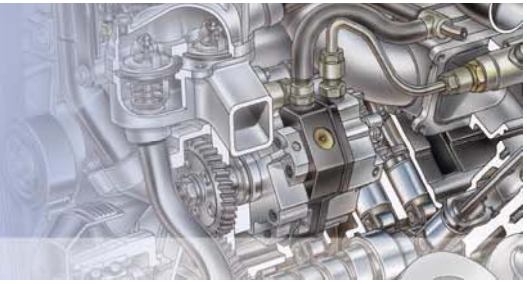
- Mass Air Flow Sensor (global)
- Injector variability (timing and quantity – esp. pilot)
- Compression ratio
- EGR distribution
- Fuel quality (cetane)
- Environmental factors
- Wear on everything

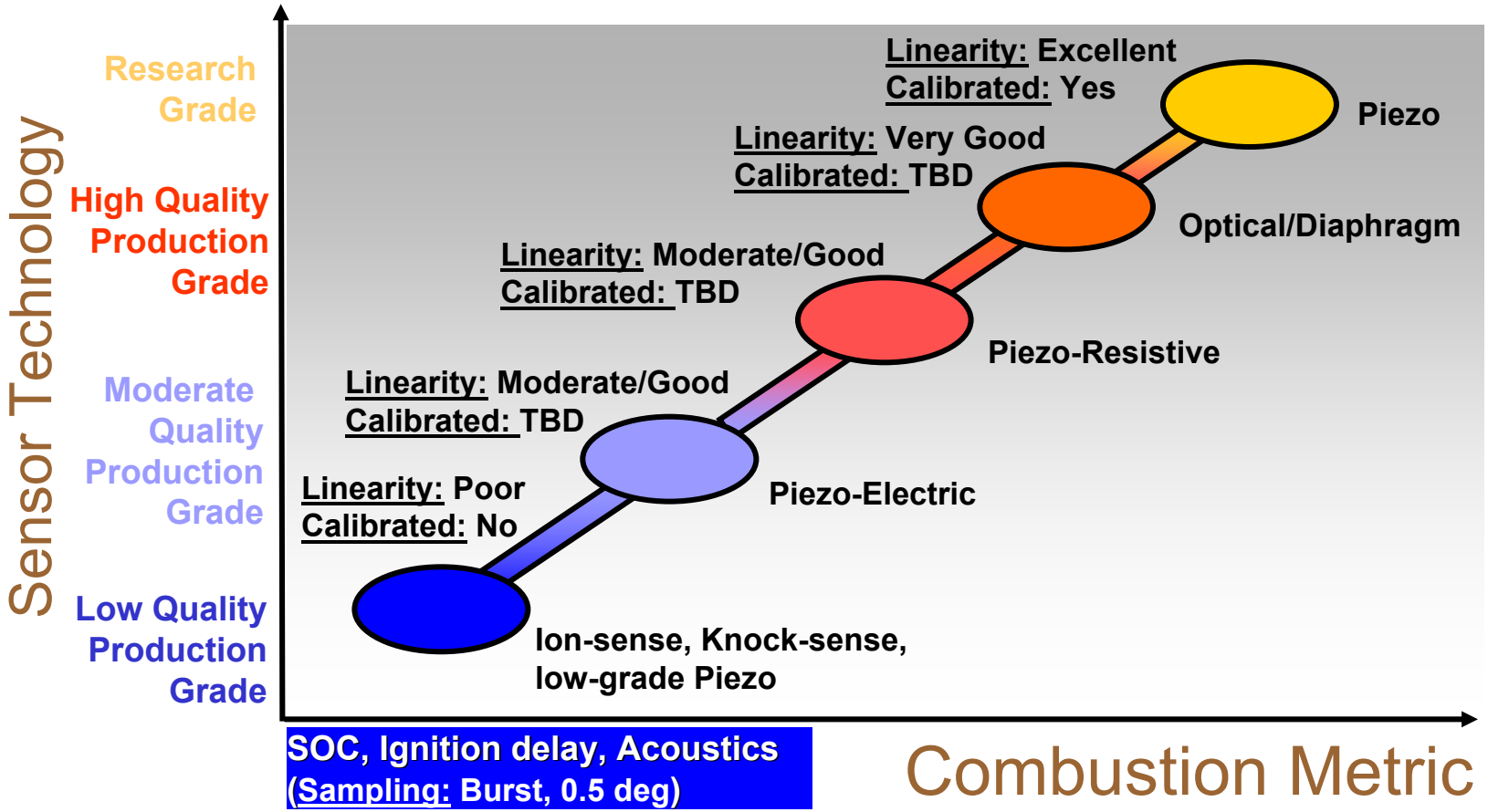
Derived combustion quantities like the 50% burn rate provide good control parameters but require
- a powerful engine ECU
- robust sensors

Tuning:

- Global EGR level (slow)
- Charge temperature control with sophisticated EGR system (slow)
- Individual injection quantity and phasing (fast)

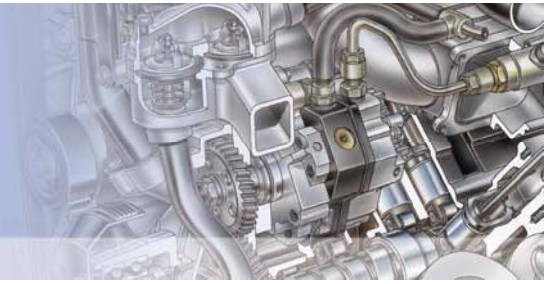
Engine-Appropriate Sensor Considerations



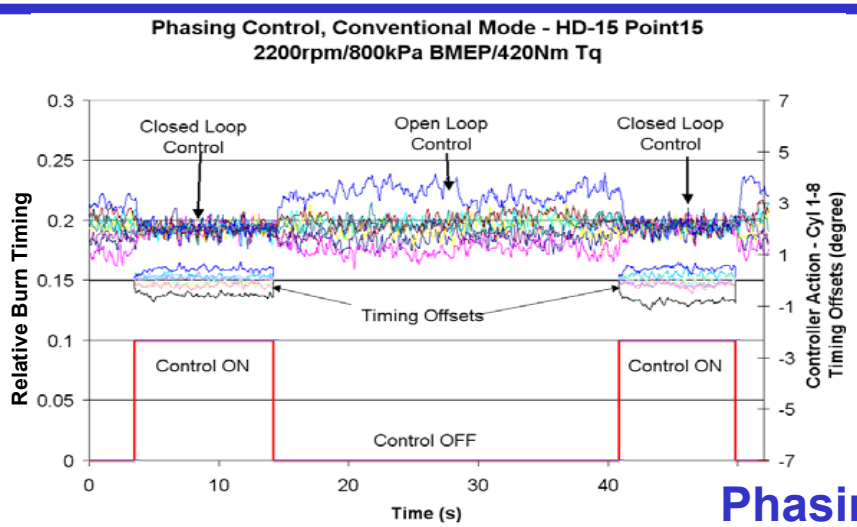


Simple Phasing and Fuel Balance Control

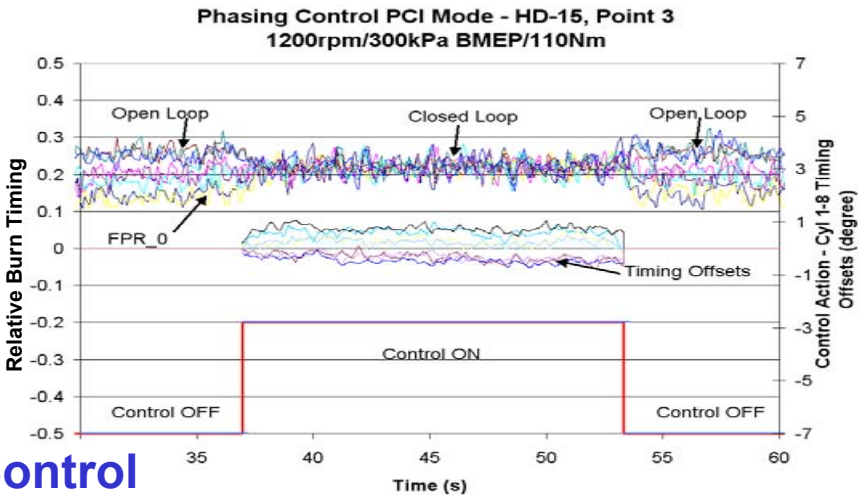
Using Pressure Feedback Control



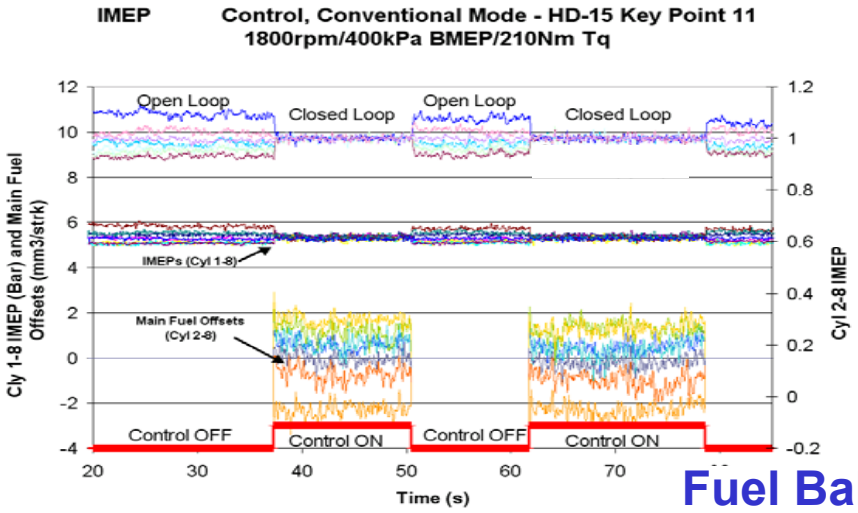
Conventional mode

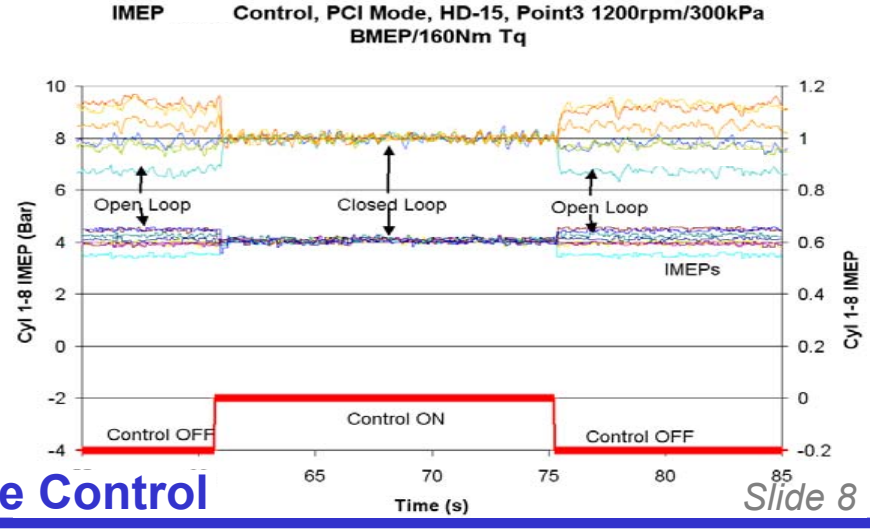


Early-PCCI mode

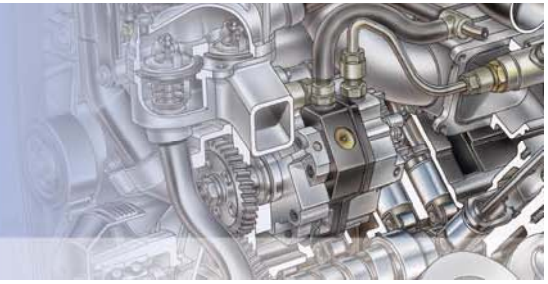


Phasing Control





Fuel Balance Control

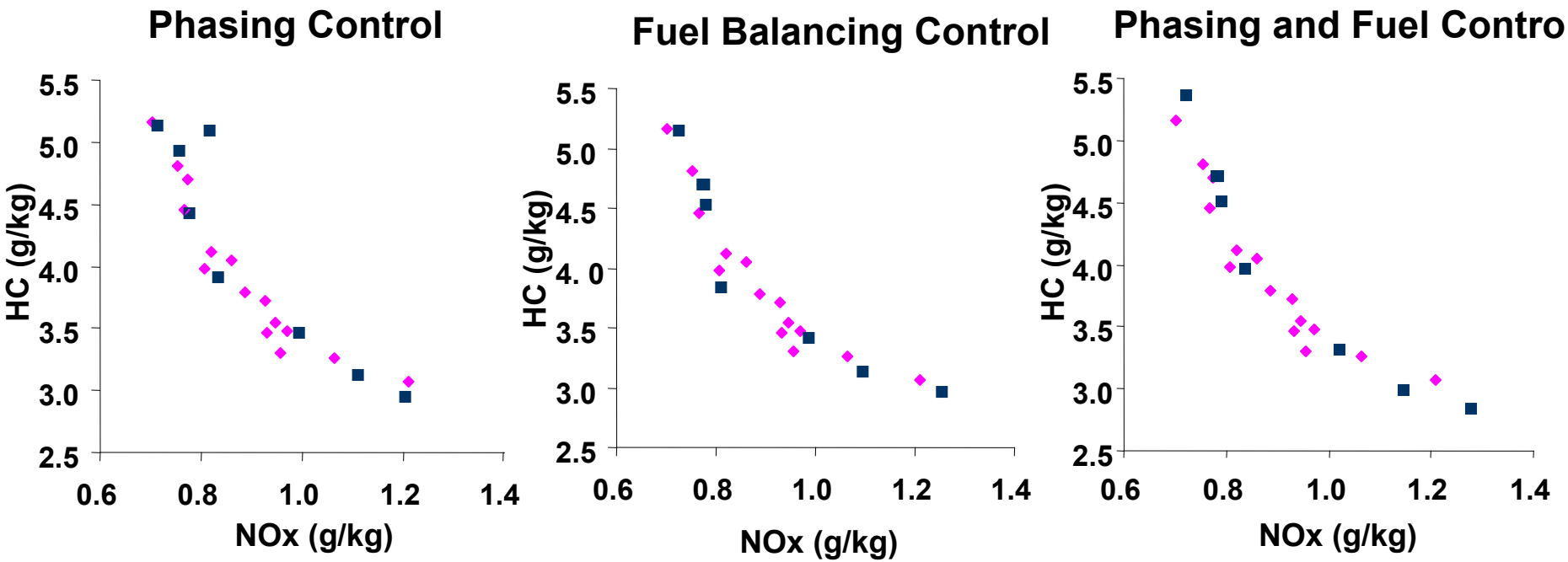


Great! - But does it work?

NOx-HC Tradeoffs with Phasing and Fuel Control
(Late-PCCI 1400 rpm, 400 kPa BMEP)

Open loop: Load Imbalance +/- 15%
Phasing in burn +/- 10%

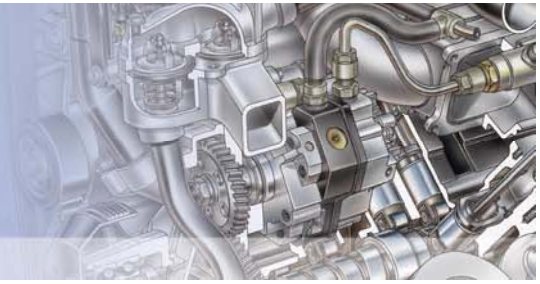
◆ Open loop ■ Closed loop



- **No NOx, HC or Smoke benefit observed due to linear emission response to the base engine cyl-to-cyl imbalance**

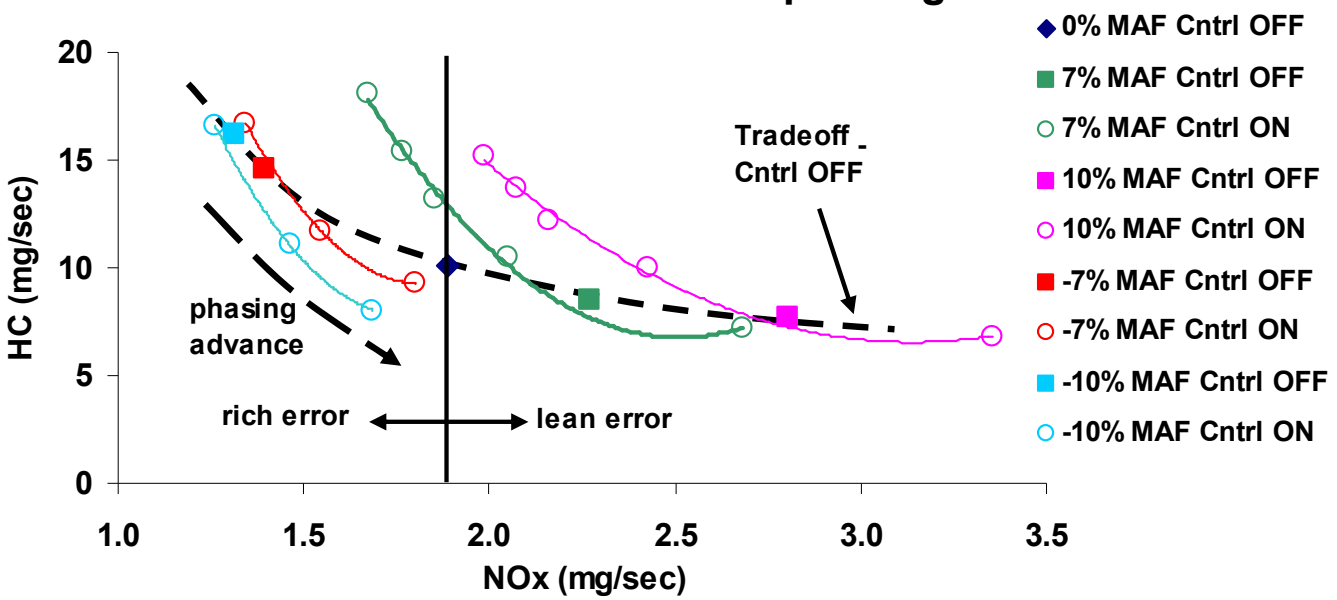
MAF Correction with Phasing Control

Late-PCCI 1400 rpm, 400 kPa BMEP



Procedure

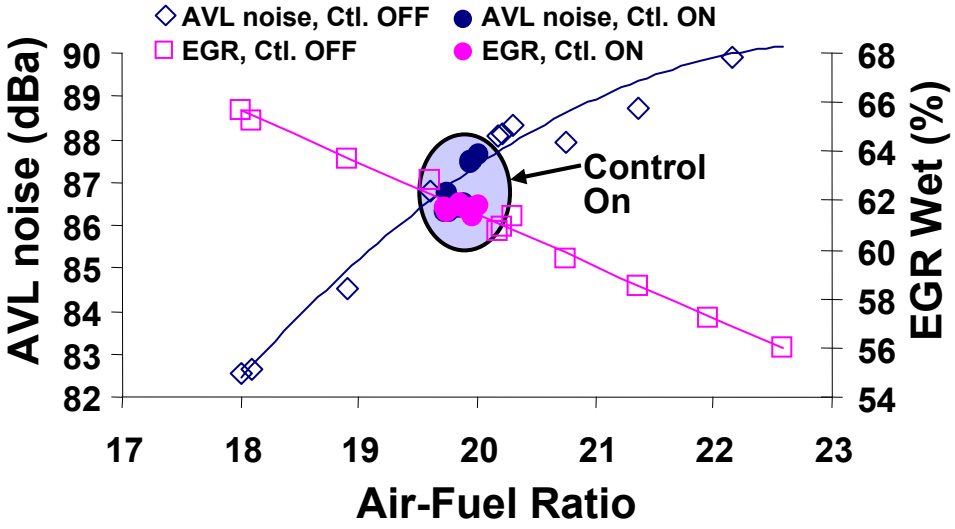
- Ran open and closed loop at each EGR
- For each EGR error, swept phasing target under C/L control
- C/L phasing uses “no EGR error” target as baseline



- HC and NOx emissions resulting in rich/lean shift due to EGR can be partially recovered through phasing correction
- **Requires individual cylinder pressure sensing**

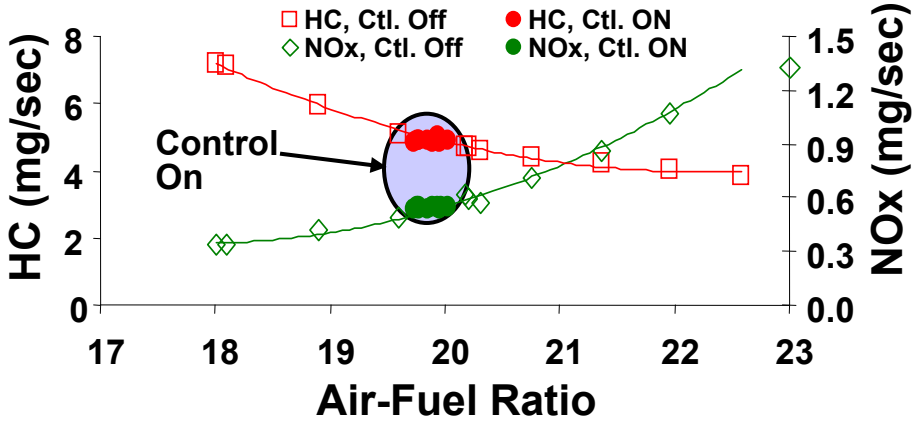
Global EGR Correction with Phasing Control

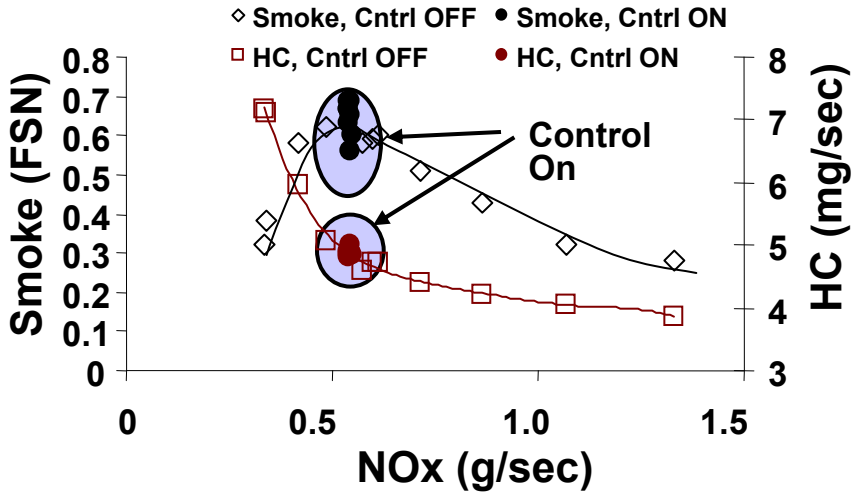
Early-PCCI at 1400 RPM, 250 kPa BMEP



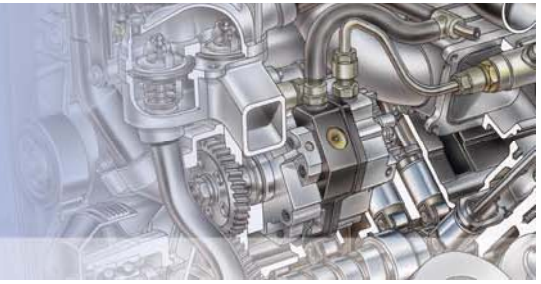
- Simulate EGR error through MAF error (+/- 11%)
- Closed-loop correction based on average combustion phasing
  - *Feedback to EGR valve*

- Effective in this case (but not in all cases)

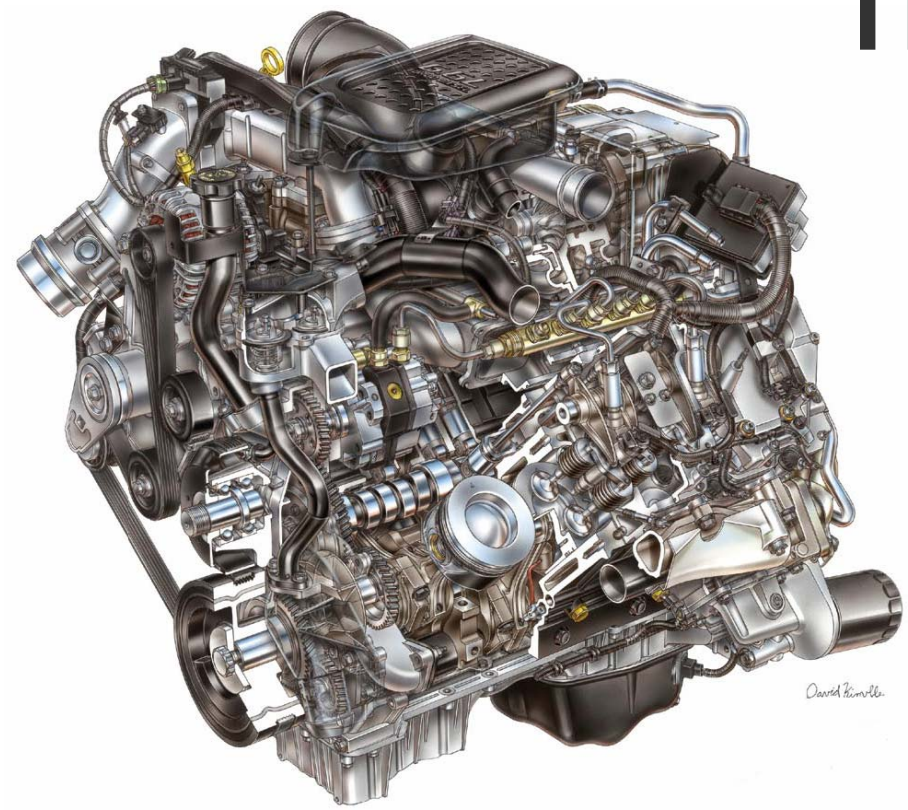




Combustion Feedback Control Shows Promise for PCCI Operation



- Premixed combustion offers the potential to significantly reduce engine out emissions
- Comb feedback may be required due to production fleet variations and environmental factors
- Individual cylinder control combustion feedback shows potential for effective load balance and phasing control
  - Not all recoveries result in emission benefits
  - Works best in non-linear tradeoff regions



Thank you for your attention