Diesel HCCI Results at Caterpillar

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Contract Monitors – Roland Gravel, John Fairbanks

DEER Conference

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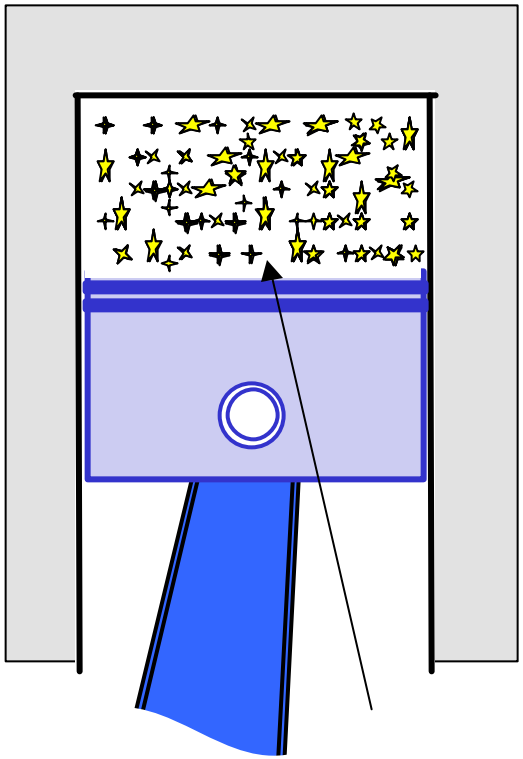
Outline

- Review challenges
- Development process
- Recent progress
  - Multi-cylinder engine
  - Operating range expansion
  - Advanced controls
  - Fuels effects
- Summary
- Future plans

HCCI - The Challenge

HCCI Engine

(Homogeneous Charge Compression Ignition)



Low temperature combustion

ultra low emissions

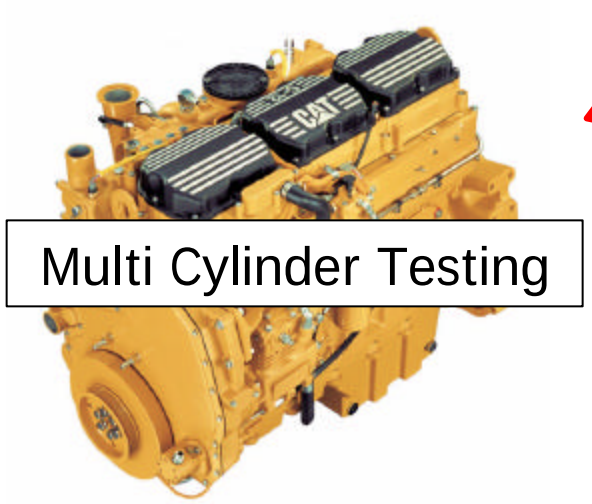
- Proper air / fuel mixing
- Limited load range
- Combustion phasing and control

HCCI Development at Caterpillar

Design

FEA

System Simulation



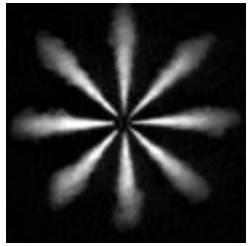
Multi Cylinder Testing

CAT3D Combustion Model

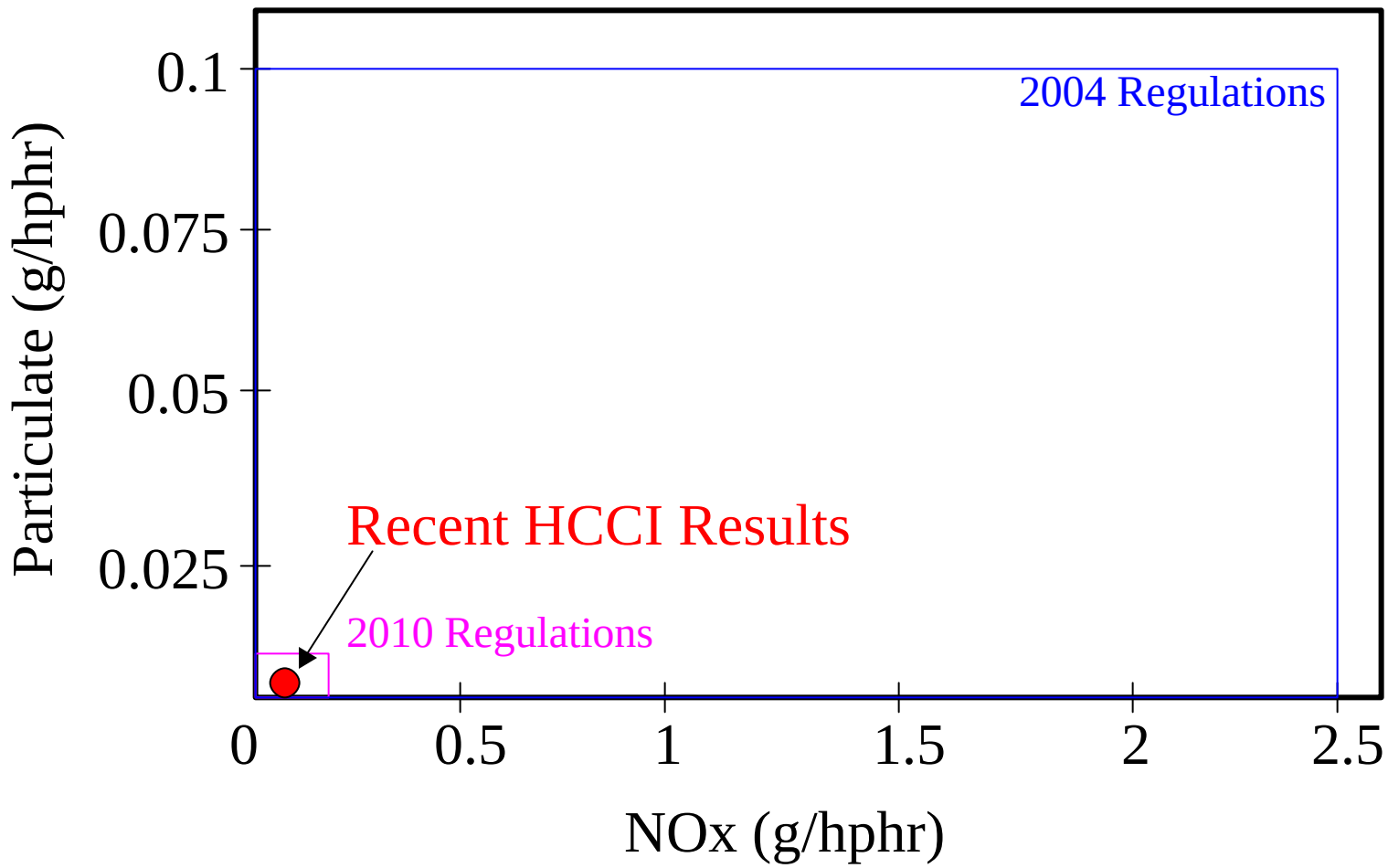
Optical Engine

Single Cylinder Testing

Spray Visualization



Ultra-Low Emissions



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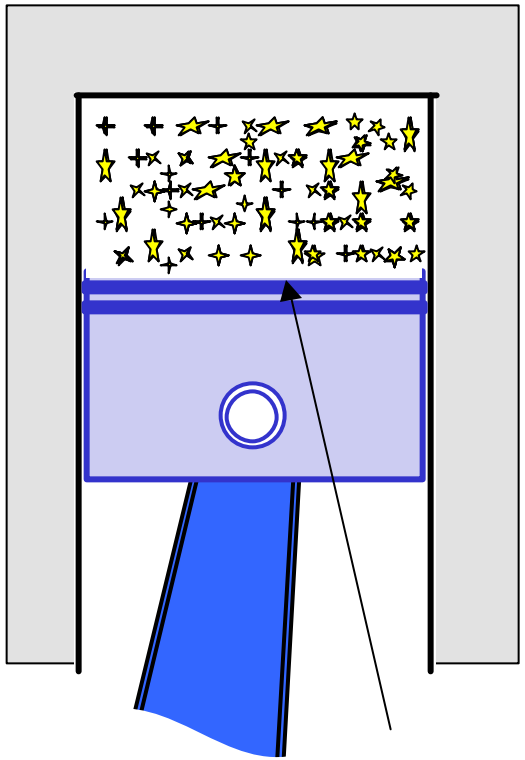

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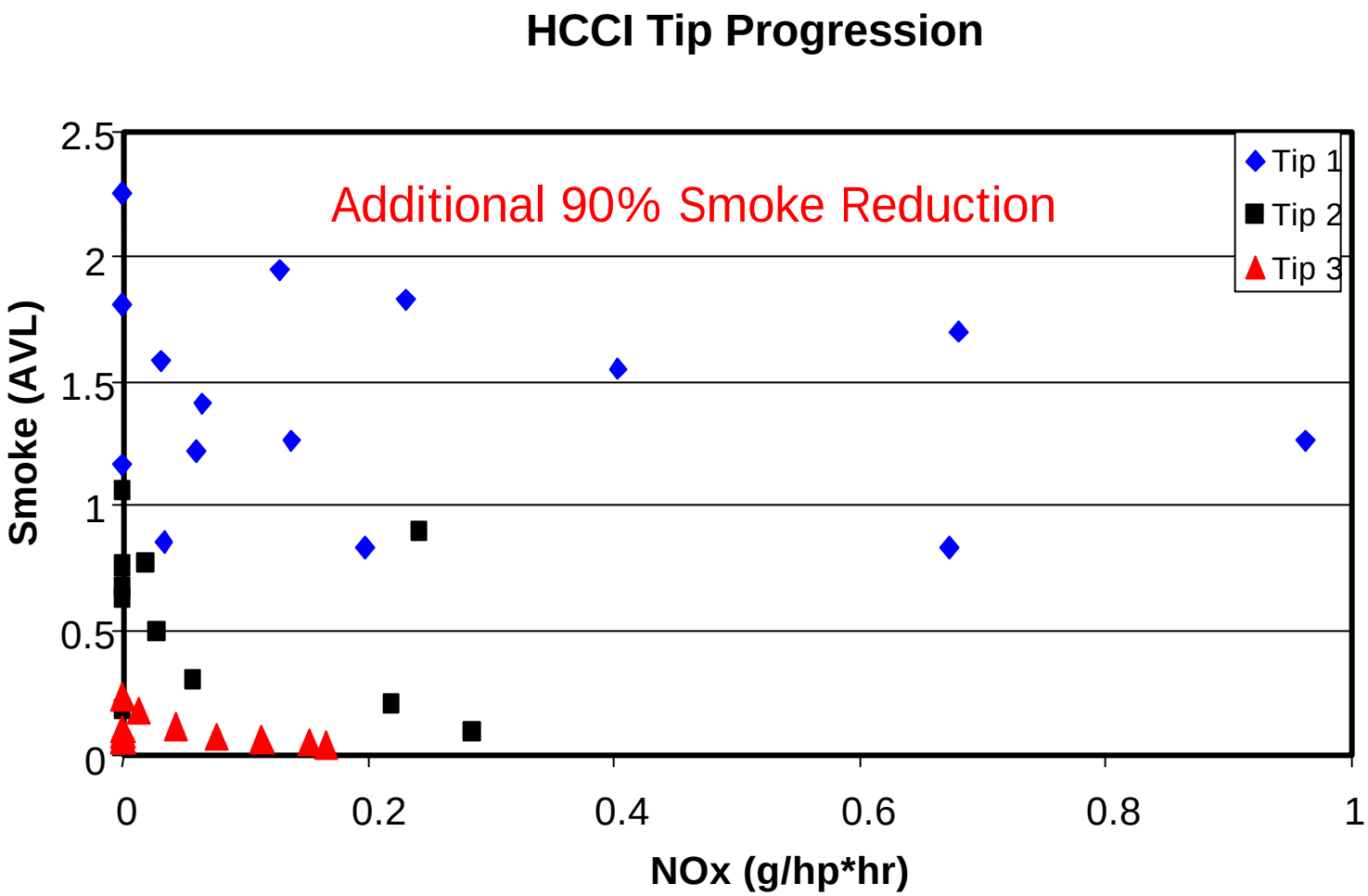
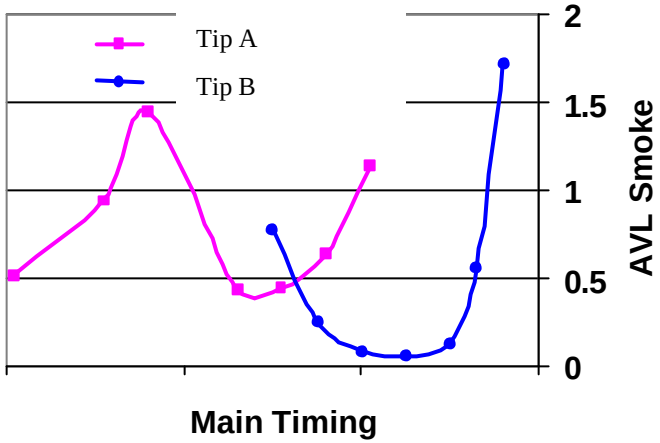
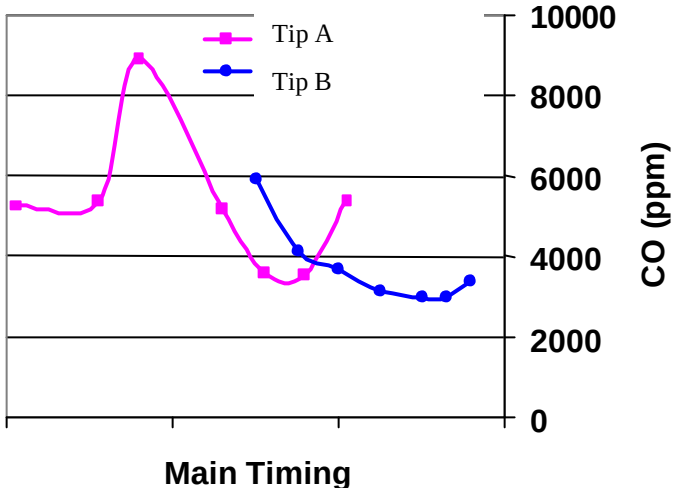
Mixture Preparation Optimization

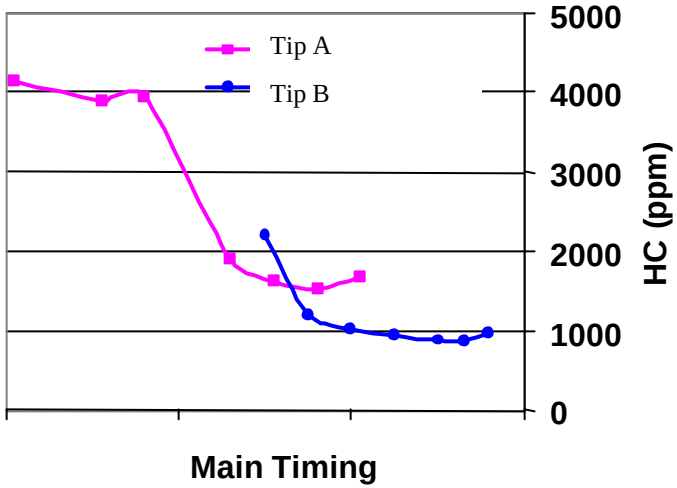


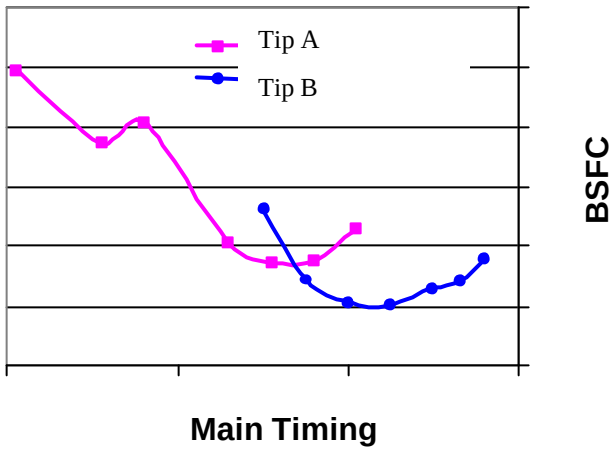
Multi-Cylinder Engine Results





1200 RPM, ~1/4 Load @ <0.04 g/hphr NOx





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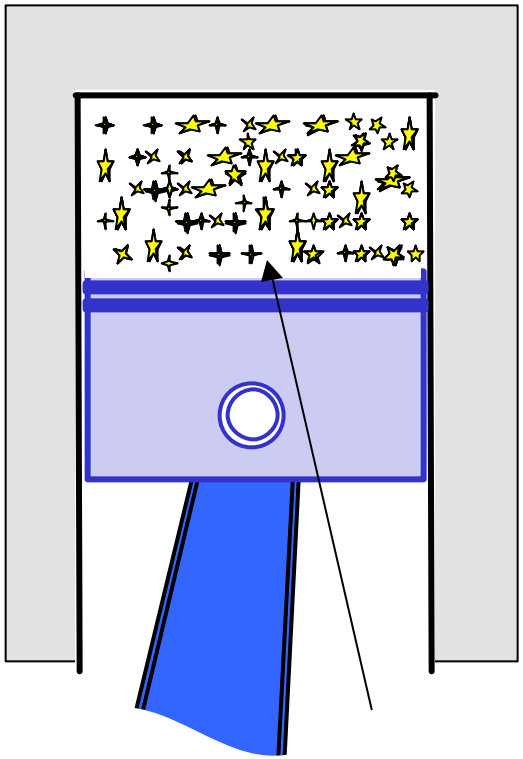

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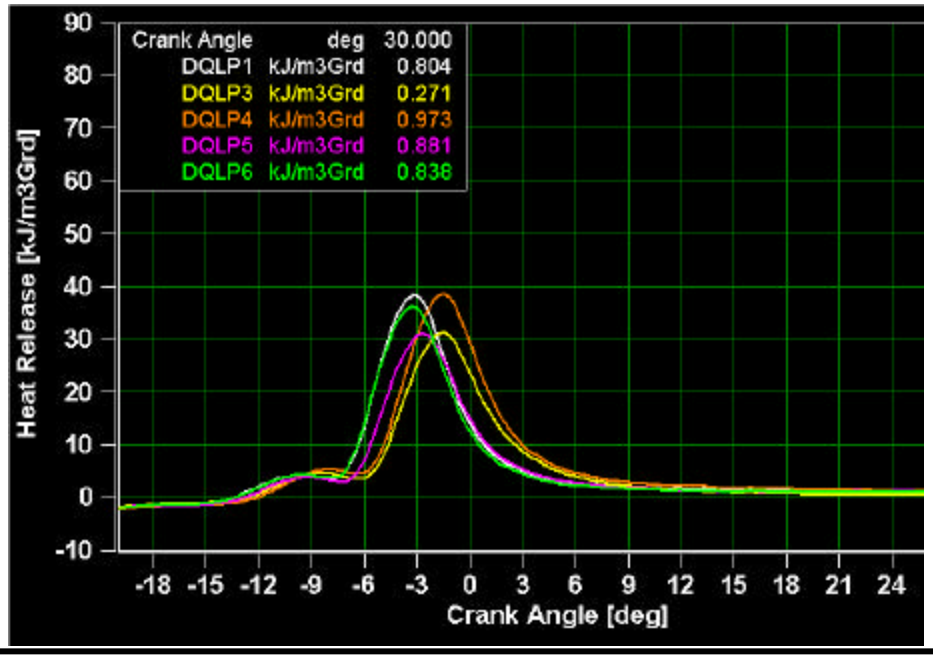
- Limited load range
- Combustion phasing and control

Light Load HCCI Operation

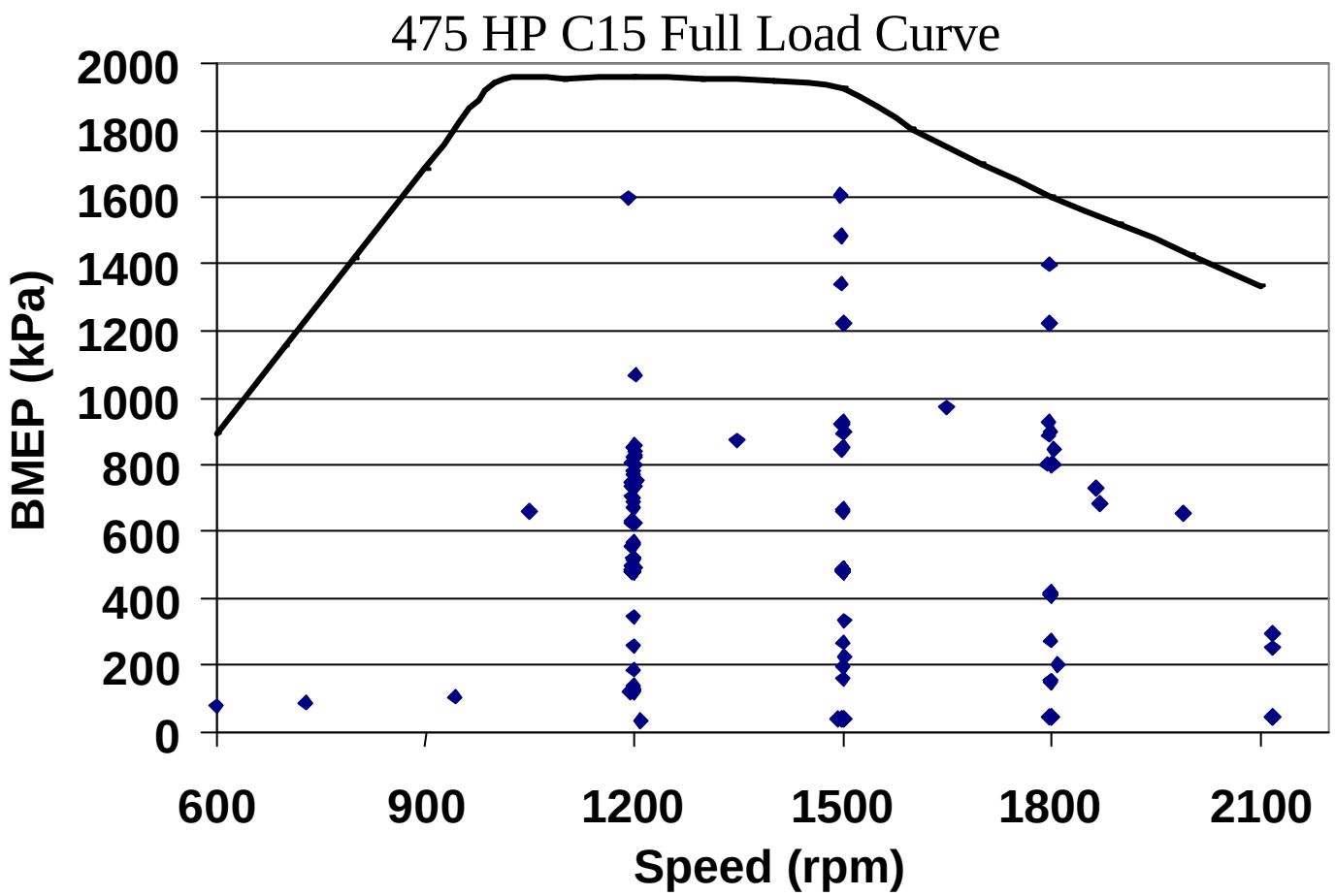
- Dec and Sjoberg (2003) examined low load HCCI operation with fully premixed iso-octane and a GDI system
- Found as load was reduced (phi<0.2), CO increased rapidly due to bulk gas quenching, combustion efficiency decreased to <50%
- Suggested there is a fundamental low load limit for HCCI driven by these bulk gas quenching phenomena

HCCI Idle Operation

Timing	BL	BL+5deg retard
CO (ppm)	5358	3610
NOx (ppm)	6	38
HC (ppm)	1580	1140
IMEPcov	7.2	5.6



Expanding HCCI Load Range



HCCI - The Challenge

HCCI Engine

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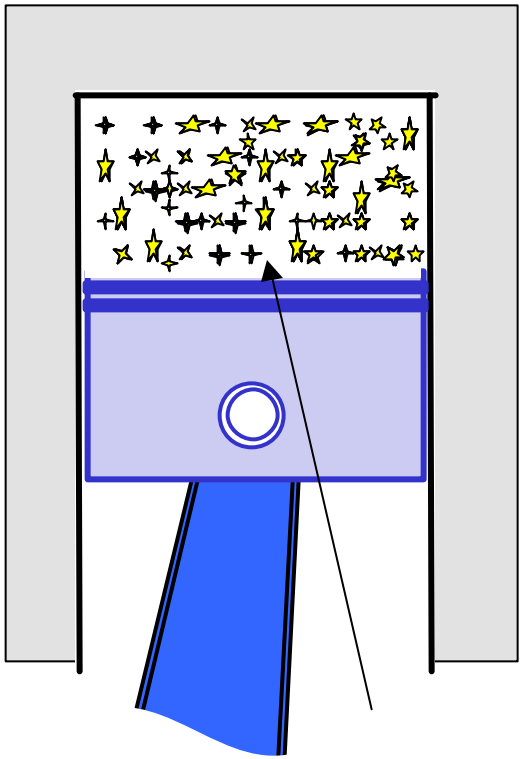

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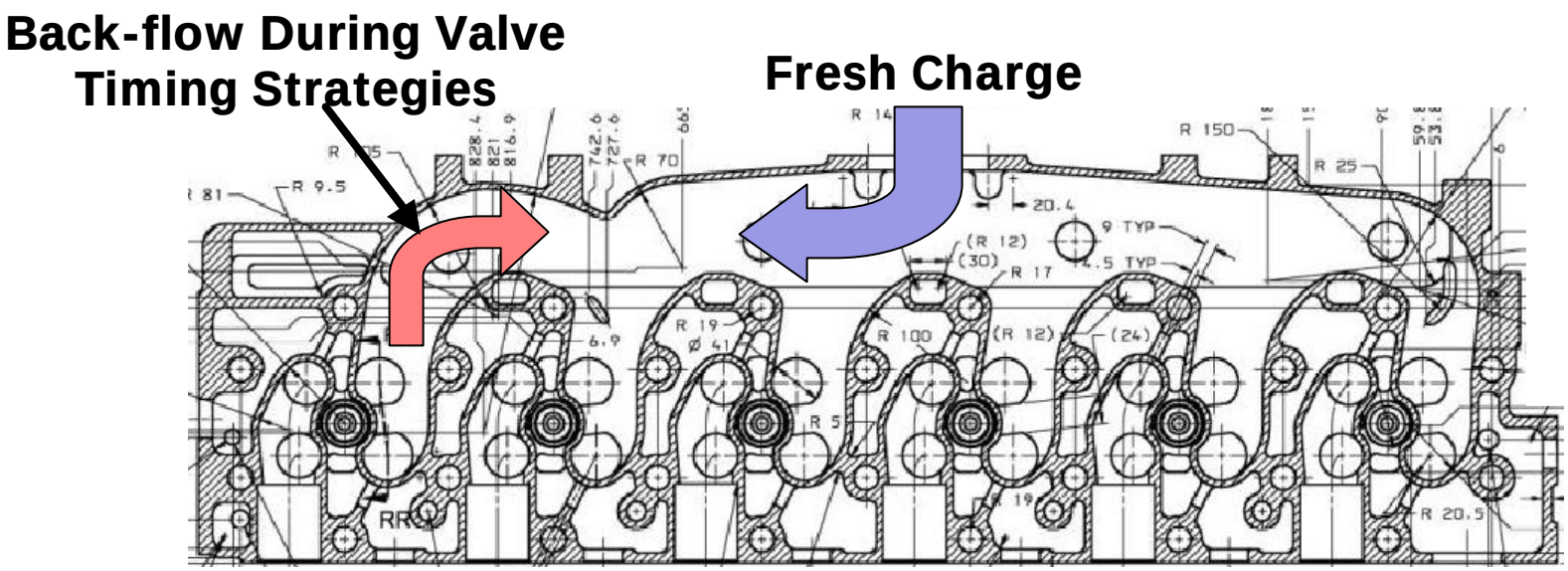
Controlling Cylinder-to-Cylinder Variability

- Charge air temperature variability, outside cylinders get less "fresh" charge
- Intake valve actuation available on current ACERT™ engines

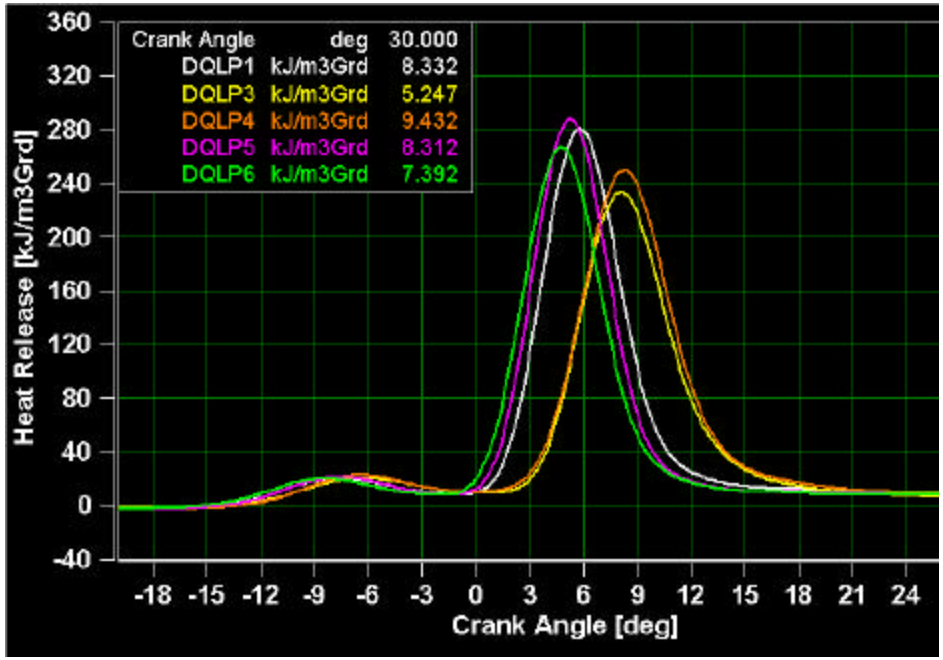


Inferred Temperature Distribution

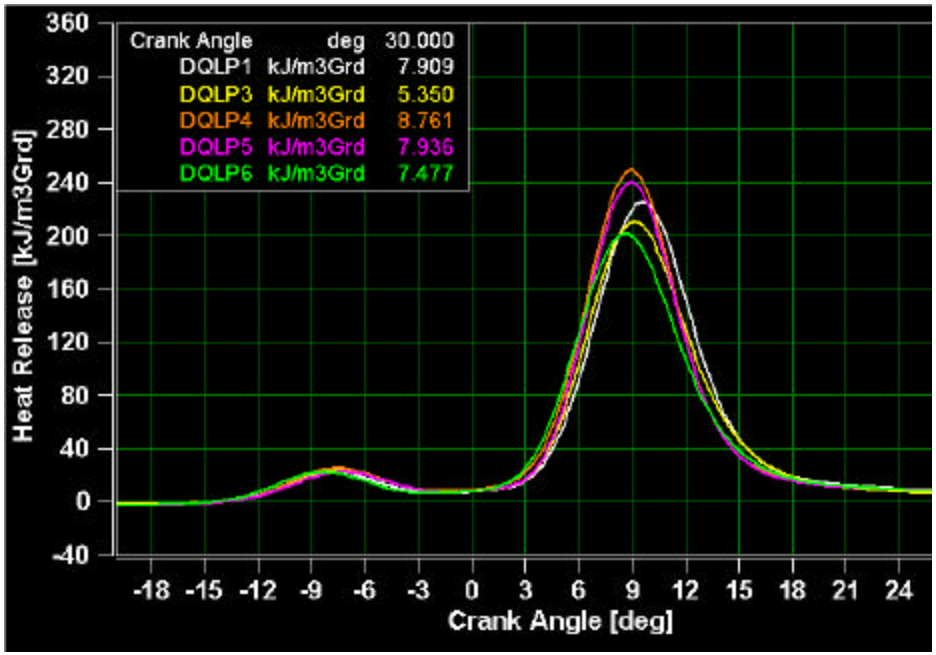
Cylinder to Cylinder Balancing

- Intake valve actuator trim strategies used to phase combustion properly
- Allows for higher power levels to be achieved

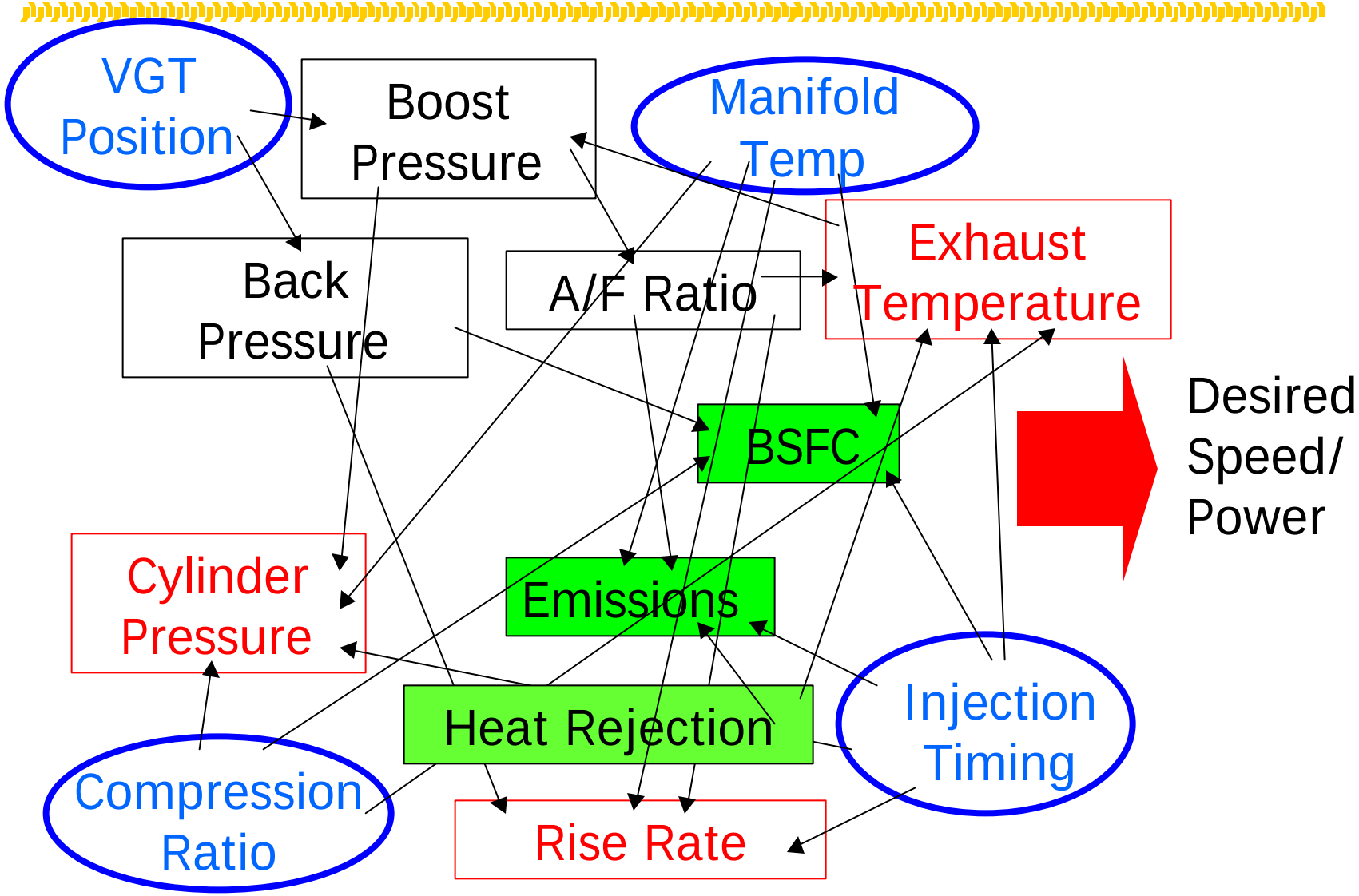
Untrimmed



Trimmed

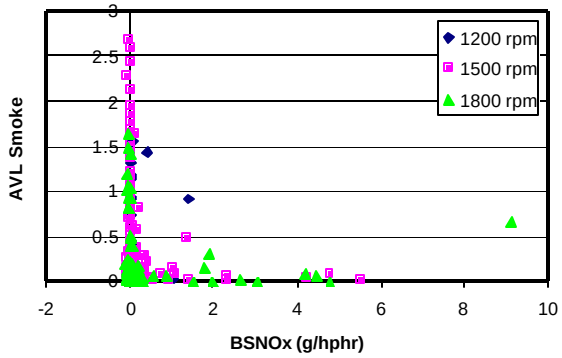


Combustion Control – System Interaction



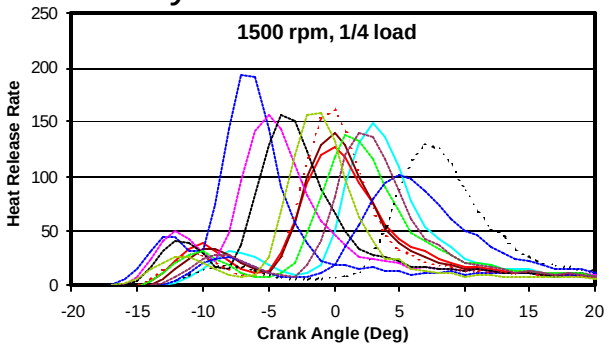
Controls Development Process

Performance/Emissions Data



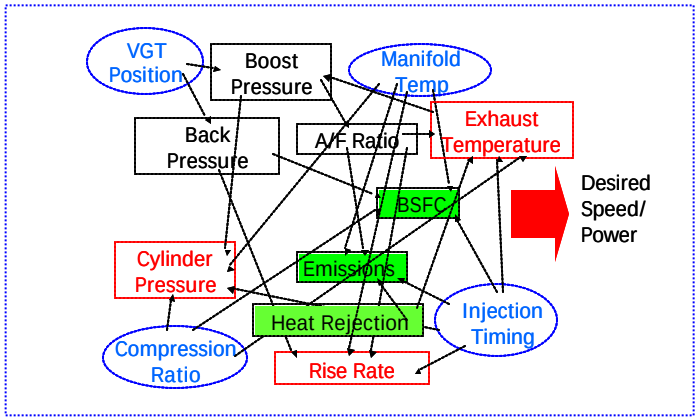
Engine Settings

In-Cylinder Pressure Data



Training Data for Neural Network

Neural Network "learns" the interactions



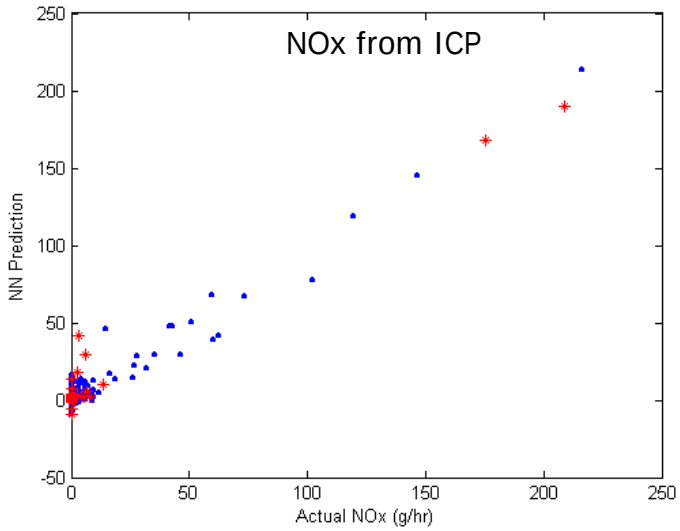
Optimum Settings

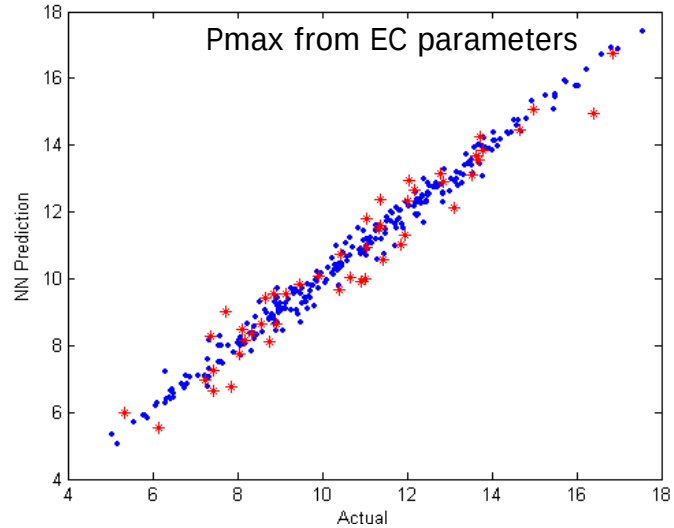
Sensors

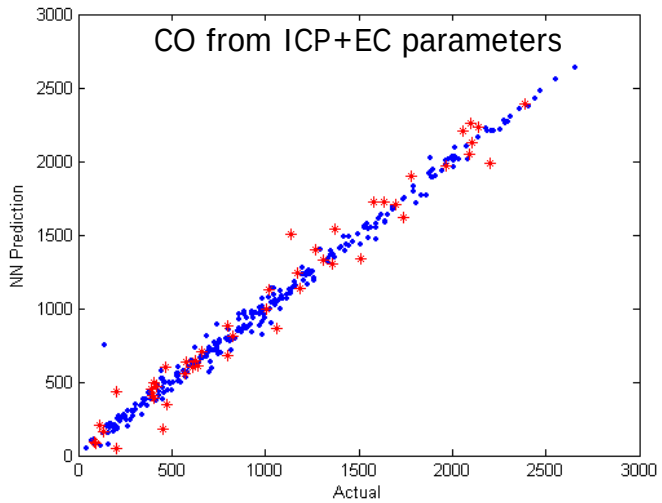
Actuators

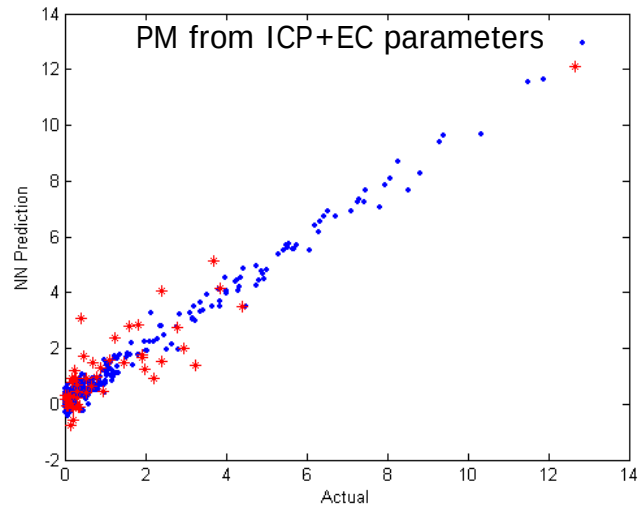
Rapid Prototype Controller

Sample Neural Net Models



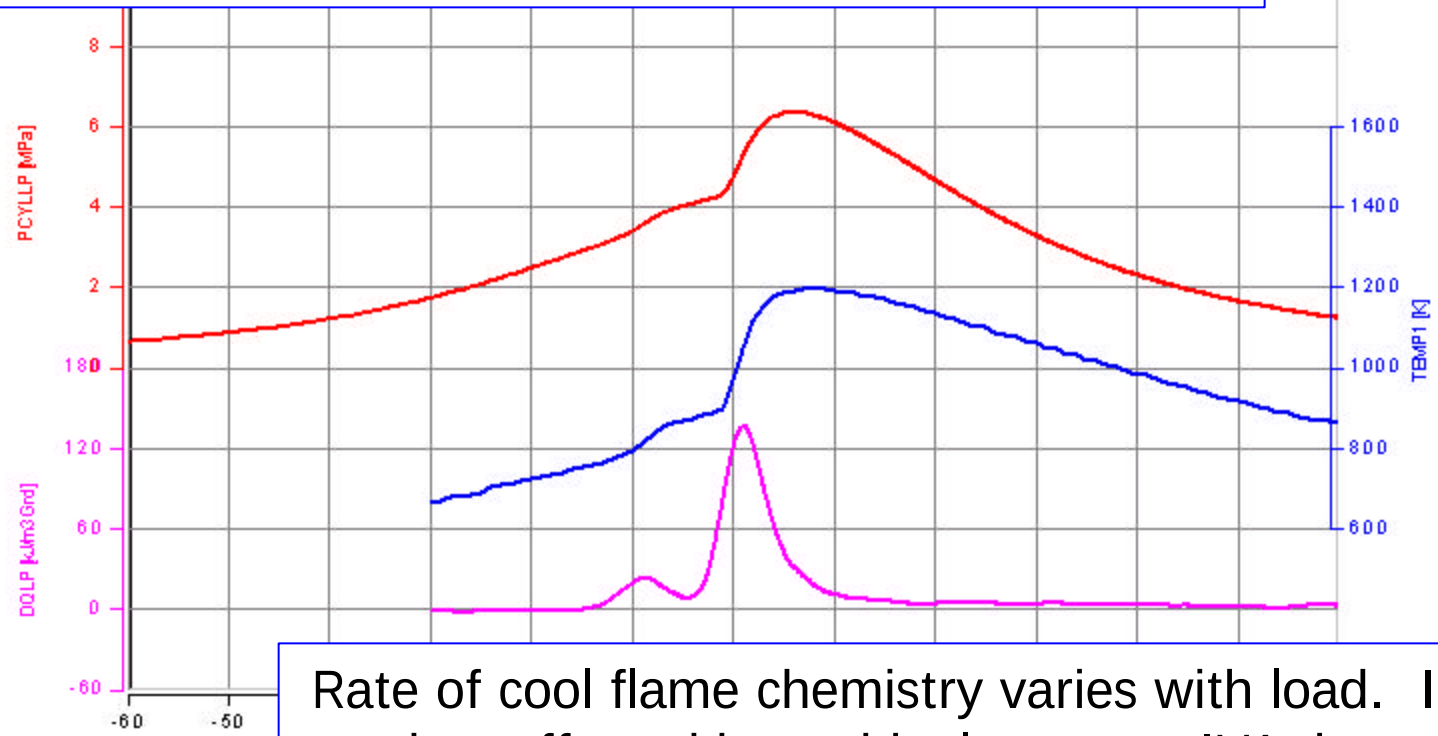






Two-Stage Combustion with Diesel Fuel

Question: Can fuel properties be manipulated in such a manner to advantageously effect cool flame chemistry and combustion phasing?



Rate of cool flame chemistry varies with load. Induction time affected by residual content, IVA, boost, etc. Amount of cool flame activity affects main combustion timing and rise rate.

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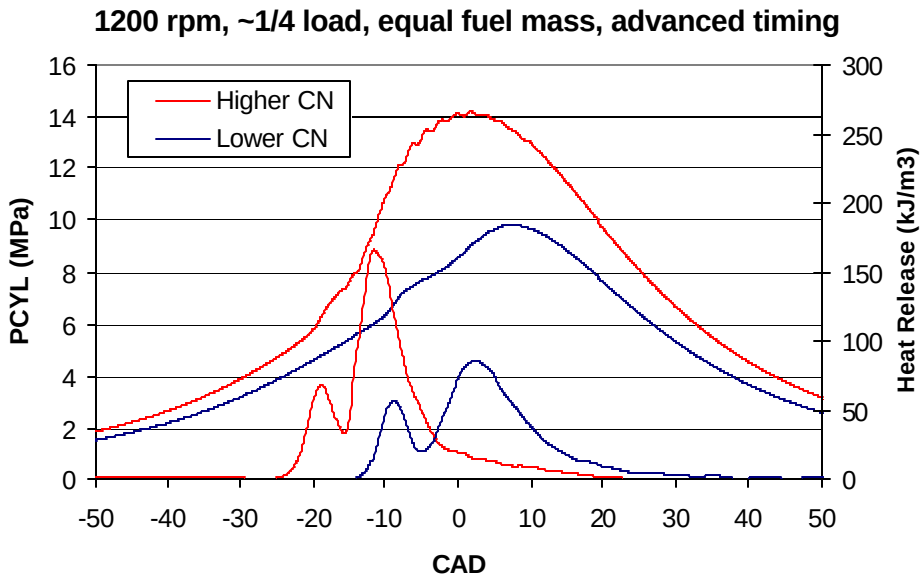
Study Fuels Effects on HCCI Combustion

- Teamed with major oil industry partner
- Developed matrix of 12 fuels
  - Diesel and gasoline like fuels
  - Vary ignition quality and volatility
  - In stock or easily blended fuels
- Test in single cylinder (~1 wk/fuel)
- Preliminary (CAT only in-house) results presented here for high and low cetane # fuels

Effect of Cetane Number

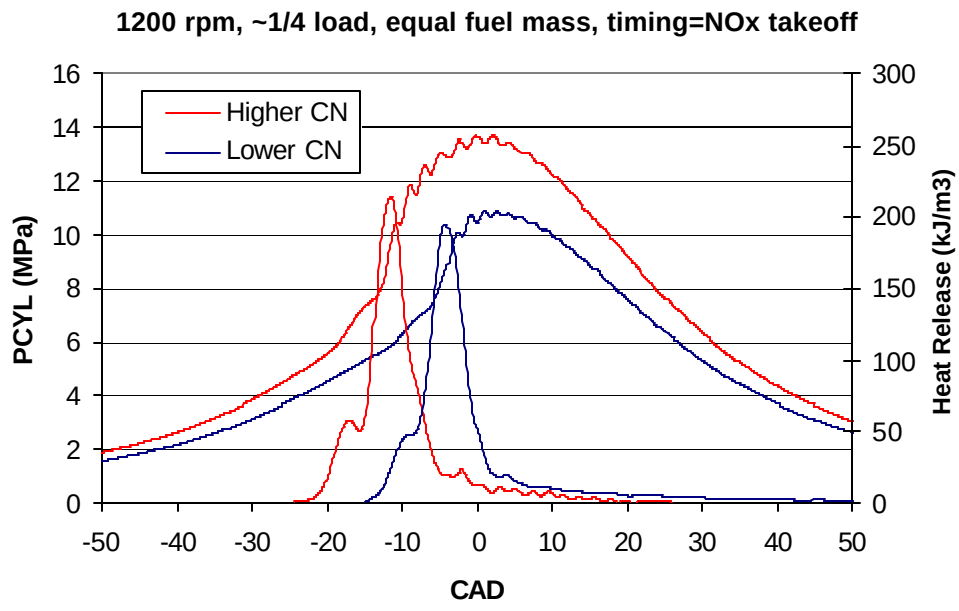


Higher CN leads to:

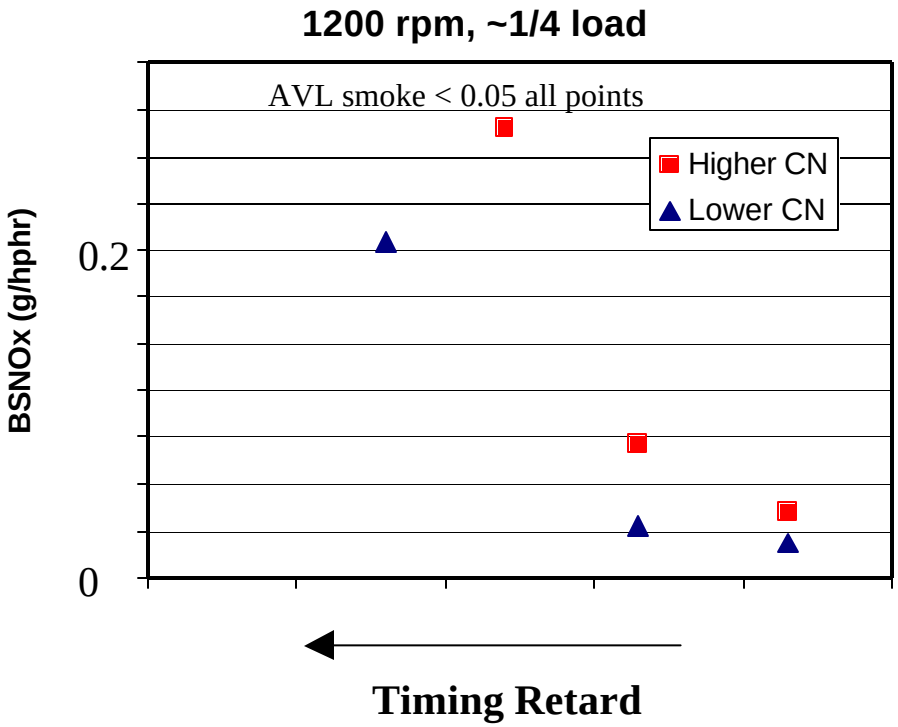
-earlier cool flame and main ignition

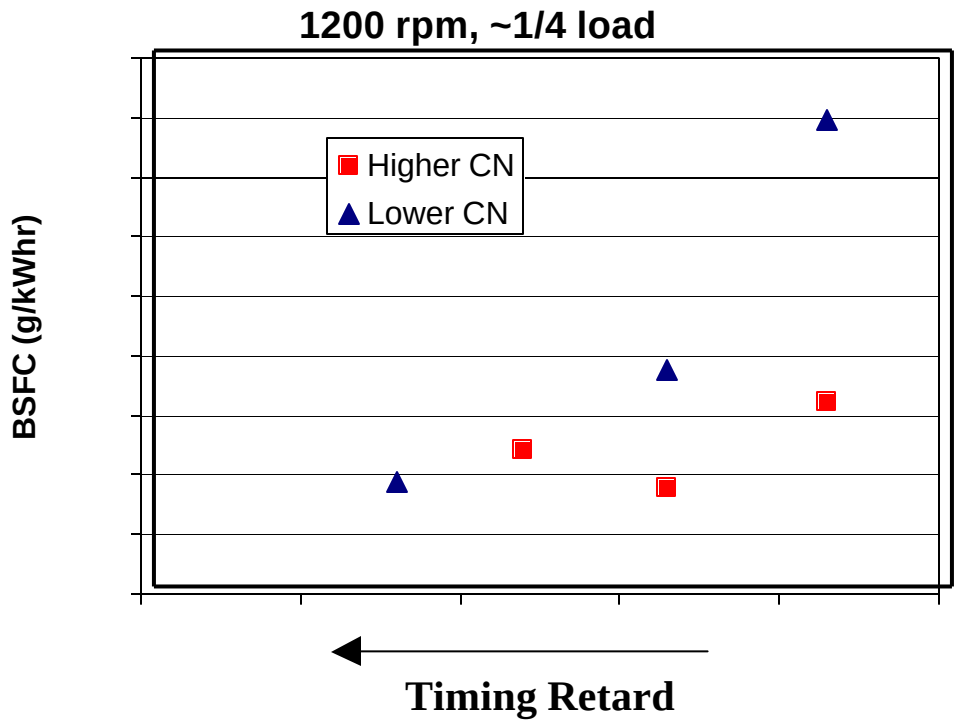
-40% increase in peak cylinder pres

-2x increase in cyl pres rise rate

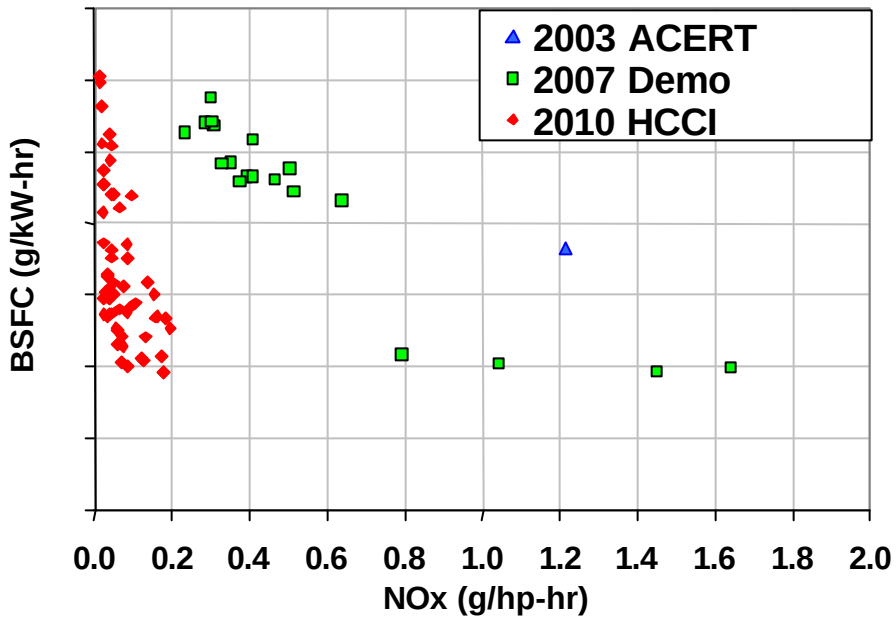


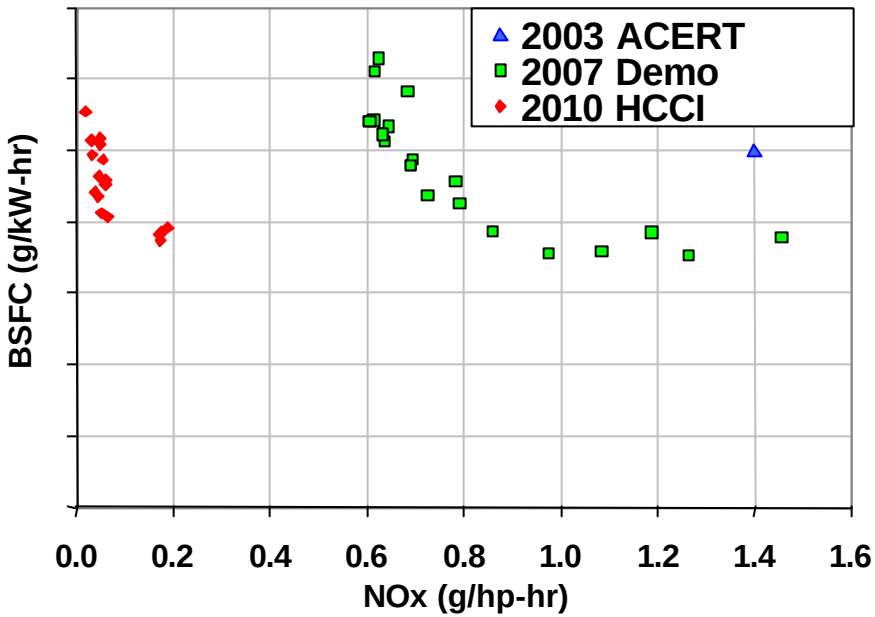
Emissions and BSFC Impact





Highly Competitive BSFC





Conclusions

- HCCI demonstrated up to 1600 bar BMEP
  - Single and multi-cylinder engines running
  - Highly competitive thermal efficiencies
- Stable HCCI combustion obtained at idle, light load conditions
- Meeting controls issue on all fronts
  - Full control system characterization under development using neural network models with in-cylinder pressure sensing
  - Cylinder variability observed, VVT appears to be viable trimming mechanism
- Fuels effects (CN) can have significant impact on performance/emissions, higher CN not right direction

Next Steps

- Advanced control algorithm integration on multi-cylinder
- Expand load limits further
- HCCI fuels effects testing
- Continue advanced fuel and air system development