

2007-2009 USA Emission Solutions for Heavy-Duty Diesel Engines

Jeffrey A. Leet

Engine Research Department
Engine & Vehicle Research Division
Southwest Research Institute®

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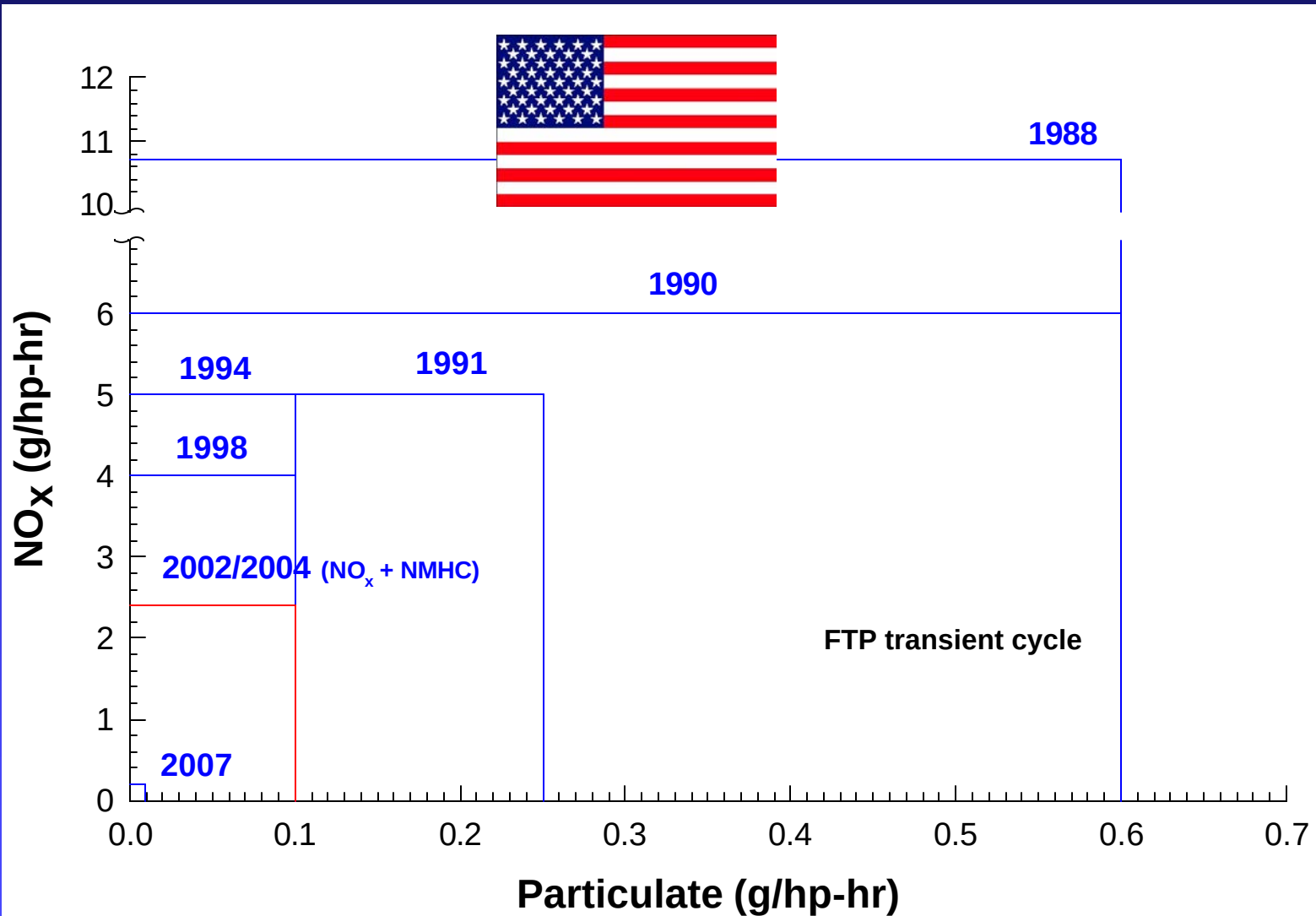


Outline

- ◆ USA Emissions Standards
- ◆ Hypothesis
- ◆ Background
- ◆ Control Technologies
 - In-Cylinder
 - Exhaust Treatment
- ◆ Summary



USA On-Highway Heavy-Duty Emission Standards



EPA Standards for HDE's in 2007

◆ PM = 0.01 g/hp-hr effective 2007 (100% of engines)

◆ Phase-in for diesel engine NO_x and NMHC is:

■ 2007:	50%*
■ 2008:	50%*
■ 2009:	50%*
■ 2010:	100%*

*percentage of fleet sold

◆ There are no technology provisions for the phase-in engines



EPA Standards for HDE's in 2007 (cont.)

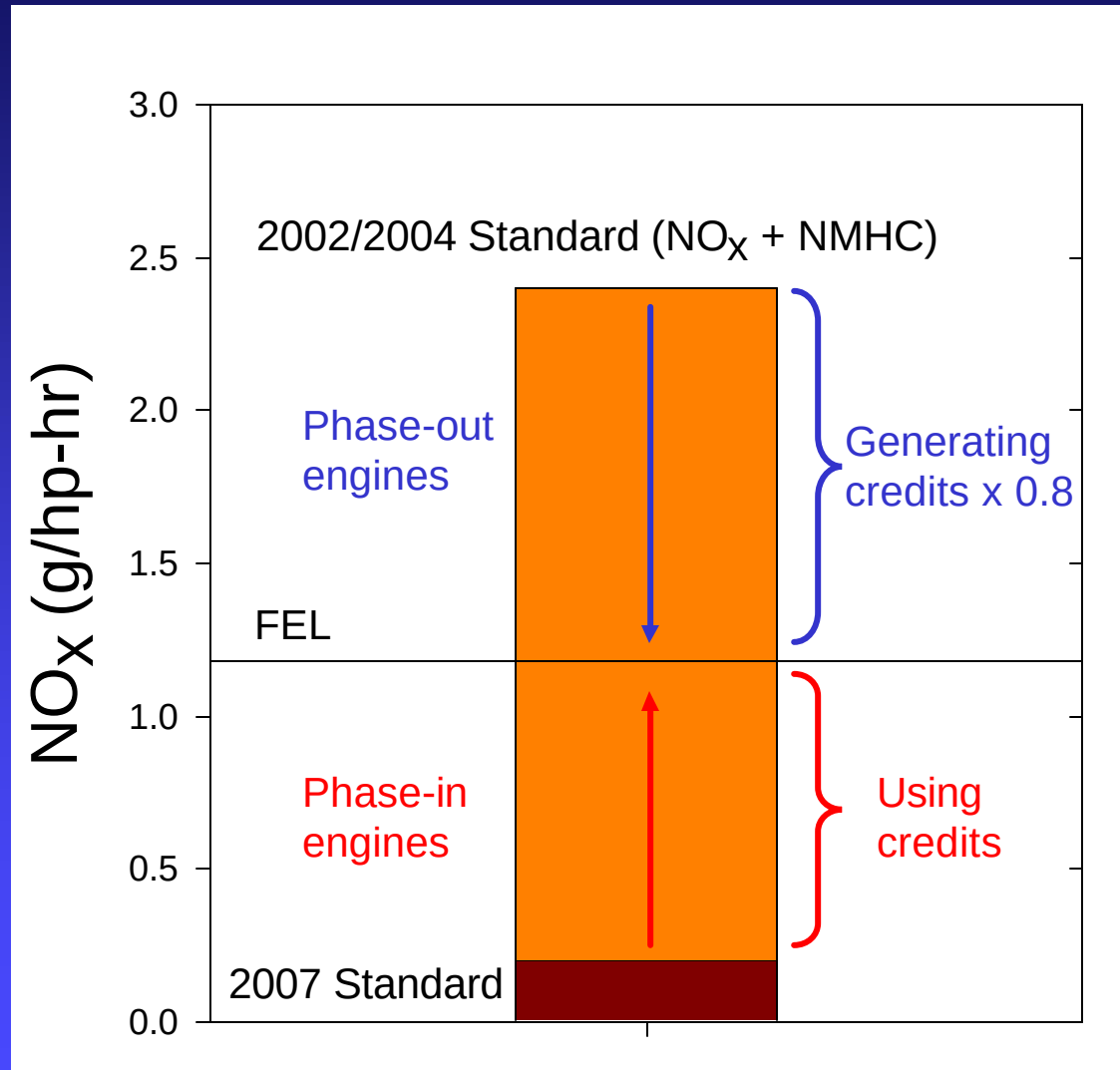
- ◆ Emissions tracked by Family Emissions Level (FEL), similar to “fleet average”
- ◆ In addition, engine manufacturers must also comply with:

Procedure	Limits	Emissions (g/hp-hr)
Supplemental Test Procedure (European Stationary Cycle)	1.0 x FTP	NOx = 0.2
		PM = 0.01
		NMHC = 0.14
		CO = 15.5
Not-to-Exceed (NTE)	1.5 x FTP	NOx = 0.3
		PM = 0.015
		NMHC = 0.21
		CO = 23.25

*More
severe than
Euro V!*



Implementation of 2007 Standards



Hypothesis

- ◆ The USA 2007-2009 emission standards for heavy-duty diesel engines can be achieved with minimal or no exhaust treatment for NO_x
 - *It is assumed that a Catalyzed Diesel Particulate Filter (cDPF) will be required to achieve 0.01 g/hp-hr Particulate Matter (PM)*



Background

- ◆ 90%+ reductions are required in 2010 to be demonstrated across:
 - cold- and hot-start FTP's
 - ESC
 - NTE
- ◆ Without Homogenous Charge Compression Ignition (HCCI), in-cylinder controls, alone, will be unable to achieve 2010's levels
- ◆ Exhaust treatment systems have demonstrated ability to achieve 2010 but many issues remain:
 - cost
 - regeneration
 - packaging
 - fuel consumption penalty

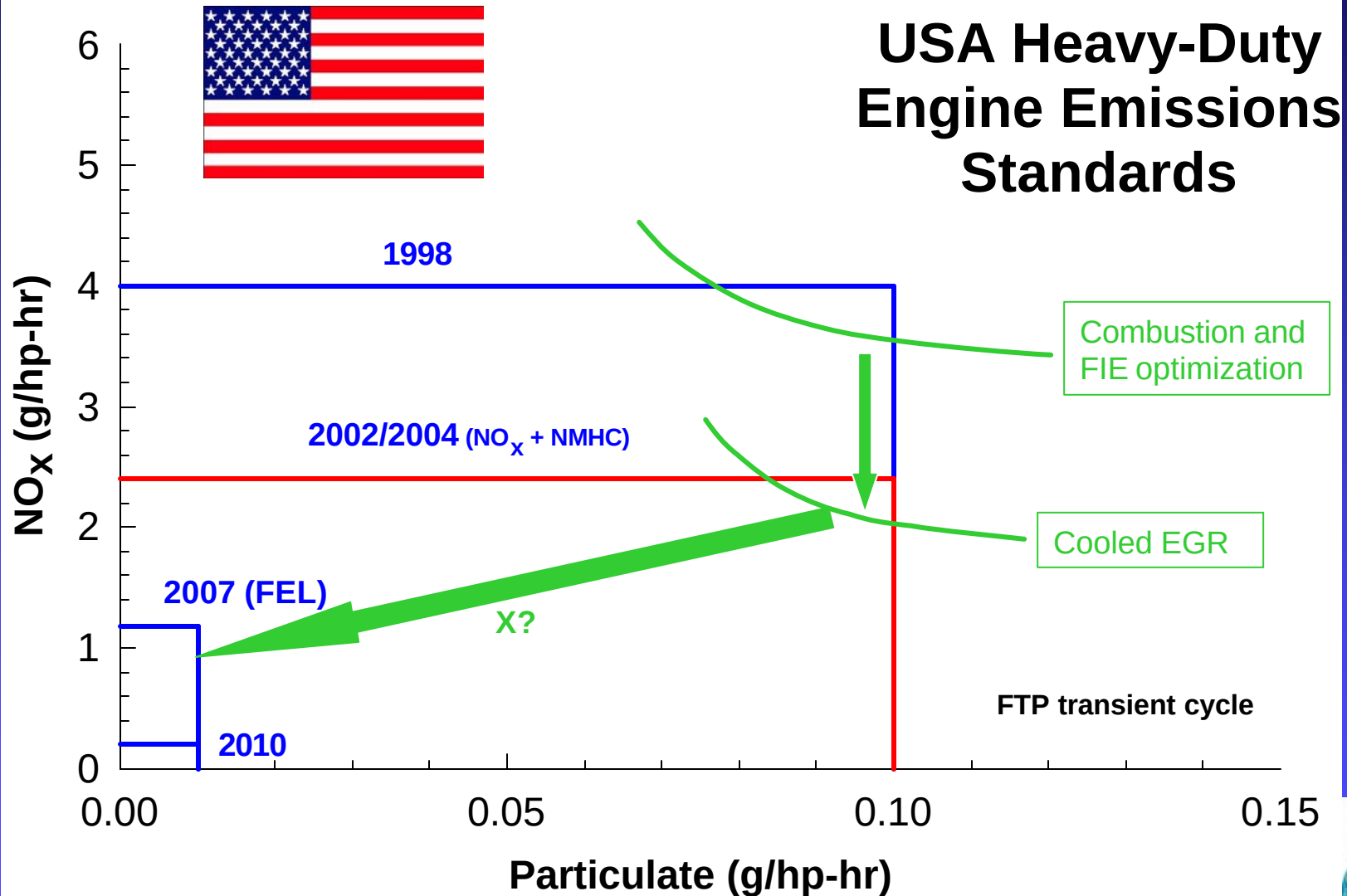


Background (cont.)

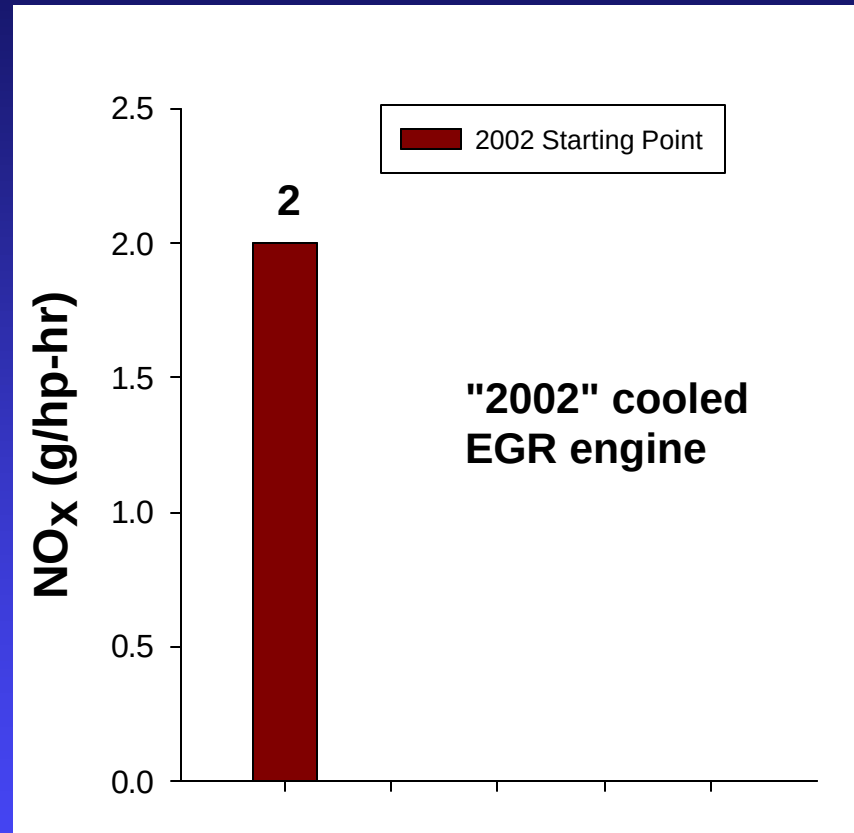
- ◆ A systems approach will be required in order to comply with the 2007 and 2010 standards
 - In-cylinder methods
 - Exhaust treatment methods
- ◆ SwRI believes that further reductions of in-cylinder (engine-out) NO_x emissions are possible and cost effective



2007-2010 Regulations



2007-2009: What's Possible?



Technologies

→ In-Cylinder

- High boost/high EGR
- Combustion modifications
- Fuel injection improvements
- Variable Valve Actuation (VVA)
- Model-based controls
- Water-fuel emulsions

◆ Exhaust Treatment

- Lean NO_x catalyst
- Catalyzed Diesel Particulate Filter (cDPF)

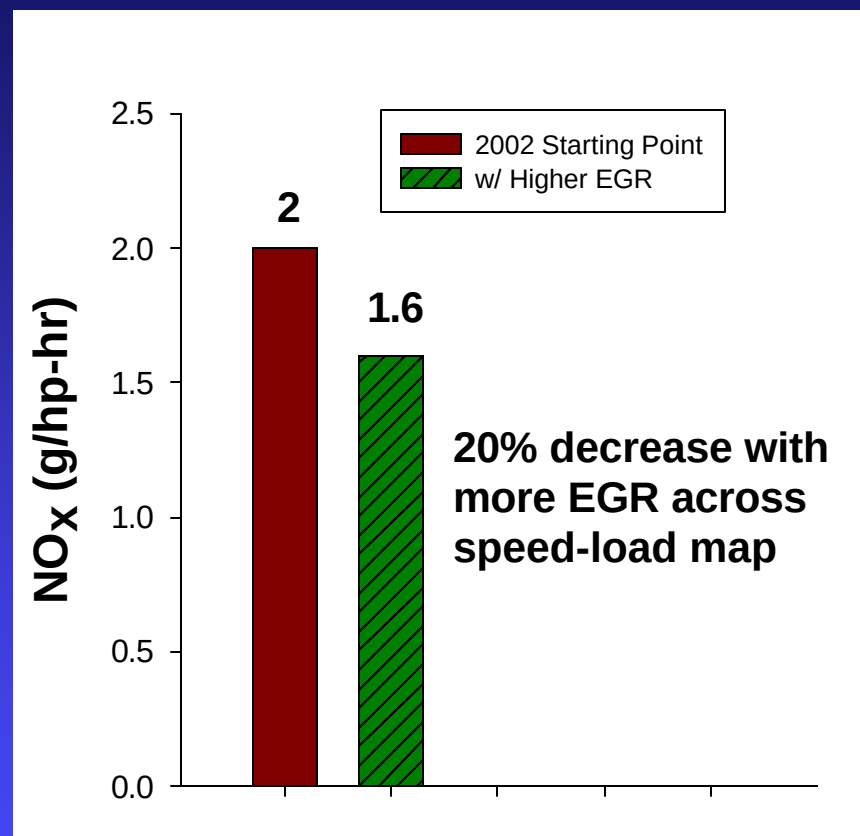


High Boost/High EGR

- ◆ External, cooled EGR will predominate in the USA from 2002-2007
- ◆ Additional NO_x reduction can be achieved especially since a cDPF will remove the soot (assuming $\eta > 95\%$)
- ◆ Achieve higher EGR levels while maintaining high BMEP levels via
 - Variable Geometry Turbochargers (VGT)
 - higher boost levels
 - increased peak cylinder pressures (> 200 bar)



2007-2009: What's Possible?



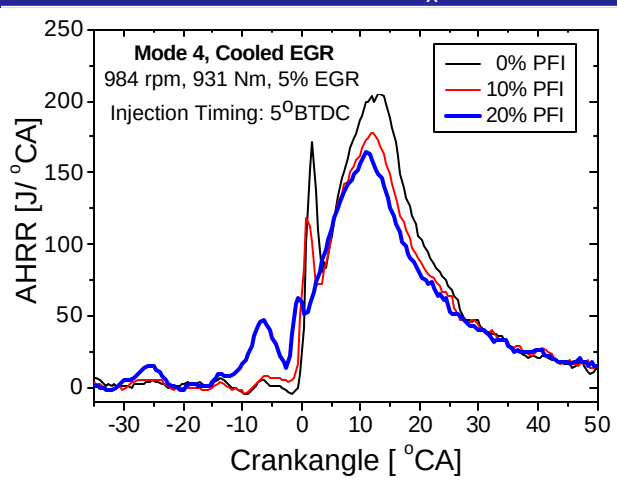
*projections



Modified Combustion for NO_x Control

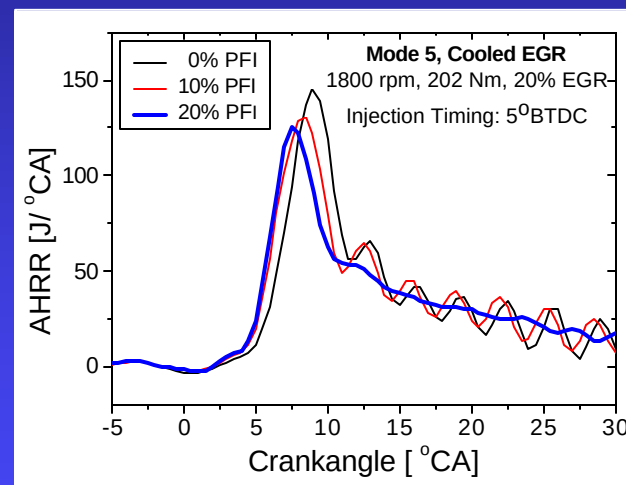
- ◆ Partial Premixed Controlled Compression Ignition (PCCI) - can be used at light- to mid-load to reduce NO_x

High load: little or no NO_x reduction



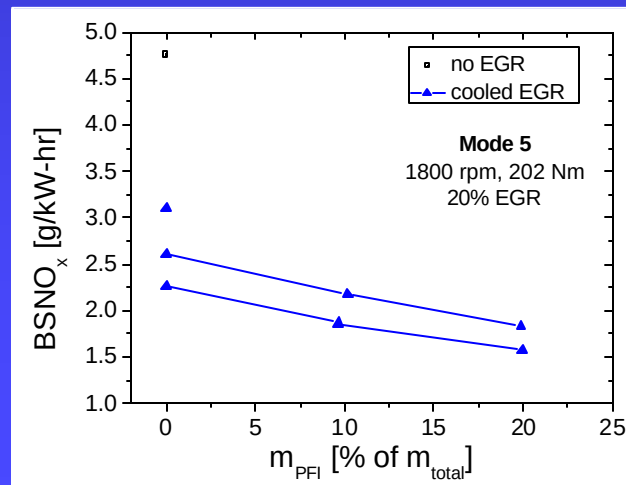
Controlling combustion initiation of the premixed portion allows for simultaneous burning with the diffusion-limited combustion...

Light load



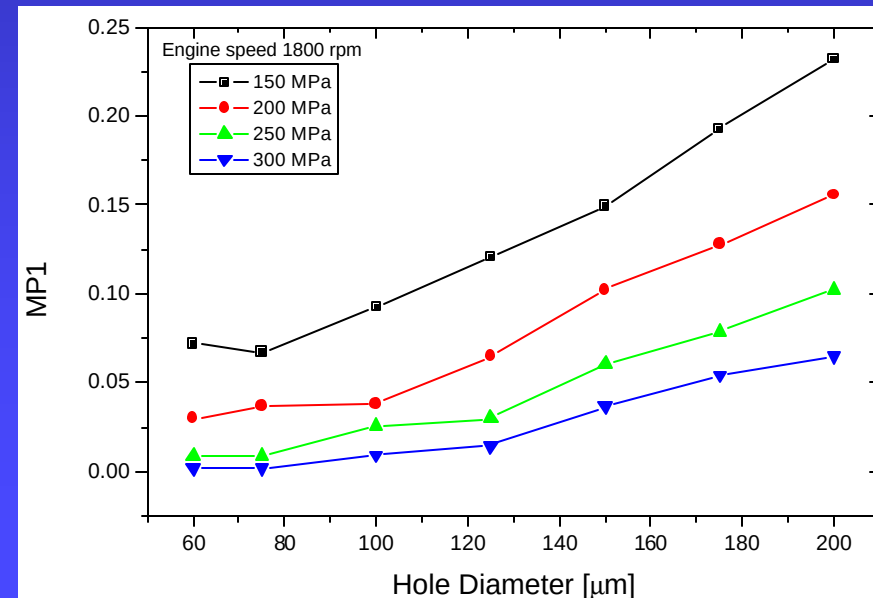
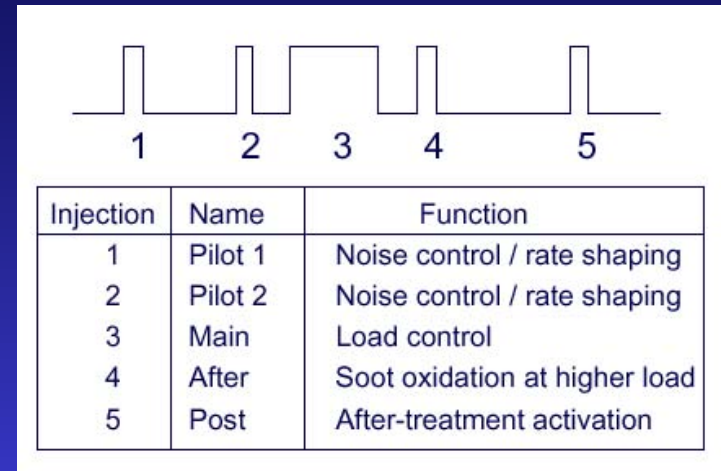
...resulting in a 20-30% NO_x reduction at light load

Simescu, et. al., SAE Paper 2002-01-0963

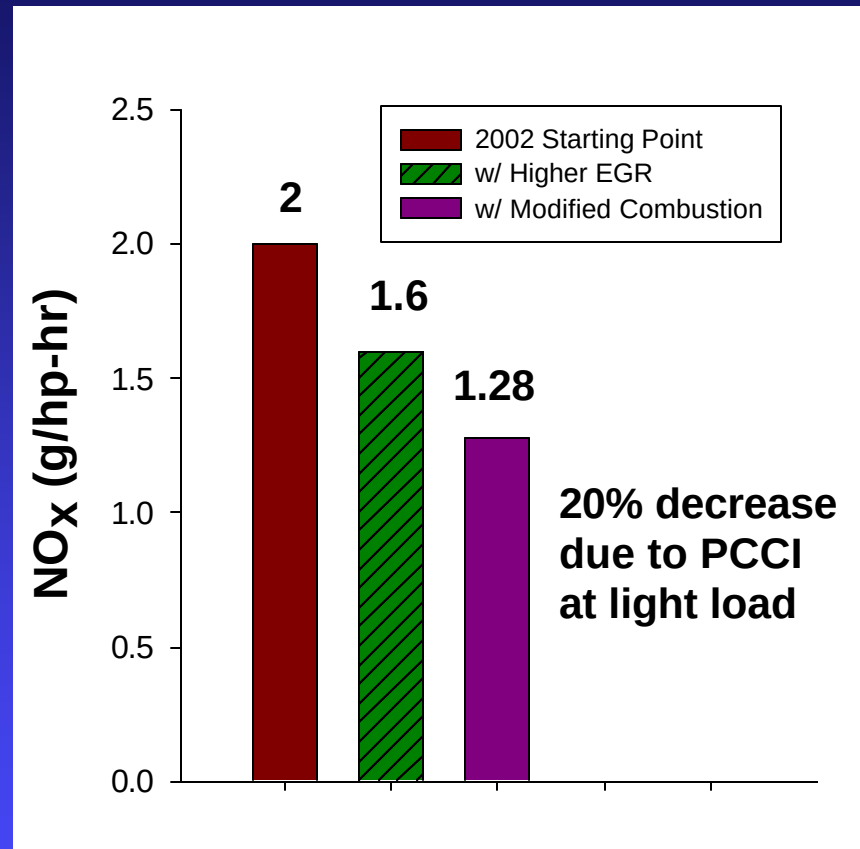


Fuel Injection Improvements

- ◆ Important for PCCI
- ◆ Multi-injection fuel injection systems (*3-5 pulses per cycle*) for PCCI, noise, cDPF regeneration:
 - E3 unit injector
 - HEUI-C intensifier
 - Common rail
- ◆ Fuel-air mixing can still be improved by high injection pressure and smaller injector hole sizes



2007-2009: What's Possible?



*projections



Variable Valve Actuation

◆ VVA has many advantages for HD diesel engines

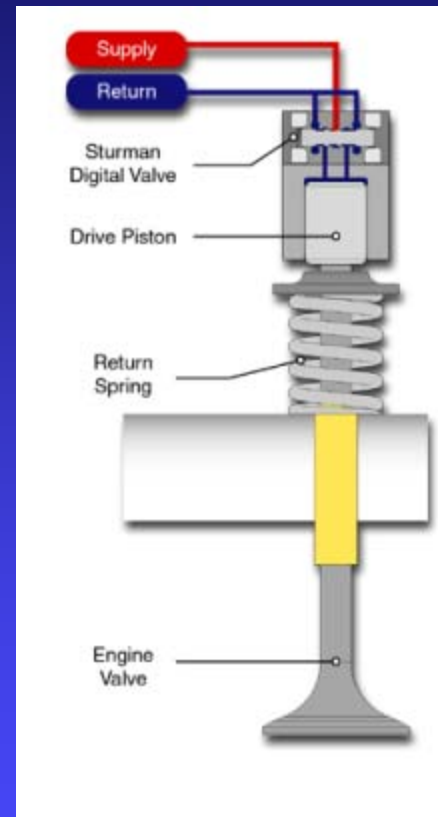
■ NO_x control:

- lower NO_x via Miller Cycle
- better residual control for PCCI

■ Secondary:

- better cold-starting
- cylinder de-activation
- part load BSFC improvement
- variable swirl ratio
- ability to increase exhaust temperatures for exhaust treatment devices
- engine braking

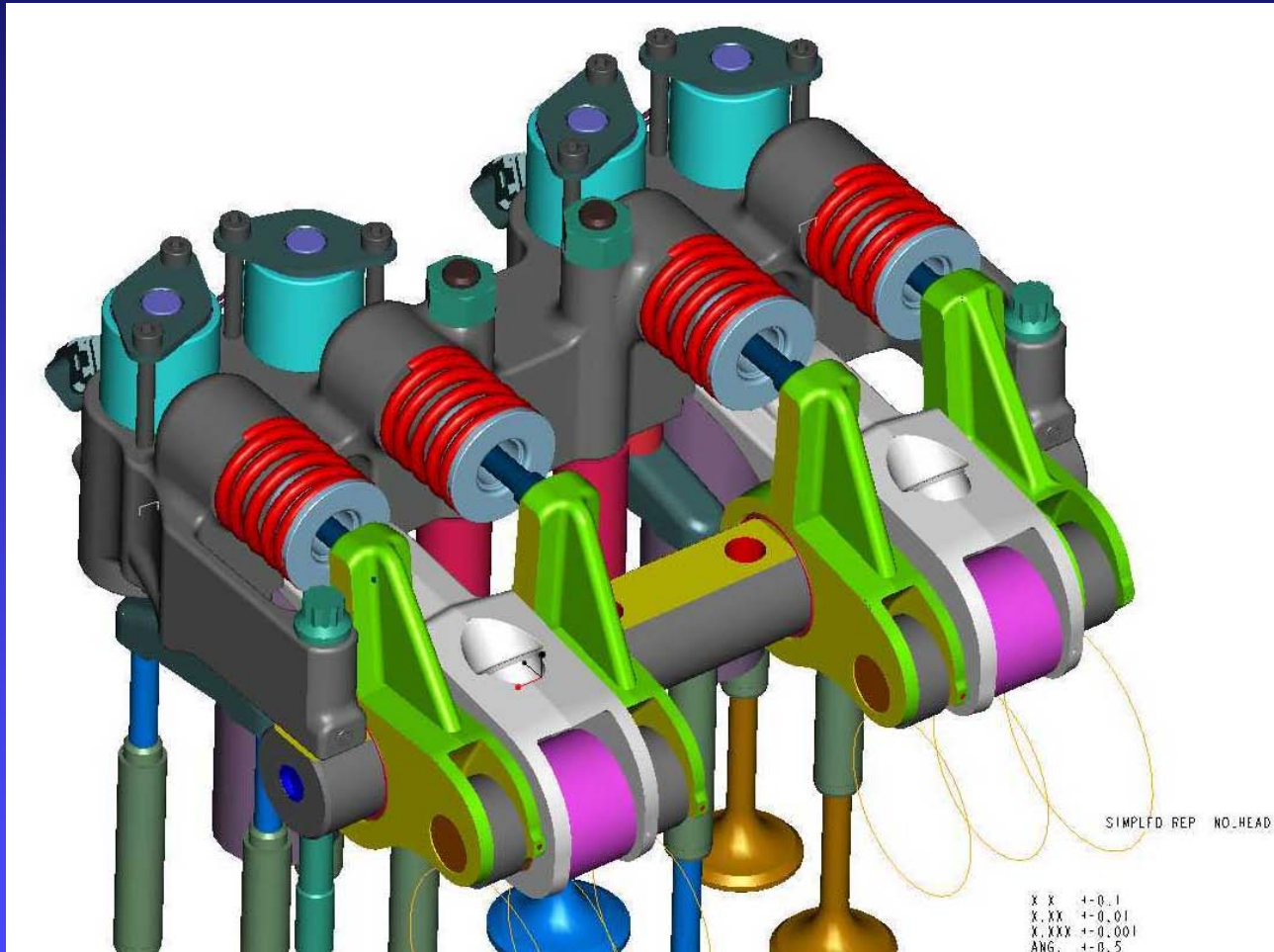
◆ Near-production systems are becoming available now



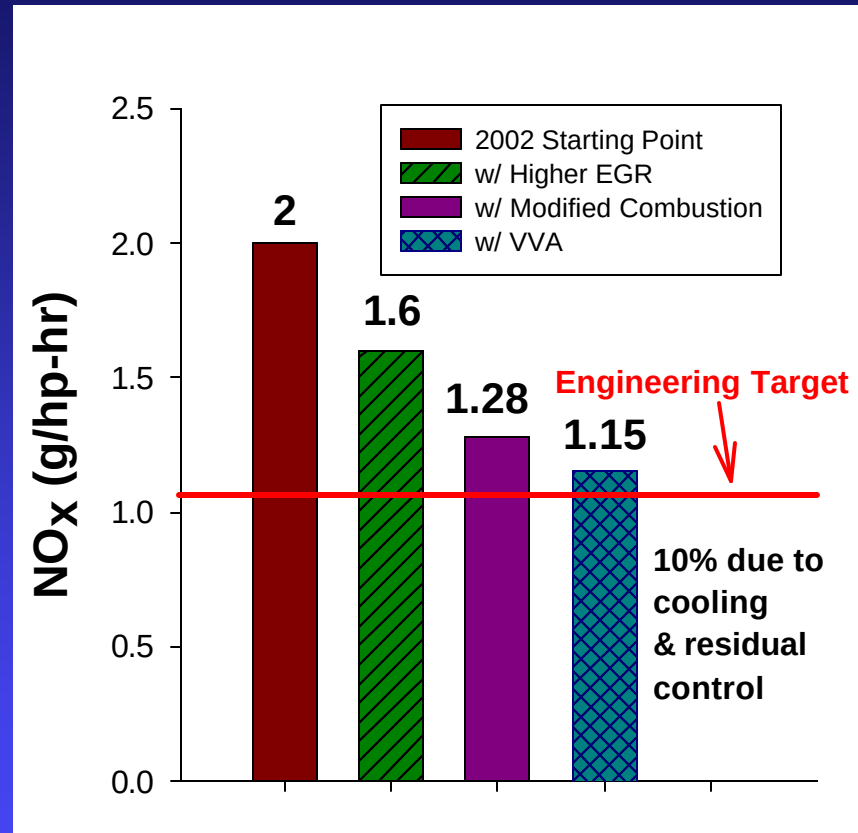
Hydraulic Valve Actuation
from Sturman Industries



Jacobs' Lost Motion Hydraulic Valve Actuation System



2007-2009: What's Possible?

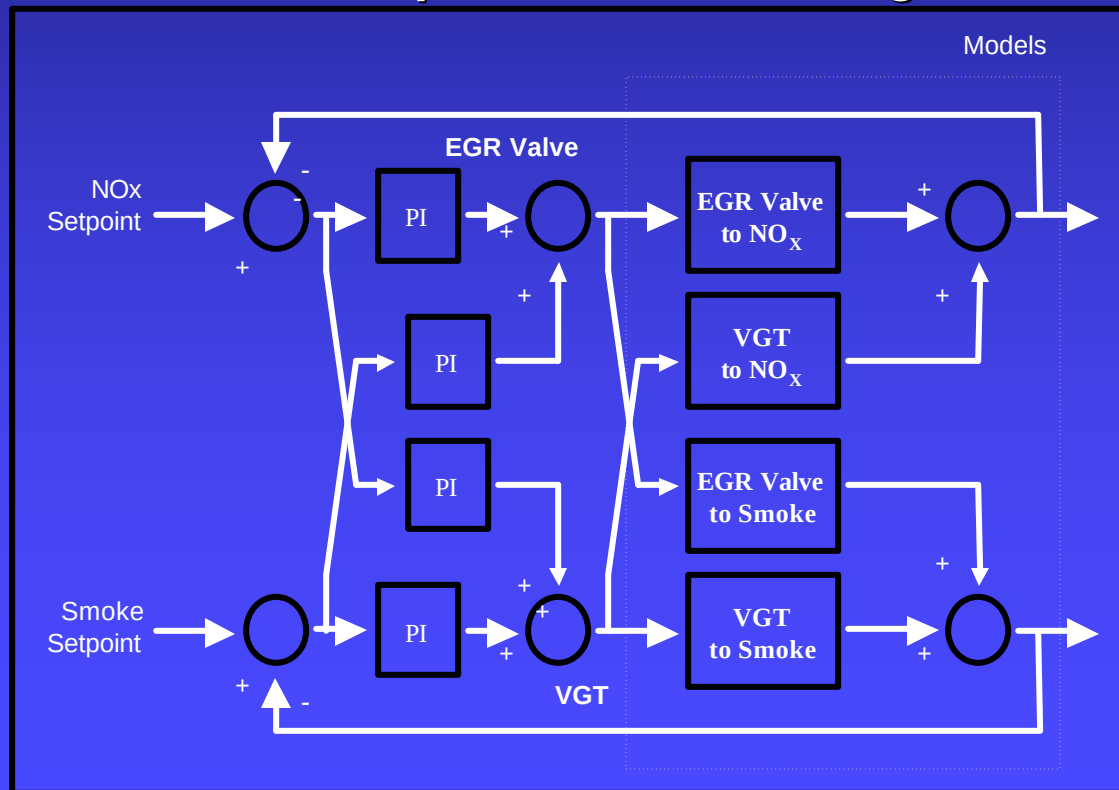


*projections



Model-Based Controls

- ◆ Advanced model-based algorithms include both engine and exhaust treatment control
- ◆ Multivariable control in diesel engines
 - Engine control variables have increased
 - Look-up tables are no longer sufficient



EGR/VGT control strategies development using multivariable control design techniques



Technologies

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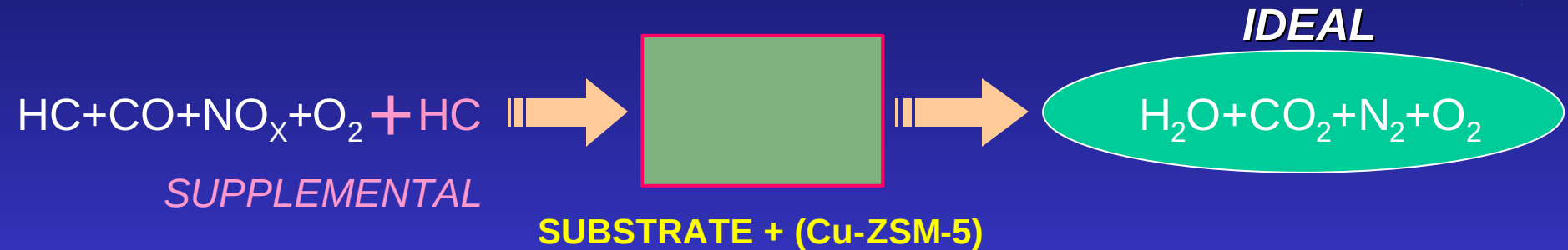
→ Exhaust Treatment

- Lean NO_x catalyst
- Catalyzed Diesel Particulate Filter (cDPF)



Lean NO_x Catalysts

EXHAUST CATALYSIS PROCESS



Advantages

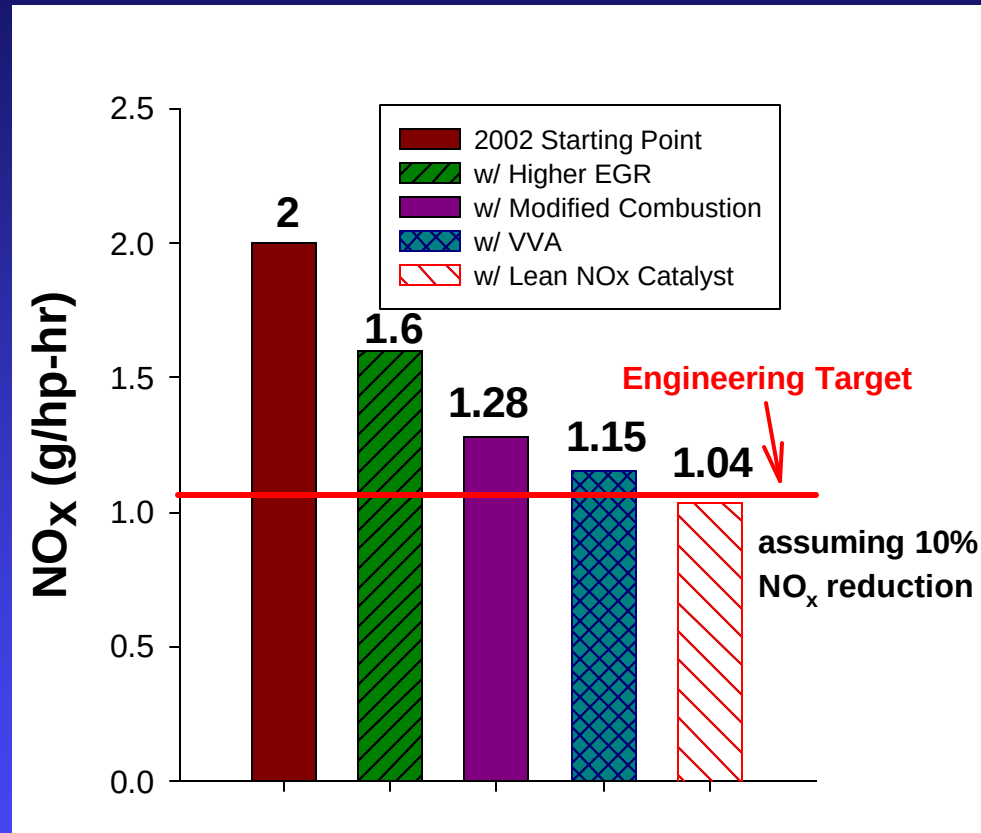
- Uses same on-board reductant
- Good sulfur tolerance
- Provides added margin for calibration, if needed

Disadvantages

- Low cycle NO_x conversion (<30%)
- Narrow exhaust temperature range of operation
- High fuel consumption penalty (~10%)
- Durability



2007-2009: What's Possible?



*projections



Summary

- ◆ Future emission standards in the USA are very severe requiring a systems solution
- ◆ Lean NO_x adsorbers may not be sufficiently developed for 2007-2009 timeframe and may not be necessary
- ◆ In-cylinder controls should be sufficient for 1.18 g/hp-hr NO_x in 2007
 - possible need for additional NO_x control via a lean NO_x catalyst to provide a margin



Summary (cont.)

- ◆ Offering an engine with minimal exhaust treatment and further improved in-cylinder controls will:
 - Reduce the costs of exhaust treatment portion
 - Improve the durability of exhaust treatment
 - Reduce the packaging volume
 - Show an engine manufacturer as a technological leader
 - Provide a product distinction in a crowded market

