

# **NEW DIESEL EMISSIONS CONTROL STRATEGY for US TIER 2**

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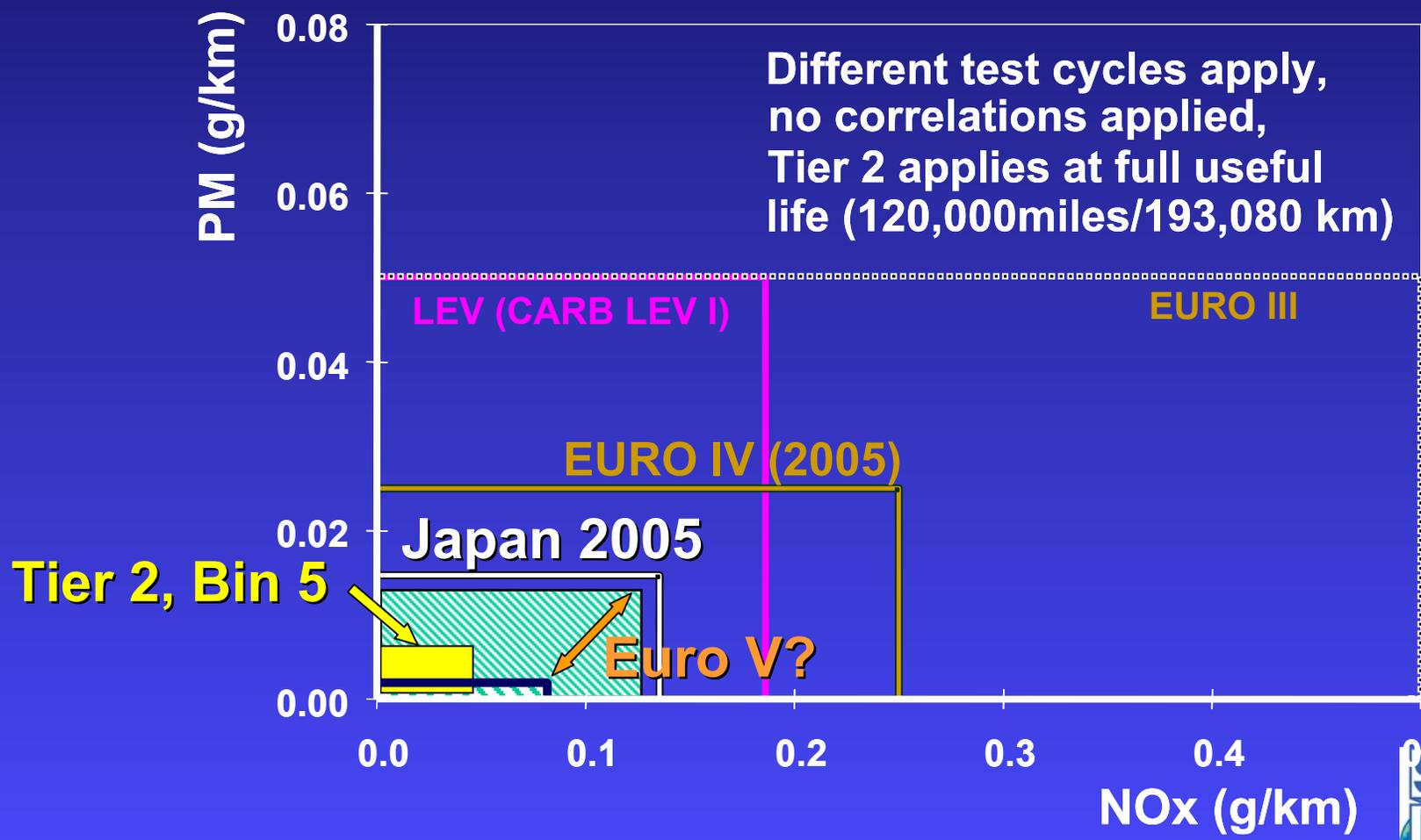


# Outline

- ◆ Emissions Regulations
- ◆ SwRI's Tier 2 Concept
  - Modified Combustion
  - Dual-Loop EGR
  - 4-way Catalyst System
- ◆ Combustion Characteristics
- ◆ Tailpipe Emissions
- ◆ Summary



# Emissions Regulations - Light Duty

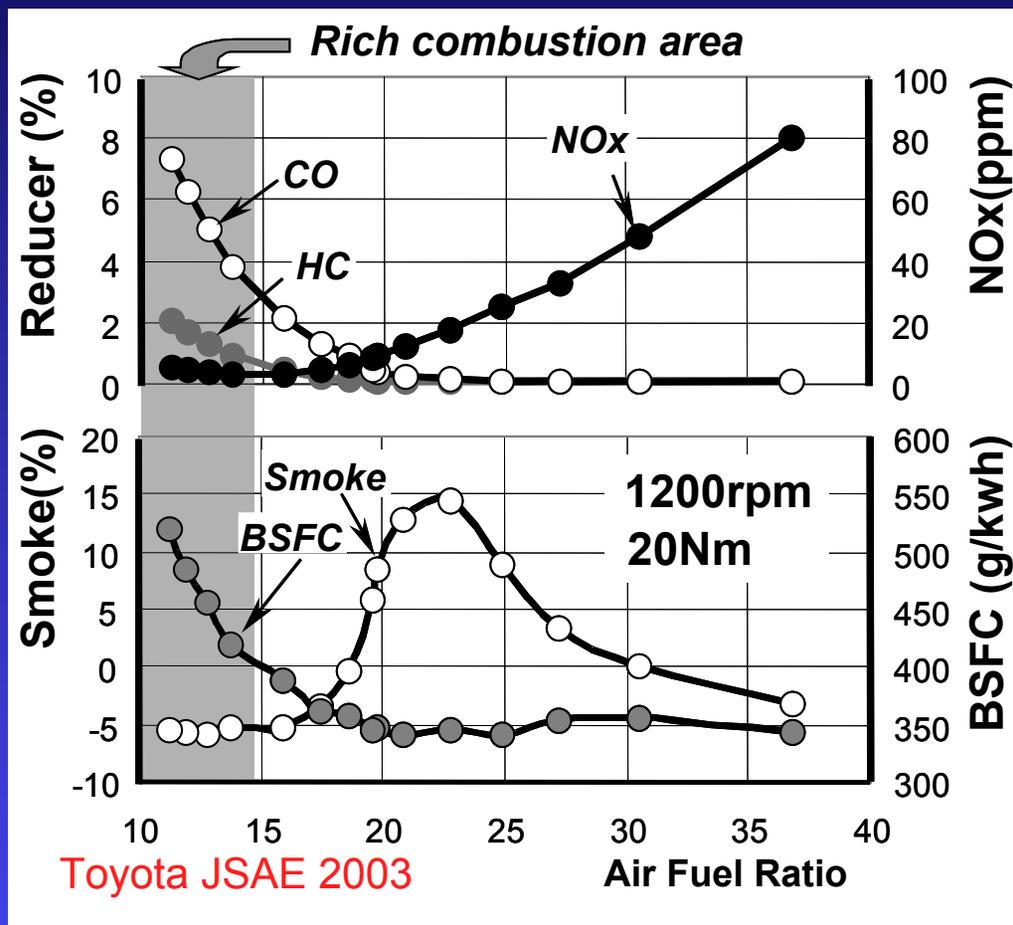


# SwRI's Tier 2 Concept



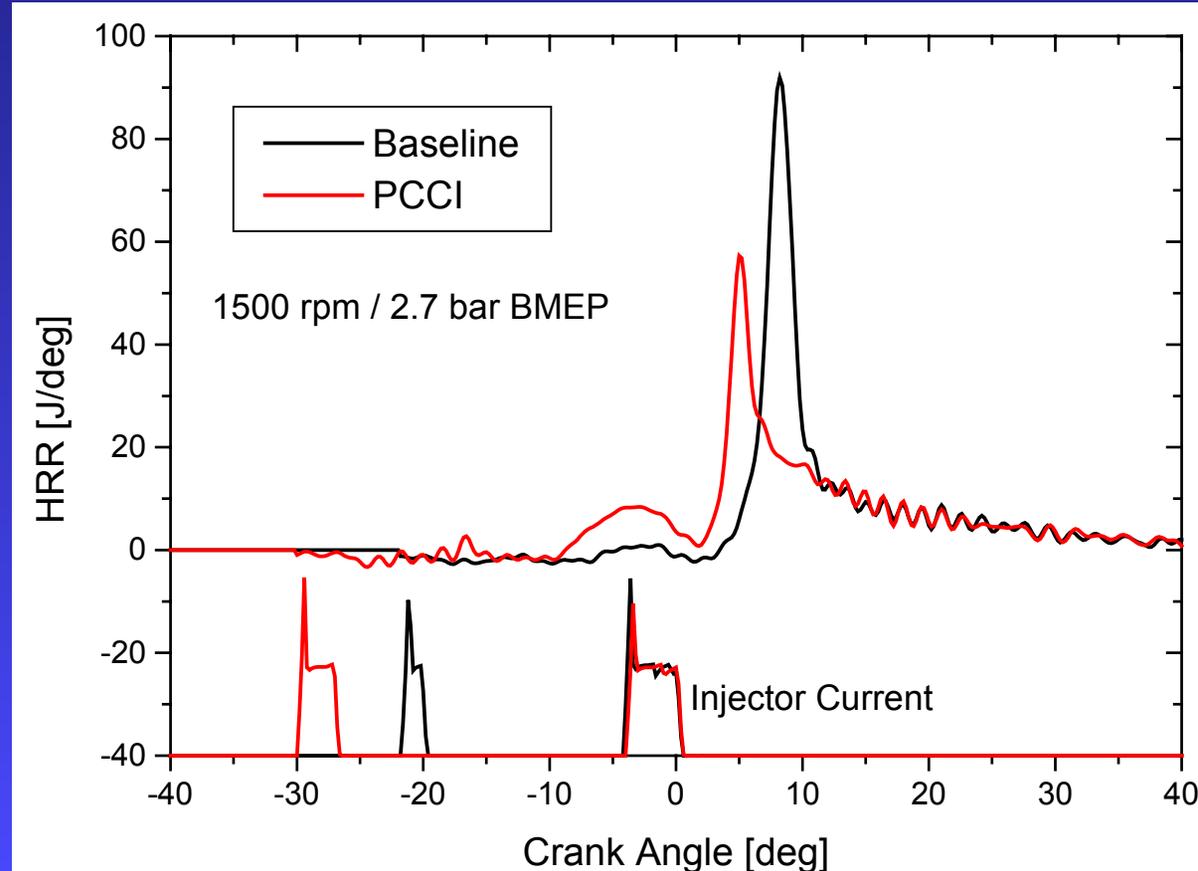
# Modified Combustion Processes: Low Temperature Combustion (LTC)

- ◆ Decreasing A/F and/or increasing EGR eventually
  - reduces combustion temperatures → low NOx
  - freezes soot formation reactions → low soot
- ◆ Increases HC and CO which is good for regeneration of exhaust treatment devices
- ◆ Potentially no BSFC penalty for lean operation
- ◆ Limited to light-load operation (< 5 bar BMEP)

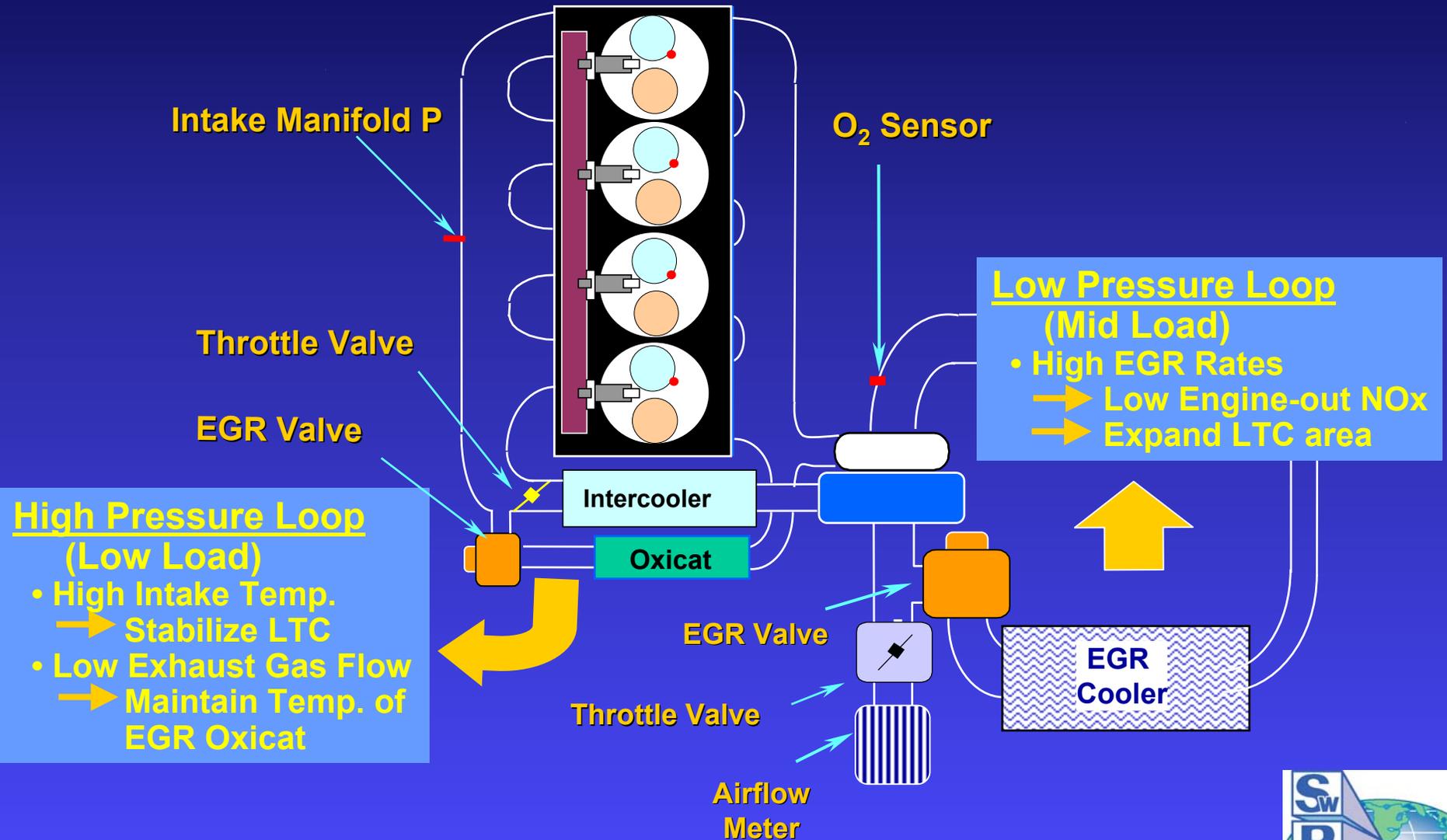


# Modified Combustion Processes: Premixed Controlled Compression Ignition (PCCI)

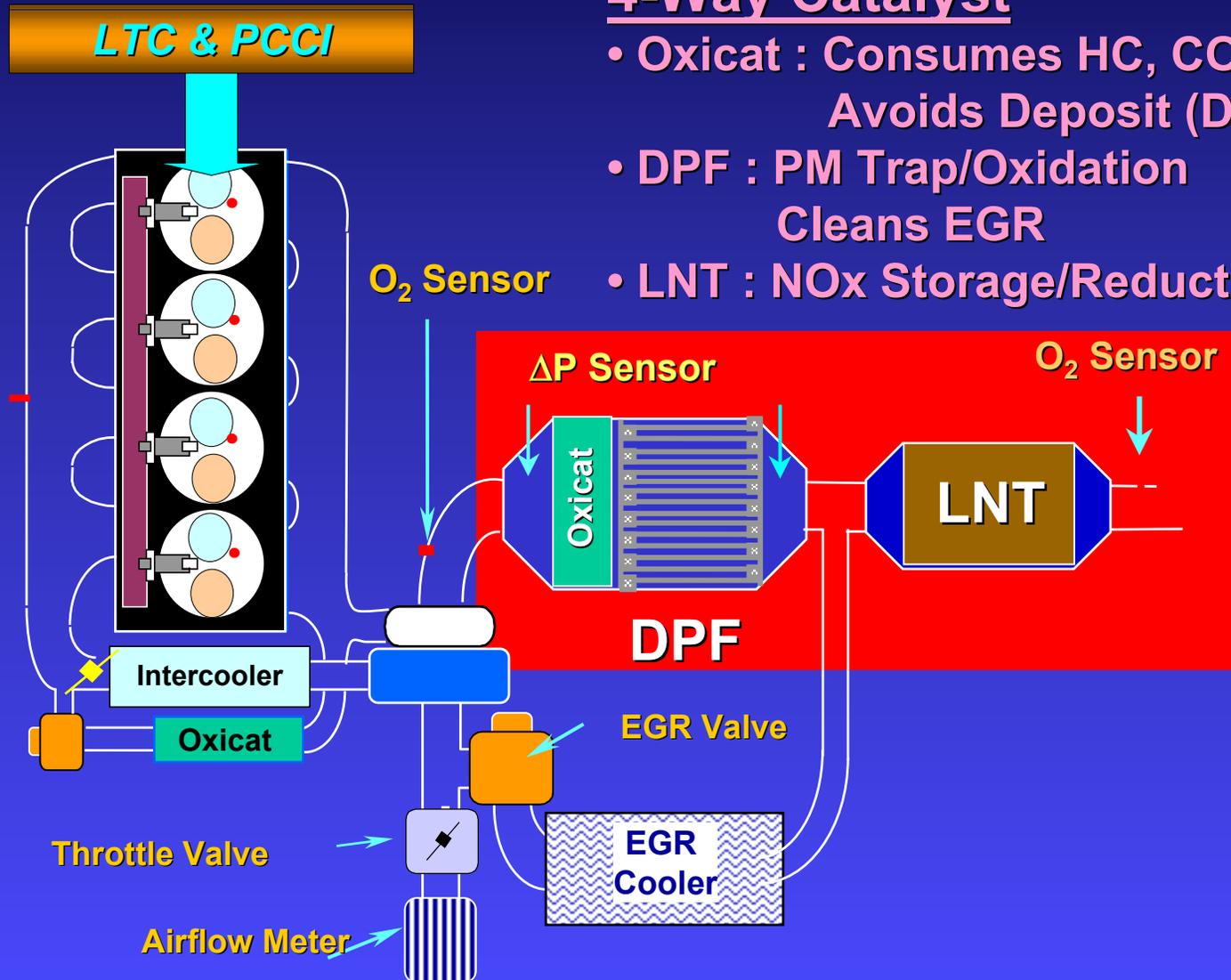
- ◆ Premixing 20-50% of charge followed by main injection
  - Larger pilot quantities than conventional pilot injections
- ◆ Increases amount of fuel undergoing lean combustion to  
↓  $\text{NO}_x$
- ◆ A subset of HCCI
- ◆ Useful to stabilize rich combustion under high load conditions by reducing ignition delay
- ◆ Used at mid to high loads



# Elements Necessary for LTC: SwRI's Dual-Loop EGR System



# SwRI's Dual-Loop EGR and 4-Way Catalyst System



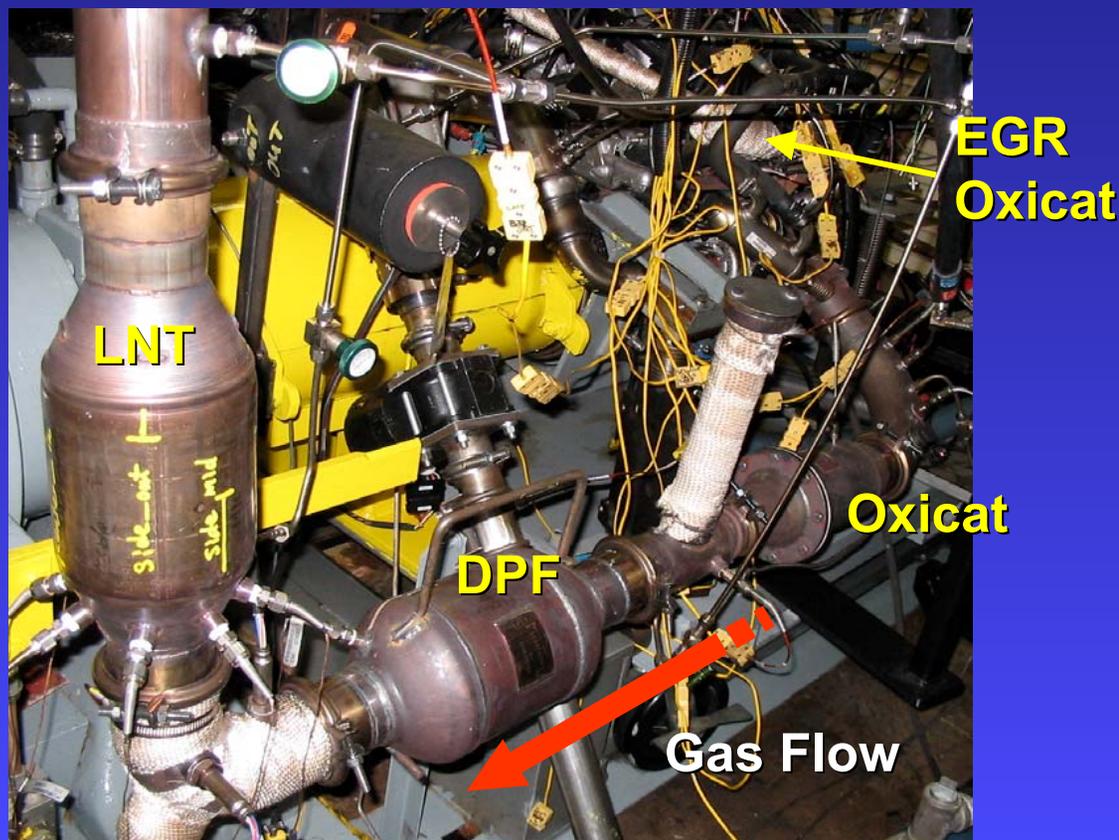
## 4-Way Catalyst

- Oxicat : Consumes HC, CO, O<sub>2</sub>  
Avoids Deposit (DPF Front)
- DPF : PM Trap/Oxidation  
Cleans EGR
- LNT : NO<sub>x</sub> Storage/Reduction

# Exhaust Treatment Example

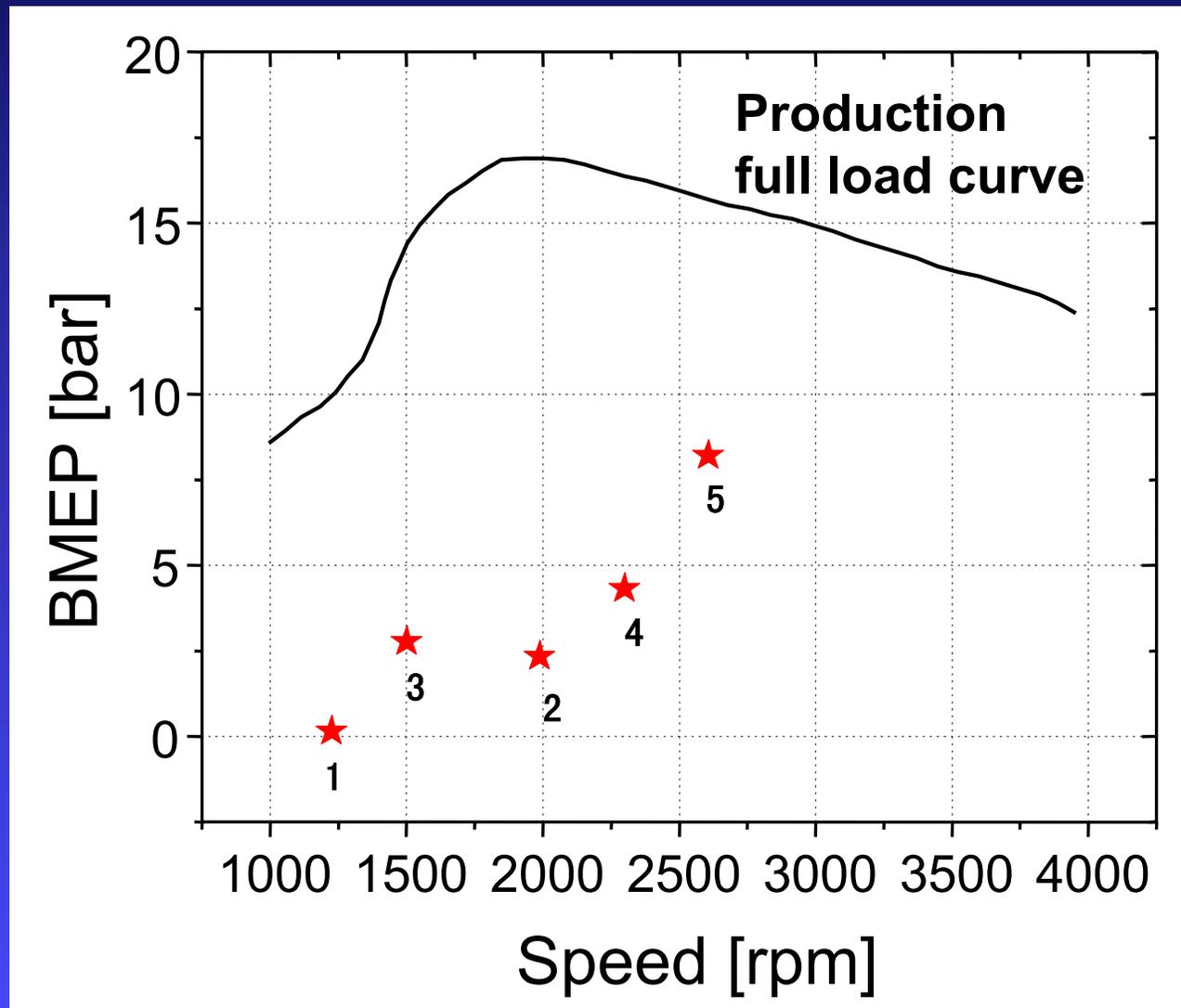
(SwRI IR Project 03.R9467, PSA DW10 2L Engine)

- ◆ Oxidation Catalyst: Pt based,  $V=1.2L$
- ◆ DPF: Catalyzed, SiC, wall-flow,  $V=2.5L$
- ◆ LNT: mass-produced for gasoline DI in Japan,  $V=1.7L$



# Test Modes - Analog of US FTP-75 Cycle

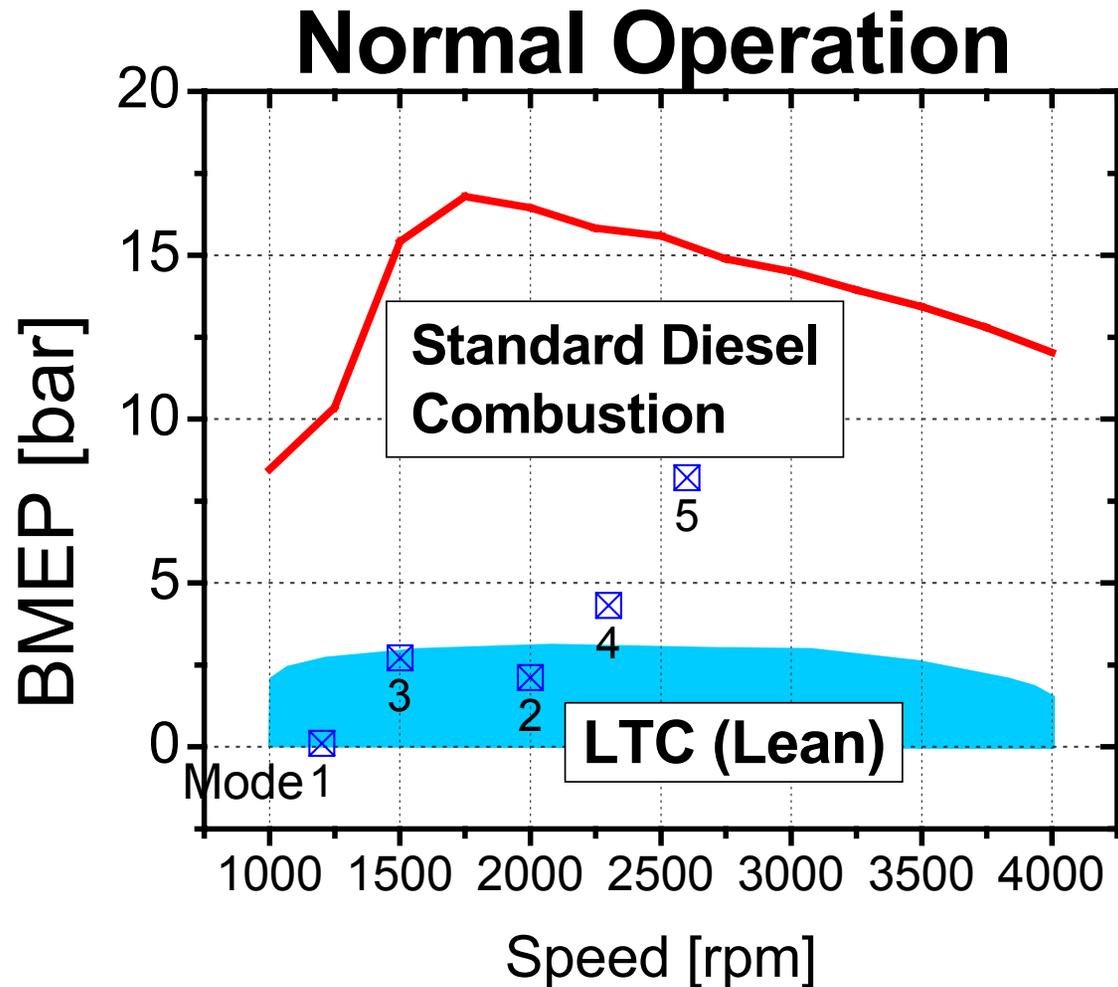
(ref. SAE Paper 2001-01-0148)



# Tier 2 Combustion Strategies



# Strategy: Normal Operation



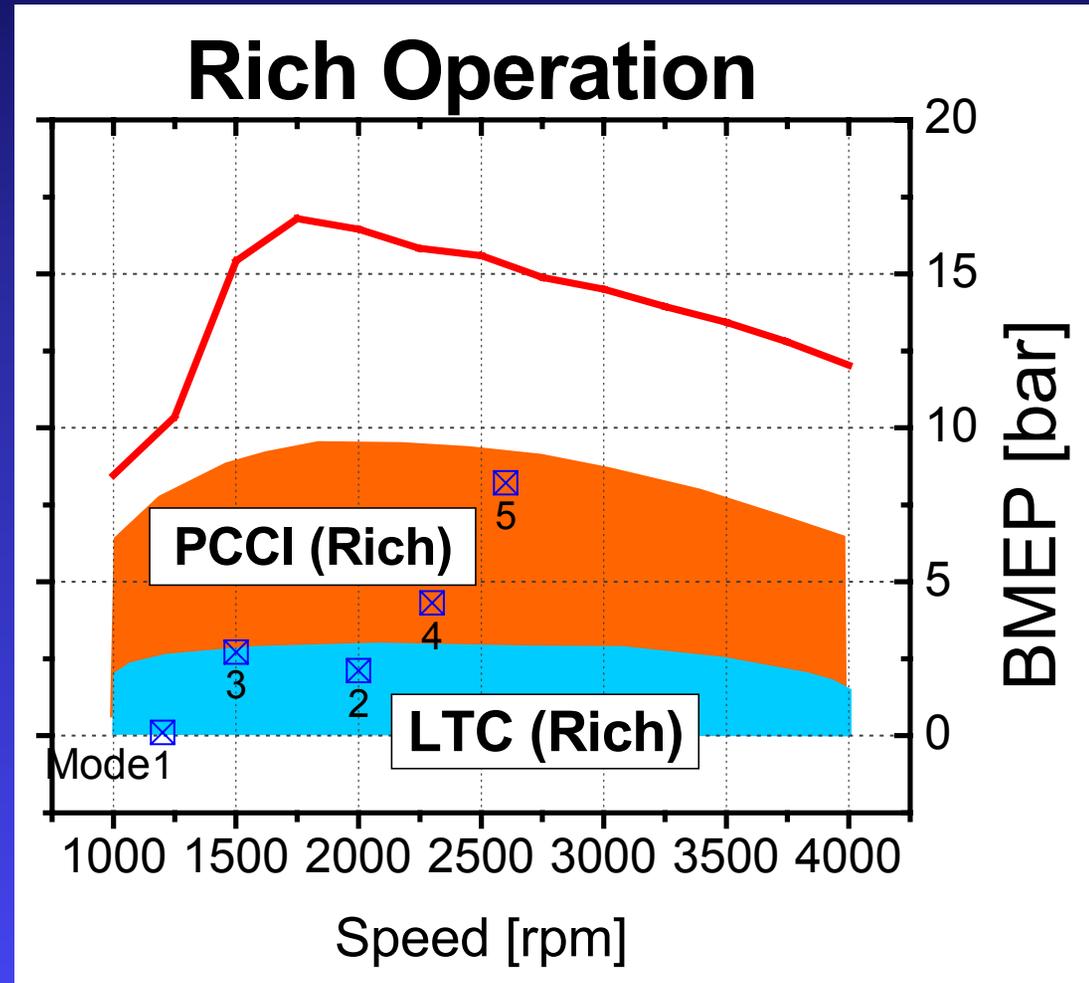
## ◆ LTC Lean produces:

- low engine-out NO<sub>x</sub> (<15 ppm)
- high HC (~2000 ppmC) and CO (~2%) for activating oxidation catalyst and DPF



# Strategy: Rich Operation for LNT Regeneration

- ◆ Operate rich (~12.5-14:1 air-fuel ratio) for a few seconds every several minutes
- ◆ Provides reductant to regenerate stored nitrates in the LNT



# Comments

- ◆ **Approaches shown:**
  - capitalize on inherently low engine-out NO<sub>x</sub> and smoke emissions at low load
  - use airflow control and minor in-cylinder fuel increases to run rich temporarily
- ◆ **Control strategies depend upon the formulation of the LNT and orientation of the exhaust treatment components**

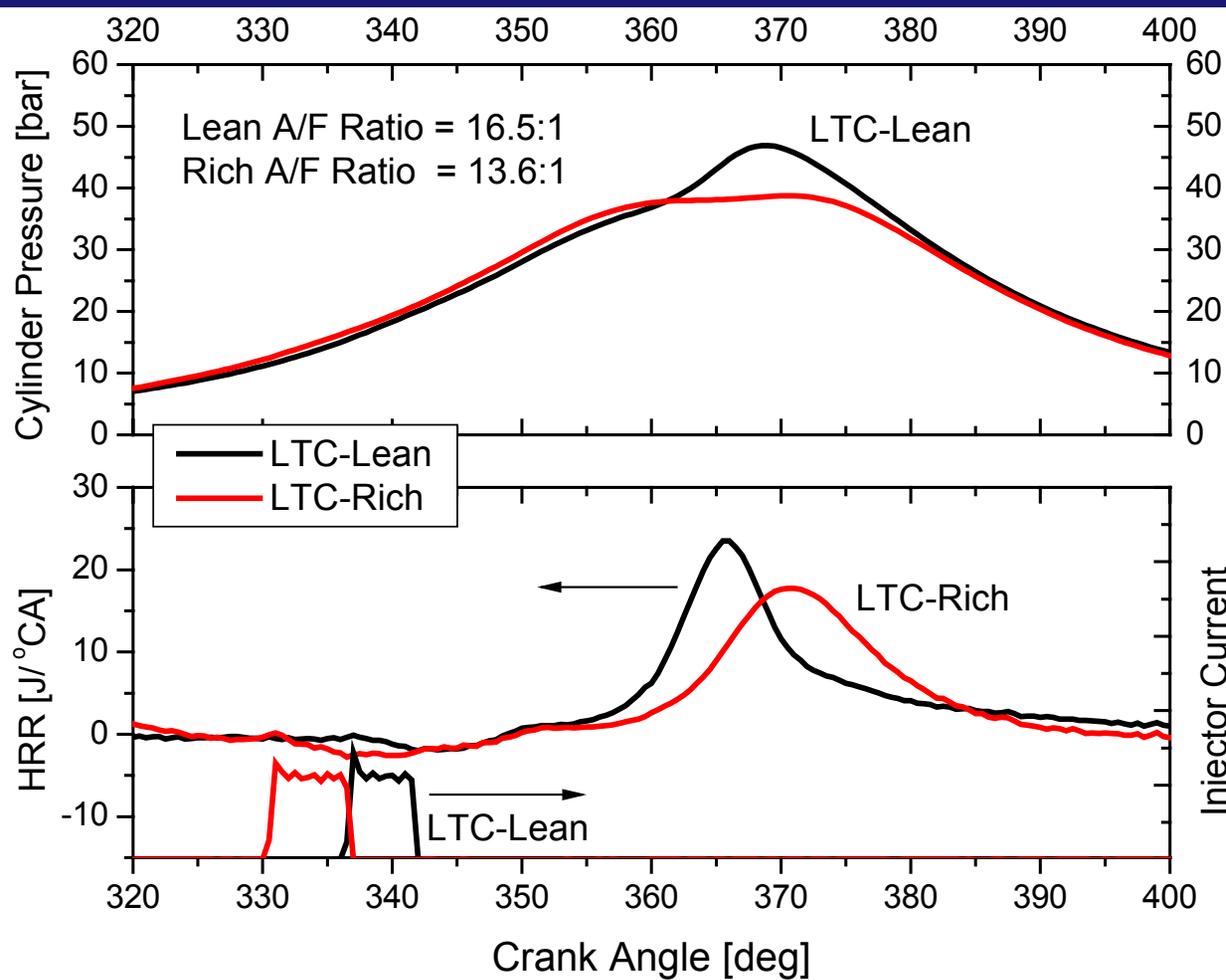


# Combustion Characteristics



# Combustion Characteristics - Mode 1

(1200rpm, 0.8bar BMEP, PSA DW10)

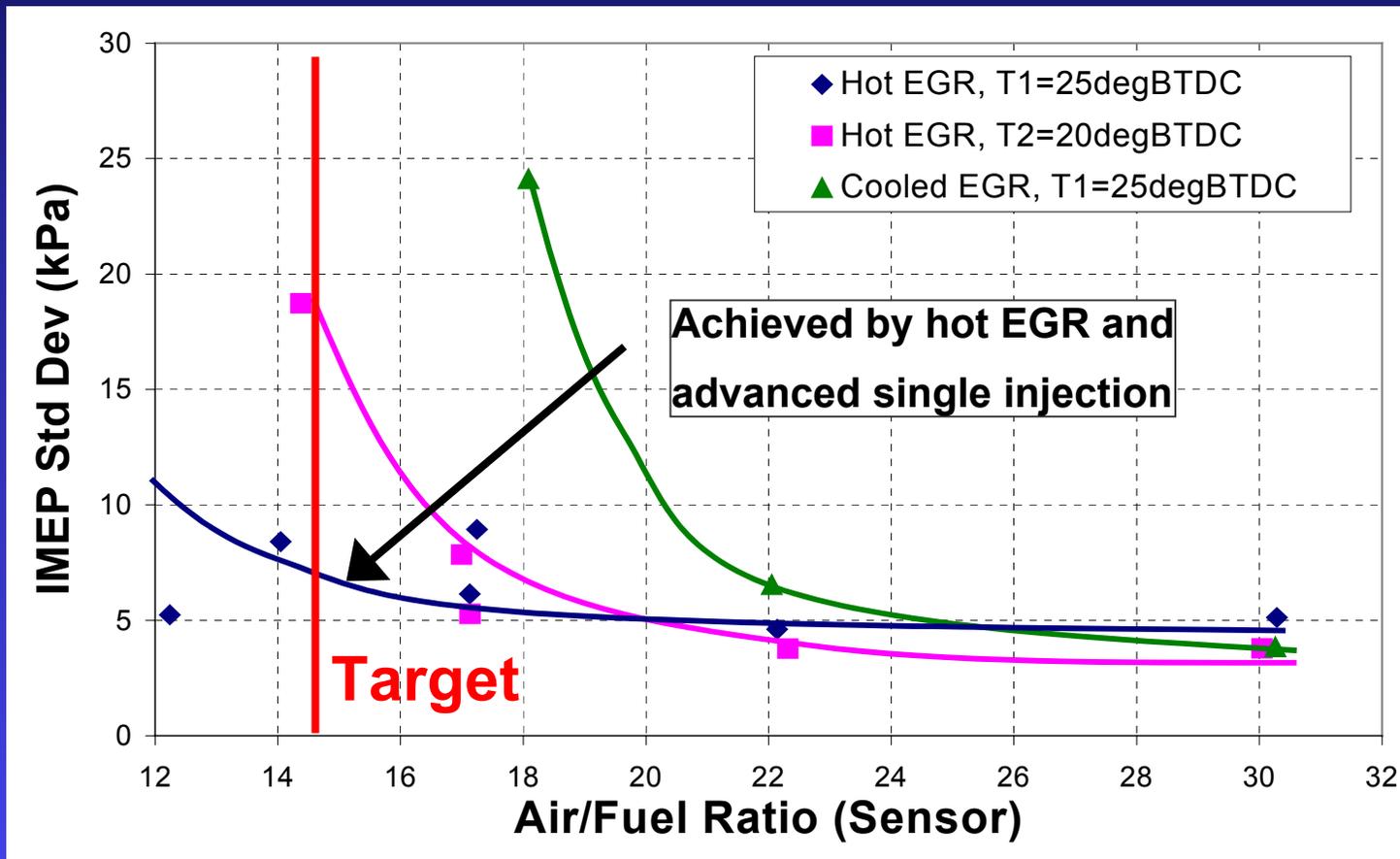


- ◆ Single injection, advanced from standard diesel
- ◆ Hot, high pressure EGR (>60%)
- ◆ Smooth combustion
- ◆ 300°C LNT bed temperature for steady-state lean
- ◆ LTC Rich used for LNT regeneration
  - no post
  - no exhaust port injection



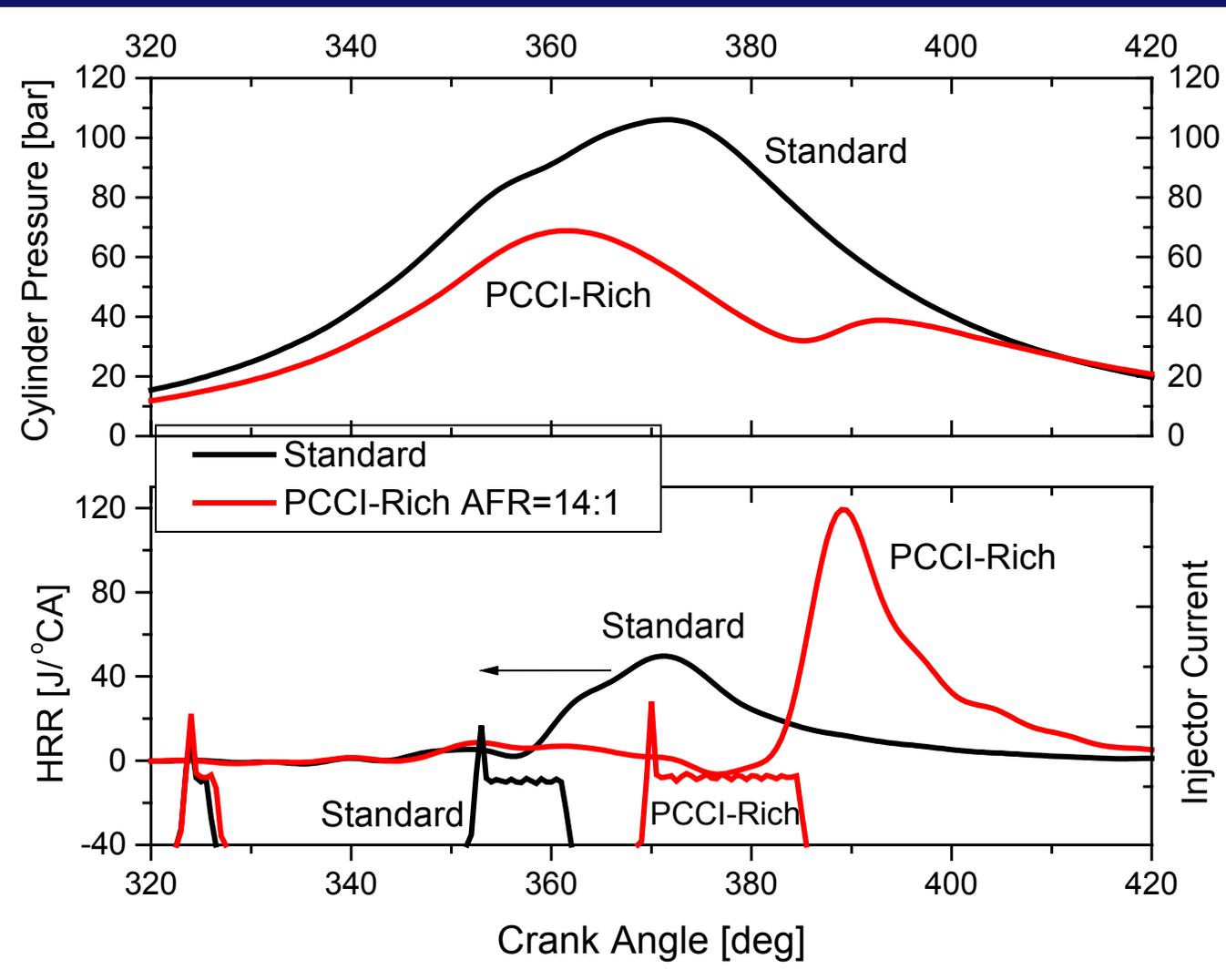
# Approach to Stabilize Combustion at Light Load - Mode 1

- ◆ 60-70% EGR causes instability
- ◆ Use of higher temperature EGR stabilizes combustion
- ◆ High-pressure EGR loop used
- ◆ Timing advance required



# Combustion Characteristics - Mode 5

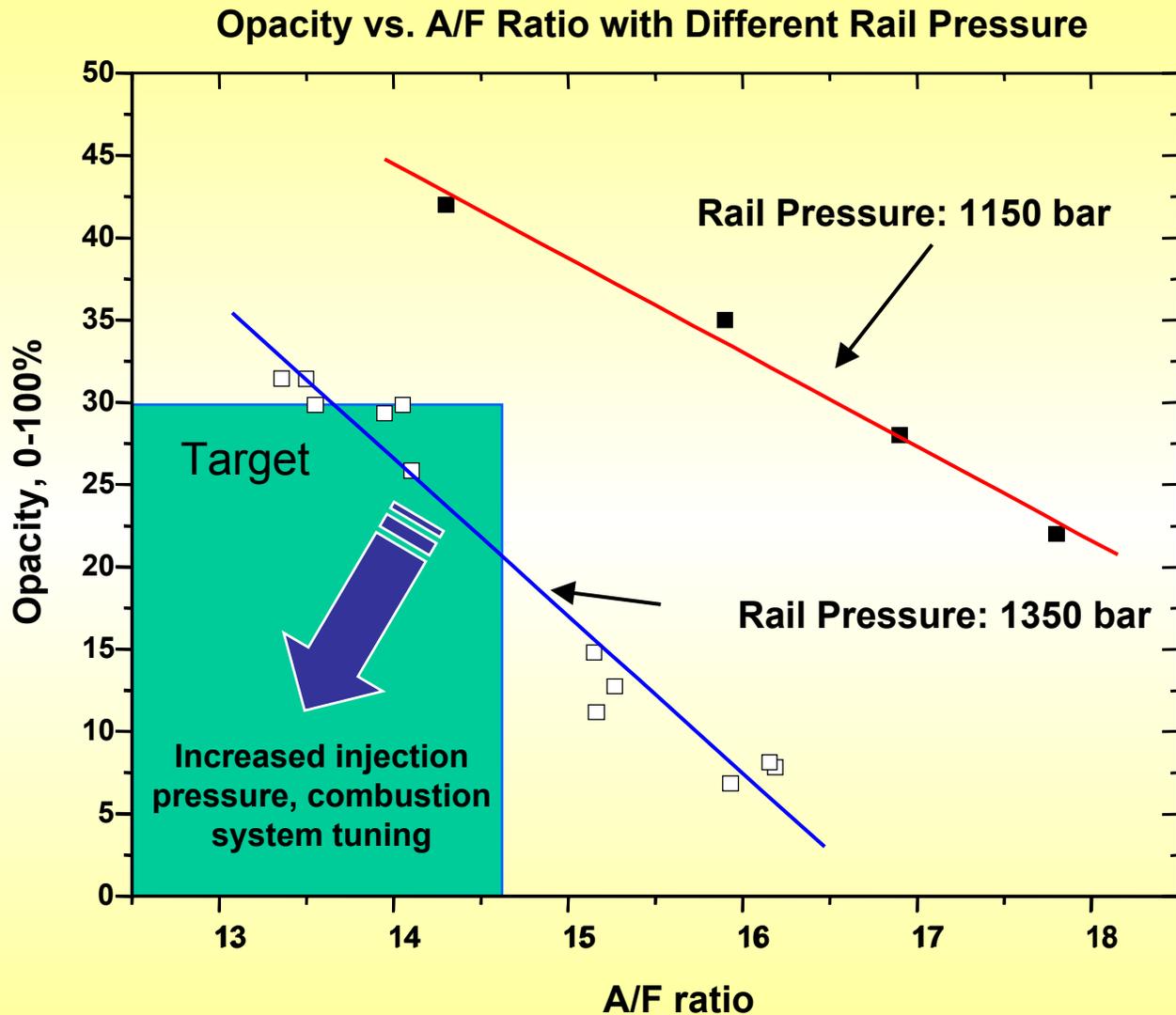
(2600rpm, 8.2bar BMEP, PSA DW10)



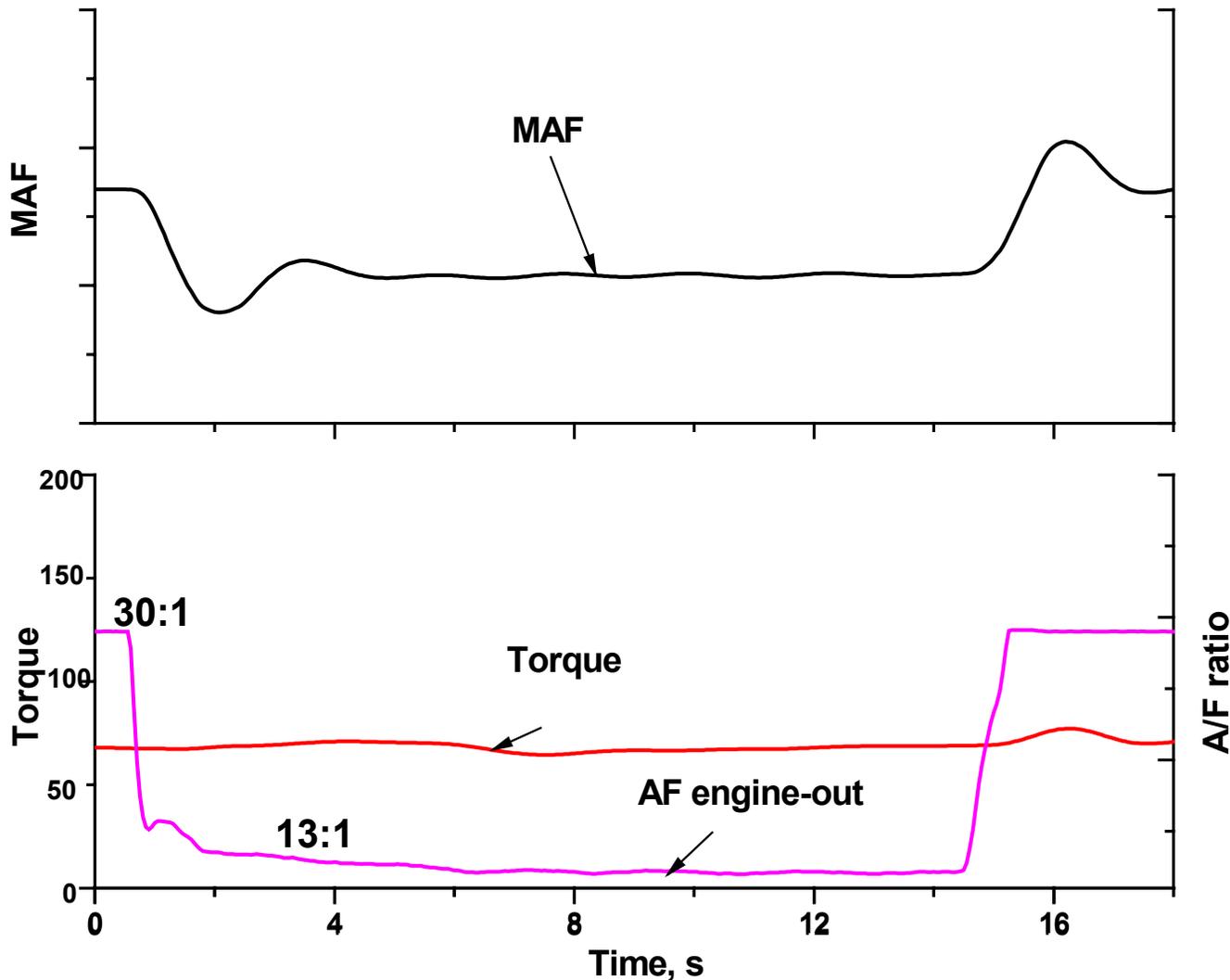
- ◆ No post injection
- ◆ < 30% peak opacity with 1350 bar peak injection pressure
- ◆ Main timing for PCCI-rich is 8° ATDC - smoke control



# Peak Opacity vs. A/F Ratio and Rail Pressure: PCCI - Mode 5



# Constant Torque during Rich-Lean Switching (Mode 4)



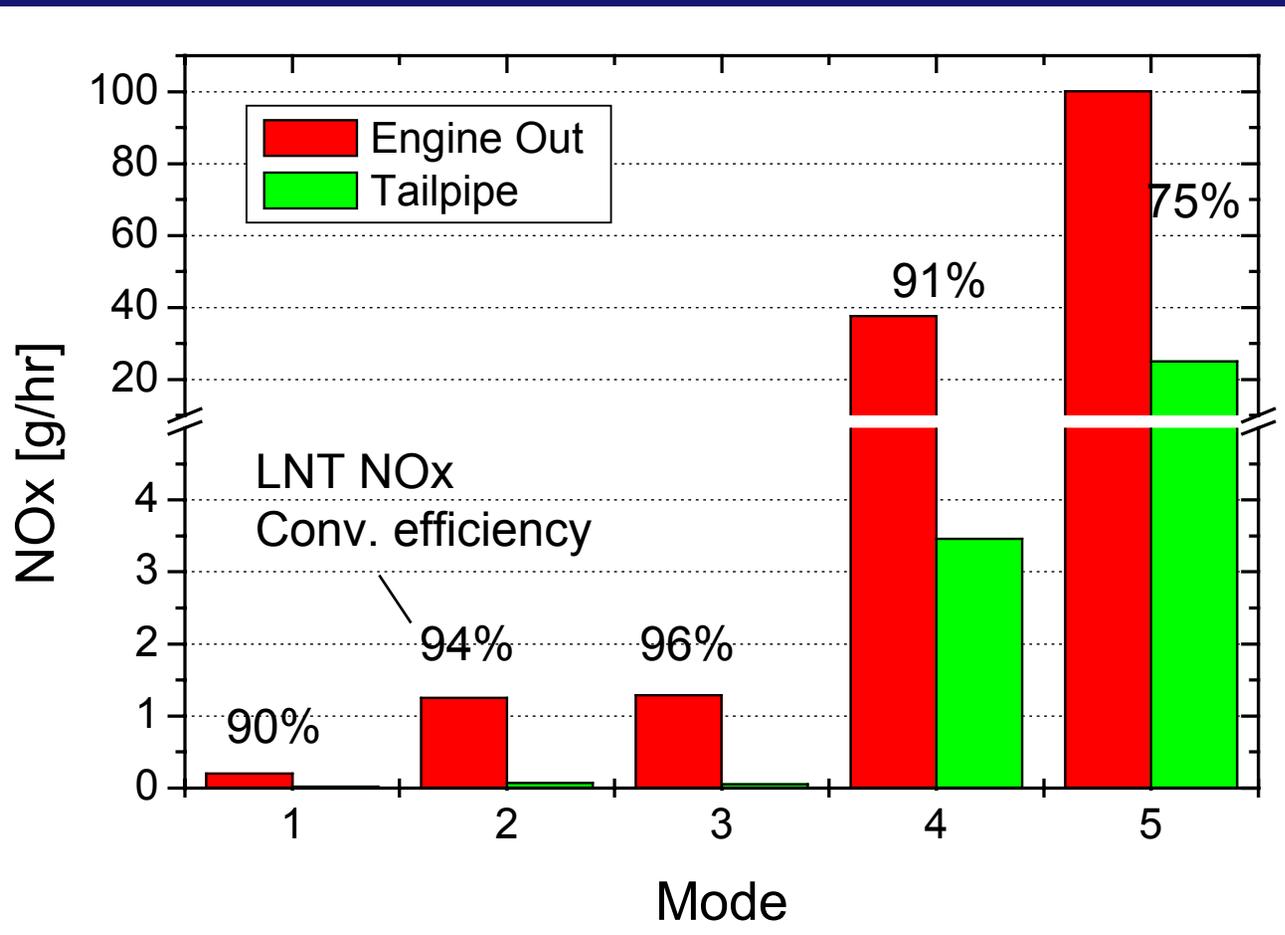
- ◆ Airflow-based control
- ◆ Over-shooting of the throttle results in rapid A/F change
- ◆ Minimal torque fluctuations



# Tailpipe Emissions with Four-Way Catalyst System



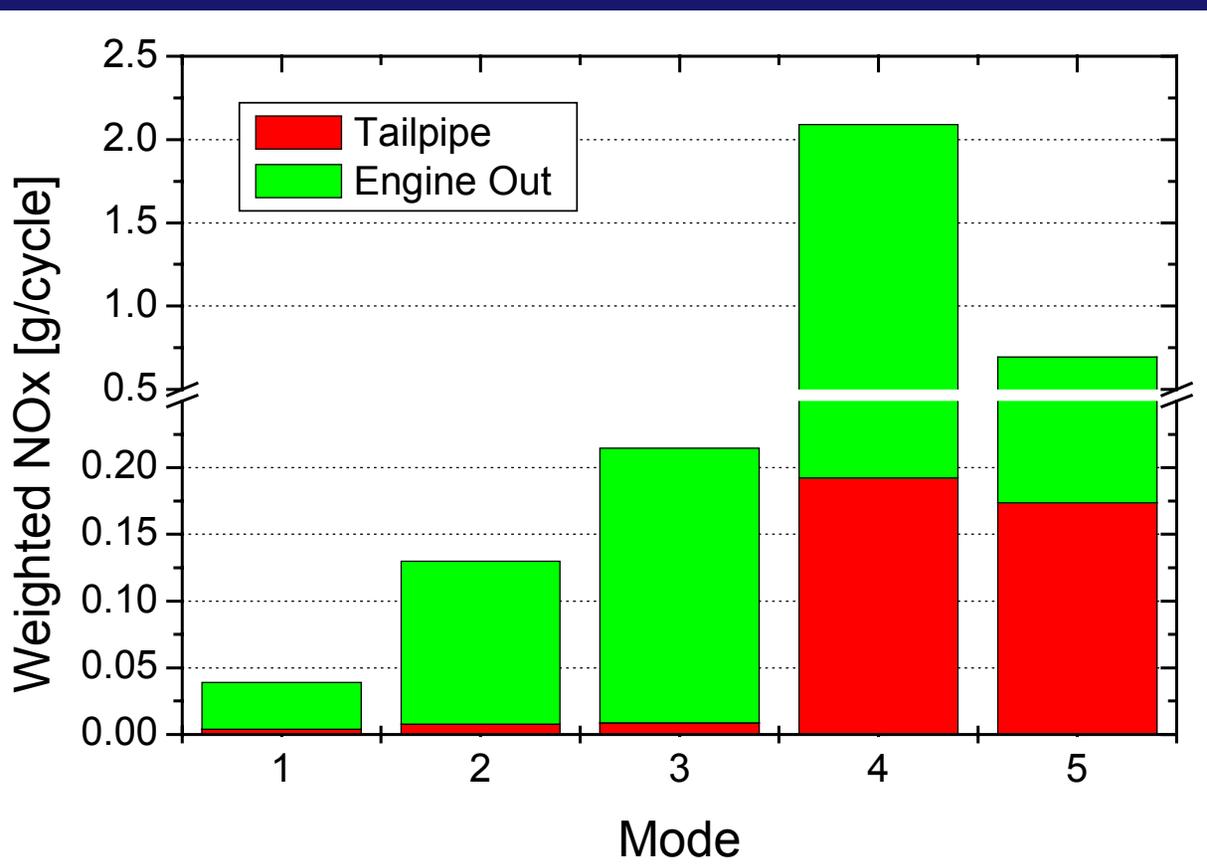
# NO<sub>x</sub> Emissions over 5 Test Modes



- ◆ NO<sub>x</sub> conversion efficiencies for a given LNT regeneration strategy
- ◆ Modes 1-3 have very low engine-out NO<sub>x</sub> due to LTC. LNT will store the remainder.
- ◆ Mode 5 has a low conversion eff. due to high exhaust temperatures



# Estimated Cycle NOx Results



- ◆ Weighted engine-out NOx over cycle = 0.287 g/mile
- ◆ Weighted tailpipe NOx = 0.035 g/mile
  - Tier 2, Bin 5 limit is 0.07 g/mile
- ◆ Average weighted NOx reduction = 88%
- ◆ Initial results done with open-loop fuel control
  - airflow based control will reduce BSFC penalty



# Summary

- ◆ **SwRI has developed a combustion control concept capable of achieving US Tier 2, Bin 5 for light-duty diesels with a 4-way catalyst system**
- ◆ **Issues:**
  - control algorithms for rich-lean switching
  - control algorithms for mode switching
  - avoiding uncontrolled exotherms in LNT during de-sulfation
  - DPF regeneration
  - minimizing fuel consumption/ $\text{CO}_2$  penalties over transient cycles
  - high load operation (e.g., US 06 cycle)



***THANK YOU!***

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