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# The Effect of Heavy-Duty Diesel Emission Standards on U.S. Army Ground Vehicles

SERDP (Strategic Environmental Research and Development Program) - 'Environmental Impact of Fuel Use on Military Engines'

December 5, 2007

# Report Documentation Page

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# Outline

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- **Fuels and Lubricants Discussion**
- **Current Army Ground Vehicle Engine Philosophy and Conclusion**

# Conclusion

- The Army can not buy 2007 compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

# Introduction to Army Ground Vehicles

P.J. Schihl

# Representative Army Ground Vehicles

## COMBAT VEHICLES

- M1 Abrams (AGT-1500)
- M109/M110 Self Propelled Howitzer (8V71T)
- M2/M3 Bradley (VTA-903)
- M88 Medium Recovery Vehicle (TCM-1790)
- M578 – Light Armored Recovery Vehicle (LRC) – (8V71T)
- M60 family (TCM-1790)
- Chaparral Missile Launcher (6V53T)
- FAASV – Fast Assault Ammunition Supply Vehicle (8V71T)
- M551 Sheridan Assault Vehicle (6V53T)
- Stryker (3126)
- MRAP Mine Resistant Ambush Protected (ITEC I6)

## TACTICAL VEHICLES

- HET Heavy Equipment Transporter (8V92TA)
- HEMTT Heavy Expanded Mobility Tactical Truck (8V92TA)
- PLS Palletized Loading System (8V92TA)
- 2.5 Ton Truck (LD-465/LDT-465)
- M939 5 Ton Truck (NHC 250/6CTA8.3)
- M915/M916 Line Hauler (NTC400/S-60)
- M917, M918, M919 Tractor (NTC 400)
- HMMWV (GM 6.2/6.5 IDI)
- CUCV Commercial Utility Cargo Vehicle (GM 6.2/6.5 IDI)
- FMTV Family of Medium Tactical Vehicles (C7)

LEGEND: **red: two-stroke diesel** **white: four-stroke diesel** **yellow: gas turbine**

# Army Ground Vehicles

**300,000 +** **tactical and combat vehicles (150 – 1500 BHP)**

**240,000 +** **trucks – class 2 thru class 8 + (150 – 500 BHP)**

**40,000 +** **2-stroke powered vehicles (200 – 500 BHP)**

**M113 Personal Carrier**

**PLS – Palletized Loading System**

**MRAP - Mine Resistant Ambush Protected**

**HEMTT – Heavy Expanded Mobility Tactical Truck**

*FVPDS (Jan. 2000)

Fielded Vehicle Performance Data Systems

# Army Ground Vehicle Propulsion Challenges

**‘Traditional Issues’**

1. Cooling
2. Fuel Effects
3. Filtration

**Evolving Need for Better Protection, i.e. More Weight**

1. Cooling
2. Sluggish Mobility

The Army vehicle cooling point is high tractive effort to weight under desert-like operating conditions (ex. 5 ton wheeled vehicle ~0.6 while 15+ ton tracked vehicle ~0.7 both at 120 F ambient or higher)

# Overview Heavy-Duty Diesel Emission Standards

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# Regulatory Approach (2007)

**EPA finalized motor vehicle diesel fuel regulations and the heavy duty diesel *on-road* exhaust emissions regulations in January 2001.**

**Took a dual approach to reduce air emissions by:**

1. Reduction in diesel fuel sulfur concentration to 15ppm starting June 2006.
   - Enable the use of exhaust system aftertreatment devices
   - **JP-8 specification calls for < 3000 ppm!**
2. Establish stringent exhaust emission standards - effective **2007.**
   - Phased-in approach; fully meet standards in **2010**
   - Require aftertreatment device(s)
     - Particulate filters in 2007
     - NOx aftertreatment 2010 (traps or urea SCR)

**(Both regulations implemented with a phased approach)**

**Off-road standards similar in nature and 'lag' on-road standards by approximately three years depending on engine rated power**

# Potential Impacts to DoD

- **Ground tactical vehicles (i.e. HEMMT, PLS, HMMWV) operating in the U.S. required to meet the fuel 15 ppm sulfur regulation**
  - JP-8 does not meet this requirement (specification < 3000 ppm)

- **Procure vehicles with pollution control technology**
  - Potential performance degradation (fuel consumption, reliability, durability)
  - The current leading pollution control technology candidates are intolerant of high sulfur fuel
  - Significant increase in vehicle thermal load

- **Nebulous world wide operation since low sulfur fuel is not available world wide:**
  - Low sulfur diesel fuel is an enabler for pollution control devices

**(Combat vehicles (i.e. Abrams, Bradley, Stryker) are automatically exempt under 40 CFR, 89.908)**

# DoD Interaction with EPA

- **EPA approved NSE request for JP-8 exclusion from on-road 2006 and off-road 2007 diesel fuel regulations**
- **'Blanket NSE' granted from meeting 2007+ heavy-duty, on-road emission standards (August 23, 2005)**
- **'Blanket NSE' granted from 2004 on-road emission standards (November 15, 2006)**
- **Off-Road equipment Tier IV emission standards NSE submitted to the EPA**

# Emission Control Technology Discussion

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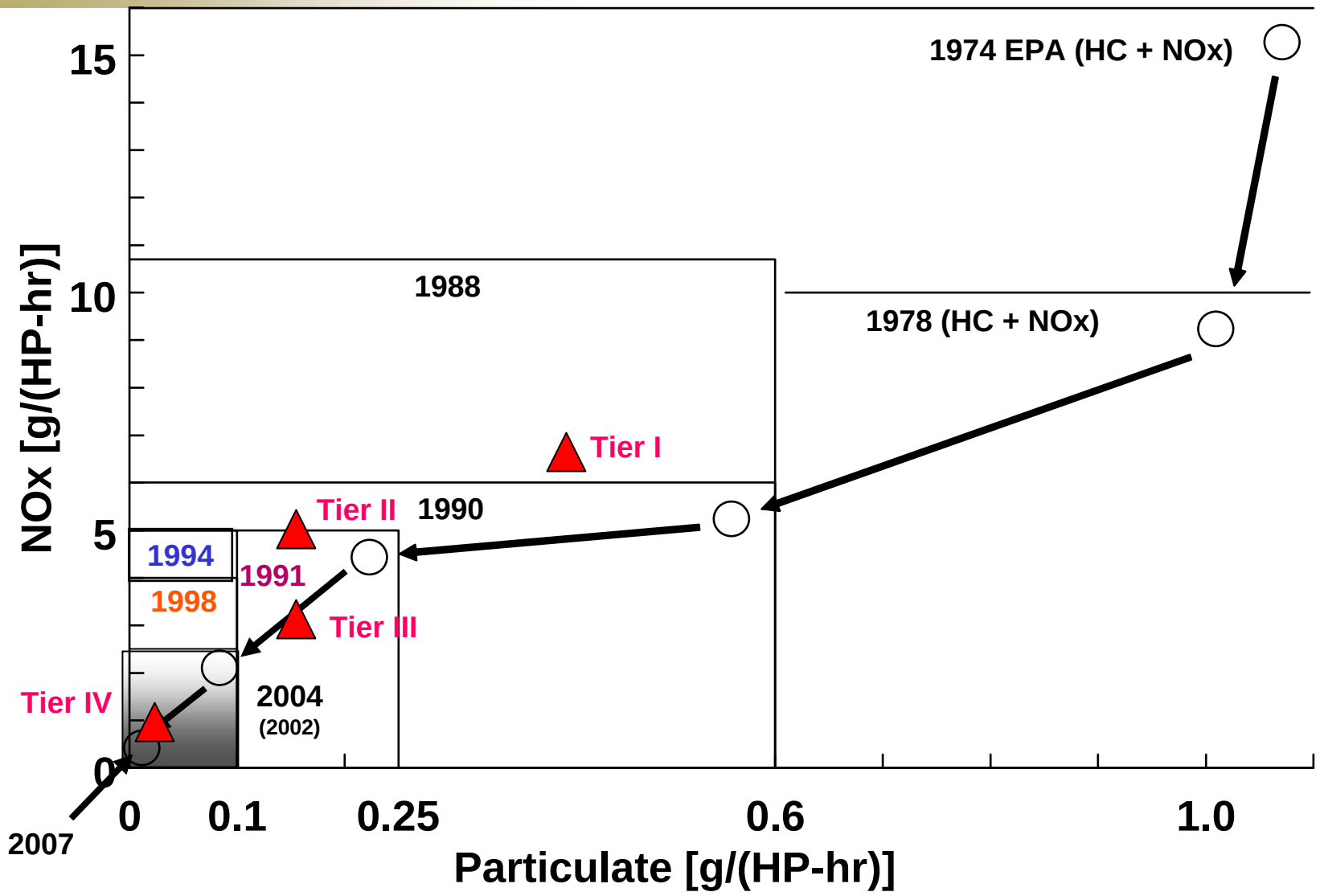
# On-Road Versus Off-Road HD Standards (300 – 600 BHP)



# On-Road Emission Standards



## Impact of 2004 Standards on Commercial Heavy-Duty Diesel Engines

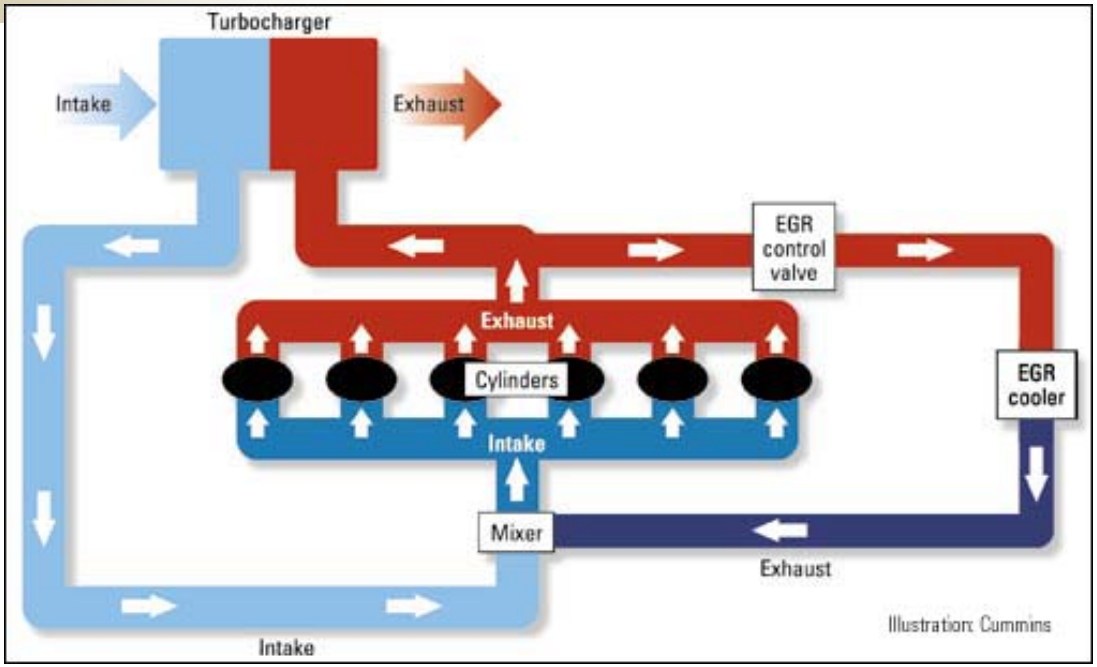
- **C**ooled **E**xhaust **G**as **R**ecirculation (**EGR**)
- **ACERT™** – **A**dvanced **C**ombustion and **E**missions **R**eduction **T**echnology

## Impact of 2007 Emission Standards on Commercial Heavy-Duty Diesel Engines

- **C**ooled **E**xhaust **G**as **R**ecirculation (**EGR**) with advanced combustion and closed-loop engine system controls
- **ACERT™** – **A**dvanced **C**ombustion and **E**missions **R**eduction **T**echnology plus aftertreatment (catalytic converter) and closed-loop engine system controls along with low pressure and ‘filtered’ EGR loop
- New combustion regimes that may require specified fuel properties
- *High Pressure Common Rail fuel systems that require a lubricity additive through a slow dosing fuel filter (OEMs need more flexible fuel systems for multiple event, high pressure fuel injection)*

# What is cooled EGR? (High Pressure)

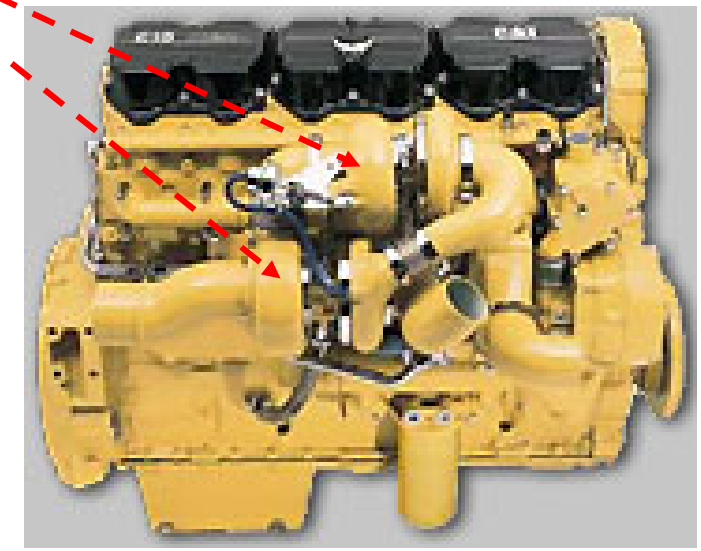




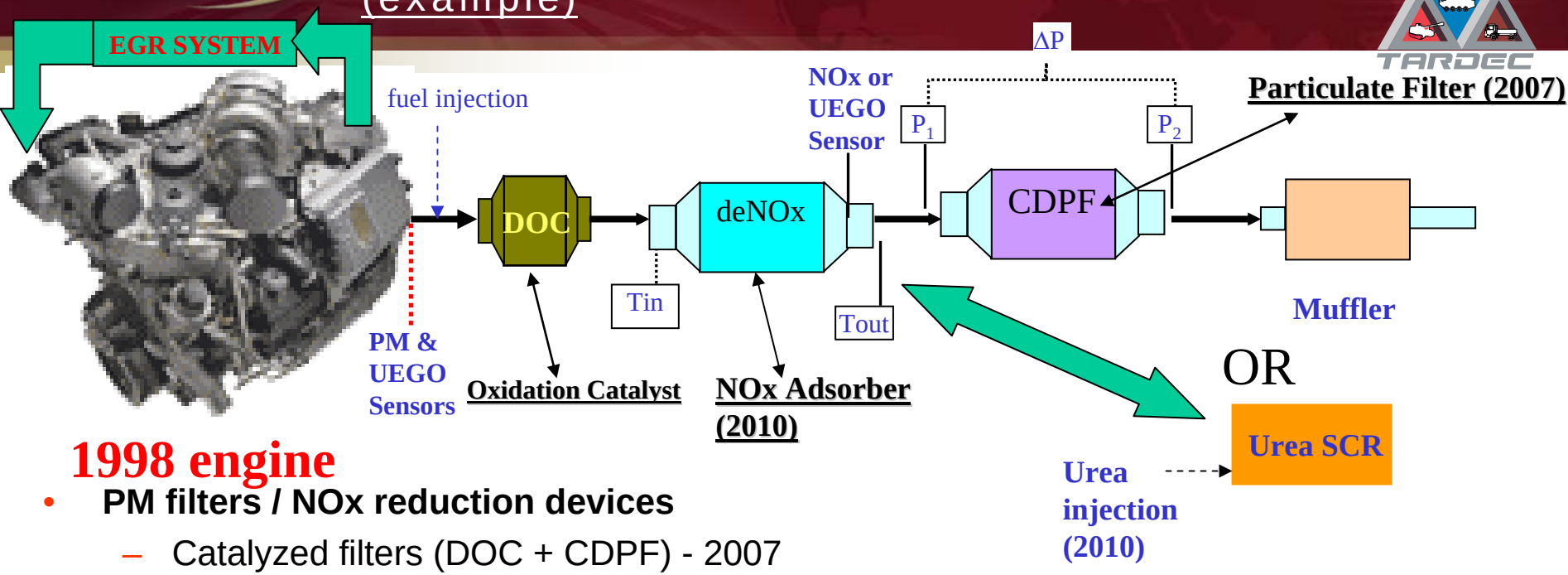

- Reduce nitrous oxides ($NO_x$) through 'cooler' combustion temperatures
- Recirculate and cool exhaust gas downstream of turbine (turbocharger) ; require back pressure restriction to flow exhaust gas to intake system **(fuel economy penalty)**
- **Cool exhaust gas** before dumping into intake system; **additional engine system cooling requirement)**; non-ram air scenarios will have additional fuel economy penalty
- Temperature control of EGR crucial in order to avoid formation of **sulfuric acid that expedites engine wear and reduces durability of EGR cooler and control valve**
- This concept introduces particulates into cylinder ; **requires more frequent oil change w/o certification of proper lubricant**

# What is ACERT™?


- Caterpillar trademark non-EGR solution
- Limited variable intake valve timing ; **extra valve train sophistication**
  - **'cooler' combustion temperatures**
- **Two stages of turbocharging (single stage for smaller displacement engines)**
- **Additional charge air cooling necessary** ; increase in required engine system heat rejection – **not as significant impact as cooled EGR**
- **Passive oxidation catalyst** (catalytic converter) and **diesel particulate filter (DPF)** in some applications along with **low pressure EGR** on 2007 MY applications



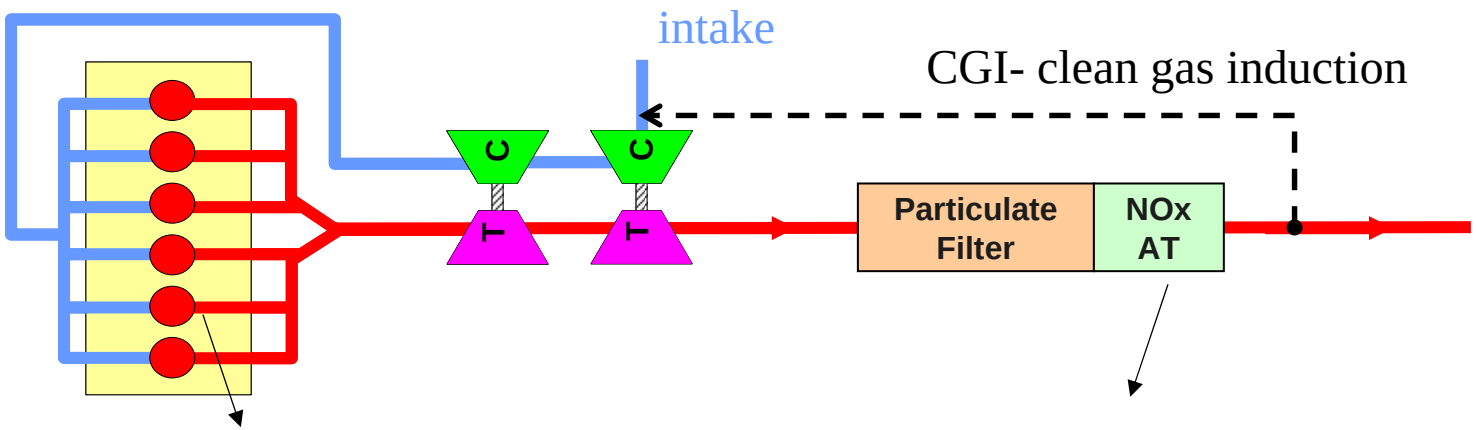
# 2007 Emission Issues : Aftertreatment Devices (example)




## 1998 engine

- **PM filters / NOx reduction devices**
  - Catalyzed filters (DOC + CDPF) - 2007
  - NOx trap (adsorber) vs. Urea SCR (selective catalytic reductant) – 2010
  - Additional space claim , **conservatively 2.5 - 5 times the engine displacement**
- **NOx trap requires 15 ppm fuel sulfur level**
- Likely to include high levels of EGR in additional to NOx aftertreatment device
  - higher heat rejection (~ 50% increase vs. MY1998)
- Push toward new oil formulation to extend CDPF lifetime
- Urea SCR requires on-vehicle, urea storage tank and 'safeties' to ensure vehicle operator compliance; urea quality sensor, cold weather freeze avoidance, empty tank precautions

## Potential ACERT Solution




**Engine NOx Technology**

- Advanced Diesel Combustion

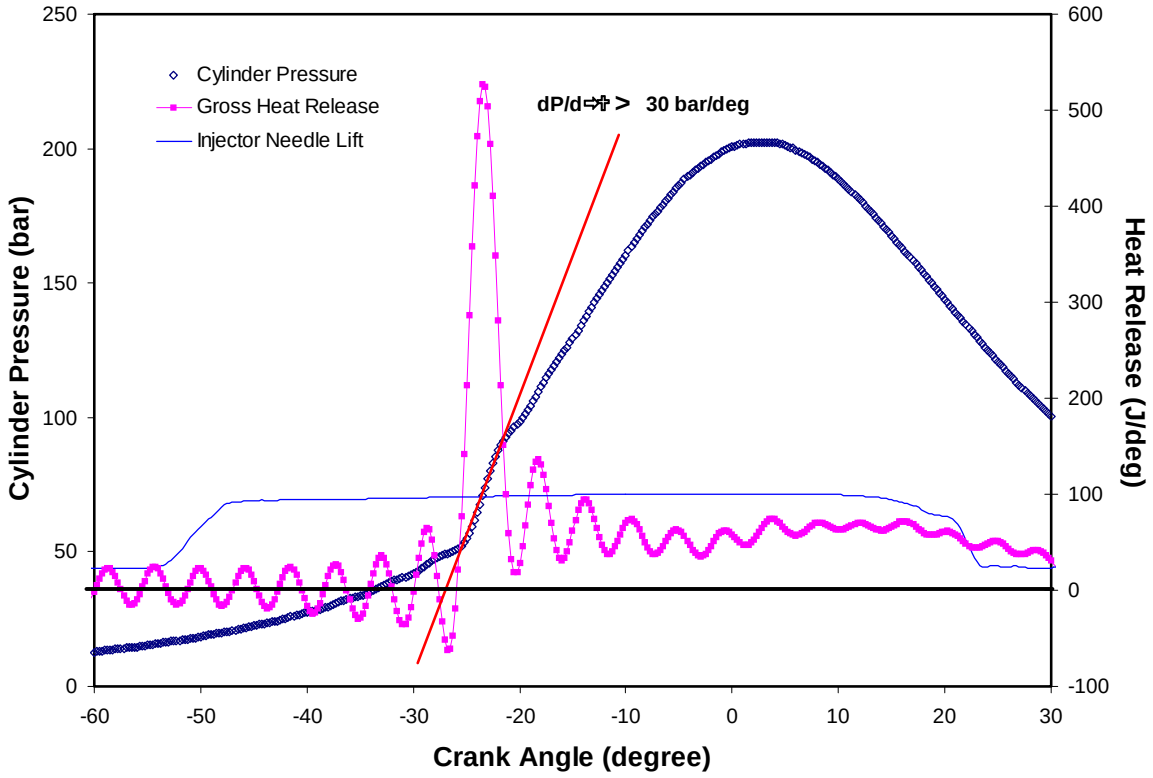
**Aftertreatment NOx Technology Options**

- DeNOx Catalyst
- NOx Adsorber
- Urea SCR

# New Combustion Regimes



- High Pressure Rise Strategies: HCCI, PCCI, etc.
  - fuel ignition quality and evaporation characteristics important
  - JP-8 ‘loose’ property specifications, i.e. CN dependent on supply source



# Fuels and Lubricants Discussion

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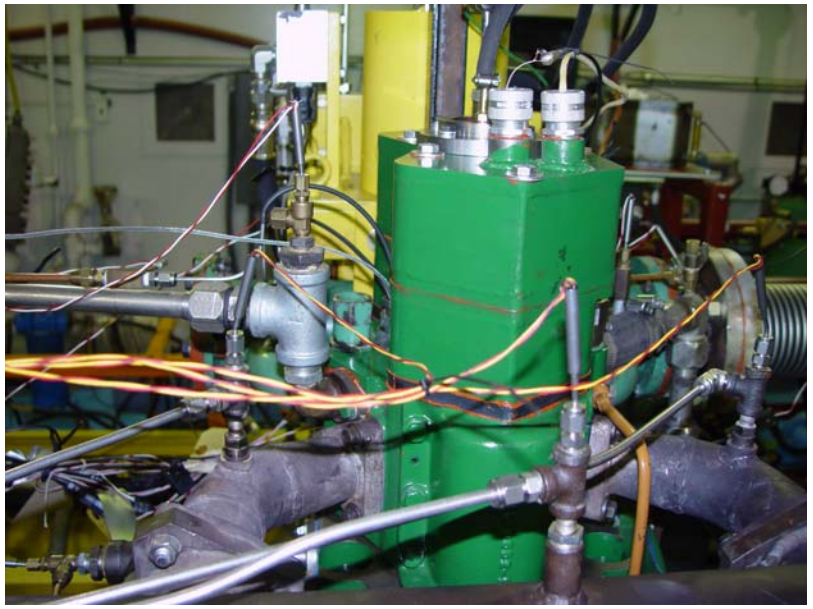
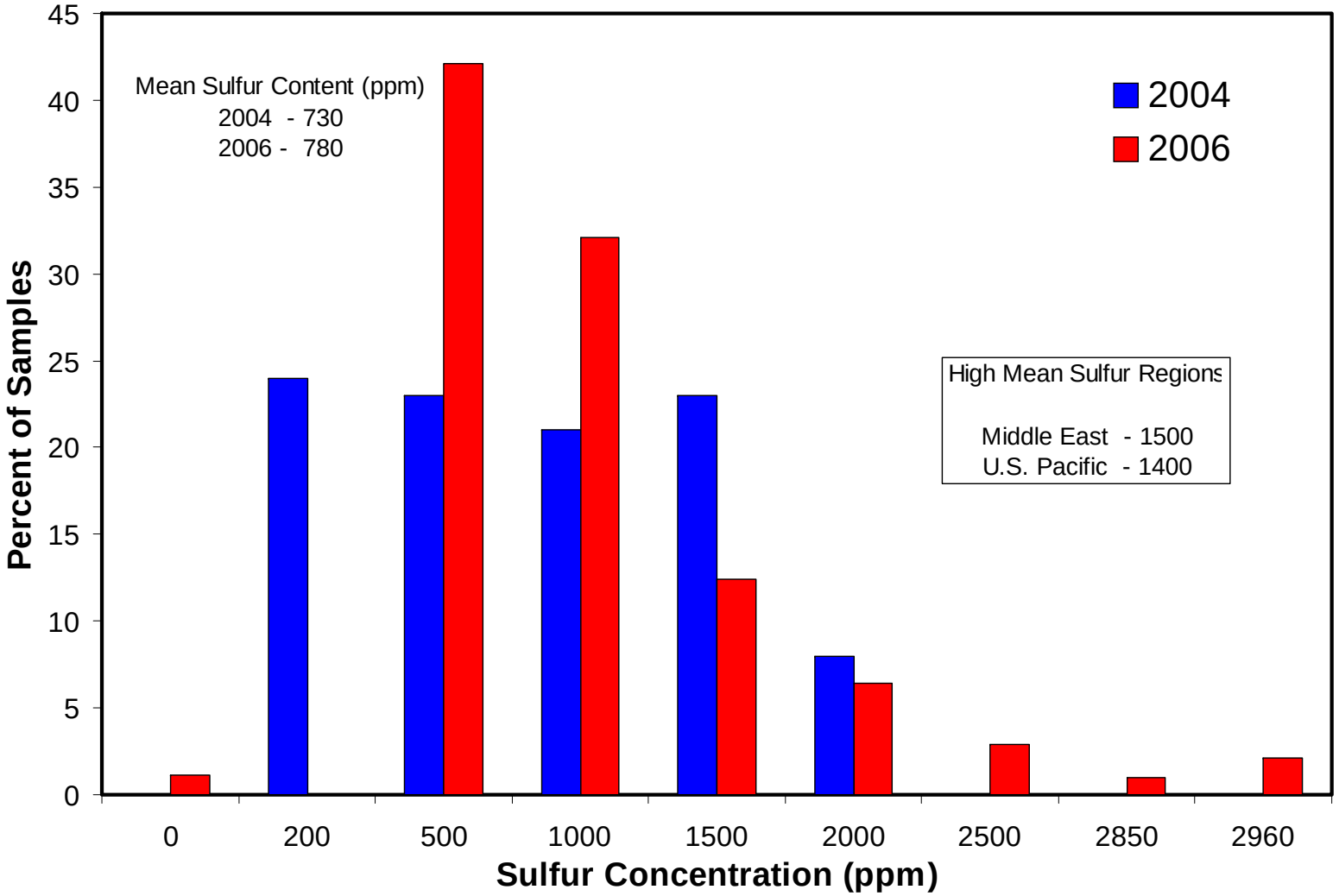
# JP-8 Property Specifications

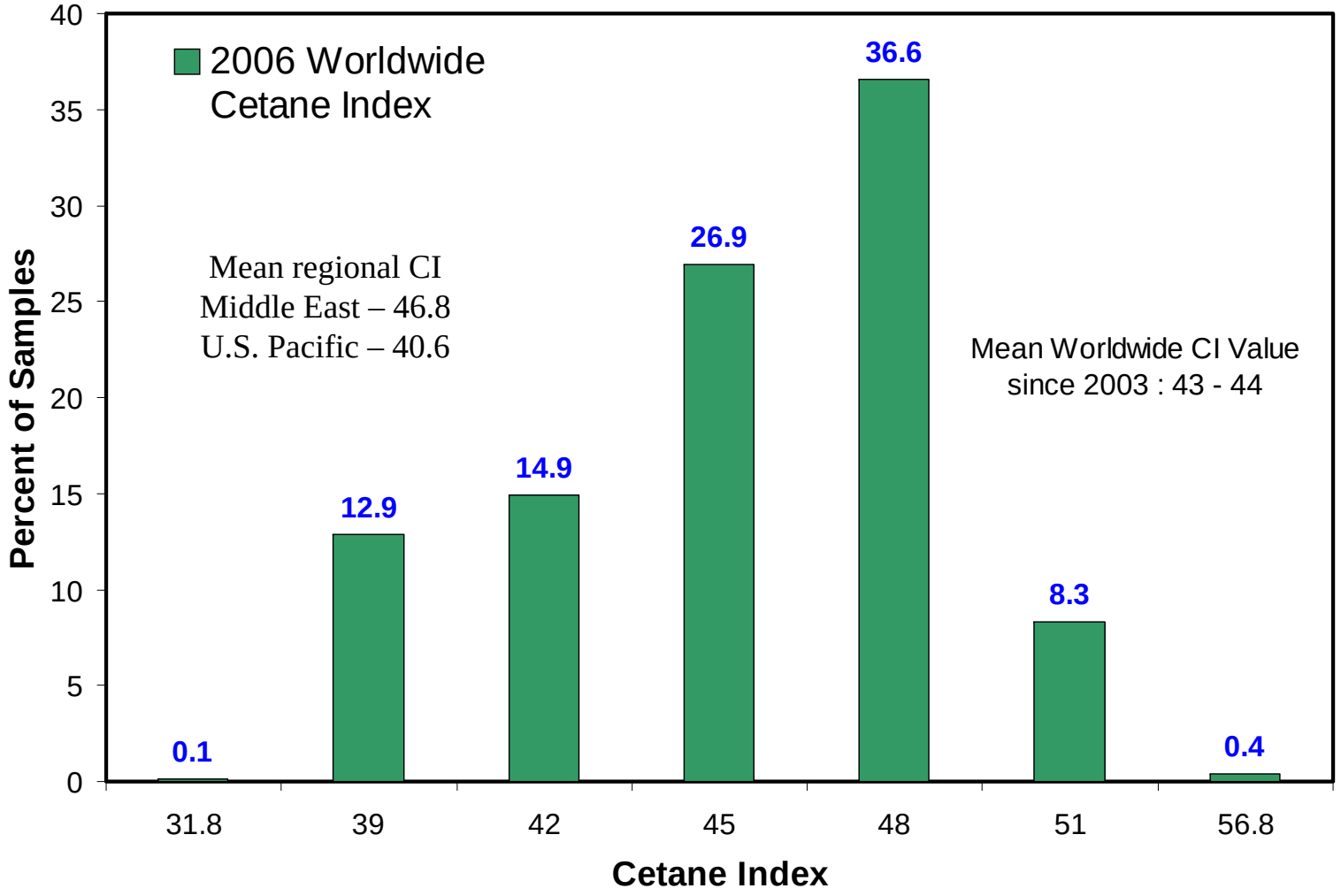
- **Sulfur content: max. 3000 ppm**
- Aromatics: max. 25%
- Specific gravity: 0.775 – 0.84
- Evaporation Characteristics:
  - 10% recovery: max. 205 C (186 C)
  - End point: max. 300 C (330 C)
- Net Heating Value: min. 42.8 MJ/kg
- **Cetane Index: none**



# JP-8 Fuel Sulfur Content Example: Worldwide

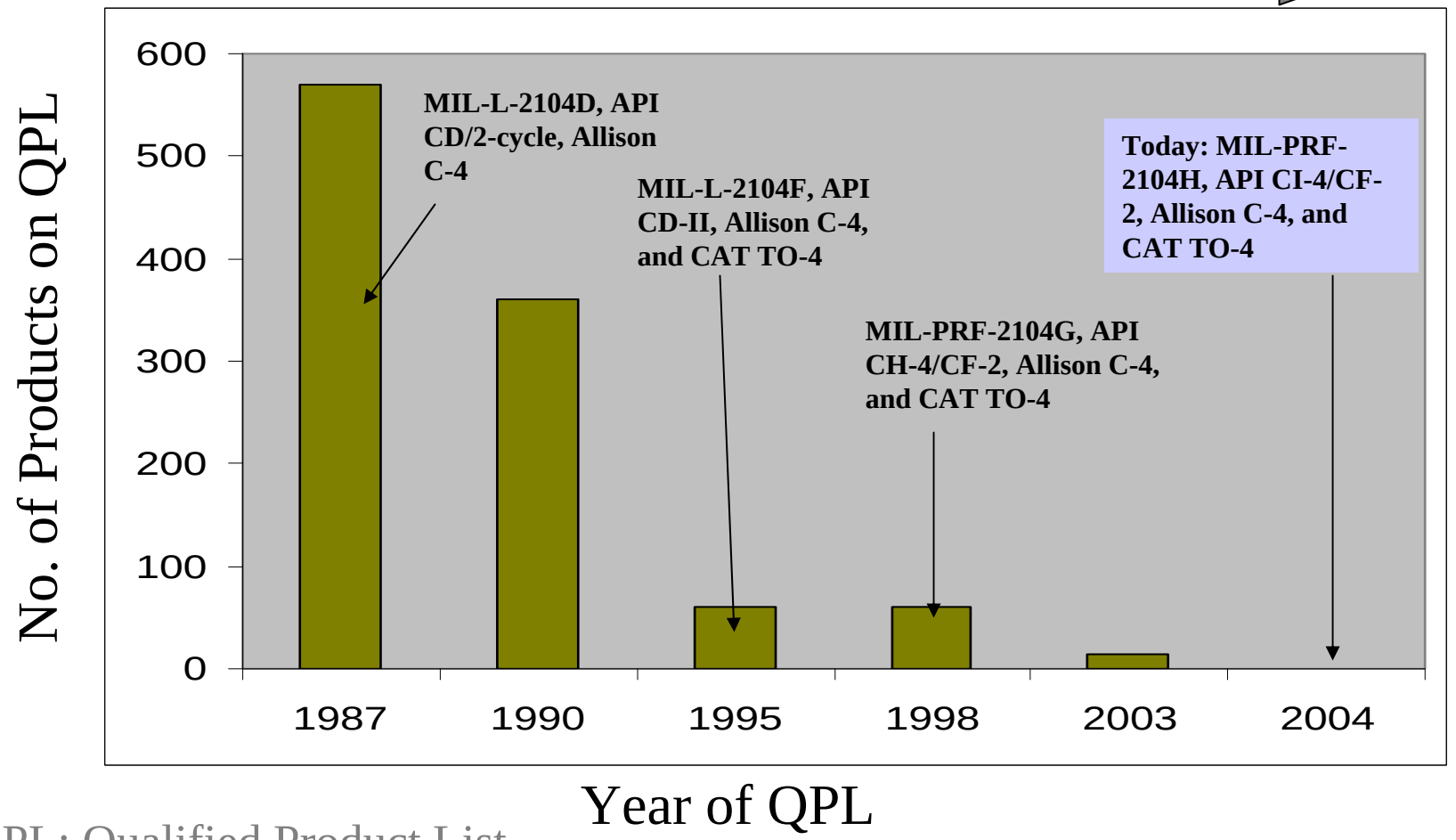


# JP-8 Cetane Index Worldwide Trend in 2006



# Impact of Emission Standards on Military Heavy-Duty Diesel Engine/Transmission Oils (E/TO)

Increasing performance and test costs




QPL: Qualified Product List

# Impact of Emission Standards on Military Heavy-Duty Diesel Engine/Transmission Oils (E/TO) – Performance concerns

- US Market Drivers for lubricants
  - Ultra-low-sulfur fuels (ULSF)
  - Compatibility with pollution prevention devices (toward low ash, phosphorus, and sulfur concentrations)

- Some additive technologies proven to work well with higher sulfur fuels will not be allowed in the future
  - Additives with phosphorus and ZDDP (zinc dialkyl dithiophosphate)
  - Due to 'poisoning' of pollution devices

- Military exposure to high sulfur fuels raises concerns regarding engine protection with lubricant technology developed around ULSF
  - Logistic and Maintainability concerns

- Unknown impact of future engine oils on transmission performance
  - No commercial interest.

# Solution Pathways – Short Term to 2004 Heavy-Duty On-Road Emission Standards



- EGR Engines
  - Issues: increased heat rejection and system volume, fuel and lubricant compatibility (reliability and durability issues)
  - Solution: employ EPA granted NSE, remove EGR system, recalibration of engine to meet military performance demands

- Non-EGR Engines
  - Issue: JP-8 compatibility and thermal management system requirements
  - Solution: ensure JP-8 compatibility with engine system and compliance with military performance demands; ensure thermal management system meets vehicle requirements

# Current Army Ground Vehicle Engine Philosophy and Conclusion

# Solution Pathways – Long Term to 2007/2010 Heavy-Duty On-Road Emission Standards

- All engine systems have or are head toward some type of aftertreatment system with advanced combustion strategies and closed loop control
  - NOx trap, catalyzed filters (CDPF/DOC), urea or fuel based SCR
  - HCCI, PCCI, and other more 'homogeneous combustion modes'
  - LTC : low temperature combustion for light loads, possible regeneration strategy
  - **Heavy use of cooled EGR (>50% heat rejection increase vs. MY 1998)**
    - possible low pressure cooled EGR in some cases
  - Exhaust sensors for temperature(s), pressure(s), NOx concentration, $O_2$ concentration, ammonia, urea
    - Closed loop control package for monitoring and regenerating aftertreatment devices
  - **Commercial diesel fuel properties may require tighter combustion related property specifications for advanced combustion system operating modes**

# Solution Pathways – Long Term to 2007/2010 Heavy-Duty On-Road Emission Standards

- Engine systems **must be modified** to meet military requirements
  - Use of blanket NSE for MY 2007+ engine systems
  - Removal of EGR system
  - Removal of aftertreatment devices
  - Recalibration
  - Ensure high sulfur fuel tolerant and oil compatible components
  - **Unknown on how to handle fuel lubricity filter technology**

# Conclusion

- The Army can not buy 2007 compliant COTS engines and directly integrate into current and new heavy-duty vehicles.

# THANKS!