



The U.S. Army, Diesel Engines, and Heavy-Duty Emission Standards



TARDEC Propulsion Laboratory

SUPERIOR TECHNOLOGY

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FOR A

SUPERIOR ARMY



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U.S. ARMY TANK-AUTOMOTIVE RESEARCH DEVELOPMENT AND ENGINEERING CENTER

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Background - Army Ground Vehicles

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

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)

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)

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



Army Ground Vehicles

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

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

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

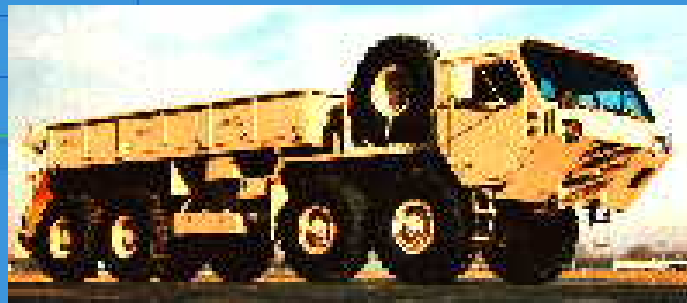
40,000 + 2-stroke powered vehicles (200 – 500 BHP)



M113 Personal Carrier



PLS – Palletized Loading System



HEMTT – Heavy Expanded Mobility Tactical Truck

***FVPDS (Jan. 2000)**

Fielded Vehicle Performance Data Systems

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Army Ground Vehicle Propulsion Challenges

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1. Cooling
2. Cooling
3. Cooling
4. Fuel Effects
5. Filtration



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)





High Power Density Propulsion Systems

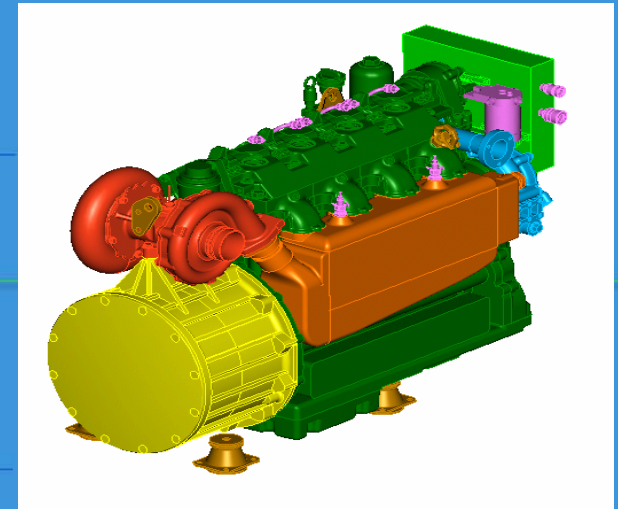
SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

1. Army definition of power density (PD):

- $PD = \text{sprocket (wheel) power} / \text{total propulsion system volume}$
- Air filtration requirements, thermal management system, transmission, engine (fuel), ducting requirements
- Ex. Bradley FIV: $PD=3$

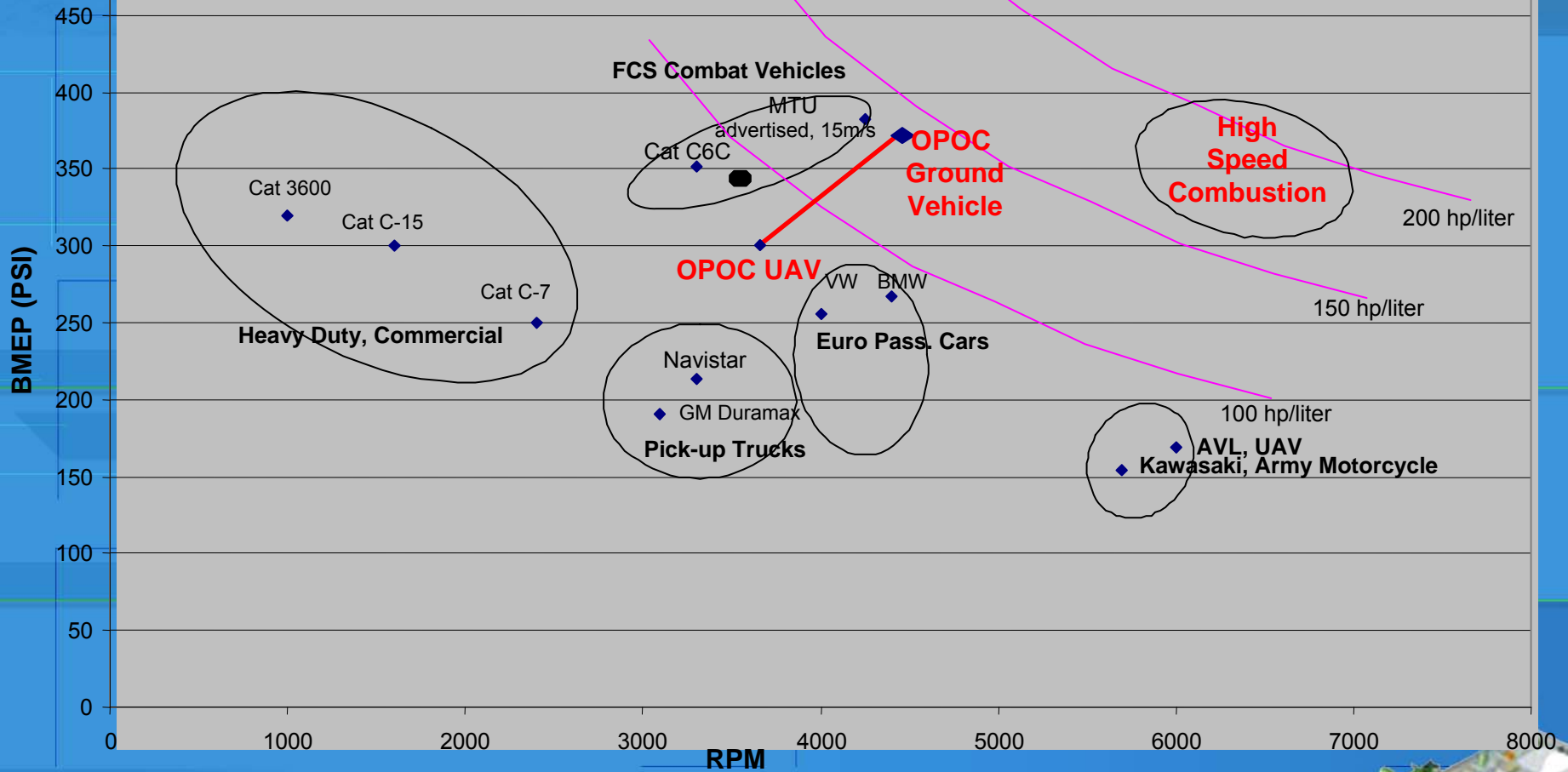
2. High Power Density Engines (Future Combat System ~ 20 ton vehicle)

- Bradley FIV: Cummins VTA903 41 BHP/L
- 'Hot Rod' Cummins ISB 92 BHP/L
- MTU HPD Family 125 BHP/L



Current Diesel Engine Power Density

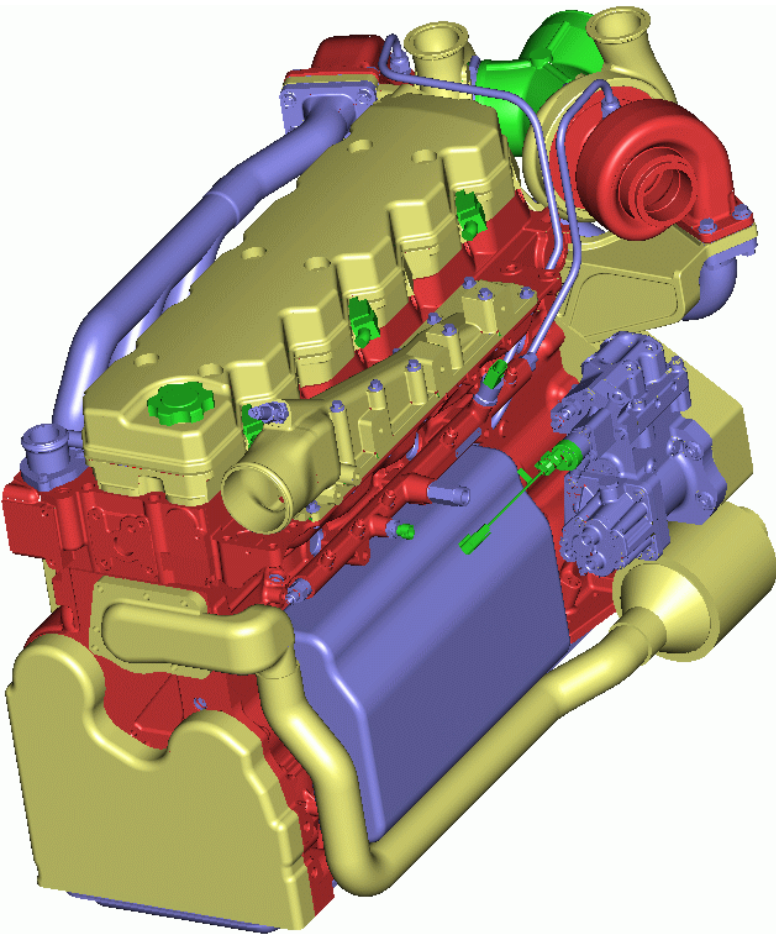
SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY



HP/Liter of Displ. = $BMEP \times RPM / 12,984$



FCS Ricardo/Cummins ISB



Type of Engine	Diesel
Number of cylinders	6
Cylinder Arrangement	In-line
Bore	4.02 inches
Stroke	4.72 inches
Displacement	359 in³
Power hp at rated speed	550hp@3600 rpm
Max torque at speed	796ftlb@2400 rpm
Compression Ratio	14.5

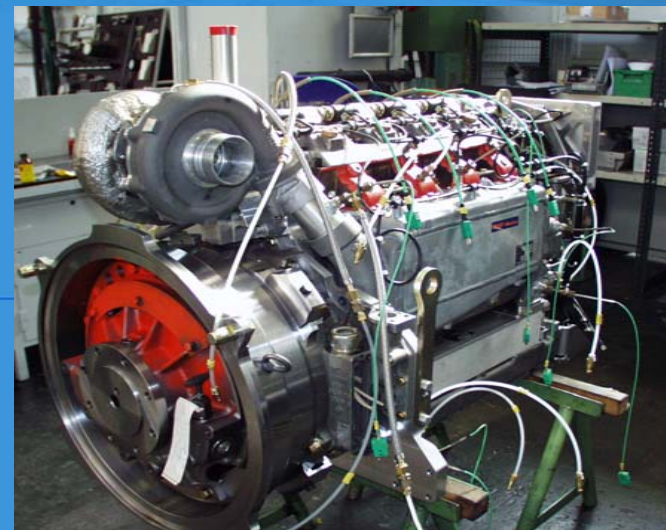
Demonstrated 40 Hour NATO Test



Detroit Diesel - MTU 4L890 Characteristics

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Type of Engine	4-Stroke Diesel
Number of Cylinders	4
Cylinder Arrangement	Inline
Bore	4.53 in
Stroke	4.21 in
Displacement	271 in ³
Power hp at rated speed	550 hp @ 4250 rpm
Max torque at speed	920 Nm @ 4250 rpm
Compression Ratio	13
Injection System Type	Common Rail direct injection
Peak Injection Pressure	1800 bar / 26125 psi
Peak Cylinder Pressure	212 bar / 3074 psi
Induction Air Consumption	4514 lbs / hr
Fuel Flow @ Maximum Power	196 lbs / hr
Turbo Pressure Ratio	4.39





Current and Future Military Combat Engine Technology Needs

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1. High pressure ratio and wide range turbocharging: $PR > 5$
2. Advanced combustion systems with multi-fuel capability (DF-2, JP-8, JP-5, Jet A, Jet A1)
 - Closed-loop in-cylinder control
 - High pressure, flexible fuel injection systems with high volumetric delivery rate
 - Push toward high load, low air-fuel ratio heat release
3. High temperature in-cylinder package
 - Reduce CAC requirements (higher intake manifold temp.)
 - High oil sump temperatures
 - Combustion surface high temperature capability
4. Strategic and innovate cooling strategies





Emissions Discussion

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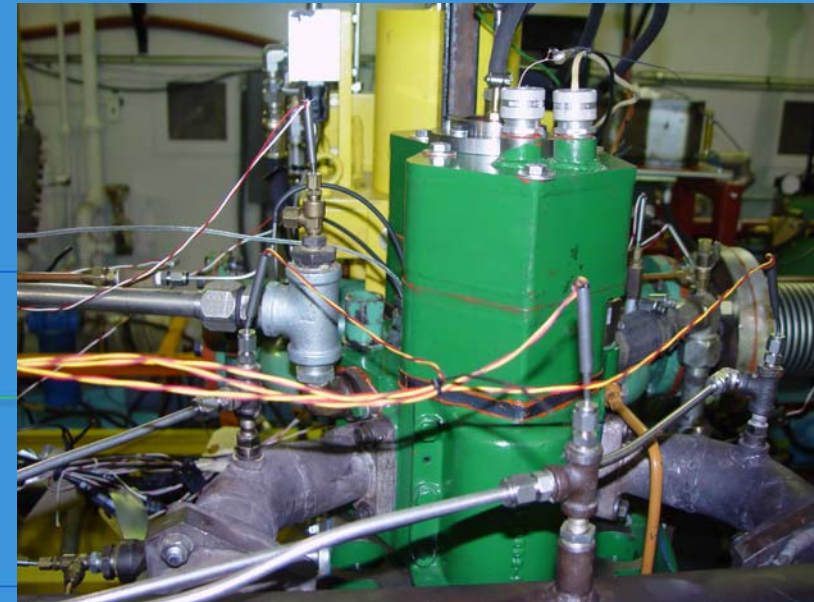




JP-8 Property Specifications

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- **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**





Fuel Challenges

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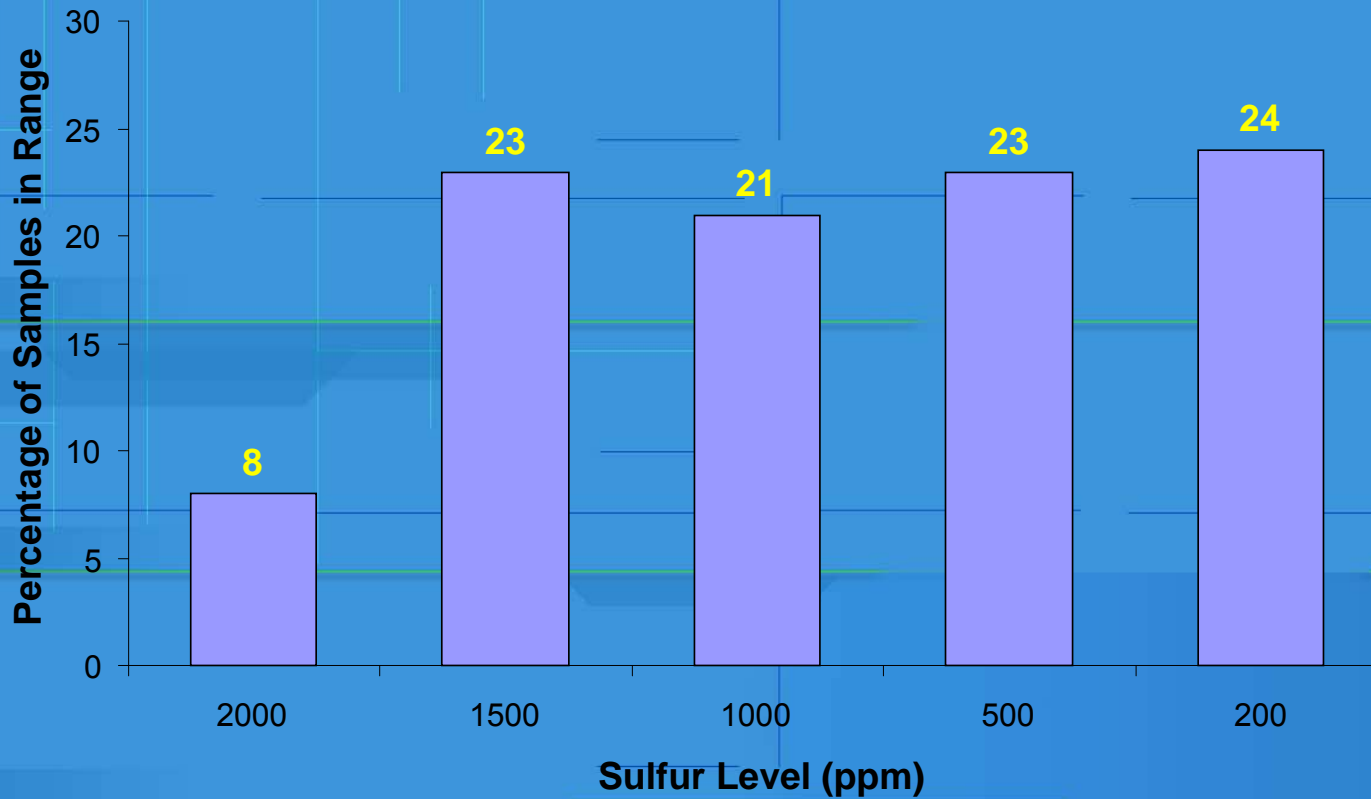


JP-8 Fuel Sulfur Content

Example: Fuel Supply in Iraq

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JP-8 Sulfur Concentration Samples from Iraq (2004)

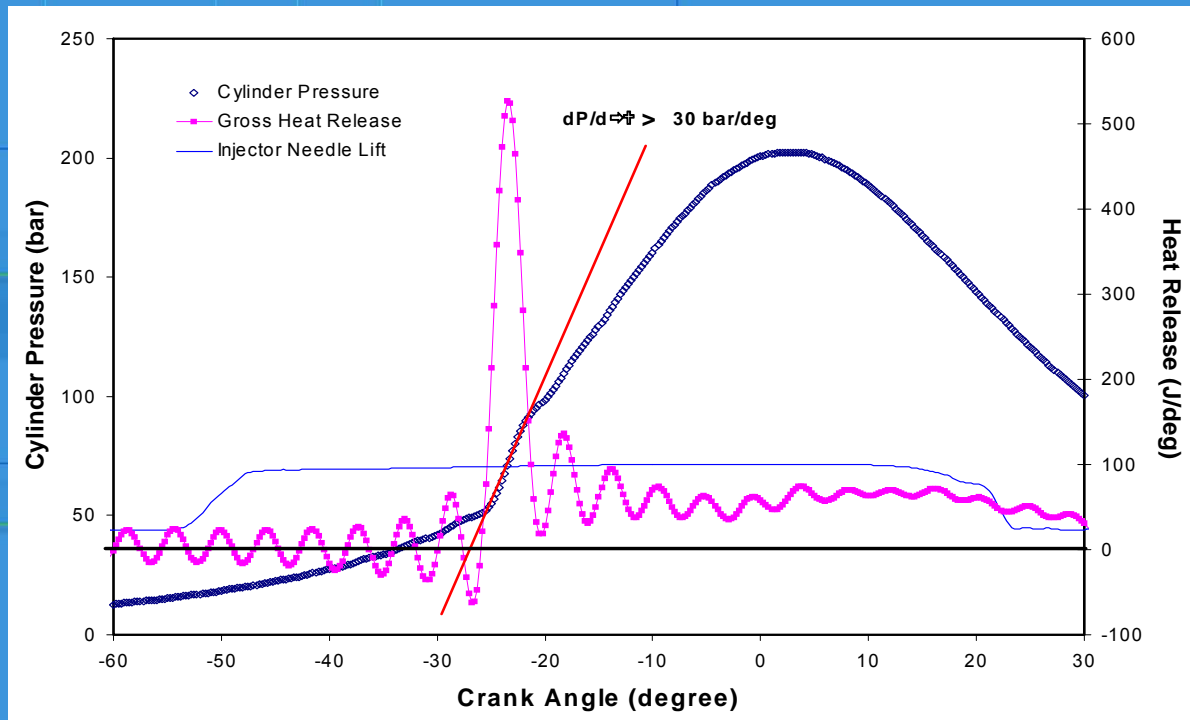




New Combustion Regimes

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- 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



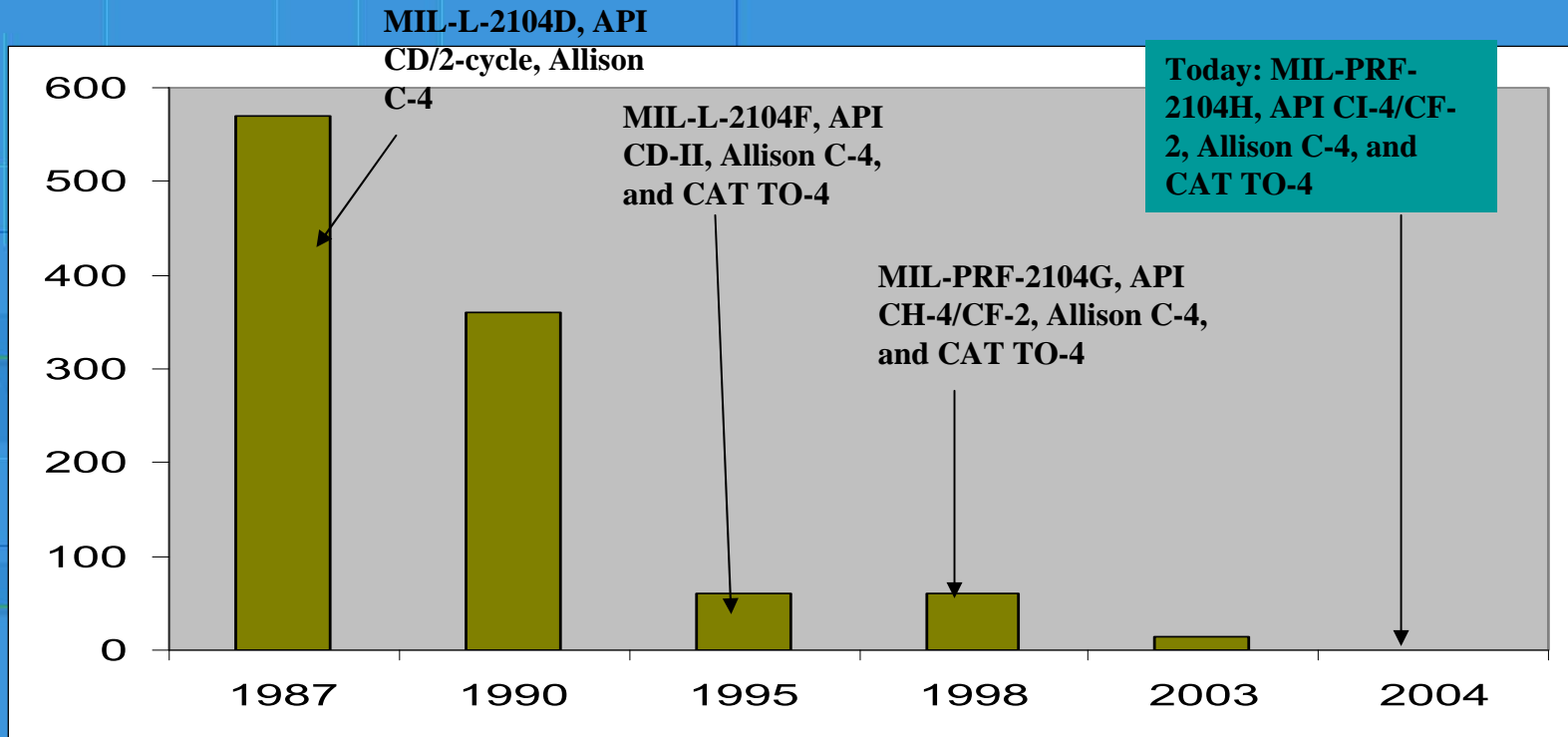


Impact of Emission Standards on Military Heavy-Duty Diesel Engine/Transmission Oils (E/TO)

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Increasing performance and test costs 

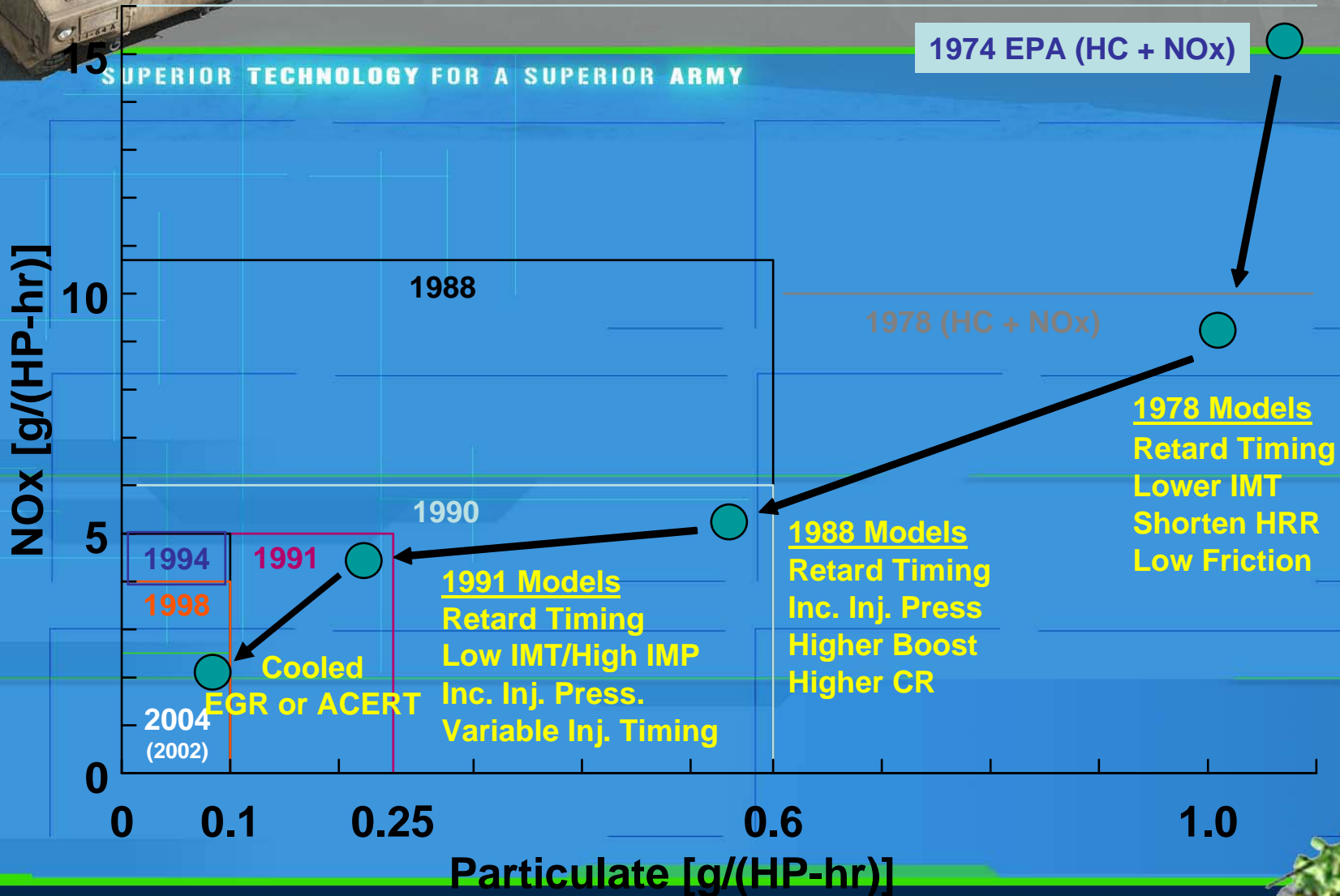
No. of Products on QPL



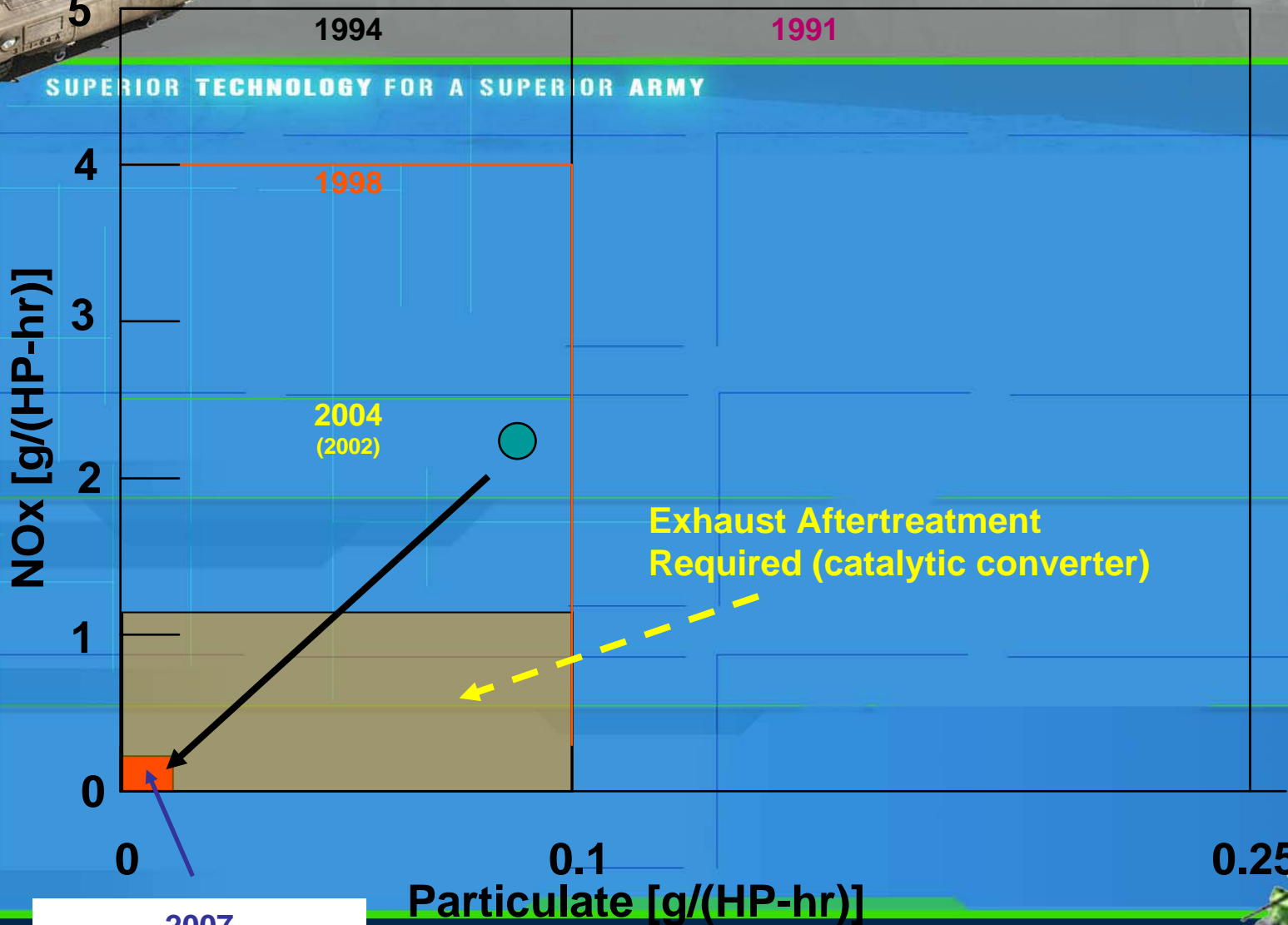
Year of QPL



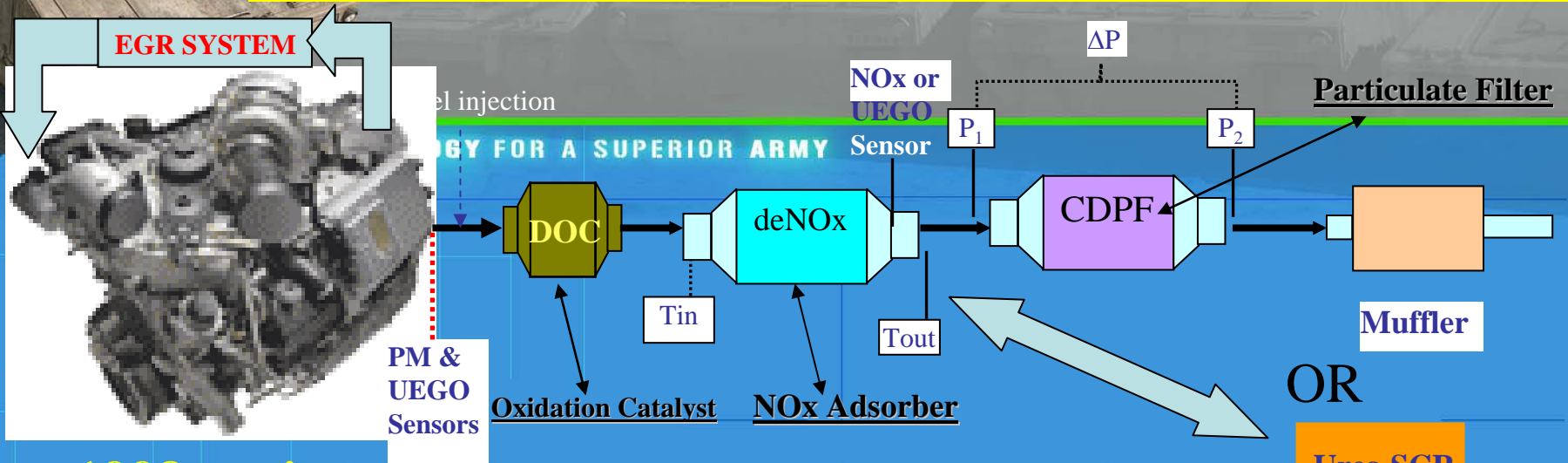
Evolution of Heavy-Duty Engine Emission Control – 2004



Evolution of Heavy-Duty Engine Emission Control – 2007



2007 (2010) Emission Issues : Aftertreatment Devices (example)



1998 engine

PM filters / NOx reduction devices

- ✓ Catalyzed filters (DOC + CDPF)
- ✓ NOx trap (adsorber) vs. Urea SCR (selective catalytic reductant)
- ✓ Additional space claim , **conservatively 5 x engine displacement**

NOx trap requires < 15 ppm fuel sulfur level

- Likely to include high levels of EGR in addition 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





Heavy-Duty Reaction to 2004 and 2007 Standards

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Impact of 2004 Standards on Commercial Heavy-Duty Diesel Engines

- Cooled Exhaust Gas Recirculation (EGR)
- ACERT™ – Advanced Combustion and Emissions Reduction Technology

Impact of 2007/2010 Emission Standards on Commercial Heavy-Duty Diesel Engines

- Cooled Exhaust Gas Recirculation (EGR) with advanced combustion and closed-loop engine system controls
- ACERT™ – Advanced Combustion and Emissions Reduction Technology plus aftertreatment (oxidation catalyst) and closed-loop engine system controls along with low pressure and 'filtered' EGR loop
- New combustion regimes that may require specified fuel properties

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The Governing Equation

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JP-8 + MILSPEC OIL + operating environment +
2007 commercial engine hardware = { α }

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Army Ground Vehicle Emission Policy

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- **Combat vehicle: permanent armor/attached weapon system – National Security Exemption (NSE) via 40 CFR, 89.908**
- **‘Tactical Vehicles’**
 - ✓ Without ANY armor – NSE from 2004 and 2007 standards (i.e. meet 1998)
 - ✓ With ANY armor – NSE from ALL standards

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

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- All engine systems heading 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, O₂ concentration
 - 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

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- 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





THANK YOU!

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