EPA Engine Emissions Overview

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August, 2003
Notes compiled from the TMC Diesel Emissions Summit – Phoenix, June 2003
EPA Emissions Regulations
Jeff Holmstead – U.S. EPA Head of Air Quality Compliance

• 2007 Regulations Once Implemented will:
  – Prevent 8000 Premature Deaths per year
  – Prevent 1,000,000 Respiratory Ailments

• Particulate Size
  – Research suggests that it is not the mass of the particulates, but the quantity that is harmful (ultra fine particulates). EPA regulates mass rather than quantity and this is under review.

• After-Treatment Technology Neutral
  – EPA is not opposed to SCR after-treatment, but needs to be assured that engine will not run if urea supply is depleted.

• Fuel Supply
  – Low sulfur fuel (15 ppm vs 500 ppm) will be available in 80 percent of the locations by mid 2006.
Emission Regulation History

PM (g/bhp-hr)

NOx (g/bhp-hr)

1990

1991

2002/2004

1998

1994

2010

2007
Emissions Defined
NOx

- Nitrous Oxides are formed in the combustion chamber when fuel is burned at high temperatures.
- High temperatures are created when droplets of fuel burn.
- If the injection spray were fine enough, and the spray diffused well enough, the chamber would exhibit a homogeneous burn and there would be no hot spots to form NOx.
Particulate Matter

- **Soot (85%)**
  - Soot is carbon left over from the combustion process.
  - In ideal complete combustion, there would be no soot.
- **Volatile Fraction (15%)**
  - The volatile fraction of particulate matter is made up of sulfides and other components that condense (or solidify) as they are cooled while leaving the combustion chamber.
Emissions Reduction Strategies
NOx Reduction Strategies

- High EGR Rates
- ACERT
- NOx Adsorbers
- Lean NOx Catalyst
- Selective Catalyst Reductant
Higher EGR Rates

- Exhaust Gas Recirculation (EGR) diverts some of the exhausts gas, cools it, and sends it into the intake manifold.
- The cooled inert exhaust lowers the cylinder temperature, thereby reducing NOx.
- Higher rates of EGR will reduce NOx further.
- Disads:
  - Reduces power density of engine
  - Reduces fuel economy
  - Increases Heat Rejection into the cooling system.
ACERT

• ACERT is an accumulation of many factors, but a main strategy is increasing the percent of fresh air in the intake charge by boosting intake pressure.

• This strategy reduces NOx by flooding the cylinder with oxygen, stretching out the injection cycle, and attempting to approach an homogeneous burn.

• Disads:
  – Reduces power density of engine
  – Reduces fuel economy
  – Increases Heat Rejection into the cooling system.
NOx Adsorbers

- NOx Adsorbers collect NOx on the surface of a precious metal matrix in the exhaust stream.
- Diesel fuel is injected into the matrix periodically to strip off the NOx and convert it into N₂.
- During use, sulfur builds up on the sites, blocking the NOx adsorption. The unit must then be heated to just below the point of catalyst degradation to burn off the sulfur. Twin units are required so that one can be taken off-line during de-sulfurization.
- This device is very effective (+60%) at reducing NOx
NOx Adsorbers

- Disads:
  - Precious metal content makes it very expensive
  - Reduced fuel economy because diesel fuel is consumed in process
  - Fueling the engine with high sulfur fuel will destroy effectiveness
  - Not as efficient as SCR in reducing NOx
  - Large physical size, especially if twin units are required.
Lean NOx Catalyst

- Lean NOx Catalyst is similar to the NOx Adsorber, but is less effective (20%) and uses little precious metal.
- Diesel fuel is injected into the matrix periodically to strip off the NOx and convert it into $N_2$.
- This device is available today.
- Disads:
  - Not adequately effective to be useful in 2007
  - Reduced fuel economy because diesel fuel is consumed in process
Selective Catalyst Reductant (SCR)

- SCR injects Urea into the exhaust stream which in combination with a catalyst will reduce NOx.
- SCR is used in Europe currently, while DDC and Volvo have demonstration units running in North America

**Advantages:**
- SCR is effective enough that EGR could be eliminated.
- Timing can be advanced to pre-2002 levels, improving fuel economy.

**Disads:**
- Requires infrastructure to distribute Urea at truck stops.
- Uses 4 gallons of Urea for every 100 gallons of diesel
- Packaging
- Urea must be protected from freezing
Cummins
Selective Catalyst Reductant (SCR)

Urea Tank With Heated Lines.

Fleetguard SCR Catalyst
Detroit Diesel
Selective Catalyst Reductant (SCR)
Detroit Diesel
Selective Catalyst Reductant (SCR)

- Urea Tank
- PM Filter
- SCR Catalyst
- Cross Section of SCR Catalyst
Selective Catalyst Reductant (SCR)

**CAT**

**Electric Power**
- 3516 Ethanol DeNOx After treatment
- 3500 SCR System
- Modular SCR

**Mobile**
- Ammonia SCR Truck
- Urea SCR Truck Demo
- C-12 SCR Test Engine Demo’d NOx Red
- Component Development
  - Catalyst
  - Injection System
  - Control System

**Years**
- 1970’s
- 1980’s
- 1990’s
- 2000
- 2001
- 2002
- 2003

**SCR Test Evaluation**
On-Highway
Volvo
Selective Catalyst Reductant (SCR)
## NOx Strategy Comparison

<table>
<thead>
<tr>
<th></th>
<th>High EGR</th>
<th>ACERT</th>
<th>Selective Catalyst</th>
<th>NOx Adsorber</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Economy</strong></td>
<td>-0.30%</td>
<td>? Same as EGR ?</td>
<td>6%</td>
<td>-3%</td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
<td>55%</td>
<td>? Same as EGR ?</td>
<td>-20%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>-5%</td>
<td>? Same as EGR ?</td>
<td>6%</td>
<td>0%</td>
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<tr>
<td><strong>Weight</strong></td>
<td>50 Lb Increase</td>
<td>? Same as EGR ?</td>
<td>400 Lb Decrease</td>
<td>300 Lb Increase</td>
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<tr>
<td><strong>Oil Exchange</strong></td>
<td>1x</td>
<td>1x</td>
<td>2x</td>
<td>1x</td>
</tr>
<tr>
<td><strong>Urea Infrastructure</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Drivers Responsibility</strong></td>
<td>None</td>
<td>None</td>
<td>Urea Refill</td>
<td>None</td>
</tr>
</tbody>
</table>

- Cummins
- Caterpillar
- Detroit Diesel
- International
- Volvo Mack
Particulate Matter Reduction Strategies

- Diesel Oxidation Catalyst
- Catalytic Soot Filter
- Active Particulate Filter
Diesel Oxidation Catalyst

- Diesel Oxidation Catalyst removes the volatile fraction of the particulates.
- The volatile fraction is formed primarily from sulfides that condense out of the exhaust stream as it is cooled.
- Today’s Technology
- Disads:
  - Only effective on the 15% fraction that constitutes the volatile particulates.
Catalytic Soot Filter

- Catalytic Soot Filter captures soot and burns it at exhaust system temperatures attained at heavy load in warm climates.
- Works very well as long as high exhaust temperatures are reached (operation units functioning well in California).
- Passive device that does not require a control system.
- Disads
  - Not a viable solution for use in cold climates
Active Diesel Particulate Filter

- The same concept as the Catalytic Soot Filter, the Diesel Particulate Filter collects soot in a metal filter matrix and then burns it off using high temperatures.
- Additional heat is used to burn off the soot by adding a fuel source and controlling burn temperature. Disads
  - Filter must be cleaned periodically
  - Ceramic components are susceptible to damage
  - Packaging
### EPA Variable Cost Estimates

(per engine)

<table>
<thead>
<tr>
<th>Engine Class</th>
<th>Model Year</th>
<th>NOx Aftertreatment</th>
<th>PM Filter</th>
<th>Oxidation Catalyst</th>
<th>Closed Crankcase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Heavy</td>
<td>2007</td>
<td>$1000</td>
<td>$730</td>
<td>$206</td>
<td>$37</td>
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<tr>
<td>Light Heavy</td>
<td>2012</td>
<td>$590</td>
<td>$425</td>
<td>$206</td>
<td>$10</td>
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<tr>
<td>Medium Heavy</td>
<td>2007</td>
<td>$1310</td>
<td>$950</td>
<td>$261</td>
<td>$42</td>
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<tr>
<td>Medium Heavy</td>
<td>2012</td>
<td>$690</td>
<td>$530</td>
<td>$261</td>
<td>$12</td>
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<tr>
<td>Heavy Heavy</td>
<td>2007</td>
<td>$1650</td>
<td>$1190</td>
<td>$338</td>
<td>$49</td>
</tr>
<tr>
<td>Heavy Heavy</td>
<td>2012</td>
<td>$930</td>
<td>$690</td>
<td>$338</td>
<td>$15</td>
</tr>
</tbody>
</table>
Engine Manufacturer Strategies
Detroit Diesel

• **Strategy**
  - SCR after-treatment to control NOx
  - Active Diesel Particulate Filter to control PM
  - Eliminate EGR

• **Contacts**
  - Tim Tindall – Emissions Compliance DDC
  - Ranier Schmueckle - Freightliner
DDC Truck Engine Availability

Series 60
- 2003: EGR
- 2004: PM Filter / EGR, SCR or NOx Adsorber
- 2007: PM Filter / EGR, SCR or NOx Adsorber

MBE4000
- 2003: EGR
- 2004: PM Filter / EGR, SCR or NOx Adsorber

MBE900
- 2003: EGR
- 2004: PM Filter / EGR, SCR or NOx Adsorber

New Engine Platform
- 2007: PM Filter / EGR, SCR or NOx Adsorber
Volvo - Mack

• **Strategy**
  – SCR after-treatment to control NOx
  – Active Diesel Particulate Filter to control PM
  – Cooled EGR?

• **Contacts**
  – Anthony Greszler – Mack Trucks
  – Michel Gigou - Volvo
International

• Strategy
  – NOx Adsorber to control NOx
    • Because International builds medium to light duty engines, the life of the adsorber is less of an issue. Their life expectancy is 180,000 miles vs 435,000 miles for heavy.
  – Active Diesel Particulate Filter to control PM?
  – EGR?

• Contacts
  – Patrick Charbonneau – International Truck & Engine
  – Daniel Ustian – Navistar International Corp
Cummins

• Strategy
  – Higher Rates of Cooled EGR to control NOx
  – Active Diesel Particulate Filter to control PM

• Contacts
  – Steve Charlton - Cummins
Caterpillar

• **Strategy**
  – ACERT to control NOx
  – Aftertreatment for further NOx reduction
  – Active Diesel Particulate Filter to control PM

• **Contact**
  – John Campbell – Caterpillar Inc.
ACERT™ Is The Foundation for 2007/2010

• Cat's Technology Strategy & Approach
  – Build Upon 03 ACERT™
  – Continue to Enhance Engine Performance While Incrementally Introducing Advanced Aftertreatment
  – Investigate Multiple NOx Aftertreatment Technologies
  – Provide Best Value To Customer and Optimum Technology to Truck OEMs
Industry Issues
Low Sulfur Fuel

- All Engine OEMs are in agreement that 2007 can only be met with 15 ppm low sulfur fuel.
- Low sulfur fuel inherently burns cleaner.
- Today’s higher sulfur fuels (500 ppm) would contaminate the diesel particulate filters being relied upon to control particulates.
- Field tests on 2007 engines prior to the mid-2006 projection of 80% availability of low sulfur fuel will be met with dedicated corridors of availability coordinated by the engine OEMs.
Urea

- The Urea compound used in SCR is a mix of 33% Urea and 67% water.
- The substance is colorless and odorless.
- Produced in large quantities already.
- Cost is similar to diesel fuel.
Reasons for Custom Apparatus Emission Regulation Relief in 2007 and beyond.

- Packaging of after-treatment devices will displace the emergency equipment carried on the apparatus.
- Additional heat from more EGR will affect cab ergonomics.
- Cost of redesign for low-volume manufacturers will be burdensome.
Question for FAMA to Resolve

- Should we continue to seek relief from the EPA for 2007?
- FAMA Chassis Subcommittee Agenda
  - Agree on common approach to EPA
  - Brainstorm additional rationale for EPA relief
  - Determine tasks and timelines.
  - Forecast of hours or money impact on each manufacturer