Fuel Reformer, LNT and SCR Aftertreatment System
Meeting Emissions Useful Life Requirements

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2009 DOE DEER Conference
Dearborn, MI
August 5, 2009
Topics

- Introduction to Eaton Aftertreatment
- Vehicle and Dyno Test Results
- Durability Test Results
- System Packaging
- Summary
Introduction
Eaton Aftertreatment System

How it Works:

• Engine NOx is reduced by the Lean NOx Trap (LNT) and Selective Catalytic Reduction (SCR) catalysts.

• The LNT stores NOx and undergoes controlled periodic regeneration, releasing the NOx as nitrogen and ammonia.

• The SCR collects the released ammonia and uses it to continuously treat the remaining NOx.

• A Diesel Particulate Filter (DPF) traps Particulate Matter (PM) and undergoes periodic regeneration.
Customer Values & Product Differentiation

- Compliance with strict diesel emission standards
- **Single fluid system** (one dosing system needed)
- **Independent** of urea solution & infrastructure
  - Eliminates urea sensors and compliance-related penalties
- Reliable aftertreatment system
- Flexible, customized and **smaller packaging**
- Scalable with engine power (size)
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Vehicle Testing

• Accumulated ~ 26,000 miles operation
• Variety of Ambient Conditions
  • Temperature from -40 to 51 C
  • Altitude to 11,158 feet

• Achieving 80%+ NOx reduction under majority of driving conditions
• Automatic aftertreatment operation (transparent to driver)
  • No drivability issues
Vehicle Testing – Cold Weather (-20 F)

City NOx Conversion of 84.1%

Highway NOx Conversion of 86.6%

Highway = 55mph two lane road

Meets in use requirements for cold weather testing
FTP Test Results – Combined Cycle
Initial Results  (Removed ~1.7 g/bhp-hr NOx)

<table>
<thead>
<tr>
<th></th>
<th>Hot Cycle</th>
<th>Cold Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Out</td>
<td>(1.81 g/bhp-hr)</td>
<td>(0.15 g/bhp-hr)</td>
</tr>
<tr>
<td>System NOx Efficiency</td>
<td>92% (Combined)</td>
<td></td>
</tr>
</tbody>
</table>

System NOx Efficiency = 92% (Combined)
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Durability

Aftertreatment Durability Aging

- **Application**
  - Aged on an Off-Highway Engine at an OEM test facility to end-of-emissions life conditions

- **Sulfur Loading Assumptions**
  - Total Sulfur in exhaust: 12 ppm on a fuel basis
    - 7 ppm from diesel fuel
    - 5 ppm from oil
  - Triggered DeSOx Event: 0.5 g/L Sulfur on LNT
  - LNT Sizing: 1.5 times engine displacement
Durability

End-of-Life Emissions Requirements

- Off-Highway Analysis
  - 500 DeSOx events required – 8000 hour useful emissions life
    - One DeSOx event every 16 hours

- On-Highway Analysis – Medium Duty Vehicles
  - 225 DeSOx events required – 185,000 miles useful emissions life
    - One DeSOx event every 822 miles

- On-Highway Analysis – Heavy Duty Vehicles
  - 500 DeSOx events required – 435,000 miles useful emissions life
    - One DeSOx event every 870 miles
Durability

NOx System Efficiency

Constant Control Settings
- 50% Load
- 75% Load
- 100% Load
- SCR Contribution

Final Performance (Optimized Settings)
- 1800 rpm - 50%: 93%
- 1800 rpm - 75%: 87%
- 1800 rpm - 100%: 79%

Stable SCR Contribution

After DeSOx #
Durability Performance Summary

EAS performance results following 500 DeSOx Cycles
Meets Off-Road Final Tier 4 and HD On-road Emission Standards

<table>
<thead>
<tr>
<th></th>
<th>System NOx Conversion</th>
<th>Tailpipe NOx (g/kW-hr)</th>
<th>Tailpipe HC (g/kW-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800 rpm - 50% load</td>
<td>93%</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>1800 rpm - 75% load</td>
<td>87%</td>
<td>0.20</td>
<td>0.19</td>
</tr>
<tr>
<td>1800 rpm - 100% load</td>
<td>79%</td>
<td>0.36</td>
<td>0.20</td>
</tr>
</tbody>
</table>

- Demonstrated NOx Margin (<0.4 g/kW-hr)
  - ¼ of NOx standard @ 50% load
  - ½ of NOx standard @ 75% load
  - Slightly below NOx standard @ 100% load (safely within NTE zone)
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System Packaging
Flexible Options to Meet OEM Applications

Alpha On-Highway

Beta On-Highway

Compact Option
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Summary

- Vehicle Testing
  - Demonstrated 80%+ NOx reduction (cold temperature & high altitude)

- Dyno Testing
  - Demonstrated Viability for FTP testing

- Durability Testing
  - Met stringent durability requirements (Off-Highway & HD On-Highway)

- System Packaging
  - Flexible packaging options to meet OEM needs

- Targeted launch dates
  - 2012 targeted for On-Highway
  - 2013 targeted for Off-Highway
  - Joint Development with global engine OEM’s
Acknowledgements

• Eaton Aftertreatment Team
  • Southfield, MI
  • Galesburg, MI
  • Santa Clara, CA
  • Pune, India

• OEM Partners & Suppliers