Biodiesel Effects on the Operation of U.S. Light-Duty Tier 2 Engine and Aftertreatment Systems

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Overview

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- Control System Overview
- Fuel Specifications
- Test Results
  - NOx Adsorber System Test Results
  - SCR System
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    - NH3 / NOx Storage and Release
    - Certification Test Cycle Results
  - Comparison NOx Adsorber / SCR System
- Summary and Conclusions
Project Goals

- Evaluate the impact of Biodiesel fuel blends on the performance of advanced emission control systems for light-duty diesels e.g. conversion efficiencies, regeneration effects (NAC/DPF and SCR/DPF)

- Understand effects over time (system aging)

- Assess engine and fuel system operation impacts at end of project (i.e. combustion chamber, fuel injection system, fuel pump)
Hardware Overview – SCR System

Exhaust Controller Sensors

RTD  RTD Lambda  NOx  RTD  Differential pressure  RTD NOx

Turbine  DOC  SCR  DPF

Inlet  Outlet

Emission sample  T/p  T/p  Emission sample  T/p Smoke sample  T/p  T/p  Emission sample including FTIR

Additional Data Acquisition
Hardware Overview – SCR System

Turbo

DOC

Flex

Temperature Sensor
Urea dosing valve
NOx Sensor
Diff. Pressure Sensor
Mixer

Temperature Sensor
Urea dosing valve
NOx Sensor
Diff. Pressure Sensor
Mixer

2.047” (52mm)

13”

135°

115°

20”

12”

SCR

DPF
### Hardware Overview – Test Engine Hardware

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Engine Power</td>
<td>113 kW at 4000 rpm</td>
</tr>
<tr>
<td>Peak Torque</td>
<td>360 Nm at 2000 rpm</td>
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<tr>
<td>Maximum Engine Speed</td>
<td>4700 rpm</td>
</tr>
<tr>
<td>Maximum BMEP</td>
<td>21 bar</td>
</tr>
<tr>
<td>Cylinder Number and Arrangement</td>
<td>4 Cylinder Inline</td>
</tr>
<tr>
<td>Firing Order</td>
<td>1 – 3 – 4 – 2</td>
</tr>
<tr>
<td>Valve Train</td>
<td>4 Valve DOHC</td>
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<tr>
<td>Bore to Stroke Ratio</td>
<td>1.0034</td>
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<tr>
<td>Displacement</td>
<td>2.15 l</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>18</td>
</tr>
<tr>
<td>Fuel Injection System</td>
<td>2\textsuperscript{nd} Generation Common Rail</td>
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</tbody>
</table>

![Graph](image)
Hardware Overview – Test Vehicle Hardware
Control System Overview
## Fuel Comparison

<table>
<thead>
<tr>
<th></th>
<th>ULSD Base Fuel</th>
<th>B20</th>
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</thead>
<tbody>
<tr>
<td>Density (kg/dm³)</td>
<td>0.846</td>
<td>0.853</td>
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<tr>
<td>Cetane Number</td>
<td>42.0</td>
<td>43.2</td>
</tr>
<tr>
<td>Carbon (wt%)</td>
<td>87.08</td>
<td>85.04</td>
</tr>
<tr>
<td>Oxygen (wt%)</td>
<td>0.00</td>
<td>2.37</td>
</tr>
<tr>
<td>Hydrogen (wt%)</td>
<td>12.92</td>
<td>12.59</td>
</tr>
<tr>
<td>Kinematic Viscosity at 40°C [mm²/sec]</td>
<td>2.28</td>
<td>2.74</td>
</tr>
</tbody>
</table>
Test Results – Useful Life NOx Adsorber System

- **PM [mg/mile]**
  - 0 hr - FTP 75 composite
  - Intermediate life - FTP 75 composite
  - Full usefull life - FTP 75 composite

- **NOx [g/mile]**
  - 50,000 mile Standard
  - 120,000 mile Standard

- **NMHC [g/mile]**
  - 50,000 mile Standard

- **CO [g/mile]**
Test Results – SCR System

Rapid Warm-up

Window 1
- Lambda Ctrl in idling
- Increased Rail pressure
- Advanced timing
- Pilot 1 and 2 ON
- Reduced Boost
- Reduced EGR

Combustion adjustment to minimize HC emissions

Window 2
- Increased Rail pressure
- Start of retarding of timing
- Pilot 1 and 2 ON
- Reduced Boost
- Optimized EGR
- Pilot 1 timing and Qnty correction

To light off DOC – Combustion Optimization to increase engine out temp

Window 3
- Reduced Rail pressure
- Retarded timing
- Pilot 2 OFF
- Post 2 ON
- Increased Boost & EGR
- Pilot 1 timing and Qnty correction

Use exotherm across DOC to heat up SCR

No RWU Window 0

Temperature [deg C]

Time [s]

Coolant temperature [deg C]
Test Results – SCR System

Rapid Warm-up

BASE = NAC DPF - RWU calibration

BASE with RWU

Idling Driving

57
40
97
Test Results – SCR System
Storage and Release

B20 = 33.4%
ULSD = 32.1%

220 sec

Vehicle speed [mph]

B20 = 91.8%
ULSD = 91.9%

NOx [ppm]

NO/NOx ratio [%]

Time [sec]
Test Results – SCR System

Storage and Release

Vehicle speed [mph]

Vehicle speed

B20 = 33.4%
ULSD = 32.1%

B20 = 91.8%
ULSD = 91.9%

220 sec

Accumulated NOx [g]

B20 - After DOC
B20 - Tail pipe
ULSD - After DOC
ULSD - Tail pipe

1.0043g 1.0104g

B20 - SCR Bed Temperature
ULSD - SCR Bed Temperature

Test Results – SCR System

Storage and Release

Temperature [°C]
Test Results – SCR System

Vehicle Test Results

- NMHC [g/mile]
- CO [g/mile]
- PM [mg/mile]
- NOx [g/mile]

Different test conditions and emissions for SCR system are shown.
## Vehicle Test Results

### NREL SCR DPF aftertreatment system evaluation using B20 and ULSD fuel

<table>
<thead>
<tr>
<th>Date</th>
<th>Test #</th>
<th>Fuel</th>
<th>Test Type</th>
<th>Result</th>
<th>HC  g/mile</th>
<th>NMHC g/mile</th>
<th>CO  g/mile</th>
<th>NOx g/mile</th>
<th>CO2  g/mile</th>
<th>PM mg/mile</th>
<th>Fuel Econ miles/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAY 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2/15/08</td>
<td>2006-0227-071</td>
<td>B20</td>
<td>FTP2BAG</td>
<td>C-LA4</td>
<td>0.103</td>
<td>0.042</td>
<td>0.464</td>
<td>0.070</td>
<td>366.6</td>
<td>0.65</td>
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<td>0.077</td>
<td>0.021</td>
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<tr>
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<td>0.071</td>
<td>0.020</td>
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<td>339.782</td>
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<tr>
<td>2/15/08</td>
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<td>HFET/US06</td>
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<td>0.029</td>
<td>0.000</td>
<td>0.119</td>
<td>0.026</td>
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<tr>
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<td>0.040</td>
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<td>FTP2BAG</td>
<td>H-LA4</td>
<td>0.061</td>
<td>0.005</td>
<td>0.264</td>
<td>0.026</td>
<td>311.1</td>
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<td>0.462</td>
<td>0.121</td>
<td>287.3</td>
<td>7.14</td>
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<tr>
<td><strong>DAY 2</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>2/27/07</td>
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<td>FTP2BAG</td>
<td>C-LA4</td>
<td>0.082</td>
<td>0.022</td>
<td>0.258</td>
<td>0.067</td>
<td>371.3</td>
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<tr>
<td>2/27/07</td>
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<td>ULSD</td>
<td>FTP2BAG</td>
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<td>0.131</td>
<td>289.2</td>
<td>4.77</td>
<td>35.1</td>
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</table>
Test Results
Comparison NOx Adsorber SCR System

NOx emissions [g/mile]

- BASE: 0.74, 0.72
- T2B5 base cal engine out: 0.34, 0.31
- Tail pipe NAC: 0.03, 0.05
- Tail pipe SCR: 0.04, 0.04

Fuel economy [mpg]

- BASE: 35.28, 34.84
- T2B5 base cal engine out: 3.176, 3.173
- Tail pipe NAC: 30.73, 30.72
- Tail pipe SCR: 30.06, 29.96

FTP75
Test Results
Comparison NOx Adsorber SCR System

**NOx emissions [g/mile]**
- BASE: 0.49
- T2B5 base cal engine out: 0.35
- Tail pipe NAC: 0.03
- Tail pipe SCR: 0.01

**Fuel economy [mpg]**
- BASE: 59.07
- T2B5 base cal engine out: 50.25
- Tail pipe NAC: 48.97
- Tail pipe SCR: 47.73

HWFET
Summary and Conclusions

- Successful completion of the NOx adsorber durability task resulted in compliance with emission standards for 120,000 miles with useful life aged catalysts.

- SCR system development completed in test cell and vehicle with the successful demonstration of compliance with Tier 2 Bin 5 emission standards.

- Detailed investigations on rapid warm-up, storage and release as well as total system performance were conducted and shared with the development team.

- SCR system durability task completed and final emissions evaluation is currently underway.

- Detailed engine and fuel injection system evaluation currently underway.
Acknowledgments

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