Fleet Performance Results Using Biodiesel (B20)

Kenneth Proc
National Renewable Energy Laboratory
Golden, Colorado

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U.S. Department of Energy
Office of FreedomCAR and Vehicle Technologies
NREL’s Fleet Test and Evaluation Team

• Focused on evaluating advanced technologies in medium and heavy vehicle applications

• Main goals:
  – Facilitate the transition of advanced technologies from R&D to the marketplace
  – Provide potential users with accurate and unbiased information on vehicle performance and costs

• Completed B20 fleet projects
  – United States Postal Service (USPS) engine teardown
  – Denver Regional Transportation District (RTD) bus evaluation

• Biodiesel Blend Evaluation Team – Active Projects
  – USPS Cargo Vans
  – St. Louis Metro Transit Buses
  – Water Separator Working Group
USPS Engine Analysis – Description

• Comparison of engines and fuel systems operating on B20 to diesel

• Eight Postal Service vehicles total from Southern Florida fleets
  – Four 1996 Mack tractors
  – Four 1993 Ford cargo vans

• Engine and fuel system teardown
  – Measured component wear
  – Sludge analysis

• Maintenance history analysis
  – Engine and fuels system costs
USPS Engine Analysis – Results

• No major differences noted between B20 and diesel

• Measured wear considered normal for accumulated mileage

• Sludge noted on top of cylinder heads of Mack B20 engines

• Fuel injector wear in Mack B20 engines
USPS Engine Analysis – Conclusions

• Mack cylinder head sludge suspected cause is out-of-specification B20 fuel

• Both Mack B20 engines required injector nozzle replacement
  – May be attributable to B20 use and off-spec. fuel

• Mack tractors had similar maintenance costs with the exception of injector replacement

• Differences not observed in Ford cargo vans
RTD In-use Evaluation – Description

- Comparison of transit buses operating on B20 to diesel
- Nine mechanically identical transit buses
  - 2000 Orion V; Cummins ISM
  - Five operated on B20, four on diesel
- “Skip” route in Boulder, CO – identical duty cycle
- Data collection began in late July 2004
- NREL documented vehicle performance and operation (mileage accumulation, fuel use, maintenance costs) and analyzed results
RTD In-Use Evaluation – Analysis

• Two year data analysis
  August 2004 – July 2006

• Fuel and Maintenance
  – Mileage accumulation
  – Fuel economy
  – Maintenance costs
  – Road calls
  – Fuel Analysis
    • Blend level
  – Oil Analysis
    • Wear Metals
    • TBN, ZDDP, soot

• Other
  – Emissions testing
  – Filter Plugging
  – Component analysis
RTD In-Use Evaluation – Fuel Economy

Fuel Economy Comparison

- Diesel Group
- B20 Group

• 4.41 mpg diesel, 4.41 mpg B20
RTD In-Use Evaluation – Emissions

- NOx (g/mi)
- THC X 10 (g/mi)
- CO (g/mi)
- PM X 10 (g/mi)
- Fuel Economy (mpg)

Baseline Conventional Diesel Fuel
B20 Fuel

Error bars show 95% confidence interval of the mean.
RTD In-Use Evaluation – Conclusions

- On-road fuel economy – no difference
- Total maintenance costs – similar
- Fuel System and Engine maintenance costs – no significant difference
- Road calls – similar for both groups
- Filter plugging issues and plant sterols
- B20 splash-blending issues, generally B20 in tank
- Limited lube oil data suggests no harm with B20 use
- Significant emissions reductions including NO\textsubscript{x}
B20 Fleet Evaluation Team

- Early NBB requests of OEMs
  - Warranty support for B20
  - All wanted more field data

- Major OEMs, industry experts, and stakeholders participation

- Biodiesel proponents: “No B20 issues in the field”

- OEMs: “Prove it with quantifiable data”

- Active since 2003
Team Members

- Bosch
- Case New Holland
- Caterpillar
- Cummins
- DaimlerChrysler
- Delphi Diesel Systems
- Department of Defense
- Engine Manufacturers Association
- Fleetguard
- Ford Motor Co.
- General Motors
- International
- John Deere
- National Biodiesel Board
- National Renewable Energy Laboratory
- Parker - Racor
- Siemens Diesel Systems
- Stanadyne Corp.
- Volkswagen AG
- Volvo Truck
USPS Cargo Van Evaluation - Approach

- 10 identical Postal Service cargo vans
  - 2004 International trucks
  - DT466 (7.6L) engines
  - 5 on B20, 5 on D2

<table>
<thead>
<tr>
<th>Vehicle Information</th>
<th>Evaluation Trucks (B20 and Diesel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Trucks</td>
<td>5 B20, 5 Diesel</td>
</tr>
<tr>
<td>Chassis Manufacturer/Model</td>
<td>International Model 27-11</td>
</tr>
<tr>
<td>Chassis Model Year</td>
<td>2004</td>
</tr>
<tr>
<td>Engine Manufacturer/Model</td>
<td>International DT466 (7.6L)</td>
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<tr>
<td>Engine Ratings</td>
<td>225 hp @ 2,000 rpm</td>
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<tr>
<td></td>
<td>620 lb-ft @ 1,400 rpm</td>
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<tr>
<td>Diesel Fuel System Capacity</td>
<td>50 gal</td>
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<tr>
<td>Transmission Manufacturer/Model</td>
<td>Allison MD 3060-3000 HS</td>
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<tr>
<td>Curb Weight</td>
<td>18,270 lb</td>
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<tr>
<td>Gross Vehicle Weight Rating (GVWR)</td>
<td>42,100 lb</td>
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</tbody>
</table>
USPS Cargo Van Evaluation -
Approach

• B20 vehicles operated at Orlando Postal Service facility, diesel comparison at West Palm Beach

• Operational data collection
  – Fueling data from USPS database
  – Labor, parts from maintenance records

• Fuel sampling and analysis
  – Streicher Mobile Fueling

• Lube oil collection
  – International a partner for oil analysis
<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Frequency Recorded</th>
<th>Data Items</th>
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</thead>
<tbody>
<tr>
<td>Vehicle Specification and Performance Expectations</td>
<td></td>
<td>Shown in Appendix A</td>
</tr>
<tr>
<td>Vehicle System Descriptions</td>
<td>Start of data collection and changes as needed</td>
<td>General description of daily use of vehicles; more detailed information if available</td>
</tr>
<tr>
<td>Vehicle Operating Cycle</td>
<td>Start of data collection and changes as needed</td>
<td>Odometer reading</td>
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<tr>
<td>Vehicle Use in Service</td>
<td>At each time use is measured</td>
<td>GPS data (if needed)</td>
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<tr>
<td>Fuel Consumption</td>
<td>Each time a vehicle is fueled</td>
<td>Amount of fuel</td>
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<tr>
<td></td>
<td></td>
<td>Odometer reading</td>
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<tr>
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<td></td>
<td>Date</td>
</tr>
<tr>
<td></td>
<td>Each time the fuel price changes at a given site</td>
<td>Price per unit</td>
</tr>
<tr>
<td>Engine Oil Consumption and Changes</td>
<td>Each time oil is added</td>
<td>Amount of Oil</td>
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<tr>
<td></td>
<td></td>
<td>Odometer reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date</td>
</tr>
<tr>
<td></td>
<td>Each time oil is changed as recommended by the engine manufacturer</td>
<td>Price per quart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount of oil</td>
</tr>
<tr>
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<td></td>
<td>Odometer reading</td>
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<tr>
<td></td>
<td></td>
<td>Date</td>
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<tr>
<td>Maintenance</td>
<td>For each work order</td>
<td>Type of maintenance: scheduled, unscheduled, road call, system category</td>
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<tr>
<td></td>
<td></td>
<td>Labor hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date of repair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of days out of service</td>
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<tr>
<td></td>
<td></td>
<td>Odometer reading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parts replaced</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parts cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description of reported problem</td>
</tr>
<tr>
<td>Safety Incidents</td>
<td>Each occurrence</td>
<td>Description of each accident or incident involving the test or control vehicles, including collisions, and maintenance and fueling incidents</td>
</tr>
</tbody>
</table>
USPS Cargo Van Evaluation - Status

- Cargo vans in service early 2005
  - 325,000 miles on B20 (since new)
  - Over 65,000 gallons consumed
USPS Cargo Van Evaluation - Status

- Maintenance records received
  - Being entered into NREL database
  - Analysis period TBD

- Fuel samples
  - B100 (B99) deliveries
  - Vehicle fuel samples taken when problem occurs
  - Filter plugging, 2 received since November 2006

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<thead>
<tr>
<th>Method</th>
<th>Test</th>
<th>Result</th>
<th>Units</th>
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<tbody>
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<td>EN 14538</td>
<td>Sodium (Na) Content</td>
<td>0.7</td>
<td>ppm Wt</td>
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<tr>
<td></td>
<td>Potassium (K) Content</td>
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<td>ppm Wt</td>
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<tr>
<td></td>
<td>Calcium (Ca) Content</td>
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<td>ppm Wt</td>
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<tr>
<td></td>
<td>Magnesium (Mg) Content</td>
<td>&lt;0.1</td>
<td>ppm Wt</td>
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<td>D93a-06</td>
<td>Flash Point (PMCC) Proc. &quot;A&quot;</td>
<td>153</td>
<td>deg C</td>
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<tr>
<td>D2709-06</td>
<td>Sediment &amp; Water by Centrifuge</td>
<td>&lt;0.025</td>
<td>Vol %</td>
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<tr>
<td>D2500-05</td>
<td>Cloud Point</td>
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<td>deg C</td>
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<tr>
<td>D664-06a</td>
<td>Total Acid Number-Modified</td>
<td>0.54</td>
<td>mg KOH/g</td>
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<td>Mod</td>
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<td>D6584-05e1</td>
<td>Glycerin, Free</td>
<td>0.025</td>
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<td>D4951-06</td>
<td>Glycerin, Total</td>
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<td>Wt %</td>
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<td>Phosphorus (P) Content</td>
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<td>EN 14112</td>
<td>Oxidation Stability Induction Period @ 110°C</td>
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USPS Cargo Van Evaluation - Status

- **Oil Samples**
  - 6 week maintenance intervals
  - Wear metals, soot, fuel dilution

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<tr>
<th>Fuel</th>
<th>VIS100</th>
<th>Soot</th>
<th>TBN</th>
<th>Wear Metals (PPM)</th>
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<tr>
<td>Dil%</td>
<td>CST</td>
<td>%</td>
<td>Al</td>
<td>Cr</td>
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<tr>
<td>0</td>
<td>11.34</td>
<td>0</td>
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<td>2.88</td>
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<td>4.94</td>
<td>11.58</td>
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<thead>
<tr>
<th>Sn</th>
<th>Ni</th>
<th>Pb</th>
<th>Na</th>
<th>Mo</th>
<th>Fe</th>
<th>Cu</th>
<th>Si</th>
<th>Cr</th>
<th>Al</th>
<th>%</th>
<th>CST</th>
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St. Louis Metro In-use Evaluation – Description

• Comparison of transit buses operating on B20 to ULSD

• 15 mechanically identical transit buses
  – 2002 Gillig Phantom; Cummins ISM (2004 emissions certification) with EGR
  – 8 operated on B20, 7 on ULSD

• Drive cycles matched between B20 and diesel groups
  – Average speed
  – Stops per mile
  – Passengers per mile

• Project underway Oct 06

• NREL documenting vehicle performance and operation (mileage accumulation, fuel use, maintenance costs) and analyze results
Biodiesel Water Separator Effectiveness Testing

Working Group
- 6 companies participating
- Testing plan agreed upon by working group after reviewing initial proposals from SWRI. New plan is being priced.

Testing Overview
- NREL and NBB will supply fuel samples to SWRI that are representative of what is available in the marketplace.
- Down-selection of biodiesel fuels will be based on fuels best meeting ASTM D-6751 requirements.
- Down-selection of ULSDF will be based on SAE J1488 recommended values for IFT greater than 25 mN/m and MSEP value greater than 80.
- Additional testing will be done on the biodiesel blends prior to SAE J1488-Emulsified Water Removal Test Method testing.
- Any blend sample showing less than 95% efficiency will have B100 properties analyzed.
Biodiesel Blend Evaluation Team – Moving Forward

• USPS new cargo van evaluation
  – 10 identical 2004 International trucks
  – DT466 (7.6L) engines
  – Fuel and maintenance comparisons
  – Fuel and oil analysis

• St. Louis Metro bus evaluation
  – 15 identical 2002 Gillig buses
  – Cummins ISM (with EGR)
  – Fuel and maintenance comparisons
  – Fuel and oil analysis

• Working groups
  – Water separator effectiveness

• Biodiesel quality surveys
  – Separate B100 and B20 surveys
  – BQ9000 properties and metals (B100)
Information

- SAE Paper 2005-01-3641 Operating Experience and Teardown Analysis for Engines Operated on Biodiesel Blends (B20)

- SAE Paper 2006-01-3253 100,000-Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20)

- Contact information
  - Ken Proc
    Senior Project Leader
    National Renewable Energy Laboratory
    Golden, CO
    303-275-4424
    kenneth_proc@nrel.gov