Effects of Natural Gas Fuel Composition on Vehicle Emissions

Clean Fuels Program Advisory Group Meeting
February 6, 2013
AQMD, CARB and CEC co-funded CE-CERT to evaluate the effects of natural gas fuel composition on vehicle emissions, especially for heavy-duty vehicles

- Assess the viability of natural gas blends with higher Wobbe numbers (Hot Gas)
- Used for CARB’s regulatory development to amend CNG fuel standards for motor vehicles
Project Scope

- Evaluate emissions and fuel economy for vehicles operating on various natural gas fuel compositions
  - Phase 1: 2 light-duty vehicles on 4 blends
  - Phase 2: 4 heavy-duty vehicles on 6-7 blends
- Comparison between test gases for criteria pollutants, fuel economy, PM number and size distribution, ammonia and carbonyl compounds
- $729K total project cost
  - CEC $400K, CARB $279K, AQMD $50K
Light Duty Vehicles Testing

• Test Vehicles
  – 2006 Honda Civic GX, SULEV
  – 2002 Ford Crown Victoria, ULEV

• Test Fuels

<table>
<thead>
<tr>
<th>Gas</th>
<th>Description</th>
<th>methane</th>
<th>ethane</th>
<th>propane</th>
<th>l-butane</th>
<th>N₂</th>
<th>MN</th>
<th>Wobbe</th>
<th>HHV</th>
<th>H/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseline, Pipeline gas</td>
<td>96.05</td>
<td>1.79</td>
<td>0.37</td>
<td>0.17</td>
<td>1.62</td>
<td>97</td>
<td>1345</td>
<td>1021</td>
<td>3.94</td>
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<td>2</td>
<td>CARB certification gas</td>
<td>90.20</td>
<td>4.04</td>
<td>2.03</td>
<td>3.73</td>
<td>86</td>
<td>1329</td>
<td>1038</td>
<td>3.84</td>
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<tr>
<td>3</td>
<td>Hi Wobbe</td>
<td>83.92</td>
<td>9.43</td>
<td>3.79</td>
<td>1.86</td>
<td>1.00</td>
<td>68</td>
<td>1438</td>
<td>1177</td>
<td>3.63</td>
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<tr>
<td>4</td>
<td>Modified gas 3</td>
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<td>6.86</td>
<td>3.76</td>
<td>1.85</td>
<td>3.50</td>
<td>68</td>
<td>1385</td>
<td>1131</td>
<td>3.66</td>
</tr>
</tbody>
</table>

• FTP and Unified Cycle
• Testing at CE-CERT’s Vehicle Emissions Research Lab
Test Results
Light Duty Vehicles

• Clear trend for fuel economy, CO$_2$ and NMHC for richer gases with higher WN (CNG #3 & 4)
  - Better fuel economy
  - Higher CO$_2$ emissions (Honda)
  - Very low NMHC levels, but levels increased for richer gases

• No clear trend for THC, CO and NOx
  - THC showed higher emissions for higher MN (CNG #1 & 2) for Crown Victoria, but no trends for Honda
  - CO emissions higher for CNG #3 & 4 for Honda under some test conditions, but no effects for Crown Victoria
  - Only limited fuel effects for NOx for both vehicles
Heavy Duty Vehicles Testing

• Test Vehicles

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Engine</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transit Bus</td>
<td>2009 Cummins 8.9L ISL-G (stoichiometric)</td>
<td>TWC and EGR</td>
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<tr>
<td>2</td>
<td>Transit Bus</td>
<td>2004 JD 8.1L 6081H* (lean burn)</td>
<td>OC</td>
</tr>
<tr>
<td>3</td>
<td>Transit Bus</td>
<td>2003 Cummins 8.3L C-Gas Plus (lean burn)</td>
<td>OC</td>
</tr>
<tr>
<td>4</td>
<td>Refuse Truck</td>
<td>2002 Cummins 8.3L C-Gas Plus (lean burn)</td>
<td>OC</td>
</tr>
</tbody>
</table>

*JD bus was tested twice due to a mechanical malfunction

• Test Cycles
  – Buses: Central Business District
  – Refuse Truck: William H. Martin

• Testing at CE-CERT’s Heavy Duty Chassis Dynamometer Facility
## Heavy Duty Vehicles Test Fuels

<table>
<thead>
<tr>
<th>Gas #</th>
<th>Description</th>
<th>Methane</th>
<th>Ethane</th>
<th>Propane</th>
<th>MN</th>
<th>WN</th>
<th>HHV</th>
<th>H/C Ratio</th>
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<tbody>
<tr>
<td>1</td>
<td>Baseline, Texas Pipeline</td>
<td>96</td>
<td>1.8</td>
<td>0.4</td>
<td>99</td>
<td>1339</td>
<td>1021</td>
<td>3.94</td>
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<td>Baseline, Rocky Mtn Pipeline</td>
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<td>3.5</td>
<td>0.6</td>
<td>95</td>
<td>1361</td>
<td>1046</td>
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<td>3</td>
<td>Peruvian LNG</td>
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<td>0</td>
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<td>1385</td>
<td>1083</td>
<td>3.81</td>
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<td>High Propane</td>
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<tr>
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<td>L-CNG*</td>
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<td>103.1</td>
<td>1370</td>
<td>1029</td>
<td>3.96</td>
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</table>

*L-CNG is tested only with the refuse collection truck*
Heavy Duty Test – NOx (Buses)

- NOx emission levels for the Cummins ISL-G bus and C-Gas Plus bus were significantly lower than those of the JD bus.
- For JD and C-Gas Plus buses, higher NOx emissions for the richer gases containing higher levels of heavier hydrocarbons but no significant trend for the ISL-G bus.
Heavy Duty Test – NOx (Refuse Truck)

- Refuse truck showed the strongest fuel effects compared to the three buses, especially for the compaction segment with NOx increase of 286% over CNG 1.
Total PM mass emissions were low for all three buses on an absolute level, and are at the same levels as the tunnel background.

For the post-repair JD bus, the Cummins ISL-G bus, and the Cummins C-gas Plus bus, there were essentially no differences between PM mass for different fuel blends.
Richer gases with more higher hydrocarbons showing lower PM levels, while the gases with higher MN showed higher PM levels.
Lean burn engine vehicles showed clear trends for some emissions:
- Higher fuel economy, NOx and NMHC for richer gases (CNG #3, 4, 5 & 6)
  - NOx increase as much as 286% for refuse truck (compaction)
- Higher THC, CH4 and formaldehyde for lower WN gases (CNG #1, 2, & 7)
- Higher PM for lower WN (refuse truck)
  - PM emissions very low, close to background level for buses

Cummins ISL-G bus showed no fuel effects except for fuel economy, and had the lowest emissions except CO & NH₃

Refuse truck showed the strongest fuel effects

No strong fuel effects for CO and CO₂
Proposed Testing Project

• Retest John Deere bus
  – Redo testing of gases that were only tested during the initial testing (CNG #1, 2 and 3)

• Testing of an ISL-G refuse truck or drayage truck
  – Determine if fuel effects are not significant for different cycles for ISL-G engines

• 195K total project cost estimate
  – $120K from CARB, requesting $75K from AQMD