Comparison of Emissions from Diesel and CNG Buses with After-treatment

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Project Background

• CARB has reported benefits offered by diesel transit bus with a trap and low-sulfur fuel relative to benefits offered by CNG transit bus without after-treatment

• This presentation focuses on comparison of same diesel bus relative to CNG bus outfitted with OEM catalyst
An “apples-to-apples” comparison of “state of the art” technology based on speciated emission profiles

<table>
<thead>
<tr>
<th></th>
<th>Diesel Bus (Diesel_Trap)</th>
<th>CNG Bus (CNG_OxiCat)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>engine</strong></td>
<td>1998 DDC Series 50</td>
<td>2001 Cummins Westport C Gas Plus</td>
</tr>
<tr>
<td><strong>fuel</strong></td>
<td>BP/ARCO’s ECD-1 (15 ppm sulfur)</td>
<td>(pipeline) CNG meeting CARB spec’s</td>
</tr>
<tr>
<td><strong>after-treatment</strong></td>
<td>JMI’s CRT™</td>
<td>OEM Catalyst</td>
</tr>
<tr>
<td><strong>Chassis</strong></td>
<td>New Flyer 40 passenger</td>
<td>New Flyer 40 passenger</td>
</tr>
</tbody>
</table>
Scope of Presentation

- Chassis dynamometer testing at CARB’s Heavy-Duty Emissions Laboratory in Los Angeles

- Central Business District Cycle (particle sizing under steady state)

- Exhaust Emission Profile Speciation:
  - Criteria gases and PM
  - Unregulated gases, toxic hydrocarbons, and mutagen emissions

- Other info. available: Steady Steady results, additional assay results, metals and carbon emissions, and ultrafine particle size characterization (to be reported by CARB in future publications)
After-treatment for both diesel bus (i.e. trap) and CNG bus (i.e. catalyst) results in significant reduction of emissions relative to uncontrolled levels.

References:    SAE Tech. Paper 2003-01-1900
6th ETH Nanoparticle Conference, Aug. 2002, Zurich
SAE Tech. Paper 2002-01-1722
Average PM and NOx Emissions - CBD

<table>
<thead>
<tr>
<th></th>
<th>Diesel Trap</th>
<th>CNG_OxiCat</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂, g/mi</td>
<td>16.7</td>
<td>2.1</td>
</tr>
<tr>
<td>NOₓ, g/mi</td>
<td>31.1</td>
<td>13.9</td>
</tr>
<tr>
<td>PM, mg/mi</td>
<td>14.2</td>
<td>20.7</td>
</tr>
</tbody>
</table>
Average HC, CO2, and CO Emissions - CBD

<table>
<thead>
<tr>
<th></th>
<th>Diesel_Trap</th>
<th>CNG_OxiCat</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 (GC), g/mi</td>
<td>non-detect</td>
<td>13.7</td>
</tr>
<tr>
<td>THC (FID), g/mi</td>
<td>non-detect</td>
<td>14.1</td>
</tr>
<tr>
<td>CO2/100, g/mi</td>
<td>25.13</td>
<td>19.87</td>
</tr>
<tr>
<td>CO, g/mi</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

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Average NMOG Emissions - CBD

<table>
<thead>
<tr>
<th></th>
<th>Diesel_Trap</th>
<th>CNG_OxiCat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonyls, mg/mi</td>
<td>15</td>
<td>80.1</td>
</tr>
<tr>
<td>NMHC, mg/mi</td>
<td>36</td>
<td>184</td>
</tr>
</tbody>
</table>
Average PAH Emissions - CBD

<table>
<thead>
<tr>
<th></th>
<th>Diesel Trap</th>
<th>CNG_OxiCat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light PAHs, (ug/mi)</td>
<td>350</td>
<td>70</td>
</tr>
<tr>
<td>Heavy PAHs, (ug/mi)</td>
<td>0.09</td>
<td>1</td>
</tr>
</tbody>
</table>

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CNG Buses: Steady-State Cruise (55 mph)

Mini-diluter

\[
dN/d\log D_p \text{ (cm}^{-3}\text{)}
\]

- Cummins w/Oxi Cat
- DDC CNG-3 w/Oxi Cat
- DDC CNG-3

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CNG Buses: Idle

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Mini-diluter

Cummins w/Oxi Cat
DDC CNG-3 w/Oxi Cat
DDC CNG-3

\( \frac{dN}{d\log D_p} \) (cm\(^{-3}\))

\( D_p \) (nm)

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Relative Tailpipe Average Emission of Species of Toxic Significance - CBD

Results show cycle dependence

- PM, mg/mi
- NOx, g/mi
- NO2, g/mi
- CO, g/mi
- NMHC, mg/mi
- Heavy PAHs, (ug/mi)
- Light PAHs, (ug/mi)
- Benzene, mg/mi
- Formaldehyde, mg/mi
- Acetaldehyde, mg/mi
- Mutagenic Activity, TA98(+S9) Revert/ug
- Mutagen Emissions, TA98 (+S9) Revert/mile X10E5
Summary of CBD Results

• CNG_OxiCat and Diesel_Trap total PM emissions are similar and CO emissions are the same.

• CNG_OxiCat offers potential reductions for NOx, NO2, CO2, and PAH emissions.

• Diesel_Trap offers potential reductions for HC, carbonyls, benzene, and mutagen emissions.

http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm
Final Remarks

• CNG catalysts reduce ultrafine particle numbers for some operating conditions.

• Results show duty cycle dependence.

• Results support dual fuel path regulations for California.

• Results are “snap-shot” of two buses only.

• As technology evolves, emission profiles will change.

• After-treatment durability, deterioration, and vehicle maintenance effects were not investigated.

• Dilution tunnel background concentrations are important factors. Tunnel blank is not constant or negligible.
Further Research Needs

- How to use results to determine toxicity equivalency?

- CNG PM is not a Toxic Air Contaminant (TAC) while Diesel PM is a TAC. This includes after-treatment.

- Results must be confirmed. Concurrent studies by: BP/ARCO, USDOE, International, MTC, others?