ARB’s Study of Emissions from “Late-model” Diesel and CNG Heavy-duty Transit Buses: Preliminary Nanoparticle Measurement Results

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Global Objectives

- Take “snap-shot” of in-use fleet (not fleet average) and...

- Compare “toxicity” between similar “green” diesel and alternative fuel (CNG) technologies

- Assess duty cycle effects

- Investigate ultrafine (<100nm) emissions
Project Scope

- Testing at ARB’s Heavy-duty Vehicle Emissions Laboratory (HDVEL) in Los Angeles
- Three vehicle configurations:
  - CNG without oxidation catalyst
  - Diesel (OEM catalyzed muffler) - BP/ECD-1 (11 ppm S)
  - Diesel (CRT™) - BP/ECD-1 (11 ppm S)
- Five driving schedules + corresponding tunnel blanks:
  - Idle
  - Steady State+load (55mph, ~60% available power)
  - CBD - Central Business District Cycle
  - UDDS - Urban Dynamometer Driving Cycle
  - NYBC - New York Bus Cycle
- PM samples collected over multiple cycles
Project Scope (cont’d)

- Emissions: TPM, THC/NMHC, NO$_x$, CO, CO$_2$ and NO$_2$
- On-site Analysis for Speciation of Air Toxic HC’s
- Carbonyl Compounds
- Phase distribution of PAH’s
- PM extractions for Ames Bioassay
- Elemental Carbon/Organic Carbon Split (TOR)
- Elemental Analysis (XRF)
- Size-segregated mass emissions (MOUDI)
- Particle number and size distribution (2 SMPS’s, ELPI)
- Fuel and lube oil analysis
## Test Vehicles

<table>
<thead>
<tr>
<th></th>
<th>&quot;CNG&quot;</th>
<th>&quot;Diesel (OEM)&quot;</th>
<th>&quot;CRT&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
<td>2000 DDC Series 50G</td>
<td>1998 DDC Series 50</td>
<td>1998 DDC Series 50</td>
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<tr>
<td><strong>Aftertreatment</strong></td>
<td>None</td>
<td>OEM Catalyzed Muffler</td>
<td>CRT™</td>
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<tr>
<td><strong>Fuel</strong></td>
<td>CNG</td>
<td>ECD-1</td>
<td>ECD-1</td>
</tr>
<tr>
<td><strong>Odometer</strong></td>
<td>19,629</td>
<td>15,169</td>
<td>15,569</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>33,150 lbs</td>
<td>30,510</td>
<td>30,510</td>
</tr>
</tbody>
</table>

- Los Angeles County Metropolitan Transit Authority fleet
- 8.5 liter, 4-stroke, turbocharged, 4-cylinder, New Flyer Low 40 passenger transit buses
Experimental Setup

Not to scale

Constant Volume Sampling Dilution Tunnel

3-stage Filter

Primary Dilution Tunnel

EC/OC Elements

Mini-diluter

ELPI

VEHICLE EXHAUST

SECONDARY DILUTION TUNNEL

PM filters

MOUDI

PM filters

PUF/XAD

CVS BLOWER

CVS SAMPLE BAGS (CO and CO2)

Air Toxic HC's SPECIATION BAGS (8.0L TEDLAR)

On-site GC's-FID
Average NO\textsubscript{x} and Raw PM Emissions-CBD

Note:  
1] CRT mass emissions were comparable to background levels
2] PM emissions uncorrected for Tunnel Blanks
3] CNG engine software upgraded and O\textsubscript{2} sensor module replaced prior to re-test
Average HC and CO Emissions-CBD

Note: THC for diesel/NMHC for CNG
Ultrafine Particles

- Two SMPS sampling locations/systems:
  - CVS dilution tunnel
  - Raw exhaust single-stage Dekati mini-diluter:
    - Two dilution ratios: ~65 and ~18
    - Oil-free compressor, dessicant/carbon/HEPA-filtered air
    - Aerosol transport lines: residence time ~ 1 to 1.5 sec
- Full scans (size-scan mode) for steady state, idle, and tunnel blanks (size range 6 – 237 nm)
- Single diameter real-time recording (size-filtered mode) for transient cycles (8, 20, 80, and 140 nm)
- Results shown = actual measured traces uncorrected for dilution or losses
Average of Individual Scans - **Mini-diluter- SS Tests**

**SIZE-SCAN MODE**

- CRT 3&4 (DR~65)
- CRT 1&2
- Diesel (OEM)
- CNG
- CNG retest #1 (DR~18)
- CNG retest #2

Note: CNG retest#1 = 55mph, 0% gradient, CNG retest#2=55mph,0.6% gradient
Individual Diameter Traces - Mini-diluter - 4 CBD Cycles
SIZE-FILTERED MODE

CNG re-test
DR~18

Time of Day

CRT Traces - CBD Tests
SIZE-FILTERED MODE

Orange = CVS

Purple = Mini-diluter, DR=18

Orange = CVS
Purple = Mini-diluter, DR=18

Central Business District (CBD) Cycle
Individual Diameter Traces - CVS - CBD Tests
SIZE-FILTERED MODE

Diesel (OEM)

CRT
Individual Diameter Traces - CVS - CBD Tests
SIZE-FILTERED MODE

CNG re-test

CNG

CNG
Average of Individual Scans - Dilution Comparison - CBD Tests
SIZE-SCAN MODE

CVS

Mini-diluter

AVERAGES

DR~65
**CVS Tunnel Blanks**

AVERAGES of TB Scans collected during testing of vehicle listed in legend

- **CNG**
- **Diesel (OEM)**
- **CRT**
- **CNG retest**

Total Concentration [# cm$^{-3}$]

**dN/dlogD$_p$**

- **CNG**
- **Diesel (OEM)**
- **CRT**
- **CNG retest**

**School bus+trap testing**

**CRC lab inter-comparison HD Class 8 truck testing**

**School bus+trap testing**

**Feb** **June**

**D$_p$ (nm)**
Remarks for Regulated Emissions over CBD

• CRT showed reductions in CO (87%), THC (100%), and raw/uncorrected PM (88%) relative to Diesel (OEM)

• CRT and Diesel OEM NO\textsubscript{x} not significantly different

• Significantly different NO\textsubscript{2}/NO\textsubscript{x} ratios in CRT (50%) and Diesel OEM (3%)

• Raw/uncorrected PM for CNG and CNG re-test showed reduction of 66 to 72%, respectively, relative to Diesel (OEM)

• CNG NO\textsubscript{x} exhibited high variability. CNG re-test NO\textsubscript{x} was 75% of Diesel (OEM) NO\textsubscript{x}

• Because of composition of PM from CRT and role/magnitude of tunnel background, we may define “MINIMUM” reduction efficiency for PM traps if current sampling methods continue to be used
Remarks for Ultrafine Particles

- CRT showed reduction in particle counts for all particles in measured range for SS tests
- Only accumulation mode was evident in diesel for SS tests
- For SS, modes in CNG size distributions were not distinct, but nanoparticle (<50nm) concentrations were higher than for CRT
- Transient and cold-start resulted in highest numbers of ultrafines for all vehicles
- For SS, total counts for CNG and CRT were equivalent and lower than baseline
Remarks for Ultrafine Particles (cont’d)

- For CBD, CNG nanoparticles were smaller and more numerous than for baseline and CRT
- For CBD, CNG re-test resulted in highest 8 nm and 20 nm nanoparticle concentrations. Observed increase in THC’s may explain
- Vehicle conditioning/tunnel artifacts play role when measuring CVS ultrafine concentrations for low emission vehicles
- Relative size distributions appear to be preserved between CVS and mini-diluter systems for 3 vehicle types examined