Public Workshop on Proposed Revisions to the Low-Emission Vehicle Program: Emission Limits for Particle Mass, Solid Particle Number, and Black Carbon

Air Resources Board
El Monte, California
May 18, 2010

http://www.arb.ca.gov/msprog/levprog/leviii/meetings/051810/pm_disc_paper-v6.pdf
ARB Policy Drivers

- GHGs and PM are Board priorities
- Time to take concurrent steps for reducing air and climate pollution
- Lock in benefit of PM overcompliance of current gasoline vehicles
- Arrest upward pressure on PM by some low-CO$_2$ technologies
- Update policy with latest science
- Guide development of future vehicle technology
Reason for Proposed PM Mass and Number Standards

- Anticipated widespread adoption of lower-CO₂ GDI technology
- GDI can increase current PFI vehicle PM (and BC) emissions from <1 mg/mi to 2-20 mg/mi
- Well-engineered GDI can limit PM emissions to <3 mg/mi
Propose low-CO$_2$ Technology

Proposed standards can be met without a gasoline particle filter, by using improved GDI technology. Options include:

- center guided spray vs. wall guided spray
- piezoelectric metering vs. solenoid metering
- cold start strategies
- modified catalyst design
Proposed Rules

• **Particle Mass and Particle Number:** by MY 2014 vehicles must meet either
  – a PM mass standard, *or*
  – a new solid particle number (SPN) standard
    (manufacturer chooses which standard by make/model)

• **Black Carbon:** by MY 2017 vehicles must
  – include BC in calculation of CO$_2$E GHG emissions
Particle Mass and Particle Number
Optional Solid Particle Number Standard

- Compliance flexibility for auto maker
  - Coordination with European SPN Standards
- Recognition that particle number has potential adverse health impacts
- For very low emissions, simpler, faster, more precise measurement method than gravimetric approach (40 CFR Part 1065)
  - Roughly equivalent PM mass reduction because majority of GDI PM mass is solid particles > 23 nm
## Proposed Limits

<table>
<thead>
<tr>
<th>Vehicle Category (lbs)</th>
<th>LEV II Standards</th>
<th>Proposed Standards (full useful life)</th>
<th>Interim (MY 2014)</th>
<th>Final (MY 2017)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM g/mi</td>
<td>SPN #/mi</td>
<td>PM g/mi</td>
<td>SPN #/mi</td>
</tr>
<tr>
<td>LDV (0 - 8,500)</td>
<td>0.010</td>
<td>-</td>
<td>0.006</td>
<td>$6 \times 10^{12}$</td>
</tr>
<tr>
<td>MDPV (8,501 - 10,000)</td>
<td>0.010</td>
<td>-</td>
<td>0.006</td>
<td>$6 \times 10^{12}$</td>
</tr>
<tr>
<td>MDV (8,501 - 14,000)</td>
<td>0.060 - 0.012</td>
<td>-</td>
<td>Final (MY 2016)</td>
<td>PM g/mi</td>
</tr>
<tr>
<td></td>
<td>0.008 - 0.012</td>
<td>TBD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Manufacturer must choose to comply with either the PM standard or the SPN standard*
PM and SPN Measurement Methods

• Particle Mass (PM)
  – Federal reference method for CVS sampling:
    Title 40 CFR Part 1065

• Solid Particle Number (SPN)
  – Federal reference method for CVS sampling:
    applicable sections of Title 40 CFR Part 1065
  – European PMP protocol for solid particles > 23 nm
Relationship between Mass and SPN for Wall-guided Stoichiometric GDI

<table>
<thead>
<tr>
<th>Veh.</th>
<th>PM (mg/mi)</th>
<th>SPN (#/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.38</td>
<td>5.95E+12</td>
</tr>
<tr>
<td>2</td>
<td>5.97</td>
<td>4.39E+12</td>
</tr>
<tr>
<td>3</td>
<td>3.80</td>
<td>3.07E+12</td>
</tr>
<tr>
<td>4</td>
<td>3.79</td>
<td>not collected</td>
</tr>
<tr>
<td>5</td>
<td>3.29</td>
<td>not collected</td>
</tr>
<tr>
<td>6</td>
<td>3.07</td>
<td>3.98E+12</td>
</tr>
</tbody>
</table>

- SPN measured using original PMP protocol dilution factor. New PMP dilution adjustment gives higher results.
- Tested using CA Summer Fuel.
- We are also reviewing recent Ford findings regarding AVL Soot vs. PM (SAE 2010-01-0789)
Black Carbon
Black Carbon (BC): Strong climate forcer

- 500 to 2000 more potent than CO$_2$
- GDI PM emissions are mostly BC (PFI PM is mostly organic carbon)
- Near-term opportunity to reduce/postpone climate change impact of rising GHG
- On-road and off-road mobile sources: 20% and 23% of statewide BC emissions, respectively
BC Causes Significant Warming Impact

- Large direct BC warming
  Additional warming from BC deposition on snow

- Whiter PM components may partially offset BC warming

Sources: IPCC AR4 WG1 2007 for all, except Ramanathan & Carmichael 2008 BC bar
California BC Emissions in 2006

Wildfire 29%
Managed Burning 14%
Residential 8%

On-Road Transportation 20%
Gasoline 5%
Diesel 15%

Off-Road Transportation 23%

Proposed Rule

• **Recommendation:**
  – Add BC into a CO$_2$-equivalency framework

• **Seeking input on:**
  – Choosing appropriate GWP for BC
  – Estimating PM mass emission rate
  – Determining BC fraction of PM by either:
    • Default value (BC = 67% of PM mass), or
    • BC Measurement
## BC Global Warming Potential (GWP)

<table>
<thead>
<tr>
<th>Source</th>
<th>100-yr</th>
<th>20-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond and Sun, 2005</td>
<td>680</td>
<td>2,200</td>
</tr>
<tr>
<td>Hansen et al., 2007</td>
<td>~500</td>
<td>~2,000</td>
</tr>
<tr>
<td>Reddy and Boucher, 2007</td>
<td>480</td>
<td>--</td>
</tr>
<tr>
<td>Forster et al., 2007</td>
<td>510</td>
<td>--</td>
</tr>
<tr>
<td>Rypdal et al., 2009</td>
<td>830</td>
<td>2,900</td>
</tr>
</tbody>
</table>
Choice of GWP Horizon for BC

Need input: Use 20-yr GWP (2000), instead of 100-yr GWP (500)?

– Prominent scientists recommend 20-yr GWP as most appropriate

– BC exerts rapid warming effect in the vicinity of the source

– Shorter time horizon reflects how rapidly the BC control can produce climate benefits
## Impact of Including BC as GHG

<table>
<thead>
<tr>
<th>GHG Emissions (gCO₂e/mi)a</th>
<th>100-year</th>
<th>20-year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂</strong></td>
<td>1</td>
<td>337</td>
</tr>
<tr>
<td><strong>AC CO₂ (indirect)</strong></td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td><strong>AC Refrigerant</strong></td>
<td>1,430</td>
<td>6</td>
</tr>
<tr>
<td><strong>N₂O</strong></td>
<td>298</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>CH₄</strong></td>
<td>25</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>BCb</strong></td>
<td>500</td>
<td>0.3</td>
</tr>
</tbody>
</table>

a-GWPs updated for IPCC 2007 AR4 values  
b-BC emissions are based on 3 mg/mi PM emissions, 67% black carbon fraction
BC Measurement Methods

• Filter-based thermal-optical method (mass)
  ➢ “IMPROVE A” & NIOSH 5040
  ➢ Large database available nationwide for emission inventory and ambient air monitoring

• Optical method (light absorption)
  ➢ Particle soot absorption photometer, aethalometer, and photoacoustic analyzer
  ➢ Real-time measurements to monitor transient events
  ➢ Provides a simpler and faster test procedure
  ➢ Optical absorption can be converted into an equivalent mass
Remaining Questions / Issues
Ongoing Activities

• Continue collaborative testing approach
  – SPN / AVL-Soot / PM
  – Consider SFTP

• Define limits

• Cost estimates

• Define BC treatment and measurement methods

• Update ARB test procedures

• Public Workshop in August
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