Comparison of light-duty NOx emission rates estimated from MOVES with real-world measurements

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Contribution of Light-duty Gasoline NOx Emissions to the National Emissions Inventory

- Mobile sources contribute ~54% of NOx emissions in the 2014 NEI
- ~65% of which are on-road emissions
- ~37% of which are light-duty gasoline running emissions
- In counties observed with large NOx discrepancy between monitored and modeled values during 2011 summer months, starts and diesel extended idle emissions are minor contributors to total NOx
## Data for Evaluating Light Duty Rates

<table>
<thead>
<tr>
<th></th>
<th>Tunnels</th>
<th>Inspection/Maintenance</th>
<th>Remote Sensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual vehicle</td>
<td>No: Fleet average</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>measurements?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cities</td>
<td>Two</td>
<td>Denver</td>
<td>Fourteen</td>
</tr>
<tr>
<td>Ability to capture rare high emitters?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Known operating conditions? (for replicating in MOVES)</td>
<td>Estimated based on sample vehicle speed traces in 1996</td>
<td>Yes: preconditioned IM240</td>
<td>Yes: vehicle speed &amp; acceleration recorded</td>
</tr>
<tr>
<td>Real-world driving conditions?</td>
<td>1 km of driving through Caldecott Tunnel on urban freeway. ¼ km of driving of major arterial (3-lanes in both directions) in Van Nuys Tunnel</td>
<td>IM240 driving cycle on chassis dynamometer</td>
<td>Snapshot (typically during vehicle acceleration on freeway ramps)</td>
</tr>
<tr>
<td>Known vehicle characteristics? (car/truck, gas/diesel, model year/age)</td>
<td>Some: age distribution and fleet mix measured in 2006 for Caldecott Tunnel, and 2010 in Van Nuys.</td>
<td>Yes</td>
<td>Yes: from VIN decoding</td>
</tr>
</tbody>
</table>
Comparison to Tunnel Studies

- **Caldecott Tunnel, Oakland, CA**
  - Summer, 1997\textsuperscript{2}, 2001\textsuperscript{3}, 2006\textsuperscript{4}, 2010\textsuperscript{5,6} (UC-Berkeley)
  - 37 mph, 4% uphill grade
  - 2 tunnel bores, with light-duty-only bore

- **Van Nuys Tunnel, Los Angeles, CA**
  - Summer, 2010\textsuperscript{7}
  - 41 mph, 1.7% downhill grade (entrance), 1% uphill grade (exit)
  - Single bore with mixed traffic (1.3% heavy-duty traffic)

- MOVES run in project-mode with local inputs
  - Roadway conditions (grade, speed)
  - Vehicle operating modes from 1 Hz speed trace data
  - Vehicle fleet mix (LD vs. HD)
  - Vehicle age distribution
  - Local fuel properties (fuel survey data)
  - July average for temperature/humidity for 5 pm
California Caveat

- MOVES is not designed to model California emissions

- MOVES runs for the Caldecott tunnel were adjusted to account for the California LEV standards, but do not account for the California pre-1994 vehicle NOx standards, which are much tighter than the Federal standards
Large range of MOVES emission rates in 2010 due to uncertainty about the age distribution of vehicles in the tunnel.

Caldecott Tunnel, Oxides of Nitrogen (NOx)

**Gasoline**

**Diesel Fuel**

**Error bars**

<table>
<thead>
<tr>
<th>Source of light-duty age distribution in 2010 (average age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Van Nuys 2010 (8.5 yrs)</td>
</tr>
<tr>
<td>Mid EMFAC2014 Contra Costa County (7.4 yrs)</td>
</tr>
<tr>
<td>Low Caldecott Tunnel 2006 (5.7 yrs)</td>
</tr>
</tbody>
</table>

MOVES error bars: MOVES emission rates estimated from using a range the least aggressive, average, and most aggressive vehicle speed traces measured in Caldecott in 1994. In 2010, the age distribution also varied.

Caldecott error bars: 95% confidence intervals of emission rates derived from tunnel measurements, reported studies²,³,⁴,⁵,⁶.
MOVES gasoline rates are higher than Caldecott for all calendar years.

MOVES HD diesel rates compare well to Caldecott 1997 and 2006 measurements.

MOVES HD diesel rates are significantly lower than Caldecott in 2010.
Light-duty gas/Heavy-duty diesel vehicle miles traveled split estimated from EMFAC2014 for Contra Costa County.
MOVES estimates higher gasoline emissions

MOVES estimates lower diesel emissions

Oxides of Nitrogen (NOx) Caldecott Tunnel, July 2010

Oxides of Nitrogen (NOx) Van Nuys Tunnel, July 2010
Denver I/M Dynamometer Testing Data

• Denver Inspection & Maintenance (I/M) test data on light-duty vehicles
  – NOx emissions on IM240 cycle
  – Random evaluation sample
    • Calendar years 2008-2015
    • Corrected for bias due to testing exemption for clean cars
  – Tier 1 cars (1996-2000 model years)
  – Tier 2 cars and trucks (2010-2016 model years)

• MOVES comparisons
  – Compare emissions by vehicle age and vehicle class, and federal emission standards (Tier 1 and Tier 2)
  – Simulate IM240 using MOVES base rates
  – No MOVES adjustments for temperature/humidity and fuel properties
Denver I/M Comparison to MOVES

- MOVES is higher than I/M data for pre-2000 (Tier 1) cars
- MOVES is lower than I/M data for 2010+ (Tier 2) cars
- Tier 2 light trucks estimated well
- MOVES deterioration trends compare well
-Projected impact on NOx inventory: MOVES higher than an inventory developed using I/M data for calendar year 2010 and earlier, and lower for 2015 and later

**Tier 1 cars**

**Tier 2 cars**

**Tier 2 trucks**
Evaluation using Onroad Remote Sensing Device (RSD) Data

- Studies conducted by University of Denver[8]
  - Individual vehicles measured remotely from the road-side
  - Using the FEAT remote sensor
  - Reported percent concentration of NO†
- Vehicle information (i.e., make and model) obtained from license plate and vehicle registration data
- Data includes
  - Vehicle operating conditions (speed/acceleration/vehicle specific power (VSP))
  - Measurement conditions (temperature/humidity/road grade)
  - Flags for invalid measurements

† Converted to fuel-specific rates (g/kg fuel) in NO₂ mass-equivalence
## RSD Data Summary

<table>
<thead>
<tr>
<th>RSD Sites</th>
<th>Calendar Years</th>
<th>Number of Valid Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles, CA (LA710)</td>
<td>1999</td>
<td>9,336</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>1999</td>
<td>12,965</td>
</tr>
<tr>
<td>Riverside, CA</td>
<td>1999-2001</td>
<td>49,878</td>
</tr>
<tr>
<td>San Jose, CA</td>
<td>1999, 2008</td>
<td>49,550</td>
</tr>
<tr>
<td>Fresno, CA</td>
<td>2008</td>
<td>11,595</td>
</tr>
<tr>
<td>Van Nuys, CA</td>
<td>2010</td>
<td>10,669</td>
</tr>
<tr>
<td>Glenwood Springs, CO</td>
<td>2001</td>
<td>324</td>
</tr>
<tr>
<td>Grand Junction, CO</td>
<td>2001</td>
<td>3,346</td>
</tr>
<tr>
<td>Denver, CO (Speer Blvd)</td>
<td>2002</td>
<td>8,311</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>670,819</strong></td>
</tr>
</tbody>
</table>
MOVES Model Runs

• Project-scale runs with inputs customized to remote sensing sites
  – Operating mode distribution (function of vehicle speed, acceleration, VSP)
  – Age distribution
  – Vehicle class distribution (passenger car vs. truck)
  – Adoption of 1994-and-later California vehicle emission standards, where applicable†
    – Calendar-specific fuel sulfur level based on EPA’s fuel compliance data⁹
    – Inspection & Maintenance programs, where applicable
    – Local temperature/humidity

• National-scale runs
  – Use MOVES default inputs
  – Do not account for the measurement conditions

† Pre-1994 California emission standards not modeled
Comparisons of RSD and MOVES

- Measured:
  - RSD data
  - RSD regression line
  - RSD 95% confidence band

- Modeled:
  - MOVES project-scale regression line
  - MOVES project-scale 95% confidence band
  - MOVES national-scale

![Graph showing comparisons between measured and modeled data for RSD and MOVES.](image-url)
Comparisons of RSD and MOVES

• MOVES project-scale
  – Under-predicts onroad remote sensing measurements
  – For most years, MOVES predictions within the data variability
  – Demonstrates the importance of accounting for the measurement conditions (e.g. fleet composition, vehicle activity) when evaluating MOVES

• MOVES national-scale
  – Using the MOVES default inputs can show clear over-prediction
  – Consistent with what’s reported in the literature\(^1\)
  – NOT a proper way to compare MOVES to independent data

• MOVES national scale ≠ NEI MOVES emissions
  – EPA and states develop county-level MOVES inputs for the NEI
  – NEI may use national defaults for some inputs (e.g. age distribution, vehicle speed), when data not provided from states

\(^1\) Consistent with what’s reported in the literature.
• EPA’s evaluation of MOVES light-duty NOx emission rates is mixed, but has not concluded there is an overestimation of NOx

• California tunnel studies suggest MOVES NOx emission rates may be too high in 1999-2010 calendar years
  – Uncertainties remain regarding key model inputs (e.g. vehicle age distributions)
  – Pre-1994 California emission standards not modeled, which may account for some of the difference in emissions from the tunnel and California RSD locations compared to MOVES

• Denver I/M dynamometer data suggest MOVES NOx emission rates may be too high for Tier 1 passenger cars, and may be too low for Tier 2 passenger cars

• Roadside RSD studies suggest MOVES light-duty NOx emission rates are low but generally within the data variability
  – When using appropriate MOVES inputs
  – When using national defaults, MOVES appears high compared to RSD data
Next Steps

• We are continuing to evaluate MOVES NOx emission rates, including comparing rates to additional vehicle emission studies

• We are evaluating and improving the MOVES inputs used in the National Emissions Inventory

• We have conducted sensitivity analysis to evaluate the most important inputs for conducting MOVES comparisons to tunnel and roadside studies
  – See Poster Presentation: “Sensitivity of MOVES-estimated vehicle emissions to inputs when comparing to real-world measurements”

• We encourage further work in evaluating MOVES and improving MOVES inputs for all scales of modeling


