The USEPA MOVES Model: A Midcourse Review

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Outline of Topics

1. Background
2. Model History/Evolution
3. Current Uncertainties in Data/Methods
4. Inventory Results
5. Final Remarks
Background

- Synthesis of observations built from:
  - CRC E-116 – Development of MOVES Evaporative Input
  - Various US and Canadian MOVES Projects

- External review; views are those of the participants:
  - Jeremy G. Heiken – On-road model review and development since 1989
  - CRC Projects completed in collaboration with Sierra Research (Jim Lyons, Tom Carlson, Mark Hixson & Dennis McClement)
EPA On-Road Model History

- MOBILE Model (1978 to 2004)
  - MOBILE1 released in 1978
  - MOBILE6.2 released in 2004

- MOVES Model
  - Concept release 2004 (energy calculations)
  - Draft release 2009 (criteria pollutants)
  - MOVES2010 (December 2009)
  - MOVES2014 (July 2014)
History Matters

- The development path has impacted the form and function of the on-road models
- Successive versions of MOBILE built off each other
- MOVES is the first wholesale model revision
  - New concepts
  - Data & Method
  - Platform
- MOVES has “evolved” through successive releases
MOVES Development

- Vision
  - New modeling approach to complement the anticipated watershed of instrumented vehicle data
  - Locally collected emissions/activity collection

- Original Concept (2004)
  - Transcend scales (microscale, macroscale, regional)
  - Advanced vehicle technologies
  - Fuel choice evaluations (full fuel lifecycle)
  - Instrumented vehicle emissions based
    - Light & heavy-duty
Evolutionary Causes

- Priorities change with regulatory actions
- Adding features while maintaining model performance
- Need for agency consistency with other modeling tools (e.g., fuel economy/GHG modeling)
## Evolution of Original Concepts

<table>
<thead>
<tr>
<th>Element</th>
<th>Draft 2004</th>
<th>2010</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transcend Scales</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fuel Choice, Lifecycle Modeling</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Advanced Technology Vehicles</td>
<td>Yes</td>
<td>Partial</td>
<td>No</td>
</tr>
<tr>
<td>HD Instrumented Vehicle Emission Data</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LD Instrumented Vehicle Emissions Data</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Notable Achievements beyond Concept

- Modal method for evaporative emissions
- Improved method for light-duty exhaust deterioration
- Incorporation of comprehensive light-duty PM test program
- Data and regulatory updates
- Improved fuel parameter modeling
- Updated chemical and photochemical model speciation
- Incorporation of non-road sources
Example Area of Uncertainty

- Light-duty (LD) gasoline exhaust underlying data record is fragmented supporting THC, NOx and CO emissions calculations. 3 primary components (with distinct sources):
  - Low-power running exhaust
  - High-power running exhaust
  - Start exhaust
LD Gasoline Exhaust is Significant

LD Gasoline Exhaust Share of Total On-Road Inventory

CRC E-101 3-City Average

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>2011 (Annual)</th>
<th>2022 (Annual)</th>
</tr>
</thead>
<tbody>
<tr>
<td>THC</td>
<td>51%</td>
<td>41%</td>
</tr>
<tr>
<td>CO</td>
<td>86%</td>
<td>87%</td>
</tr>
<tr>
<td>NOX</td>
<td>48%</td>
<td>44%</td>
</tr>
<tr>
<td>PM2.5</td>
<td>17%</td>
<td>46%</td>
</tr>
</tbody>
</table>
3 Components to LD Gasoline Exhaust

- Running Exhaust (Low Power)
  - AZ I/M data (Tier 0 & Tier 1) – 1 Hz resolution
  - FTP75 cycle data (NLEV & Tier 2)

- Running Exhaust (High Power)
  - EPA US06/MEC lab data (Tier 0 & Tier 1) - 1 Hz resolution
  - IUVP US06 cycle data (NLEV & Tier 2)

- Start Exhaust
  - EPA MSOD (Tier 0)
  - IUVP (NLEV & Tier 2)
3 Components to LD Gasoline Exhaust

- **Running (Low Power)**
  - AZ I/M data – robust random sample, best quantification of deterioration

- **Running (High Power)**
  - Results are normalized/scaled to low power rates (AZ I/M)
  - Deterioration rate not explicit (implicitly equal to low-power running exhaust)

- **Start Exhaust**
  - Tier 0 rates are not age specific (no deterioration)
  - NLEV & Tier 2 rate deterioration scaled to low-power running exhaust including a MOBILE model adjustment
Service Life Exhaust Emissions

- Total exhaust emissions per vehicle over its lifetime
  - 2016MY vehicle examined from 2016 through 2046
- National average in-use conditions (Ambient, fuels, I/M)
- Quantification of the relative contributions by exhaust component
  - Low-power running exhaust
  - High-power running exhaust
  - Start exhaust
Service Life NOx Exhaust, Tier 2 Bin 5 Vehicle

Light-Duty Truck
25,144 grams/vehicle

Passenger Car
19,265 grams/vehicle

- Running (High Power): 39%
- Running (Low Power): 33%
- Start: 28%

- Running (High Power): 53%
- Running (Low Power): 31%
- Start: 16%
Service Life THC Exhaust, Tier 2 Bin 5 Vehicle

Light-Duty Truck
19,143 grams/vehicle

- Running (High Power): 81%
- Running (Low Power): 16%
- Start: 3%

Passenger Car
18,345 grams/vehicle

- Running (High Power): 88%
- Running (Low Power): 8%
- Start: 3%
LD Gasoline Exhaust Summary

- While the LD gasoline exhaust data used in MOVES represents the best available – the underlying test record is fragmented and not ideally suited for approach.
  - Low-power running exhaust gets priority focus but is the smallest contributor.
    - MOVES validation efforts focus on the low-power running exhaust component (RSD, I/M data)
  - Future focus needs to be on the full power range of running exhaust and start exhaust.
    - Current uncertainty in deterioration for high-power running exhaust and start exhaust and I/M effects.
Emission Inventory Results

- CRC E-101 examined 3 locations picked for diversity of input
  - Maricopa County (Phoenix)
  - Wayne County (Detroit)
  - Fulton County (Atlanta)
- Detailed inventory examination using local input (2011 to 2050)
- Sensitivity Analyses
  - I/M, fuels and modeling variables
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fulton County (GA)</th>
<th>Maricopa County (AZ)</th>
<th>Wayne County (MI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan Statistical Area</td>
<td>Atlanta-Sandy Springs-Roswell</td>
<td>Phoenix-Mesa- Glendale</td>
<td>Detroit-Warren-Livonia</td>
</tr>
<tr>
<td>Human Population (2011)</td>
<td>949,599</td>
<td>3,880,244</td>
<td>1,802,096</td>
</tr>
<tr>
<td>County Population Rank within State (2011)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Area (mi²)</td>
<td>534</td>
<td>9,224</td>
<td>673</td>
</tr>
<tr>
<td>Mean Temperature:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July Min/Max (°F)</td>
<td>71/91</td>
<td>80/105</td>
<td>69/89</td>
</tr>
<tr>
<td>January Min/Max (°F)</td>
<td>29/48</td>
<td>40/67</td>
<td>15/29</td>
</tr>
<tr>
<td>Vehicle Population (2011)</td>
<td>807,939</td>
<td>2,787,358</td>
<td>1,214,732</td>
</tr>
<tr>
<td>Vehicle Miles Traveled (2011, Annual)</td>
<td>12,221,921,568</td>
<td>32,442,909,320</td>
<td>16,694,871,362</td>
</tr>
<tr>
<td>Forecasted Growth in On-Road Activity</td>
<td>Moderate</td>
<td>National-average light and heavy-duty proportion; motorcycle usage twice the national average</td>
<td>National-average light and heavy-duty proportion</td>
</tr>
<tr>
<td>Vehicle Class VMT Splits (2011)</td>
<td>Greater light-duty proportion (than the national average)</td>
<td>National-average light and heavy-duty proportion; motorcycle usage twice the national average</td>
<td>National-average light and heavy-duty proportion</td>
</tr>
<tr>
<td>Average Age, Light-Duty Vehicle (2011, Years)</td>
<td>8.4</td>
<td>8.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Rural Interstate Roadways</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>I/M Program</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Gasoline Program</td>
<td>Conventional gasoline with local summer season RVP limit</td>
<td>Reformulated gasoline with local winter season RVP limit</td>
<td>Conventional gasoline with local summer season RVP limit</td>
</tr>
</tbody>
</table>
Annual On-Road Inventory (2011 to 2050)
PM2.5 (Excludes Brake/Tire Wear)

Normalized Emissions (2011 = 1.0)

Year

Detroit
Atlanta
Phoenix
# Sensitivity Scenarios

## Change in Total On-Road Inventory, THC

<table>
<thead>
<tr>
<th>Local Program Parameter</th>
<th>Low</th>
<th>High</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add I/M Program</td>
<td>-18%</td>
<td>-2%</td>
<td>-10%</td>
</tr>
<tr>
<td>Increase RVP by 1 PSI</td>
<td>-1%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Add Reformulated Gasoline</td>
<td>-14%</td>
<td>0%</td>
<td>-6%</td>
</tr>
</tbody>
</table>

## Change in Total On-Road Inventory, NOx

<table>
<thead>
<tr>
<th>Local Program Parameter</th>
<th>Low</th>
<th>High</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add I/M Program</td>
<td>-12%</td>
<td>-2%</td>
<td>-7%</td>
</tr>
<tr>
<td>Increase RVP by 1 PSI</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Add Reformulated Gasoline</td>
<td>-10%</td>
<td>0%</td>
<td>-3%</td>
</tr>
</tbody>
</table>
Emission Inventory Findings

- 3 locations selected for variance in underlying inventory assumptions:
  - Future inventory trends are dominated by the national vehicle and fuel controls.
  - By 2022, the average declines in THC, NOx, PM2.5, and CO emissions from 2011 are 55%, 71%, 73% and 43%, respectively.
  - By 2050 in all but one case, emissions remain below 2022 in spite of another 28 years of growth in on-road activity.
Final Remarks

- The complete model revision (MOVES) is a remarkable achievement
  - New methods require new data; legacy data is not suitable.
- There will always be uncertainty; models continually require updating. Current examples:
  - LD Gasoline vehicle exhaust
  - Variability in SCR/DPF control effectiveness
  - Trips (i.e., starts) as the primary activity basis
  - Winter season fuels modeling
Final Remarks (Continued)

- Given that:
  - National fuel and emissions control programs dominate on-road inventory trends &
  - Two sectors - LD gasoline and HD diesel - dominate the on-road inventory

- Then:
  - It is critical that future data collection/analysis be done to replace theoretical effectiveness of LD Tier 2, LD Tier 3 and HD 2007+ MY standards:
Final Remarks (Concluded)

- Further reading/resources:
  - CRC E-101/E-116 reports
  - EPA Response Document(s)
  - EPA’s MOVES Model Review Work Group (planned updates for the next version of MOVES)