MOVES

Motor Vehicle Emission Simulator

Model Evaluation

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Agenda

- Background on MOVES model evaluation
- Context of current MOVES evaluation
- MOVES2014a comparisons to
  - Inspection/Maintenance (I/M) & remote sensing data (RSD)
  - Tunnel studies
- Summary

MOVES Evaluation

- Why?
  - A key recommendation in the National Research Council's review of EPA's mobile source modeling program[1]
  - A key element of EPA's quality assurance guidance for developing models[2]
  - A critical component of EPA's development and upkeep of MOVES
- Objectives
  - To assess model performance in accurately estimating current emission inventories and forecasting emission trends
  - To identify areas in clear need of improvement
  - To guide future work and research needs

MOVES Evaluation (cont'd)

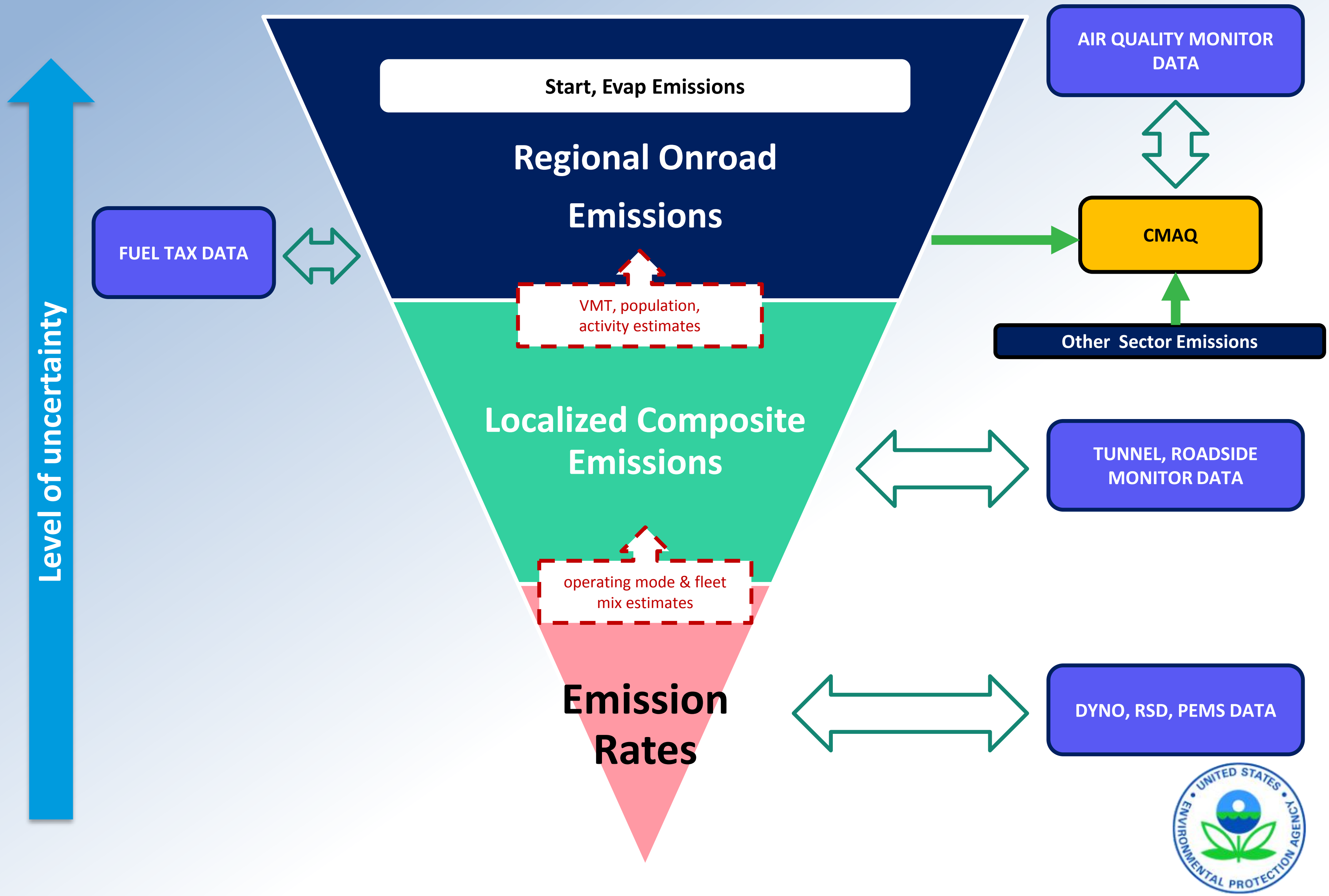
- Priorities
  - Major sources of emissions (e.g., light-duty gasoline, heavy-duty diesel)
  - Areas where significant independent data/studies available
- Assessment
  - If systematic bias is observed across multiple data sources, it is indicative of model underperformance
  - If the model predictions are generally within the variability of independent measurements, it gives confidence that the model is predicting real-world emissions reasonably well
- Improper means of evaluation
  - Comparisons against measurements based only on a few vehicles
  - Not sufficiently customizing MOVES inputs to account for the measurement conditions (i.e., fleet composition, vehicle activity)

Types of Evaluation

- Emission rates
  - Using dynamometer, RSD, and PEMS measurements
    - Large samples with best chance to capture rare high emitters
    - Known operating conditions (i.e., pre-conditioned IM240 drive cycle)
  - Comparing MOVES predictions to such measurements is the most controlled comparison
    - Activity and fleet variables such as vehicle mix and vehicle age are known for a given study
    - Eliminates sources of significant variability inherent in comparisons to ambient monitor data, and even in tunnel and roadside measurements

Types of Evaluation (cont'd)

- "Localized composite" emissions
  - Using composite emission measurements from tunnel or roadside emission monitors where
    - Vehicle emissions are predominant
    - Vehicle activity and fleet mix can be accounted for to some degree
  - Provides a snapshot of overall model performance, for the narrow operating conditions represented at the specific location
- Regional air quality
  - Evaluation of air quality model results (CMAQ) vs. air quality monitor data
- "Macro-scale" fuel consumption
  - Comparison of "bottom-up" fuel consumption to "top-down" fuel tax data



Level of uncertainty
FUEL TAX DATA
Start, Evap Emissions
Regional Onroad Emissions
VMT, population, activity estimates
Localized Composite Emissions
operating mode & fleet mix estimates
Emission Rates
AIR QUALITY MONITOR DATA
CMAQ
Other Sector Emissions
TUNNEL, ROADSIDE MONITOR DATA
DYNO, RSD, PEMS DATA
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

History

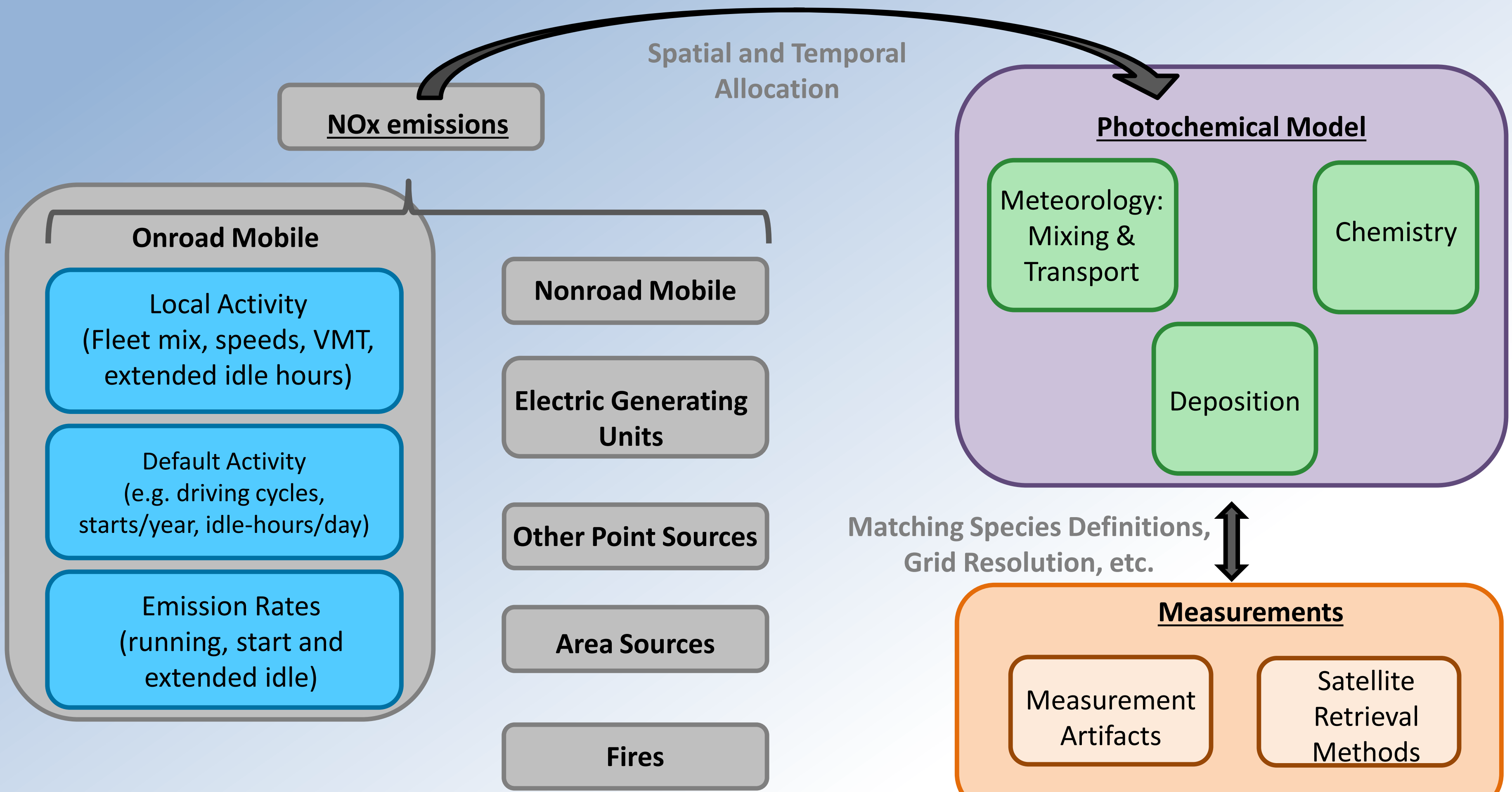
- EPA's evaluation work on MOVES began with MOVES2004, focused on fuel consumption
- For MOVES2010a, we evaluated model performance using several methods and found that:
  - Emission rate comparisons against multiple data showed no systematic bias for both light-duty and heavy-duty vehicles
  - Tunnel comparisons showed
    - MOVES predictions were higher than the observed for LD, but MOVES compared well for HD
    - MOVES trends over time are consistent with observations

Evaluation Type	Analysis	
Emission Rates	**Light-Duty** Atlanta RSD CRC E-23 Chicago RSD Chicago I/M Dyno Kansas City Study Dyno NCSU PEMS (NC State)	**Heavy-Duty** CRC E-55 Dyno HD in-use compliance Houston drayage
Localized Composite	Caldecott Tunnel - range analysis Van Nuys Tunnel (Fujita, et. al) Borman Expressway	
Fuel	FHWA Fuel Sales 2000-2007	

Current Context

- Several recent studies[3,4] have shown differences between air quality model estimates and monitored values for nitrogen oxides suggesting AQ models appear to overestimate NOx
- Staff across EPA are investigating various aspects of the issue

MOVES is just one complex part of the modeling system:



NOx Evaluation Efforts for MOVES2014a

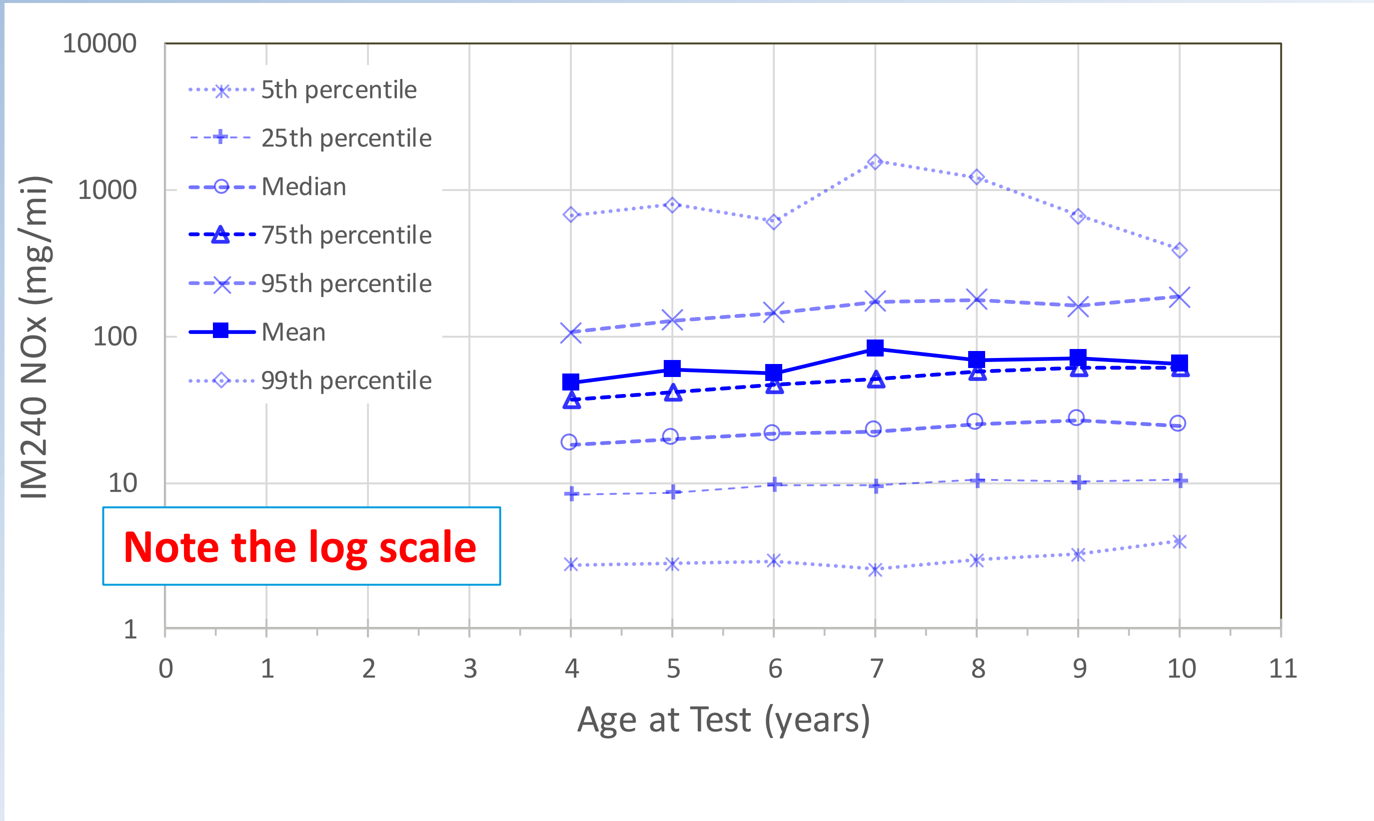
- Focus on light-duty gasoline passenger cars and trucks
  - Most evidence[5] suggests that MOVES under-predicts NOx for HD diesel
- Focus on running exhaust emissions
  - Due to lack of significant sources of independent data for start emissions
  - Running exhaust emissions contribute over 80% of NOx emissions from onroad gasoline and diesel

Comparison to Denver I/M Data

- **GOAL:** compare MOVES **BASE RATES** to external data
  - Taken from input database
    - No modifications or adjustments (humidity, I/M compliance, etc.)
- **SCOPE:** running emissions for
  - Light-duty cars and trucks
    - Tier 2 vehicles (in MY 2010-2016)
      - Bins 8, 5, 4, 3, 2
    - Tier 1 cars (in MY 1996-2000)
- **BASIS:** NO_X emissions on IM240 cycle
  - Denver I/M: measurements
  - Using random sample
    - CY 2008-2015
  - MOVES2014a: simulate IM240 using modal rates
    - Average by age

Denver I/M Data (cont'd)

- Light-duty cars
  - Tier 2 (Bin 5 and equivalent) meeting 70 mg/mi NOx FTP standard
- Distribution spans over 3 orders of magnitude



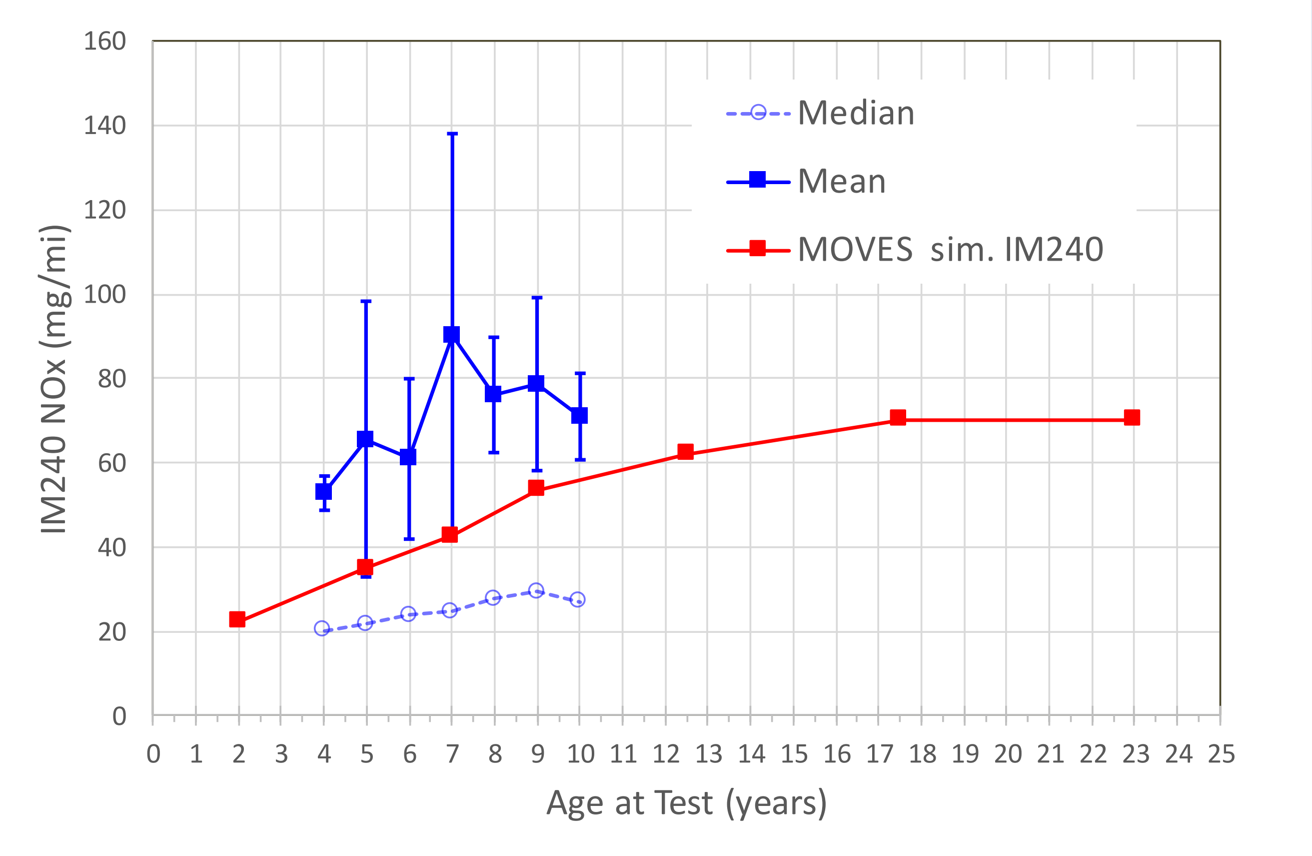
Preliminary Results for Tier 2 Cars: MOVES2014a Rates vs. Denver I/M

Tier 2

Passenger Cars

MOVES:
Simulated IM240
by age,
for MY 2010-2016

Denver:
Mean IM240
by age, for
"Bin-5"
(70 mg/mi NOx FTP std)



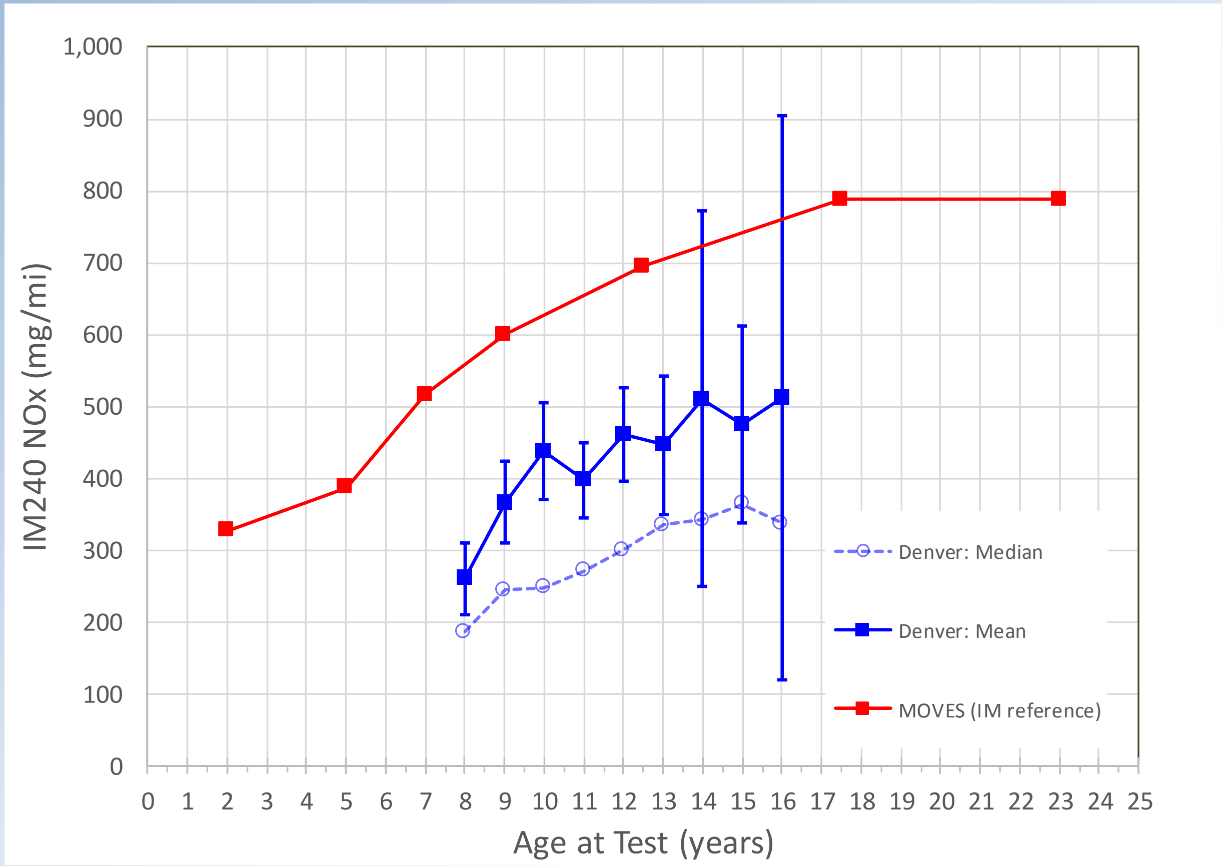
MOVES rates appear lower than corresponding I/M results.

Preliminary Results for Tier 1 Cars: MOVES2014a Rates vs. Denver I/M

Tier 1
Passenger Cars

MOVES:
Simulated IM240
by age,
for MY 1996-2000

Denver:
Mean IM240
by age, for
Tier 1
(600 mg/mi NOx FTP std)



MOVES rates appear higher than corresponding I/M results.

Limitations & Areas for More Work

- **Sample sizes (for each age level)**
  - T1: 10 – 370 vehicles
  - T2: 240 – 2,460 vehicles
  - Larger samples probably give a more representative comparison
- **Fuel properties**
  - Data collected over 8 years
  - Fuels changing over time
- **Temperature**
  - Don’t expect effect for hot-running operation
- **Altitude** (adjust if appropriate)
- **Potential positive bias due to “clean screen”**
  - Vehicles screened by remote sensing
  - “Clean” vehicles exempted from inspection

Comparisons to Remote Sensing Data

- University of Denver collected a series of remote sensing data, funded by Coordinating Research Council
  - Measurement sites in Arizona, California, Colorado, Illinois, Maryland, Nebraska, Nevada, Pennsylvania, Texas, Oklahoma, Utah, and Washington
  - Typically collected at on-ramps during weekdays
- Remote sensing measured the ratios of CO, HC, NO*, to CO2 in the exhaust and reported the percent concentrations of pollutants
- RSD databases include
  - Measurement conditions (i.e., speed, acceleration, temperature, and humidity)
  - Vehicle information (i.e., Vehicle Identification Number (VIN))
  - Flags for invalid measurements

* Recent RSD data include NO2 concentrations, as well as NO concentrations

RSD Data

- Current analysis includes RSD data that were collected over multiple years at the same location
  - Phoenix, AZ, Denver, CO, Chicago, IL, and Tulsa, OK
  - In calendar years 1999 to 2007 and 2013 to 2015
  - Total number of measurements: ~400,000

RSD Sites	Number of Measurements (light-duty cars and trucks combined)
Phoenix, AZ	95,266
Chicago, IL	107,007
Denver, CO	127,518
Tulsa, OK	64,658

MOVES Runs

- **MOVES project scale** used to simulate the measurement conditions, as much as possible
- County inputs include:

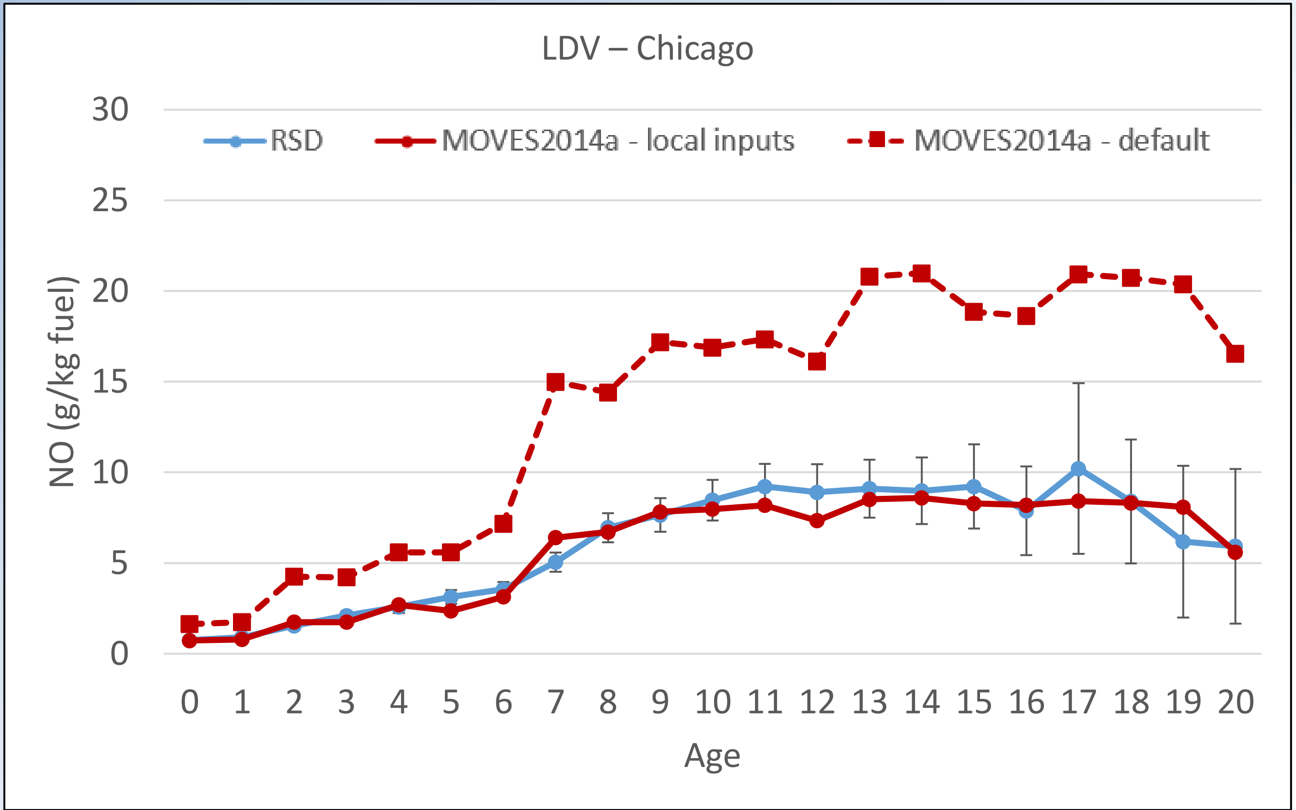
Input	Time & Location-Specific	MOVES Default
Operating Mode Distribution	X	
Age Distribution	X	
Fuel Properties		X*
Meteorology	X	
Inspection/Maintenance		X

**With the exception of sulfur, MOVES defaults were used for all fuel properties.*

- Pollutants – nitric oxide (NO) and total energy consumption

Project Scale vs. MOVES National Scale

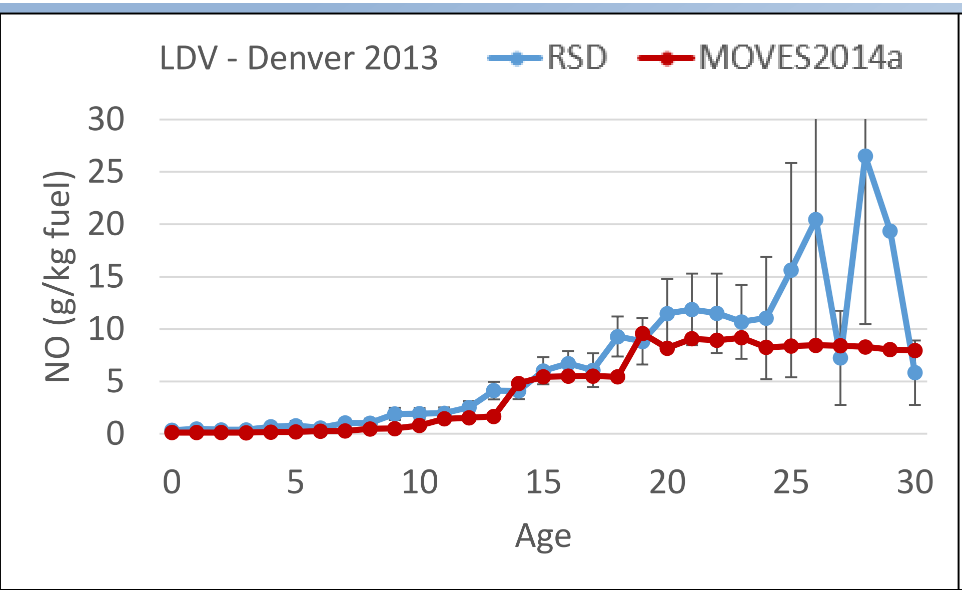
- MOVES national scale runs using the default inputs result in significantly higher emissions than the project scale runs
  - MOVES can show clear over-prediction when not properly modeled
- Highlights the importance of modelling the measurement conditions as much as possible using the project scale when evaluating MOVES

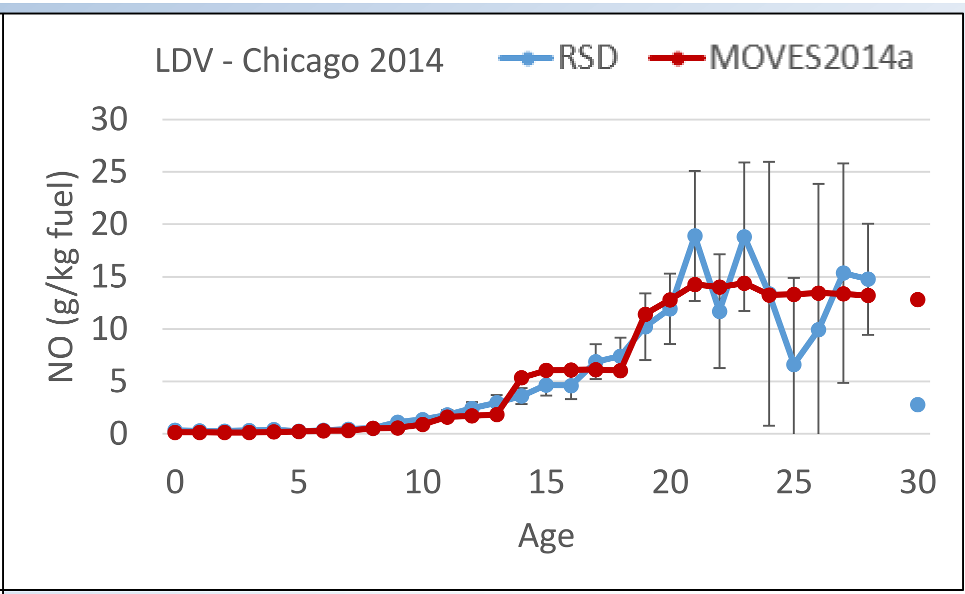


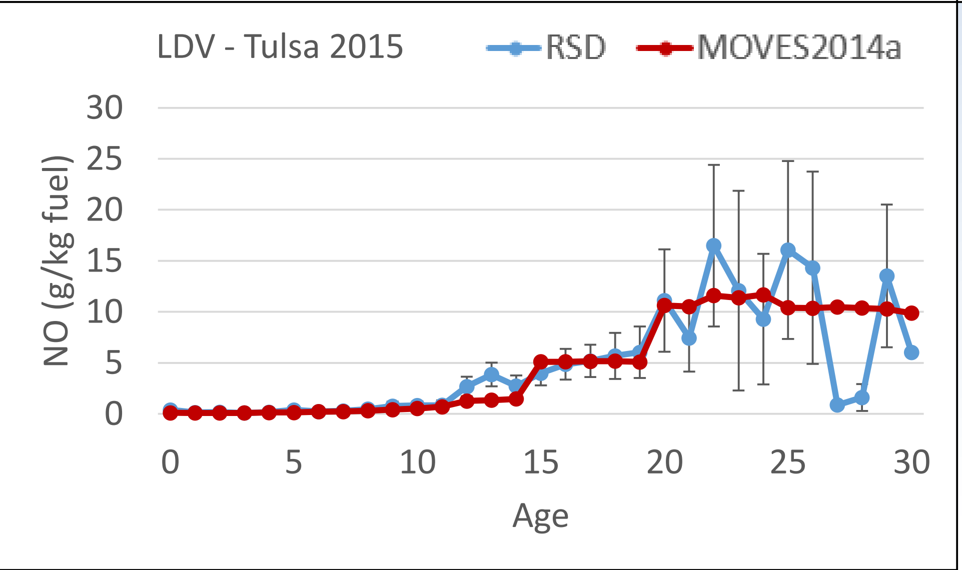
Sample Results – Comparisons to RSD

- Showing illustrative results
  - Only light-duty passenger cars
  - For select calendar years
- Comparisons for light-duty trucks similar to passenger cars
- RSD sites differ in age distributions, operating mode distributions, presence of I/M programs, altitude, etc.

Sample Results: MOVES2014a vs. RSD for CY2013-2015

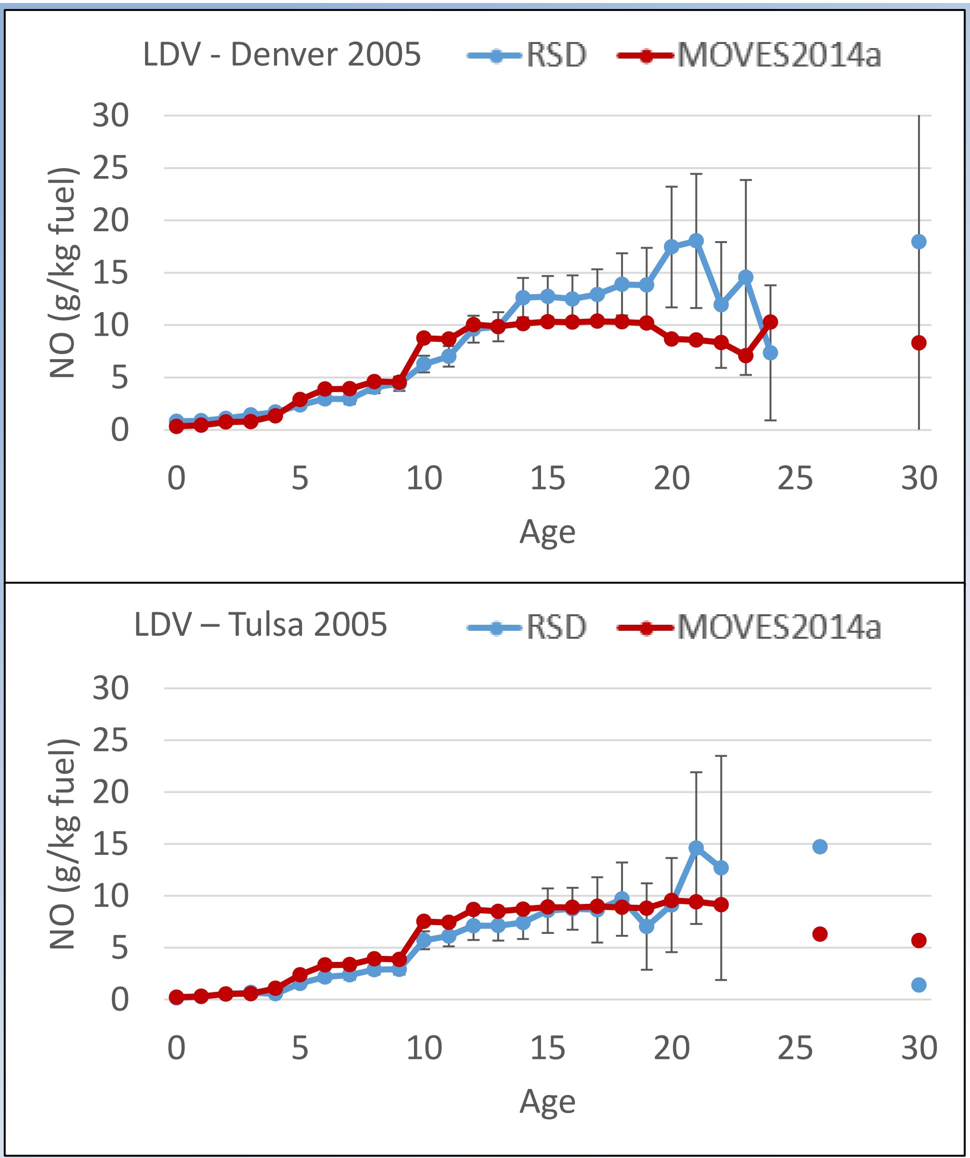






- MOVES2014a lower for Tier 2 vehicles
- For Tier 1 vehicles, MOVES2014a generally within the variability of the data

Sample Results: MOVES2014a vs. RSD for CY2005



- MOVES2014a lower or within the variability of the data for Tier 2 vehicles
- MOVES2014a higher than RSD for Tier 1 vehicles

Next Steps – Comparisons to RSD

- Analyze other available RSD datasets
- Understand variations between RSD sites and calendar years
- Evaluate fuel consumption in MOVES
  - Since comparisons made in fuel-based emission rates

Tunnel Comparisons

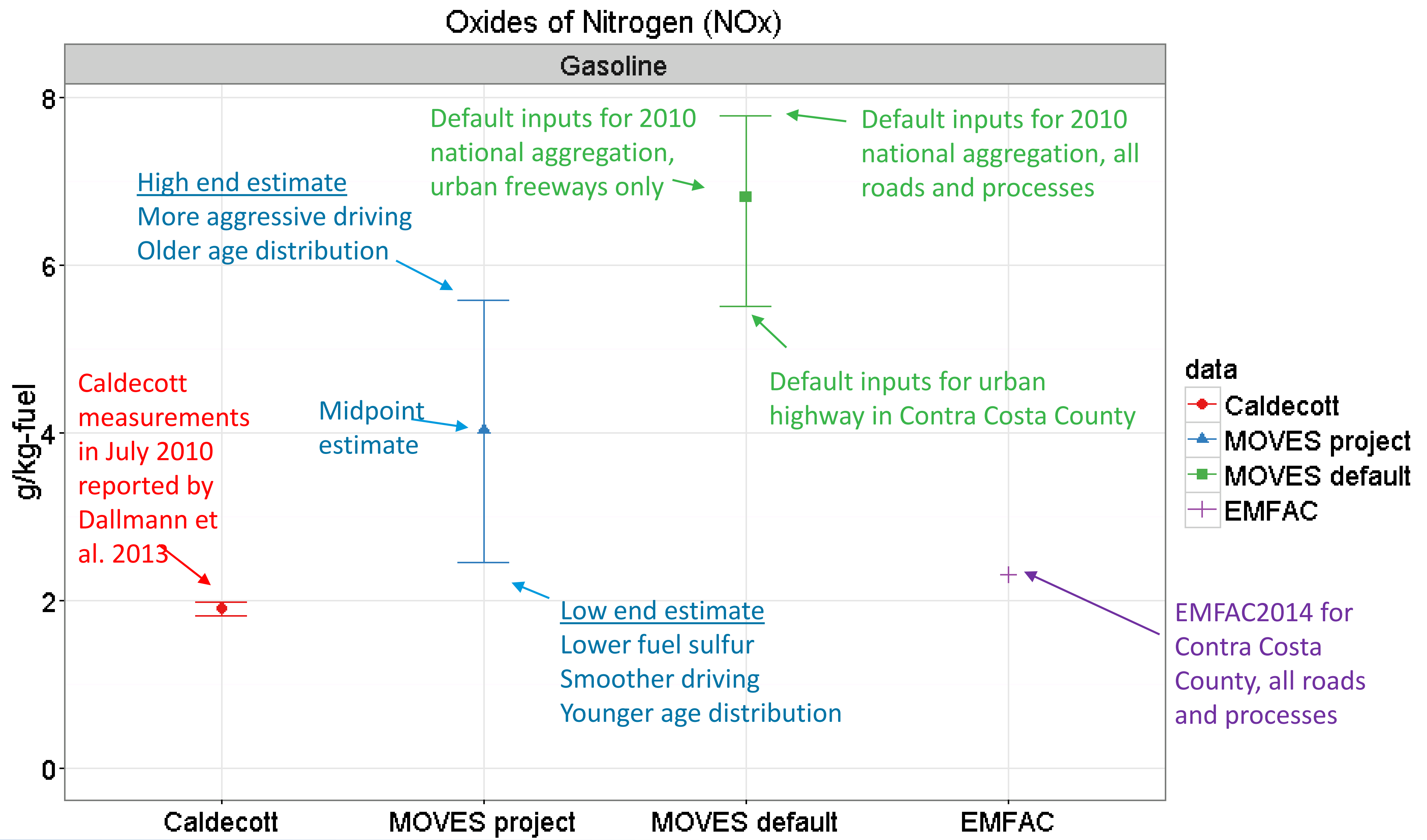
- Caldecott Tunnel
  - 1 km long tunnel in Oakland, California
  - 4% uphill grade (eastbound)
  - 3 separate two-lane traffic bores
  - Bore 2 is limited to light-duty vehicles (switches direction with flow of commuter traffic)
- UC-Berkeley derived fleet-average emission rates from their most recent campaign (2010)[6,7]
  - Measured pollution concentrations: 4-6 pm, 8 weekdays, July 2010

Picture from Dallmann et al. 2013[7]

MOVES2014a Comparison to Caldecott Tunnel

- MOVES default runs
  - Run at National-scale
- MOVES project-scale used to model the tunnel conditions
  - Created inputs from measurements conditions, e.g.
    - 4% grade
    - CA standards
      - Section 177/LEV inputs for CA standards on 1994+ vehicles
  - Lower, midpoint, and upper bound for uncertain inputs
    - Age distributions
    - Driving cycles
    - Fuel sulfur levels

Tunnel Comparison - Preliminary Results



Tunnel Comparisons - Observations and Limitations

- Observations
  - Key sources of uncertainty for project-level runs
    - For NOx g/kg-fuel: **age distributions, LEV inputs**
    - For NOx grams**: age distributions, LEV inputs, driving cycles**
  - In the case of Caldecott Tunnel, using national defaults produced substantially higher emission rates than using project-level inputs
- Limitations
  - Caldecott tunnel gasoline measurements have tended to be lower than other remote sensing studies[8,9]
  - MOVES data is not based on CA vehicles or fuels, e.g.
    - Section 177/LEV inputs do not account for differences in CA and National vehicle program for pre-1994 vehicles

Summary

- When doing comparisons to RSD and tunnel measurements, it is important to properly model the measurement conditions
- We will be continuing and refining our comparison of MOVES2014a to I/M, RSD, and tunnel measurements
- Additional work exploring other aspects of the air quality modeling system is also ongoing

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