MOVES
Motor Vehicle Emission Simulator

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

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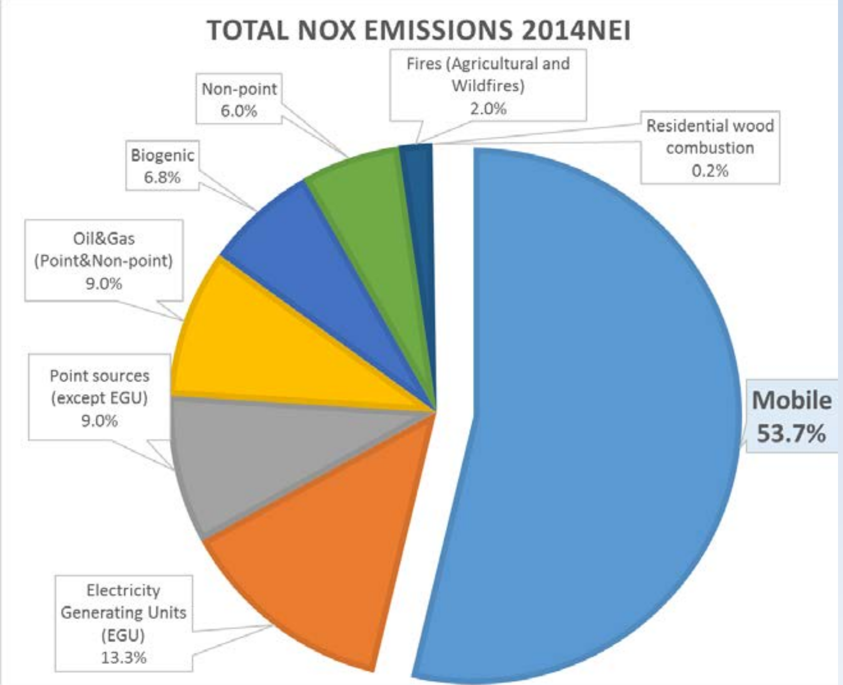
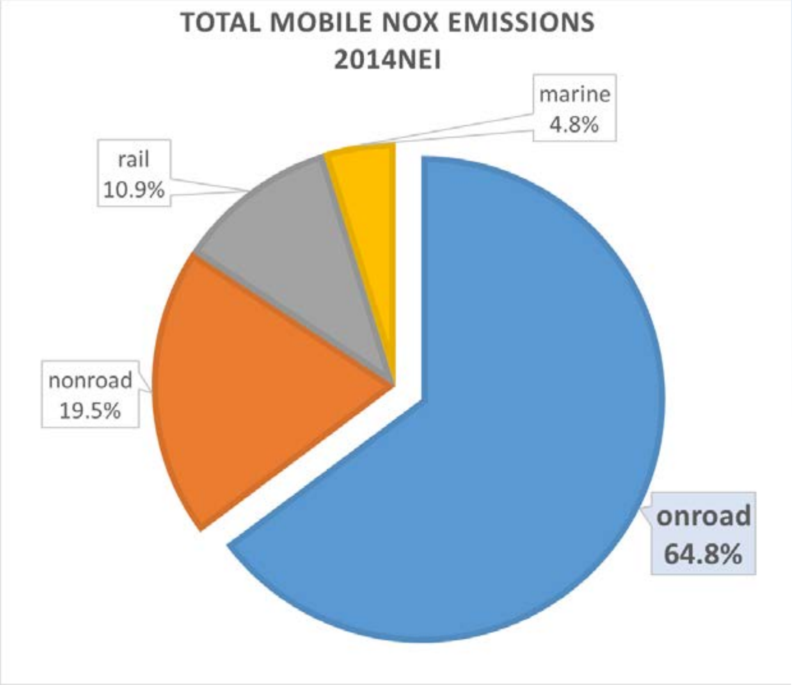
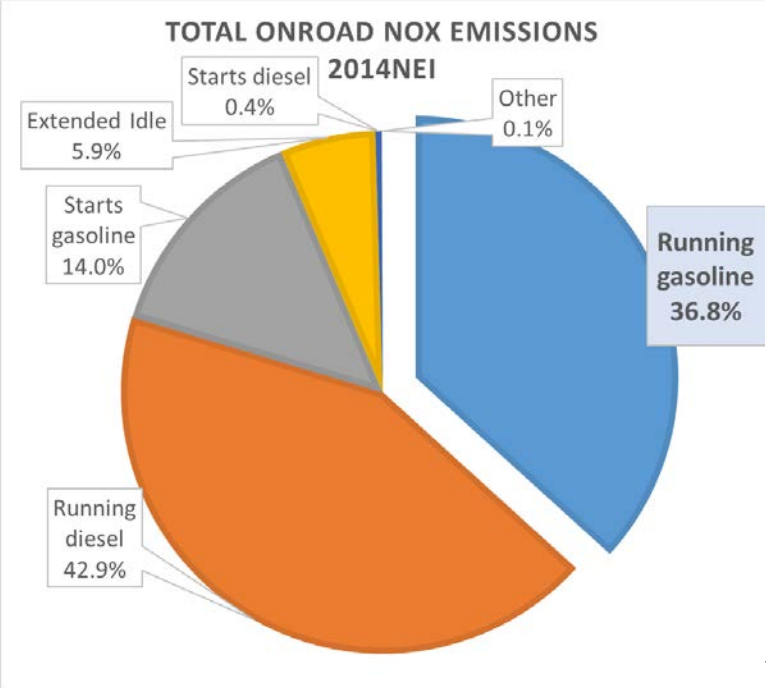
Contribution of Light-duty Gasoline NOx Emissions to the National Emissions Inventory

- 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

	Tunnels	Inspection/Maintenance	Remote Sensing
Individual vehicle measurements?	No: Fleet average	Yes	Yes
Calendar Years	1997,2001,2003,2006,2010	2008-2015	1999-2015
Number of cities	Two	Denver	Fourteen
Ability to capture rare high emitters?	Yes	Yes	Yes
Known operating conditions ? (for replicating in MOVES)	Estimated based on sample vehicle speed traces in 1996	Yes: preconditioned IM240	Yes: vehicle speed & acceleration recorded
Real-world driving conditions?	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	IM240 driving cycle on chassis dynamometer	Snapshot (typically during vehicle acceleration on freeway ramps)
Known vehicle characteristics? (car/truck, gas/diesel, model year/age)	Some: age distribution and fleet mix measured in 2006 for Caldecott Tunnel, and 2010 in Van Nuys.	Yes	Yes: from VIN decoding

Comparison to Tunnel Studies

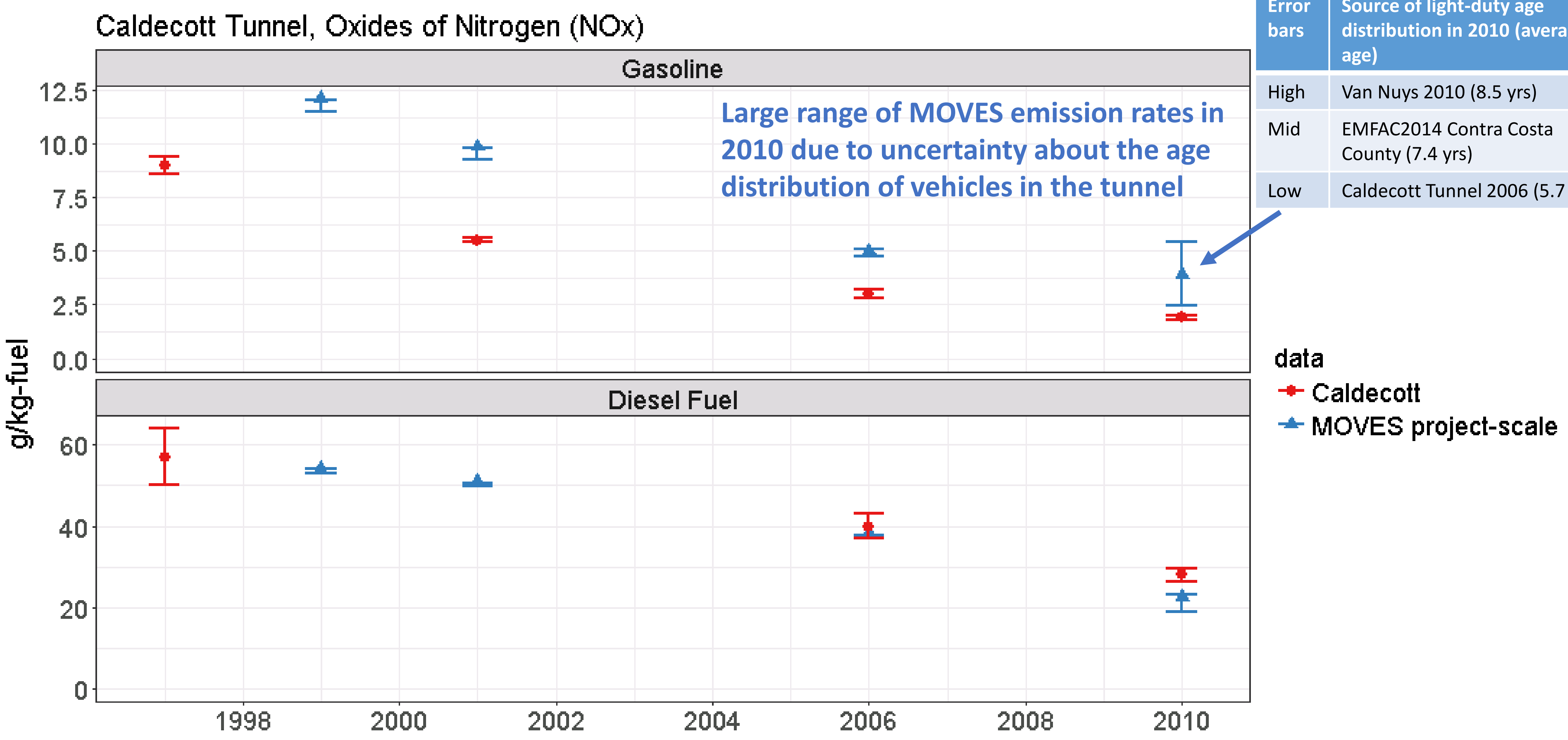
- Caldecott Tunnel, Oakland, CA
  - Summer, 1997[2], 2001[3], 2006[4], 2010[5,6] (UC-Berkeley)
  - 37 mph, 4% uphill grade
  - 2 tunnel bores, with light-duty-only bore
- Van Nuys Tunnel, Los Angeles, CA
  - Summer, 2010[7]
  - 41 mph, 1.7% downhill grade (entrance), 1% uphill grade (exit)
  - Single 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

Caldecott Tunnel
Image from Dallman et al. (2012)[6]

Van Nuys Tunnel *Sherman Way, Image from Google StreetView*

California Caveat

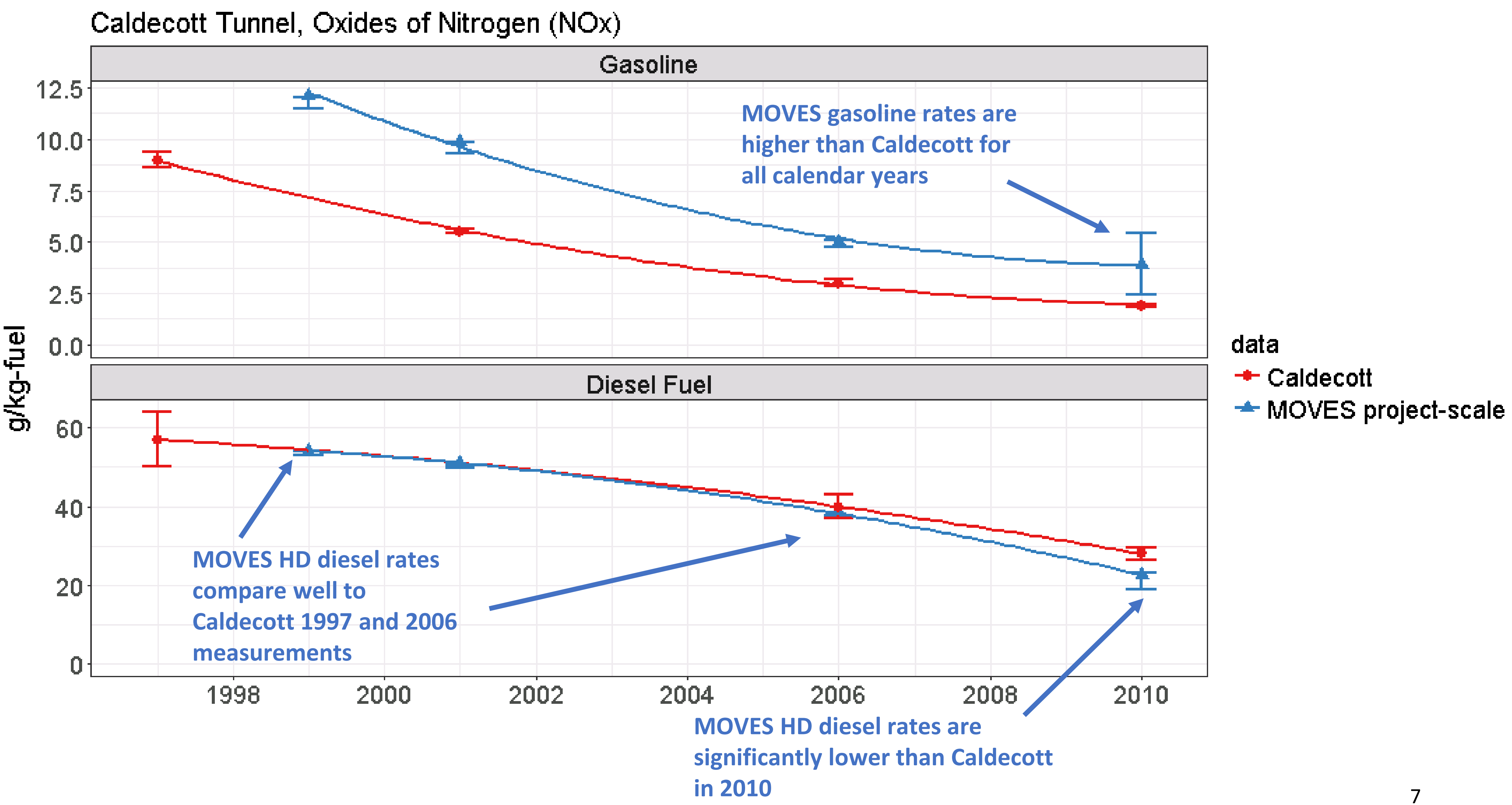
- MOVES is not designed to model California emissions
- MOVES runs for the Caldecott tunnel were adjusted to account for the California LEV standards, but do not account for the California pre-1994 vehicle NOx standards, which are much tighter than the Federal standards

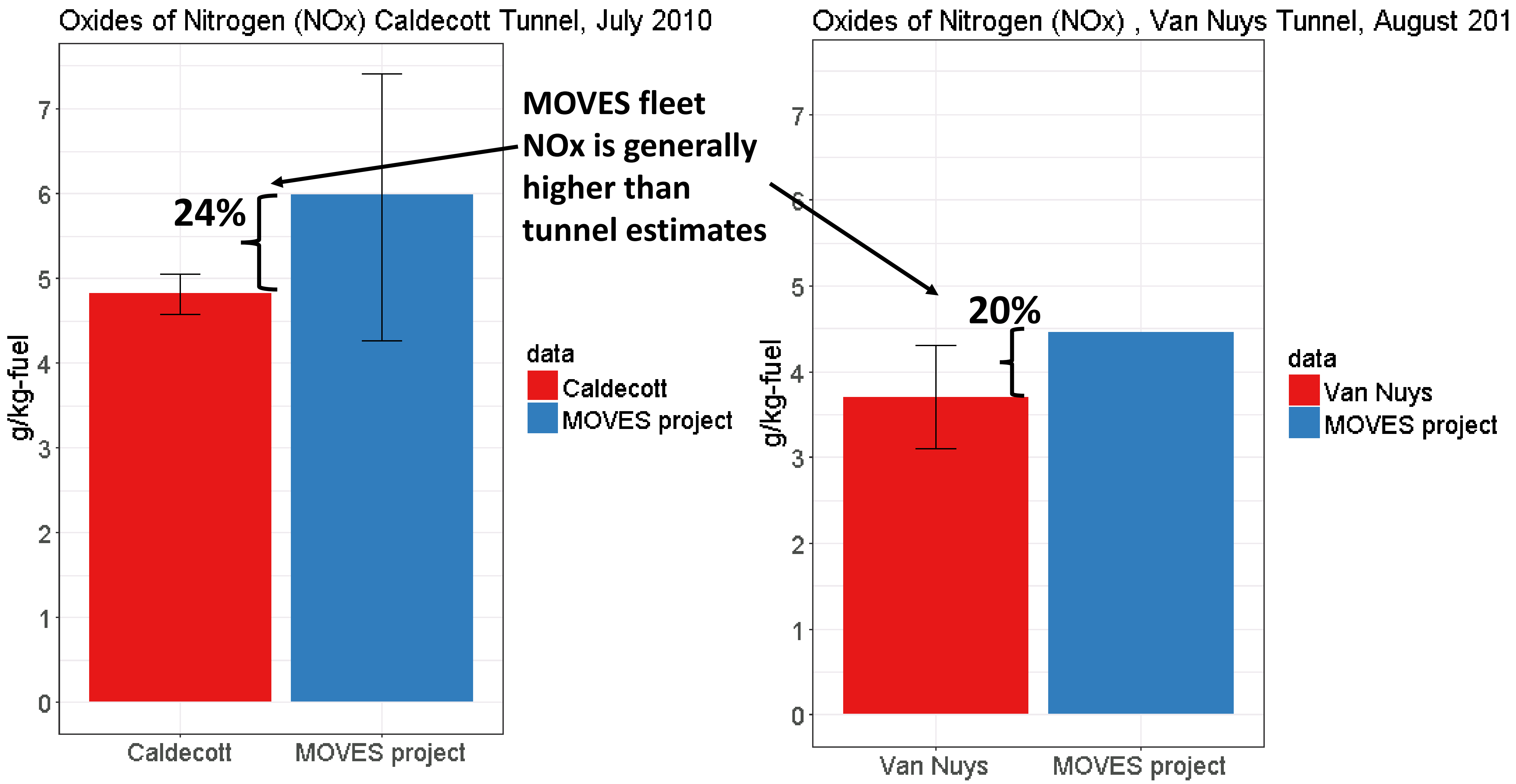


Error bars	Source of light-duty age distribution in 2010 (average age)
High	Van Nuys 2010 (8.5 yrs)
Mid	EMFAC2014 Contra Costa County (7.4 yrs)
Low	Caldecott Tunnel 2006 (5.7 yrs)

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.

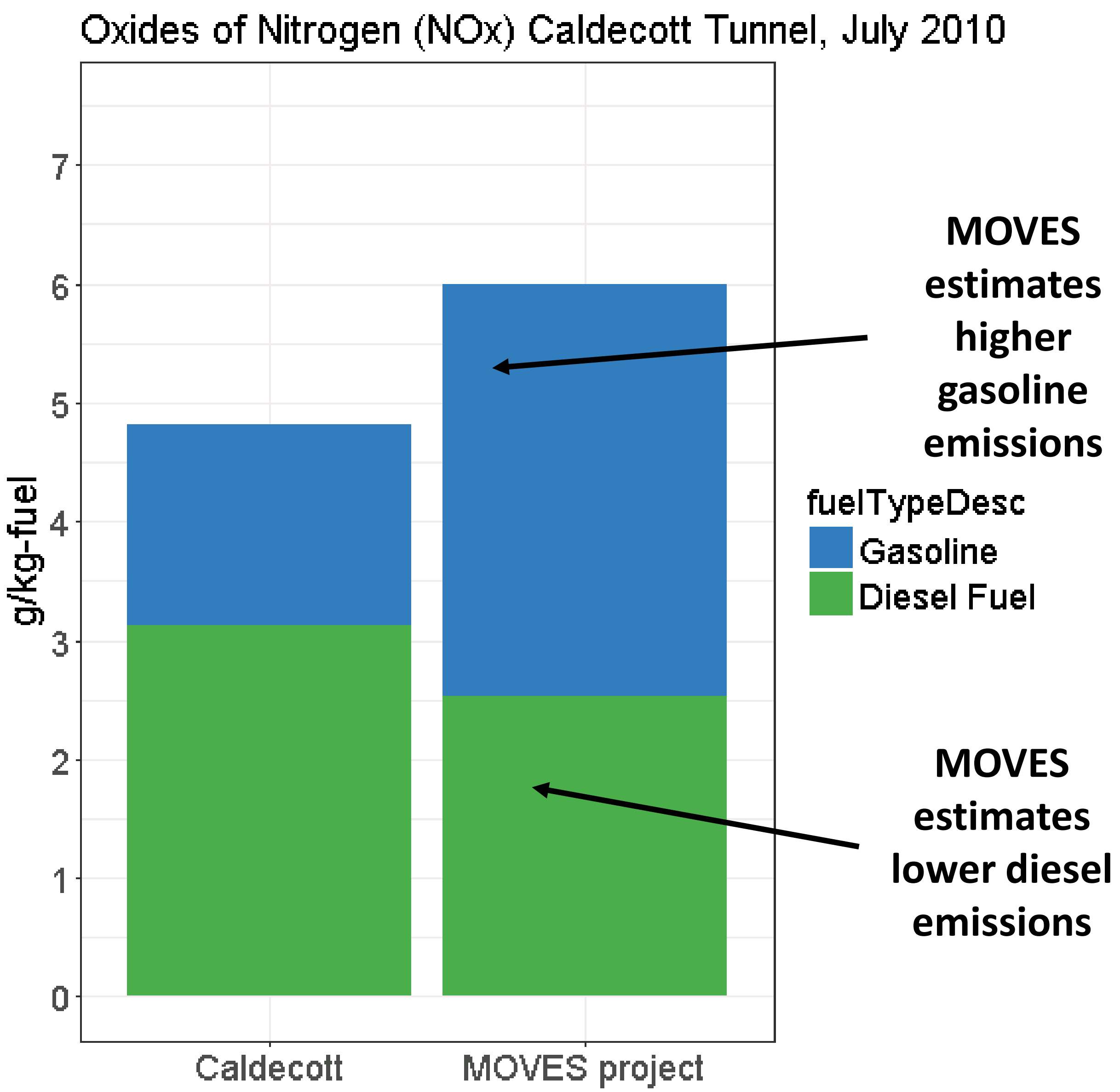
Caldecott error bars: 95% confidence intervals of emission rates derived from tunnel measurements, reported studies[2,3,4,5,6].

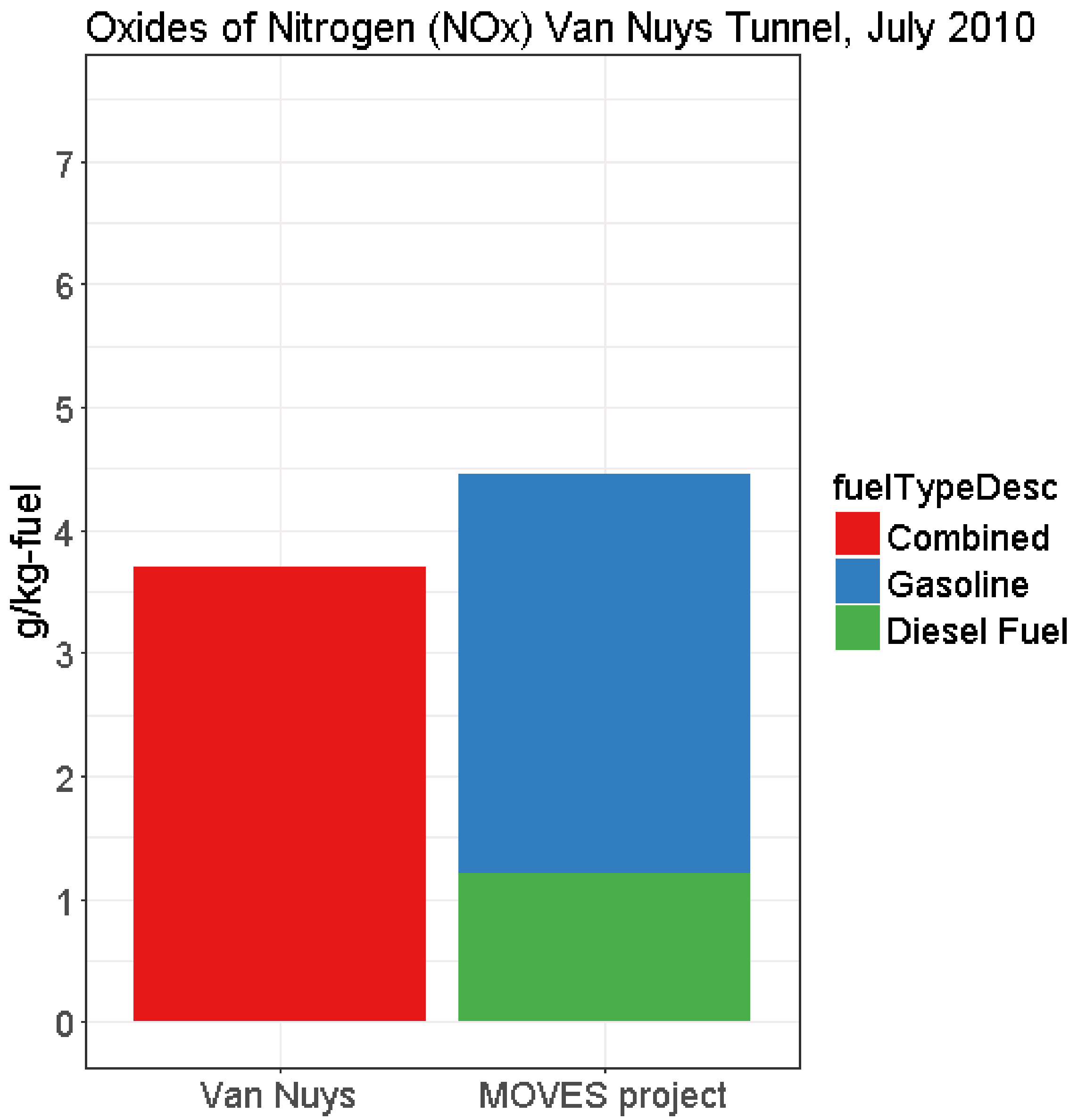

Caldecott Tunnel, Oxides of Nitrogen (NOx)
Gasoline
Diesel Fuel
g/kg-fuel
12.5
10.0
7.5
5.0
2.5
0.0
60
40
20
0
1998
2000
2002
2004
2006
2008
2010
data
Caldecott
MOVES project-scale
MOVES gasoline rates are higher than Caldecott for all calendar years
MOVES HD diesel rates compare well to Caldecott 1997 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

Light-duty gas/Heavy-duty diesel split estimated from counts made during the study


Oxides of Nitrogen (NOx) Caldecott Tunnel, July 2010
g/kg-fuel
0
1
2
3
4
5
6
7
Caldecott
MOVES project
MOVES estimates higher gasoline emissions
MOVES estimates lower diesel emissions
fuelTypeDesc
Gasoline
Diesel Fuel


Oxides of Nitrogen (NOx) Van Nuys Tunnel, July 2010
g/kg-fuel
0
1
2
3
4
5
6
7
Van Nuys
MOVES project
fuelTypeDesc
Combined
Gasoline
Diesel Fuel

Denver I/M Dynamometer Testing Data

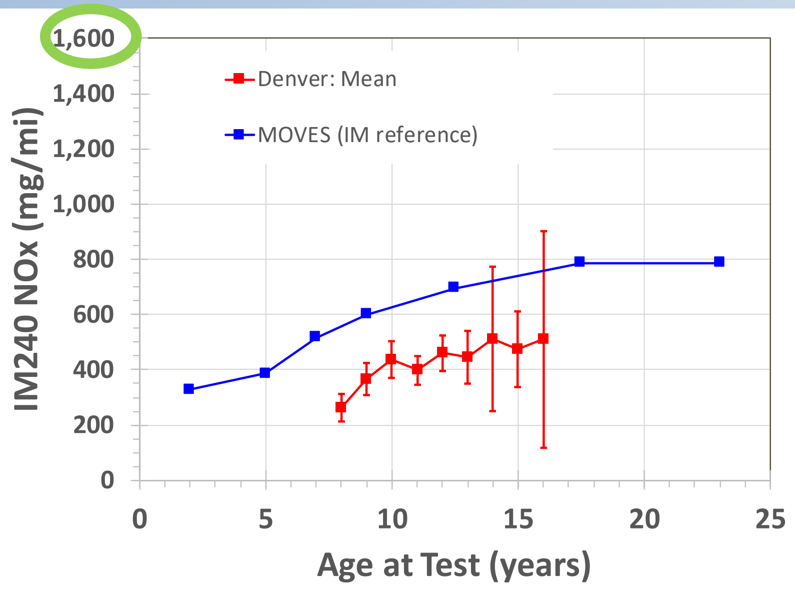
- Denver Inspection & Maintenance (I/M) test data on light-duty vehicles
  - NOx emissions on IM240 cycle
  - Random evaluation sample
    - Calendar years 2008-2015
    - Corrected for bias due to testing exemption for clean cars
  - Tier 1 cars (1996-2000 model years)
  - Tier 2 cars and trucks (2010-2016 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 Post, 2007

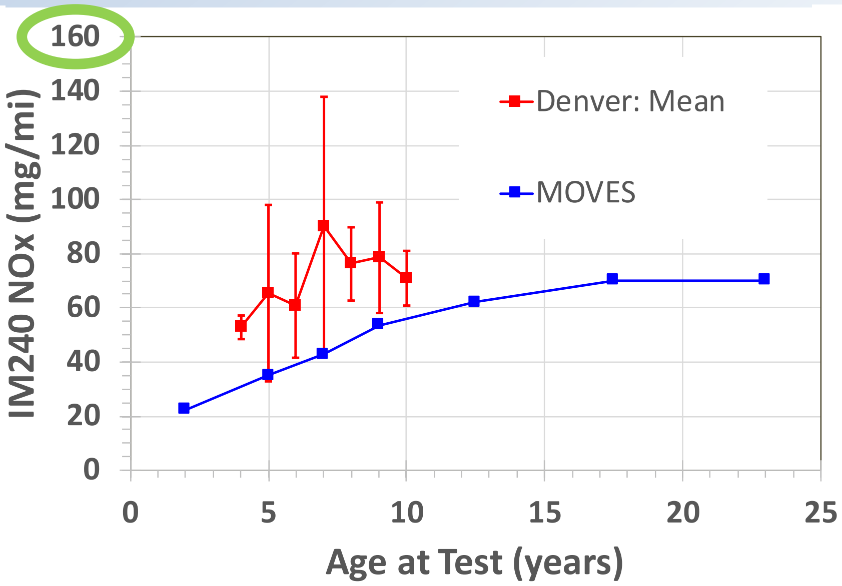
Denver I/M Comparison to MOVES

- 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

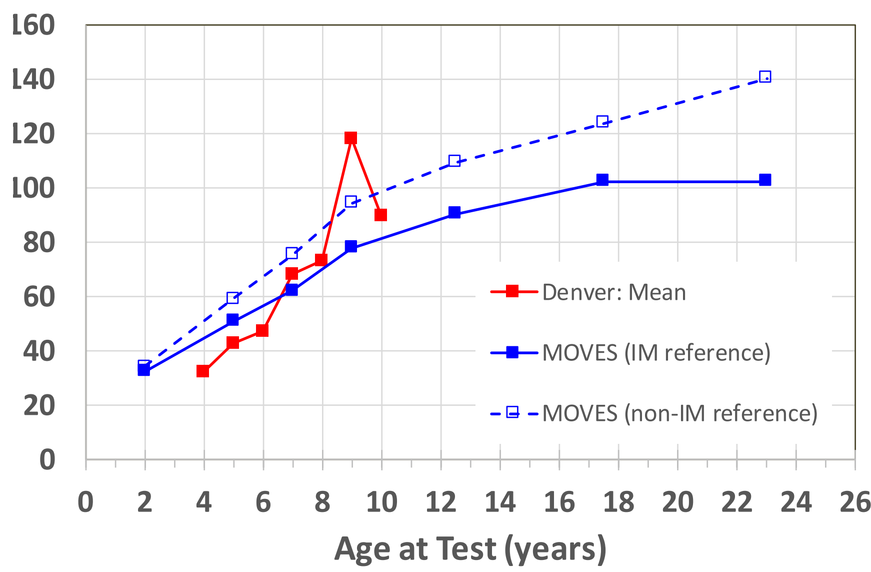
Tier 1 cars



Tier 2 cars

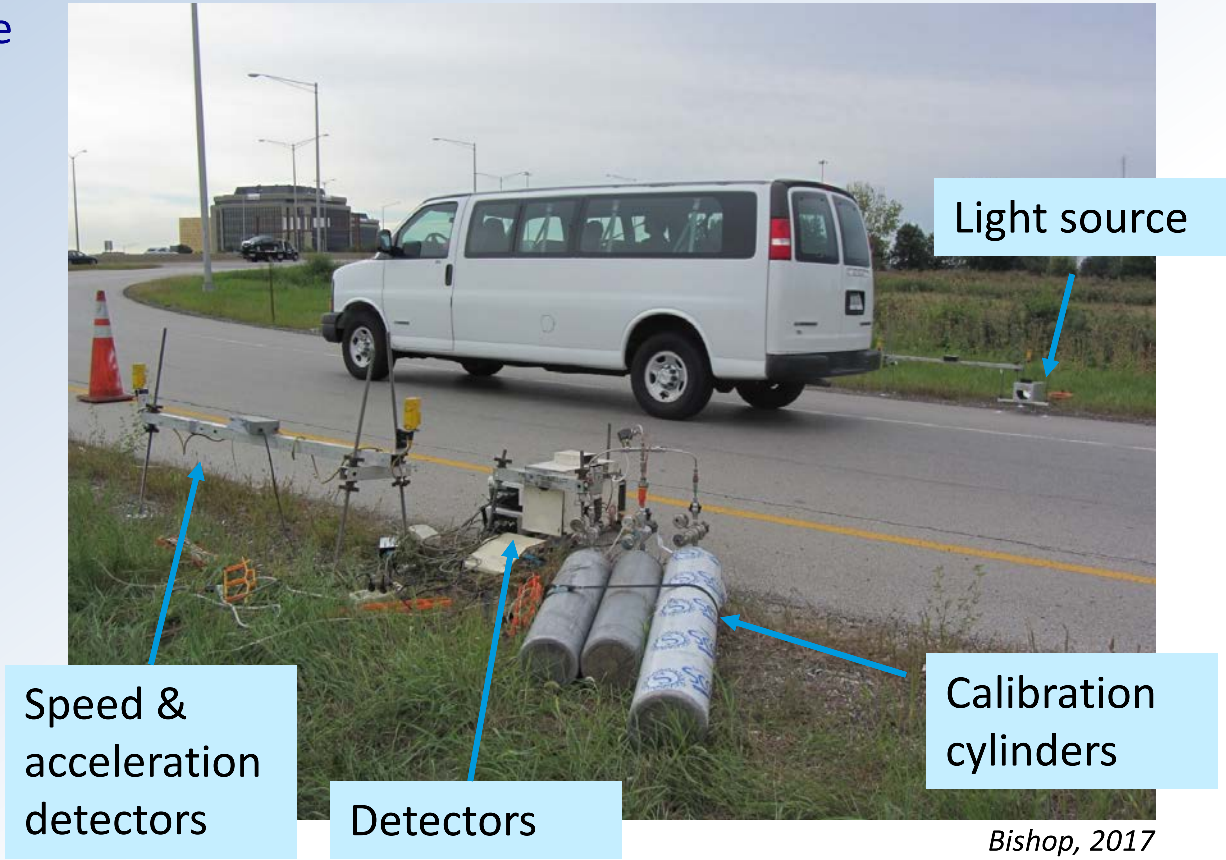


Tier 2 trucks



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



Bishop, 2017

† Converted to fuel-specific rates (g/kg fuel) in NO_2 mass-equivalence

RSD Data Summary

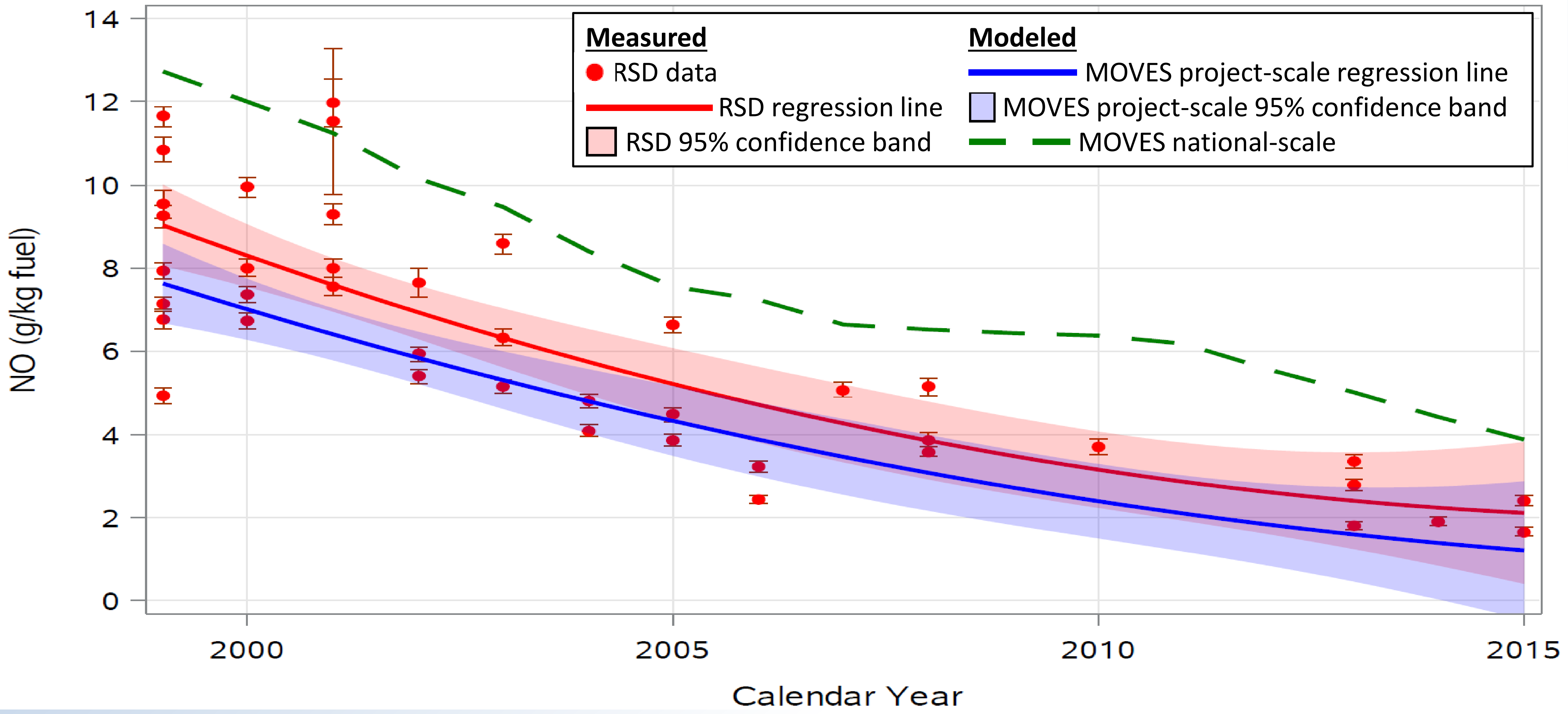
RSD Sites	Calendar Years	Number of Valid Measurements
Phoenix, AZ	1999, 2000, 2002, 2004, 2006	95,226
Los Angeles, CA (LA710)	1999	9,336
Sacramento, CA	1999	12,965
Riverside, CA	1999-2001	49,878
San Jose, CA	1999, 2008	49,550
Fresno, CA	2008	11,595
Van Nuys, CA	2010	10,669
Los Angeles, CA (LaBrea Blvd)	1999, 2001, 2003, 2005, 2008, 2013, 2015	120,436
Denver, CO (6th Ave)	1999-2001, 2003, 2005, 2007, 2013	127,518
Glenwood Springs, CO	2001	324
Grand Junction, CO	2001	3,346
Denver, CO (Speer Blvd)	2002	8,311
Chicago, IL	1999, 2000, 2002, 2004, 2006, 2014	107,007
Tulsa, OK	2003, 2005, 2013, 2015	64,658
TOTAL		**670,819**

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 data[9]
  - 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



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

Summary

- EPA's evaluation of MOVES lightduty 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

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