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Update to onroad ammonia rates in MOVES4 and the impact on urban inventories

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Seattle, WA

Ammonia Emissions from Vehicles

- NH_3 is not a direct combustion product.
  - <u>In gasoline vehicles</u>: byproduct of NO reduction over the three-way catalyst under fuel rich conditions
  - <u>In diesel vehicles</u>: byproduct from excess use of urea in Selective Catalytic Reduction (SCR) systems
- NH_3 is primarily emitted when the vehicle is running (not during the start process, not when idling)

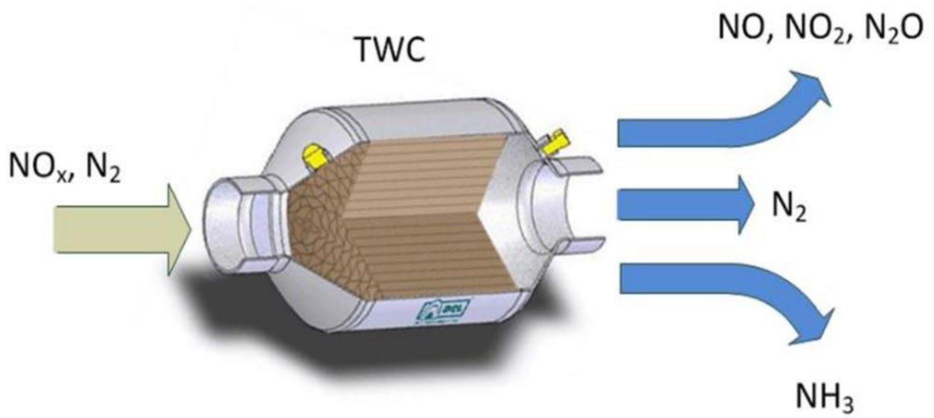
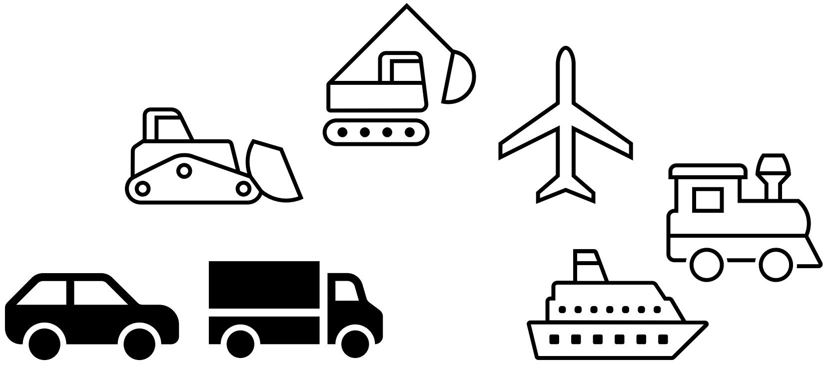


**Figure from Woodburn, J., Merkisz, J., and Bielaczyc, P., "The Formation of Ammonia in Three-Way Catalysts Fitted to Spark Ignition Engines - Mechanisms and Magnitudes," SAE Technical Paper 2022-01-1026, 2022, doi:10.4271/2022-01-1026.*

Ammonia Emissions Inventory - Mobile Sources

- Mobile sources: marine, aircraft, locomotive, **onroad**, nonroad.

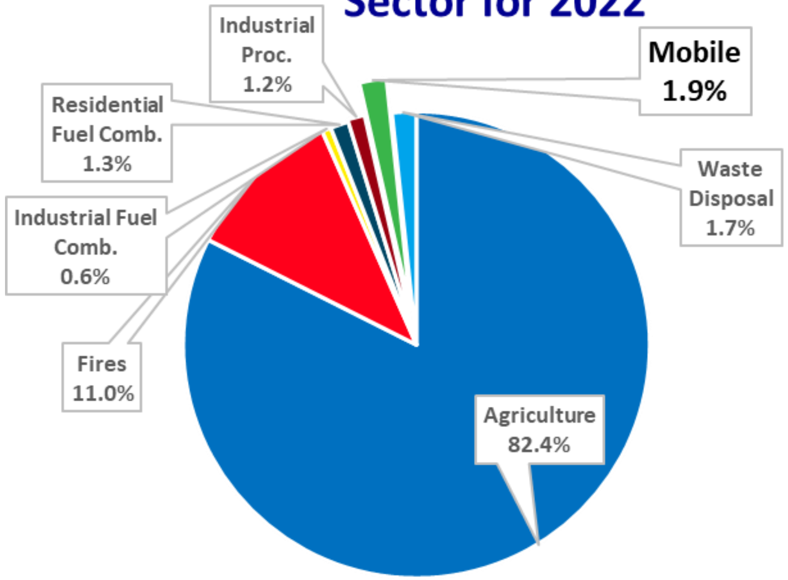


- US inventory of **onroad** NH_3 emissions is estimated using EPA's MOtor Vehicle Emission Simulator (MOVES)
  - Regulatory model to estimate emissions from onroad vehicles and nonroad equipment for criteria pollutants and GHGs.
  - In MOVES3 and earlier versions, ammonia data based on small study of vehicles carried out in 2001.

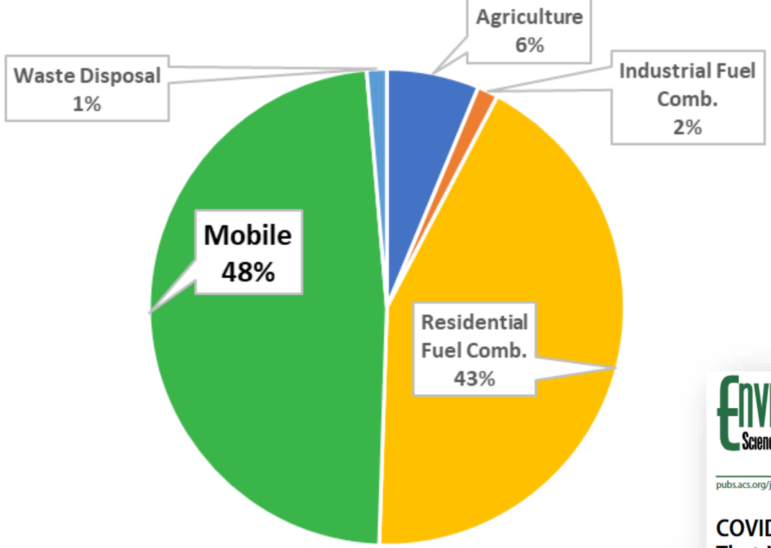
MOVES
Motor Vehicle Emission Simulator

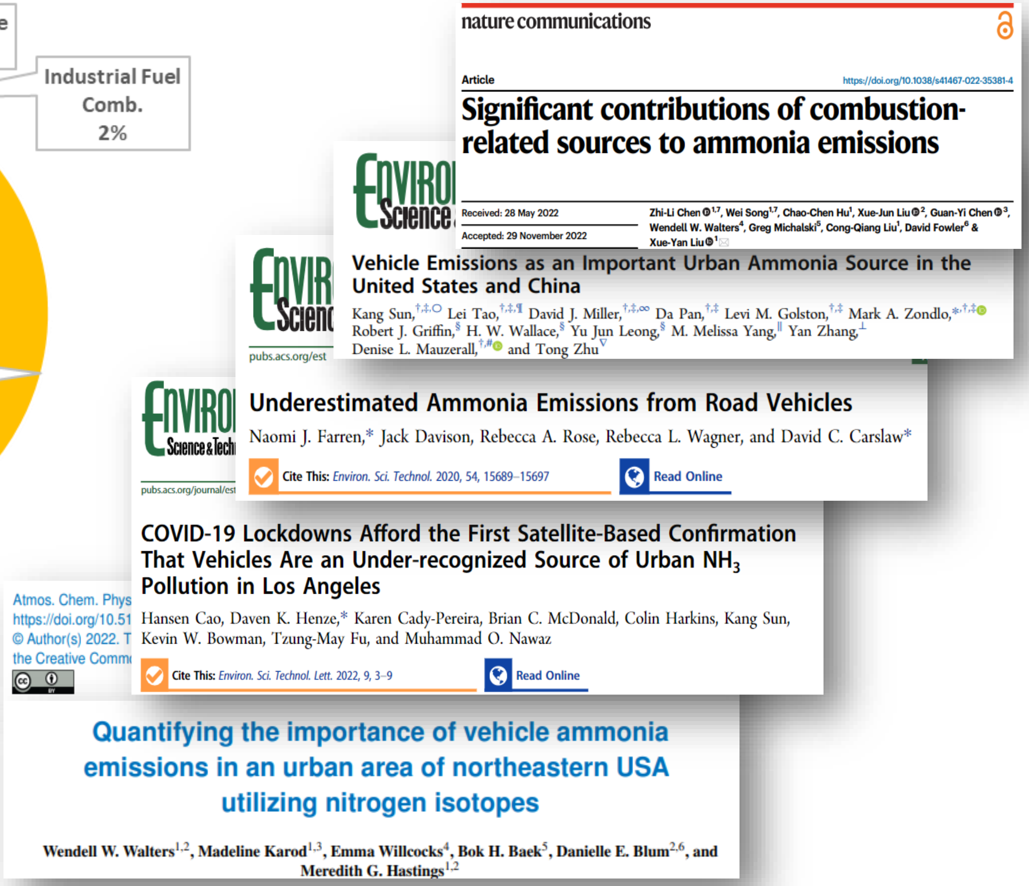
National vs Urban Ammonia Inventory

National NH_3 Emissions by Sector for 2022



Washington DC - NH_3 Emissions by Sector for 2022




nature communications

Article https://doi.org/10.1038/s41467-022-35381-4

Significant contributions of combustion-related sources to ammonia emissions

Received: 28 May 2022
Accepted: 29 November 2022

Zhi-Li Chen, Wei Song, Chao-Chen Hu, Xue-Jun Liu, Guan-Yi Chen, Wendell W. Walters, Greg Michalski, Cong-Qiang Liu, David Fowler & Xue-Yan Liu

Vehicle Emissions as an Important Urban Ammonia Source in the United States and China

Kang Sun, Lei Tao, David J. Miller, Da Pan, Levi M. Golston, Mark A. Zondlo, Robert J. Griffin, H. W. Wallace, Yu Jun Leong, M. Melissa Yang, Yan Zhang, Denise L. Mauzerall, and Tong Zhu

pubs.acs.org/est

Underestimated Ammonia Emissions from Road Vehicles

Naomi J. Farren,* Jack Davison, Rebecca A. Rose, Rebecca L. Wagner, and David C. Carslaw*

Cite This: Environ. Sci. Technol. 2020, 54, 15689−15697 Read Online

pubs.acs.org/journal/est

COVID-19 Lockdowns Afford the First Satellite-Based Confirmation That Vehicles Are an Under-recognized Source of Urban NH_3 Pollution in Los Angeles

Hansen Cao, Daven K. Henze,* Karen Cady-Pereira, Brian C. McDonald, Colin Harkins, Kang Sun, Kevin W. Bowman, Tzung-May Fu, and Muhammad O. Nawaz

Cite This: Environ. Sci. Technol. Lett. 2022, 9, 3−9 Read Online

Atmos. Chem. Phys
https://doi.org/10.51
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Quantifying the importance of vehicle ammonia emissions in an urban area of northeastern USA utilizing nitrogen isotopes

Wendell W. Walters[1,2], Madeline Karod[1,3], Emma Willcocks[4], Bok H. Baek[5], Danielle E. Blum[2,6], and Meredith G. Hastings[1,2]

- Ammonia (NH_3) emissions in urban centers, away from agriculture, are dominated by mobile sources.
- **Literature suggests that urban NH_3 emissions are significantly underestimated.**

Data Sources – Roadside Remote Sensing

- Measurements based on spectroscopy (UV for NH_3).
- Provide a snapshot of emissions under specific real-world conditions for thousands of vehicles, one at a time.
- Adjacent sensors provide information on speed and acceleration (i.e. engine load).
- License plate reader allows retrieval of vehicle information.
- Measures NH_3:CO_2 ratios, reported as gNH_3/kg fuel

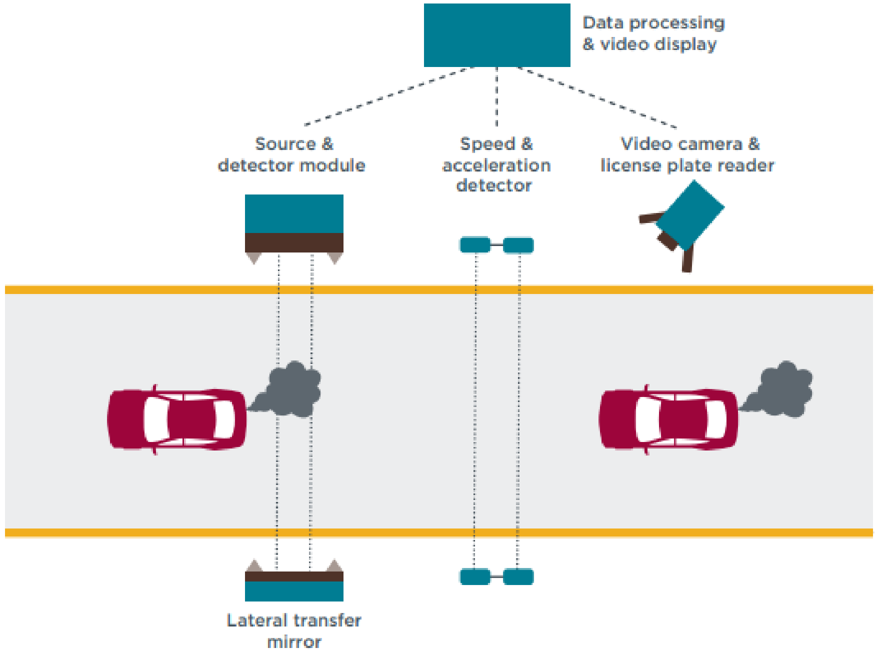


**Figure from Borken-Kleefled and Dallman, Remote Sensing of Motor Vehicle Exhaust Emissions, ICCT, 2018*

Data Sources – MOVES4 Update

- Light-duty (LD) gasoline: over 335,000 NH_3 observations from passenger cars and passenger trucks gathered by University of Denver

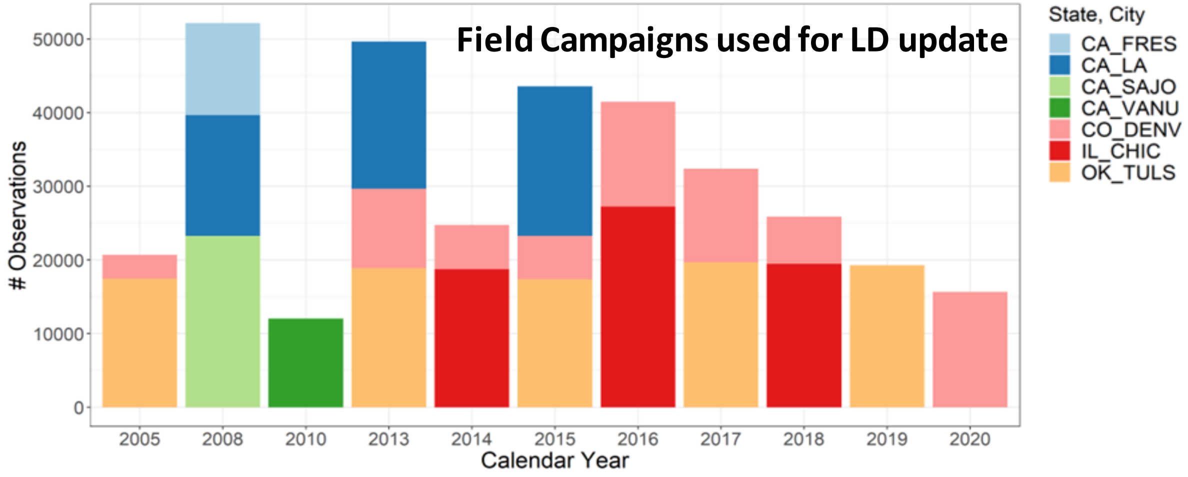


Figure from Bishop G., "On-Road Remote Sensing of Automobile Emissions in the Denver, CO Area: Winter 2020"

- Heavy-duty (HD) diesel: measurements of NH_3 from over 900 diesel trucks characterized by model year (MY) and aftertreatment system measured in Caldecott Tunnel, Oakland, CA

From Preble et al (2019)

General Methodology

- Grouped fuel-based measurements by model year and vehicle type (e.g. passenger car, truck, etc.), and convert to time-based emission rates needed for MOVES using appropriate fuel consumption rates.

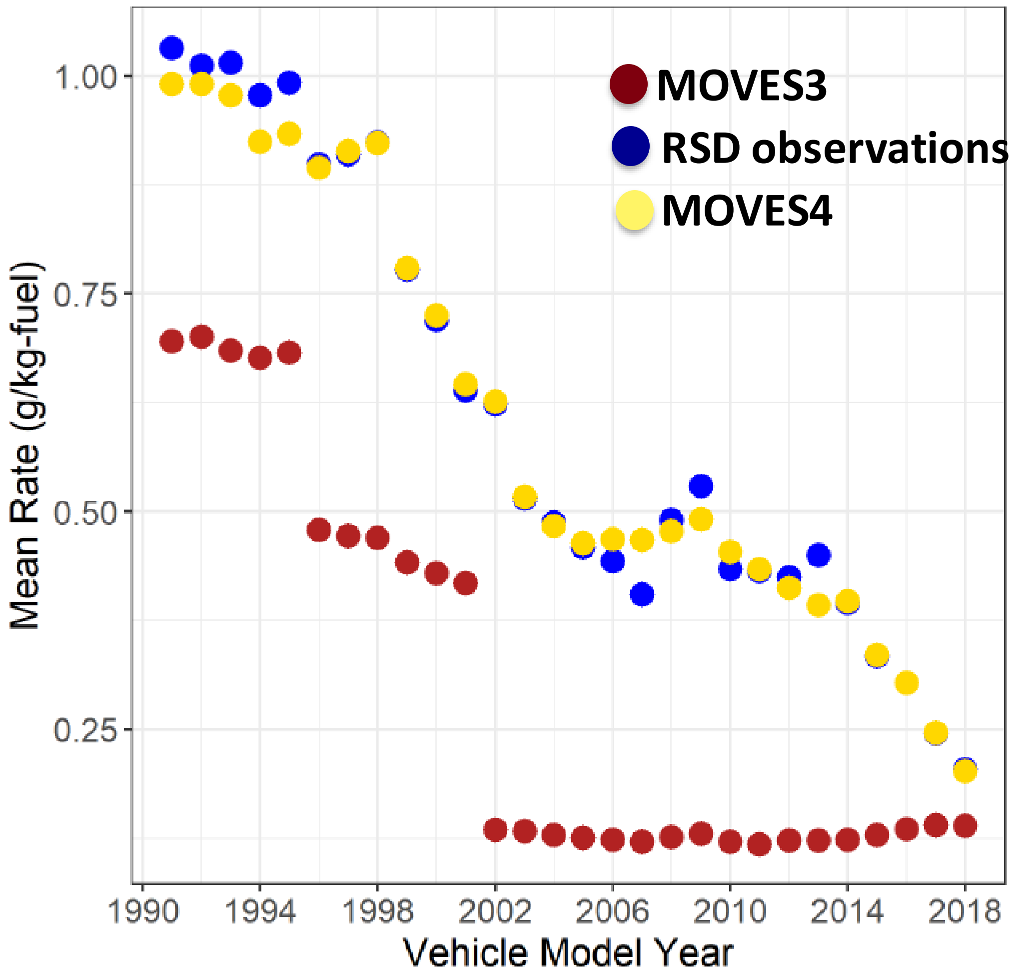
$$\underbrace{\frac{\text{g } NH_3}{\text{kg fuel}}}_{\text{Measurements}} \xrightarrow{\text{Fuel consumption rate}} \underbrace{\frac{\text{g } NH_3}{\text{hr}}}_{\text{Model}}$$

- Details of the methodology provided in MOVES technical documentation.

Updated Light Duty Emission Rates in MOVES4

- The new emission rates capture the observed magnitude and trend.
  - MOVES3 rates are significantly lower across all MY.

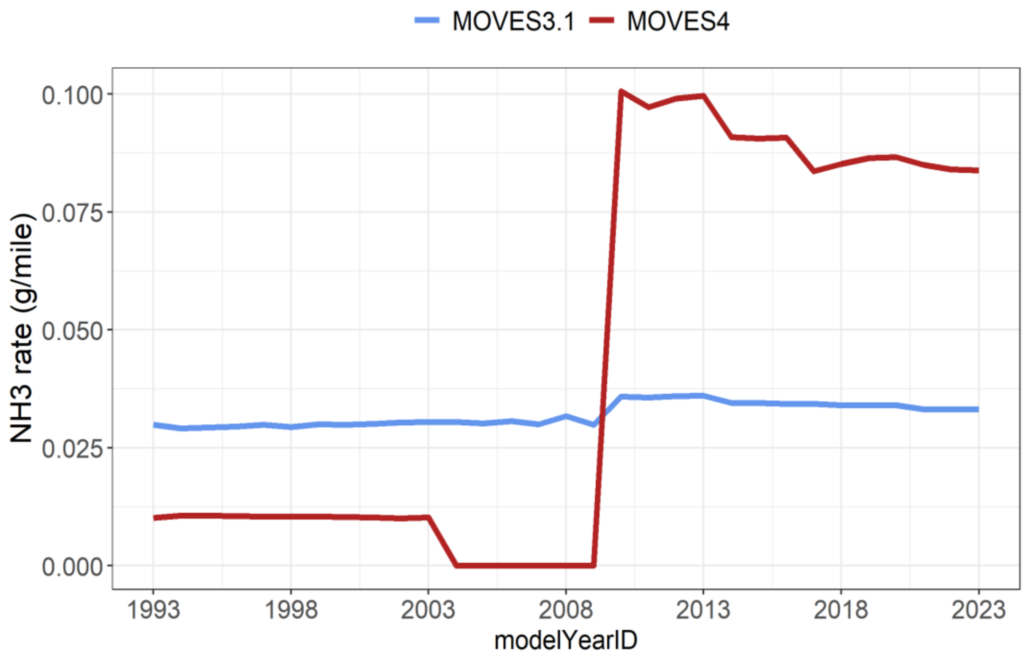
- This dataset provided information to update NH_3 emission rates for MY1990-2018 light-duty vehicles.
  - Future MY rates are kept at 2018 levels.



Updated Heavy Duty Emission Rates in MOVES4

- The new MOVES4 HD rates are lower than MOVES3 rates for <MY2010.
- For MY2010+, the new MOVES4 rates are considerably higher.
- MY2010-2018 rates applied for MY2019 and later.

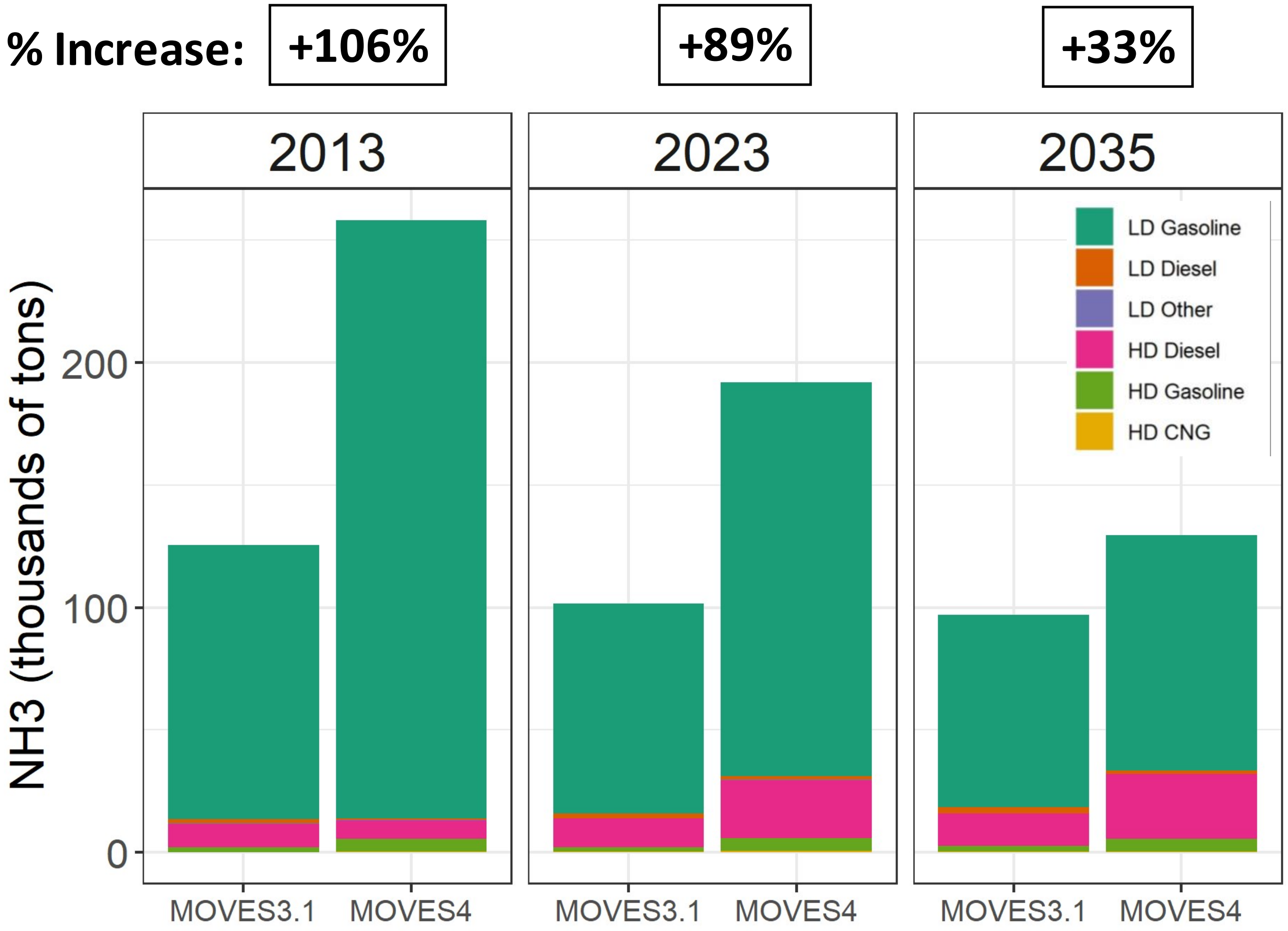
Distance-based NH_3 Emission Rates* for HD diesel vehicles



*rates shown for CY2023 for a nationally representative operating mode distribution

Impact on Onroad Emission Inventory (1/2)

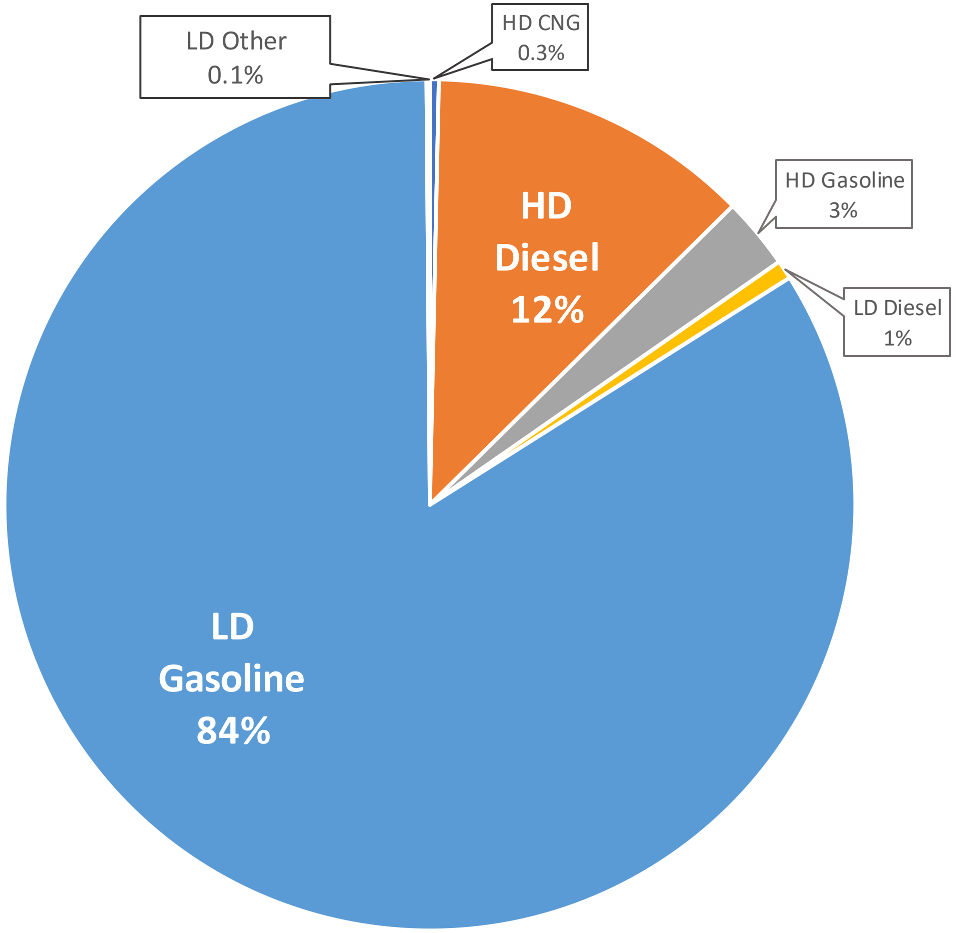
- Onroad NH_3 emissions are estimated to increase roughly by a factor of 2 for historical and near-term years.
  - Consistent with low end of range suggested by literature.
- Impact is more important for past years and, as the fleet evolves, we see less impact in future years.



Impact on Onroad Emission Inventory (2/2)

- Emissions increase for both LD gasoline and HD diesel, but the split remains similar to previous inventories.
- LD gasoline vehicles dominate the NH_3 inventory.
    - Major inventory impact would be observed in urban centers.

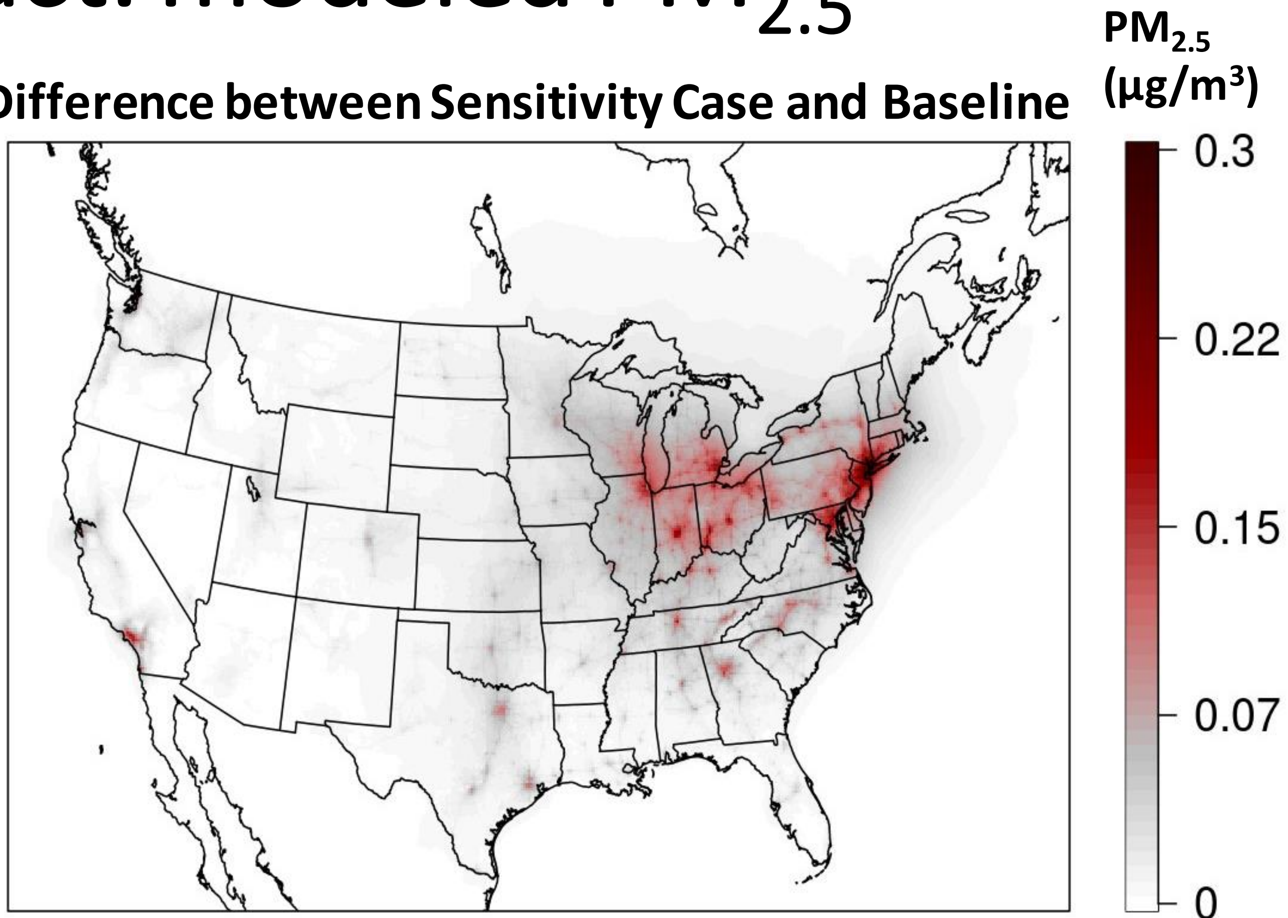
Onroad NH_3 emissions for CY 2023



Expected Air Quality Impact: modeled $PM_{2.5}$

- Explored sensitivity of modeled $PM_{2.5}$ to increase in NH_3 emissions from onroad sources.
- Enhancements in annual $PM_{2.5}$ values in the northeast region of up to 0.3 µg m^{-3}
  - Increase in $PM_{2.5}$ is particularly important during winter season.

Difference between Sensitivity Case and Baseline



Toro et al., in preparation

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Summary

- MOVES4 incorporates updated emission rates for NH_3, based on roadside remote sensing measurements from thousands of light-duty gasoline vehicles and hundreds of heavy-duty diesel trucks.

- Onroad emission inventory of NH_3 is estimated to increase roughly by a factor of 2 in historical and near-term years, but less impact is expected in future years.

- Increase in NH_3 emissions results in enhancements in modeled $PM_{2.5}$ particularly in the urban areas of the northeast region during winter.

Thank you.

Disclaimer: The views expressed in this presentation are those of the author and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

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Appendix

- Values from Preble et al. (2019) used for HD NH_3 emission rate update:

Aftertreatment	Engine Model Year	NH_3 (g/kg) fuel-based emission rate	Number of vehicles	Model year ranges used in MOVES
No DPF	1965-2003	0.02 ± 0.02	62	1960-2003
No DPF	2004-2006	0.00 ± 0.01	24	2004-2006
DPF	2007-2009	0.00 ± 0.01	181	2007-2009
DPF + SCR	2010-2018	0.18 ± 0.07	547	2010-2060
Retrofit DPF	1994-2006	0.01 ± 0.01	114	Not used

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