MOVES
Motor Vehicle Emission Simulator

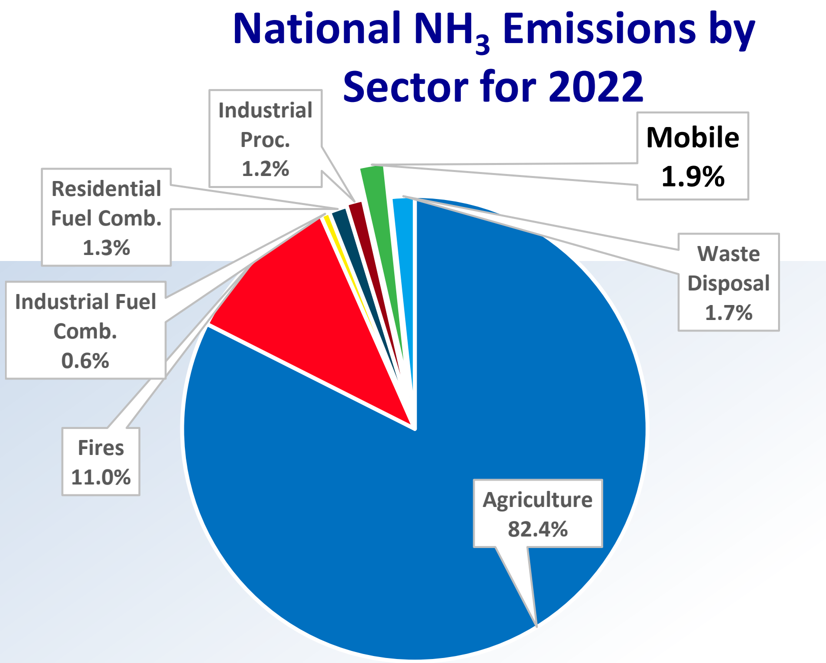
# Planned Updates to Ammonia ($NH_3$) and Nitrous Oxide ($N_2O$) in MOVES4

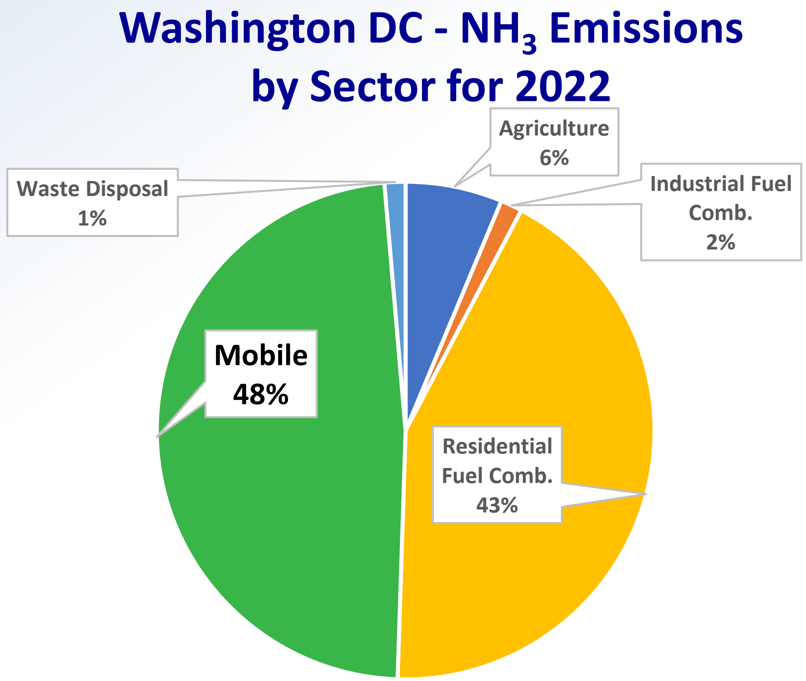
MOVES4 Data & Analysis Webinar
July 20, 2023

# AMMONIA

# Background

- Nationally, ammonia ($NH_3$) emissions are dominated by agricultural activities. In urban areas, onroad emissions are a much larger source.
- Vehicles emit $NH_3$ as an unintended byproduct from catalytic systems.
  - In heavy-duty (HD) vehicles, via overdosing of urea in Selective Catalytic Reduction systems ("ammonia slip")
  - In light-duty (LD) vehicles, via reduction of NO to $NH_3$ in three-way catalytic converters under fuel rich conditions.
- $NH_3$ is an important contributor to secondary $PM_{2.5}$.






Source: https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

# Motivation

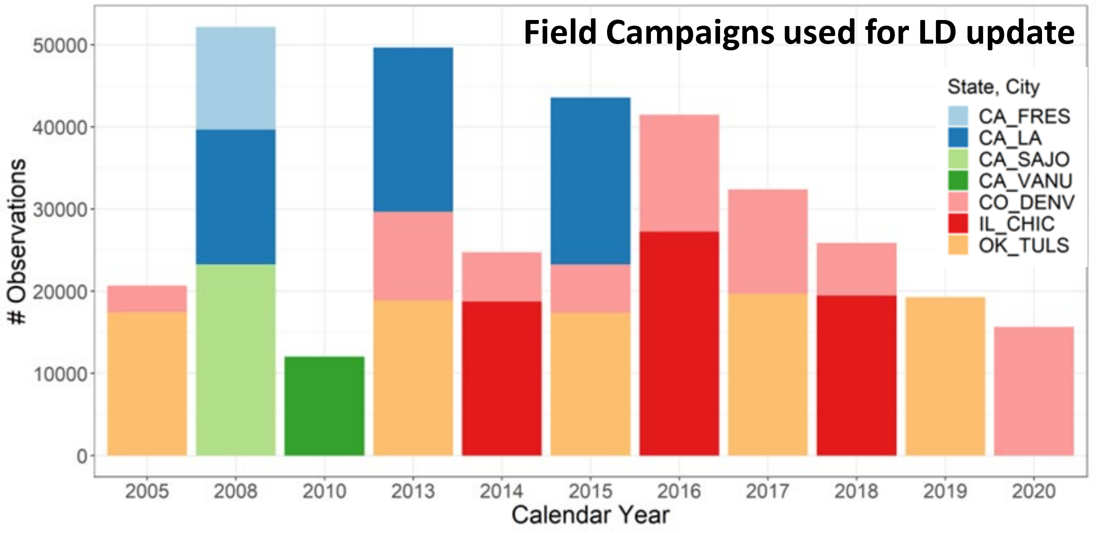
- Literature suggests that combustion-related sources of $NH_3$ are underestimated globally[(1)].

- In the US, several studies using different methodologies argue that mobile-source $NH_3$ inventories in urban areas are underestimated by 2x-3x [(2,3,4)].

- MOVES3 (and earlier versions) include $NH_3$ rates based on a 2001 study on a small number of vehicles.

# Data Sources

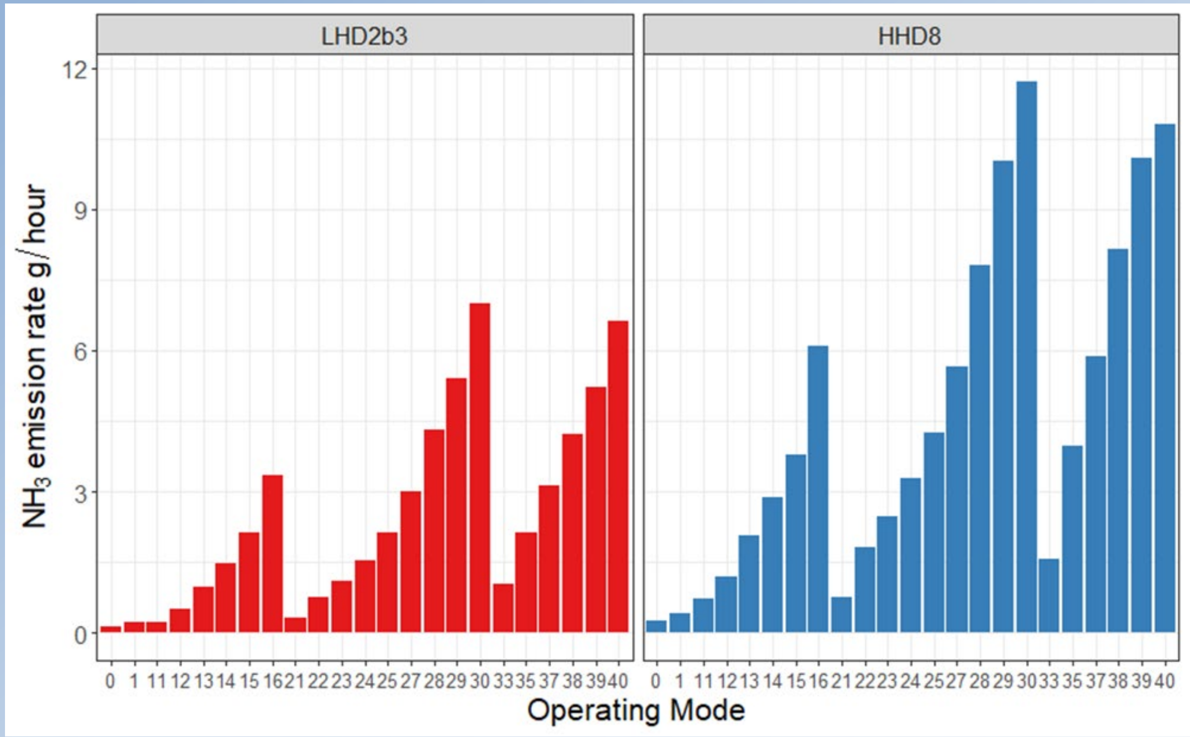
- **Remote Sensing Measurements**
  - LD gasoline update: over 335,000 light-duty gasoline $NH_3$ observations gathered by University of Denver[(5)]
  - HD diesel update: measurements of $NH_3$ from over 900 diesel trucks characterized by model year (MY) and aftertreatment system measured in Caldecott Tunnel, Oakland, CA[(6)]
  - For alternative-fueled vehicles (e.g., HD compressed natural gas (CNG), LD Ethanol (E85)), we made assumptions based on available data.




*From Preble et al (2019)*

# Overall Methodology

**Example $NH_3$ Emission Rates for HD vehicles**



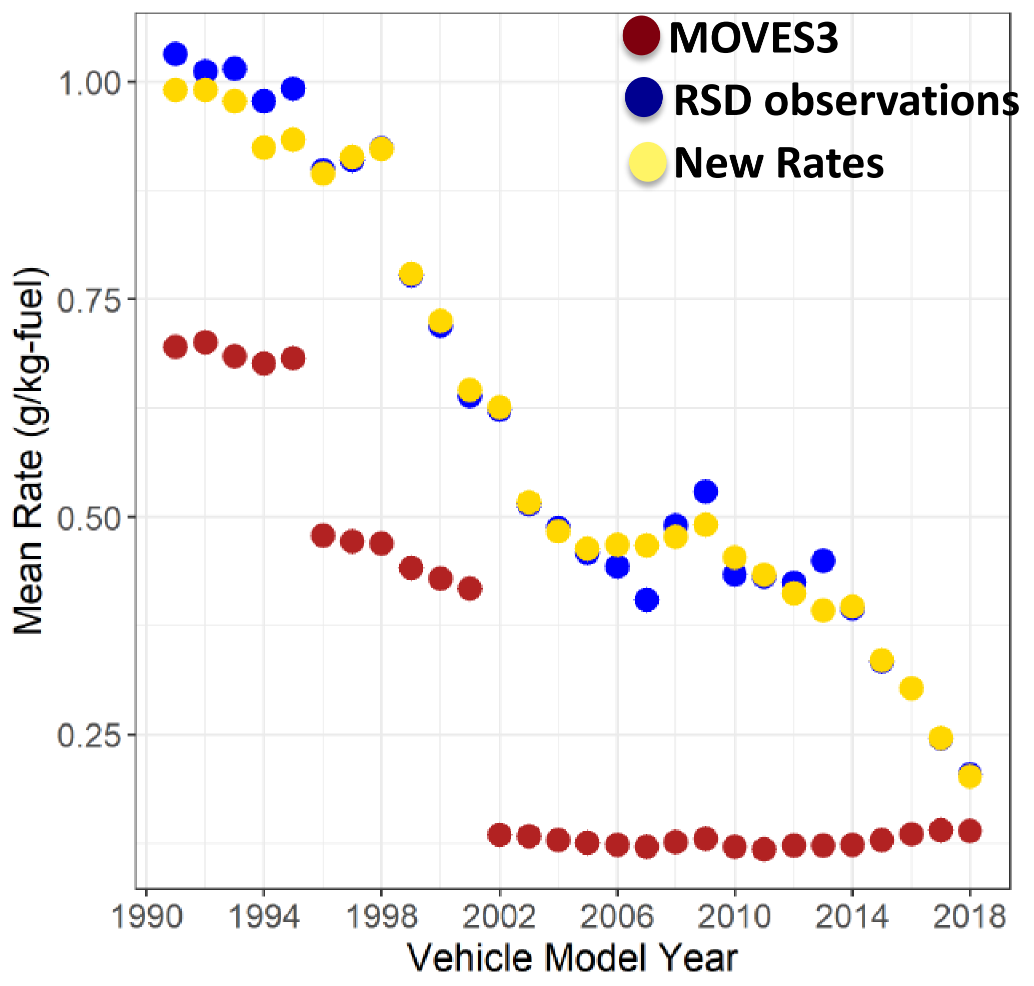

- For both LD and HD updates based on RSD observations:
  1. We averaged observed fuel-based $NH_3$ rates by model year (MY) groups and regulatory class ($\overline{FER}$).
  2. We converted these averages to time-based rates (g/hour) using appropriate fuel consumption rates grouped by operating mode, MY and regulatory class.
  3. Age effects were applied only for LD $NH_3$ since the depth of the dataset allowed it.

$$\overline{\mathbf{ER}}_{\mathbf{reg,MY,age,op}} = \mathbf{Fuel\ Rates}_{\mathbf{reg,MY,op}} \times \overline{\mathbf{FER}}_{\mathbf{reg,MY,age}}$$

# Results – LD $NH_3$

- 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.
  - In MOVES4, future MY rates are kept at 2018 levels.



# Results – HD $NH_3$ (1 of 2)

- Preble et al[6] presents tunnel measurements of $NH_3$ from HD trucks grouped by engine model year and emissions aftertreatment.

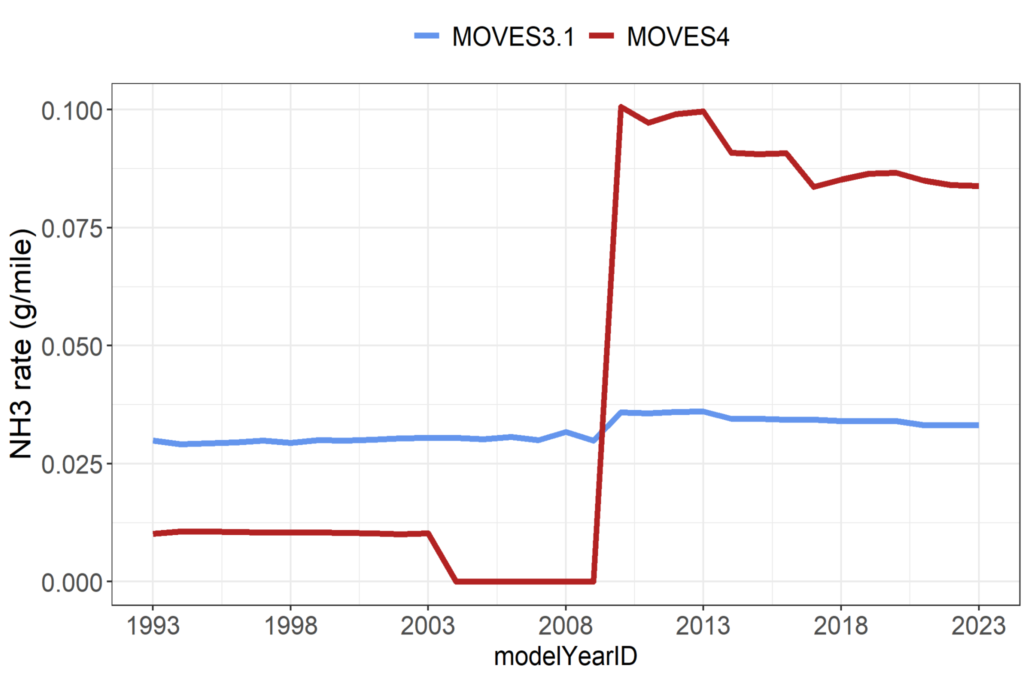
| Aftertreatment | Engine Model Year | $NH_3$ (g/kg) fuel-based emission rate | Number of vehicles | Model year ranges used in MOVES |
|---|---|---|---|---|
| No DPF | 1965-2003 | 0.02 ± 0.02 | 62 | 1960-2003 |
| No DPF | 2004-2006 | 0.00 ± 0.01 | 24 | 2004-2006 |
| DPF | 2007-2009 | 0.00 ± 0.01 | 181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

- We assigned to MY ranges used in MOVES and, using the same approach as for LD, converted to g/hour operating mode rates.

# Results – HD $NH_3$ (2 of 2)

- 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.

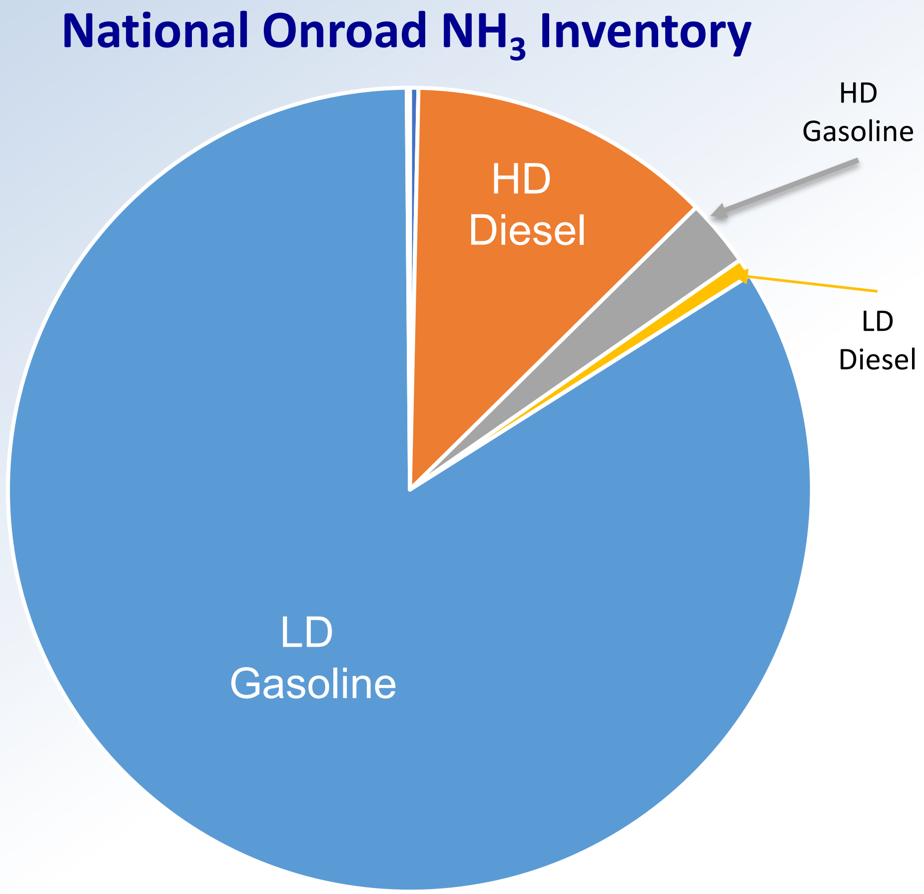
**Distance-based $NH_3$ Emission Rates* for HD diesel vehicles**




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

# Expected Inventory Impact

- MOVES4 will increase $NH_3$ emissions for both LD and HD vehicles
  - We expect that the increase in $NH_3$ emissions will be larger for past calendar years.
    - The difference will be less important in future years
  - LD gasoline emissions will continue to dominate the onroad $NH_3$ inventory

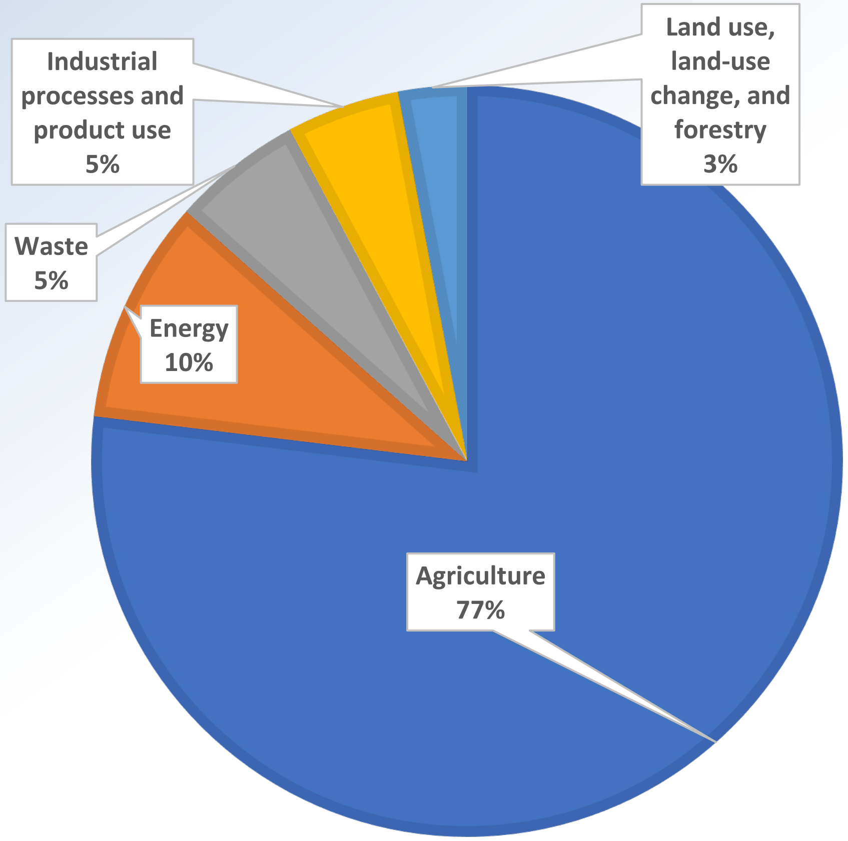


# NITROUS OXIDE ($N_2O$)

# Background

- $N_2O$ is a long-lived greenhouse gas emitted during combustion and as a byproduct from catalytic systems.
- Nationally, agriculture dominates the $N_2O$ inventory. Transportation does not constitute a significant source.
  - On a $CO_2$ equivalent basis, onroad GHGs are dominated by $CO_2$
- Study[6] used for HD $NH_3$ updates also provided $N_2O$ measurements.
- We followed the same methodology presented earlier for updating $NH_3$ emissions

**National Inventory $N_2O$ 2022**




Source: https://cfpub.epa.gov/ghgdata/inventoryexplorer/

# Results – HD $N_2O$ (1 of 2)

- Similar to $NH_3$, Preble et al[6] presents $N_2O$ measurements taken in 2015 at Port Oakland, grouped by engine model year and aftertreatment
- We use this to update $N_2O$ running emission rates for diesel vehicles for MY2004+

| Aftertreatment | Engine Model Year | $N_2O$ (g/kg) fuel-based emission rate | Number of vehicles |
|---|---|---|---|
| No DPF | 2004-2006 | 0.07 $\pm$ 0.06 | 11 |
| DPF | 2007-2009 | 0.06 $\pm$ 0.01 | 866 |
| DPF + SCR | 2010-2016 | 0.44 $\pm$ 0.11 | 300 |

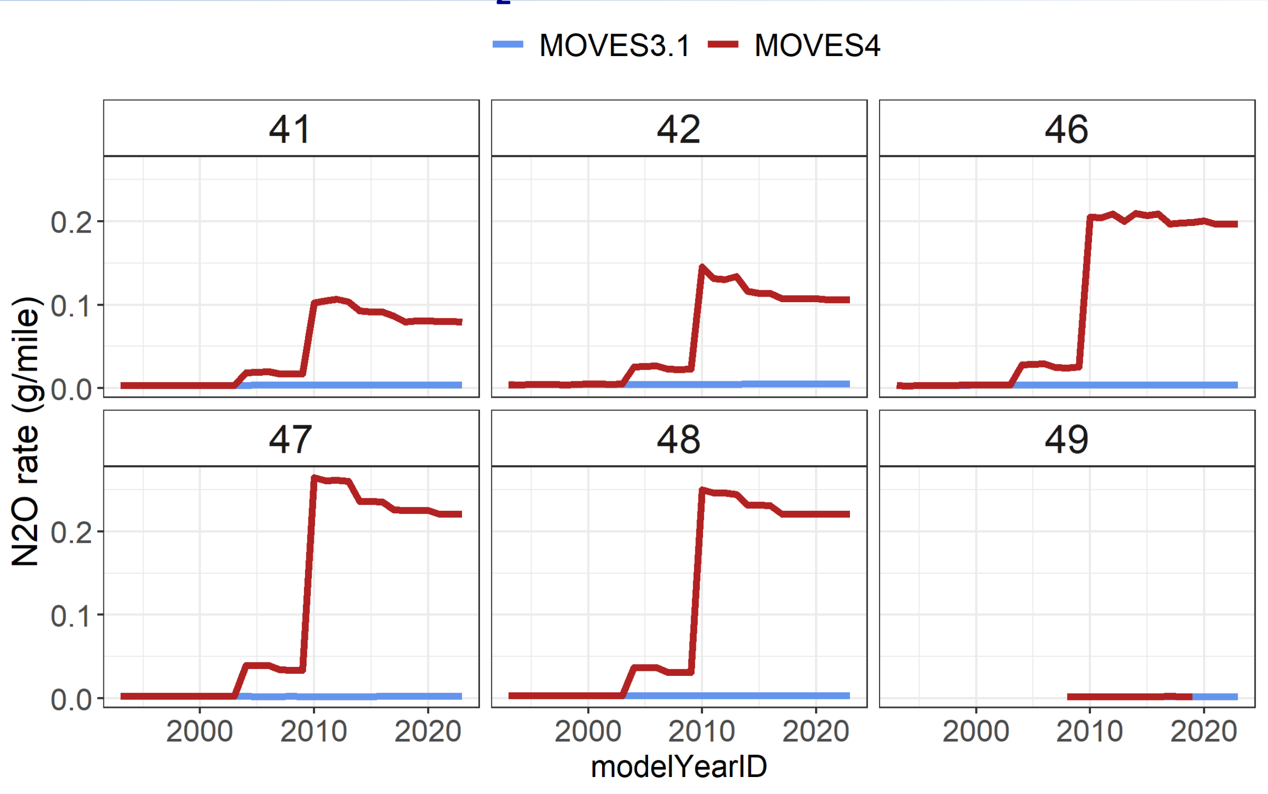
# Results – HD $N_2O$ (2 of 2)

- MOVES4 rates are considerably higher for all HD regulatory classes.

- MOVES4 estimates zero start emissions for $N_2O$ since laboratory data indicates that the start contribution to total tailpipe $N_2O$ emissions is negligible.

  - No APU or extended idle $N_2O$ emissions are modeled.

**Distance-based $N_2O$ Emission Rates* for HD vehicles**

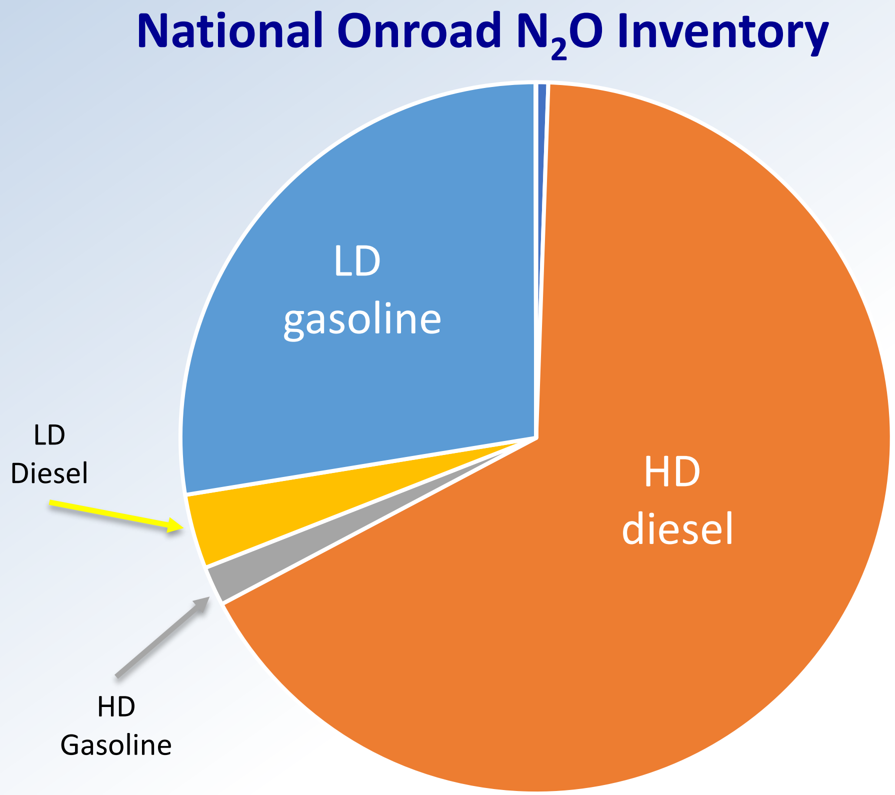



***rates shown by regulatory class for CY2023 for a nationally representative operating mode distribution***

# Expected Inventory Impact

- MOVES4 expected to increase $N_2O$ emissions*
  - LD gasoline dominate $N_2O$ emissions in past years.
  - HD diesel dominates $N_2O$ emissions in current and future years.

*(*) Note that on a $CO_2$ equivalent basis, onroad GHGs are dominated by $CO_2$; thus, changes in $N_2O$ have a small overall impact on onroad GHGs*



# Summary

- MOVES4 incorporates updates to $NH_3$ running emission rates based on remote sensing measurements for thousands of light-duty gasoline vehicles and hundreds of heavy-duty trucks.
  - We expect an increase of $NH_3$ emissions for past years, and less impact for future years.
- MOVES4 also includes updates to $N_2O$ running emissions based on remote sensing of heavy-duty trucks.
  - We expect a large increase in $N_2O$ emissions from HD vehicles for future years, but not a significant impact to the overall onroad GHG contribution.

# References


1. ***Chen, Z.L. et al.*** *Significant contributions of combustion-related sources to ammonia emissions*. Nat Commun 13, 7710 (2022), https://doi.org/10.1038/s41467-022-35381-4
2. ***Walters, W. W., et al***: *Quantifying the importance of vehicle ammonia emissions in an urban area of northeastern USA utilizing nitrogen isotopes*, Atmos. Chem. Phys., 22, 13431–13448, (2022), https://doi.org/10.5194/acp-22-13431-2022
3. ***Sun K. et al***. *Vehicle Emissions as an Important Urban Ammonia Source in the United States and China,* Environmental Science & Technology 51 (4), 2472-2481, (2017), https://doi.org/10.1021/acs.est.6b02805
4. ***Cao H. et al.***, *COVID-19 Lockdowns Afford the First Satellite-Based Confirmation That Vehicles Are an Under-recognized Source of Urban NH3 Pollution in Los Angeles*, Environmental Science & Technology Letters (2022) 9 (1), 3-9, https://doi.org/10.1021/acs.estlett.1c00730
5. ***Fuel Efficiency Automobile Test Data Repository*** | University of Denver Research | Digital Commons @ DU, https://digitalcommons.du.edu/feat/
6. ***Preble C. et al.,*** *Control Technology-Driven Changes to In-Use Heavy-Duty Diesel Truck Emissions of Nitrogenous Species and Related Environmental Impacts*, Environmental Science & Technology 2019 53 (24), 14568-14576, https://doi.org/10.1021/acs.est.9b04763