Recent Updates to EPA's MOtor Vehicle Emission Simulator (MOVES)

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

What is MOVES?

- MOVES is EPA's MOtor Vehicle Emission Simulator
- Estimates emissions and energy use for onroad vehicles and many categories of nonroad equipment
- Estimates emissions of criteria pollutants, greenhouse gases (GHGs), and air toxics, as well as fuel consumption and energy demand
- Accounts for national emission standards, vehicle populations and activity, state and local rules, fuels & temperatures

- Used by U.S. EPA and by U.S. state and local governments, as well as by others with an interest in mobile source emissions
  - Estimates criteria pollutant benefits for EPA rules
  - Input to air quality modeling
  - Required for (non-California) states and local governments meeting Clean Air Act requirements
- **MOVES4 was released August 30, 2023**

MOVES4 Review

- Peer review of underlying data and algorithms by independent experts
  - Provided rigorous review of MOVES data and methods
  - Search https://cfpub.epa.gov/si/ for Record ID: 356887 and 356914
- Beta testing by experienced MOVES modelers
  - Tested functionality of updates and identified bugs in new features
- MOVES4 “release candidate” shared on GitHub 6/13/2023
  - Provided opportunity for broad range of modelers to give feedback on operability of the model before it was finalized

MOVES4—Overview of Changes

- Accounts for finalized emission rules
  - Does not cover proposed regulations
- Updates modeling of electric vehicles
- Updates default data and projections for vehicle populations and activity
- Updates default data and projections for fuel properties
- Improves emission rates and emission adjustments

Emission Standards (1 of 2)

HD2027 rule

- Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards
- Published in January 2023
- This rule sets tighter emission standards for NO_x, PM, VOC and CO from heavy-duty onroad vehicles and engines starting in model year 2027

Heavy-duty diesel vehicles:

- Reduce NO_x emission rates for running, start, and extended idle processes for MY 2027+
- Adjustment for running and extended idle NO_x for ambient temperatures below 77°F
- Additional minor changes.

Heavy-duty gasoline vehicles:

- Revised NO_x, $PM_{2.5}$, HC and CO emission rates for running processes only
- Revised refueling emissions to account for new HD ORVR requirements

Heavy-duty natural gas vehicles:

- No updates were made since the average NO_x emissions are already close to 0.1 g/hp-hr

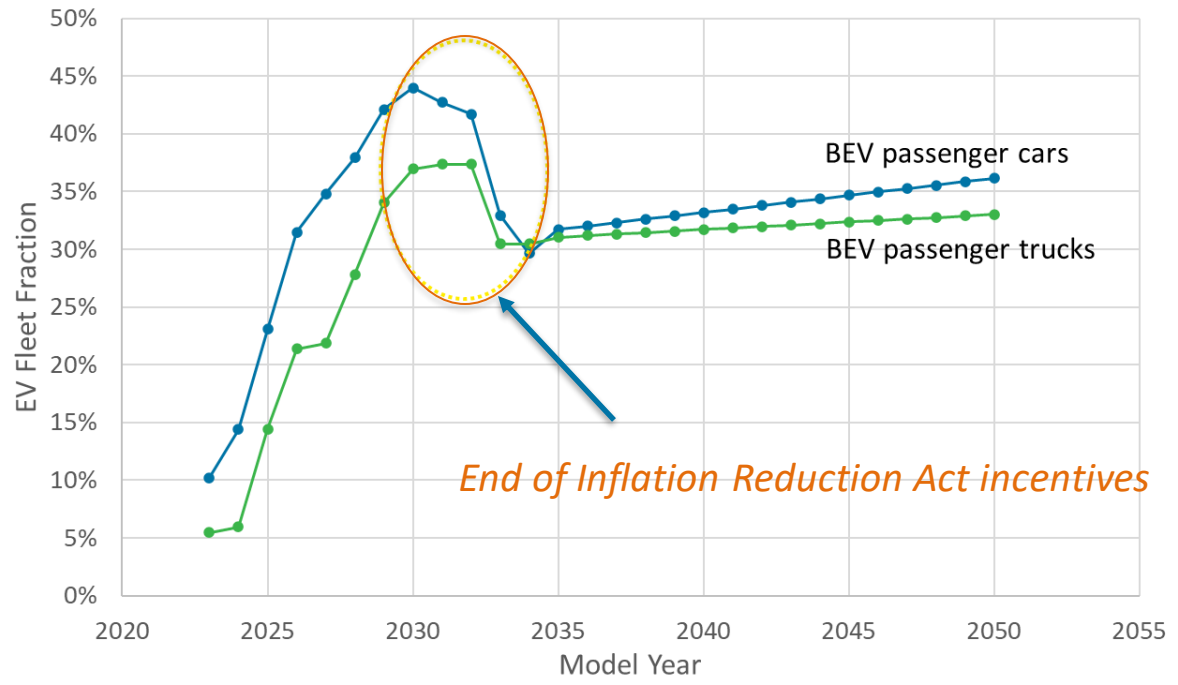
Emission Standards (2 of 2)

- **LD GHG 2023-2026 rule**
  - Incorporated greenhouse gas standards for light-duty passenger cars and trucks (LDGHG 2023)
  - Rule was published in December 2021
  - These standards set tighter carbon dioxide (CO_2) limits for light duty (LD)
- **Removal of HDGHG2 trailer program**
  - A 2021 appeals court ruling vacated the portions of the 2016 HDGHG2 rule that apply to trailers
  - We revised MOVES inputs that describe weight, aerodynamics, rolling resistance and "other efficiency improvements" for combination trucks of MY2018 and later
  - This change slightly increases the modeled emissions of CO_2 and other pollutants from these trucks

Modeling of EVs

- Better estimates of energy use by electric vehicles (EVs)
- Forecasts default national EV fleet fractions and provides Alternate Vehicle and Fuel Technology (AVFT) Tool allowing users to enter local EV fractions
- Adjusts HC and NOx from internal combustion engine (ICE) vehicles to account for Tier 3 fleet averaging with EVs
  - Increases average ICE g/mile emission rates
- Adds
  - Heavy-duty battery EVs and fuel cell vehicles
  - EV and CNG long-haul combination trucks
    - Including ability to model hotelling from these vehicles

Vehicle Populations and Activity

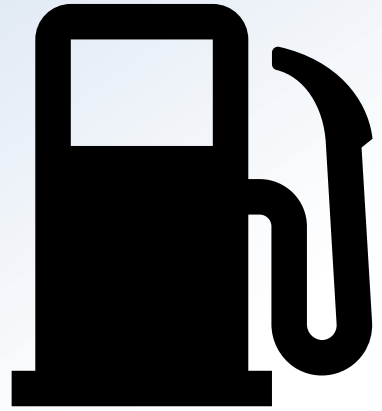


Light-Duty National Default EV Fleet Fraction

- Adds default EV fraction projections for LD & HD
- Updated default VMT and vehicle populations from latest historical data and projections
  - Historical data from Highway Statistics (2021) and National Transit Database (2021)
  - Projections from DOE Annual Energy Outlook 2023
- Updated age distributions
  - MOVES default age distributions based on 2020 registration data
  - On average, cars are older than in MOVES3
- Updated LD mileage accumulation
- Lower glider fractions
- Other changes

Fuel Changes

- Updated fuel carbon and energy content for diesel and gasoline fuels (including biofuel blends)
- Revised 2018+ gasoline properties based on updated refinery batch data
  - Reductions in gasoline sulfur content produced reductions in nonroad SO_2 emissions as well as onroad



Updated Emission Rates and Adjustments

- We have updated specific vehicle emission rates and adjustment factors based on new data and improved analysis
- Including:
  - Updated emission rates for NH_3, N_2O, NO & NO_2
    - Real-world measurements show ammonia emissions from both gasoline and diesel vehicles are much higher than MOVES3 predicted.
    - Similarly, nitrous oxide (N_2O) emissions have increased due to tunnel study data for HD diesel vehicles
    - And, for a given quantity of HDD NOx emissions, MOVES4 estimates more NO and less NO_2.
  - Streamlined emission speciation for air quality modeling

Additional Updates

- Updated refueling vapor emissions based on data from EPA study
- Updated PM rates to account for new info on vehicle engine (PFI/GDI) mix
- Restructured crankcase emission calculations
- Corrected extended idle rates for elemental carbon (EC) and Non-EC PM
- Updated HD diesel deterioration
- Updated NO_x humidity adjustments

COMPARISONS

How do MOVES4 results differ from MOVES3?

National Comparisons:

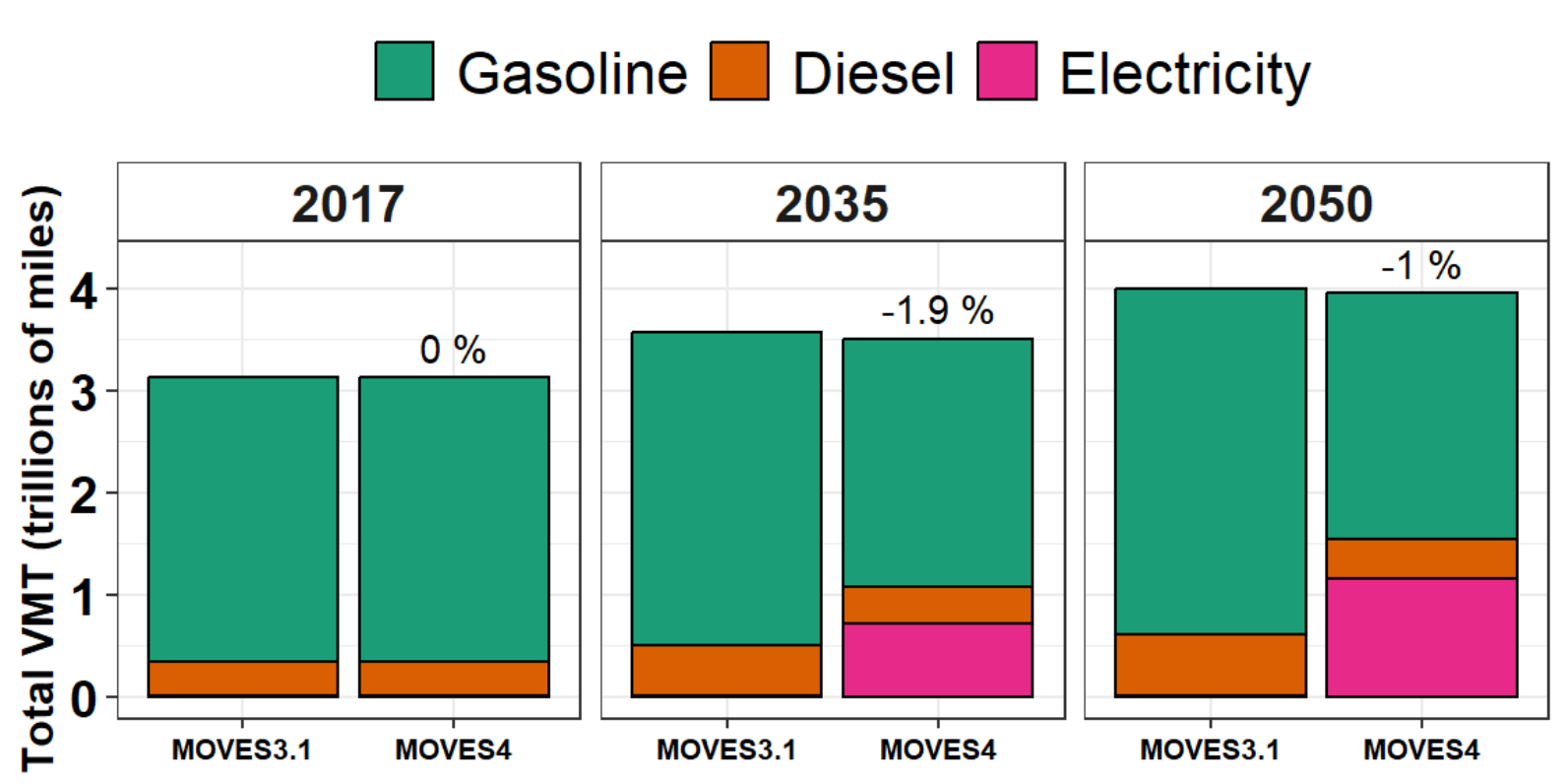
- MOVES4 output is compared to MOVES3.1
- Both use MOVES default inputs
  - Averaged across entire year and entire U.S.
- Activity is different for MOVES3 and MOVES4

Sample County Comparisons:

- Available in MOVES Overview report
- Show similar trends

For the most accurate results for a given time and location, you must run MOVES for the specific case using accurate local inputs.

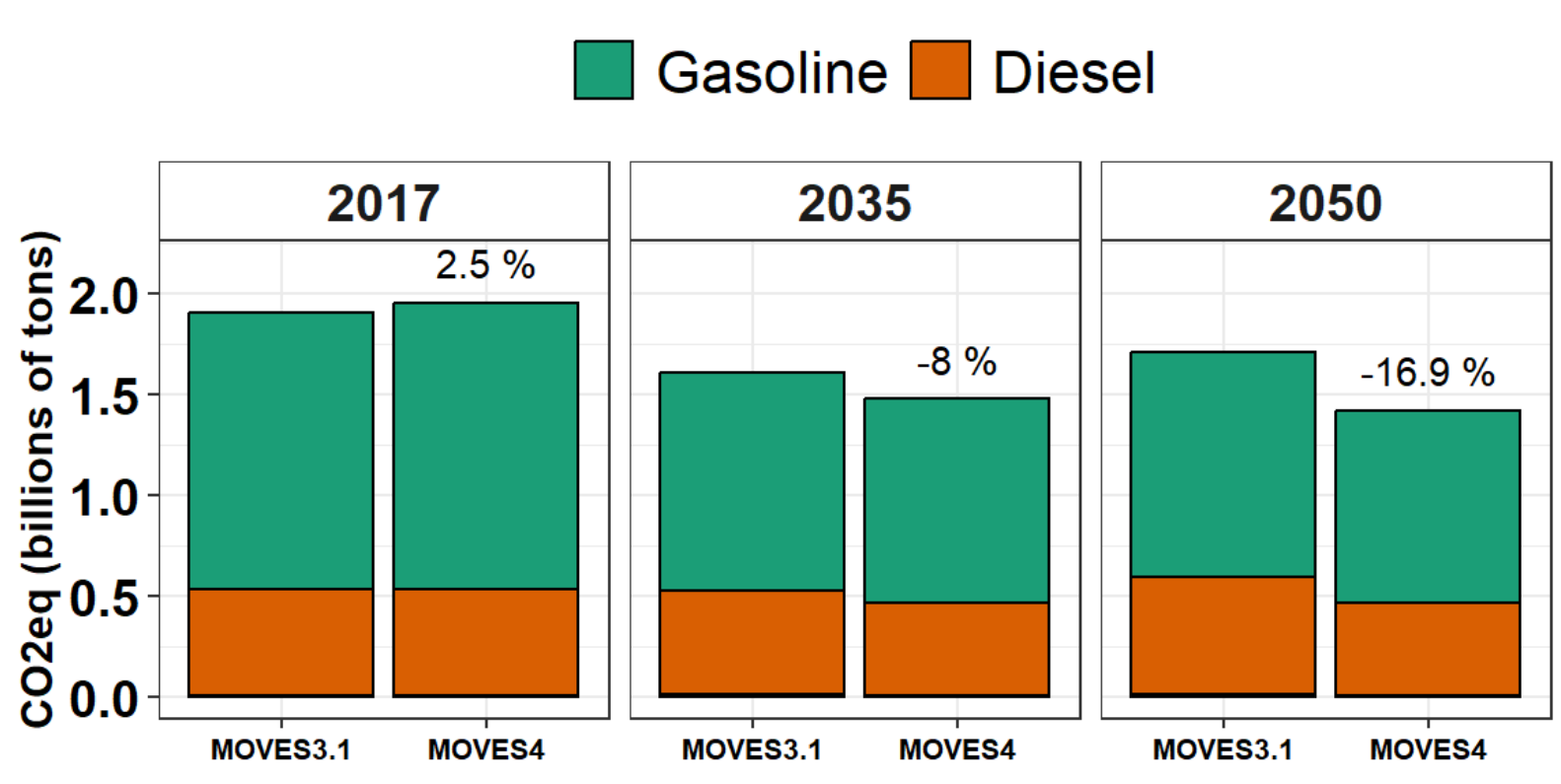
National VMT



National onroad vehicle miles travelled (VMT) in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

- VMT from gasoline vehicles dominates in both models in all three years
- Note shift from gasoline and diesel to electric vehicles in MOVES4
  - Reflects expected trends based on current rules & national incentives
- Also, a very slight decrease in projections of total vehicle miles travelled
- See MOVES4 Population & Activity report for details

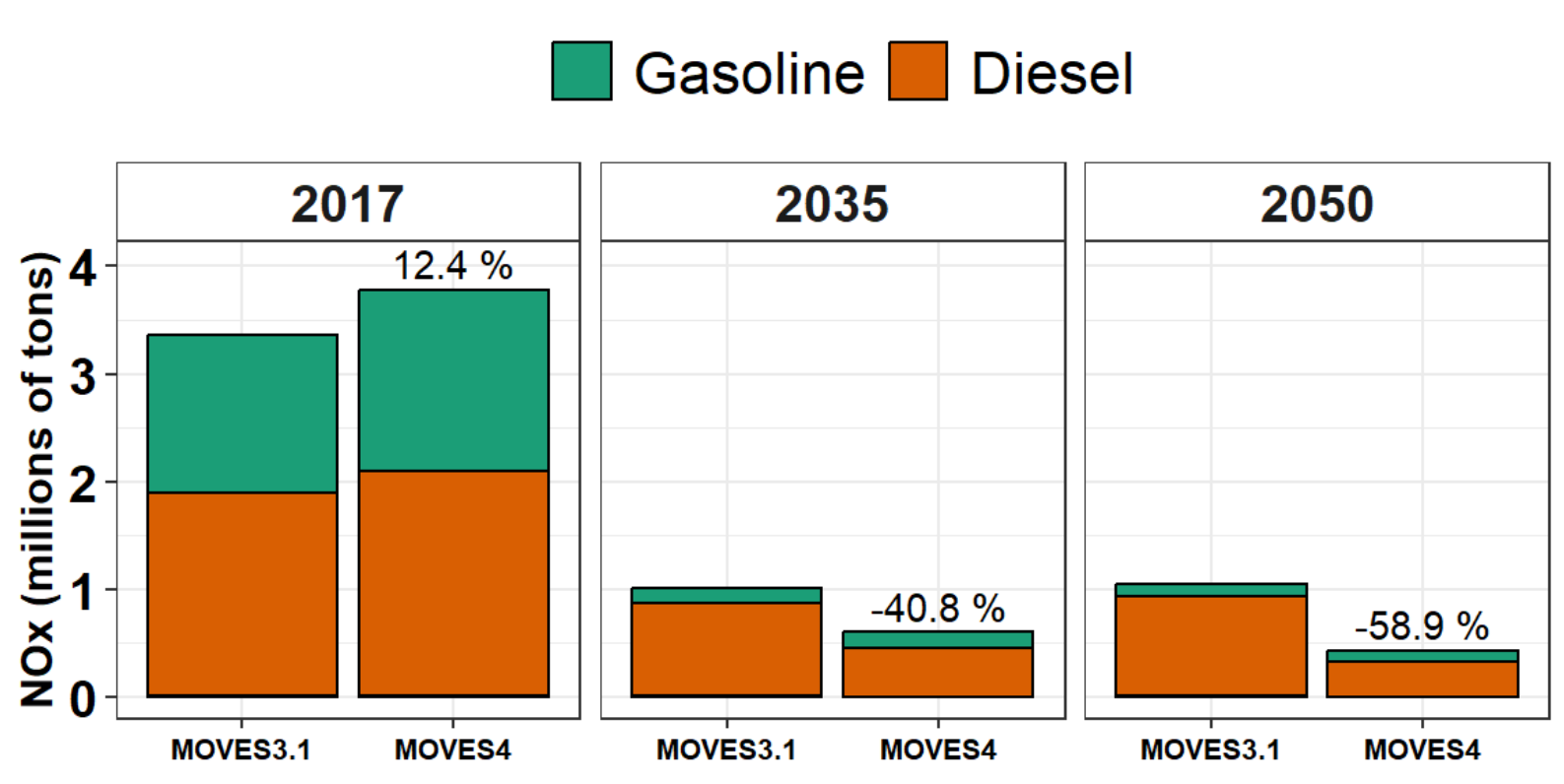
National GHG Totals



- Graph shows net CO_2 equivalent emissions based on the emissions of CO_2, CH_4 and N_2O weighted by their global warming potentials
- MOVES4 increase in N_2O is outweighed by decreases in CO_2 and CH_4

National onroad CO_2 equivalent in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

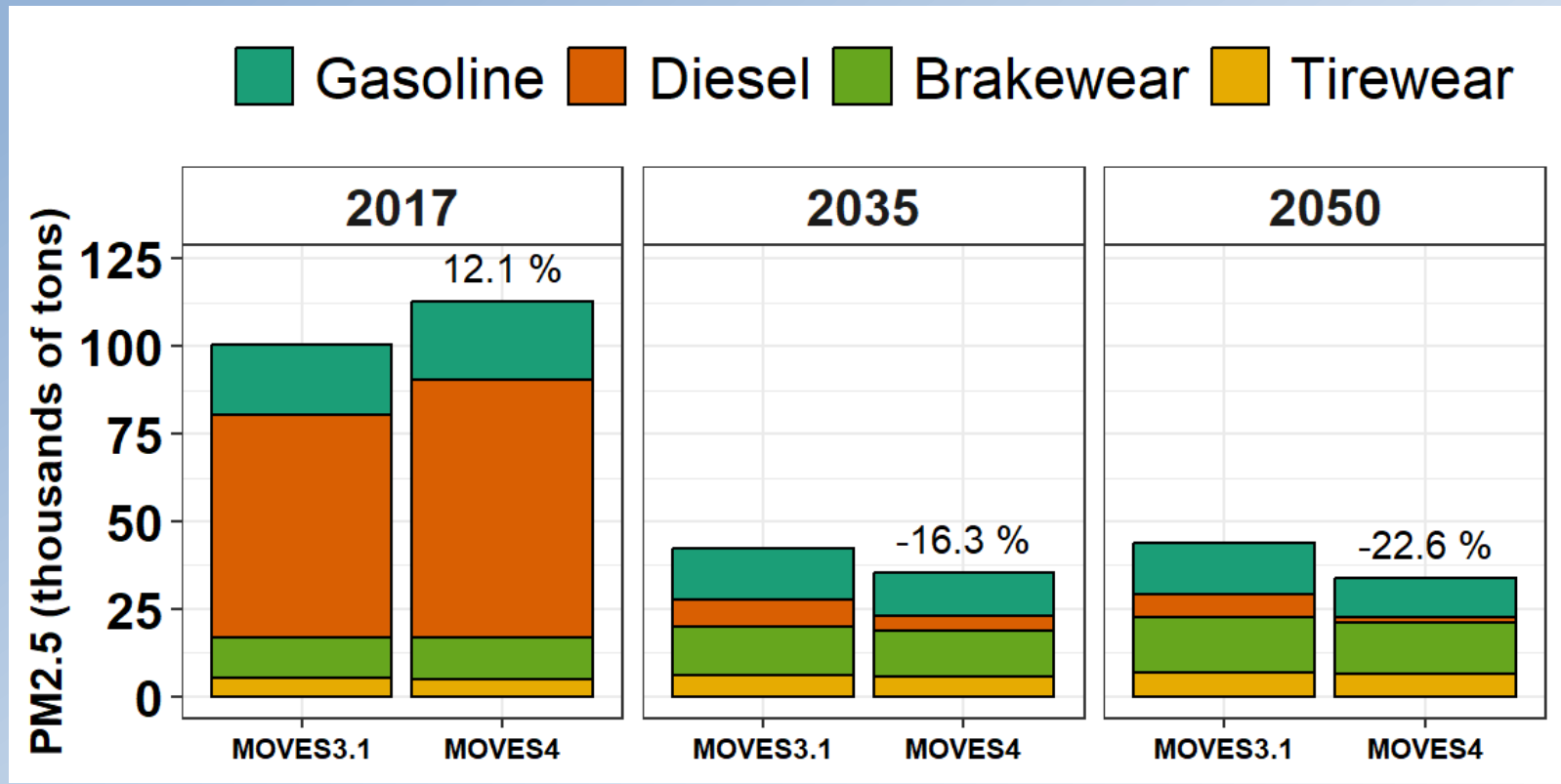
National Oxides of Nitrogen



- In both versions, national NO_X emissions decline over time with the phase-in of light-duty and heavy-duty rules.
- MOVES4 shows additional declines due to phase-in of the Heavy-Duty NOx Rule for 2027 and Later (HD2027)
- Also, MOVES4 has growing share of electric vehicles

National onroad NO_x emissions in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

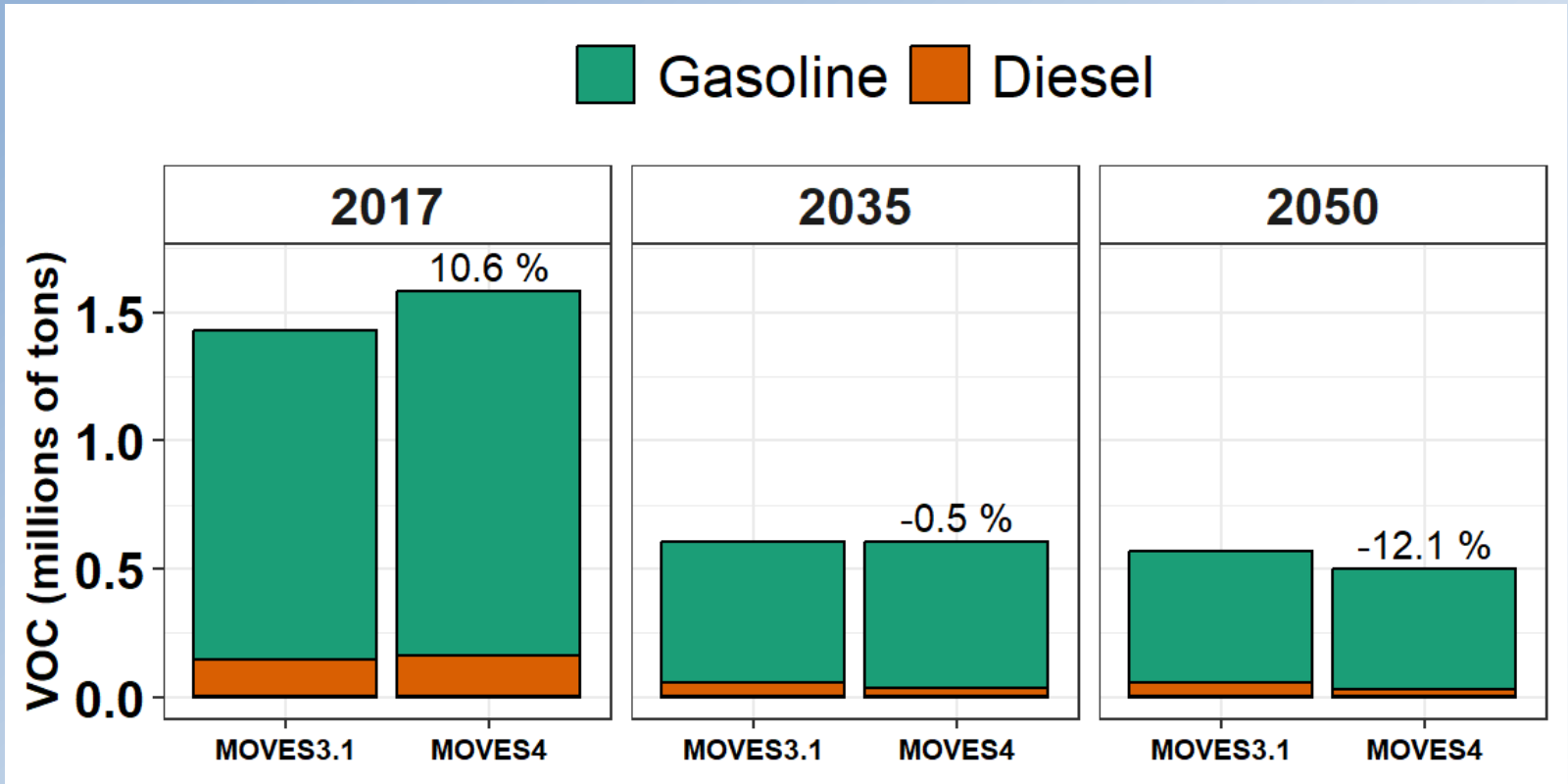
National Particulate Matter



National onroad $PM_{2.5}$ emissions in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

- $PM_{2.5}$ inventory declines with the phase-in of light-duty and heavy-duty PM regulations.
- Compared to MOVES3, MOVES4 results in less PM exhaust primarily due to a reduction in the number of glider vehicles and shifts to electric vehicles.
- Brake and tire wear emissions are similar in MOVES3 and MOVES4.
  - MOVES uses the same brake and tire wear rates for all fuel types

National Volatile Organic Compounds



National onroad VOC emissions in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

- VOC emissions are dominated by gasoline vehicles
- Both models show reductions due to Tier 3 standards
- MOVES4 shows additional reductions from increased fractions of EVs

MOVES
Motor Vehicle Emission Simulator

Resources

MOVES Website

https://www.epa.gov/moves is the starting point for all MOVES information, with links to:

- Latest model (MOVES4)
- Limited use models (MOVES3)
- Tools
- Training
- Background Information
  - Technical Reports
  - Software Information

MOVES Overview Report

Overview of EPA's MOtor Vehicle Emission Simulator (MOVES4) (pdf)

MOVES4 Webinars

- July 20, 2023 public webinar included three presentations:
  - MOVES4: Overview of Planned Updates
  - Planned Updates to Ammonia (NH3) and Nitrous Oxide (N2O) in MOVES4
  - EPA Plans for Electric Vehicles Modeling in MOVES4
- September 13, 2023 public webinar included:
  - Overview of how MOVES4 emission results compare to MOVES3
  - Guidance on how and when to use MOVES4 for SIP development, transportation conformity, general conformity, and other purposes
  - Information on MOVES4 tools & inputs, including how to update MOVES3 inputs to work with MOVES4

MOVES GitHub Site

- https://github.com/USEPA/EPA_MOVES_Model has links to the MOVES source code and up-to-date information on bugs and workarounds
- https://github.com/USEPA/EPA_MOVES_Model/tree/master/docs has links to additional user support documents, including:

- *Anatomy of a Runspec*
- *Command Line MOVES*
- *Input DB changes in MOVES4*
- *Tips for faster MOVES runs*
- *Onroad Cheat Sheet*
- *Nonroad Cheat Sheet*

These documents are also available in the docs folder of the MOVES installation directory

Additional Resources

- MOVES4 Policy Guidance and Technical Guidance are also available at: www.epa.gov/state-and-local-transportation/policy-and-technical-guidance-state-and-local-transportation#emission
- MOVES4 Federal Register Notice: https://www.govinfo.gov/content/pkg/FR-2023-09-12/pdf/2023-19116.pdf
- Coming soon: other guidance updates, updated training materials
- Join EPA's MOVES listserv to receive MOVES announcements, including training: www.epa.gov/moves/forms/epa-mobilenews-listserv

MOVES
Motor Vehicle Emission Simulator

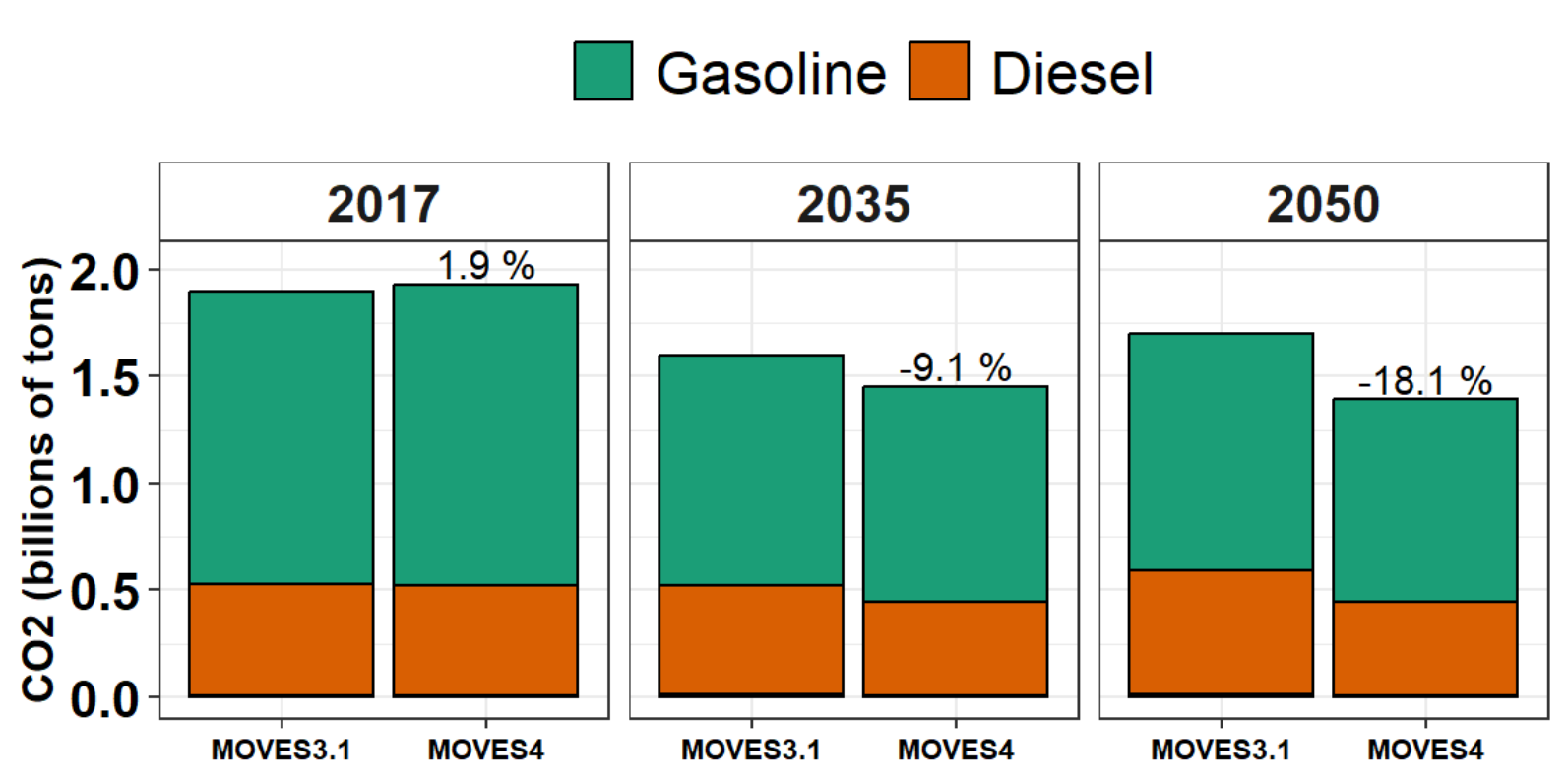
Questions?

APPENDICES

Acronyms

ACT	California Advanced Clean Trucks rule
AVFT	Alternate Vehicle Fuel and Technologies
CNG	Compressed natural gas
DOE	Department of Energy
DOT	Department of Transportation
EC	Elemental carbon
EPA	Environmental Protection Agency
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GDI	Gasoline direct injection
GHG	Greenhouse gas
g/hp-hr	Grams per horsepower-hour
g/mi	Grams per mile
HD	Heavy duty
HD2027	Heavy-Duty Engine and Vehicle Standards starting in 2027
HDGHG2	2016 Heavy Duty GHG rule
ICE	Internal combustion engine
I/M	Inspection and Maintenance program
LD	Light duty
LDV	Light-duty vehicle (i.e. car)
LDT	Light-duty truck
MOVES	Motor Vehicle Emission Simulator
MY	Model year
Non-EC	Particulate matter other than elemental carbon
ORVR	Onboard Refueling Vapor Recovery
PM	Particulate matter
RFG	Reformulated gasoline
SIP	State implementation plan
SUVs	Sport utility vehicle
VMT	Vehicle miles travelled

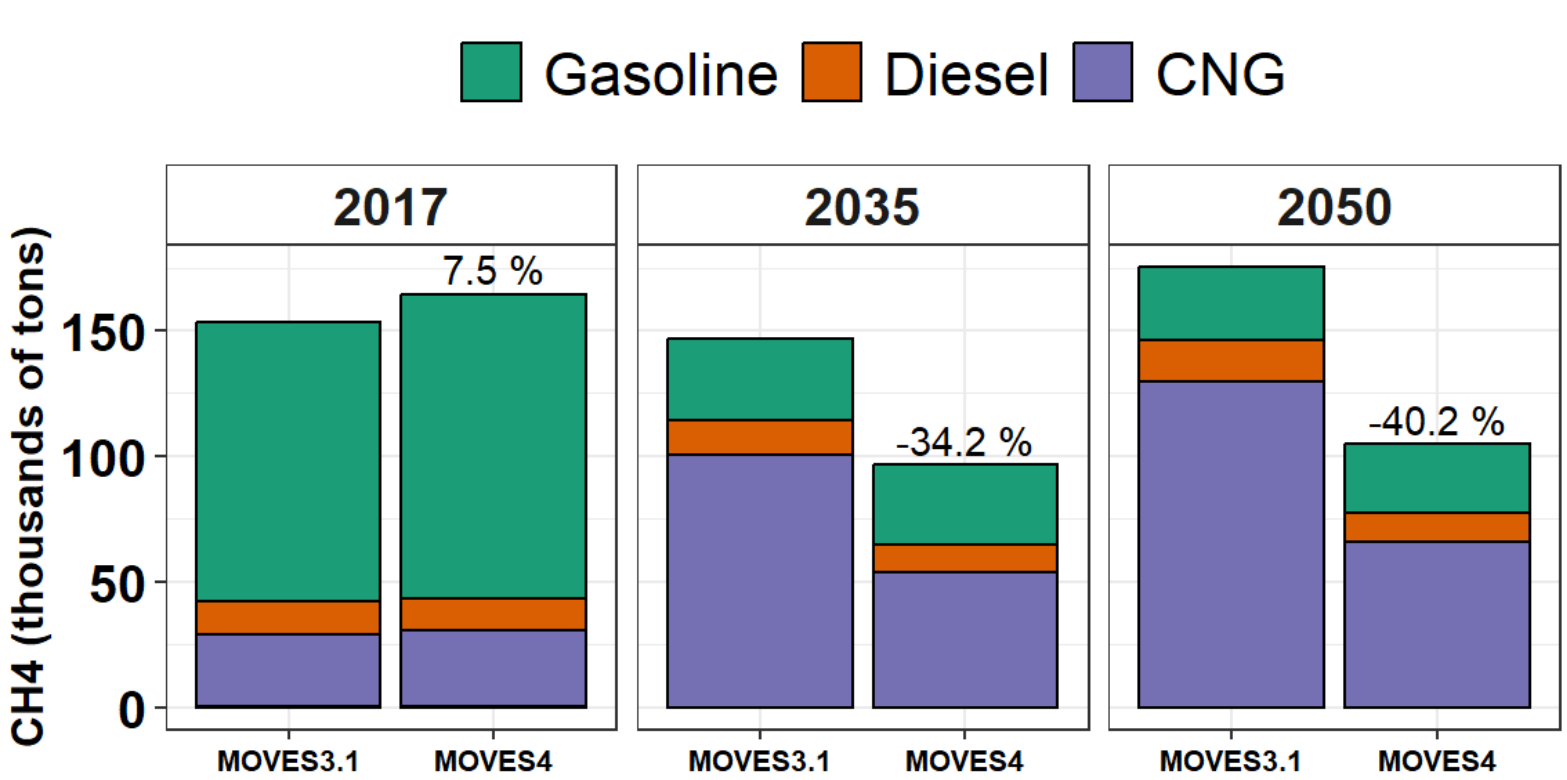
National Carbon Dioxide



- MOVES4 projects greater CO_2 decreases over time than MOVES3.
- Captures changes in fleet mix and activity
- Also phase-in of the Revised Light Duty GHG Standards for 2023 and Later
- See MOVES4 technical reports for details

National onroad carbon dioxide (CO_2) in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

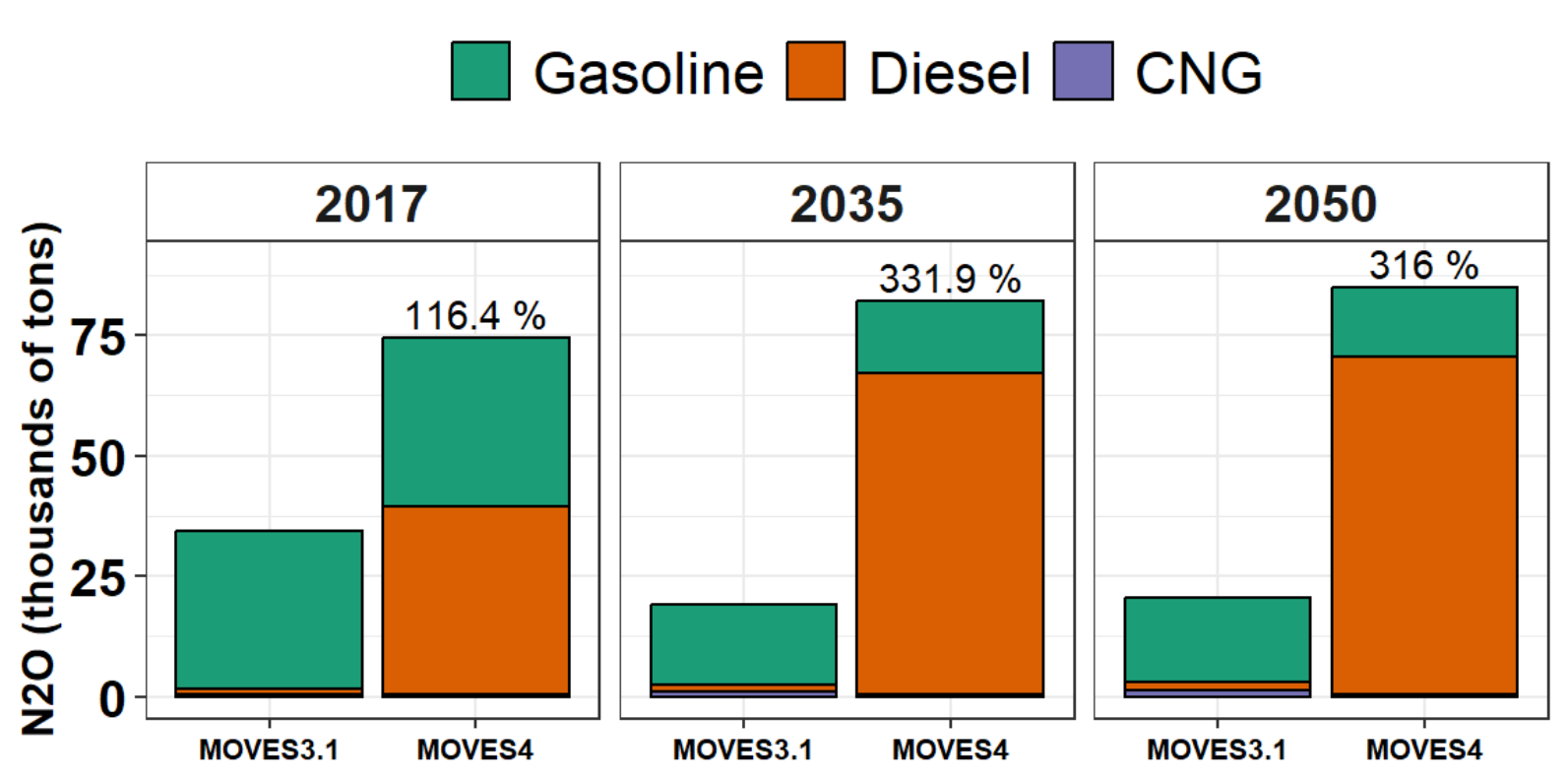
National Methane



- MOVES4 projects declining CH_4
- Reflects shift from compressed natural gas (CNG) vehicles, which have high methane emissions, to electric vehicles, which have none
- See MOVES4 Population & Activity report for details

National onroad methane (CH_4) in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

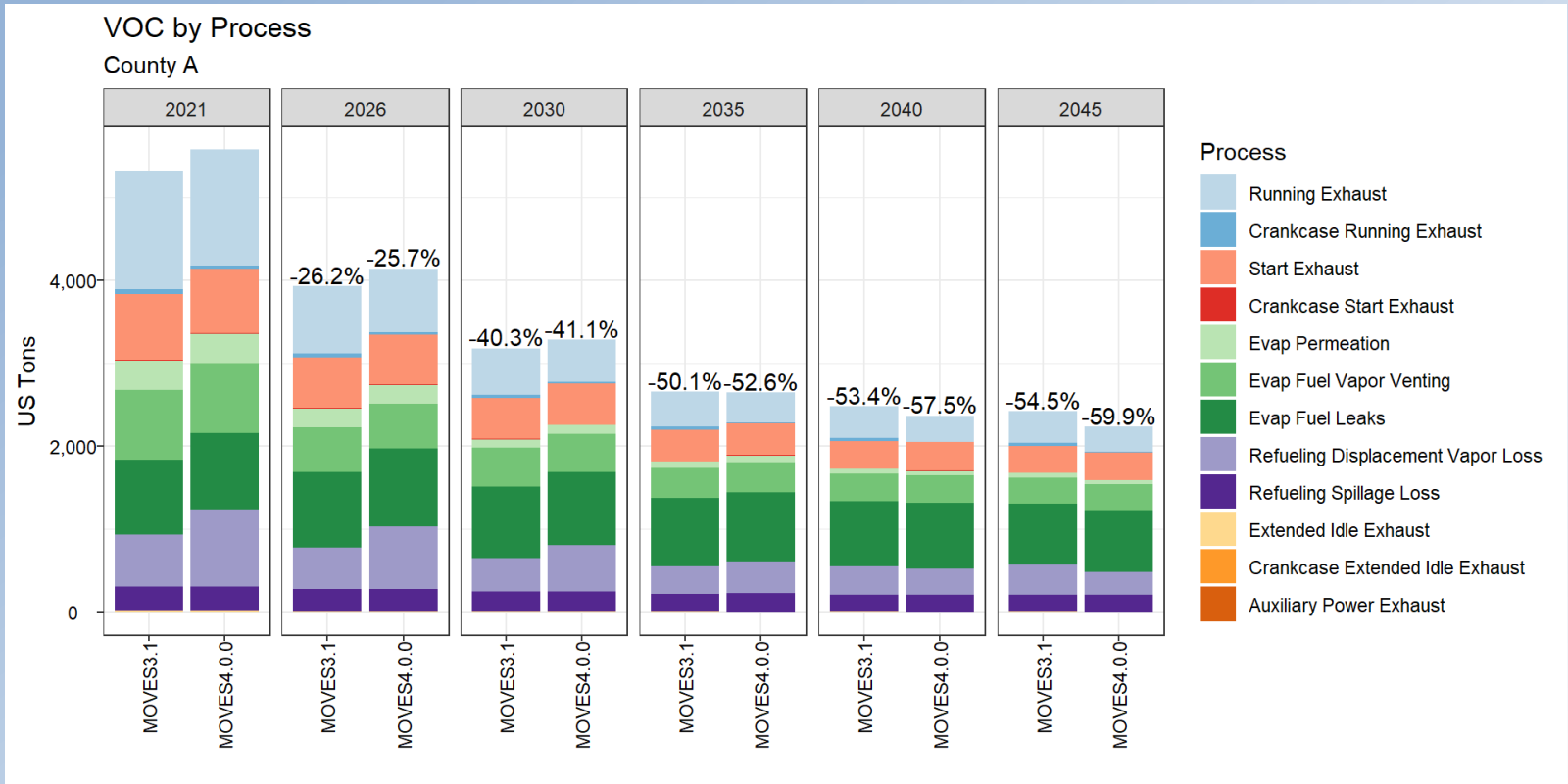
National Nitrous Oxide



- MOVES4 projects higher N_2O
- Reflects incorporation of new real-world data for diesel vehicles
- See July webinar and MOVES4 Heavy Duty technical report for more information

National onroad nitrous oxide (N_2O) in MOVES4 as compared to MOVES3.1. Percentage values indicate change between MOVES3.1 and MOVES4.

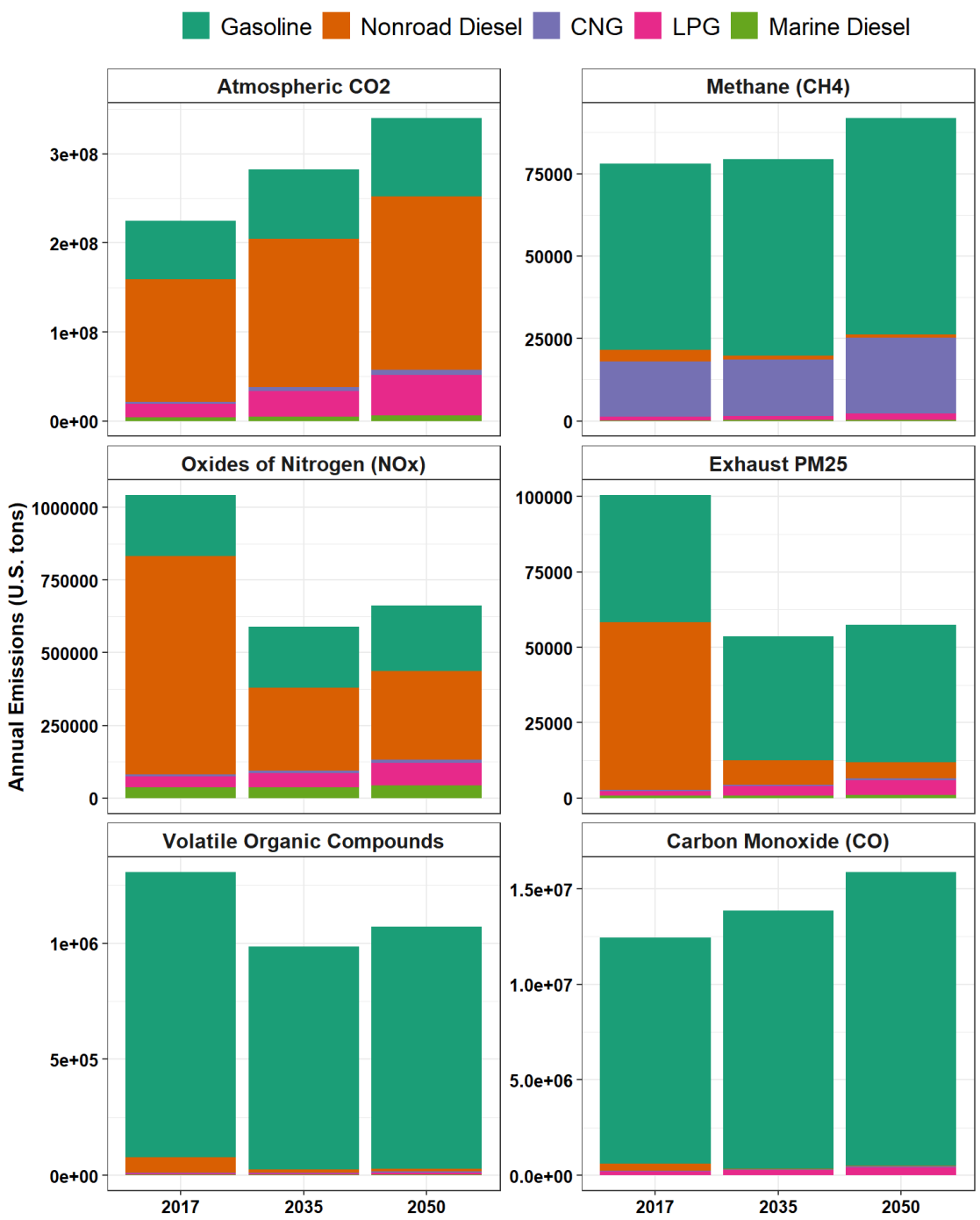
Sample County VOC



Sample county-specific onroad VOC emissions in MOVES3 and MOVES4, by emission process. Percentage values indicate change compared to calendar year 2021

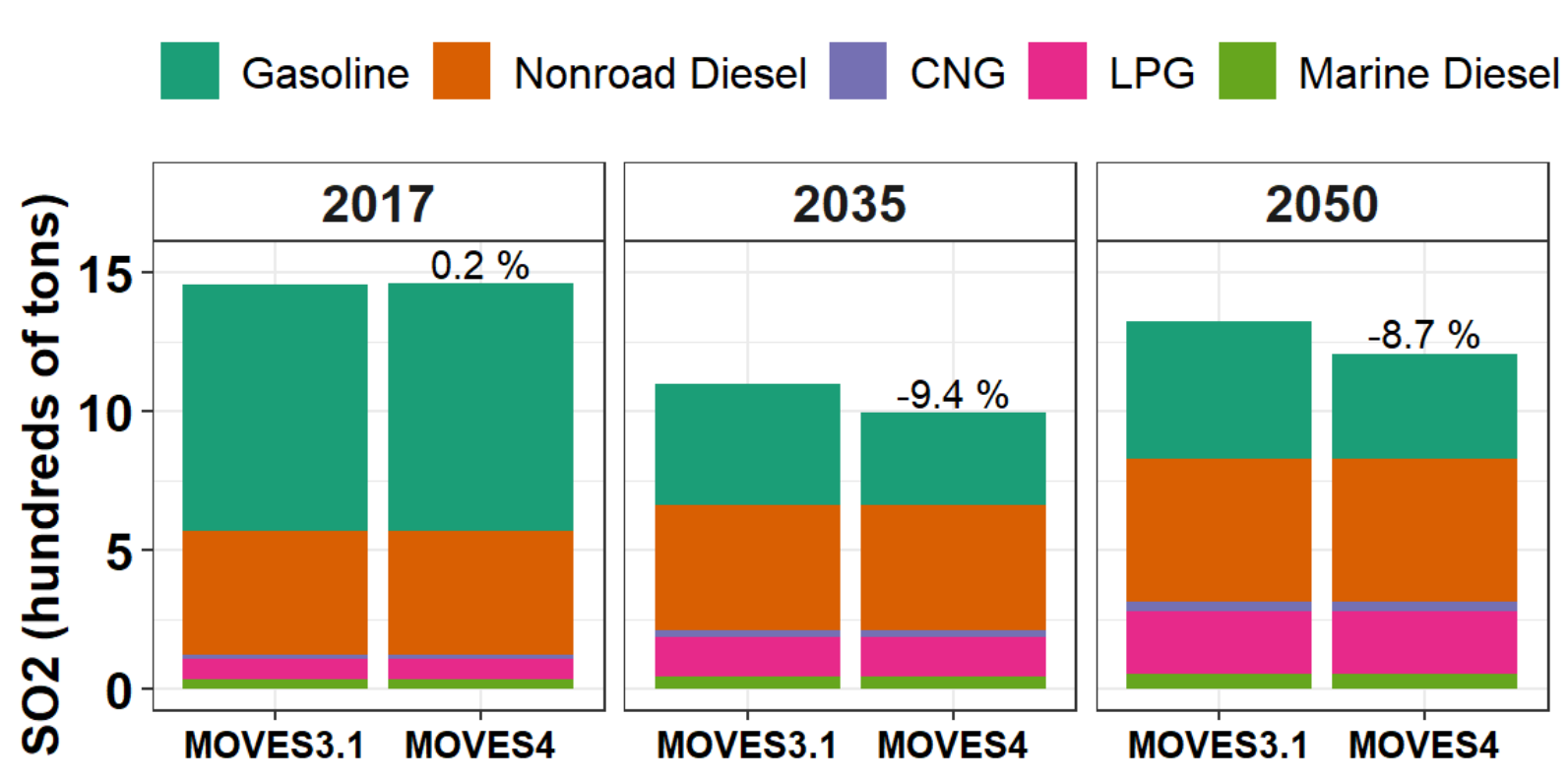
- This graph shows County A VOC by emission process; County B is similar
- Trends in total VOCs echo the national case
- Detail by process highlights the importance of evaporative emissions (greens and purples)
- Note that MOVES4 initially has higher refueling vapor emissions (lavender)
  - For more information see the July 20 webinar and the MOVES4 Evaporative Emissions technical reports

Nonroad Emissions



- Nonroad-specific inputs have not changed in MOVES4 so most emission results are identical in MOVES3 and MOVES4
- Because nonroad activity varies substantially with season and geography, results for specific times and locations will differ from these national results

Nonroad Sulfur Dioxide



- The one notable nonroad difference for MOVES4 is lower SO_2 emissions
- This reflects MOVES4 updates to gasoline sulfur content