EMFAC

# EMFAC2025
# Technical Documentation

June 2026

CALIFORNIA
AIR RESOURCES BOARD

# EMFAC2025 Technical Documentation Version 2.1.1

---

### Authoring Organization

California Air Resources Board
Air Quality Planning & Science Division
Mobile Source Analysis Branch

### Publication Date

June 2026

### Contact

emfac@arb.ca.gov

### Website

https://emfac.arb.ca.gov/

### Recommended Citation

California Air Resources Board. (2026). *EMFAC2025 Technical Documentation Version 2.1.1*. https://emfac.arb.ca.gov/emfac2025-techdoc/.

---

# Dedication

This EMFAC2025 Technical Documentation is dedicated to Jeff Long, whose decades of expertise and steady guidance shaped California's mobile-source emissions inventory. Jeff shared his knowledge generously and supported the EMFAC team for many years with integrity and care. Those who worked with him remember how he could recall the history of EMFAC with near-pinpoint accuracy. That institutional memory was invaluable, but what people carry with them just as much is his patience, his laughter, the way he brought a quiet warmth to the work and made even the most technical discussions feel human. His contributions strengthened the State's efforts to reduce air pollution and protect public health. His attitude, passion, and perseverance remain in the people he mentored and in the rigor reflected in this model.

# Table of Contents

# List of Figures

# List of Tables

## Executive Summary

The EMissions FACtor (EMFAC) model is California's state-of-the-science emission inventory model designed to quantify emissions from on-road motor vehicles, including cars, trucks, and buses in California. EMFAC2025 is the latest iteration of EMFAC, building on the decades of on-road emissions inventory development efforts. The model will continue to support the California Air Resources Board's (CARB) planning and policy development to improve air quality and reduce greenhouse gas emissions in California.

CARB released the first version of EMFAC2025, v2.0.0, on May 14, 2025. However, unlawful Congressional Resolutions adopted after the release of EMFAC2025 purported to disapprove the U.S. Environmental Protection Agency's (U.S. EPA) actions to grant California's Clean Air Act waiver requests for the following regulations: Advanced Clean Cars II (ACC II), Advanced Clean Trucks (ACT), Heavy-Duty Omnibus (Omnibus), Zero-Emission Airport Shuttle, and Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions (Warranty Phase 1). While the congressional actions are being contested, EMFAC2025 Version 2.1.0 was released on March 4, 2026 to reflect the regulatory conditions, removing the emissions benefits of the challenged regulations. In addition, EMFAC2025 v2.1.0 removes the benefits of federal greenhouse gas (GHG) regulations that have been repealed, including the Heavy-Duty GHG Phase 1, Phase 2, and Phase 3 standards, as well as the Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles.

CARB staff have improved and updated the EMFAC Web Platform (https://emfac.arb.ca.gov/) to serve EMFAC2025 and previous versions back to EMFAC2017. The Web Platform, first introduced in 2021 with the release of EMFAC2021, provides all functionalities of the EMFAC PC application in an easy-to-use web interface. Users can access emissions inventories generated using EMFAC's default vehicle activity, generate emissions inventories using custom activity inputs, and produce emission factors using user-defined ambient temperature and relative humidity for project-level conformity assessment. By relying on pre-generated data in a queuing system, the EMFAC Web Platform reduces the burden of processing computationally expensive EMFAC model runs for users.

This Technical Documentation provides a detailed account of major changes and updates in EMFAC2025 and summarizes differences from the previous version, EMFAC2021. For instructions on how to use EMFAC2025, including installation and navigation of the user interface, refer to the EMFAC2025 User's Guide (CARB, 2025). Components, methodologies, data, and logic retained from prior versions are not covered in this document.

## Structure of This Document

The Introduction (Chapter 1) provides an overview of EMFAC2025, including major updates, features, architecture, and the web platform. Chapter 2 details new EMFAC2025 features: light-duty vehicles aged 45 years and older, high-speed driving, and the split of light heavy-duty trucks into public and other categories. Chapters 3 through 8 present comprehensive updates to vehicle populations, activity data, emission rates, fuel properties, and energy consumption in EMFAC2025. Chapter 9 describes new regulations and their implementation in EMFAC2025, along with California's recent regulatory challenges posed by the federal government. Chapter 10 presents EMFAC2025 statewide results for vehicle populations, activity, and total emissions, with comparisons to EMFAC2021.

## New Features

To improve and refine California's on-road mobile source emissions inventory and in response to stakeholder input, EMFAC2025 introduces several new features:

- **Light-Duty Vehicles of Age 45 Years and Older**: EMFAC2025 introduces a new "Age45+" module to account for light-duty vehicles aged 45 years and older. Although these relatively small but old vehicles were not included in previous versions of EMFAC, they account for a sizable amount of emissions in EMFAC2025, as such vehicles are retained longer than expected and newer vehicles are much cleaner. The module uses DMV registration data, vehicle activity information from a survey CARB conducted among Age45+ vehicle owners, and EMFAC's emission factors to integrate these old vehicles into both running-exhaust and start-emission calculations, improving the accuracy of light-duty inventories. See Section 2.1 for details.
- **High-Speed Driving**: EMFAC2025 introduces a light-duty high-speed driving update that extends activity and emission factors up to 90 mph; previously, speeds were capped at 70 mph. Speed distributions of vehicle miles traveled (VMT) are also updated to better account for the high speeds using the national emissions inventory (NEI) dataset. New speed correction factors (SCF) for HC, $NO_x$, CO, and $CO_2$ are derived from dynamometer testing of in-use vehicles and applied to relevant light-duty technology groups. See Section 2.2 for details.
- **Light Heavy-Duty Trucks Split to Public and Other Categories**: Beginning with EMFAC2025, light heavy-duty truck categories LHD1 and LHD2 are split into Public and Other. Public fleets are subject to State and Local Government Fleet requirements under the Advanced Clean Fleets regulation. See Section 2.3 for details.

# Overview of Major Updates

## Fleet Characterization

- **Light-Duty Fleet Characterization**: EMFAC2025 updates light-duty fleet population and new sales using DMV registration data from calendar years 2000 through 2022 (compared to 2000 through 2019 in EMFAC2021).
- **Heavy-Duty Fleet Characterization**: EMFAC2025 reflects updated vehicle population, new vehicle sales, and retention rates for heavy-duty fleets for calendar years 2020–2022. Primary data sources include processed DMV vehicle registration data, International Registration Plan (IRP) Clearinghouse data, and International Fuel Tax Agreement (IFTA) data. Additional sources include Automated License Plate Reader (ALPR) data for age distributions of out-of-state trucks, vehicle lists from major ports (T7 POLA and T7 POAK), California Highway Patrol (CHP) school bus inspection records, and the Truck Regulations Upload, Compliance, and Reporting System (TRUCRS) data for diesel Truck and Bus Rule exemptions.
- **Transit Buses and Natural Gas Vehicles**: EMFAC2025 uses the same methodology as EMFAC2021 for transit bus and natural gas vehicle inventory development, with updated data.
- **Heavy-Duty Vehicle Miles Traveled Reallocation**: EMFAC2025 reallocates heavy-duty VMT across sub-areas using telematics data and Caltrans Annual Average Daily Traffic (AADT) data, replacing older survey-based approaches. This process adjusts population distribution while keeping statewide totals fixed and is iterated until VMT per sub-area matches telematics-based percentages.

## Vehicle Population and VMT Forecasting

- **Accrual Rate Update**: EMFAC2025 updates mileage accrual rates using 2001–2022 Bureau of Automotive Repair (BAR) Smog Check data by vehicle age, class, and region, assuming diesel rates equal to gasoline. Electric vehicle accruals are set at 70% of those for internal combustion vehicles in 2017, increasing linearly to 100% by 2025, as in EMFAC2021; however, the accruals vary by vehicle class and region in EMFAC2025.
- **Retention Rate Update**: EMFAC2025 updates retention rates using 2005–2022 DMV data, excluding inconsistent years. Rates are computed from the proportion of vehicles retained by model year across consecutive calendar years, averaged by age, and fitted with regression curves.
- **Vehicle Start Adjustment**: EMFAC2025 retains baseline light-duty vehicle starts from EMFAC2017 but applies an adjustment scalar to scale vehicle starts based on VMT per vehicle.
- **Light-Duty VMT and New Vehicle Sales Forecasting**: EMFAC2025 uses the same

forecasting scheme that has been used since EMFAC2014, with VMT projected under two regimes: a near-term forecast (2023–2027) using multivariate regression of socioeconomic variables, and a long-term forecast (2028–2050) assuming constant VMT per capita and applying human population growth rate. For new vehicle sales, EMFAC2025 employs a new modeling method of running a short-run multivariable regression (calendar year < 2025) and a long-run equilibrium model (calendar year ≥ 2025), with results showing decreased forecasted sales compared to EMFAC2021 due to slower economic growth, lower forecasted human population, and stagnant VMT trends.

- **Zero-Emissions Vehicle Regional Allocation**: EMFAC2025 incorporates projections from the California Energy Commission's (CEC) 2025 Integrated Energy Policy Report (IEPR) and improves regional forecast accuracy using county-level Zero-Emission Vehicle (ZEV) market share projections from the Automobile and Technology Lifecycle-Based Assignment-Lite (ATLAS-Lite) model. Unlike EMFAC2021's uniform share assumption across the State, ATLAS-Lite enables spatial disaggregation based on household vehicle choice, synthetic populations, and vehicle attributes. Results were validated against DMV data and show regional differences in early ZEV adoption.
- **Heavy-Duty Retention Rates, New Sales, and VMT Forecasting**: EMFAC2025 updates heavy-duty retention rates by incorporating fleet size (≥50 vs. <50 vehicles) using DMV and Dun & Bradstreet (D&B) data, capturing differences in scrappage patterns. New vehicle sales forecasting continues the EMFAC2021 method but now uses a 3-year average (2020–2022) to smooth out irregular purchase patterns. VMT forecasting also follows EMFAC2021 methodology.

## Emission Rates

- **Heavy-Duty Emission Rate Update**: EMFAC2025 updates diesel heavy-duty vehicle emissions using chassis dynamometers and portable emission measurement systems (PEMS) data from the In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles (HDIUT), the Heavy-Duty Truck and Bus Surveillance Program (TBSP), and a 200-vehicle emission test study. Start emissions are re-identified using standardized criteria. Base emission rates and deterioration rates were updated using results from a combination of dynamometer and PEMS data. Speed correction factors are now based on detailed PEMS data by weight class and model year. A micro-trip method aggregates PEMS data into 5-mph bins to better reflect real-world running emissions. To update emission rates of medium heavy-duty vehicles, EMFAC2025 used additional in-use test data and excludes engines with corrective action through CARB's in-use compliance program as of 2022. Natural gas (NG) heavy-duty vehicle emission rates were updated using reanalyzed PEMS data from the 200-vehicle study, applying new binning and micro-trip methods. The start emissions are included in running exhaust for NG heavy-duty vehicles.
- **Light-Duty Emission Rate Update**: EMFAC2025 retains the methodology from EMFAC2021 to determine base emission rates (BER) using emission regimes (low, normal, moderate, and high) and regime fractions. LEV III groups without sufficient data use the Ratio of Standards (ROS) approach. BERs are based on U.S. EPA's In-Use Vehicle Program

(IUVP) and CARB's Vehicle Surveillance Program (VSP) data. Light-duty HC, CO, and $NO_x$ SCFs were updated using new dynamometer data from arterial, freeway, and Unified Cycles. Best-fit equations were derived from data covering Pre-LEV, LEV I, LEV II, and LEV III vehicles.

## Fuel Properties

- **Reid Vapor Pressure Update**: Reid vapor pressure (RVP) values in EMFAC2025 were updated using 2008--2022 CARB service station data to reflect current fuel formulations.
- **Fuel Sulfur Content Update**: EMFAC2025 updates fuel sulfur content using 2008--2022 CARB service station data by RVP control region. Weighted averages yield 6.5 ppm for gasoline and 5.2 ppm for diesel, replacing the 15 ppm standard used in EMFAC2021.
- **Fuel Mix Update**: EMFAC2025 updates fuel mix assumptions for gasoline and diesel using data from the Low Carbon Fuel Standard (LCFS) regulation, including renewable gasoline and renewable diesel to better account for GHG emissions.

## Electric Vehicle Energy Consumption

In EMFAC2021, heavy-duty ZEVs were assumed to be entirely battery electric vehicles (BEV). In EMFAC2025, the ZEV population is split into BEVs and fuel cell electric vehicles (FCEV) to support hydrogen demand assessment.

Other updates include revised BEV and plug-in hybrid electric vehicle (PHEV) energy consumption rates and electric VMT (eVMT) speed distributions using real-world data, resulting in higher energy consumption rates at low speeds and lower rates at high speeds compared to EMFAC2021. EMFAC2025 provides electricity (kWh) and hydrogen (kg) consumption estimates.

## Regulations and Policies

Policies and regulations covered in this version of EMFAC are listed below.

- **Clean Truck Check**: Applying from 2023 to all on-road, non-gasoline heavy-duty vehicles over 14,000 lbs, Clean Truck Check requires owners to demonstrate that their emissions control systems are properly functioning, thereby reducing excess $NO_x$ and PM from poor maintenance or tampering.
- **Advanced Clean Fleets**: EMFAC2025 reflects the Advanced Clean Fleets regulation's state and local government fleet requirements, which phase in ZEVs for public fleets: 50% for model year 2024–2026 and 100% for model year 2027 and newer. EMFAC2025 also includes the requirement that 100% of California-certified truck sales be ZEVs beginning in 2036.
- **Federal Clean Trucks Plan**: In 2022, U.S. EPA adopted the Clean Trucks Plan, setting stricter emission standards for federally certified heavy-duty engines over 10,000 lbs. starting in 2027. The regulation is expected to significantly reduce $NO_x$ and PM emissions.

# 1 Introduction

EMFAC2025 is the latest version of the California Air Resources Board's (CARB) EMission FACtors (EMFAC) model. It provides state-of-the-science estimates of on-road motor vehicle emissions for regulatory and air quality planning in California. EMFAC quantifies emissions from all on-road motor vehicles in California, ranging from motorcycles and passenger cars to motorhomes and heavy-duty trucks. The model supports CARB's efforts to control greenhouse gases, criteria pollutants, and air toxics. EMFAC serves the basis of CARB's motor vehicle regulations and supports key programs such as the Scoping Plan and State Implementation Plans. The model is regularly updated to incorporate the latest data, regulations, and scientific advancements.

EMFAC is developed through rigorous data collection and analysis, including laboratory and on-road emissions testing, detailed vehicle population and activity studies, and integration of emerging "Big Data" sources. The model reflects the most current regulations from both California and the federal government. CARB collaborates with state agencies, Air Districts, Metropolitan Planning Organizations (MPO), community stakeholders, U.S. EPA, and researchers to ensure EMFAC remains accurate and relevant.

EMFAC is updated every three to four years to ensure it provides the most recent planning assumptions for transportation conformity determinations and State Implementation Plan (SIP) development, as required by the Clean Air Act (U.S. EPA and U.S. DOT, 2008). Each EMFAC version is submitted to the U.S. EPA for approval and is authorized for use in California-specific planning. EMFAC2025 builds on the advancements of EMFAC2014, EMFAC2017, and EMFAC2021, introducing updated methodologies, new data sources, and the latest regulatory requirements to improve emissions inventories for on-road vehicles statewide.

## 1.1 Major Updates and Features

EMFAC2025 introduces several important updates and enhancements:

- Improved accounting for emissions from vehicles aged 45 years and older, which, though a small population, contribute a significant share of emissions.
- Enhanced estimates of vehicle miles traveled (VMT) and emissions at higher speeds, reflecting real-world driving behavior.
- Updated emission rates and speed correction factors for both light-duty and heavy-duty vehicles by incorporating the latest in-use emissions testing data from chassis dynamometer and Portable Emissions Measurement System (PEMS) tests.
- More granular modeling of Zero-Emission Vehicle (ZEV) adoption at the county level, with projections through 2035.
- More sophisticated forecasting light-duty vehicle sales and vehicle activity, integrating

recent socioeconomic, demographic, and regulatory data.

- Use of Big Data sources, or large quantities of vehicle activity data from telematics providers, to better characterize heavy-duty truck operations and activity patterns.
- Electric fuel types are now separated into Battery Electric and Fuel Cell Electric fuel types, with improved reporting of electricity consumptions for battery vehicles and hydrogen consumptions for fuel cell vehicles.
- Refined methodologies for estimating VMT, vehicle population, and age distributions using the latest DMV registration and other relevant datasets.
- Integration of new federal and state rulemakings, such as Clean Truck Check (CTC), Advanced Clean Fleets (ACF), and the Federal Clean Trucks Plan.

## 1.2 Modeling Architecture

EMFAC2025 is provided as a PC application developed using a modular, Python and MySQL-based computational framework. Over the years, this framework has been substantially refined to improve model stability and leverage high performance computing resources, enabling efficient data processing, transparency, and flexibility for future updates. These enhancements allow users to generate on-road emissions inventories more efficiently, accommodating the increasing complexity of California's vehicle fleet and regulatory environment.

## 1.3 EMFAC Features

EMFAC2025 supports three main modes of operation to accommodate various user needs. Figure 1.1 provides an overview of these modes:

- **Default Activity Mode:** Generates emissions inventories using CARB's default activity data and methodologies.
- **Custom Activity Mode:** Allows users to input project-specific activity data, including VMT from planning agencies, for conformity and SIP work.
- **Project-Level Assessment (PL) Mode:** Supports detailed, project-specific emission rate analyses using user-defined meteorological and activity inputs.

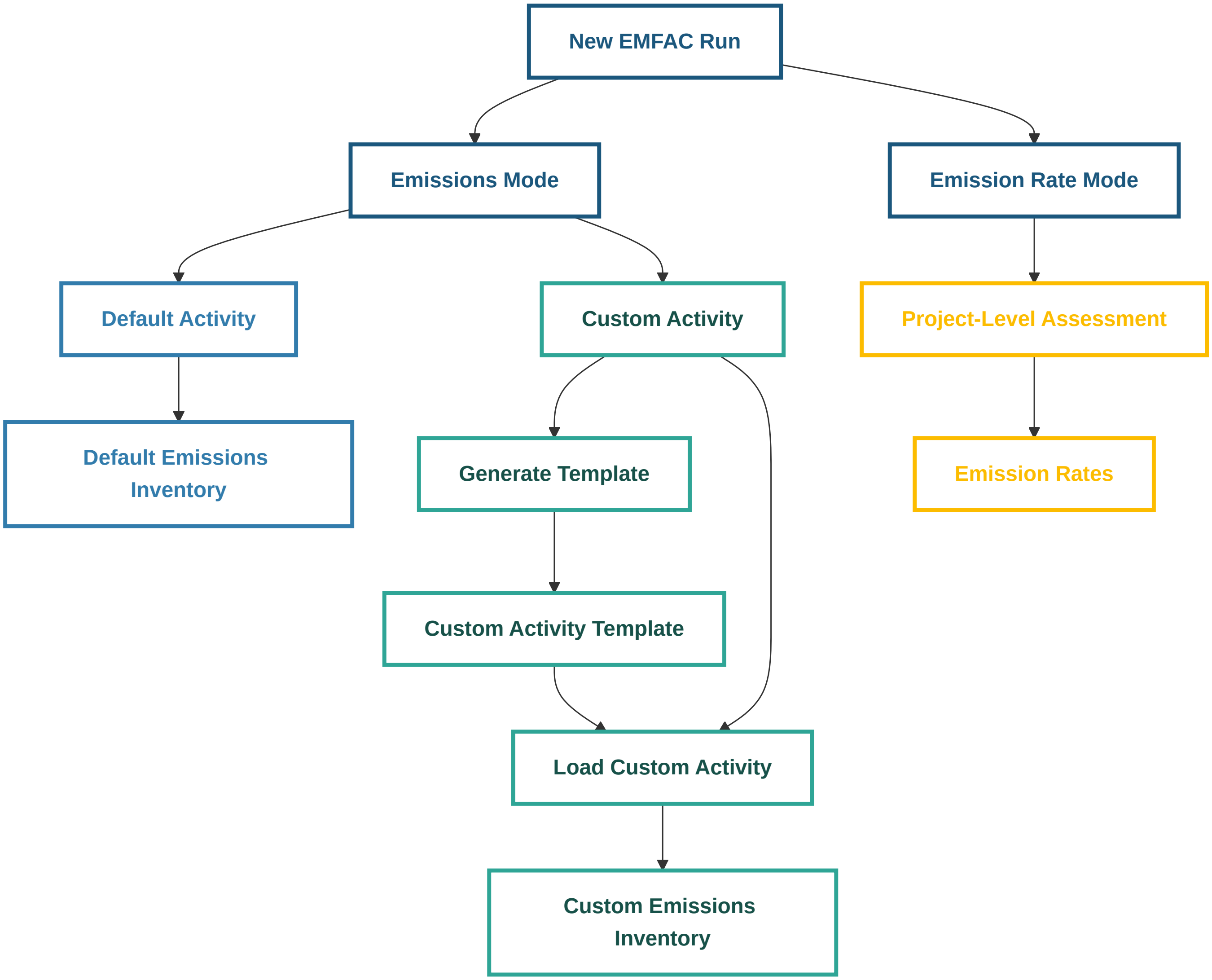


Figure 1.1: Workflow for EMFAC's Three Main Modes: Default Activity, Custom Activity, and Project-Level Assessment

## 1.4 EMFAC Web Platform

With EMFAC2021, the EMFAC Web Platform (https://emfac.arb.ca.gov/) was introduced to provide EMFAC emissions inventories generated using the Default Activity Mode, along with the functionality of the Custom Activity Mode and Project-Level Assessment Mode, through an easy-to-use web interface. With EMFAC2025, the EMFAC Web Platform has been further refined to help users process large numbers of EMFAC runs more efficiently.

Because the EMFAC Web Platform provides the core features of the PC application, most users can generate EMFAC outputs more efficiently using the web platform without running the computationally expensive model locally. Users are encouraged to use the EMFAC Web Platform for EMFAC2025 as well as previous versions.

# 2 New Features

EMFAC2025 introduces several new features to enhance the accuracy of on-road mobile source emissions inventories in California. Section 2.1 describes the new module for estimating emissions from light-duty vehicles aged 45 years and older, which contribute disproportionately to total emissions despite representing a small fraction of the total fleet. Section 2.2 focuses on the update on high-speed driving of light-duty vehicles, which incorporates new activity and speed correction factors to better model emissions in speed bins from 70 to 90 mph. Section 2.3 details the split of light heavy-duty trucks (LHD1 and LHD2) into public and other categories to better reflect the Advanced Clean Fleets regulation requirements for public fleets.

## 2.1 Light-Duty Vehicles of Age 45 Years and Older

### 2.1.1 Background

EMFAC2025 introduces a module to estimate emissions and activity for light-duty vehicles (LDA, LDT1, LDT2, and MDV) that are 45 years old or older (Age45+). Earlier EMFAC versions (EMFAC2021 and prior) did not include these vehicles due to their small share of the total vehicle population and the lack of reliable activity data. In calendar year 2022, approximately 540,000 light-duty Age45+ vehicles were registered, representing 2.1% of all light-duty vehicles registered at DMV. Most of these vehicles are classic cars retained for collectible or sentimental reasons, as well as older vehicles used for various purposes. As newer vehicles become cleaner, the relative contribution of these older vehicles to total emissions increases, since they generally have higher emission rates. By explicitly modeling Age45+ vehicles, EMFAC2025 further improves the accuracy of light-duty emissions inventories and provides more robust support for regulatory and air quality planning. Note that U.S. EPA's MOVES5 model extended its previous 30-year age limit to 40 years (U.S. EPA, 2024), allowing for more accurate modeling of emissions from older vehicles.

### 2.1.2 Method

EMFAC2025 estimates emissions from Age45+ vehicles by integrating DMV registration data, survey-based activity estimates, and existing emission rates in EMFAC. CARB staff used historical DMV records to estimate population and retention rates and conducted an Age45+ vehicle owner survey to determine typical usage patterns, such as annual mileage accrual and vehicle starts. Age-specific emission rates are then applied to the resulting population and activity data. This approach ensures that emissions from these rarely used but high-emitting vehicles are accurately represented in the inventory. EMFAC2025 aggregates these age-specific Age45+ vehicle population, activity, and emission rates internally and generates outputs as a single model year of age 45 for each calendar year.

#### 2.1.2.1 Age45+ Vehicle Owner Survey

A key challenge of modeling Age45+ vehicles is the limited availability of reliable data on their activity, such as annual mileage accrual and survival rates. Existing data sources do not fully cover this age group. For example, California's Smog Check Program, a main source of vehicle accrual rates, only includes vehicles from model year 1976 onward. CARB also obtained mileage data for Age45+ vehicles from the Southern California American Automobile Association (AAA), but this information was limited to insurance subscribers in Southern California. Age45+ vehicles include classic cars, which are often used less frequently, stored for extended periods, and maintained differently than vehicles used for daily transportation. Other Age45+ vehicles may be used and maintained as much as newer vehicles. These factors make it challenging to estimate their activity and emission characteristics.

To address this data gap, CARB conducted a survey. CARB sent 25,000 mailouts to Age45+ vehicle owners, representing 5% of model year 1978 and older vehicles. The sample was selected randomly and stratified by county and age group using DMV vehicle registration data of year 2022. Respondents completed an online survey with seven short questions and two open-ended comment sections about vehicle use, annual mileage, storage, and start frequency.

The survey was conducted with mailings sent at the end of July 2023. Data collection occurred from August to September 2023. There were 2,960 responses, with 2,889 passing quality checks, resulting in a response rate of approximately 12%. Most respondents reported infrequent use of their vehicles, often for special occasions or leisure, and many indicated that their vehicles are stored for long periods. The results of the survey responses relevant to the implementation of Age45+ vehicles in EMFAC are summarized below.

Table 2.1 shows that the survey responses closely match the DMV2022 data for model year distributions, with only minor differences, such as a slight overrepresentation of older vehicles in the survey. Similarly, Table 2.2 demonstrates that the county distribution in the survey responses is consistent with DMV2022 data. Together, these tables indicate that the survey participants are representative of the overall Age45+ vehicle population in California, providing confidence in the reliability of the survey data for estimating Age45+ vehicle activity and emissions.

Table 2.1: Age45+ Vehicle Age Distribution

| Model Year | DMV Database | Survey Responses |
|---|---|---|
| 1910s or older | 0.1% | 0.1% |
| 1920s | 1.3% | 1.8% |
| 1930s | 4.2% | 5.6% |
| 1940s | 3.8% | 4.5% |
| 1950s | 13.8% | 15.3% |
| 1960s | 42.0% | 41.4% |
| 1970s | 34.8% | 31.4% |

Table 2.2: Age45+ Vehicle County Distribution

| County | DMV2022 | Survey Responses |
|---|---|---|
| Los Angeles | 21% | 17% |
| San Diego | 8% | 8% |
| Orange | 7% | 7% |
| Riverside | 5% | 5% |
| Sacramento | 5% | 5% |
| Santa Clara | 4% | 4% |
| San Bernardino | 5% | 4% |
| Alameda | 3% | 3% |
| Other counties | 42% | 47% |

Table 2.3 summarizes the annual mileage accrual rates from the survey. CARB staff reviewed the data and excluded responses with obvious errors or invalid values, resulting in 2,767 valid responses. The median annual mileage is 300 miles, while the mean is 786 miles. The first quartile is 100 miles, and the third quartile is 1,000 miles. The distribution is skewed, indicating that while most Age45+ vehicles are driven very little, a small subset are reported to be driven significantly more, with some reaching up to 26,000 miles per year.

Table 2.3: Age45+ Vehicle Annual Mileage Accrual Rates

| Statistic | Value |
|---|---|
| Counts | 2,767 |
| Minimum | 0 |
| 1st Quartile | 100 |
| Median | 300 |
| Mean | 786 |
| 3rd Quartile | 1,000 |
| Maximum | 26,000 |

Figure 2.1 shows the distribution of driving frequencies for Age45+ vehicles, based on survey responses. The frequency values also indicate that they are driven infrequently, with most vehicles being started less than once per day and, most commonly, once a month. CARB staff used this information to estimate the number of vehicle starts per day for Age45+ vehicles, which is used in the calculations of start emissions.

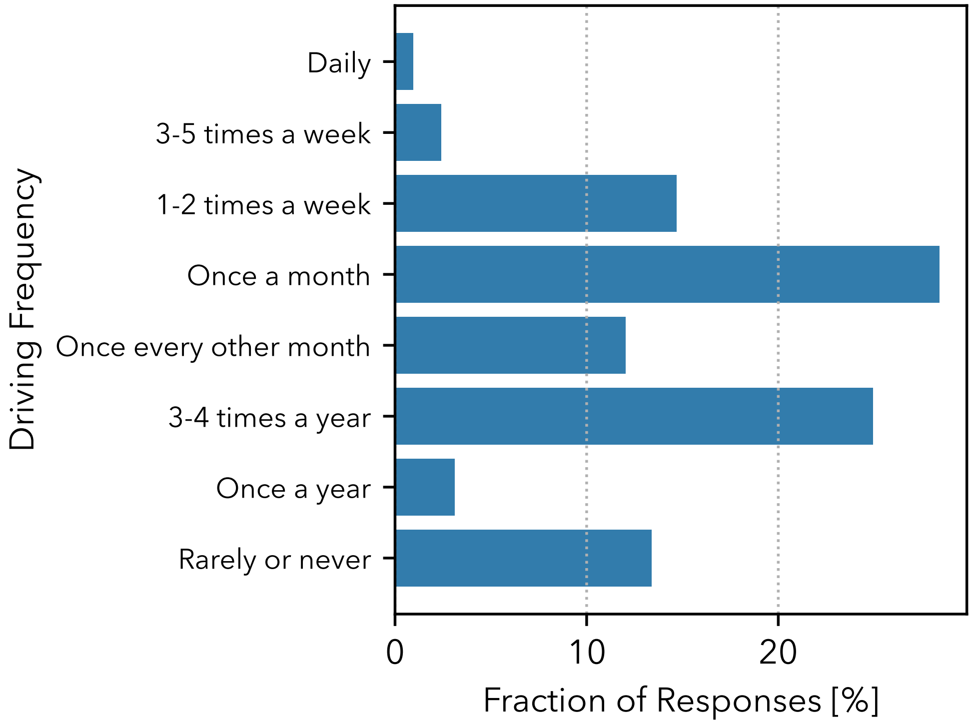


Figure 2.1: Driving Frequency for Age45+ Vehicles

#### 2.1.2.2 Vehicle Population

The Age45+ vehicle population is estimated using DMV records for past years and regression-based estimates for future years. Historical population data for Age45+ vehicles were obtained from DMV records for 2001 to 2022. The Age45+ population includes all internal combustion vehicles (gasoline, diesel, and natural gas) from the DMV records. However, since more than 99% of these vehicles are gasoline, all Age45+ vehicles are assumed to be gasoline vehicles.

Based on the historical population, year-to-year retention rates were calculated for 2001 to 2022. Retention rate is defined as the proportion of vehicles from a given model year that remain registered and active in subsequent years. These retention rates were then used to estimate retention for the year 2000 and for future years starting in 2023. Figure 2.2 shows the retention rates of Age45+ vehicles from 2001 to 2022, along with the regression line for future years. Using the historical DMV data and retention rates derived from the regression fit for the future year, the Age45+ vehicle population for each year from 2000 to 2050 is estimated as shown in Figure 2.3. Note that retention rates remain above one until approximately 2030, indicating that the Age45+ vehicle population is growing. Although the projected trajectory eventually drops below one, this will be revisited in future releases of the model, as retention rates may not decrease as linearly as currently predicted.

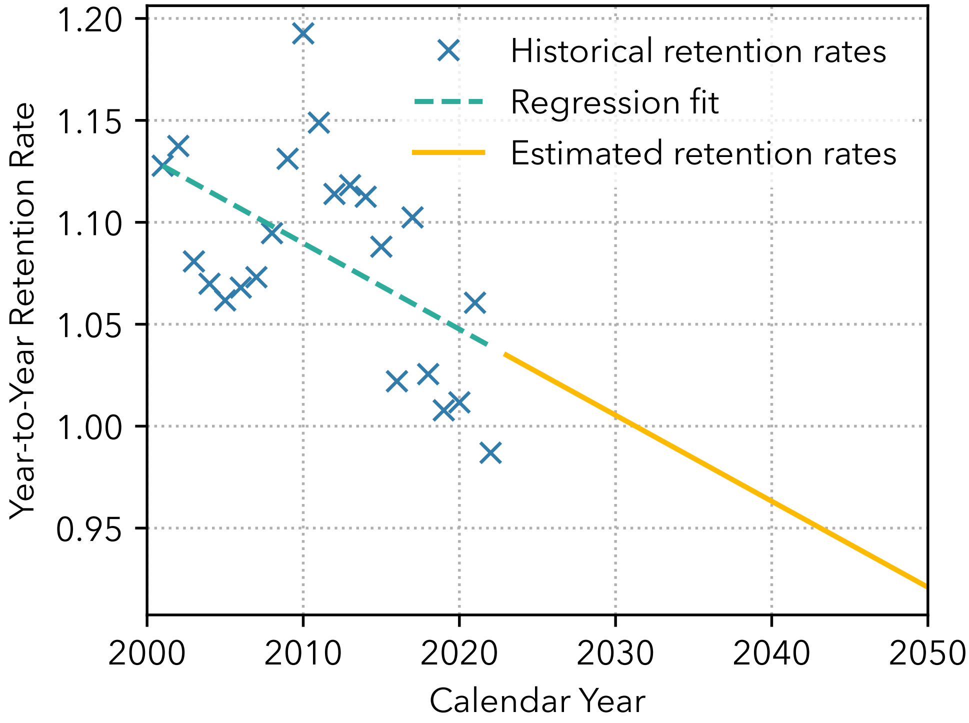


Figure 2.2: Retention Rates for Age45+ Vehicles. Data from 2001 to 2022 are based on DMV records. The orange line shows the regression fit, which is used to estimate retention rates for 2023 and later years.

The estimated population of Age45+ vehicles is further divided by Geographic Area Index

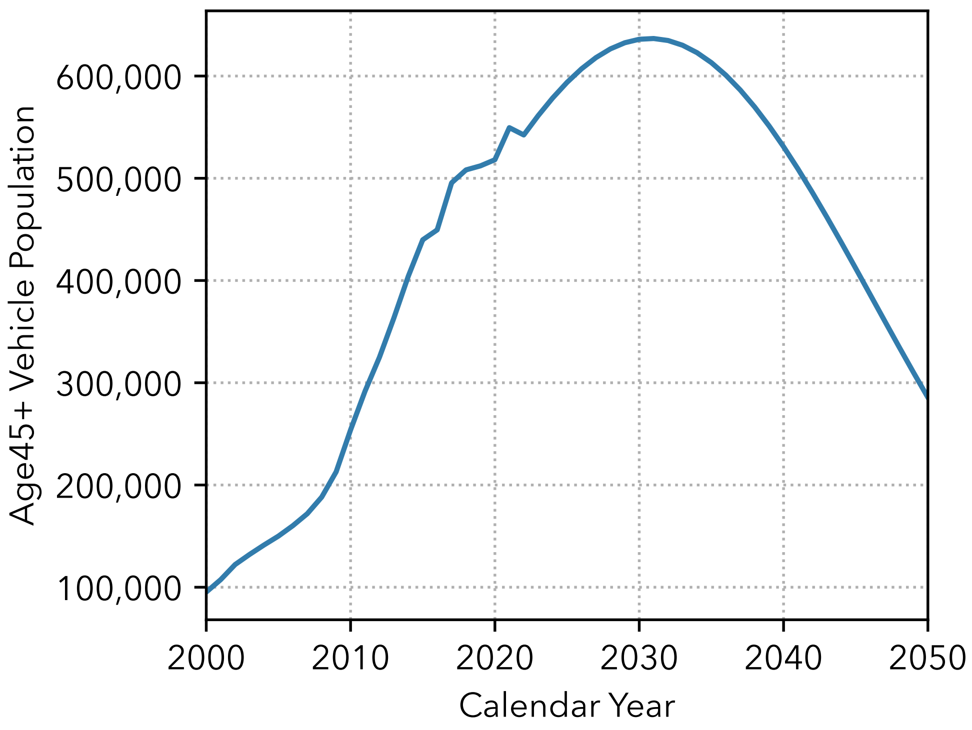


Figure 2.3: Age45+ Vehicle Population. Data from 2001 to 2022 are from DMV records; values for 2023 to 2050 are projections based on regression-derived retention rates.

(GAI) and the four light-duty vehicle classes, using historical distributions from DMV data. The age distribution of Age45+ vehicles from DMV2022 is used to determine the age breakdown of the vehicle population, which is then used to calculate age-specific emission rates.

#### 2.1.2.3 Vehicle Activity

Estimating vehicle miles traveled (VMT) for Age45+ vehicles is essential for calculating running exhaust emissions. Figure 2.4 summarizes the annual mileage accrual rates of light-duty vehicles. The blue line indicates the average annual mileage accrual rates of passenger cars, and the dotted line shows a regression fit, both of which are used for LDA mileage accrual estimation in EMFAC2025. The yellow line represents data obtained from AAA Southern California, showing the annual mileage accrual rates for Age45+ vehicles among their insurance subscribers. The navy line indicates the annual mileage accrual rates for Age45+ vehicles based on the survey results. Based on these data, CARB staff determined to use the average annual mileage from the survey, which is 786 miles, as the annual mileage accrual rate for all Age45+ vehicles in EMFAC2025. This value is multiplied by the Age45 vehicle population to calculate total vehicle miles traveled (VMT).

Based on the survey responses of driving frequency (see Figure 2.1), the average vehicle start frequency for Age45+ vehicles is estimated to be 0.14 starts per day. This value is used to calculate emissions from vehicle starts.

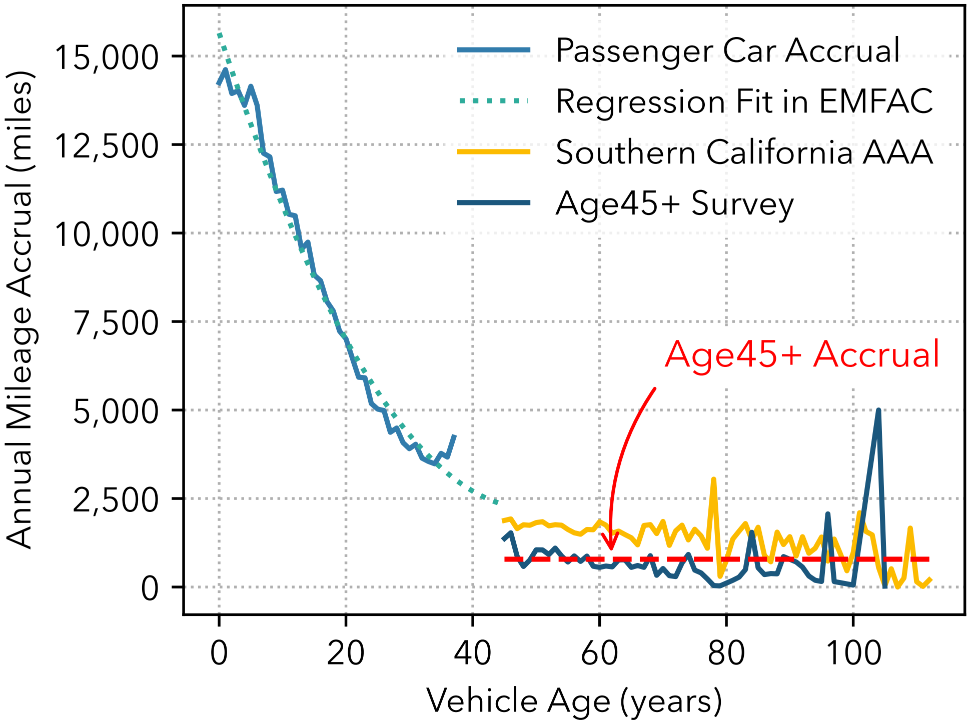


Figure 2.4: Accrual Rate Analysis for Age45+ Vehicles

#### 2.1.2.4 Emission Rates

Emission rates for Age45+ vehicles are based on EMFAC baseline emission rates for each model year. These rates account for the effects of vehicle aging, deterioration, and vehicle technology groups. EMFAC applies these age-specific emission factors to the estimated population and activity data for Age45+ vehicles so that their emissions are accurately represented in inventory outputs.

## 2.2 High-Speed Driving

### 2.2.1 Background

The light-duty high-speed update to incorporate activity and emission factors is newly introduced in EMFAC2025. Previous EMFAC versions assumed no driving activity above 70 mph. The emission rate used at 70 mph was applied to any higher speed bin if the user input activity at speeds over 70 mph. The update discussed here addresses the speed bins from the 70 to 90 mph range.

There were two separate parts to the high-speed driving update. The first was an update to light-duty activity, specifically the light-duty speed distributions. The activity update is only relevant for the Default Activity mode of EMFAC2025. SIP and conformity analyses use Custom Activity modes (see Figure 1.1) to run EMFAC with MPO, rather than default, activity data. The second part of the update was to determine and implement high-speed SCFs to account for emissions at the higher speed bins. The latter update is relevant for both default mode runs as well as SIP and conformity analysis.

### 2.2.2 Light-Duty Vehicle Activity By Speed

#### 2.2.2.1 Data Sources and Analysis

The national emissions inventory (NEI) dataset for California, obtained from U.S. EPA, was used to update the light-duty VMT speed distribution. This is a dataset based on StreetLight data collected during calendar year 2020. There were three primary processing steps that had to be performed on the NEI dataset to make it compatible with EMFAC2025. The first was to convert the time speed distributions to VMT speed distributions. The second was shifting the speed bin bounds of the NEI dataset to align with those used in EMFAC. And the third was to combine certain aspects of the NEI data that are at a more granular level than is needed for EMFAC.

In the first processing step, the NEI dataset speed distributions were converted from time fractions to VMT fractions. To convert to VMT, every speed bin's time fraction in a distribution was multiplied by its speed bin midpoint. The resulting distribution initially has values that sum to much greater than 1, so a renormalization is required to obtain the final VMT distributions.

EMFAC uses upper-bound speed bins that all have a width of 5 mph, while NEI used midpoint-labeled speed bins with a width of 5 mph (with one exception, the first speed bin that has a width of 2.5 mph). This means the second EMFAC speed bin, labeled as the "10 mph" speed bin, includes VMT driven between 5 and 10 mph. However, the second NEI speed bin includes VMT driven from 2.5 to 7.5 mph. Because of this 2.5 mph offset, the NEI speed bins cannot be directly compared to those of EMFAC. To correct this, every NEI 5 mph bin was split into half such that all bins had a 2.5 mph width. Pairs of 2.5 mph bins were then summed back together such that the resulting bounds of each speed bin aligned with the speed bin bounds of EMFAC. For example, the second NEI speed bin mentioned above was split into two bins that included 2.5–5 and 5–7.5 mph, the VMT fraction from the 5–7.5 bin was then recombined with the VMT fraction from the 7.5–10 mph bin, resulting in the NEI's VMT fraction for the 5–10 mph range, which then fully aligns with a corresponding EMFAC speed bin.

The third processing step with NEI data involved aggregating some of its data. The original dataset included VMT distributions (not absolute VMT) for each county, hour of day, month of year, source type, road type, and weekend/weekday. Because the EMFAC model is intended to represent a general weekday, only data for weekday distributions and the source type of passenger cars were used. However, multiple distributions for different road types had to be averaged together since EMFAC does not handle VMT on different road types. CARB staff used the default outputs of U.S. EPA's MOtor Vehicle Emission Simulator (MOVES) to determine county-specific road-type VMT distributions within California and aggregated the road types together.

Finally, because the dataset was from calendar year 2020, which was highly anomalous due to the COVID-19 pandemic, only months from January and February were averaged together, and data from March to December were excluded. Though January–February data do not fully represent annual conditions, they are the most reliable months available from 2020. We will update the model as more complete and more recent datasets become available.

The maximum speed bin in the NEI dataset was 75 mph, but that speed bin included the fraction of all miles driven at speeds above that speed bin as well. The UC Davis Dataset (CARB contract 12-319) was used to bin the 75 mph speed bin out into separate higher speed bins. Based on the 200+ internal combustion engine (ICE) vehicles logged in the UC Davis study, the magnitude of the three additional higher-speed bins, at 80, 85, and 90 mph, was determined (relative to the 75 mph speed bin), and applied to all speed distributions in the NEI dataset.

#### 2.2.2.2 Light-Duty Vehicle Activity Results

Figure 2.5 compares the final statewide light-duty combustion VMT (cVMT) distributions used in EMFAC2025 and EMFAC2021. EMFAC2025 has a larger fraction of speeds driven both at lower (<25 mph) and at higher (>70 mph) speeds, relative to EMFAC2021. Because fuel consumption and emissions tend to be worse at either lower or higher speeds, this update impacts emissions of several pollutants. However, the impacts are not straightforward due to the fuel matching applied in EMFAC. Because this update shifts cVMT to speeds where fuel efficiency is lower, and the overall cVMT in the model is constrained by total fuel sales in California, the end result is that this activity update decreases the total cVMT estimated by EMFAC2025.

### 2.2.3 Speed Correction Factors (SCF)

A test plan was developed to test vehicles at high speeds, as CARB's light-duty surveillance program does not conduct testing at high speeds. The highest speed cycle used in the light-duty surveillance program is Freeway Cycle (FC) 7, averaging 73 mph. From a few recent studies, it is revealed that FC7 does not represent the real-world maximum speed in California. Moreover, recent data collected from light-duty passenger vehicles in a study conducted by UC Davis highlights that 19.6% of vehicle miles traveled (VMT) is driven at speeds 70 mph or faster (Tal *et al.*, 2020). This data was collected from GPS and telematics from the vehicles.

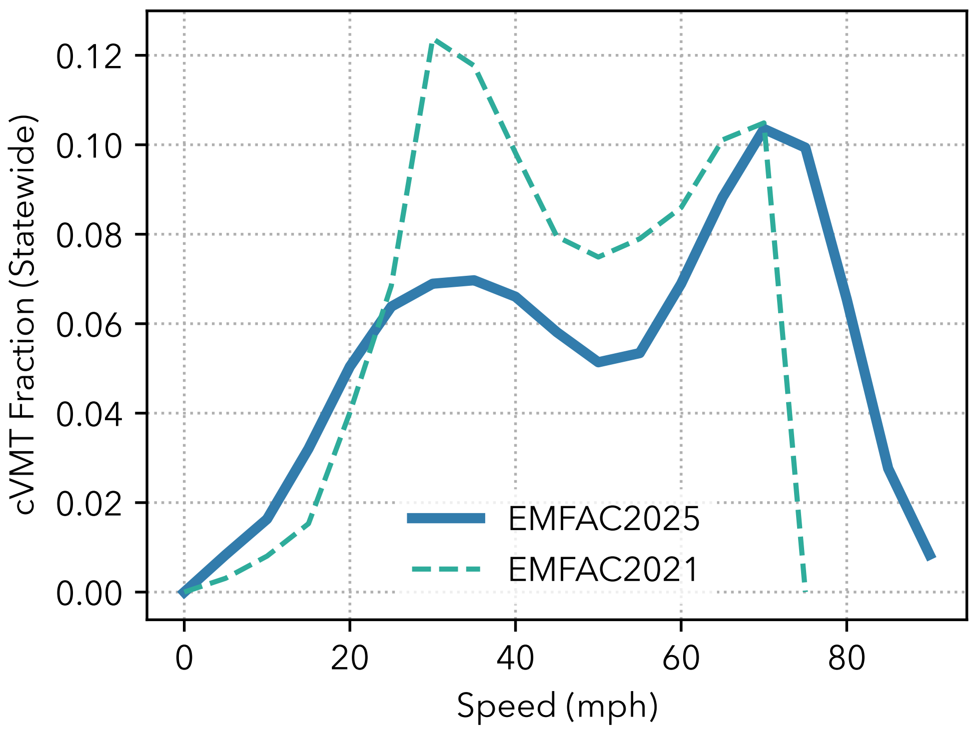


Figure 2.5: Statewide Speed Distribution of Combustion Vehicle Miles Traveled (cVMT)

The high-speed test plan was developed using a few test cycles which include the Unified Cycle (UC), the Federal Test Procedure (FTP), and FC5 to FC7. Furthermore, new cycles, FC8, 9, and 10 were developed based off of FC7. Table 2.4 illustrates the various cycles involved in the high-speed test plan.

Table 2.4: High-Speed Test Plan Cycles

| Test Cycles | Mean Speed (mph) |
|---|---|
| Federal Test Procedure | 21.2 |
| Unified Cycle | 22.9 |
| Freeway Cycle 5 | 56.5 |
| Freeway Cycle 6 | 65.2 |
| Freeway Cycle 7 | 72.9 |
| Freeway Cycle 8 | 83 |
| Freeway Cycle 9 | 93 |
| Freeway Cycle 10 | 103 |

#### 2.2.3.1 Data Collection

Test vehicles included passenger cars, SUVs, and trucks with model years ranging from 2015–2023 with Gross Vehicle Weight Ratings (GVWR) up to 10,000 lbs. Table 2.5 lists the vehicles, technology groups, and the mileages of the vehicles tested.

Table 2.5: High-Speed Test Plan: Vehicles Tested

| No. | Vehicle | Technology Group | Mileage (miles) |
|---|---|---|---|
| 1 | 2022 Nissan Altima | SULEV30 | 36,994 |
| 2 | 2023 Chevy Camaro | ULEV50 | 28,652 |
| 3 | 2022 Honda Civic | SULEV30 | 49,428 |
| 4 | 2023 Nissan Maxima | ULEV125 | 11,921 |
| 5 | 2023 Toyota 4Runner | ULEV70 | 11,679 |
| 6 | 2015 Toyota Corolla | ULEV125 | 115,948 |
| 7 | 2016 Ford F150 | ULEV125 | 51,688 |
| 8 | 2015 Honda Accord | SULEV30 | 105,337 |
| 9 | 2015 Toyota Camry | LEVII ULEV | 93,357 |
| 10 | 2015 Honda Civic | LEVII SULEV | 76,271 |

The emissions gathered in these tests included HC, $NO_x$, CO, and $CO_2$. First, each pollutant is normalized by the UC Bag 2 data for each vehicle. The normalized data is then averaged for each cycle for all vehicles. Following that, the normalized mean is then graphed for a regression analysis to reveal a trendline formula, the formula used to calculate the SCF for each speed bin.

After determining the formula, the speed bins are used as inputs with the range for high-speed testing being from 70 to 90 mph. The resulting data represents the SCFs which go up to 103 mph in the testing conducted. However, currently EMFAC VMT fractions only go up to 90 mph.

#### 2.2.3.2 Speed Correction Factor Results

##### 2.2.3.2.1 HC High-Speed Speed Correction Factors

In Figure 2.6, the analysis of the 10 tested vehicles shows the HC emissions for the mean speed of each test cycle.

This chart shows normalized and mean emissions of HC from EMFAC2021 (green line) and the updates that went into EMFAC2025 (blue line). CARB staff can see the change in emissions reflected by the vehicles tested from the high-speed test plan. The best fit equation was calculated through the data and was determined to be the exponential equation as indicated

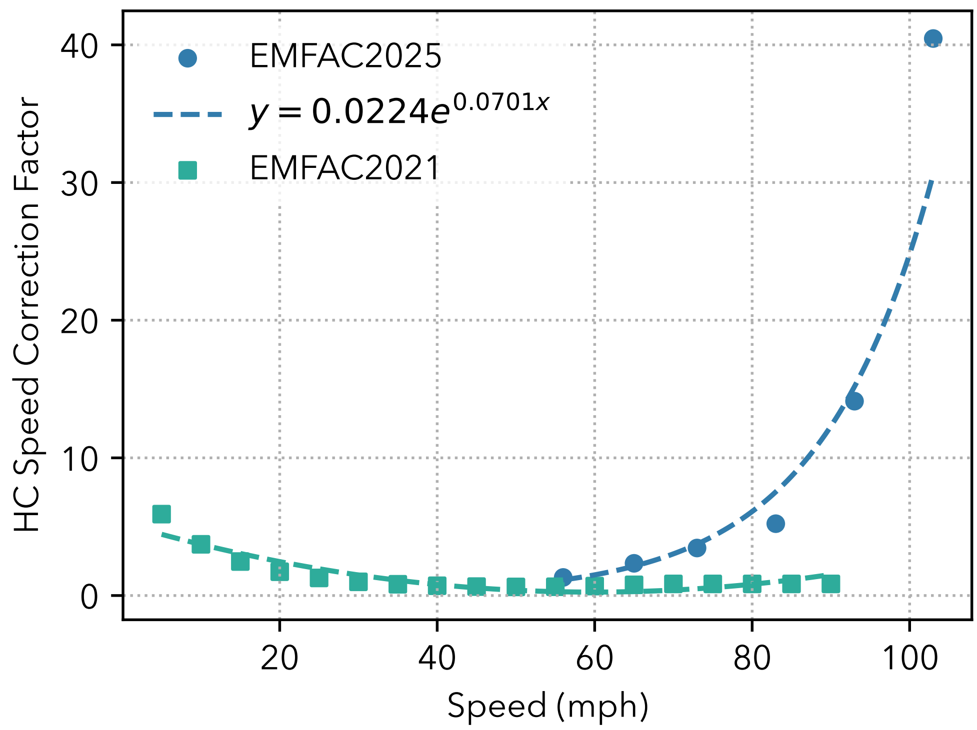


Figure 2.6: High-Speed Emission Rate Regression Fit Derived for HC

as Equation (2.1).

$$y = 0.0224e^{0.0701x} \tag{2.1}$$

Using Equation (2.1) above, the SCFs were calculated and are shown in Table 2.6 by speed bins for speed bins of 70 to 90 mph. It is important to note that the values for each speed bin for all pollutants are calculated with the midpoint speed of the bin, that is 67.5 mph for the 70 mph speed bin, and so on for the rest of the bins.

Table 2.6: High-Speed HC Speed Correction Factors

| Speed Bin | Mid-Point Speed (mph) | HC SCF |
|---|---|---|
| 70 | 67.5 | 2.54 |
| 75 | 72.5 | 3.61 |
| 80 | 77.5 | 5.12 |
| 85 | 82.5 | 7.27 |
| 90 | 87.5 | 10.3 |

As mentioned above, the emissions are normalized to the mean emissions of UC Bag 2 and their results are shown as speed correction factors in Table 2.6 and plotted in Figure 2.7 by speed bin. Table 2.6 and subsequent SCF tables apply as scalars to the base emission rate. For example, the 70 mph value (2.54) is multiplied by the emission rate at 27 mph. The range of the speed bins in the figure is extended to 100 mph although the EMFAC2025 SCFs are applied only up to 90 mph. The same analysis method conducted for HC is carried forward for the remaining pollutants of $NO_x$, CO, and $CO_2$.

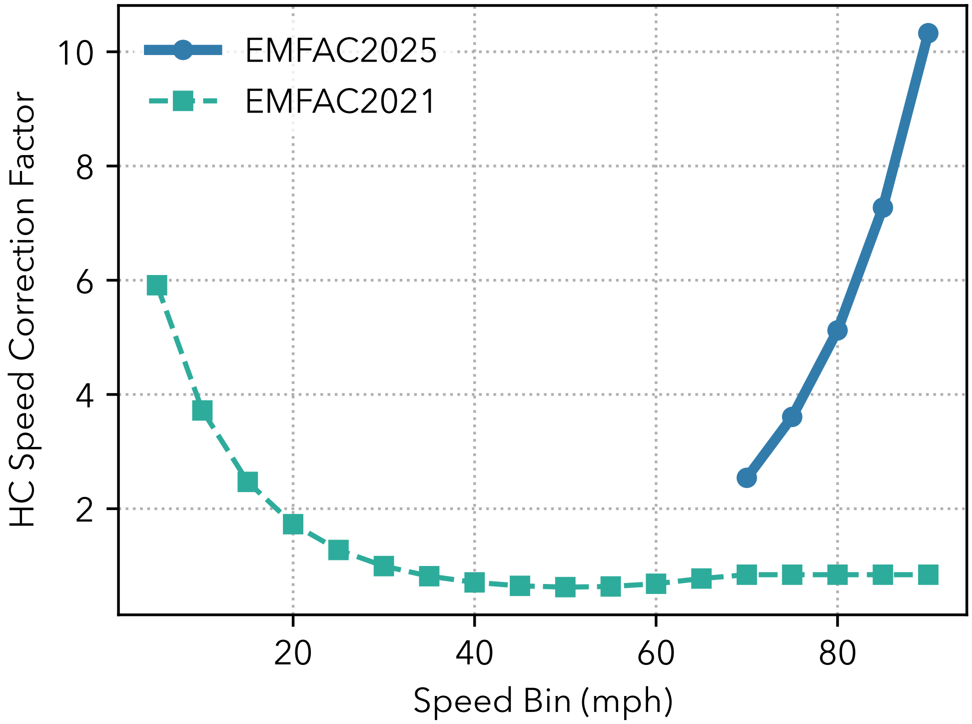


Figure 2.7: HC Speed Correction Factors

#### 2.2.3.2.2 $NO_x$ High-Speed Speed Correction Factors

In Figure 2.8, the analysis of the 10 tested vehicles shows the normalized mean $NO_x$ emissions for the average speed corresponding to each FC.

Similar to HC, this chart shows normalized mean emissions of $NO_x$ from EMFAC2021 (green) and the updates that went into EMFAC2025 (blue). The best fit equation derived from the regression analysis reveals a second order polynomial as indicated in Equation (2.2).

$$y = 0.0031x^2 - 0.2942x + 7.6195 \tag{2.2}$$

Using the equation above, the SCFs were calculated and are shown in Table 2.7 by speed bins for speed bins from 70 to 90 mph.

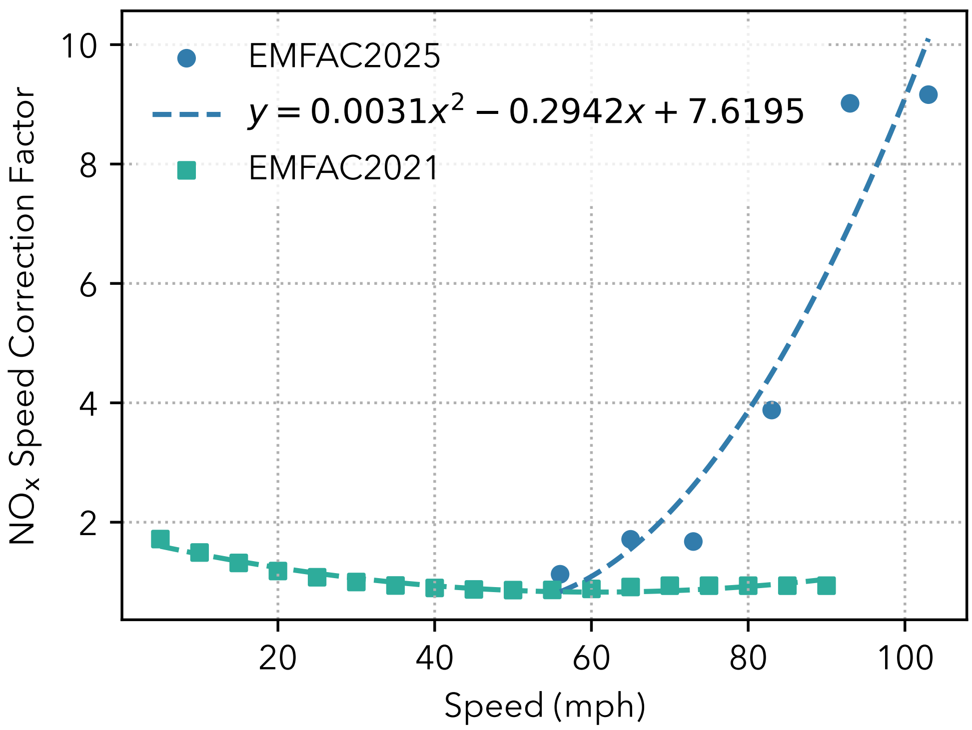


Figure 2.8: High-Speed Emission Rate Regression Fit Derived for $NO_x$

Table 2.7: High-Speed $NO_x$ Speed Correction Factors

| Speed Bin | Mid-Point Speed (mph) | $NO_x$ SCFs |
|---|---|---|
| 70 | 67.5 | 1.84 |
| 75 | 72.5 | 2.53 |
| 80 | 77.5 | 3.38 |
| 85 | 82.5 | 4.38 |
| 90 | 87.5 | 5.54 |

In Figure 2.9, the $NO_x$ SCFs are shown. Similar to the HC SCFs, the graphs are normalized to 27 mph, the average speed of UC Bag 2. For EMFAC2025 the graph illustrates that emission rates increase with increasing speed.

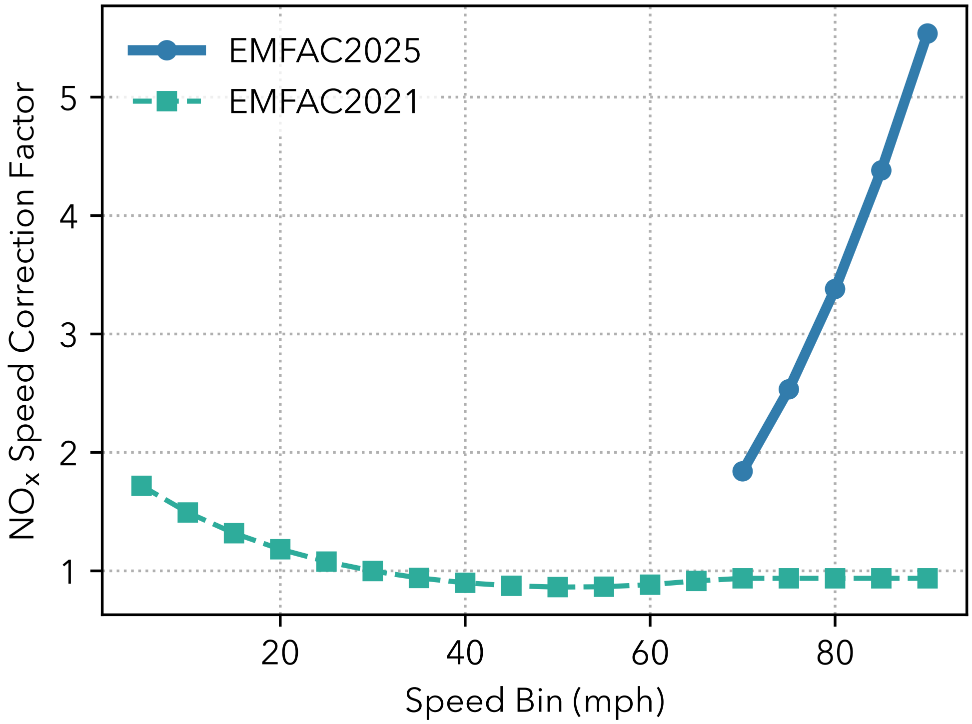


Figure 2.9: $NO_x$ Speed Correction Factors

#### 2.2.3.2.3 CO High-Speed Speed Correction Factors

In Figure 2.10, the analysis of the 10 tested vehicles shows the normalized mean CO emissions for the average speed corresponding to each FC.

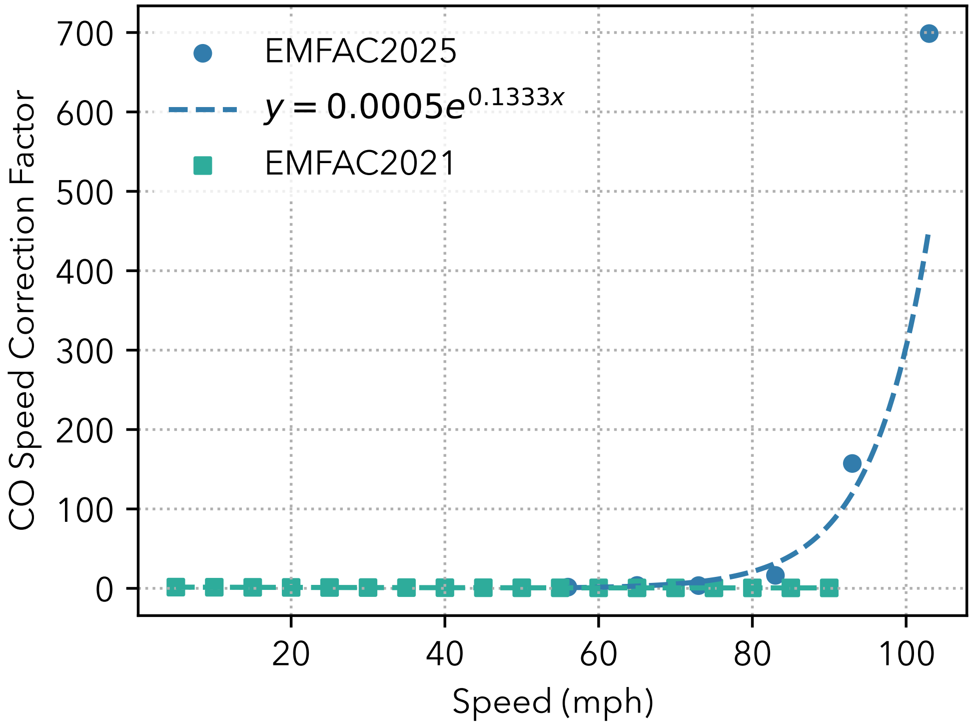


Figure 2.10: High-Speed Emission Rate Regression Fit Derived for CO

This chart shows emissions of CO from EMFAC2021 (green line) and the updates that went into EMFAC2025 (blue line). The SCFs for CO follow an exponential fit as indicated in Equation (2.3).

$$y = 0.0005e^{0.1333x} \tag{2.3}$$

Using the equation above, the emissions were calculated and are shown in Table 2.8 by speed bins for speed bins of 70 to 90 mph.

Table 2.8: High-Speed CO Speed Correction Factors

| Speed Bin | Mid-Point Speed (mph) | CO SCFs |
|---|---|---|
| 70 | 67.5 | 3.99 |
| 75 | 72.5 | 7.78 |
| 80 | 77.5 | 15.2 |
| 85 | 82.5 | 29.5 |
| 90 | 87.5 | 57.5 |

In Figure 2.11, the CO SCFs are shown. Again, similar to the HC and $NO_x$ SCFs, the graphs are normalized to 27 mph, the average speed of UC Bag 2. As illustrated by the graph, when the speed bin increases, the emission rates increase.

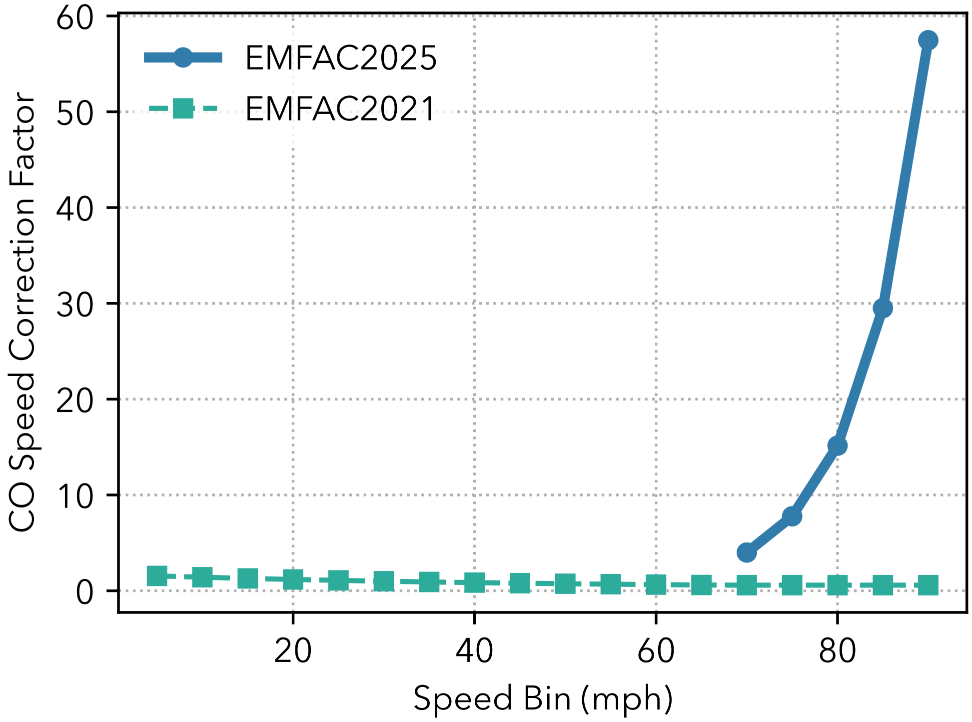


Figure 2.11: CO Speed Correction Factors

#### 2.2.3.2.4 $CO_2$ High-Speed Speed Correction Factors

In Figure 2.12, the $CO_2$ SCFs are shown. Again, similar to the HC, $NO_x$ and CO SCFs, the graphs are normalized to 27 mph, the average speed of UC Bag 2. As illustrated by the graph, emission rates increase with increasing speed.

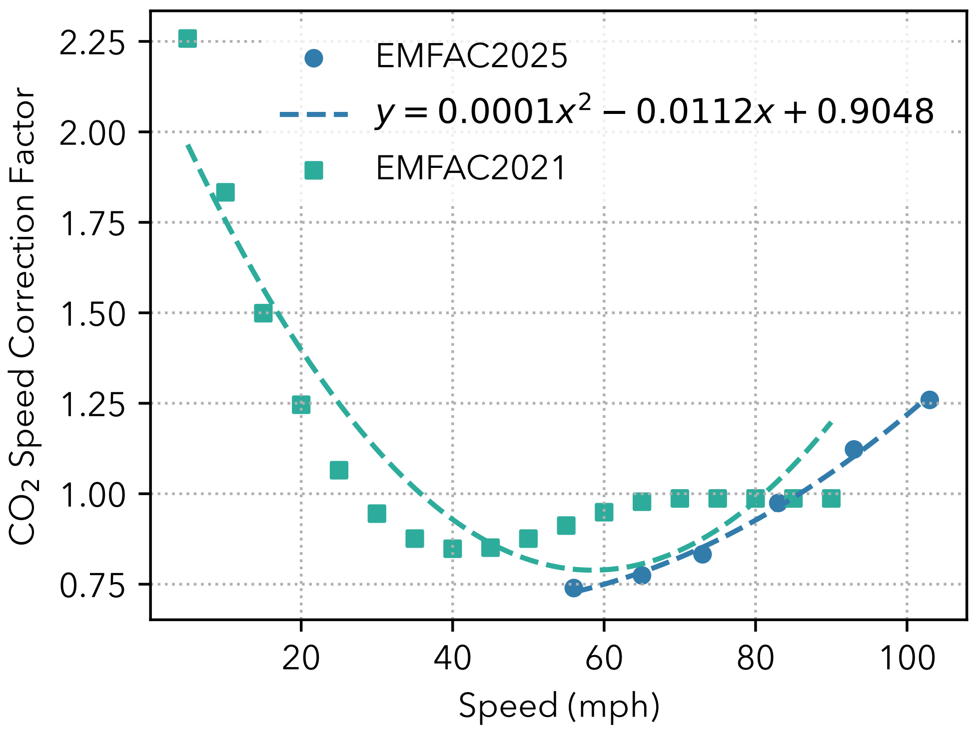


Figure 2.12: High-Speed Emission Rate Regression Fit Derived for $CO_2$

In all the previously listed pollutants, CARB staff normalized the data so that at 27 mph the SCF equaled 1. The SCFs for $CO_2$ follow a second order polynomial fit, indicated as Equation (2.4). For $CO_2$, however, CARB staff further scaled the EMFAC2025 (blue line) data such that its 65 mph speed bin equaled the value of the EMFAC2021 (green line) 65 mph speed bin.

$$y = 0.0001x^2 - 0.0112x + 0.9048 \tag{2.4}$$

Using the equation above, the emissions were calculated and are shown in Table 2.9 by speed bins for speed bins of 70 to 90 mph.

Table 2.9: High-Speed $CO_2$ Speed Correction Factors

| Speed Bin | Mid-Point Speed (mph) | $CO_2$ SCF |
|---|---|---|
| 70 | 67.5 | 1.03 |
| 75 | 72.5 | 1.09 |
| 80 | 77.5 | 1.16 |
| 85 | 82.5 | 1.23 |
| 90 | 87.5 | 1.32 |

In Figure 2.13, the updated $CO_2$ SCFs are graphed.

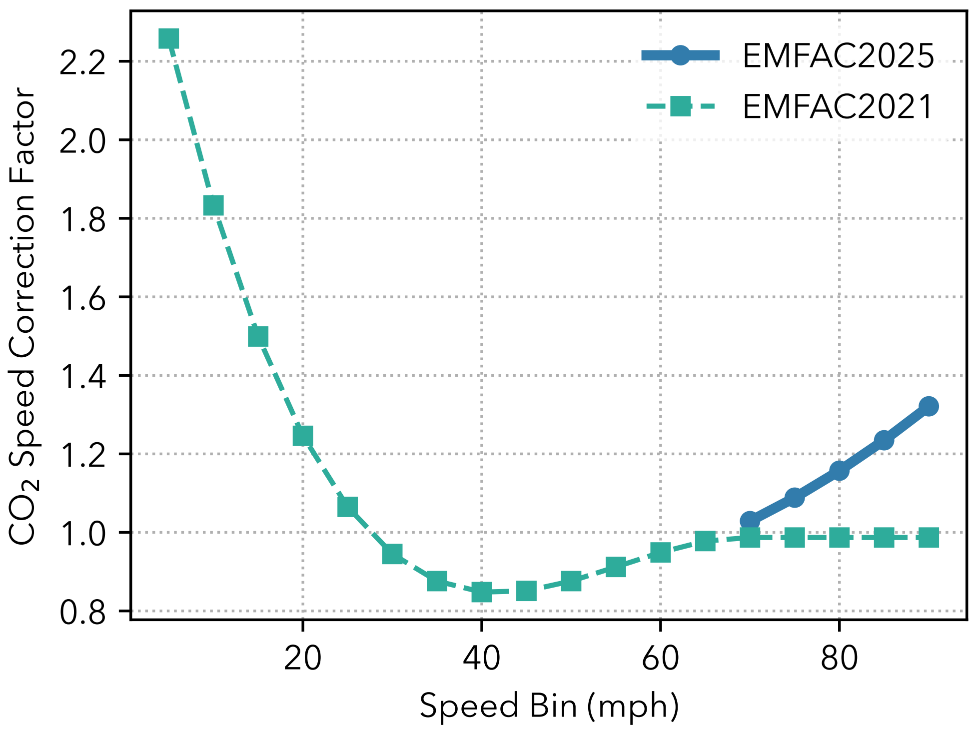


Figure 2.13: $CO_2$ Speed Correction Factors

### 2.2.4 Conclusion

The activity update was applied to a set of vehicle categories, while the SCF update was applied to specific technology groups. The activity update applies to LD groups up to GVWR 8500 lbs (LDA, LDT1, LDT2, MDV, and MCY) and broadly impacts all model years, past and future, in EMFAC2025. The technology groups impacted by the SCF update include ULEVII, SULEV30, SULEV20, ULEV50, and ULEV70, which collectively span 2004–2040 model years. For every other technology group, there is no high-speed SCF adjustment made. The emissions testing for the high-speed test plan is ongoing and as such the emission rates will continue to be refined for future versions of EMFAC.

The SCF update (excluding the activity update) will impact only 1 speed bin at 65–70 mph (midpoint 67.5 mph) because it is the first and lowest speed bin to have an updated SCF, but the highest speed bin with MPO activity. The impact of this one speed bin in the SCF update is a 15% increase of ROG and a 6% increase of $NO_x$ from light-duty vehicles (including all LD tech groups, ages, and categories). These are the effects expected to be observed in SIP and transportation conformity analysis, since they use MPO speed distributions and not the NEI activity update discussed above.

The result of both the activity and SCF updates, as reflected in EMFAC2025 default mode runs, is a 3% increase of ROG and a 5% increase in $NO_x$ for light-duty vehicles. It is initially counterintuitive that the addition of the high-speed activity up to 90 mph, on top of the SCF update, lessens the emissions impact relative to those from the SCF update alone. However, this is expected for some pollutants. Total fuel use in EMFAC2025 is constrained by fuel sales data obtained from the California Department of Tax and Fee Administration (CDTFA). When this activity update included driving at higher speeds where fuel efficiency is worse, while constraining the total fuel use, the net effect is a reduction of cVMT. In other words, this activity update caused EMFAC2025 to use its fixed quantity of fuel to travel faster (thereby emitting more per mile), but for a shorter distance. This reduction of cVMT from the activity update causes some pollutants in default mode runs to have smaller emissions increases than SIP and conformity runs with EMFAC2025 (which use MPO activity data), relative to EMFAC2021.

## 2.3 Light Heavy-Duty Trucks Split to Public and Other Categories

EMFAC light heavy-duty truck categories LHD1 and LHD2 correspond to vehicles having GVWR between 8,501 to 10,000 pounds and between 10,001 to 14,000 pounds, respectively. Historically, EMFAC grouped these vehicles by weight class ( i.e., LHD1 and LHD2) but did not further classify vehicles by fleet type. Starting with EMFAC2025, LHD1 and LHD2 are split into two categories: Public and Other. Public fleets are subject to the State and Local Government Fleet requirements of the Advanced Clean Fleets (ACF) regulation (See Section 9.2 for more information about ACF), which mandate 50% ZEV purchases for calendar years 2024–2026 and 100% ZEV purchases starting in 2027.

To determine the percentage of LHD1 and LHD2, staff used DMV data from 2013 to 2020 to estimate ratios by fuel type and sub-area. Public vehicles were identified using the DMV field “`Typ_lic_code`,” which is unique for vehicles owned by public agencies. Staff implemented these fractions in EMFAC2025 to split LHD1 and LHD2 into Public and Other categories. Statewide, Public vehicles make up 5.8% and 7.7% of LHD1 and LHD2, respectively, in calendar year 2025.

# 3 Fleet Characterization Updates

## 3.1 Light-Duty Fleet Characterization

This section describes the major updates to light-duty fleet characterization and details changes to the methodology, tools, and data sources used to characterize the vehicle population in California. It also compares fleet vehicle counts as modeled by EMFAC2025 and EMFAC2021. EMFAC2021 incorporated DMV data up to 2019, while EMFAC2025 added three additional years, using actual registration data through 2022. In the comparisons presented in this chapter, EMFAC2025 reflects DMV-based counts for calendar year 2022, whereas EMFAC2021 relies on forecasted counts for 2020 and onward.

### 3.1.1 Method

Starting in January 2018, DMV began sharing quarterly cuts of vehicle registration data with CARB. The data cuts, containing approximately 53 million records and 100 data fields, are available in January, April, July, and October of each calendar year. EMFAC2025 uses the October data cut of year 2022 as the main source of data for fleet characterization but incorporates vehicle registration status from the following April 2023 data cut to update any vehicles with pending registration.

The fleet characterization begins with loading the raw DMV data into a secured database, and then removing duplicate records to only keep the last record associated with each vehicle identification number (VIN). All newly acquired VINs are run through VINtelligence, a tool developed by S&P Global Mobility that verifies and decodes vehicle information using a VIN, to obtain details that may be missing from DMV records (such as gross vehicle weight code, model year, make name, series name, model name, body style, motive power, fuel type, displacement, battery size, etc.). Only on-road vehicles registered in the October database are analyzed and assigned a vehicle classification. Vehicles are classified based on manufacturer certification Executive Orders (EO) issued for each vehicle make, model, and model year. Finally, each record is distributed to a geographic area index (GAI) based on the registered owner address and used in the population numbers for EMFAC.

### 3.1.2 Vehicle Population

Figure 3.1 compares gasoline LDA vehicle populations in EMFAC2025 and EMFAC2021. As shown, EMFAC2025 projects a faster decline in vehicle populations, showing a 6.3% decrease from 2020 to 2022 compared to the previous model.

Figure 3.2 shows that the population counts for gasoline light-duty trucks (LDT), which include the EMFAC vehicle categories LDT1, LDT2, and MDV, are higher in EMFAC2025 than in EMFAC2021. In EMFAC2025, there is a pronounced increase in the LDT population between

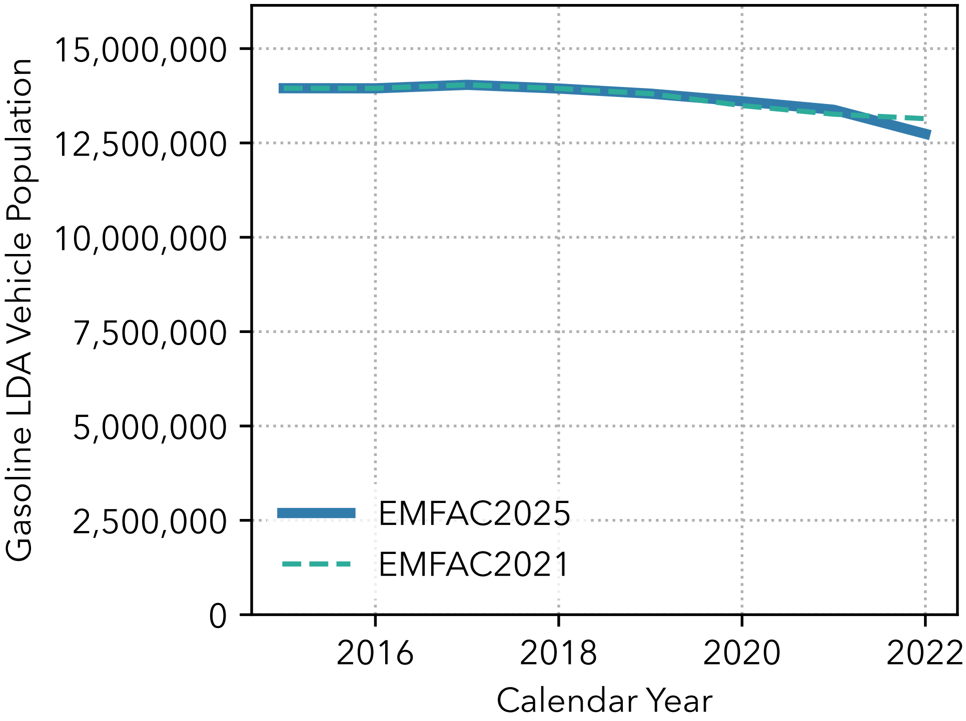


Figure 3.1: Gasoline LDA Population: EMFAC2025 vs. EMFAC2021

calendar years 2020 and 2021, followed by a slight decline in 2022. By 2022, the difference in LDT population estimates between EMFAC2025 and EMFAC2021 is relatively small, at less than 2%.

Figure 3.3 shows the population of gasoline light heavy-duty trucks (LHDT), which includes LHD1 Public, LHD1 Other, LHD2 Public, and LHD2 Other. While EMFAC2021 forecasted a steady, gradual decline in LHD populations, actual DMV registration data used in EMFAC2025 shows an increase in population in calendar year 2020, followed by a slight decline over the subsequent two years. Notably, for calendar year 2022, the EMFAC2021 projection closely matches the actual DMV-based count in EMFAC2025.

Figure 3.4 shows a sharp decline in the number of diesel LDA vehicles. Both EMFAC2025 and EMFAC2021 reflect similar trends from calendar years 2020 to 2022, indicating a continued decrease in the diesel vehicle population within this category.

As shown in Figure 3.5, EMFAC2021 predicted steady growth in diesel LDT populations. In contrast, EMFAC2025 indicates a sharp decline in calendar year 2020, followed by significant growth in 2021 and 2022. The discrepancy between the two models indicates that the 2022 population was underpredicted by nearly 20%.

For diesel LHDT vehicles shown in Figure 3.6, there is close agreement between the estimated populations from EMFAC2021 and the DMV registration counts reflected in EMFAC2025. The EMFAC2025 populations have exceeded the forecasted EMFAC2021 populations for this vehicle category by a nominal 1.2%.

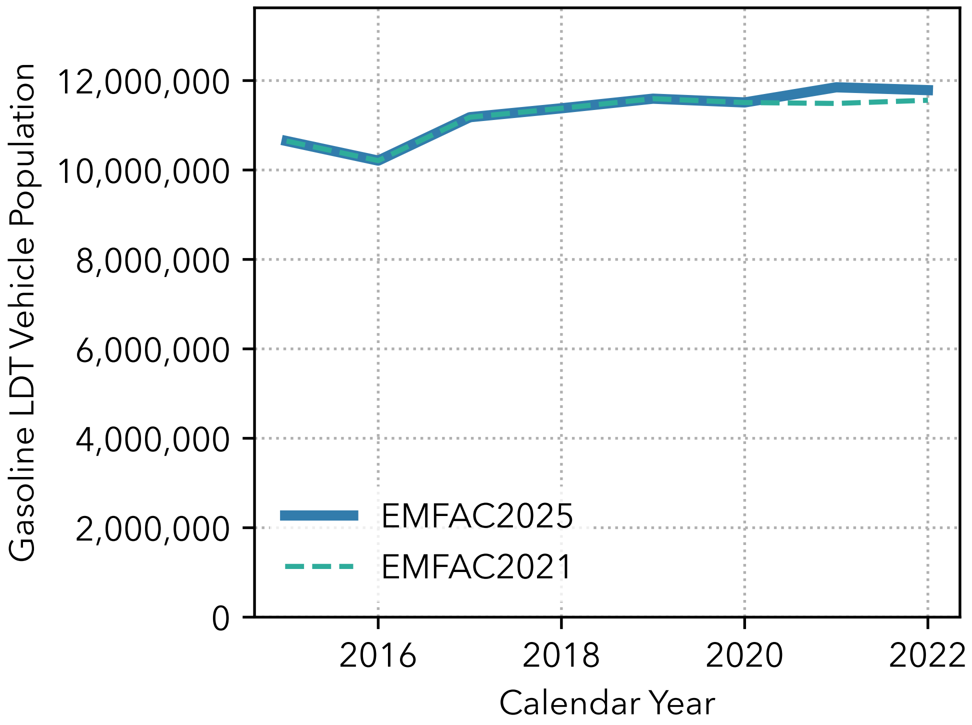


Figure 3.2: Gasoline LDT Population: EMFAC2025 vs. EMFAC2021

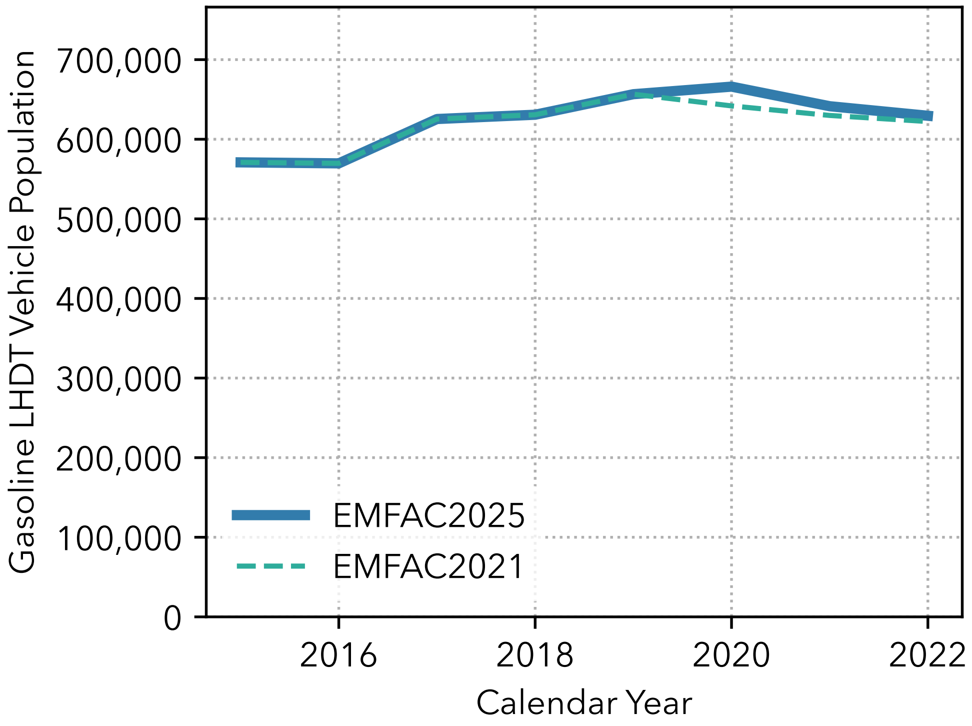


Figure 3.3: Gasoline LHDT Population: EMFAC2025 vs. EMFAC2021

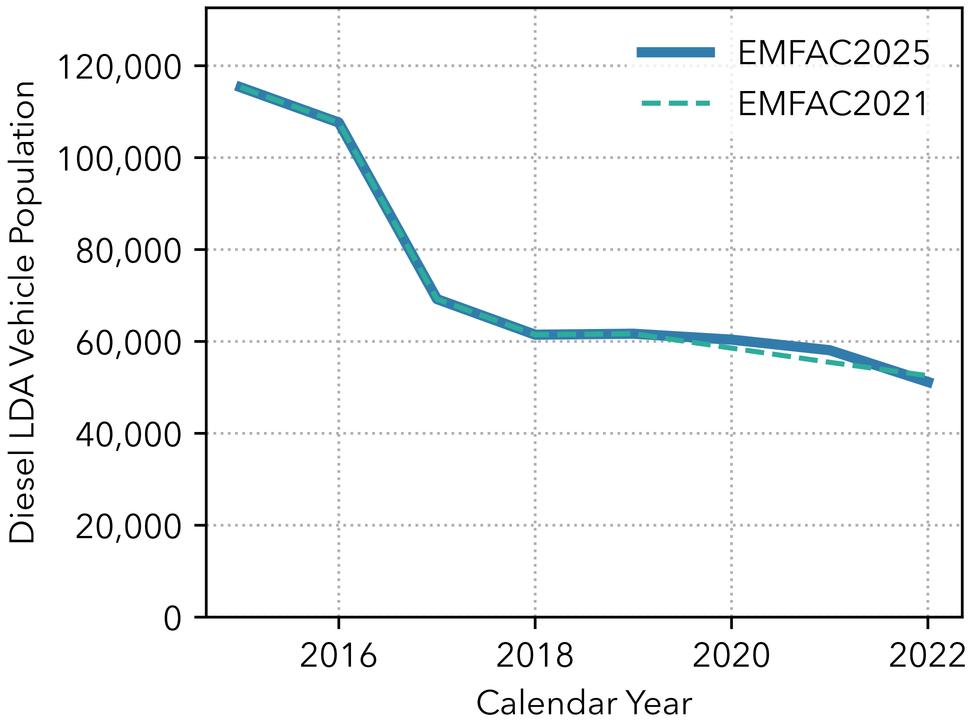


Figure 3.4: Diesel LDA Population: EMFAC2025 vs. EMFAC2021

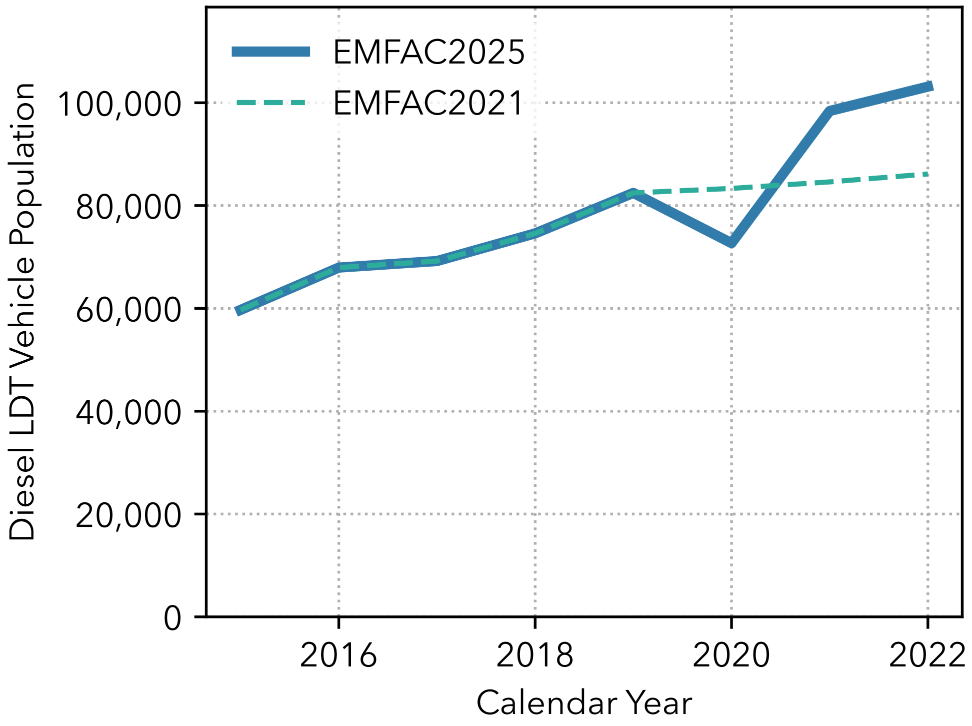


Figure 3.5: Diesel LDT Population: EMFAC2025 vs. EMFAC2021

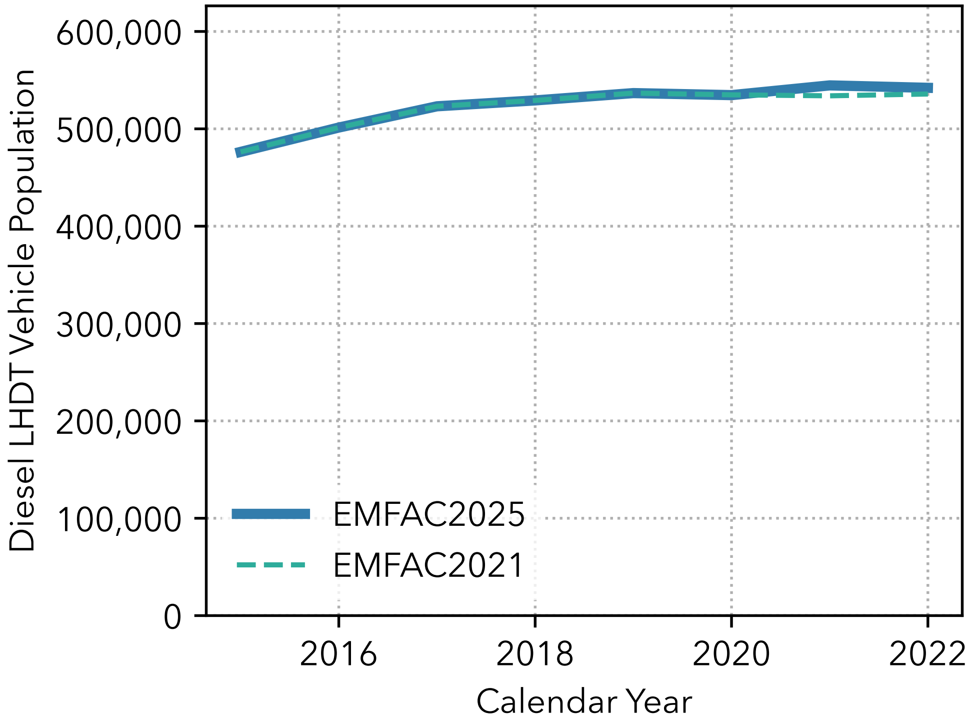


Figure 3.6: Diesel LHDT Population: EMFAC2025 vs. EMFAC2021

Figure 3.7 illustrates that the EMFAC2025 electric LDA population is substantially higher than the forecast population of EMFAC2021. Due to the slower growth rate projected by EMFAC2021, the 2022 DMV population exceeds its forecast by 25%.

According to Figure 3.8, electric LDTs have not experienced as rapid growth as their LDA counterparts. While electric LDT populations grow in EMFAC2025, the increase for these alternative fuel vehicles is slower than the rate predicted by EMFAC2021, with the actual DMV population being 23% lower than what was predicted for calendar year 2022.

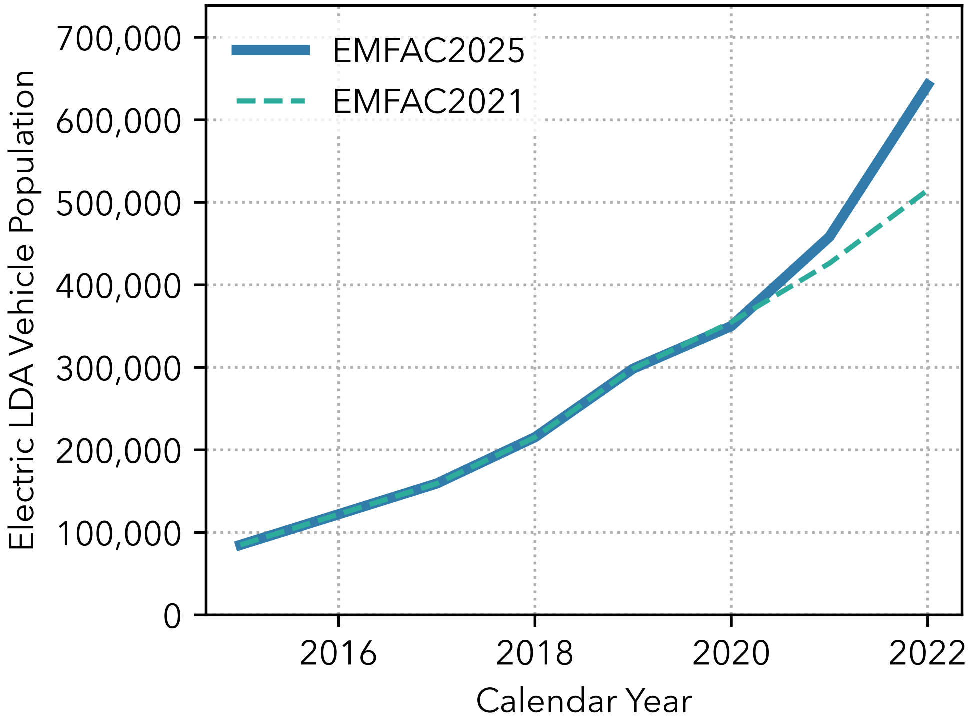


Figure 3.7: Electric LDA Population: EMFAC2025 vs. EMFAC2021

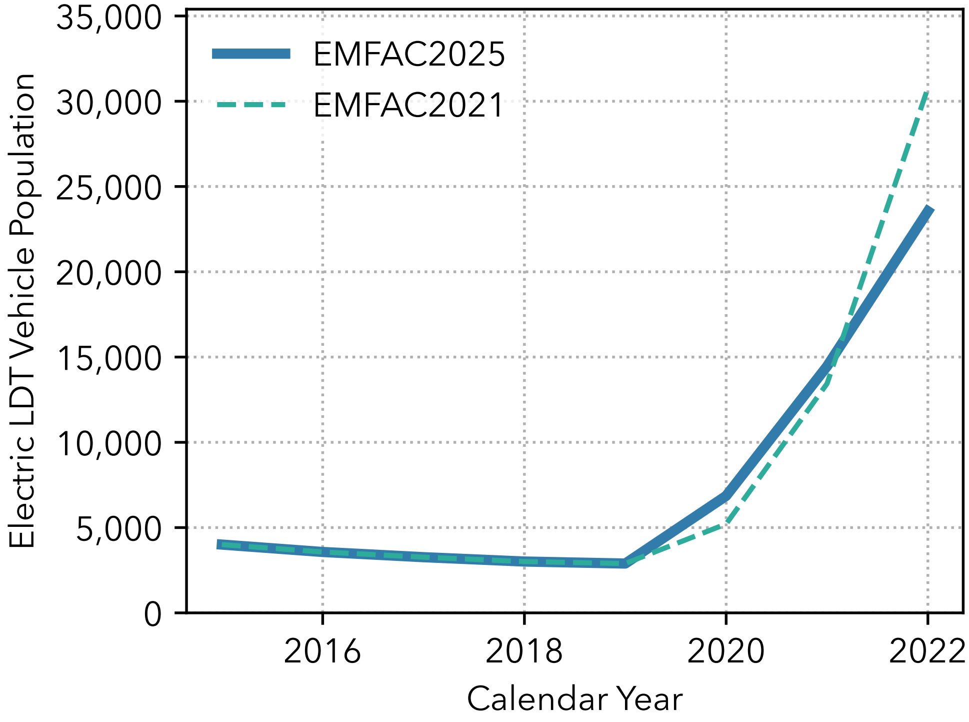


Figure 3.8: Electric LDT Population: EMFAC2025 vs. EMFAC2021

### 3.1.3 New Vehicle Sales

Figures 3.9 and 3.10 illustrate sales trends for new gasoline LDAs and LDTs sold in California. In EMFAC2021, the new sales projections for LDAs and LDTs showed similar trends from 2020 to 2022. This pattern of mirroring continues in EMFAC2025, although LDA new sales exhibit a continued decline. For calendar year 2022, the new vehicle sales counts for LDA have dropped by approximately 230,000 vehicles from the EMFAC2021 prediction.

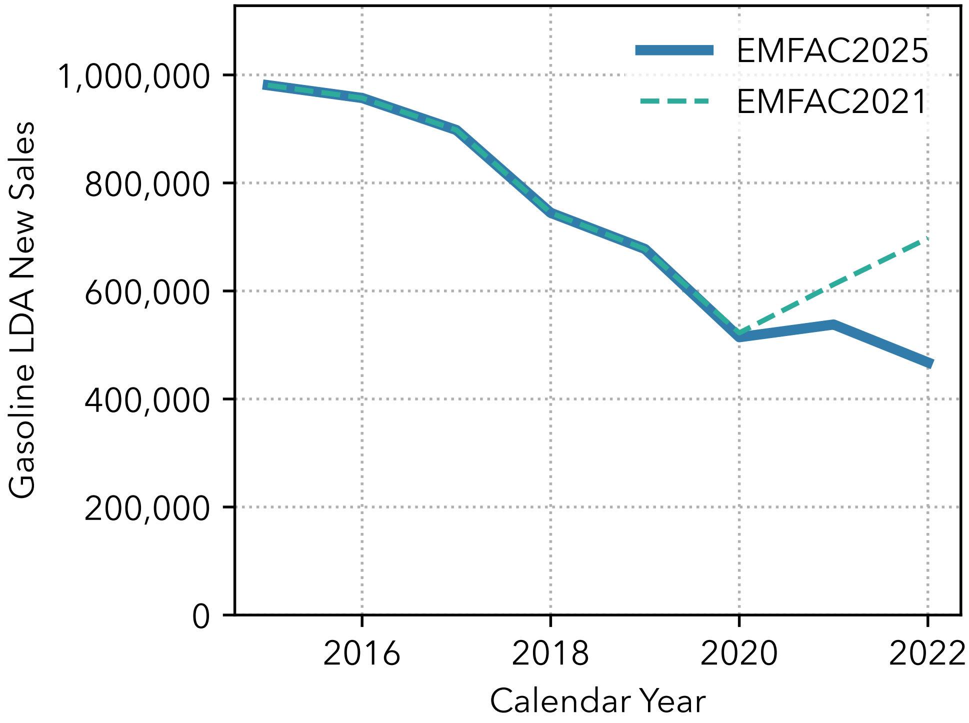


Figure 3.9: Gasoline LDA New Vehicle Sales: EMFAC2025 vs. EMFAC2021

Figures 3.11 and 3.12 display the diesel light-duty vehicle market sales. Both diesel LDAs and LDTs have experienced significant declines in recent years due in part to emissions irregularities found by CARB and EPA. While EMFAC2021 predicted modest sales increases from 2020 to 2022, EMFAC2025 shows that new LDT sales rebounded in 2020 and 2021 but dropped by more than 40% in the following calendar year 2022. Meanwhile, new diesel LDA sales remain flat in EMFAC2025.

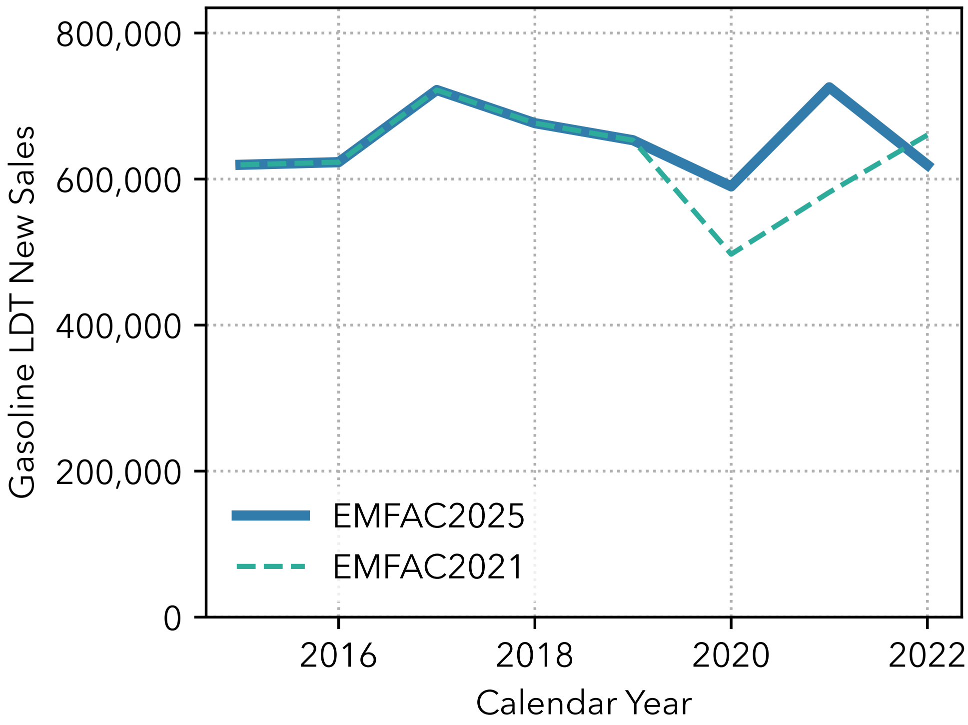


Figure 3.10: Gasoline LDT New Vehicle Sales: EMFAC2025 vs. EMFAC2021

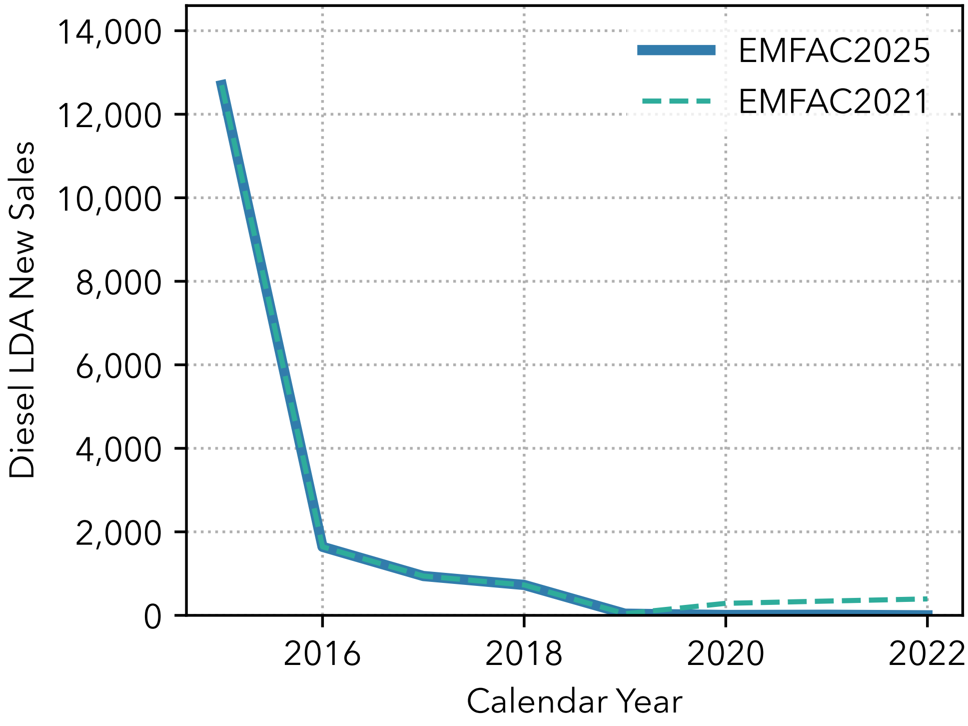


Figure 3.11: Diesel LDA New Vehicle Sales: EMFAC2025 vs. EMFAC2021

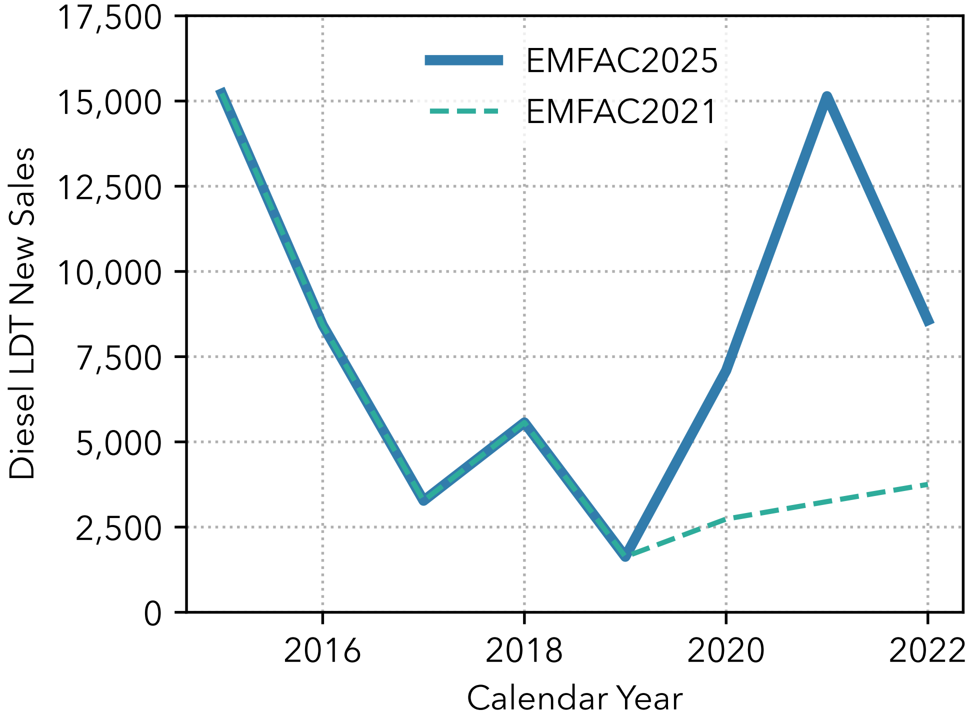


Figure 3.12: Diesel LDT New Vehicle Sales: EMFAC2025 vs. EMFAC2021

### 3.1.4 Model Year Distribution

Figures 3.13 through 3.15 illustrate the distribution of vehicle populations by model year for LDAs, LDTs, and LHDTs in both EMFAC2025 and EMFAC2021. When comparing the base years used in each model, calendar year 2022 for EMFAC2025 and calendar year 2019 for EMFAC2021, a noticeable decline in LDA vehicle counts is observed in EMFAC2025. In contrast, the model year distributions for LDTs and LHDTs follow similar trends in both models, as indicated by the close overlap of the respective lines.

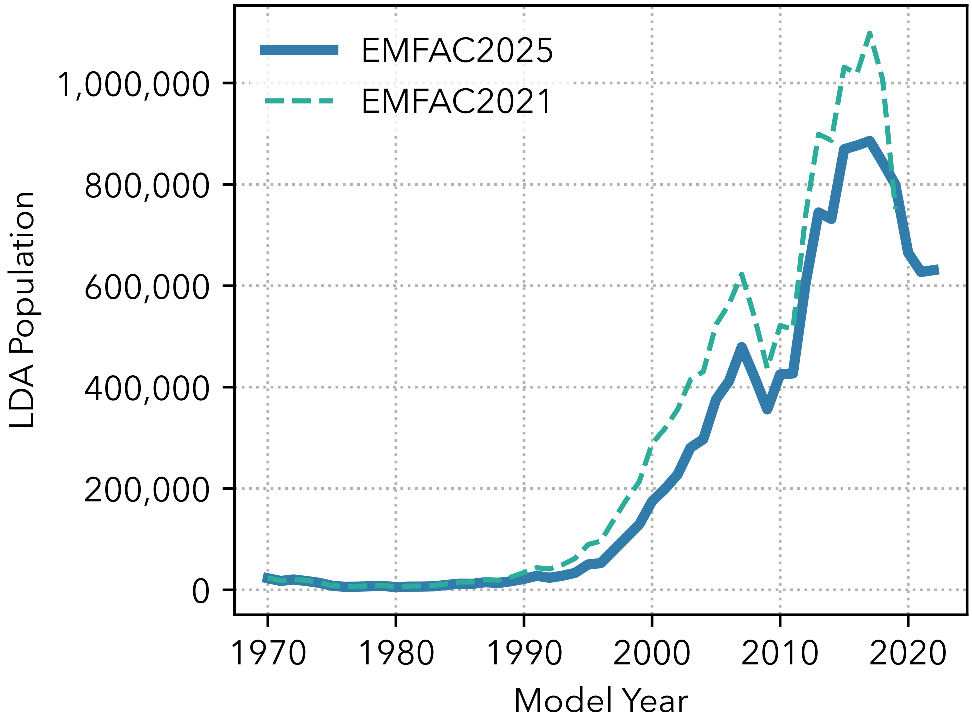


Figure 3.13: LDA Model Year Distribution: EMFAC2025 vs. EMFAC2021

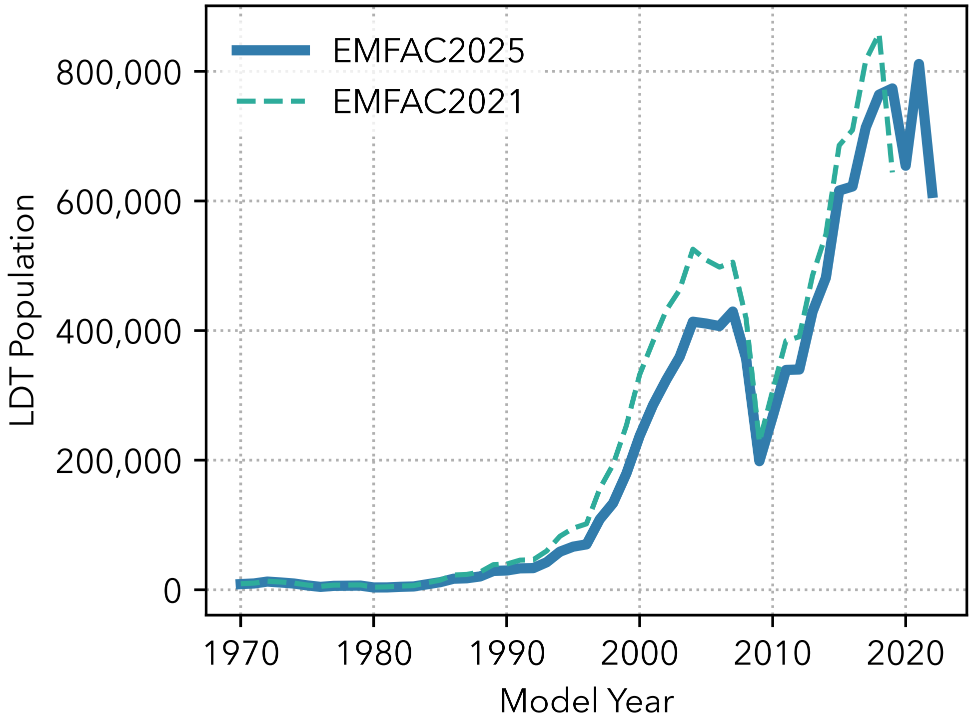


Figure 3.14: LDT Model Year Distribution: EMFAC2025 vs. EMFAC2021

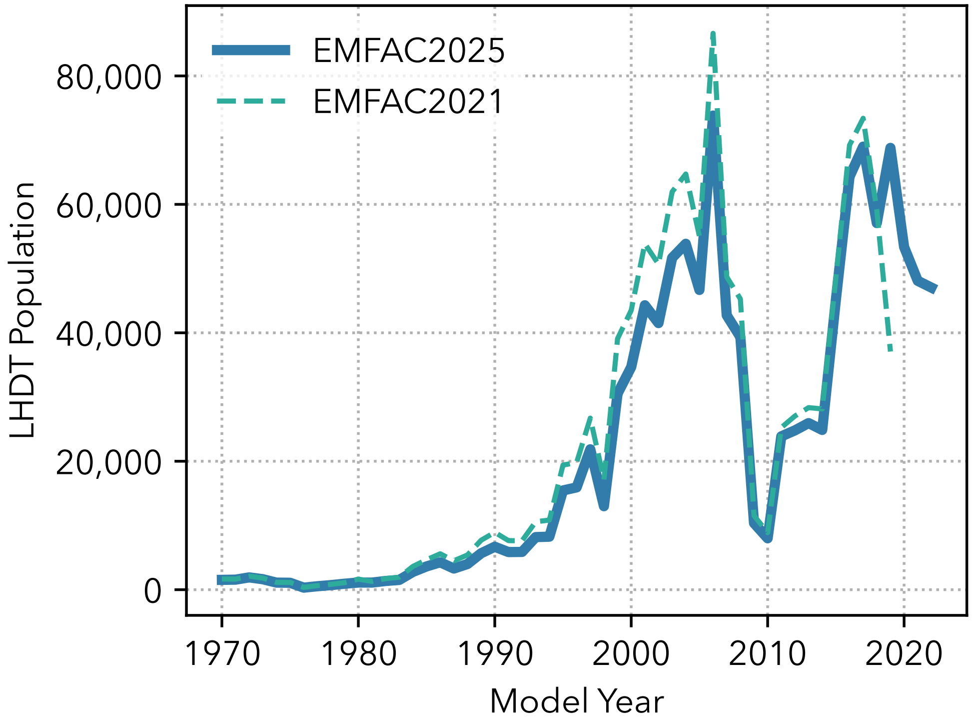


Figure 3.15: LHDT Model Year Distribution: EMFAC2025 vs. EMFAC2021

## 3.2 Heavy-Duty Fleet Characterization

This section focuses on the EMFAC2025 population trends for diesel and natural gas fueled medium heavy-duty and heavy heavy-duty (MHD and HHD) trucks and buses operating in California. Medium heavy-duty trucks have a gross vehicle weight rating (GVWR) of 14,001 to 33,000 pounds. Heavy heavy-duty trucks have a GVWR greater than 33,000 pounds. Bus fleet types include school buses, transit buses, motor coaches, and other buses. The following sections show comparisons of the population counts, new vehicle sales, and age distributions for EMFAC2025 and EMFAC2021. EMFAC2021 had a base year of 2019 while EMFAC2025 has a base year of 2022. Therefore, staff updated population data for calendar years 2020, 2021, and 2022 in EMFAC2025.

### 3.2.1 Major Data Sources for Update

**Processed DMV data:** As discussed in the light-duty vehicle section, the DMV data for historical years through 2022 was used to provide updated vehicle information for vehicles registered in California. DMV data field values are used to designate utility, public fleet vehicles, tractors, and solid waste collection vehicles. After identifying all other fleet types using all of the various data sources, the remaining trucks are designated as in-state single trucks, and the remaining buses are designated as all other buses.

**International Registration Plan (IRP) Data:** IRP Clearinghouse data is another primary data source for historical heavy-duty vehicle updates through 2022. Vehicles already registered in California can be identified as interstate trucks (CA IRP fleet) or buses (motor coach fleet). In addition, for out-of-state vehicles in states and provinces that report to the IRP Clearinghouse, updates were made using vehicle characteristics for fleets that travel to California. Out-of-state fleets report into IRP their annual mileage to California at a fleet level, and not per individual vehicle. Since out-of-state fleets may send many or none of their fleet's individual trucks to travel into California, it is more important to estimate their VMT travel in California than to estimate counts of unique out-of-state vehicles, which cannot be determined accurately. Using International Fuel Tax Agreement (IFTA) mileage data for the years 2018 through 2022, the historical ratio of VMT for out-of-state trucks as compared to VMT by CA IRP trucks was updated to 1.186 for T7 Non-neighboring Out-of-state truck (NNOOS) and to 0.364 for T7 Neighboring Out-of-state truck (NOOS) for EMFAC2025. The NNOOS and NOOS ratios were updated from 1.206 and 0.395 in EMFAC2021, respectively. These updates were made under the assumption that HHDT vehicles represented 95% of all the reported VMT and MHDT vehicles represented 5% (based on past studies). Using these ratios, VMT was calculated for T6 OOS, T7 NNOOS and T7 NOOS categories of EMFAC2021 and their populations were back-calculated with the use of mileage accrual schedules from an Eastern Research Group (ERG) report on Heavy Duty Vehicle Accrual Rates (ERG, 2019).

**Automated License Plate Reader (ALPR) data:** Age distributions of out-of-state trucks are determined by ALPR data collected along major truck corridors in southern California, including locations in Mountain Pass, Calexico, Blythe, I-710, SR-103, and I-405, during calendar year 2022. Staff obtained fleet model year distributions by matching plate characters and states (e.g., Nevada) collected by ALPR systems to the IRP database. Staff determined age distributions by calculating the difference between calendar year and model year. Figure 3.16 compares calendar year 2022 age distributions of Class 8 Out-of-State Trucks (NOOS and NNOOS) from EMFAC2021 that used previous assumptions of age distributions and EMFAC2025 that uses an age distribution based on ALPR data.

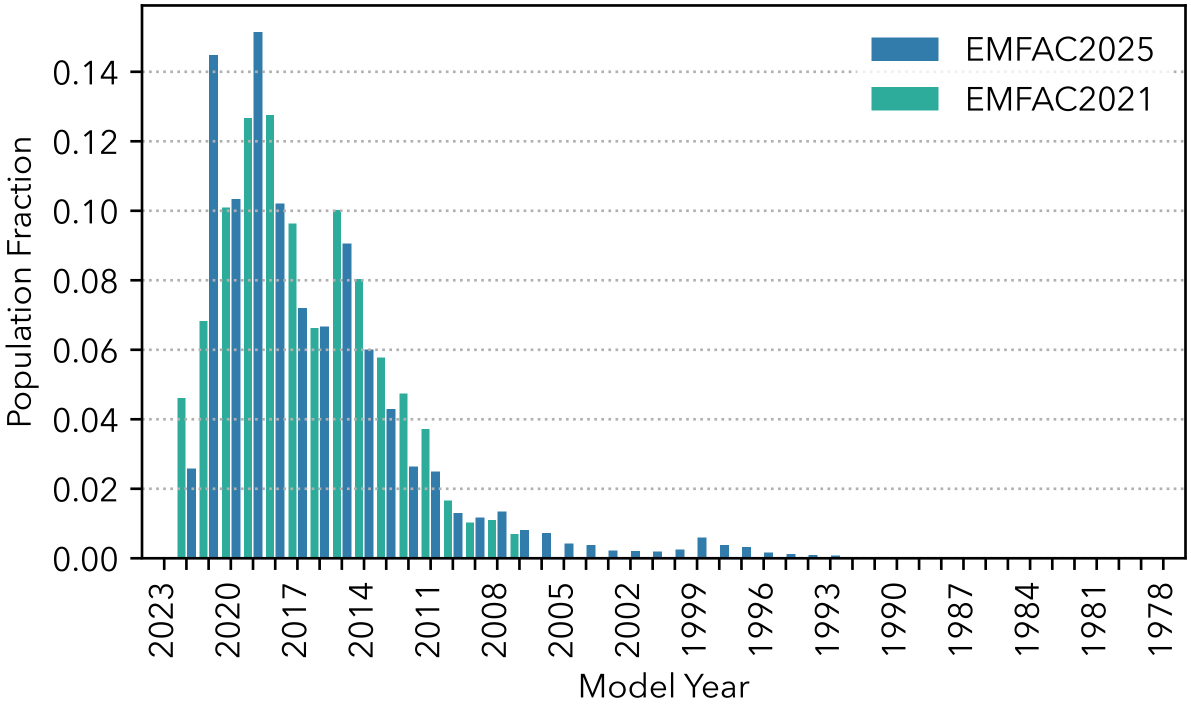


Figure 3.16: Year 2022 Age Distribution for Class 8 Out-of-State Trucks: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

**TRUCRS data for diesel Truck and Bus Rule:** Data extracted from the TRUCRS database was used to update the heavy-duty inventory as needed for fleets utilizing flexible compliance options to meet Truck and Bus Rule requirements.

**Drayage Trucks Operating at Major Ports:** The Port of Los Angeles/Long Beach (POLA) and the Port of Oakland (POAK) provided lists of VINs for vehicles that actually visited the ports to directly flag Class 8 vehicles used as port trucks. POAK provided annual lists with VIN and license plate data, which was used to update the calendar year 2020 to 2022 inventory. POLA provided VIN lists that included details on the monthly trips per VIN and the monthly average number of trucks to use for EMFAC modeling to update. The selected VINs to flag as POLA each year were based on having annual trips to the port above a certain threshold. Thresholds were calculated for each year such that the level of annual trips used to identify which VINs to flag as POLA resulted in achieving the monthly average truck counts provided by POLA. Trucks not displayed as POAK or POLA in EMFAC may be in lower weight classes, have fuel types other than diesel/electric/natural gas, be considered inactive trucks as annual visits are too low, or have out-of-state registration status. These trucks are included in other EMFAC categories for vehicle activity and emissions calculation purposes.

**California Highway Patrol (CHP) School Bus Inspections:** The CHP provided data on School Buses that receive safety inspections required by law. These datasets contain VINs which are used to determine the final count of School Buses in EMFAC2025, as the CHP lists are considered to be more accurate than school bus records in DMV data.

### 3.2.2 In-State Population

Figure 3.17 compares EMFAC2025 and EMFAC2021 vehicle population for heavy-duty instate trucks, showing those that operate within California and use diesel or natural gas fuel. CAIRP trucks were excluded here as instate, since a good portion of their miles are driven outside of California. Please note that estimates from both EMFAC2025 and EMFAC2021 are based on the DMV vehicle registration data. As shown below, EMFAC2025 has a higher actual vehicle population than was forecasted by EMFAC2021 for calendar years 2021 and 2022.

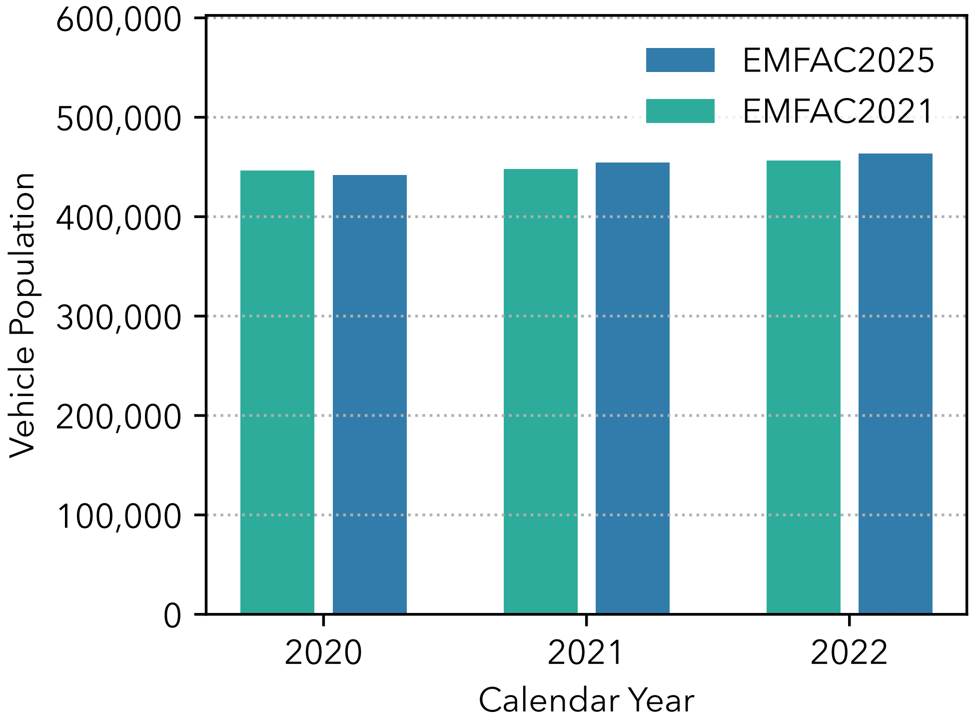


Figure 3.17: Instate Heavy Duty Vehicle Population: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

Figure 3.18 compares EMFAC2025 and EMFAC2021 new sales of heavy-duty instate trucks. New sales include all vehicles with chassis model years equal to or greater than the calendar year. For calendar years 2020 to 2022, the new vehicles sales exceeded the EMFAC2021 forecasts with an increase of 12% in 2020, 64% in 2021, and 70% in 2022.

Figure 3.19 compares EMFAC2025 and EMFAC2021 counts of vehicles with a chassis model year of 2011 and greater, which would be compliant with the Truck and Bus Rule model year 2010 engine standard requirements. For the majority of heavy-duty trucks, there is typically a one-year

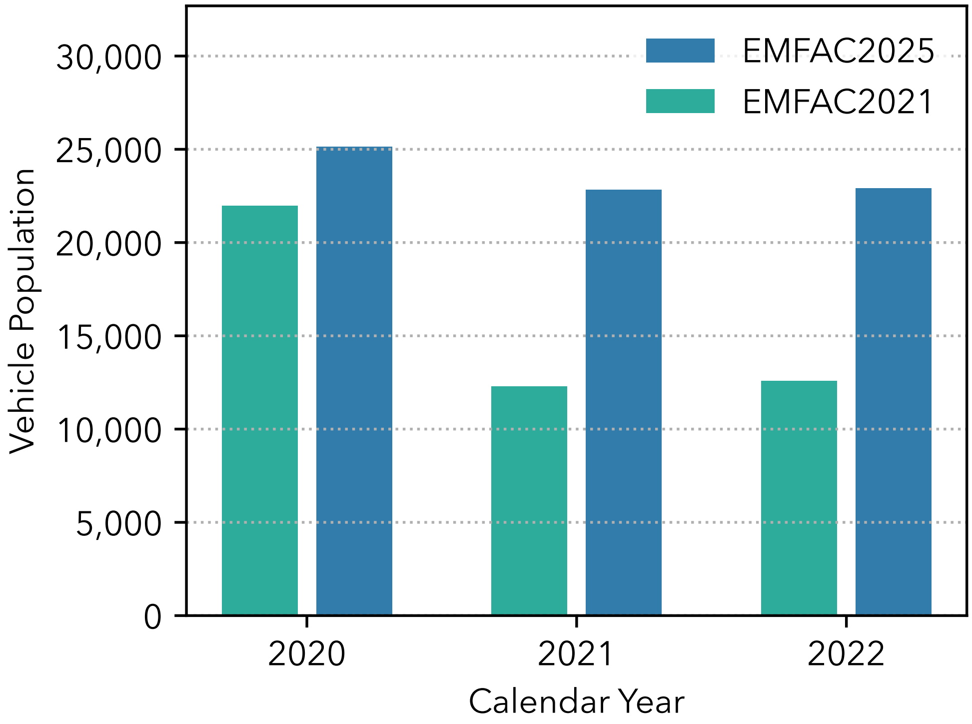


Figure 3.18: Instate Heavy Duty New Vehicle Sales: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

lag in the chassis model year from the engine model year. These population counts would include both new and used vehicle sales. The EMFAC2021 forecasted population exceeded the updated population for EMFAC2025. EMFAC2021 Truck and Bus Rule assumptions anticipated a higher rate of vehicle sales for model year 2010 engine compliant used vehicles. This is generally due to EMFAC2021 assuming a gradual turnover of the 2010 engine standard leading up to 2023, when phase-in requirements of the Truck and Bus Regulation are fully implemented. However, the EMFAC2025 update suggests that owners were hanging onto their older trucks until the very last year they are required to turn them over to a 2010 engine standard truck. The EMFAC model does assume full compliance with the Truck and Bus Regulation from calendar year 2023 and onward, except for vehicles claiming exemptions.

For the new base year of 2022, EMFAC2025 reflects an average age of 9.8 for instate heavy-duty (MHD and HHD) vehicles. EMFAC2021 used calendar year 2019 as the base year which had an average age of 8.5. Figure 3.20 compares age distributions from the 2022 calendar year base year in EMFAC2025 with EMFAC2021 forecasted values. As the chart indicates, the EMFAC2025 base year shows increases in the pre-2008 model years and decreases in the 2017–2022 model years (from both new and used vehicle purchases) as compared to the EMFAC2021 forecast. This trend corroborates the previous figure and may also be due to 2010 engine standard truck owners waiting until calendar year 2023, the final year of the Truck and Bus Regulation, to purchase a truck with a 2010 engine or later. Additionally, a greater fraction of trucks with 2010 or older engines may have been able to qualify for exemptions under the Truck and Bus Regulation than expected (e.g. the low-mileage exemption). Because out-of-compliance trucks

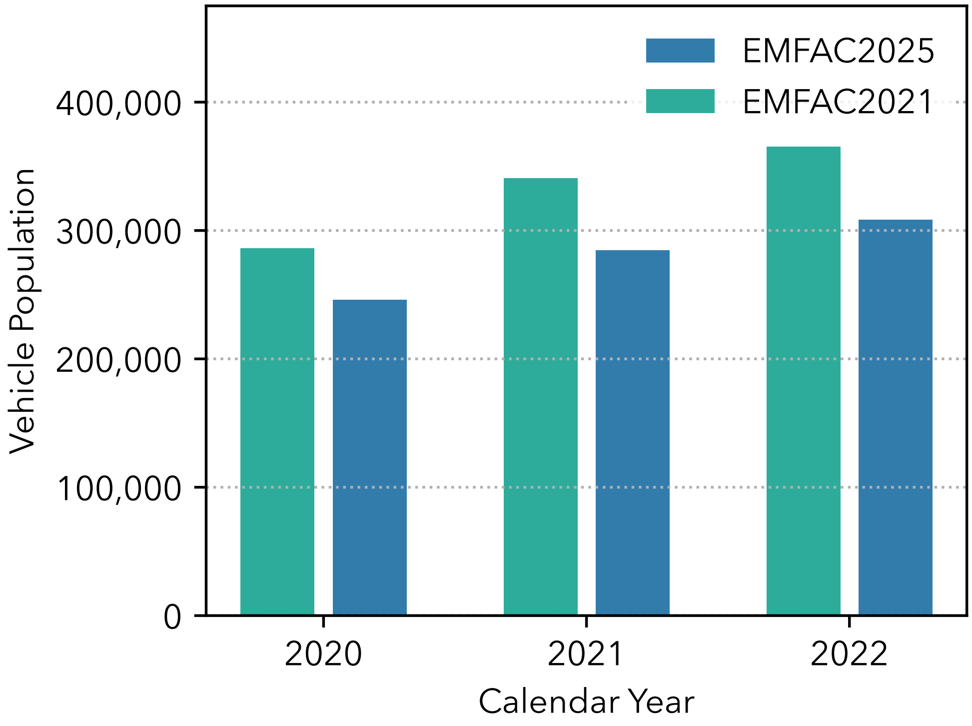


Figure 3.19: Instate Heavy-Duty Vehicle Population of Model Year 2011+: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

will have their registration withheld by the DMV, and CARB's historical counts are based on the DMV registration data, we can be certain the increased counts of older trucks in EMFAC2025 are Truck and Bus compliant, at least as of 2022. However, since many old trucks may get replaced in the final year of Truck and Bus, 2023, and it may take a year for DMV to update records and start implementing registration holds, the age distributions of the older trucks may shift significantly by calendar year 2024.

Port trucks had to meet the drayage rule that required model year 2007 or newer engines by the beginning of calendar year 2014, which lowered the average age of this fleet group. The port truck population in calendar year 2016 had an average age of 5.24. After past drayage rule requirements, no further vehicle replacements had been required through calendar year 2022 so the average age increased to 8.1 in calendar year 2022 in EMFAC2025. This is slightly younger than the projected average age of 9.0 for calendar year 2022 in EMFAC2021. The following Figure 3.21 provides a comparison of the age distributions for the 2022 calendar year in EMFAC2025 with EMFAC2021 forecasted values. It should be noted that Port trucks need to meet the 2010 engine standard requirement by January 1, 2023, as required by the Truck and Bus rule.

For HHD instate tractors, the EMFAC2021 base year of calendar year 2019 had an average age of 8.0 which has increased to 8.1 in the updated EMFAC2025 base year of calendar year 2022. A comparison of the age distributions for the 2019 calendar year in EMFAC2021 with EMFAC2025 values for heavy heavy-duty instate tractors is shown in Figure 3.22.

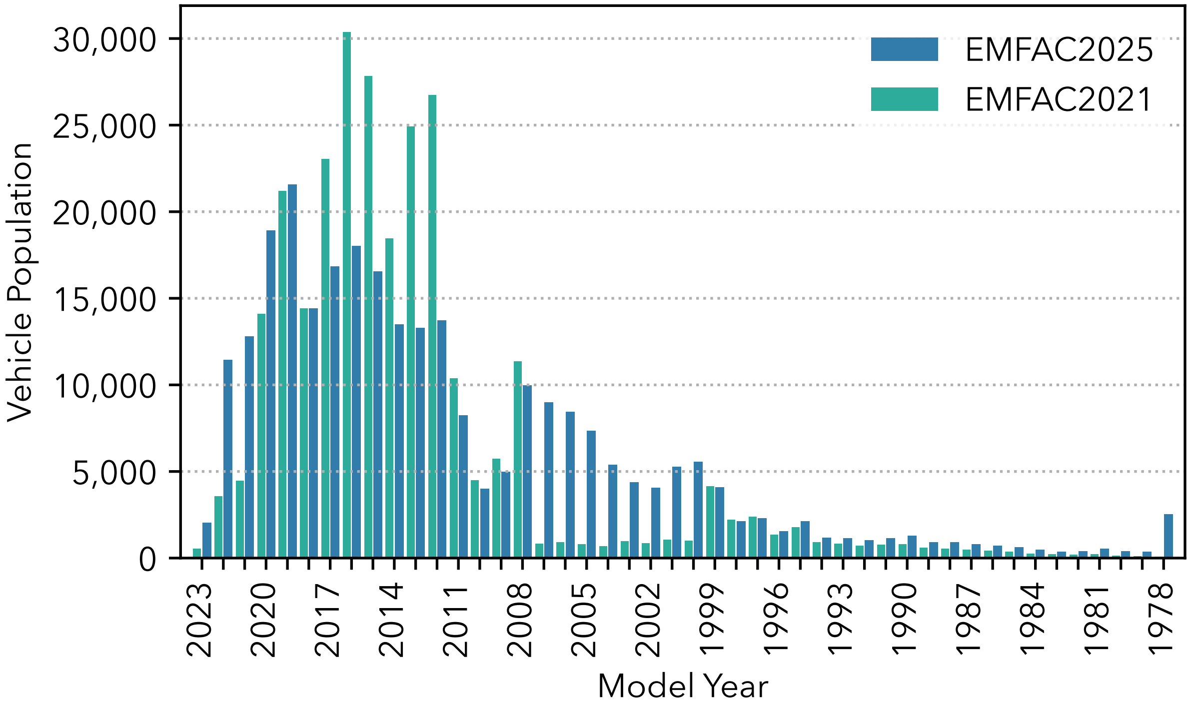


Figure 3.20: Instate Heavy-Duty Model Year Distribution in 2022: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

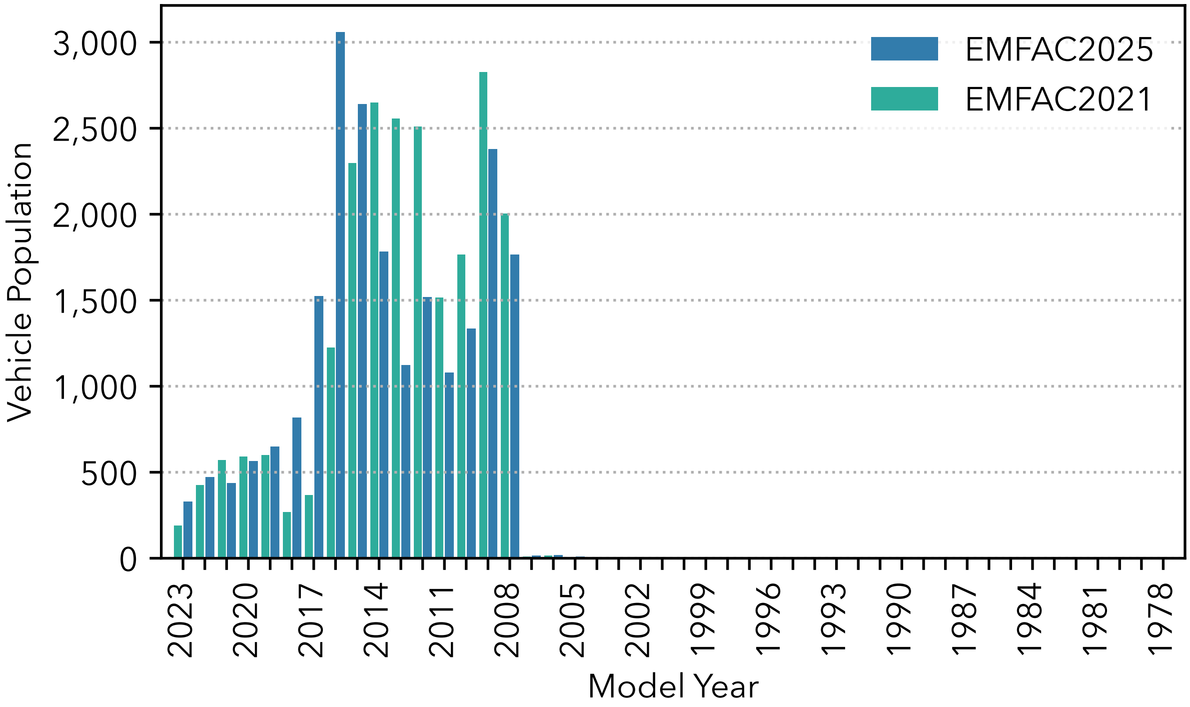


Figure 3.21: Heavy Heavy-Duty Port Truck Model Year Distribution in 2022: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

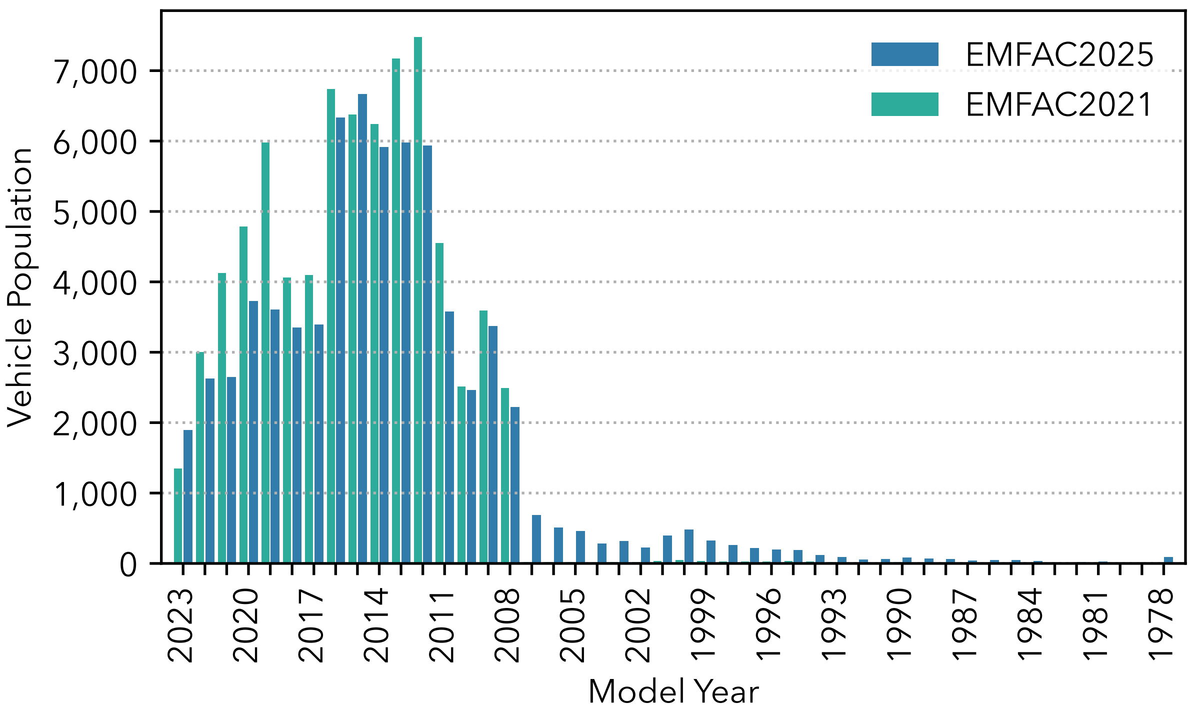


Figure 3.22: Heavy Heavy-Duty Instate Tractor Model Year Distribution in 2022: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

Figure 3.23 compares the base year populations of medium heavy-duty instate vehicles in EMFAC2025 and EMFAC2021. The EMFAC2021 base year of calendar year 2019 had an average age of 11.1, which has decreased slightly to 10.5 in the updated EMFAC2025 base year of 2022. This is higher than the average age of 8.8 years that EMFAC2021 projected for calendar year 2022.

### 3.2.3 California Interstate (CAIRP) Heavy-Duty Fleet Population

The following figure compares EMFAC2025 and EMFAC2021 vehicle populations for heavy-duty Interstate trucks that report into the International Registration Plan (CAIRP) and designate their base jurisdiction as California. These trucks are authorized to operate within California and within other states or provinces. The assumption made for the trucks in this fleet is that although they are based in California, they will drive a significant fraction of their VMT outside of California. Ultimately each of these trucks will generate less in-state emissions than in-state trucks will. In Figure 3.24 EMFAC2025 shows similar counts in calendar year 2020 but with increasing counts for calendar year 2021 and 2022 relative to the forecasted vehicle population by EMFAC2021.

For the heavy heavy-duty (Class 8 or GVWR > 33,000 lbs) CAIRP, the calendar year 2019 fleet had an average age of 5.4 in the base year for EMFAC2021. This vehicle group was projected to have an age of 5.1 in calendar year 2022 by EMFAC2021, very close to the age estimate from EMFAC2025 of the same calendar year, vehicle class and weight group, 5.06 years old. A comparison is shown in Figure 3.25.

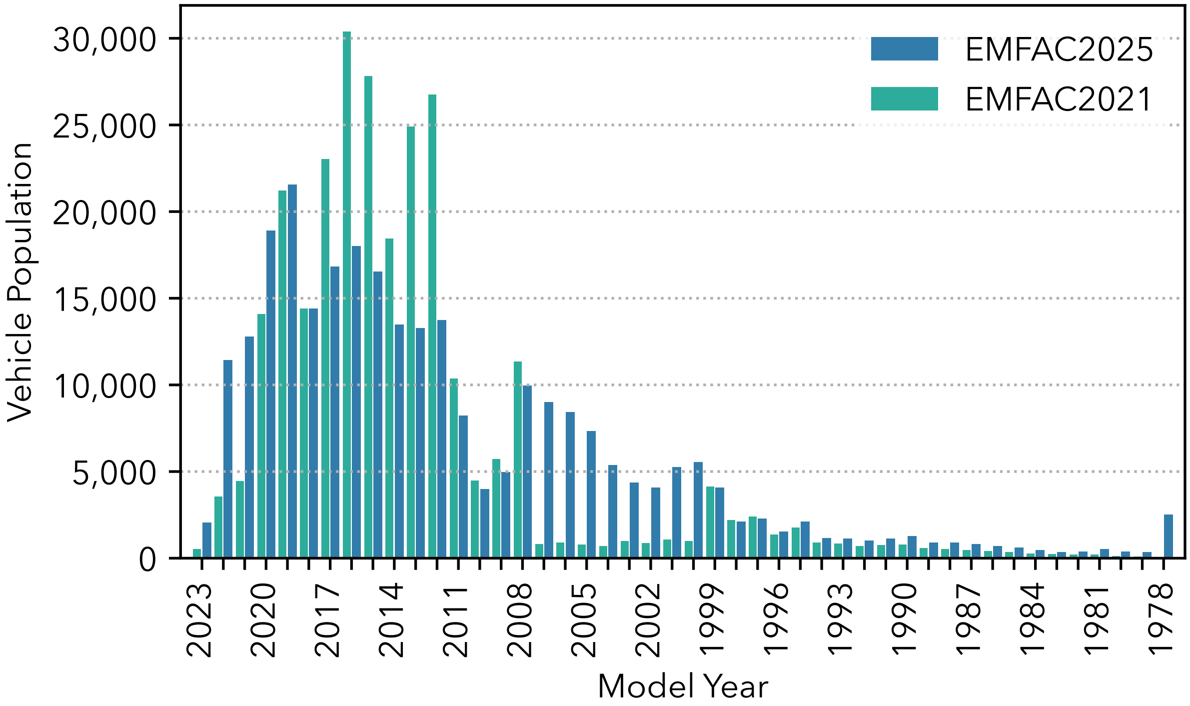


Figure 3.23: Medium Heavy-Duty Instate Model Year Distribution in 2022: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

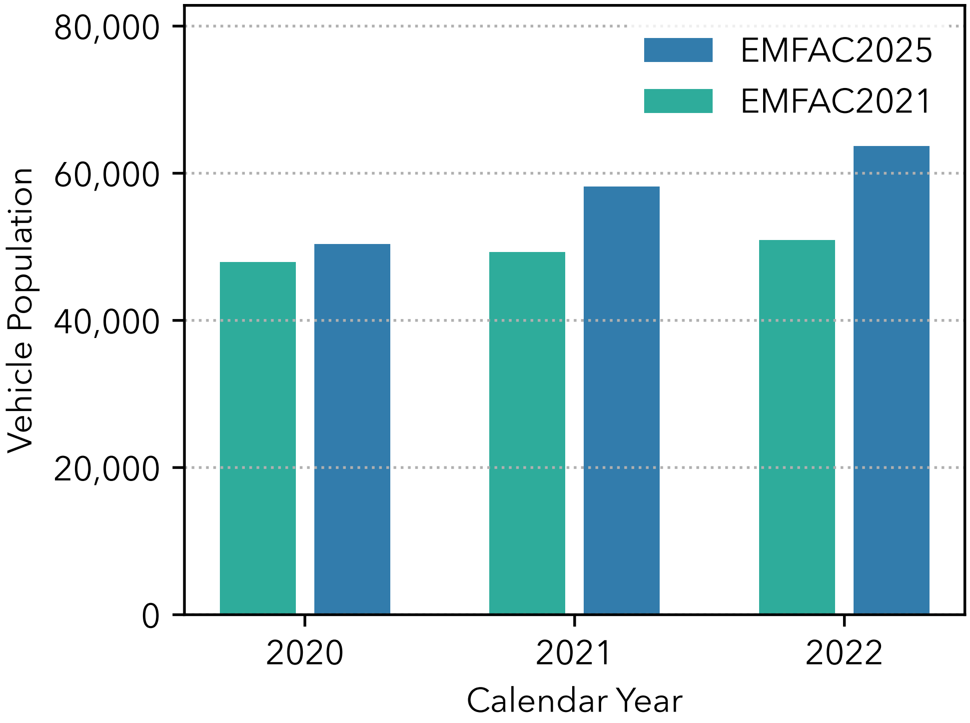


Figure 3.24: CAIRP Heavy-Duty Vehicle Population: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

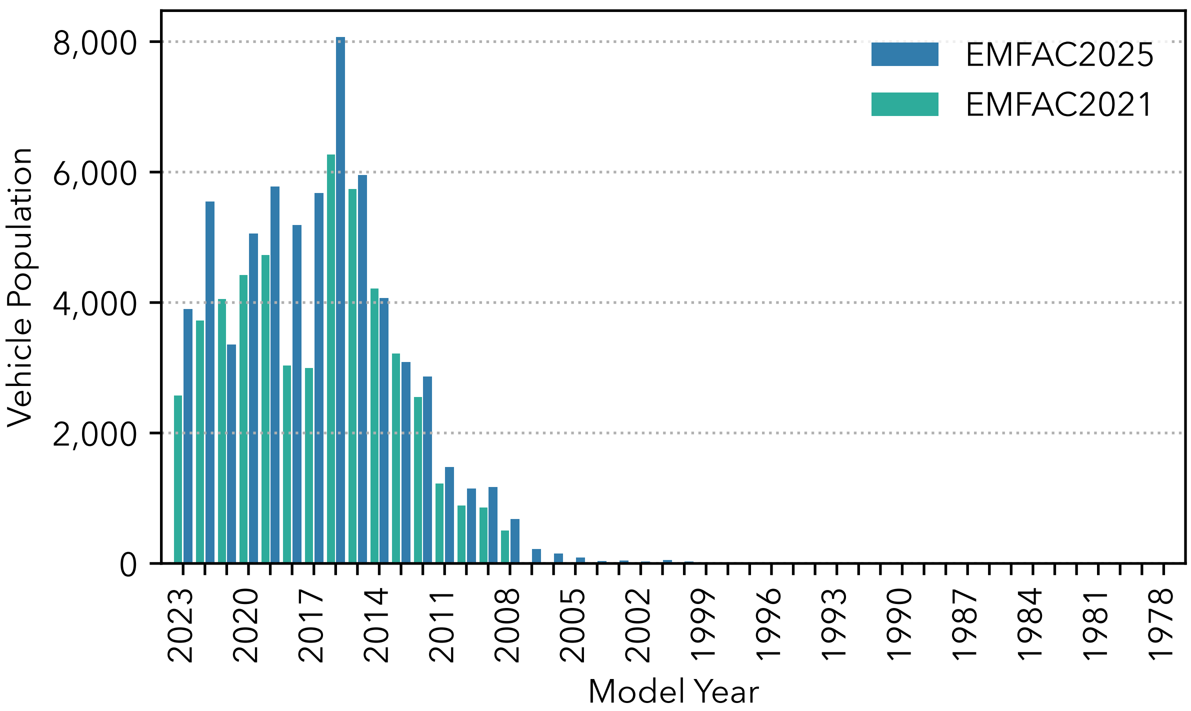


Figure 3.25: Comparison between EMFAC2025 (Actual) and EMFAC2021 (Forecasted) Heavy Heavy-Duty CAIRP Model Year Distribution in Calendar Year 2022

### 3.2.4 Bus Fleet Population

Bus fleet types presented in this section include school buses, motor coaches, and other buses. The urban transit bus inventory has a separate module that began with EMFAC2017 and is discussed separately. Figure 3.26 displays the updated heavy-duty bus population for calendar years 2020–2022. For all three years EMFAC2025 shows slightly lower bus counts than were forecasted by EMFAC2021.

EMFAC2025 continues to make use of California Highway Patrol inspection reports to quantify the school bus population. The DMV appears to undercount school buses each year, compared to the CHP. Because the CHP inspects each in-use school bus every two years, their VIN lists are considered to be more accurate. The DMV counts are ultimately scaled up (typically around 20% each year) to align with the CHP list of distinct school bus VINs. Figure 3.27 compares the age distributions for heavy-duty buses. EMFAC2021 has estimated the calendar year 2022 to have an average age of 11.8, while EMFAC2025 showed the year’s age to be slightly older, at 12.5.

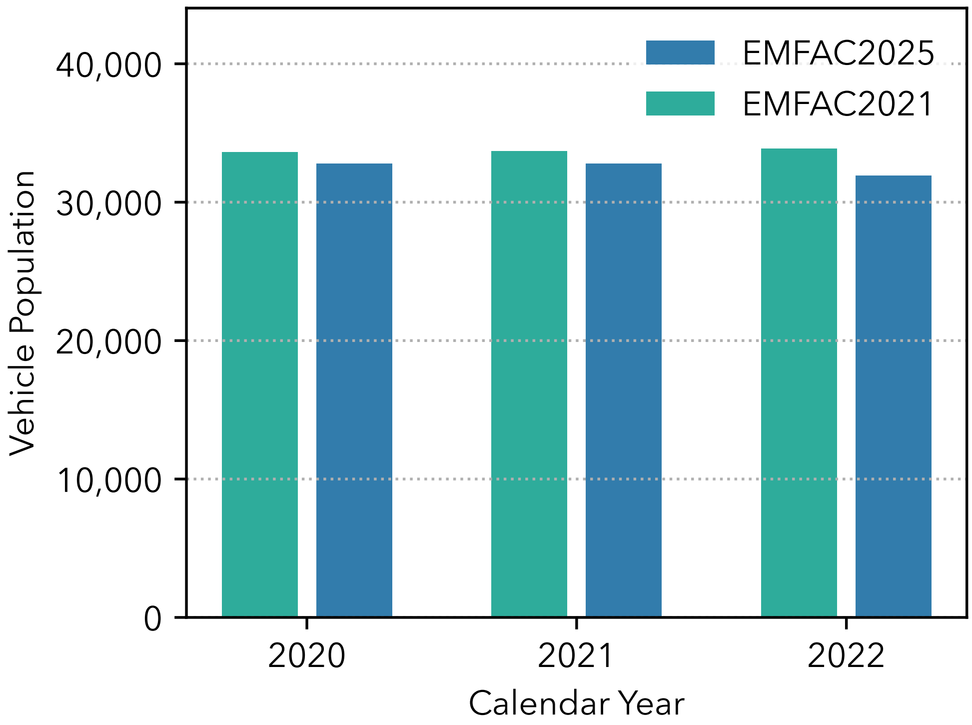


Figure 3.26: Heavy-Duty Bus Vehicle Population: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted). Urban Transit Buses are excluded.

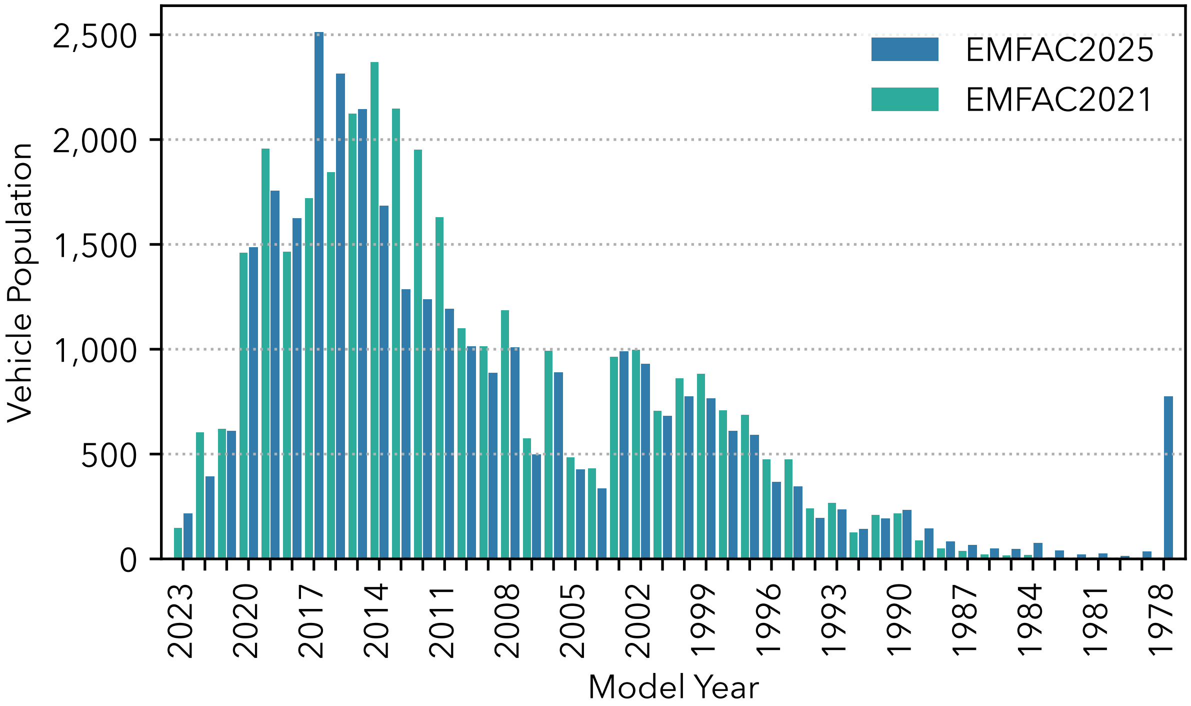


Figure 3.27: Heavy-Duty Bus Model Year Distribution in 2022: EMFAC2025 (Actual) vs. EMFAC2021 (Forecasted)

## 3.3 Transit Bus

Staff followed the same methodology as EMFAC2021 for developing the transit bus (UBUS) inventory. The only change comes from the data sources. Staff used two main data sources for transit buses in EMFAC2025: National Transit Database (NTD) and Innovative Clean Transit (ICT) Reports. As part of the ICT regulation, all transit agencies in California are required to report their inventory annually. Hence, staff used these reports to extract the population of transit buses. However, ICT reports do not contain bus activity such as VMT. As a result, staff employed NTD reports to extract the VMT per bus at the transit agency level, estimating the VMT based on ICT report population.

EMFAC2025 used NTD and ICT reports from calendar year 2023 to develop the UBUS inventory based on ICT rule phase-in (FTA, 2024, CARB, 2024). For more details about the projections and ICT phase-in, refer to Section 4.2.3 of EMFAC2021 Technical Documentation (CARB, 2021).

Figure 3.28 and Figure 3.29 compare the UBUS populations and VMT between EMFAC2025 and EMFAC2021, respectively.

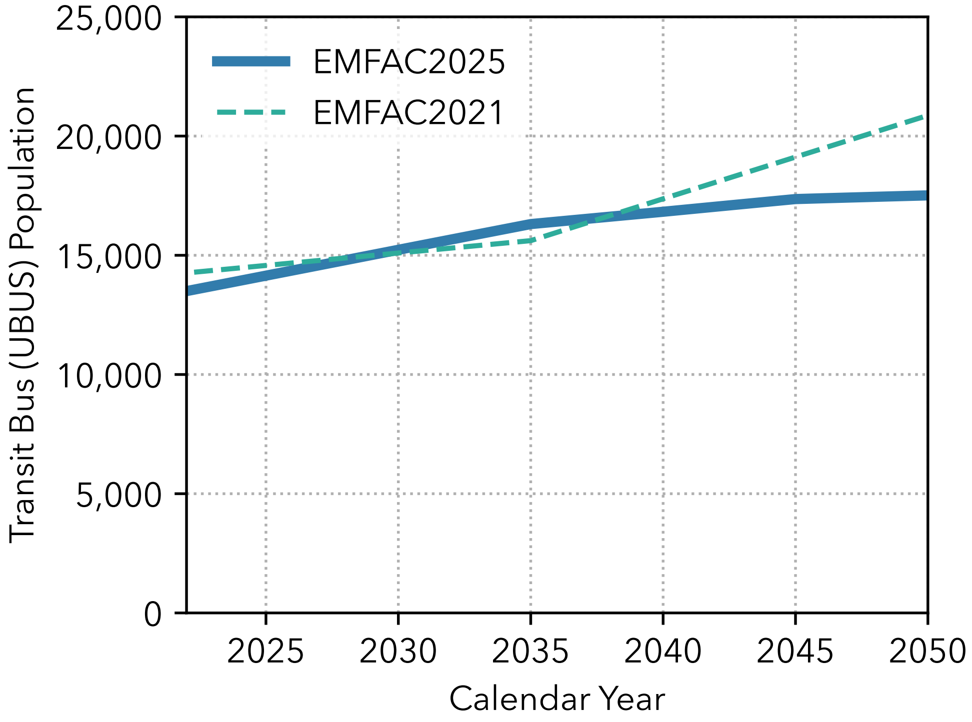


Figure 3.28: Transit Bus (UBUS) Population: EMFAC2025 vs. EMFAC2021

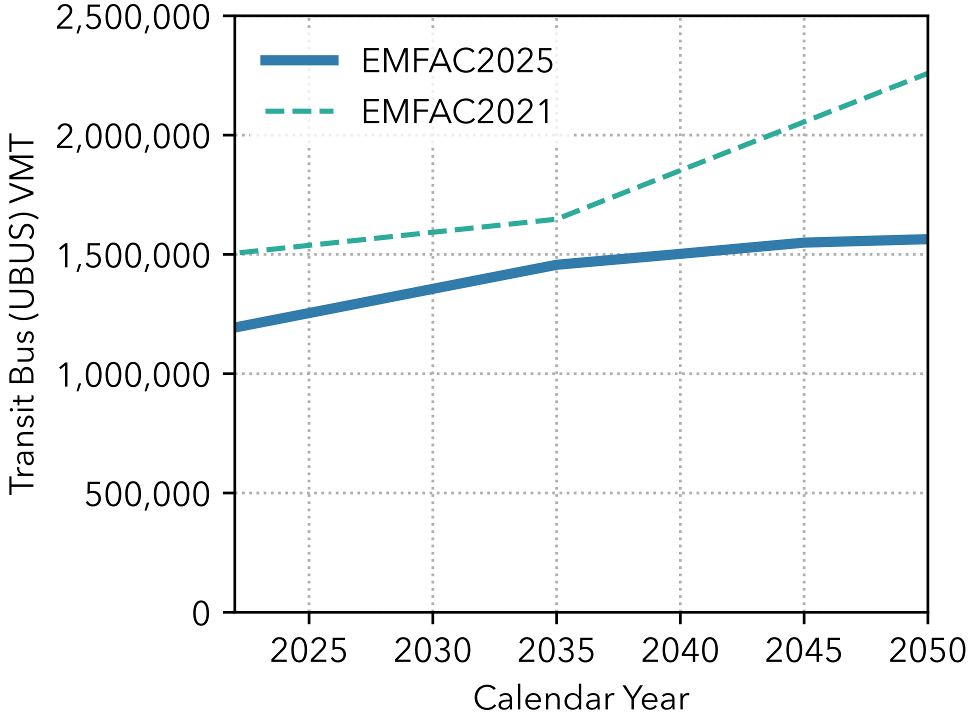


Figure 3.29: Transit Bus (UBUS) Vehicle Miles Traveled: EMFAC2025 vs. EMFAC2021

## 3.4 Natural Gas Vehicles

Following the same methodology used in EMFAC2021, staff incorporated the most recent vehicle registration data acquired from DMV to update the natural gas module. Similar to EMFAC2021, staff used two prediction classes: a flat average and a linear regression class. The flat average class assumes a constant fraction of natural gas penetration, while the linear regression class assumes that the natural gas fraction increases as a function of model year until it reaches 100%. As in EMFAC2021, EMFAC2025 applied fractions obtained from the DMV directly. Figure 3.30 compares the heavy-duty natural gas population in EMFAC2021 and EMFAC2025. For more details regarding the methodology, please refer to EMFAC2021 Technical Documentation Section 4.2.4 (CARB, 2021).

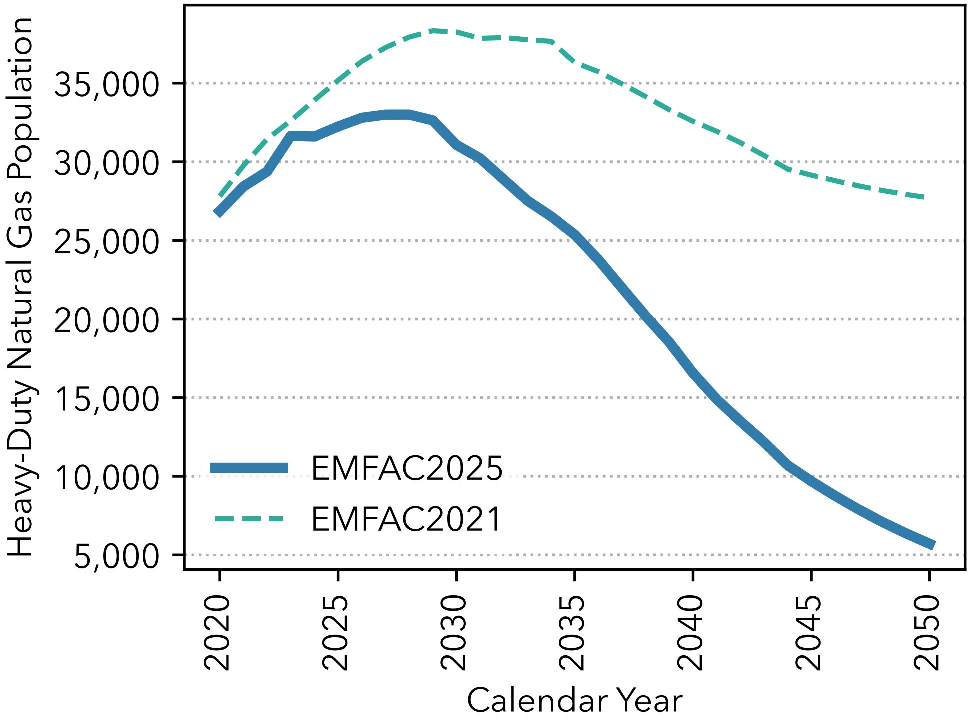


Figure 3.30: Projected Statewide Heavy-Duty Natural Gas Population

## 3.5 Heavy-Duty Vehicle Miles Traveled Reallocation

EMFAC estimates VMT at the sub-area level by combining population counts from registration data sources in a given sub-area and per-vehicle mileage accrual rates from the California Vehicle Inventory and Use Survey, which was last updated in EMFAC2021 (CARB, 2021). Additionally, accrual rates are adjusted for interstate fleet categories to account only for mileage within California.

Many truck fleet types operate significant distances from the sub-area in which they are registered. Therefore, the initial estimates for truck populations operating within a given sub-area are reallocated across all sub-areas within the State to reflect the latest information on truck operation. EMFAC historically relied on origin-destination survey data. Reallocation of out-of-state and IRP vehicles was based on a Caltrans study from 1999 (CARB, 2006), and other regional categories were based on a study from 2008 that was part of the Truck and Bus Regulation rulemaking (CARB, 2010). Staff updated truck populations, and therefore VMT, reallocation using a large volume of telematics data provided through an agreement with Geotab, along with Caltrans Annual Average Daily Traffic (AADT) data to validate the results.

The reallocation process for population and VMT starts with base year population data. The base year population data for 2022 serves as the input for the heavy-duty vehicles activity module to generate VMT. Figure 3.31 illustrates the process for calculating base year VMT and the process of incorporating high-resolution Geotab telematics data (shown in the red box), which modifies the distribution of population at the sub-area level. Initially, the population is adjusted using percentages derived from Geotab telematics data. This updated population is then input into the module to calculate the VMT at the sub-area resolution. The percentage of VMT per sub-area is checked to ensure it matches the initial percentages derived from the Geotab telematics data. If there is a difference, the reallocation process is repeated iteratively until the percentage of VMT per sub-area aligns with the Geotab telematics data. This iterative process is depicted in the loop within the flow chart. It is important to note that the total population of vehicles for each vehicle class in California remains constant, as this data is based on the most recent updates from the DMV.

While Geotab provides a representative subset of the general commercial population, it is 100% sampled VMT. Geotab provides a set of expansion factors as multipliers that, when applied to the sampled counts, estimate the general VMT. Geotab uses nationwide FHWA counting stations to create expansion factors for traffic volume using a concrete statistical model. For this update, staff complemented Geotab expansion factors with Caltrans AADT counting stations for two reasons: First, Caltrans AADT has more counting stations than FHWA (about 3,500 vs. 350 locations); second, Caltrans constantly monitors and updates the traffic volume at these locations.

After validating and updating the VMT data, staff used the revised distribution of population and VMT per sub-area to update the model input file for the base year population. Using the updated base year population and VMT, staff then forecasted and backcasted population and VMT for both future and historical years.

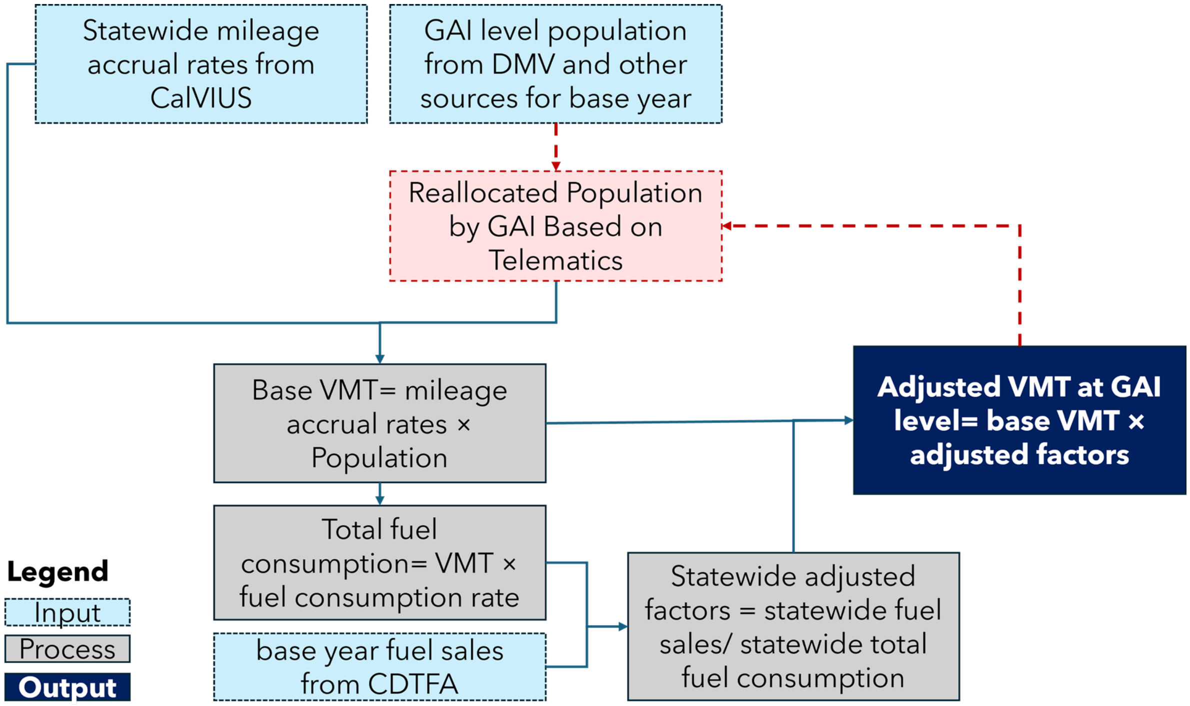


Figure 3.31: Process for Reallocation Heavy-Duty VMT in EMFAC2025

For historical years, staff started with the population data from 2008, the year when the last survey for VMT reallocation was conducted. The original population for 2008 served as the starting point, and the reallocated population data for 2022 was the endpoint. Using linear interpolation, staff calculated the population for each intermediate year by assuming a constant annual growth rate. This approach provided a continuous population series from 2008 to 2022. After establishing the interpolated population data, staff calculated the annual population growth rate for each vehicle class by determining the year-over-year percentage change in population from 2008 to 2022. Staff then applied these growth rates to adjust the population of specific vehicle classes, ensuring that the growth trends were accurately reflected.

Figure 3.32 compares heavy-duty VMT between EMFAC2025 and EMFAC2021 for sub-areas with the highest VMT. Compared to EMFAC2021, the updated VMT fractions in EMFAC2025 have the most significant relative decreases in Los Angeles (SC), Kern (SJV), and San Bernardino (MD), while Riverside (SC), San Joaquin Valley (SJV), and Sacramento (SV) have the most significant relative increases.

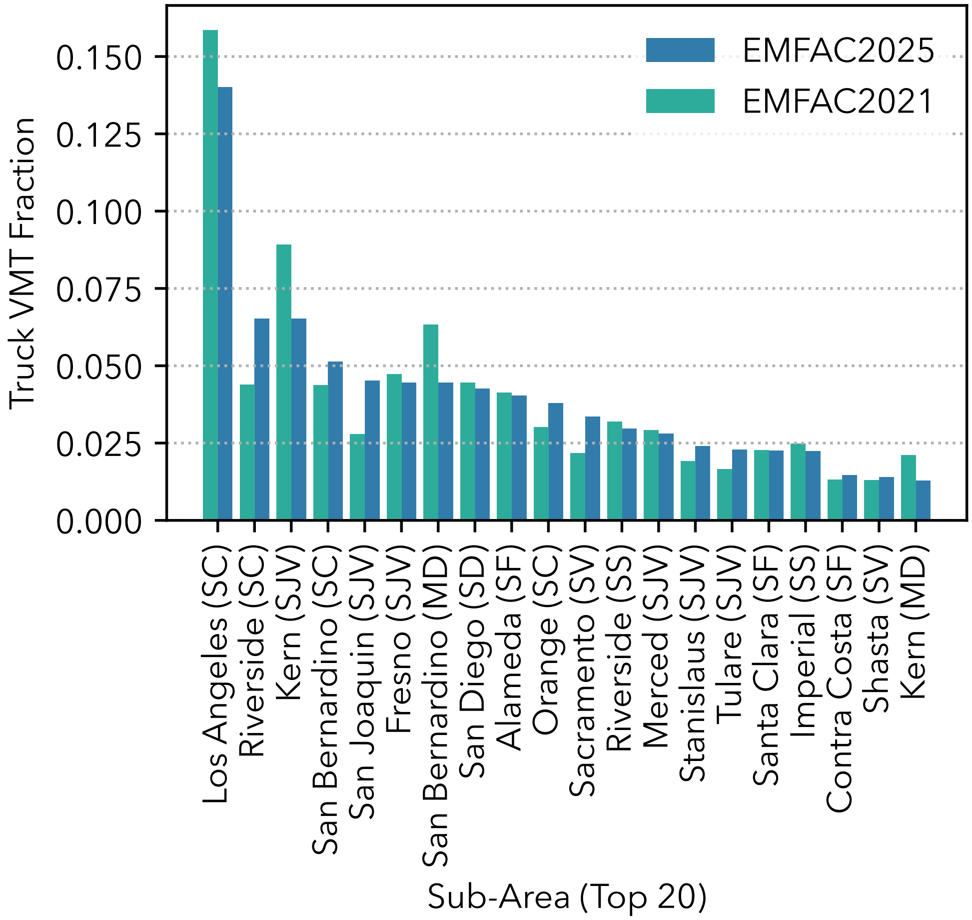


Figure 3.32: Heavy-Duty VMT Fractions in 20 Sub-Areas with Highest VMT

# 4 Updates on Vehicle Population and Vehicle Miles Traveled Forecasting

## 4.1 Vehicle Mileage Accrual Update

The mileage accrual rate is an estimate of the miles per year traveled per vehicle. Bureau of Automotive Repair (BAR) Smog Check Data was used to derive regional mileage accrual rates by vehicle age and class for light-duty vehicles using methods similar to those employed since EMFAC2007. Due to insufficient Smog Check program data for diesel vehicles, it was assumed that their mileage accrual rates are the same as those of gasoline-powered vehicles in the same class.

BAR Smog Check data for calendar years 2001 through 2022 were used to develop updated mileage accrual rates. Vehicle records were matched across biennial review years (such as 2001 with 2003, 2002 with 2004, etc., up to 2021 with 2022). The first record from the earlier year was matched to the first record from the later year. For each matched pair, the difference in odometer readings and test dates was computed. To avoid errors from five-digit odometer displays, only positive mileage differences were used. Based on the differences in dates and odometer readings between biennial review tests, miles per day were computed. These values were then converted to annual miles of accrual using 365 days per year. To eliminate potential data entry errors, outliers above 200,000 annual miles were excluded, following the National Highway Administration National Household Travel Survey methodology (ORNL, 2011).

For each region and vehicle class, the average mileage accrual by age was computed and used to develop regression equations. Where possible, updated regression equations for mileage accrual were determined by grouping similar Sub-Areas (See Table A-3 for definitions) together as a Region. The regional grouping is illustrated in Figure 4.1. For LHD1, LHD2, and Motor Homes, there was only sufficient data to establish statewide average mileage accrual rates. In addition, where insufficient data were available for individual vehicle classes, some classes were combined into a single grouping (such as LHD1 and LHD2). Table 4.1 summarizes the groupings used to compute the mileage accrual rates.

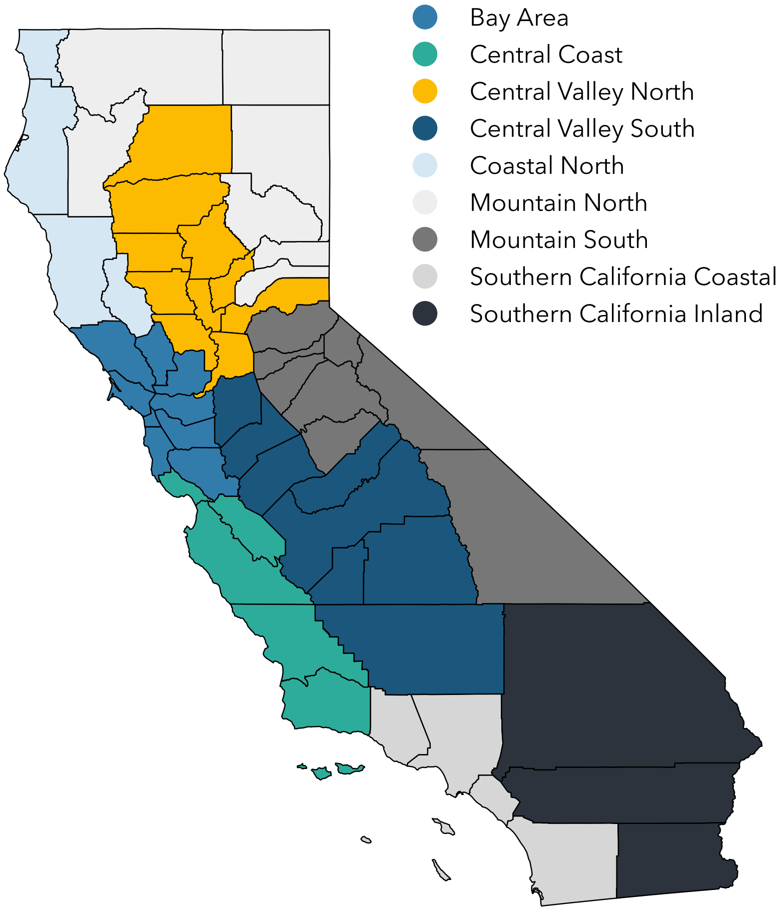


Figure 4.1: Regional Groupings for Deriving Accrual Rates

Table 4.1: Geographic Grouping for Accrual Rate Calculation.

| Vehicle Category | Grouping |
|---|---|
| LDA (Passenger Cars) | Regional (groups of similar Sub-Areas) |
| LDT1 (Light-Duty Trucks; GVWR <6,000 lbs. and ETW ≤3,750 lbs.) | Regional (groups of similar Sub-Areas) |
| LDT2 (Light-Duty Trucks; GVWR <6,000 lbs. and ETW 3,751–5,750 lbs.) | Regional (groups of similar Sub-Areas) |
| MDV (Medium-Duty Trucks; GVWR 6,000–8,500 lbs.) | Regional (groups of similar Sub-Areas) |
| LHD1 & LHD2 (Light-Heavy Duty Trucks; GVWR 8,501–14,000 lbs.) | Statewide |
| MH (Motor Homes) | Statewide |

In EMFAC2021, confidential data provided by vehicle manufacturers was analyzed to estimate the average annual mileage for electric vehicles. Based on this data, the average annual accrual rate for the base year 2015 was set at 70% of the statewide gasoline average annual mileage by vehicle age. As battery range is expected to improve over time, this 70% baseline is gradually increased each year, reaching 100% by calendar year 2025. The same methodology is incorporated in EMFAC2025. However, in EMFAC2021, electric accrual rates were uniform across all light-duty vehicle classes and regions. In contrast, EMFAC2025 updates these rates to vary by vehicle class and region while still adhering to the 70%–100% phase-in schedule.

Examples of accrual rate curves developed through this analysis are illustrated in Figures 4.2 to 4.4. Figure 4.2 compares EMFAC2021 and EMFAC2025 annual mileage accrual for LDA in Los Angeles County (South Coast Air Basin), with EMFAC2025 values based on the South California coastal region. Figure 4.3 presents the same comparison for LDA in Kern County (San Joaquin Valley Air Basin), using EMFAC2025 mileage accrual from the Central Valley South Region. Figure 4.4 compares statewide mileage accrual for the Light Heavy-Duty Trucks (LHD1, LHD2) category between EMFAC2021 and EMFAC2025. Annual mileage accrual rates for Age45+ light-duty vehicles are described in Section 2.1.2.3.

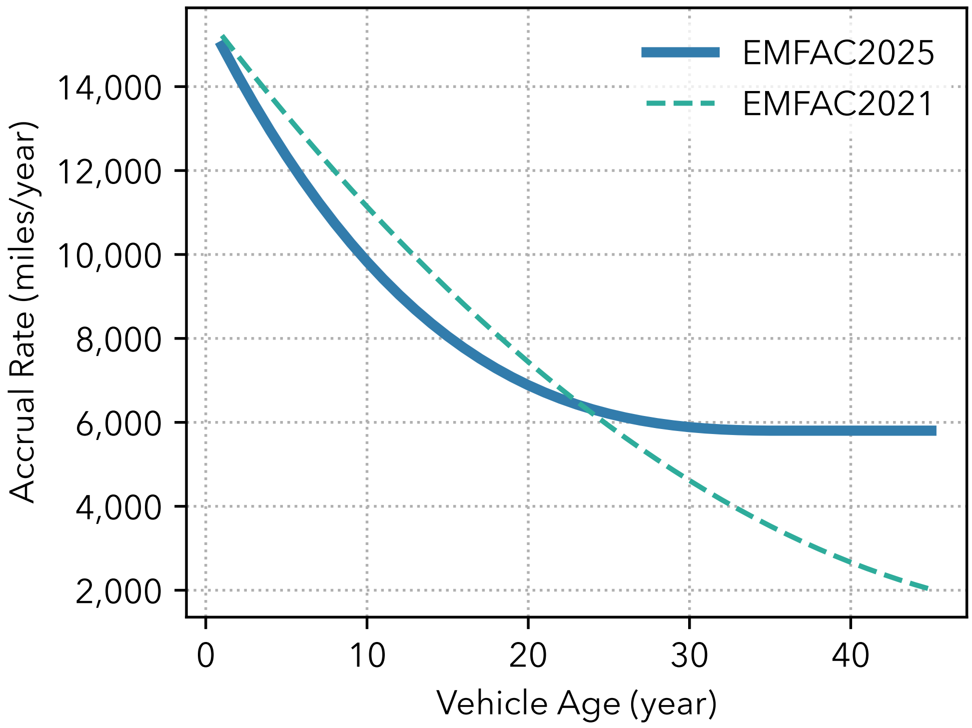


Figure 4.2: Annual Mileage Accrual for Passenger Cars (LDA) for Los Angeles County in the South Coast Air Basin

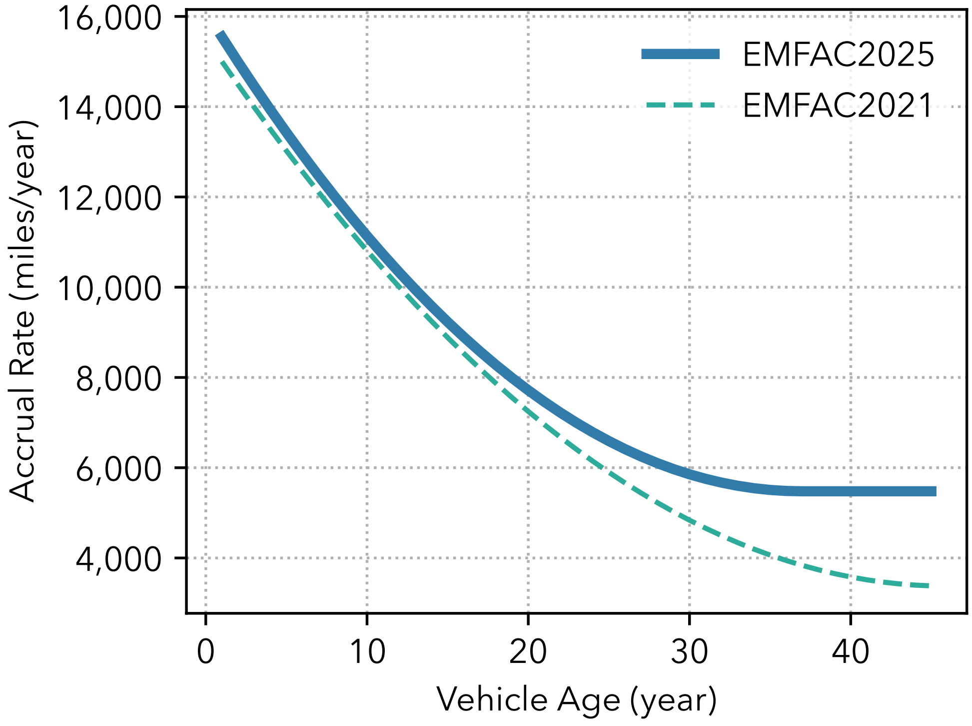


Figure 4.3: Annual Mileage Accrual for Passenger Car (LDA) for Kern County in the San Joaquin Valley Air Basin

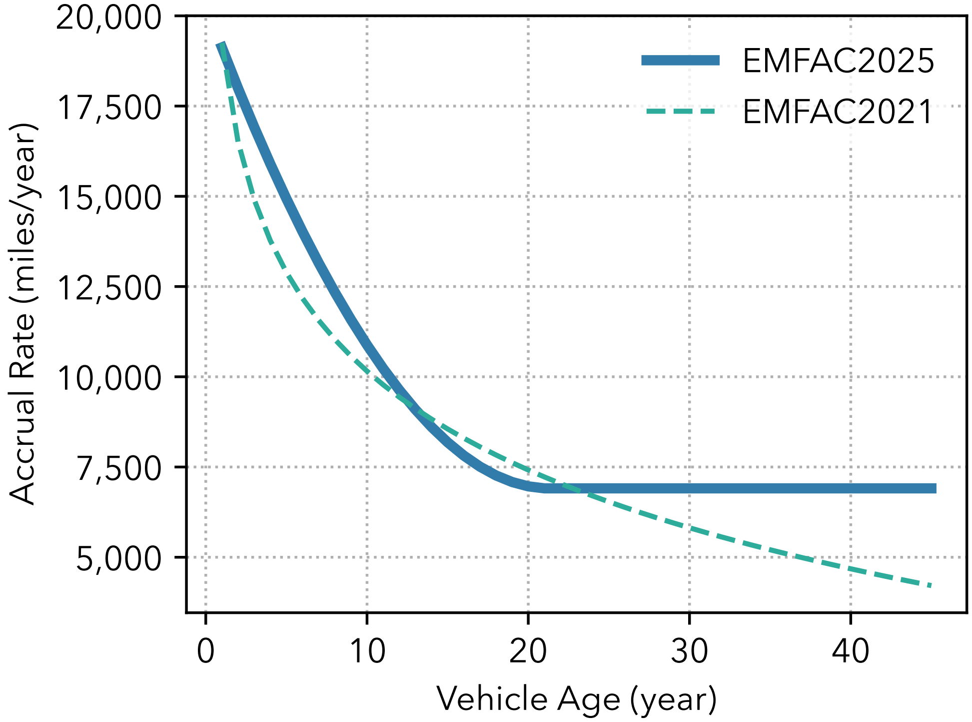


Figure 4.4: Statewide Annual Mileage Accrual Curves for Light Heavy-Duty Trucks (LHD1, LHD2)

## 4.2 Retention Rate Update

Retention rates were last updated in EMFAC2017, which used DMV-registered vehicle counts from calendar year 2005 through 2016. In EMFAC2025, the retention rates were updated using DMV data from 2005 through 2022. Although available, data from earlier years of 2000–2004 and 2012–2013 was excluded due to inconsistencies in the DMV records.

Retention rates for each vehicle class were computed using the proportion of vehicles remaining, for a given model year (MY), across each pair of consecutive calendar year (CY), across all the years of DMV data used in the analysis. DMV-registered vehicle counts from calendar year 2005 to 2022 were grouped into calendar year pairs for e.g., 2005–2006, 2006–2007, and so on through 2021–2022, for each vehicle class, either regionally grouped or statewide. Retention rate ($RR$) for a given calendar year pair $CY$, model year, region, vehicle class, and fuel is calculated using Equation (4.1):

$$RR_{CY_n} = \frac{P_{CY_n}}{P_{CY_{n-1}}} \tag{4.1}$$

where $P_{CY}$ indicates the DMV-registered vehicle count for calendar year pair $CY$, model year, region, vehicle class, and fuel type.

These retention rates were then averaged by vehicle age to smooth out year-to-year fluctuations in the data. Retention rate curves were developed by fitting a regression through these age-averaged values. This approach differs from earlier EMFAC models, where retention rates were derived based on survival rates. Details on the previous methodology can be found in Section 3.3.3.1.3 of the EMFAC2014 Technical Documentation (CARB, 2015).

Due to limited DMV data availability by fuel type, vehicle counts were not disaggregated by fuel. As a result, the derived retention rates were applied uniformly across all fuel types. Therefore, diesel and gasoline vehicle counts were combined to derive retention rate curves. In addition, for vehicle classes with adequate data, retention rate curves were computed at the regional level (groups of similar GAIs). The regional grouping is same as the ones used in accrual rates and is illustrated in Figure 4.1. For some vehicle classes, however, only statewide retention rate curves could be developed due to data limitations.

A summary of the geographic levels used in developing retention rates for each vehicle class in EMFAC2025 is provided in Table 4.2 and Table 4.3. Migration into and out of California was unknown but was reasonably assumed to be at a state of equilibrium and could be ignored from the retention rate computational process. Retention rates, organized by vehicle class, Sub-Area, and fuel type, are ultimately assembled by age and used as inputs for vehicle activity calculations in the EMFAC model.

Table 4.2: Geographic and Fuel Groupings Used for Gasoline Vehicle Retention Rate Calculations

| Vehicle Category | Gasoline Vehicles |
|---|---|
| Passenger Cars (LDA) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Duty Trucks (LDT1) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Duty Trucks (LDT2) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Medium-Duty Trucks (MDV) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Heavy Duty Trucks (LHD1) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Heavy Duty Trucks (LHD2) | Statewide, Combined Gas and Diesel Counts |
| Heavy Duty Trucks 14,001–33,000 lbs. (T6) | Statewide, Gas Counts Only |
| Heavy Duty Trucks >33,000 lbs. (T7) | Statewide, Gas Counts Only |
| Other Buses (OBUS) | Statewide, Gas Counts Only |
| Motorcycles (MCY) | Regional (Groups of GAI) Gas Counts Only |
| School Buses (BS) | Statewide, Diesel Counts Only |
| Motor Homes (MH) | Statewide, Gas Counts Only |

Table 4.3: Geographic and Fuel Groupings Used for Diesel and Electric Vehicle Retention Rate Calculations

| Vehicle Category | Diesel & Electric Vehicles |
|---|---|
| Passenger Cars (LDA) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Duty Trucks (LDT1) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Duty Trucks (LDT2) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Medium-Duty Trucks (MDV) | Regional (Groups of GAI), Combined Gas and Diesel Counts |
| Light-Heavy Duty Trucks (LHD1) | See Section 4.6.1 |
| Light-Heavy Duty Trucks (LHD2) | See Section 4.6.1 |
| Heavy Duty Trucks 14,001–33,000 lbs. (T6) | See Section 4.6.1 |
| Heavy Duty Trucks >33,000 lbs. (T7) | See Section 4.6.1 |
| Other Buses (OBUS) | See Section 4.6.1 |
| Motorcycles (MCY) | Not Applicable |
| School Buses (BS) | See Section 4.6.1 |
| Motor Homes (MH) | Not Applicable |

Examples of retention rate curves developed through this analysis are illustrated in Figures 4.5, to 4.7. Figure 4.5 compares EMFAC2021 and EMFAC2025 retention rates for passenger cars (LDA) in Los Angeles County (South Coast Air Basin), with EMFAC2025 values based on the Southern California Coastal Region. Figure 4.6 presents the same comparison for passenger cars (LDA) in Kern County (San Joaquin Valley Air Basin), using EMFAC2025 rates from the Central Valley South Region. Figure 4.7 compares statewide retention rates for the Light Heavy-Duty Trucks (LHD2) category between EMFAC2021 and EMFAC2025.

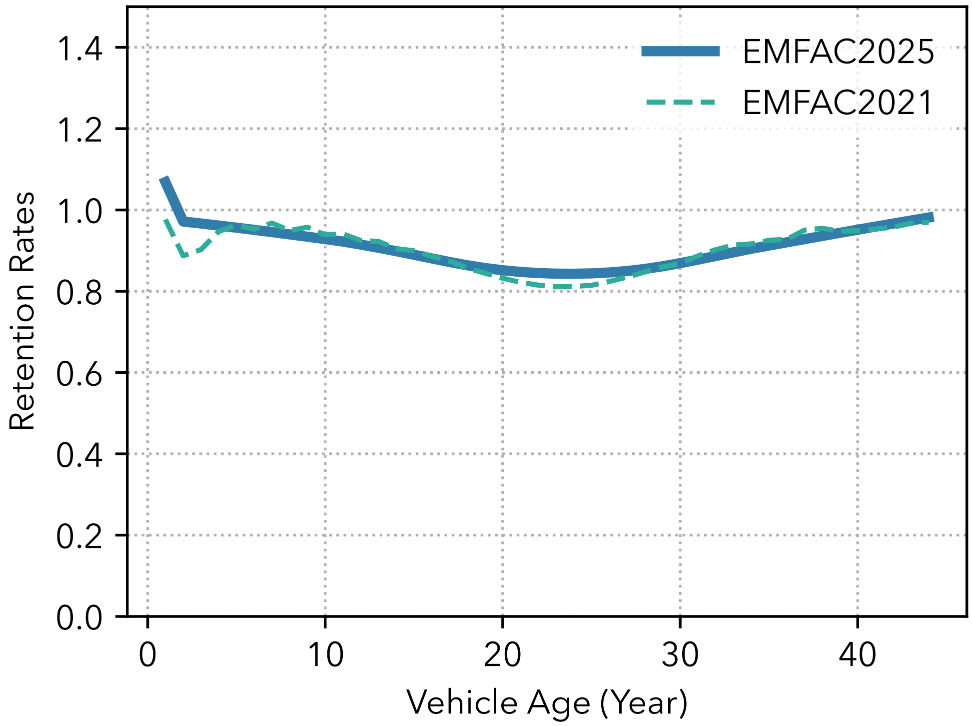


Figure 4.5: Retention Rates for Passenger Car (LDA) for Los Angeles County in the South Coast Air Basin

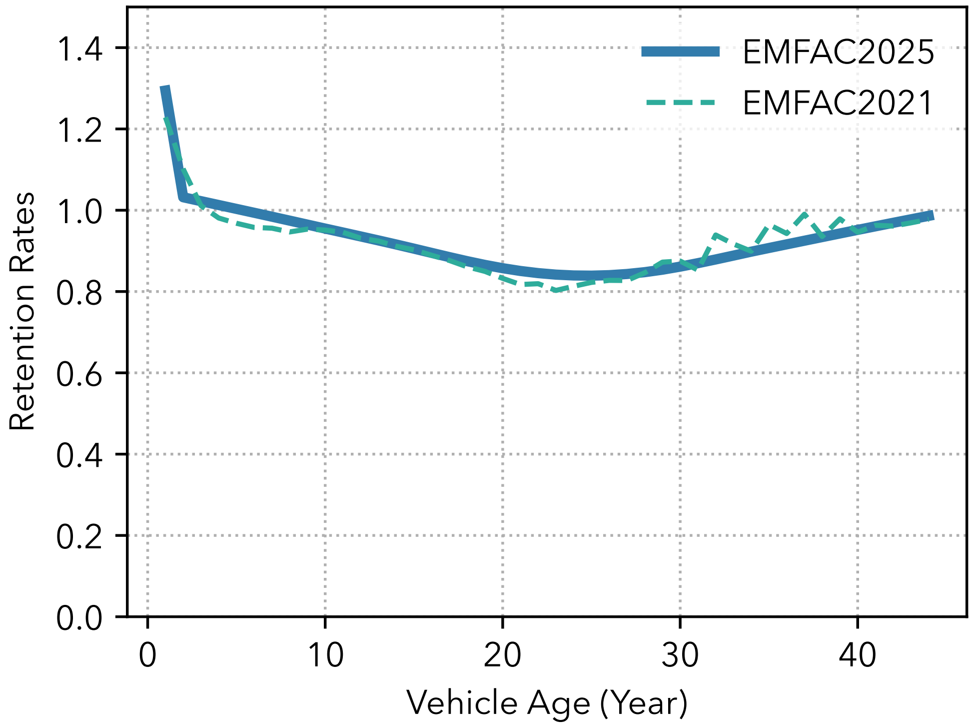


Figure 4.6: Retention Rates for Passenger Car (LDA) for Kern County in the San Joaquin Valley Air Basin

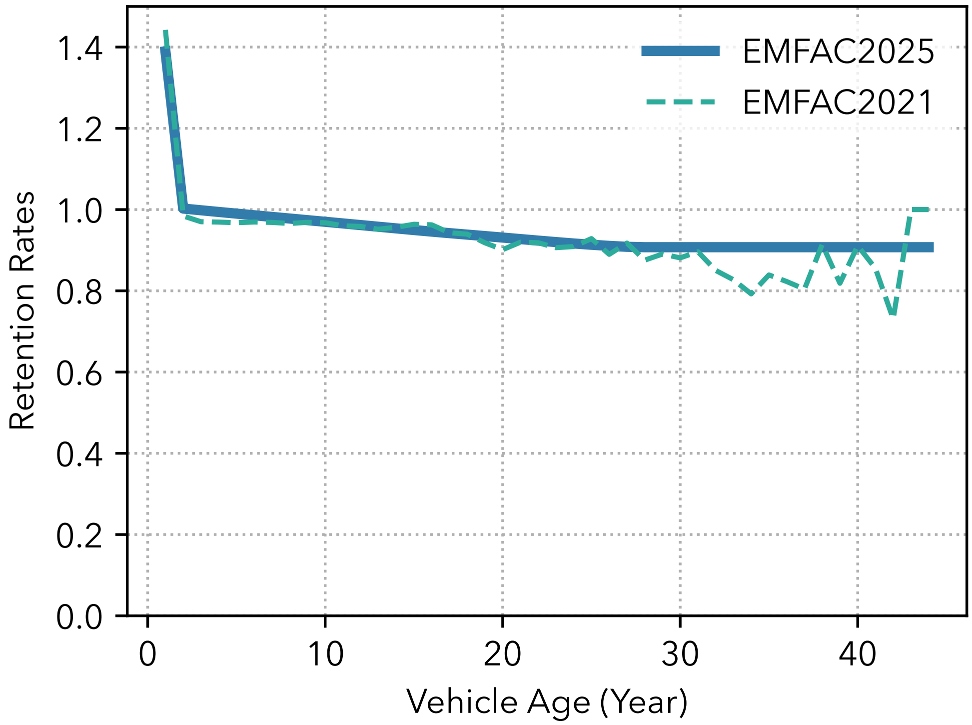


Figure 4.7: Statewide Retention Rates Curves for Light Heavy-Duty Trucks (LHD2)

## 4.3 Vehicle Start Adjustment

For gasoline light-duty vehicles, the number of vehicle starts is an important input for estimating vehicle start exhaust emissions (STREX). Vehicle start values were last updated in EMFAC2017 using data from the California Household Travel Survey (CHTS; NuStats, 2013). EMFAC2025 keeps these baseline vehicle start values but applies an adjustment factor to account for changes in vehicle miles traveled (VMT) per vehicle. The adjustment factor scales vehicle starts based on VMT per vehicle, as shown in Equation (4.2):

$$\text{Vehicle Starts}_y = \text{Vehicle Starts} \times \frac{\left(\frac{\text{VMT}}{\text{Vehicle Population}}\right)_y}{\left(\frac{\text{VMT}}{\text{Vehicle Population}}\right)_{2012}} \tag{4.2}$$

where $y$ is the year for which the vehicle starts are calculated and $\left(\frac{\text{VMT}}{\text{Vehicle Population}}\right)_{2012}$ is the VMT per capita for the year 2012, when the vehicle start data from CHTS were collected.

Figure 4.8 shows the adjustment factors for the number of vehicle starts that EMFAC uses for light-duty vehicle classes. The adjustment factors for LHD1 and LHD2 apply to both their Public and Other categories (see Section 2.3).

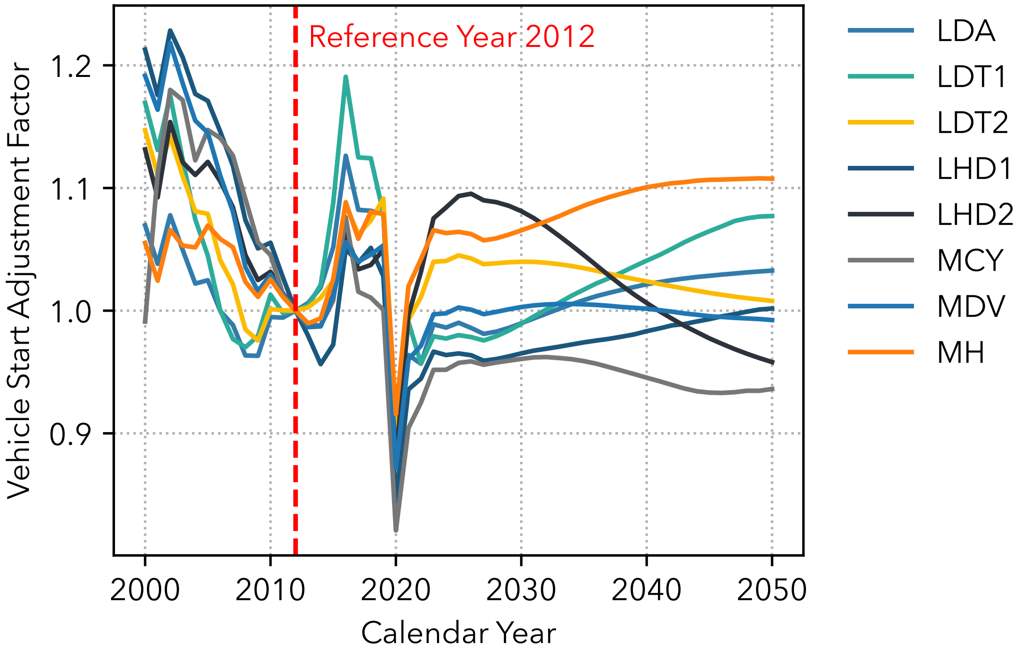


Figure 4.8: Adjustment Factors for the Number of Vehicle Starts Relative to Reference Year 2012

## 4.4 Light-Duty VMT and New Vehicle Sales Forecasting

### 4.4.1 Light-Duty VMT Forecast

EMFAC2025's forecasting methodology for future light-duty VMT generally follows the same process as EMFAC2021 and EMFAC2017. For calendar years following the base year (2022), VMT is forecasted under two regimes (near-term and long-term forecasts), summarized in Table 4.4.

Table 4.4: Methodologies Used for Light-Duty VMT Forecasting

| Years | VMT Forecasting Methodology |
|---|---|
| 2023 to 2027 | Use socioeconomic variables to forecast trends in VMT per capita and then multiply by human population to calculate VMT |
| 2028 to 2050 | VMT per capita is constant, and VMT trends follow the human population growth rate |

For near-term VMT forecasting (years 2023 to 2027), CARB staff apply a multivariate linear regression analysis using a range of socioeconomic variables to predict trends in VMT per capita. The socioeconomic variables that were considered as possible predictors of VMT per capita are listed in Table 4.5. The regression analysis is conducted at a statewide, annual scale for the historical period from 2003 to 2022. The year 2020 is excluded from the model fitting process, since it had an anomalous reduction in VMT per capita due to the COVID-19 pandemic. For purposes of this multivariate regression analysis, historical VMT was approximated based on gasoline sales data provided by the California Department of Tax and Fee Administration (CDTFA) and fuel efficiency estimates (miles per gallon) for light-duty vehicle classes from EMFAC2021.

Table 4.5: Variables and Data Sources Used for Multivariate Regression

| VMT Predictor Variable | Data Source |
|---|---|
| California human population | California Department of Finance (DOF, 2023) |
| Gas prices | California Energy Commission (CEC, 2023) |
| Federal gross domestic product | Congressional Budget Office (CBO, 2023) |
| Federal interest rate | |
| Housing starts | UCLA Anderson Economic Forecast (UCLA, 2023) |
| Unemployment rate | |
| Disposable income | |

CARB staff evaluated various combinations of these variables to identify the model that best captures historical trends in VMT per capita. A computer program was developed to automate the calculation of ordinary least squares regression fits for every possible combination of the above candidate variables. Initially, staff considered multivariate models with up to five predictor variables, including 1- and 2-year lagged versions of each variable to account for potential delayed effects. However, given the limited sample size (19 annual data points from calendar years 2003 to 2022), staff restricted the model to two predictor variables and excluded lagged terms. This decision aligns with general statistical guidance recommending a minimum of 10 observations per predictor variable to reduce the risk of overfitting. After generating all possible regression models, the following criteria were applied to identify the most appropriate model:

- The $p$-values for each predictor variable must be less than 0.05
- The adjusted $R^2$ value must be greater than 0.85
- The sign of the variable coefficients must make logical sense (e.g., the sign of the gas price coefficient should be negative, since higher gas prices should not lead to higher VMT).

After applying these criteria, the two-variable model with the highest adjusted $R^2$ was selected (Figure 4.9). This model had an adjusted $R^2$ value of 0.89. The $p$-values for each variable indicated statistical significance (Table 4.6). The chosen model that best predicted historical VMT per capita was:

$$\begin{aligned}\text{VMT per capita} = 9685.35 &- (118.65 \times \text{Unemployment Rate}) \\ &- (206.54 \times \text{Gas Price})\end{aligned}$$

Table 4.6: $p$-values for Terms in the Selected Multivariate Regression Model

| Variable | $p$-value |
|---|---|
| $y$-intercept | $1.76 \times 10^{-17}$ |
| Unemployment rate (%) | $7.28 \times 10^{-8}$ |
| Gas price (2021 USD) | 0.00079 |

For future years beyond 2027, trends in California's human population are used to forecast VMT, assuming a constant VMT per capita. Staff chose this approach because of uncertainty in the forecasted socioeconomic variables in the longer term. As a single predictor variable for light-duty VMT, human population correlates significantly with historical VMT, with an $R^2$ of 0.44 and a $p$-value of 0.0019.

It is important to note that the California Department of Finance's population forecast has been updated considerably since EMFAC2021. While the previous forecast predicted a logarithmic growth in California's population, the more recent forecast predicts a much flatter, and at times decreasing, growth rate in the state's population. While the previous forecast predicted

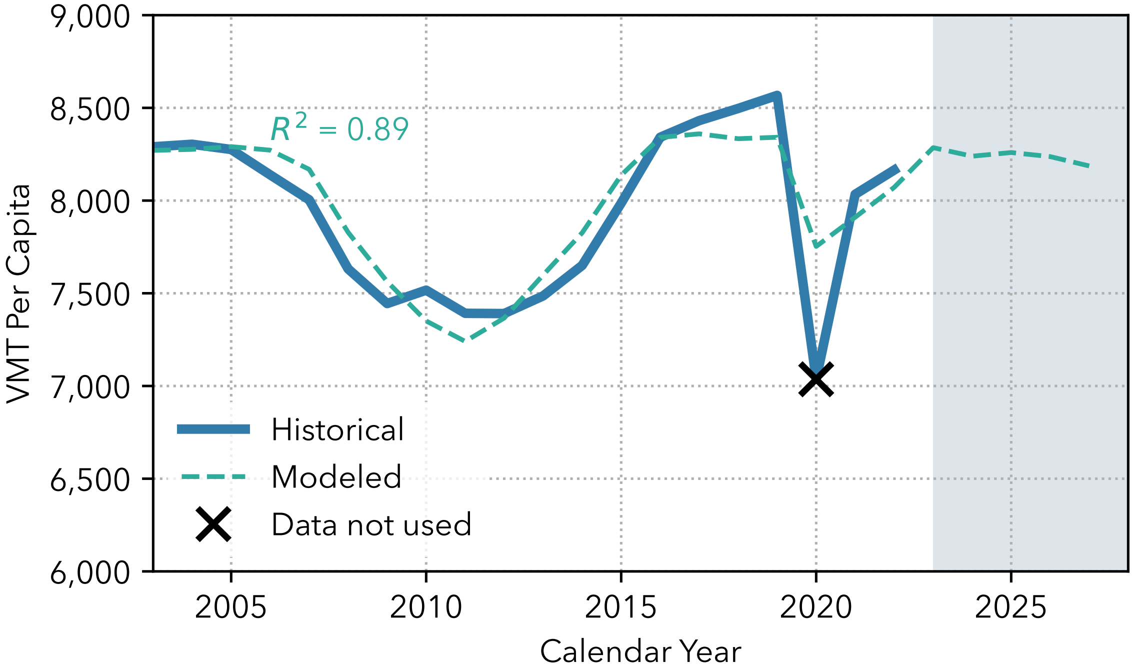


Figure 4.9: Vehicle Miles Traveled per Capita from 2003 to 2022: Historical vs. Modeled

population would grow to 44 million in 2050, the latest data estimates it will only be 40 million, staying close to the base year (2022) population of 39 million. This translates directly to the future VMT trends and is the primary cause of differing VMT trends between EMFAC2025 and EMFAC2021. The differing growth rates in human population between the two dataset versions are shown in Figure 4.10

To forecast VMT, CARB staff apply the human population growth rate relative to calendar year 2027 as shown in Equation (4.3):

$$\mathrm{VMT}_y = \mathrm{VMT}_{2027} \times \frac{\mathrm{Pop}_y}{\mathrm{Pop}_{2027}} \tag{4.3}$$

where *y* is a given year between 2028–2050 and Pop is the human population. The resulting trend in future VMT is shown in Figure 4.11

The EMFAC2025 forecast of VMT per capita (miles traveled per person per year) is shown in Figure 4.12. For pre-2020 historical years, EMFAC2025 estimates are consistently 6-7% lower than those in EMFAC2021. This reduction is primarily due to incorporation of high-speed driving, which decreased fuel efficiency. Since historical VMT is constrained by gasoline sales, the reduced fuel economy at higher speeds results in lower VMT estimates. After calendar year 2020, the gap in VMT per capita widens to 15-16%. The additional 8-9% difference is due to a slower post-pandemic VMT rebound than EMFAC2021 forecasted.

CARB's 2022 Scoping Plan established targets to reduce VMT per capita by 25% by 2030 and 30% by 2045, relative to 2019 levels. Based on fuel sales, VMT per capita in 2024 is 6% below

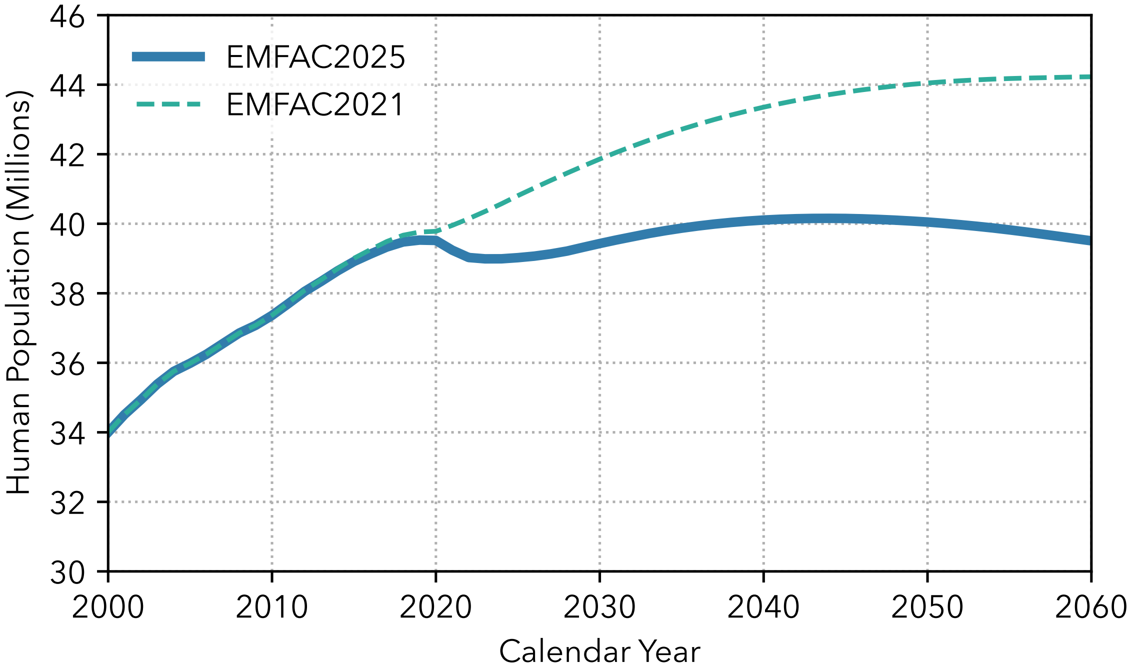


Figure 4.10: California's Human Population Growth Forecast: EMFAC2025 vs. EMFAC2021

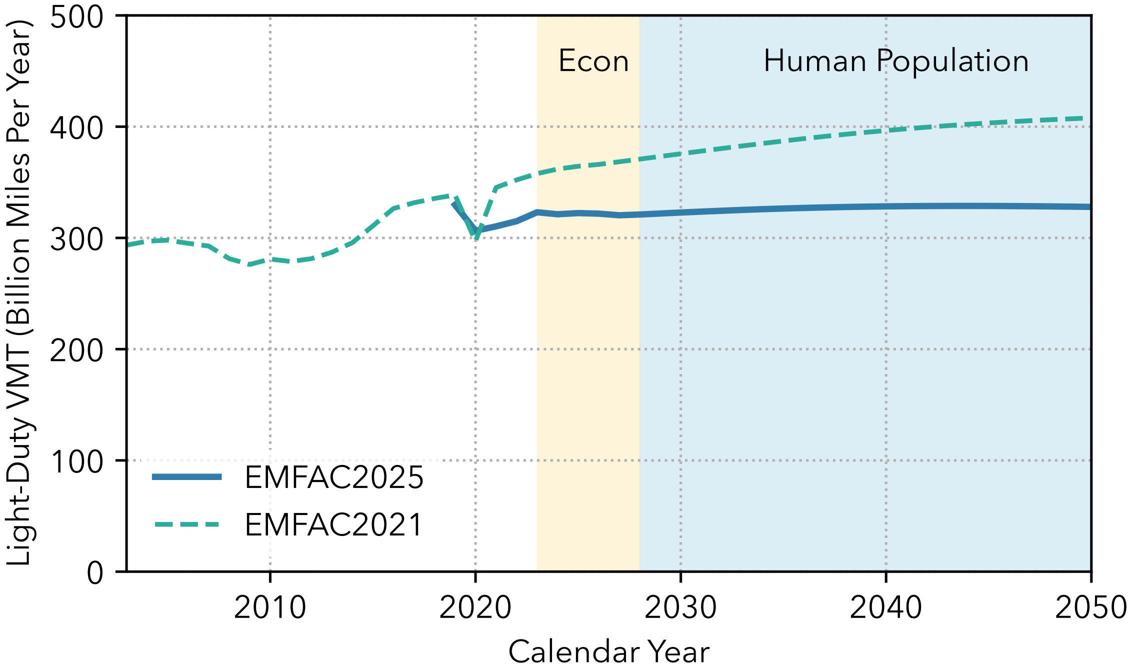


Figure 4.11: Forecasted Trends in Light-Duty Vehicle Miles Traveled, with Shaded Areas Indicating the Forecasting Methodology Used (Economic Multivariate Regression Model or Human Population Growth Rate).

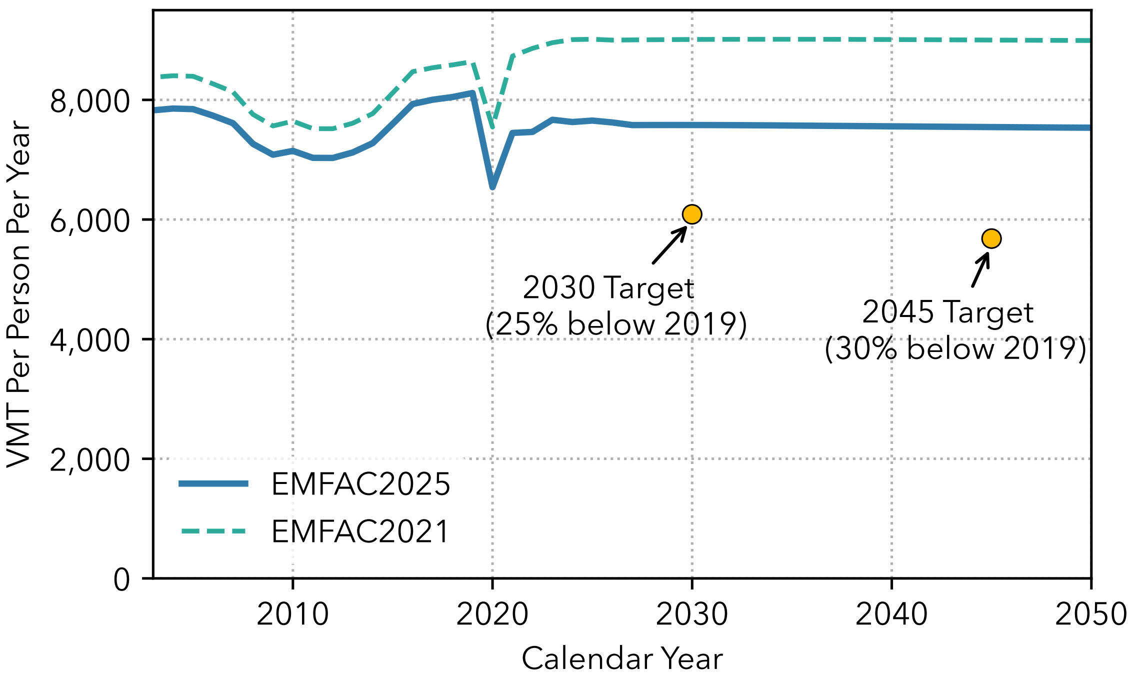


Figure 4.12: Forecasted Trends in Light-Duty Vehicle Miles Traveled Per Capita. Points indicate VMT per capita reduction targets (relative to calendar year 2019) set in the 2022 Scoping Plan.

2019, indicating modest progress towards the 2030 target.

### 4.4.2 Light-Duty New Vehicle Sales Forecast

Forecasted light-duty vehicle populations are determined by estimating the number of vehicles retained from the prior calendar year and adding in the estimated new vehicle sales, where new vehicle sales are exclusively the sales of brand new automobiles and does not include used vehicle sales. Figure 4.13 illustrates this process for EMFAC2021, where a multivariable regression was used to estimate forecasted new vehicle sales.

In EMFAC2021, the forecasting equation for statewide new sales of light-duty vehicles, of all fuel types, was developed using a multivariable regression analysis based on historical socio-econometric time-series data. EMFAC2021 included a modeling approach where variables were chosen based on the socio-economic indicators that best described the historical trend in new vehicle sales per capita. The primary data sources used for this analysis included UCLA Anderson Forecast (UCLA), California Department of Finance (DOF), and Department of Motor Vehicles (DMV) registration data.

For EMFAC2025, a multivariable regression analysis to forecast new vehicle sales per capita was only used for the short-run forecasting (calendar year < 2025) using a similar methodology as described above for EMFAC2021. Economic data provided by UCLA Anderson was used for the short-run forecasting. The data used in the regression analysis included gas price, GDP, interest rate, housing starts, unemployment, and disposable income as predictor variables.

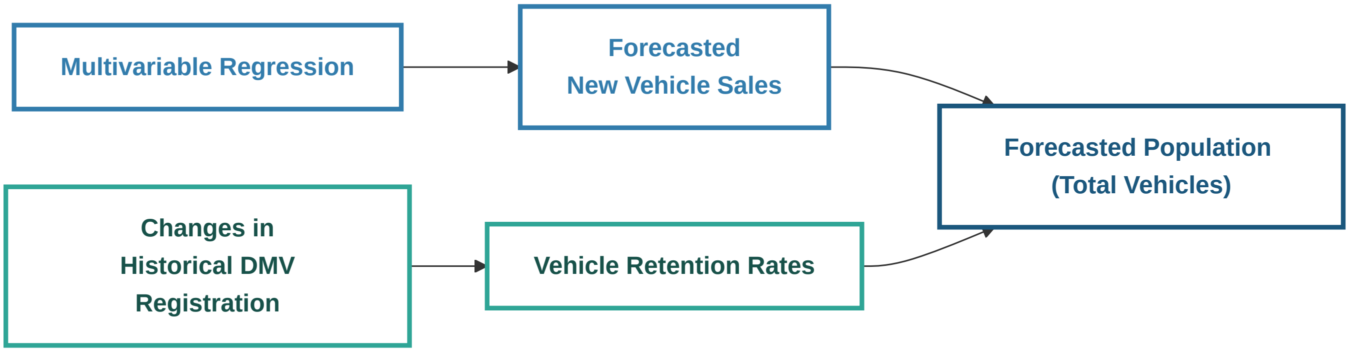


Figure 4.13: EMFAC2021 Light-Duty Vehicle Population Forecasting Methodology

Since it is impractical to look at all available combinations of the given parameters, a model was developed to create random n-variable models using a combination of the given parameters such as housing starts and unemployment rate. Each model generated was then filtered based on their $R^2$, $p$-values, and the sensibility of the coefficients (e.g., negative correlation between unemployment rate and new vehicle sales). The models were created based on historical socio-econometric data obtained for calendar years 2003 through 2021; and projection or forecast for new vehicle sales was developed for calendar years 2023 through 2050. As shown in Equation (4.4), the selected model for forecasting light-duty new vehicle sales (NVS) per capita is a function of unemployment rate and housing starts.

$$\begin{aligned} \text{NVS per capita} &= 3.56 \times 10^{-2} + (1.03 \times 10^{-4} \times \text{Housing Starts}) \\ &\quad - (1.06 \times 10^{-3} \times \text{Unemployment Rate}) \end{aligned} \tag{4.4}$$

The selected model has an adjusted $R^2$ of 0.77, and $p$-values less than 0.05 for each predictor value, illustrating the significance of the selected parameters. A two-variable regression was chosen for its simplicity and no significant increases in adjusted $R^2$ or reductions in $p$-value when using higher order regressions. Table 4.7 shows coefficient values and $p$-values for each coefficient used in the regression.

Table 4.7: EMFAC2025 Light-Duty New Sales Regression Coefficients and $p$-Values

| Variable | Coefficient | $p$-Value |
|---|---|---|
| $y$-intercept | $3.56 \times 10^{-2}$ | $5.7 \times 10^{-6}$ |
| Housing Starts | $1.03 \times 10^{-4}$ | $4.4 \times 10^{-4}$ |
| Unemployment Rate | $1.06 \times 10^{-6}$ | $3.4 \times 10^{-2}$ |

For the long-run forecasting (calendar year ≥ 2025), an equilibrium model, developed from a CARB contract with University of California San Diego (Jacobsen, 2023), was used to estimate new vehicle sales. This change in methodology is highlighted in Figure 4.14 with changes shown in the orange boxes. The multivariable regression is necessary in the short-run due to many ongoing market externalities (e.g., COVID-19 pandemic and chip shortages in 2020 and 2021) that are impacting the new vehicle sales market. Thus, the short-run multivariable regression is used as a "bridge" between historical new sales and the long-run equilibrium model.

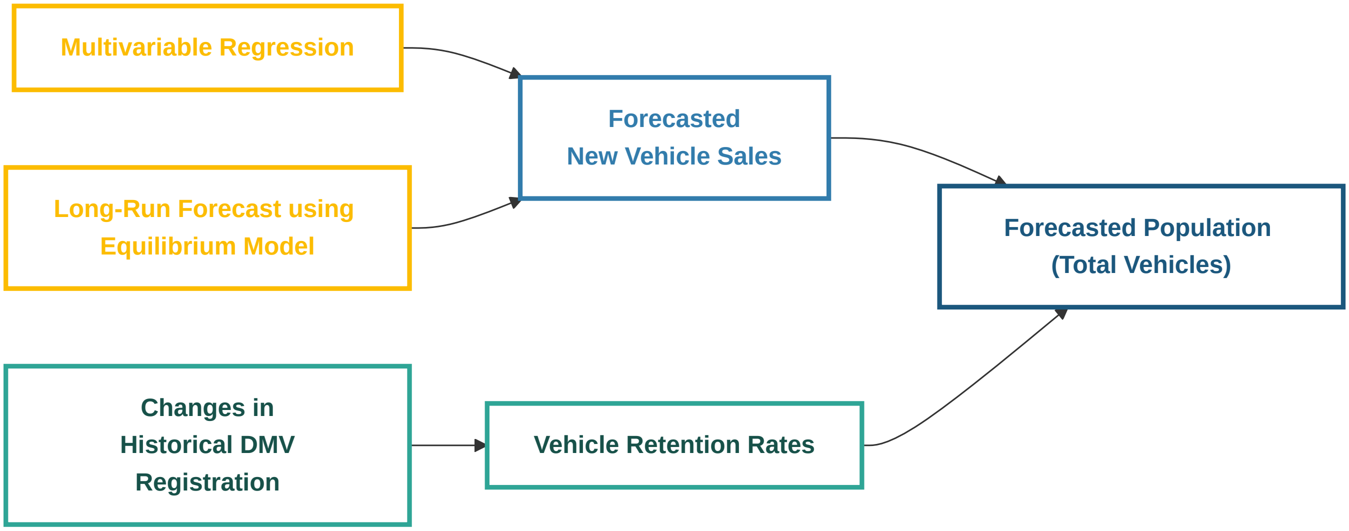


Figure 4.14: EMFAC2025 Light-Duty Vehicle Population Forecasting Methodology

The long-run equilibrium model is a dynamic equilibrium model that determines the point where supply and demand of vehicles are in balance. For example, if there is reduced travel demand forecasted in the future (e.g., lower population, better public transport forecasted, etc.), the equilibrium model will adjust the estimated sales of new vehicles, as well as the retention for older vehicles in the fleet. By using VMT forecasting as a proxy for travel demand, the equilibrium model is better equipped to capture changes in new vehicle sales based on projected travel demand and the price of vehicles rather than solely relying on historical new vehicle sales trends, as is true with the multivariable regression modeling. Please see (Jacobsen, 2023) for more details on the equilibrium model development.

Figure 4.15 shows the results for the new vehicle sales forecast for EMFAC2025 separated into short-run and long-run forecasts. Figure 4.15 also shows historical new vehicle sales and the forecasted new vehicle sales in EMFAC2021. Overall, results show that there is a decrease in forecasted new vehicle sales for EMFAC2025 compared to EMFAC2021. As discussed previously, for calendar year < 2025, this decrease is largely due to slower economic growth predicted from UCLA Anderson's economic forecast. For calendar year ≥ 2025, the long-run forecast shows stagnant growth in new vehicle sales, which can largely be attributed to little to no growth in VMT as discussed in Section 4.4.1. Since EMFAC2025 forecasts minimal VMT growth, there will likely not be a significant increase in demand for new vehicle sales.

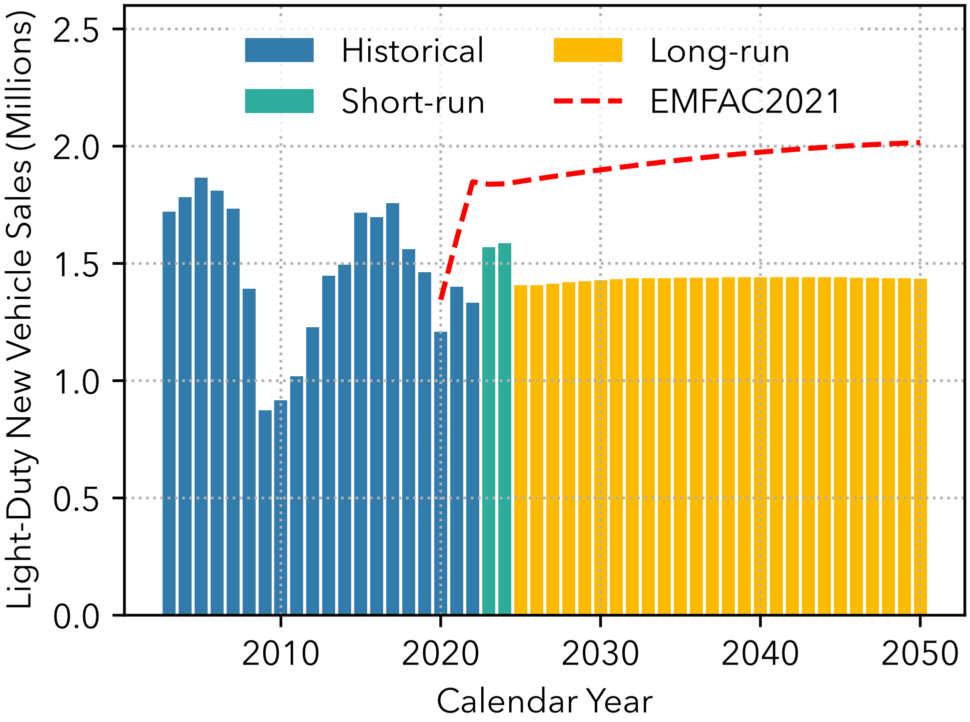


Figure 4.15: Forecasted New Vehicle Sales: EMFAC2025 vs. EMFAC2021

## 4.5 Zero-Emissions Vehicle Regional Allocation

EMFAC2021 estimates ZEV market share using light-duty vehicle choice models developed by the California Energy Commission (CEC). EMFAC2025 applies an updated version of the same framework, incorporating projections from the CEC's 2025 Integrated Energy Policy Report (IEPR) (CEC, 2025). The IEPR 2025 projections incorporate updated economic and demographic forecasts, fuel price assumptions, personal and commercial vehicle choice modeling, and current state fleet requirements for California government vehicles. They also reflect the expiration of federal tax incentives for ZEV purchases in September 2025.

CEC has developed and updated the IEPR modeling framework since 2003. It is an important tool for policymaking in California, including projecting demand for alternative fuel vehicles, forecasting future transportation energy consumption, and evaluating policy scenarios. California-specific data from the California Vehicle Survey form the foundation of the framework and are used to derive model coefficients. The survey captures the geographic distribution of households and businesses across California and includes thousands of responses, including hundreds from plug-in electric vehicle owners. ZEV new sales were mapped from IEPR vehicle classes to EMFAC vehicle classes using the ratios presented in Table 4.8.

Another update in EMFAC2025 is the regional reallocation of ZEV new sales. The EMFAC2021 forecast assumed equal ZEV sales shares across all counties; however, historical data from the Department of Motor Vehicles (DMV) indicates significant regional variation in adoption rates. To account for this variation, CARB established a contract with Lawrence Berkeley National Laboratory (Contract No. 22AQP010), titled *Spatially Disaggregated Forecasting of ZEV Adoption in California* (Jin, 2023). This project developed a vehicle-choice micro-simulator to spatially disaggregate forecast ZEV market shares at the county level, providing more regionally accurate inputs for EMFAC2025.

Table 4.8: Mapping of IEPR Vehicle Classes to EMFAC Vehicle Categories

| IEPR Vehicle Type | EMFAC Vehicle Category | | | |
|---|---|---|---|---|
| | LDA | LDT1 | LDT2 | MDV |
| S Car-Midsize | 100% | 0% | 0% | 0% |
| S SUV-Large | 19% | 0% | 0% | 81% |
| S Pickup-Heavy | 0% | 0% | 0% | 0% |
| S Car-Compact | 100% | 0% | 0% | 0% |
| P SUV-Midsize | 36% | 0% | 42% | 22% |
| S Pickup-Std | 0% | 0% | 46% | 54% |
| S SUV-Midsize | 36% | 0% | 42% | 22% |
| S SUV-Heavy | 0% | 0% | 0% | 0% |
| S Car-Subcompact | 100% | 0% | 0% | 0% |
| S Van-Heavy | 0% | 0% | 0% | 0% |
| P SUV-Large | 19% | 0% | 0% | 81% |
| P Car-Large | 100% | 0% | 0% | 0% |
| S SUV-Compact | 22% | 1% | 63% | 14% |
| P Car-Subcompact | 100% | 0% | 0% | 0% |
| S Pickup-Compact | 0% | 0% | 100% | 0% |
| P Car-Compact | 100% | 0% | 0% | 0% |
| S Van-Std | 0% | 0% | 0% | 100% |
| P SUV-Compact | 22% | 1% | 63% | 14% |
| P Car-Midsize | 100% | 0% | 0% | 0% |
| S SUV-Subcompact | 100% | 0% | 0% | 0% |
| P SUV-Subcompact | 100% | 0% | 0% | 0% |
| S Van-Minivan | 0% | 14% | 79% | 7% |
| S Car-Large | 100% | 0% | 0% | 0% |
| P Pickup-Std | 0% | 0% | 46% | 54% |
| S Car-Sport | 100% | 0% | 0% | 0% |
| P Car-Sport | 100% | 0% | 0% | 0% |
| P Pickup-Heavy | 0% | 0% | 0% | 0% |
| P Van-Std | 0% | 0% | 0% | 100% |

### 4.5.1 Regional Allocation Method

The conceptual model was developed by Clark *et al.* (2016). Car ownership typically changes over the household life cycle. Young adults often begin with no vehicle or a single car. As they form households and raise children, car ownership tends to increase to one or two vehicles. In families with older children or multiple drivers, ownership may rise to three or more cars. Later in life, as children leave home and adults enter retirement, car ownership typically declines – often returning to one or no vehicles due to changing health, mobility needs, or financial constraints. This model highlights a typical pattern in car ownership aligned with key household transitions.

Based on this concept, LBNL developed a model named Automobile and Technology Lifecycle-Based Assignment (ATLAS) aiming to simulate this vehicle transaction and technology adoption. The ATLAS model captures vehicle transaction decision process, tracks both new and used vehicle choices, and dynamically co-evolves with socio-demographic (Table 4.9) and spatial context. ATLAS provides insights into distributional effects and key drivers of adoption in both new and used vehicle markets (Jin *et al.*, 2024).

Table 4.9: Demographic Predictors Used in the Automobile and Technology Lifecycle-Based Assignment-Lite (ATLAS-Lite) Model

| Demographic predictors | Details |
|---|---|
| ZEV momentum | Past ZEV market shares |
| County demographics | Income; Average household size |
| Political ideology | Democrat vote share |
| Vehicle attributes | Price; Maintenance Cost; MPG; Acceleration; Charging time |
| Incentives | Rebate; Tax credit |
| Choice-specific | Powertrain; Body type |
| Infrastructure | Home charging availability |
| Household | Number of vehicles; Have kids; Household size; Income |

The ATLAS model was customized to support the EMFAC2025 update by providing county-level projections of new vehicle sales market share under the ZEV new sales natural growth prediction. This customized version is referred to as ATLAS-Lite. The model is used to assign new vehicle purchases by powertrain and body type to households in a cross-sectional framework. The ATLAS-Lite framework was developed according to the following steps (Figure 4.16). Table 4.10 presents the ATLAS-Lite model build variables:

- Prepare the model input including synthetic population by year, statewide ZEV new sales forecast, and vehicle attributes such as price, fuel efficiency, as well as incentives by year.

- Initialize the model by county-level ZEV new sales market share in year 2017 based on DMV registration data.
- ATLAS-Lite then models the timestep of vehicle transaction and whether the transactions lead to purchase of new vehicles at the household level (the timestep is every 2 years to mitigate the impact of pandemic, with the year 2020 skipped to represent pandemic effects).
- For each vehicle purchase that is modeled to occur in the previous step, ATLAS-Lite models the specific choice of vehicle (e.g., internal combustion engine vehicle or zero-emissions vehicles) in each household.
- Household-level vehicle choice outputs are aggregated to county-level ZEV new sales and incorporated into EMFAC2025.

CARB staff used DMV registration data to validate the model results for year 2019, 2021 and 2023. The model was only calibrated using the DMV data at year 2017, after that, each year's ZEV new sales prediction used the prior year's model output. Thus, although year 2019, 2021, and 2023 were historical years, they are from model outputs with no calibration. The comparison between the model outputs and DMV new sales market share demonstrates the model's strong performance, credibility, and robustness (Figure 4.17).

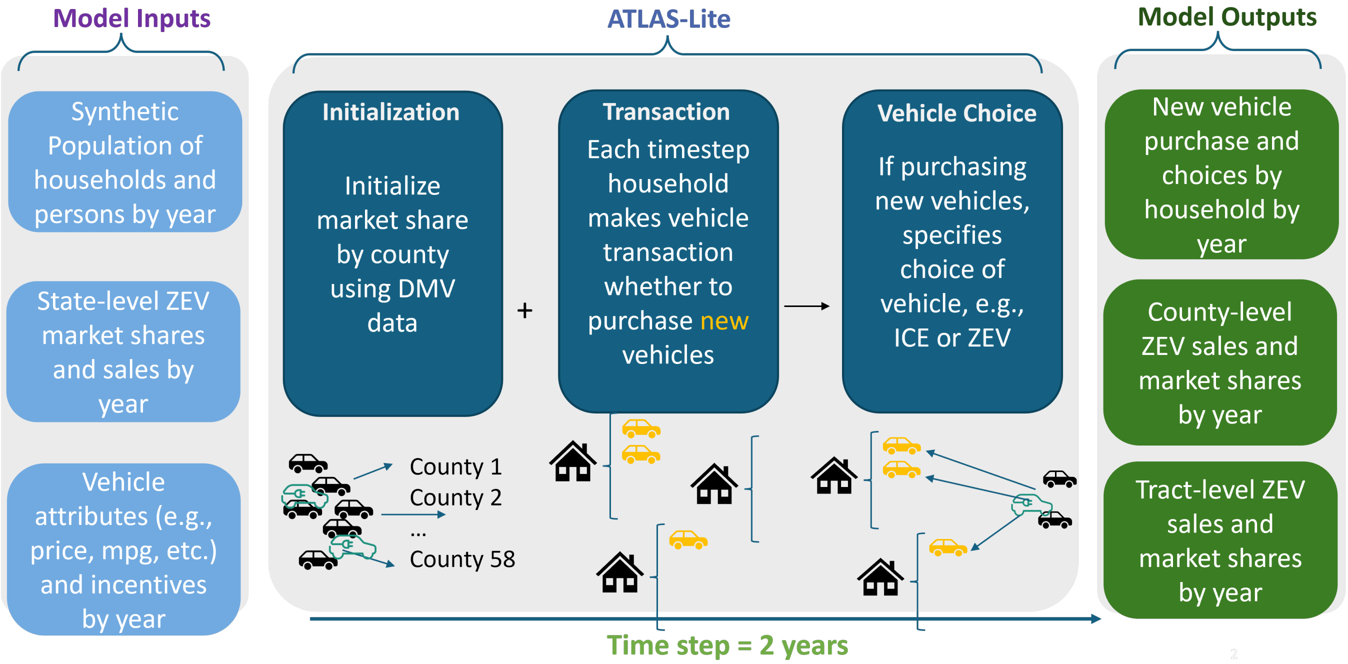


Figure 4.16: Automobile and Technology Lifecycle-Based Assignment-Lite (ATLAS-Lite) Model Framework

Table 4.10: The Automobile and Technology Lifecycle-Based Assignment-Lite (ATLAS-Lite) Model Build Variables

| Data Source | Time Range | Variables | Resolution |
|---|---|---|---|
| NHTS 2017 California (FHWA, 2018) | 2017 | Household demographic attributes, Vehicle ownership and choices | Household |
| CEC California Vehicle Survey 2019 (CEC, 2019) | 2019 | Household demographic choices, Vehicle attribute incentives | Household |
| Presidential Election Results (FEC, 2016, FEC, 2020) | 2016, 2020 | Democrat vote shares | County |
| DMV Registration Data (CARB, 2025) | 2017, 2019, 2021 | ZEV market shares | County |
| ACS 5-Year (U.S. Census Bureau, 2024) | 2017, 2019, 2022 | Location context | Census tract, County |
| Transit Access Data (Owen and Murphy, 2018) | 2017 | Job, Population density, Accessibility transit availability | Census tract |
| CNT Data (CNT, 2019) | 2019 | | Census tract |

### 4.5.2 Regional Allocation Results

Figure 4.18 displays the projected percentage of light-duty ZEVs among new vehicle sales in each California county for the years 2019, 2035, and 2045. The maps reveal a clear trend in ZEV adoption over time, with notable regional disparities in the early years across counties. The color gradient represents the ZEV share, ranging from 0 (light green) to 100% (dark green).

Figure 4.19 presents the projected growth in ZEV new sales market share for four California counties: Santa Clara, San Francisco, Riverside, and San Bernadino, from 2019 to 2050. Santa Clara and San Francisco show earlier and rapid adoption of ZEV, exceeding 50% ZEV market share by 2027. In contrast, Riverside and San Bernadino exhibit a slower adoption, ultimately reaching above 50% by 2050. The figure highlights regional disparities in ZEV adoption.

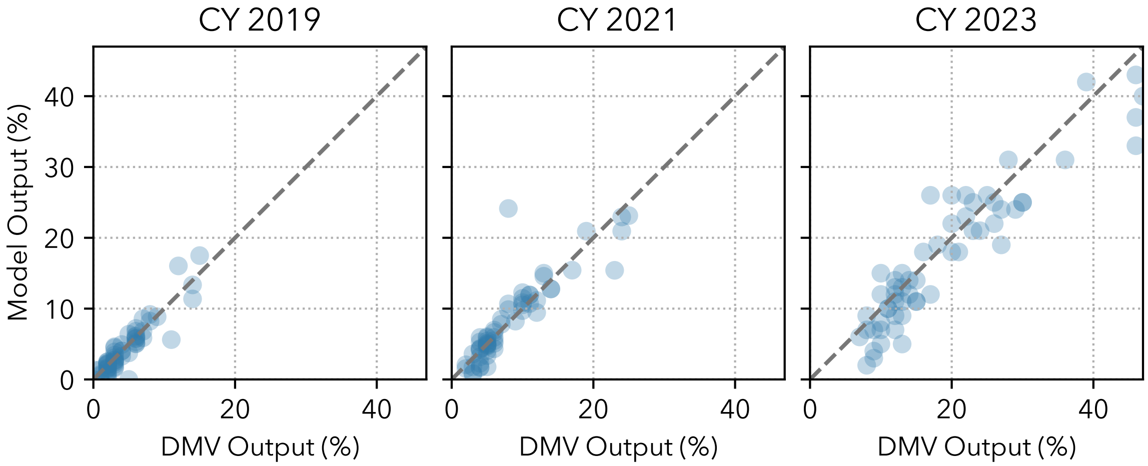


Figure 4.17: Comparison of County-level ZEV New Vehicle Sales between Model Outputs and DMV data

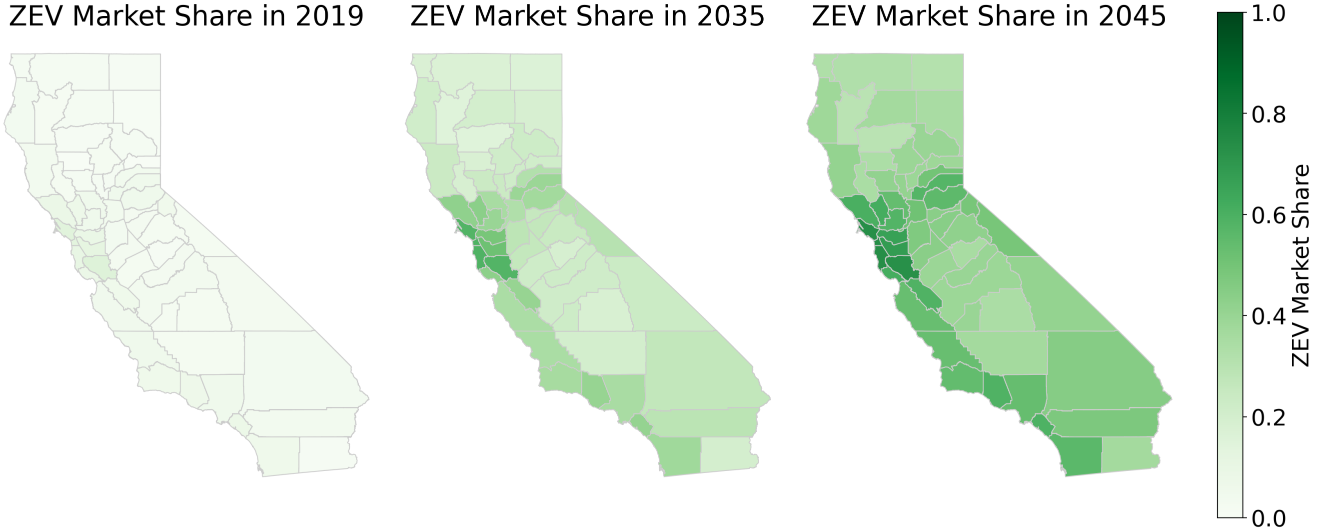


Figure 4.18: Projected County-Level ZEV Share of New Vehicle Sales in 2019, 2035, and 2045

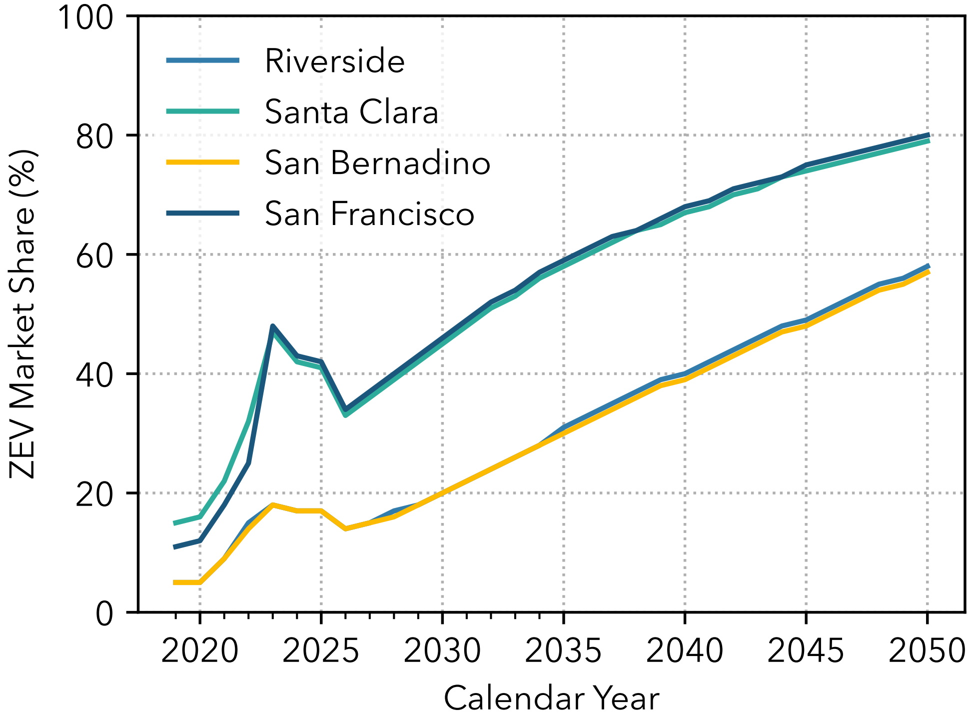


Figure 4.19: Evolution of ZEV New Sale Market Share by County

## 4.6 Heavy-Duty Retention Rates, New Sales, and VMT Forecasting

### 4.6.1 Heavy-Duty Vehicle Retention Rates

There are several processes that govern how vehicle populations of heavy-duty fleets change over time: 1) Increasing the population due to new sales, 2) Transfer of vehicle populations among different fleet types (e.g., CA IRP to port truck), 3) Decreasing the population due to scrappage, and 4) Decreasing in the population due to vehicles leaving the state. This information can be obtained by partitioning DMV registration data, considering vehicle vocation, operating industry, weight class, etc. Details about how DMV data are processed for heavy-duty vehicles can be found in heavy-duty fleet characterization Section 3.2.

In EMFAC, retention rates are a key intermediate parameter that helps quantify and forecast fleet population changes. The retention rate of the heavy-duty fleet is defined as the fraction of vehicles in a fleet that are retained (i.e., not sold, decommissioned, or replaced) on a yearly basis. In EMFAC2021, historical retention rates were calculated by the EMFAC vehicle category, using DMV registration data. Historical retention rates up to the base year were then used to calculate the forecasted vehicle populations. In EMFAC2025, the partitioning of heavy-duty fleet is further improved by considering fleet size, distinguishing larger fleet from smaller fleets with a threshold of 50 vehicles, based on Advanced Clean Fleets regulation. While CARB withdrew their waiver for the high priority fleets and drayage trucks requirements of the ACF regulation, the differentiated retention rates for larger fleets versus smaller fleets were still included in the EMFAC2025 model. This is due to the unique scrappage patterns between large and small fleets.

The methodology for back-calculating retention rates remains consistent between public and private sectors, with datasets differing. For public fleets, DMV registration data are used. For private fleets, CARB procured business ownership and address information from Dun & Bradstreet (D&B). Addresses from D&B were joined with DMV registration address to determine the fleet size of a certain private fleet operator. Therefore, in EMFAC2025, each non-public heavy-duty vehicle category has two sets of retention rates, one for fleets with 50 or more vehicles, and the other with less than 50 vehicles. The drayage fleet is an exception that does not have subcategories by fleet size.

For each vehicle category, staff used multi-year registration data to determine the year-over-year retention rates by model year and then averaged these rates across all model years. For instance, if the model year 2020 population was 1,000 in 2020, 900 in 2021, and 850 in 2022, the year-over-year survival rate would be 90% for age 1 (900/1000) and 94% for age 2 (850/900). Table 4.11 lists each heavy-duty vehicle category in EMFAC, and sources used for any updates made.

Table 4.11: EMFAC2025 Heavy-Duty Retention Rate Updates

| EMFAC2025 Vehicle Category | Data Sources used to Update Retention Rates |
|---|---|
| All Other Buses | Unchanged from EMFAC2021 |
| Motor Coach | |
| SBUS | |
| T6 OOS Class 4 | |
| T6 OOS Class 5 | |
| T6 OOS Class 6 | |
| T6 OOS Class 7 | |
| T7 NNOOS Class 8 | |
| T7 NOOS Class 8 | |
| T6 CAIRP Class 4 | Updated and sub-categorized using Dun & Bradstreet (D&B) dataset |
| T6 CAIRP Class 5 | |
| T6 CAIRP Class 6 | |
| T6 CAIRP Class 7 | |
| T6 Instate Delivery Class 4 | |
| T6 Instate Delivery Class 5 | |
| T6 Instate Delivery Class 6 | |
| T6 Instate Delivery Class 7 | |
| T6 Instate Other Class 4 | |
| T6 Instate Other Class 5 | |
| T6 Instate Other Class 6 | |
| T6 Instate Other Class 7 | |
| T6 Instate Tractor Class 4 | |
| T6 Instate Tractor Class 5 | |
| T6 Instate Tractor Class 6 | |
| T6 Instate Tractor Class 7 | |
| T6 Utility Class 4 | |
| T6 Utility Class 5 | |
| T6 Utility Class 6 | |
| T6 Utility Class 7 | |
| T7 CAIRP Class 8 | |

continues on next page

Table 4.11 – continued from previous page

| EMFAC2025 Vehicle Category | Data Sources used to Update Retention Rates |
|---|---|
| T7 Single Concrete/Transit Mix Class 8 | |
| T7 Single Dump Class 8 | |
| T7 Single Other Class 8 | |
| T7 SWCV Class 8 | |
| T7 Tractor Class 8 | |
| T7 Utility Class 8 | |
| T7 Other Port Class 8 | Updated using Dun & Bradstreet (D&B) dataset without fleet size specification |
| T7 POAK Class 8 | |
| T7 POLA Class 8 | |
| T6 Public Class 4 | Updated using DMV data without fleet size specification |
| T6 Public Class 5 | |
| T6 Public Class 6 | |
| T6 Public Class 7 | |
| T7 Public Class 8 | |

### 4.6.2 Heavy-Duty New Vehicle Sales Forecasting

EMFAC2025 continues to use the heavy-duty new vehicle sales forecasting method used in EMFAC2021, EMFAC2017, and EMFAC2014; refer to Section 3.3.4.1.2.1 of the EMFAC2014 Technical Documentation (CARB, 2015). The forecasting method begins with the national heavy-duty new vehicle sales growth trend, which is obtained from the 2023 Annual Energy Outlook (AEO) report from the U.S. Energy Information Administration (EIA). The national VMT and new sales growth trends are shown in Figure 4.20 and are referenced to the base year 2022. After which, these numbers are converted to California specific new HD vehicle sales growth trends using the ratio of national VMT growth based on AEO data vs. California's VMT growth.

While the new sales forecasting methodology has not changed, EMFAC2025 now uses the average new vehicle sales for the previous 3 calendar years (2020–2022), rather than just using the base year new vehicle sales as the starting point for new sales growth. This was done due to the unique trends in vehicle purchasing of heavy-duty vehicles. New vehicle sales trends show that for heavy-duty vehicles, it is more common to have large purchases of vehicles from fleet operators in certain calendar years, and little to no purchases in other calendar years. This trend is especially prominent at the GAI level where some vehicle categories could have no new sales in the base year. This has led to some inconsistencies in new vehicle sales with previous versions of EMFAC, where some vehicle categories had declines in total populations in the forecasted years, due to there being no new sales in the base year. The three-year average

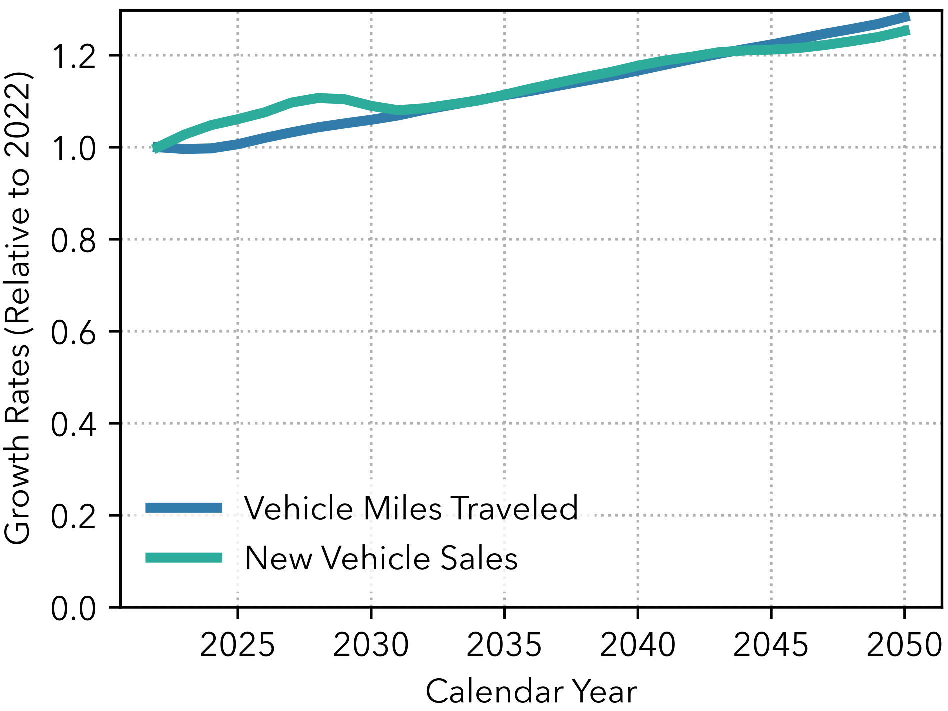


Figure 4.20: Heavy-Duty New Vehicle Sales and VMT Growth Rates Relative to Base Year (2022)

approach has alleviated this issue as now some of the intermittent large vehicle purchases are being captured for new vehicle sales forecasting.

### 4.6.3 Vehicle Miles Traveled Forecasting

EMFAC2025 continues to use the same forecasting methodology for VMT as what was used in EMFAC2021. County level VMT growth rates are extracted from the California Statewide Travel Demand Model (CSTDM) to forecast VMT from 2020 to 2050. Since the CSTDM model has not had a new release since EMFAC2021, the same forecasted growth rates are used in EMFAC2025. See section 4.5.2 in the EMFAC2021 documentation for more details on this methodology.

#### 4.6.3.1 Drayage Trucks

EMFAC2025 continues to use the same forecasting methodology as EMFAC2021, EMFAC2017, and EMFAC2014 for VMT growth rates for drayage trucks. The 2016 International Mercator Forecast was used to project drayage truck VMT growth operating at Port of Los Angeles (POLA) and Port of Long Beach (POLB). For POLA and POLB, it is expected that they will reach their capacity limit in 2035, and thus growth rates for these ports is zero for calendar year > 2035. For the Port of Oakland (POAK), growth rates are based on the moderate growth rate scenario described in the 2019-2050 Bay Area Seaport Forecast Report. “Other Ports” drayage category uses growth rates from POLA, POLB, and POAK that are adjusted by the twenty-foot equivalent unit (TEU) proportions.

#### 4.6.3.2 Construction and Motor Coach Buses

The VMT growth rates for construction and motor coach buses in EMFAC2025 were updated using projected growth in these sectors from UCLA Anderson's Annual Economic Forecast 2022. Year to year growth rates from UCLA's forecast are used to forecast VMT growth. The T7 Single Concrete/Transit Mix and the T7 Single Dump Fleets computed VMT growth rates using the construction employment data. The Motor Coach Bus Fleet computed VMT using the leisure/hospitality employment data.

#### 4.6.3.3 Public, Utility, and Solid Waste Collection Vehicles (SWCV), All Other Buses, and School Buses

EMFAC2025 uses the same methodology for forecasting VMT of public, utility, SWCV, and all other buses as EMFAC2021 and is assumed to follow the DOF-based statewide human population. These were updated to the data release from DOF from 2022, which forecasts population data for calendar year > 2023. The most recent DOF data shows a sharp decline in projected population when compared to the DOF data used for EMFAC2021. This has lead to a moderate decline in VMT growth forecasted for public, utility, SWCV, and all other buses. The school bus growth rates to forecast VMT are set at 1.0 (as it was in EMFAC2021 and EMFAC2017), reflecting no projected growth.

# 5 Heavy-Duty Emission Rate Update

## 5.1 Diesel Heavy Heavy-Duty Vehicles

To support CARB regulatory programs and better serve stakeholder needs, staff carried out multiple in-house projects as well as extramural contracts to test in-use heavy-duty diesel trucks and collect emissions data using Portable Emissions Measurement Systems (PEMS) and chassis dynamometers.

A chassis dynamometer is a testing device designed to replicate the resistance and inertia that a vehicle experiences during real-world driving conditions, particularly in urban environments. The vehicle is placed on rollers that simulate road load, allowing it to be driven in place while following a predefined driving cycle. Throughout the test, emissions analyzers continuously measure exhaust pollutants either in real time or through composite sampling, providing critical data on the vehicle's emission performance under controlled but realistic conditions.

PEMS are advanced, portable devices used to measure real-world vehicle emissions during actual on-road operation. Unlike laboratory-based testing on dynamometers, PEMS enables direct measurement of tailpipe pollutants under in-use driving conditions, including variations in speed, load, terrain, and ambient temperature. Numerous publications have focused on emission measurement under real-world driving conditions using PEMS (Zhu *et al.*, 2024, McCaffery *et al.*, 2021), and the available results provide data support for vehicle pollution control.

While dynamometer data provides standardized and repeatable data sources, PEMS data offer continuous measurements, which expand the dataset and improve representation of real-world conditions. For EMFAC2025, incorporating both data types is essential to ensure the model captures more representative emission rates across the vehicle fleet. To support this goal, CARB staff compiled a comprehensive dataset from three different data sources:

**In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles (HDIUT)**: In June 2005, the U.S. EPA adopted a manufacturer-run in-use testing program, titled *In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles (HDIUT)*. HDIUT requires engine manufacturers to measure and report in-use exhaust emissions from heavy-duty vehicles using onboard PEMS during typical over-the-road operation. Upon receipt of all the data and required information from the engine manufacturers, CARB examines the data and verifies that the emissions meet the in-use emissions standards and test requirements. HDIUT provides a large dataset (500+) to evaluate heavy-duty vehicle in-use behavior (CARB, 2024), and supported the EMFAC2025 diesel heavy-duty speed correction factor update.

**The Heavy-Duty Truck and Bus Surveillance Program (TBSP)**: The Heavy-Duty Truck and Bus Surveillance Program (TBSP) is a program run by the California Air Resources Board (CARB) to monitor and reduce emissions from heavy-duty trucks and buses. Each vehicle is tested on a chassis dynamometer as well as on the road utilizing PEMS for multiple runs. The paired dataset of on-road and laboratory dynamometer testing provides a stronger basis for incorporating a combination of both data sources into EMFAC, rather than relying solely on either on-road or laboratory data. All chassis dynamometer tests used the Burke E. Porter heavy-duty chassis dynamometer at the CARB Depot Park Facility. The heavy-duty chassis dynamometer simulates road load forces equivalent to approximately 80% of the vehicle's Gross Vehicle Weight Rating (GVWR), which corresponds to about 65,000 lbs. for HHD vehicles with the maximum GVWR. The Chassis Urban Dynamometer Driving Schedule (UDDS) is conducted under hot-start conditions. This test cycle represents one of the duty cycles that heavy-duty trucks may undergo in the real world and helps better understand the relationship between average vehicle speed and emissions to better estimate the current running emission incorporated in EMFAC2025. Each vehicle was tested 10–20 times under a total of 14 individual test conditions: AM/PM, City/Highway, Origin/Destination (in-bound/out-bound), with each PEMS test lasting 1–2 hours. Figure 5.1 presents the speed profile along one of the test routes.

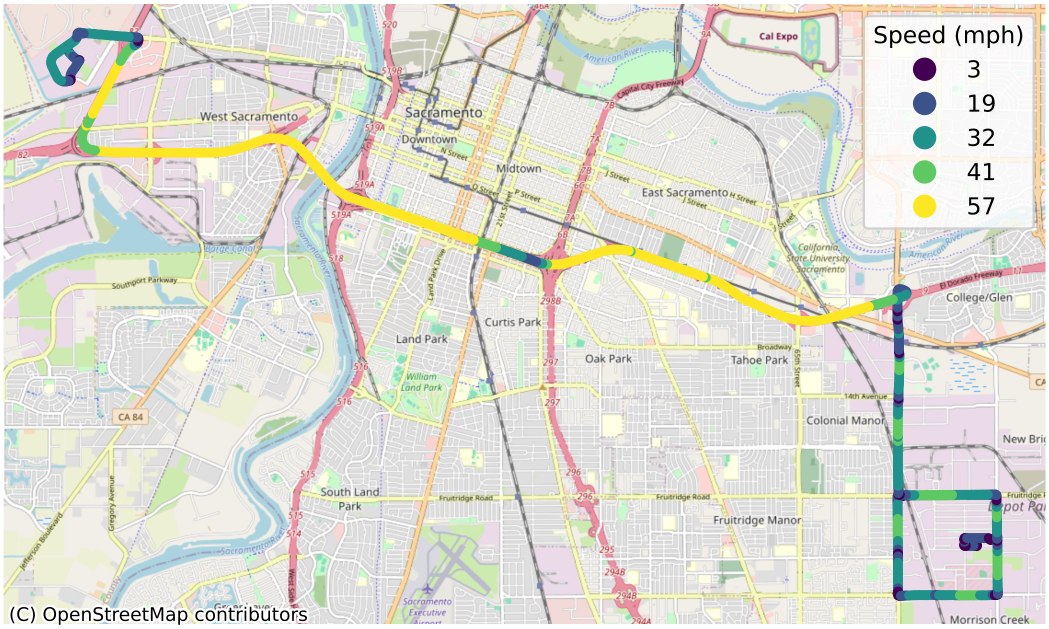


Figure 5.1: Speed Profile Along a Test Route Used for Portable Emission Measurement Systems (PEMS) Testing in CARB's Heavy-Duty Truck and Bus Surveillance Program (TBSP)

**200-vehicle PEMS study**: A real-world emissions testing program for heavy-duty vehicles (HDV) was conducted by the University of California, Riverside (UCR), in collaboration with West Virginia University (WVU). Spanning from 2017 to 2022, this program assessed over 200 HDVs across various vocations and fuel technologies under actual operating conditions. Measured emission levels varied widely across different duty cycles, test methods, engine/fuel technologies, and vocations. Heavy-duty vehicles tested ranged from model year 2001 to 2019, and most exhibited elevated in-use emissions under operational conditions different than the certification cycle. More information and results of the project can be found in the California Energy Commission's report (Leonard *et al.*, 2023).

### 5.1.1 Diesel Heavy-Duty Start Emission Rates Update

The start emission update is based on ten model year 2013 and newer Class 7 & 8 vehicles from TBSP PEMS tests. The dataset is identical to that used in EMFAC2021, except for the removal of one vehicle test due to a subsequent engine recall.

The PEMS dataset provides time-series measurements of exhaust temperature and cumulative $NO_x$ emissions from the moment the truck engine is started. It is important to distinguish between the start emission and running emission periods because they are governed by different engine operating conditions and control strategies. Start emissions typically occur when the engine and aftertreatment systems, such as Selective Catalytic Reduction (SCR), are not yet fully warmed up, leading to disproportionately high $NO_x$ emission rates. In contrast, running emissions reflect stabilized engine operation and more effective emission control performance. Accurately separating these two periods is crucial for modeling emissions, evaluating regulatory compliance, and designing effective mitigation strategies. In EMFAC2021, staff manually reviewed the data to identify the start emission period. In EMFAC2025, CARB staff apply a new methodology to re-analyze the same dataset with standardized criteria to identify the start emission period. The end of the start emission period is identified using the following criteria, with the earliest occurring event determining the cutoff:

1. The detection of the first cumulative $NO_x$ *plateau*, defined as a change of less than 0.03 grams over a duration of at least 100 seconds
2. The moment when the exhaust temperature reaches 200 °C
3. A maximum elapsed time of 20 minutes after engine start

Figure 5.2 shows a case when cumulative $NO_x$ plateau occurs at around 500 seconds, before the exhaust temperature reaches 200 °C or the 20-minute mark. Thus, the first 500 seconds are identified as the start emission period, while the period after 500 seconds is considered the running emission period.

Start emissions are calculated based on Equation (5.1). The $NO_x$ emissions during the start phase are considered to include start emissions as well as running exhaust emissions, which are emissions that would otherwise be emitted had the SCR reached operating temperatures. Thus, start emissions are obtained by subtracting the $NO_x$ running emissions from the total emissions of the start phase. A detailed discussion can be found in Section 3.2.3.6 of the EMFAC2014 technical documentation (CARB, 2015).

$$\begin{aligned}\text{Start Emissions} &= (ER_{\text{start total}} - ER_{\text{running}}) \times \text{Start Period Time} \\ &= \left(\frac{NO_x^{t_1}}{t_1} - \frac{NO_x^{t_2} - NO_x^{t_1}}{t_2 - t_1}\right) \times t_1\end{aligned} \tag{5.1}$$

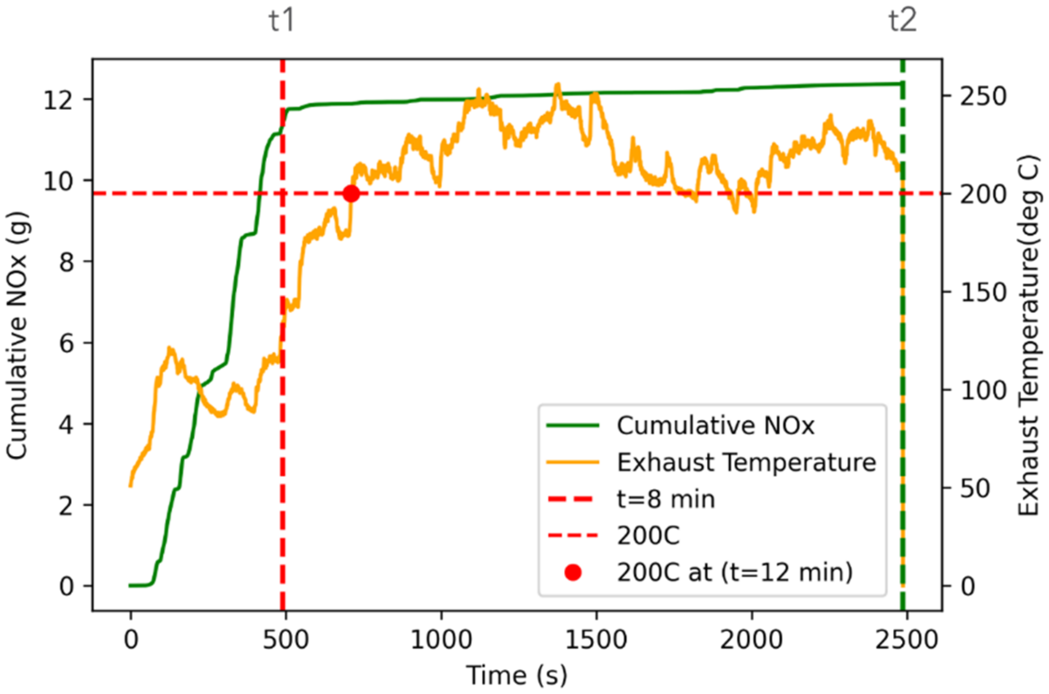


Figure 5.2: Cumulative $NO_x$ Emissions Separated into Two Phases: the Start-up Period and the Running Period

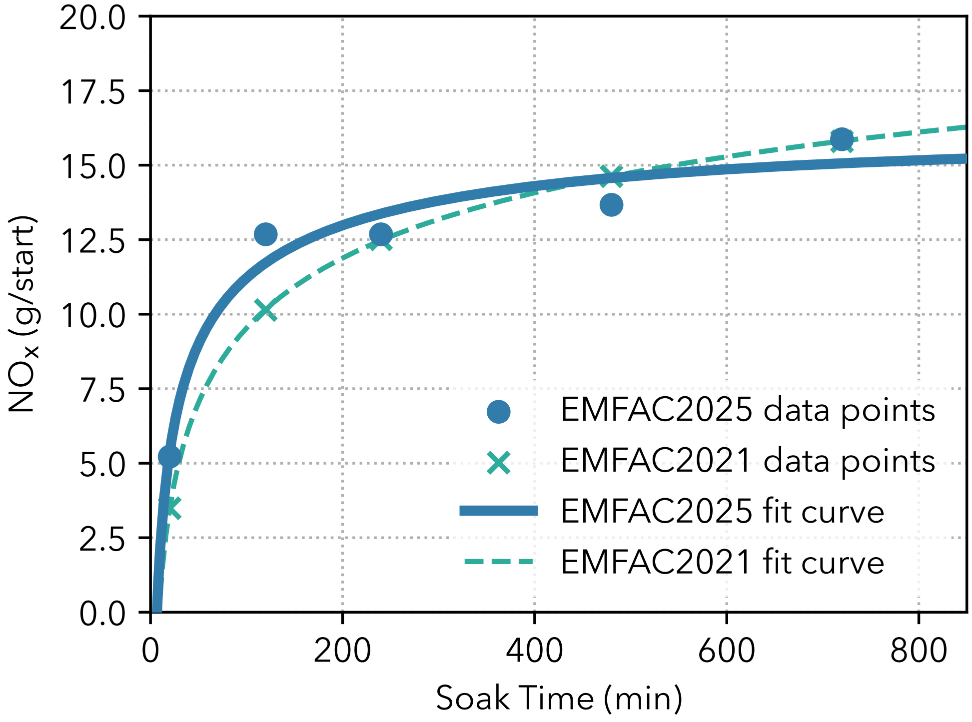


Figure 5.3: $NO_x$ Start Emissions as a Function of Soak Time for Heavy-Duty Diesel Trucks: EMFAC2021 vs. EMFAC2025

Soak time refers to the length of time the engine and aftertreatment system (SCR) have been turned off and allowed to cool before the engine is started again. Each vehicle was tested 5 times under different soak times, and the final start emission data points are shown in Figure 5.3 and Table 5.1; each data point represents the average $NO_x$ start emission across all 10 vehicles under a specific soak time.

Table 5.1: Heavy Heavy-Duty Diesel Truck $NO_x$ Start Emission Rates (g/start) by Soak Time

| Soak time | 20 min | 120 min | 240 min | 480 min | 720 min |
|---|---|---|---|---|---|
| EMFAC2025 | 5.22 | 12.68 | 12.68 | 13.67 | 15.87 |
| EMFAC2021 | 3.49 | 10.14 | 12.51 | 14.63 | 15.80 |

### 5.1.2 Analysis of Diesel Heavy-Duty Running Emissions From PEMS Testing

After identifying the start and running emission periods, the start period was excluded from the dataset. A micro-trip-based methodology was then applied to estimate the running emission rate as follows:

1. Aggregate second-by-second PEMS data points into micro-trips (Figure 5.4)
    1. Exclude extended idling events (i.e., a continuous segment of vehicle activity that meets all three criteria: all instantaneous vehicle speeds being lower than 5 mph, the total distance of less than 1 mile, and the total duration of more than 5 minutes)
    2. Merge trips < 0.25 miles
    3. Split trips > 3 miles
2. Aggregate micro-trip level data into speed bins of 5 mph
3. Develop a function of emission rate based on speed (Figure 5.5 shows a marked improvement in $R^2$ of the fitted curve after aggregating the data points into speed bins of 5 mph)
4. Determine the base emission rate at 18.8 mph based on the fitted curve (18.8 mph represents the average speed while the vehicle is in motion during the UDDS cycle. This speed reflects typical urban driving conditions under chassis dynamometer testing and ensures consistency and compatibility when integrating PEMS data with dynamometer-based emission rates.)

The objectives of applying this micro-trip methodology are:

1. To derive a representative emission rate under stabilized engine operation, excluding idling events under heavy traffic;
2. To integrate the real-world PEMS test results with laboratory-tested dynamometer data, since micro-trips resemble the pattern of dynamometer drive cycles.

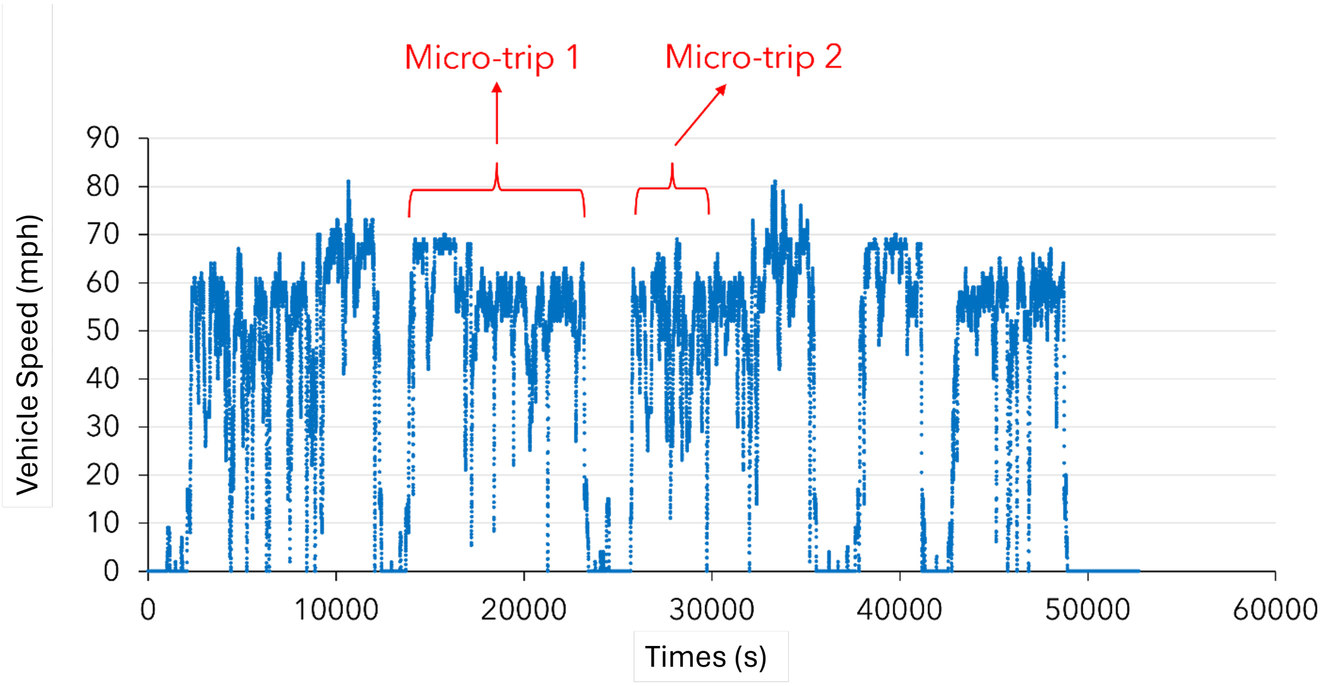


Figure 5.4: Aggregate the Second-By-Second PEMS Data Points into Micro-Trips

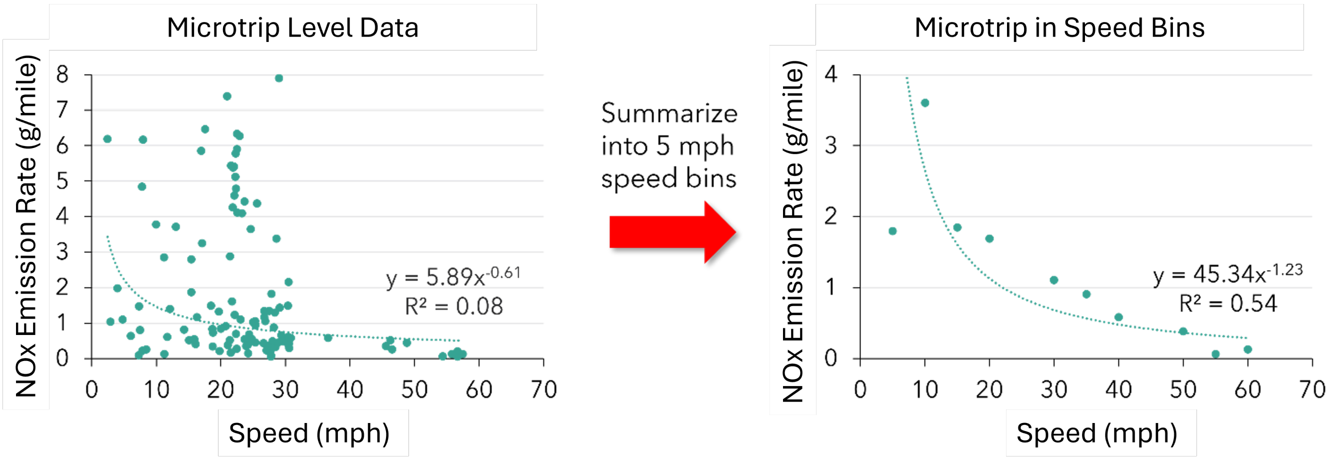


Figure 5.5: Aggregate Micro-Trip Level Data into Speed Bins of 5 mph and Develop a Function of Emission Rate

The methodology also leverages the high temporal resolution advantage of PEMS data while minimizing uncertainties and fluctuations associated with second-by-second measurements. The tested vehicle information and the sample size are listed in Table 5.2.

The average odometer reading for all data analyzed – comprising 50% UDDS dynamometer tests and 50% PEMS tests as listed in Table 5.2 – is 143,351 miles, with an average $NO_x$ emission rate of 2.02 g/mi. (CARB staff removed all recalled vehicles from the analysis in EMFAC2025.) This emission rate derived from PEMS and chassis dyno was used to adjust the base emission rate at UDDS average speed in EMFAC2025. There are an increasing number of vehicles sampled with each update of EMFAC as listed in Table 5.3.

Table 5.2: Diesel Heavy-Duty Test Vehicles and $NO_x$ Emission Rates Added in EMFAC2025

| Test Type | Vehicle ID | Emission Rate (g/mi) | Model Year | Odometer Mileage | Vehicle Class |
|---|---|---|---|---|---|
| TBSP - PEMS | 18-VEH1-2 | 2.32 | 2015 | 511406 | Class 8 |
| TBSP - PEMS | 18-VEH3-1 | 0.89 | 2014 | 134539 | Class 8 |
| TBSP - PEMS | 18-VEH4-2 | 0.90 | 2015 | 128288 | Class 8 |
| TBSP - PEMS | 18-VEH6-1 | 0.69 | 2016 | 13769 | Class 8 |
| TBSP - PEMS | 18-VEH7-1 | 1.08 | 2016 | 149709 | Class 8 |
| TBSP - PEMS | 19-VEH12-1 | 0.88 | 2016 | 101767 | Class 8 |
| TBSP - PEMS | 19-VEH1-3 | 1.14 | 2015 | 128370 | Class 8 |
| TBSP - PEMS | 19-VEH7-3 | 0.50 | 2016 | 212460 | Class 8 |
| TBSP - PEMS | 19-VEH9-1 | 2.14 | 2018 | 54343 | Class 8 |
| TBSP - PEMS | 19-VEH13-1 | 2.14 | 2013 | 151150 | Class 6 |
| TBSP - Dynamometer | M-3 | 4.23 | 2014 | 72055 | Class 8 |
| TBSP - Dynamometer | R-2 | 0.00 | 2014 | 275565 | Class 8 |
| TBSP - Dynamometer | R-3 | 0.71 | 2014 | 234326 | Class 8 |
| TBSP - Dynamometer | R-1 | 0.20 | 2014 | 290981 | Class 8 |
| TBSP - Dynamometer | V1-1 | 2.66 | 2015 | 308919 | Class 8 |
| TBSP - Dynamometer | V1-2 | 6.33 | 2015 | 511406 | Class 8 |
| TBSP - Dynamometer | V3-1 | 0.43 | 2014 | 134539 | Class 8 |
| TBSP - Dynamometer | V4-1-2 | 0.12 | 2015 | 194575 | Class 8 |
| TBSP - Dynamometer | V4-2 | 0.31 | 2015 | 128288 | Class 8 |
| TBSP - Dynamometer | V1-3 | 3.76 | 2015 | 128370 | Class 8 |
| TBSP - Dynamometer | V6-1 | 0.87 | 2016 | 13769 | Class 8 |
| TBSP - Dynamometer | V7-1 | 0.36 | 2016 | 149709 | Class 8 |
| TBSP - Dynamometer | V7-3 | 0.25 | 2016 | 212460 | Class 8 |
| TBSP - Dynamometer | V9-1 | 4.05 | 2018 | 54343 | Class 8 |
| TBSP - Dynamometer | V12-1 | 3.47 | 2016 | 101767 | Class 8 |
| 200 Vehicle - PEMS | V52 | 0.63 | 2015 | 26924 | Class 7 |
| 200 Vehicle - PEMS | V98 | 0.55 | 2015 | 33356 | Class 7 |
| 200 Vehicle - PEMS | V149 | 0.84 | 2015 | 81087.5 | Class 7 |
| 200 Vehicle - PEMS | V175 | 0.54 | 2015 | 73281.2 | Class 7 |
| 200 Vehicle - PEMS | V18089 | 0.50 | 2015 | 47246 | Class 7 |
| 200 Vehicle - PEMS | V88 | 4.25 | 2011 | 394408.8 | Class 8 |
| 200 Vehicle - PEMS | V18078 | 5.61 | 2010 | 428895.9 | Class 8 |
| 200 Vehicle - PEMS | V18079 | 6.48 | 2010 | 386668 | Class 8 |
| 200 Vehicle - PEMS | V5 | 5.90 | 2015 | 73279 | Class 8 |
| 200 Vehicle - PEMS | V50 | 5.13 | 2015 | 188031.5 | Class 8 |
| 200 Vehicle - PEMS | V18048 | 10.32 | 2015 | 184237 | Class 8 |
| 200 Vehicle - PEMS | V18049 | 4.93 | 2015 | 221199 | Class 8 |
| 200 Vehicle - PEMS | V18070 | 1.20 | 2015 | 330907.4 | Class8 |
| 200 Vehicle - PEMS | V18110 | 0.13 | 2015 | 68694.6 | Class 8 |
| 200 Vehicle - PEMS | V69 | 3.02 | 2016 | 42915.9 | Class 8 |

continues on next page

Table 5.2 – continued from previous page

| Test Type | Vehicle ID | Emission Rate (g/mi) | Model Year | Odometer Mileage | Vehicle Class |
|---|---|---|---|---|---|
| 200 Vehicle - Dynamometer | V98 | 0.04 | 2015 | 33356 | Class 7 |
| 200 Vehicle - Dynamometer | V228 | 0.12 | 2018 | 65570 | Class 7 |
| 200 Vehicle - Dynamometer | V18093 | 0.69 | 2016 | 27414 | Class 7 |
| 200 Vehicle - Dynamometer | V54 | 7.69 | 2008 |  | Class 7 |
| 200 Vehicle - Dynamometer | V146 | 1.71 | 2010 | 85371 | Class 8 |
| 200 Vehicle - Dynamometer | V5 | 4.09 | 2015 | 73279 | Class 8 |
| 200 Vehicle - Dynamometer | V18049 | 1.7 | 2015 | 221199 | Class 8 |
| 200 Vehicle - Dynamometer | V69 | 7.8 | 2016 | 42915.9 | Class 8 |
| 200 Vehicle - Dynamometer | V85 | 0.17 | 2016 | 75715.2 | Class 8 |
| 200 Vehicle - Dynamometer | V18071 | 3.82 | 2009 | 1013134 | Class 8 |
| 200 Vehicle - Dynamometer | V57 | 4.04 | 2008 | 805011.5 | Class 8 |

Table 5.3: Vehicle Sample Size Increase by Model Year (MY) with Each EMFAC Update for Diesel Heavy Heavy-Duty Trucks

|  | EMFAC2017 |  | EMFAC2021 | EMFAC2025 |
|---|---|---|---|---|
|  | MY 2010–2012 | MY 2013+ | MY 2013+ | MY 2013+ |
| Base emission rate | +7 | +18 | +26 | +36 |
| Speed correction factor | +7 | +18 | +26 | +324 |
| Start emission rate | +1 | +3 | +11 | +15 |

### 5.1.3 Base Emission Rate and Deterioration Rate Update

The Base Emission Rate (BER) is the fundamental emission rate per unit of activity (e.g., grams per mile) that represents the emissions from a given vehicle before applying correction factors. In EMFAC2025, diesel heavy-duty vehicle BERs were calculated by model year group using the following equation:

$$\text{BER (g/mi)} = (\text{ZMR} + \text{DR} \times \text{Odometer}) \times \text{SCF}$$

where ZMR = 0.60 g/mi, which is defined as the zero-mile rate (same value as EMFAC2021), DR is the deterioration rate, and SCF is the speed correction factor. This methodology is the same as EMFAC2021; more description can be found in the EMFAC2021 technical documentation.

Deterioration rate (DR) refers to the rate at which vehicle performance or emission control systems degrade over time or usage, leading to increased emissions or reduced efficiency. For example, if a new vehicle emits 0.2 g/mi $NO_x$, and after 100,000 miles it emits 0.4 g/mi, the deterioration rate reflects this increase. DRs are calculated as follows:

$$\text{DR (g/mi per 10,000 miles)} = \frac{\text{ZMR} \times \text{EIR}}{100}$$

where EIR is the emission impact rate at 1,000,000 miles.

EMFAC2021 used on-board diagnostics (OBD), from which the malfunction indicator lamp (MIL) status can be determined, as well as the fault codes that triggered the MIL for vehicles equipped with OBD systems that are required for engine model year 2013 and newer. The 'MIL on' frequency as a function of Odometer is

$$\text{MIL}_{\text{on}} = 0.016 \times \text{Odometer}^{0.37}$$

Next, an iterative procedure was used to determine deterioration rates from the MIL On function and in-use test data. Steps are described below:

Step 1. Initiate a base EIR and ZMR at 90,249 miles, the average odometer of the US-wide OBD dataset.

Step 2. Scale base EIR to other odometers using the MIL On function:

$$\text{EIR(odometer)} = \text{Base EIR}_{(90,249)} \times \frac{\text{MIL On(odometer)}}{\text{MIL On}_{(90,249)}}$$

Step 3. Use EIRs to determine odometer-dependent emission rates:

$$\text{ER(odometer)} = \text{ZMR} + \text{ZMR} \times \text{EIR(odometer)}$$

Step 4. Calculate root mean square error (RMSE) between binned in-use $\text{NO}_x$ emission rates and the modeled values.

Step 5. Continue updating the ZMR and EIR values iteratively until RMSE reaches its minimum.

EMFAC2025 incorporated the new PEMS and chassis dyno-based $\text{NO}_x$ emission rate of 2.02 g/mi at 143,351 miles. The ZMR of 0.60 g/mi was retained, but the EIR was adjusted to fit the curve through this emission rate for engine model years 2013 and newer. To match the emission rate of 2.02 g/mi at 143,351 miles, staff solved for the EIR at this odometer, which had a value of 237%. Using the equation in Step 2, a new base EIR at 90,249 miles was calculated to be 200%, which is lower than the previous base EIR of 249%. The resulting best fit emission rate equation for heavy-duty vehicles is shown in Figure 5.6.

### 5.1.4 Speed Correction Factor Update

Final running exhaust emissions are calculated by multiplying the base emission rate (BER) in g/mi by the vehicle miles traveled (VMT). The emission rate at a specific speed is derived by applying a speed correction factor (SCF) to the BER.

In EMFAC2021, there were only two SCFs: one for all T6 vehicles and one for all T7 vehicles, and all tested data were from dynamometer tests. For EMFAC2025, CARB staff incorporated PEMS test data of 556 vehicles from the HDIUT project to allow for more detailed SCFs by vocation and model year group.

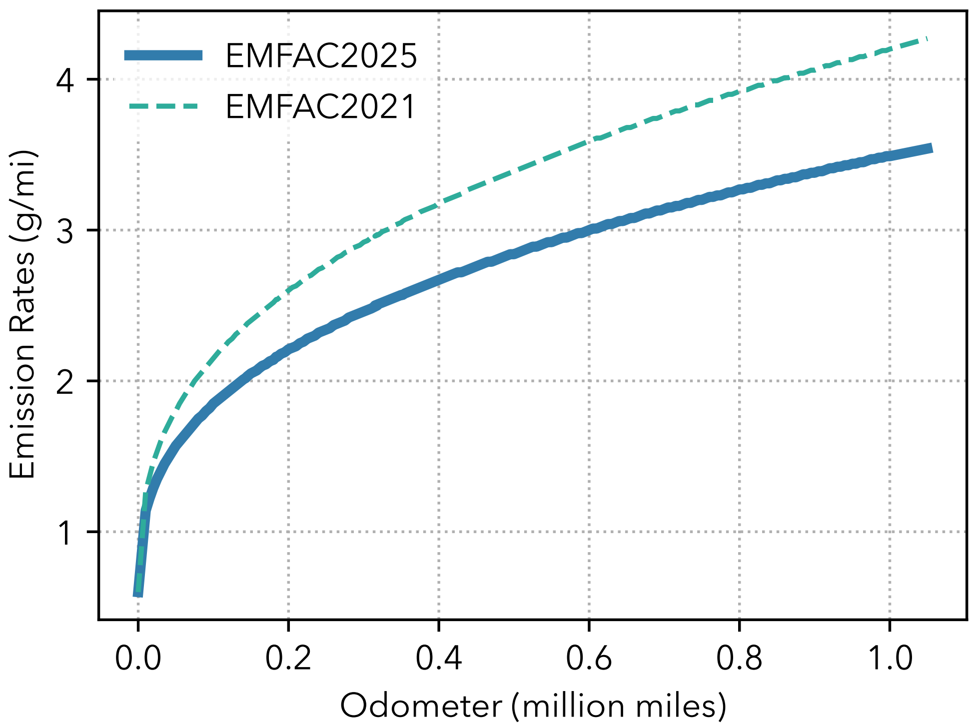


Figure 5.6: Emission Rate Deterioration Model Derived for Heavy-Duty Vehicles

CARB staff used the same micro-trip methodology described above to process the HDIUT PEMS data. In the EMFAC2025 input table, the SCF represents the $NO_x$ emission rate at various speeds, normalized to the emission rate at 18.8 mph. CARB staff updated medium heavy-duty (MHD) and heavy heavy-duty (HHD) trucks in model years 2010–2012 and model years 2013+ respectively. Figure 5.7 shows the change of SCFs between EMFAC2025 and EMFAC2021.

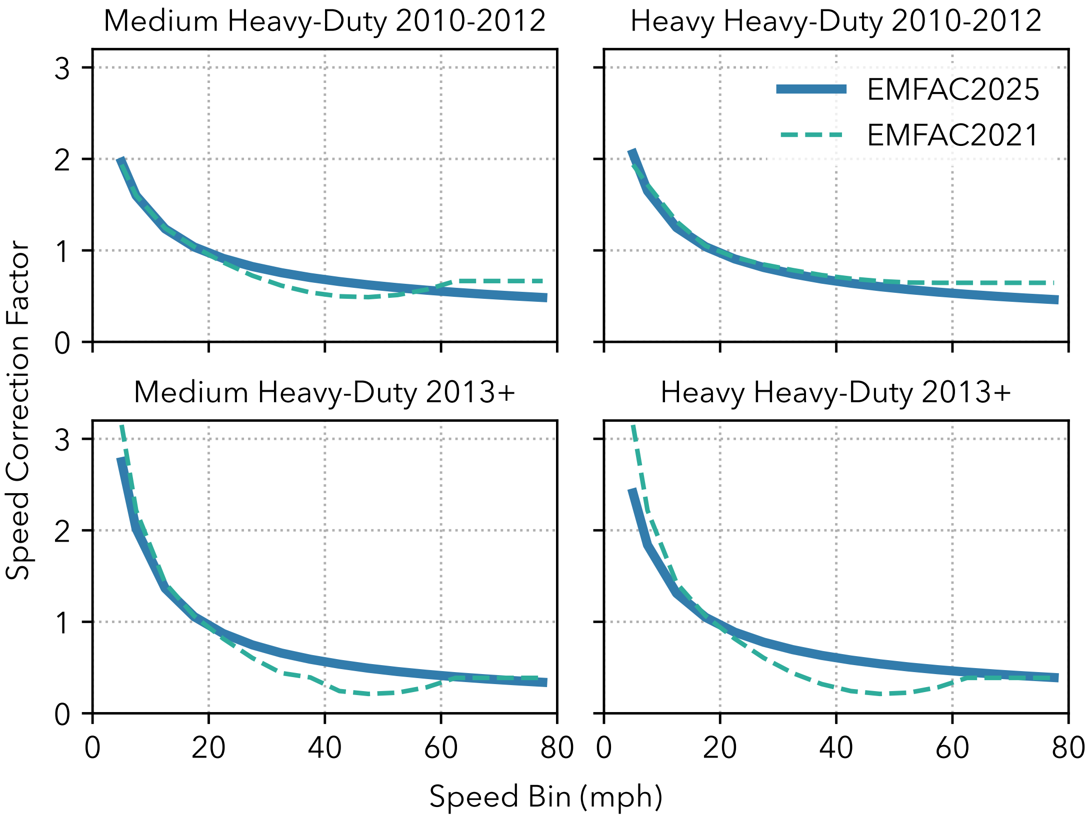


Figure 5.7: Speed Correction Factor for Medium and Heavy Heavy-Duty Vehicles: EMFAC2025 vs. EMFAC2021

## 5.2 Updates to Medium Heavy-Duty Emission Rates

In EMFAC, medium heavy-duty vehicles are defined as vehicles having GVWR between 14,001 and 33,000 lbs. or U.S. commercial vehicle classes 4–7. These categories include all EMFAC T6 categories, as well as SBUS and OBUS. In EMFAC2021, medium heavy-duty vehicles were, for the first time, informed by emissions test data. EMFAC2025 updates build on this approach by including additional test data, while removing data from engines recalled through CARB's in-use compliance program. Staff used test vehicles from CARB's Truck and Bus Surveillance Program (Class 7) and Surveillance Program for Class 4–6 Heavy-Duty Vehicles (Class 4–6). Table 5.4 lists vehicle information available for medium heavy-duty $NO_x$ emission rate updates.

Table 5.4: Medium Heavy-Duty Test Vehicles List and $NO_x$ Emission Rates

| Vehicle ID | Engine Make | Model Year | Odometer Mileage | Emission Rate (g/mi) | New Data in EMFAC2025 |
|---|---|---|---|---|---|
| 2S19H01-02 | Cummins | 2015 | 58,475 | 0.01 | No |
| 2S19H01-03 | Cummins | 2015 | 92,914 | 0.05 | No |
| 2S19H01-04 | Cummins | 2015 | 155,537 | 0.02 | No |
| 2S19H01-05 | Hino | 2017 | 69,869 | 0.16 | Yes |
| 2S23T01-02 | Cummins | 2017 | 159,688 | 0.17 | Yes |
| 2S23T01-04 | Cummins | 2020 | 43,787 | 0.13 | Yes |
| J-1 | Isuzu | 2013 | 96,562 | 0.46 | No |
| TBSP V13-1 | Hino | 2017 | 151,150 | 1.05 | No |
| 2S19H01-07 | Cummins | 2019 | 24,078 | 0.41 | Yes |
| 2S19H01-09 | Cummins | 2019 | 47,745 | 0.04 | Yes |

Unlike heavy heavy-duty vehicles, the sample size ($N = 10$) is not large enough to develop a robust deterioration function. Therefore, staff calculated a ratio between the average medium heavy-duty and heavy heavy-duty emission rates and applied that ratio to the heavy heavy-duty vehicle ZMR, which is the same approach used in EMFAC2021. The emission impact rate (EIR), which informs the deterioration function, of medium heavy-duty vehicles is assumed to be the same as heavy heavy-duty vehicles.

Initially, staff considered all engine model years 2013 and newer to develop this ratio. The estimated ratio was < 0.05 due to some heavy heavy-duty model years 2013–2015 having extremely high emission rates. To avoid underestimating medium heavy-duty vehicle emission rates, staff instead limited the ratio to engines with model year 2016 and newer. This ratio is 0.21 and was applied all engine model years 2013 and newer. The new ratio is smaller than the previous value of 0.273 used in EMFAC2021.

Figure 5.8 shows a comparison between the medium heavy-duty vehicle $NO_x$ emission rate for EMFAC2025 and EMFAC2021 (also listed in Table 5.5). Compared to EMFAC2021, $NO_x$ emission rates are 17% lower in EMFAC2025.

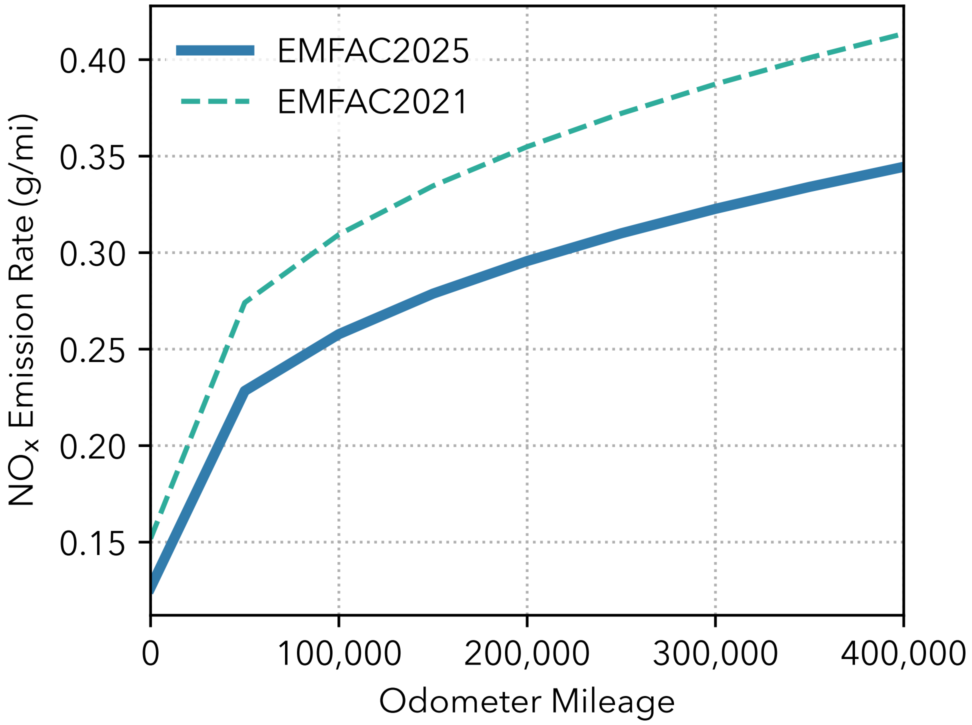


Figure 5.8: Medium Heavy-Duty Vehicle Emission Rates: EMFAC2025 vs. EMFAC2021

Table 5.5: Medium Heavy-Duty $NO_x$ Emission Rates as a Function of Odometer in EMFAC2025 and EMFAC2021 (Engine Model Years 2013 and Newer)

| Odometer Mileage | EMFAC2021 Emission Rate (g/mi) | EMFAC2025 Emission Rate (g/mi) |
|---|---|---|
| 0 | 0.152 | 0.126 |
| 50,000 | 0.274 | 0.228 |
| 100,000 | 0.309 | 0.258 |
| 150,000 | 0.335 | 0.279 |
| 200,000 | 0.355 | 0.296 |
| 250,000 | 0.372 | 0.310 |
| 300,000 | 0.387 | 0.323 |
| 350,000 | 0.401 | 0.334 |
| 400,000 | 0.413 | 0.344 |

## 5.3 $N_2O$ Emissions Update

$N_2O$ emissions for medium heavy-duty and heavy heavy-duty trucks were updated using two different data sources. EMFAC2021 previously assumed $N_2O$ emissions to be 1.6 g/gal of diesel for all model year trucks, for both idle and running operation modes.

For chassis model year 2011 and newer trucks, which are equipped with selective catalytic reduction (SCR) aftertreatment systems, EMFAC2025's running emission factors were updated based on CARB's Truck and Bus Surveillance Program data, since the TBSP dataset included trucks that were all equipped with SCRs. Data was used from vehicles tested on a chassis dynamometer using an array of cycles, including the Urban Dynamometer Driving Schedule (UDDS), Creep, Cruise, HS Cruise, Modified HS Cruise, Local Drayage, and Near Dock Drayage. The average emission rate for all cycles was 0.4 g/mi, which was used to represent all trucks with a model year of 2010 or later that were assumed to have been equipped with SCRs.

Older trucks (i.e., chassis model year before 2011) not equipped with SCR aftertreatment systems have a lower $N_2O$ emission rate. The SCR catalyst effectively reduces $NO_x$ species, but incomplete reduction of $NO_x$ increases $N_2O$ emissions, as explained in the literature (Quiros *et al.*, 2017). CARB staff therefore used the average $N_2O$ emission rate (0.05 g/mi) from a model year 2007 Conventional Diesel not equipped with SCR, as reported in Quiros *et al.* (2017), for all pre-2011 chassis model years in EMFAC2025. The pre-2010 model year emission rate was an average of multiple on-road cycles including Hill Climb, Interstate, Regional, Local, and Near-Dock routes. These updates have the counterintuitive effect of older trucks (pre-2011 model years), having lower $N_2O$ emissions than the newer trucks.

The updates described above were only applied to running emissions. EMFAC2025 continues to use the 1.6 g/gal for HD diesel idle emissions. $N_2O$ emissions for NG fuel in EMFAC2025 are treated identically to diesel, and emissions from gasoline fuels are estimated by correlations to $NO_x$ emissions from VSP data, as documented in (CARB, 2018). Table 5.6 summarizes the $N_2O$ emission rates used in EMFAC2021 and EMFAC2025.

Table 5.6: HD Diesel Emission Rates of Nitrous Oxide in EMFAC2021 and EMFAC2025

| Operation Mode, Model Year | EMFAC2025 | EMFAC2021 |
|---|---|---|
| Start Emissions, All Model Years | 1.6 g/gal | 1.6 g/gal |
| Running Emissions, Pre-2010 Model Years | 0.05 g/mi | 1.6 g/gal |
| Running Emissions, Post-2009 Model Years | 0.4 g/mi | 1.6 g/gal |

## 5.4 Natural Gas Heavy-Duty Vehicles

This section describes updates to emission rates of $NO_x$ and $CH_4$ for natural gas (NG) heavy-duty vehicles (HDV). EMFAC2025 updates the $NO_x$ emission rates for NG HDVs using Portable Emissions Measurement Systems (PEMS) data. Although this dataset was already used to calculate NG HDV emission rates in EMFAC2021, this update reanalyzes the dataset to apply a new binning method and incorporate additional test data that became available after EMFAC2021 was completed. These updates only apply to running exhaust emissions of $NO_x$. Additionally, for model year 2017 and earlier model years, EMFAC2025 updates methane emissions from blow-by processes in open crankcase NG engines. Emission rates of other pollutants/processes are unaffected.

### 5.4.1 PEMS Dataset

A multiagency-funded 200-vehicle study (Leonard *et al.*, 2023) collected on-road observations of emissions from heavy duty vehicles using PEMS. PEMS testing included nearly one hundred heavy-duty vehicles and about half of these were natural gas (NG) vehicles. Each test vehicle was instrumented with a PEMS unit that continuously measured the vehicle's emissions of gaseous pollutants for a typical day of operation. For this analysis, PEMS data from 50 NG heavy-duty vehicles were obtained covering four vocation categories and two $NO_x$ engine certification standards (0.2 g/bhp-hr and 0.02 g/bhp-hr, Table 5.7). The $NO_x$ certification standards are expressed in units of grams of $NO_x$ emitted per brake horsepower-hour (g/bhp-hr), which represents the amount of $NO_x$ produced per unit of net engine power output over time. For implementation in EMFAC, vehicles certified to the 0.2 g/bhp-hr engine $NO_x$ standard were assumed to represent model years 2007–2017 while vehicles certified to the 0.02 g/bhp-hr engine $NO_x$ standard were assumed to represent model years 2018 and later. This dataset was previously used in EMFAC2021 but was re-analyzed for EMFAC2025 using an improved data binning approach and three newly available vehicle test datasets. This PEMS analysis was used solely to update $NO_x$ emission rates of NG HDVs, not for other pollutants.

Table 5.7: Number of Natural Gas Heavy-Duty Vehicles Tested in the 200-Vehicle Study and Used for Emission Rates Analyses

| Vocation | Technology | Number of Vehicles | |
|---|---|---|---|
| | | EMFAC2021 | EMFAC2025 |
| Transit Buses | CNG 0.2 g/bhp-hr | 5 | 4 |
| | CNG 0.02 g/bhp-hr | 5 | 5 |
| School Buses | CNG 0.2 g/bhp-hr | 5 | 5 |
| | CNG 0.02 g/bhp-hr | 0 | 0 |
| Refuse Trucks | CNG 0.2 g/bhp-hr | 11 | 10 |
| | CNG 0.02 g/bhp-hr | 1 | 4 |
| Goods Movement Trucks | CNG 0.2 g/bhp-hr | 8 | 8 |
| | CNG 0.02 g/bhp-hr | 9 | 11 |
| Delivery Trucks | CNG 0.2 g/bhp-hr | 3 | 3 |
| | CNG 0.02 g/bhp-hr | 0 | 0 |
| Total | | 47 | 50 |

Staff note that the 50 vehicles analyzed for EMFAC2025 differ from the dataset of 47 vehicles that were used for EMFAC2021 (Table 5.7). This is because additional test data became available for five NG vehicles since the original analysis. Additionally, data from two previously used vehicles were excluded from the study's final dataset.

There were five vocation categories defined in the 200-vehicle study: transit buses, school buses, refuse trucks, goods movement trucks, and delivery trucks. However, since EMFAC does not have a goods movement category or a delivery truck category, these two categories were grouped together and used to characterize emission rates for all other heavy-duty trucks.

As each PEMS test in the 200-vehicle study captured emissions under a typical working day, staff treat each vocation separately, as they have distinct speeds, loads, and driving practices depending on their operational routines. For each vocation/technology group, staff calculate a base emission rate (BER), using the cycle speed of a dynamometer test cycle commonly used for that vocation. Then, staff estimate speed correction factors relative to that cycle speed. Table 5.8 lists the test cycles chosen for the four NG vehicle categories, and the cycle speed that represents the BERs.

Table 5.8: Duty Cycles and Cycle Speeds Used for Estimating Base Emission Rates of Natural Gas HDVs

| | Transit Bus | School Bus | Refuse Truck | Other HDVs* |
|---|---|---|---|---|
| Standard Cycle | OCBC | AQMD-SB | AQMD RTC | UDDS |
| Average Cycle Speed (mph) | 12.1 | 12.3 | 7.31 | 18.8 |

*Other HDVs includes all vehicles classified as goods movement or delivery trucks in the 200-vehicle study

### 5.4.2 Base Emission Rates

Previously, in EMFAC2021, CARB staff grouped the PEMS data into 10 mph speed bins based on the vehicle's instantaneous speed. For example, all data points where the instantaneous speed fell between 0–10 mph were averaged together to represent emission rates at that speed bin. However, there were two concerns with this approach: (1) that the second-by-second data can be noisy, and (2) that speed effects on emission rates are not instantaneous. Emission rates are not only dependent on the vehicle speed at a given moment, but on the driving conditions for some time before. This is a resultant of changes to the catalyst temperature and performance based on accelerating/braking, which may include lagged effects.

To account for this, CARB staff updated the binning methodology in EMFAC2025, following a similar data processing approach as for diesel HDVs (Section 5.1.2). The new approach involves grouping the data points into segments of driving conditions called *microtrips*. Microtrips are short trips (less than 3 miles) defined from start to stop. These driving segments better represent the impacts of driving conditions on emissions compared to using the instantaneous speed.

To segment the data into microtrips, CARB staff first remove observations with nonsensical, negative or null values. Non-continuous data points where there was a time gap greater than 1 second between consecutive observations were also excluded. To keep the BERs representative of running exhaust emissions, all idling events were excluded. Idling events were defined as periods when the vehicle traveled less than one mile within five minutes and the instantaneous speed never exceeded 5 mph. Then, CARB staff iterate through each vehicle's test data chronologically, checking the vehicle speed and calculating the cumulative distance traveled over time. Whenever the vehicle reaches a speed of 0 mph, CARB staff create a break in the data and a new microtrip begins. Consecutive microtrips shorter than 0.25 miles are grouped together. If the cumulative distance traveled exceeds 3 miles, CARB staff end the microtrip and start a new one.

Once the data is segmented into microtrips, CARB staff calculate the average speed, the cumulative distance traveled, and the cumulative $NO_x$ emitted for each microtrip. The emission rate (in g/mi) is determined by dividing the total $NO_x$ emissions by the total distance traveled during each microtrip. These emission rates were then grouped into speed bins using 5 mph intervals, and each speed bin was represented by its midpoint (e.g., 7.5 mph for the 5–10 mph bin). For each vehicle, CARB staff fitted a power function to the speed-binned data to model $NO_x$ emission rates as a function of speed. An example power fit result for one vehicle is shown in Figure 5.9. CARB staff solve each vehicle's power function for its respective cycle speed (Table 5.8) to estimate its base emission rate. Finally, CARB staff average the base emission rates for each vocation/technology group. The resulting BERs for all vocation/technology groups are presented in Figure 5.10 and Table 5.9.

Test data for 0.02 g/bhp-hr school buses was not available. Thus, CARB staff estimate the BER for this technology group using the ratio of 0.02 to 0.2 BERs from transit buses. For transit buses, the ratio of 0.02-g to 0.2-g emission rates was 0.20. Multiplying this by the BER of 0.2-g school buses results in a BER of 0.265.

Table 5.9: $NO_x$ Base Emission Rates for all NG HDV categories

| | | $NO_x$ Base Emission Rate (g/mi) | |
|---|---|---|---|
| | | EMFAC2021 | EMFAC2025 |
| Refuse | CNG 0.2 g/bhp-hr | 7.90 | 6.95 |
| | CNG 0.02 g/bhp-hr | 0.17 | 1.00 |
| School Bus | CNG 0.2 g/bhp-hr | 2.23 | 1.36 |
| | CNG 0.02 g/bhp-hr | 0.36 | 0.27 |
| Transit Bus | CNG 0.2 g/bhp-hr | 1.44 | 0.82 |
| | CNG 0.02 g/bhp-hr | 0.23 | 0.16 |
| HD Truck | CNG 0.2 g/bhp-hr | 1.28 | 1.28 |
| | CNG 0.02 g/bhp-hr | 0.24 | 0.26 |

### 5.4.3 Medium Heavy-Duty Vehicles

The 200-vehicle study did not conduct any PEMS tests on medium-heavy duty (T6) natural gas vehicles. Thus, to estimate base emission rates for T6 NG vehicles, CARB staff apply a ratio based on the emission rates of diesel heavy-duty trucks. The ratio of emission rates between medium and heavy heavy-duty (T7) diesel trucks was 0.21, as described in Section 5.2. Thus, CARB staff multiply the BERs of T7 NG trucks by this scalar to calculate the BERs of T6 vehicles. Results are shown in Table 5.10.

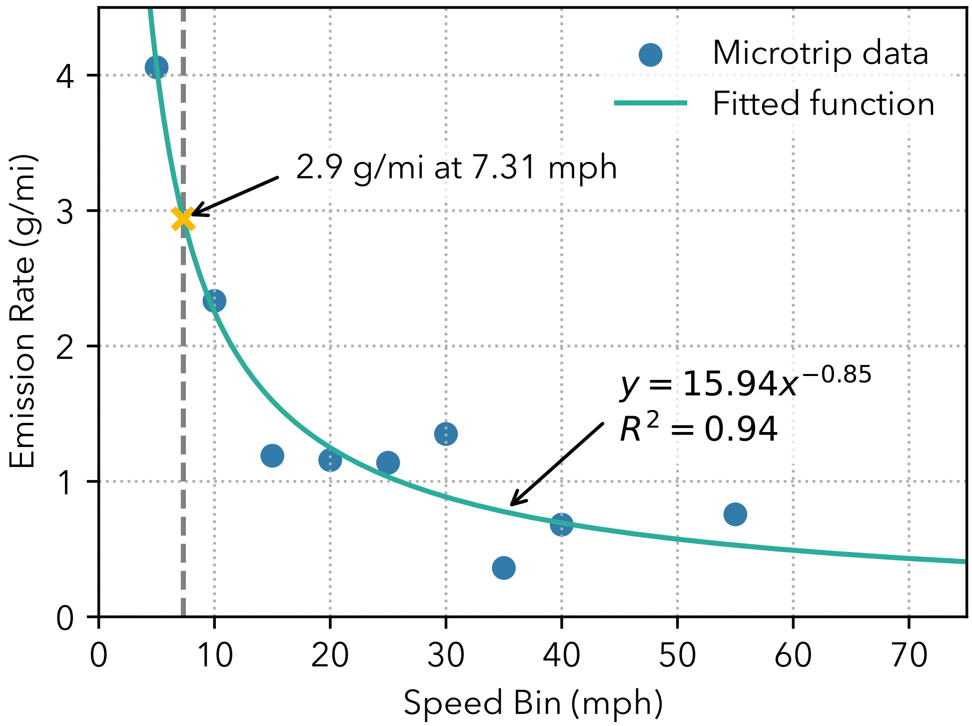


Figure 5.9: Example of a Power Function Fit Used to Calculate Base Emission Rates for a PEMS-Tested Refuse Hauler Certified to CNG 0.2 g/bhp-hr

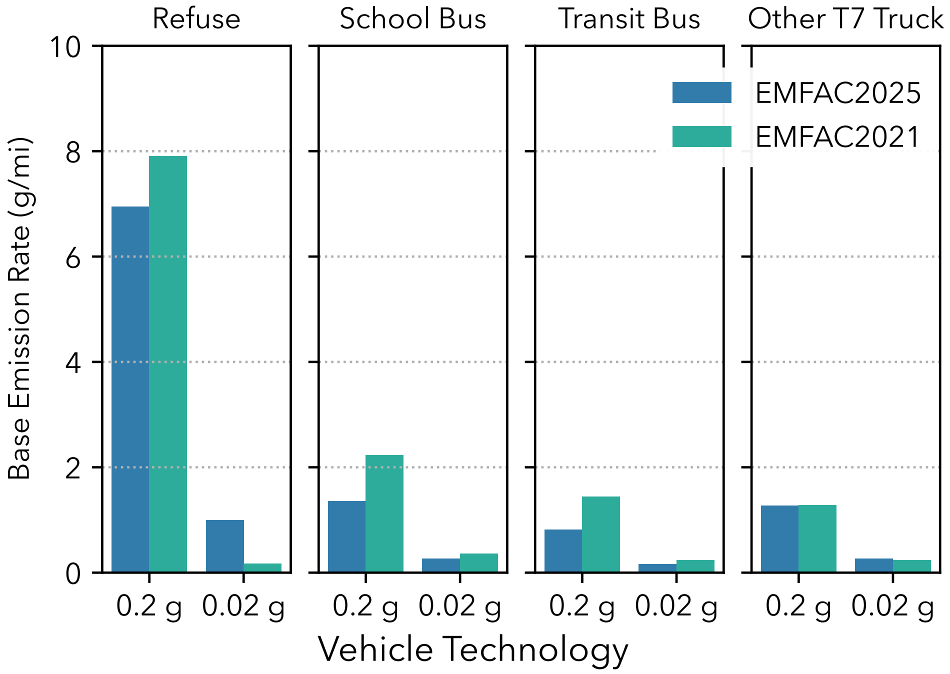


Figure 5.10: Updated $NO_x$ Base Emission Rates for Natural Gas Heavy-Duty Vehicles

Table 5.10: Base Emission Rates for T6 (Medium Heavy-Duty) Natural Gas Vehicles

| Vocation | Technology | $NO_x$ BER (g/mi) |
|---|---|---|
| T6 Transit Buses | CNG 0.2 g/bhp-hr | 0.241 |
| | CNG 0.02 g/bhp-hr | 0.047 |
| All Other T6 Vehicles | CNG 0.2 g/bhp-hr | 0.269 |
| | CNG 0.02 g/bhp-hr | 0.056 |

Similarly, T6 transit buses did not have PEMS data, so CARB staff estimated their BERs using a scalar approach. CARB staff first applied the T6/T7 ratio of 0.21. However, since this T6/T7 ratio is defined for the UDDS cycle speed of 18.8 mph, CARB staff further corrected the BER to represent the 12.1 mph speed that is used for transit buses. To do so, CARB staff use the ratio of the speed correction factors for T6 diesel trucks at 12.1 mph divided by the SCF at 18.8 mph. The resulting scalar is 1.3935. The resulting BERs after applying these two scalars, are presented in Table 5.10.

Refuse trucks and school buses do not have a T6 equivalent in EMFAC.

### 5.4.4 Speed Correction Factors

Once the BERs are known for each vocation/technology group, CARB staff calculate speed correction factors (SCF) to account for the variation in emission rates at different speeds.

To determine the SCFs, CARB staff start with the vehicle-by-vehicle, speed-binned emission rates that were calculated from the microtrips analysis. CARB staff group the vehicles by their vocation and technology group (e.g., refuse trucks certified to CNG 0.02 g/bhp-hr). CARB staff normalize all points by the BER for that vocation/technology group (shown in Figure 5.10). This defines the SCF as equal to 1 at the cycle speed at which the BER was calculated. CARB staff then fit a line through the points that represents the trend. In general, a power function represented the data well for all vehicle groups, leading to SCFs > 1 for speeds below the BER speed, and SCFs < 1 at faster speeds. In this step, six vehicles were excluded because they were determined to be outliers. An example curve fit is shown below in Figure 5.11.

Table 5.11: $NO_x$ Speed Correction Factor Equations for NG Heavy-Duty Vehicles

| | Technology | Model Years | Speed Correction Factor Equation | $R^2$ |
|---|---|---|---|---|
| Transit bus | CNG 0.2 g | 2007-2017 | $21.29 \times (\text{Speed})^{-1.04}$ | 0.88 |
| | CNG 0.02 g | 2018+ | $2.55 \times (\text{Speed})^{-0.34}$ | 0.51 |
| School bus | CNG 0.2 g | 2007-2017 | $132.14 \times (\text{Speed})^{-2.02}$ | 0.96 |
| | CNG 0.02 g | 2018+ | No test data | n.a. |
| Refuse trucks | CNG 0.2 g | 2007-2017 | $6.52 \times (\text{Speed})^{-0.88}$ | 0.95 |
| | CNG 0.02 g | 2018+ | $2.06 \times (\text{Speed})^{-0.36}$ | 0.43 |
| Other HDVs | CNG 0.2 g | 2007-2017 | $4.54 \times (\text{Speed})^{-0.56}$ | 0.67 |
| | CNG 0.02 g | 2018+ | $7.75 \times (\text{Speed})^{-0.62}$ | 0.84 |

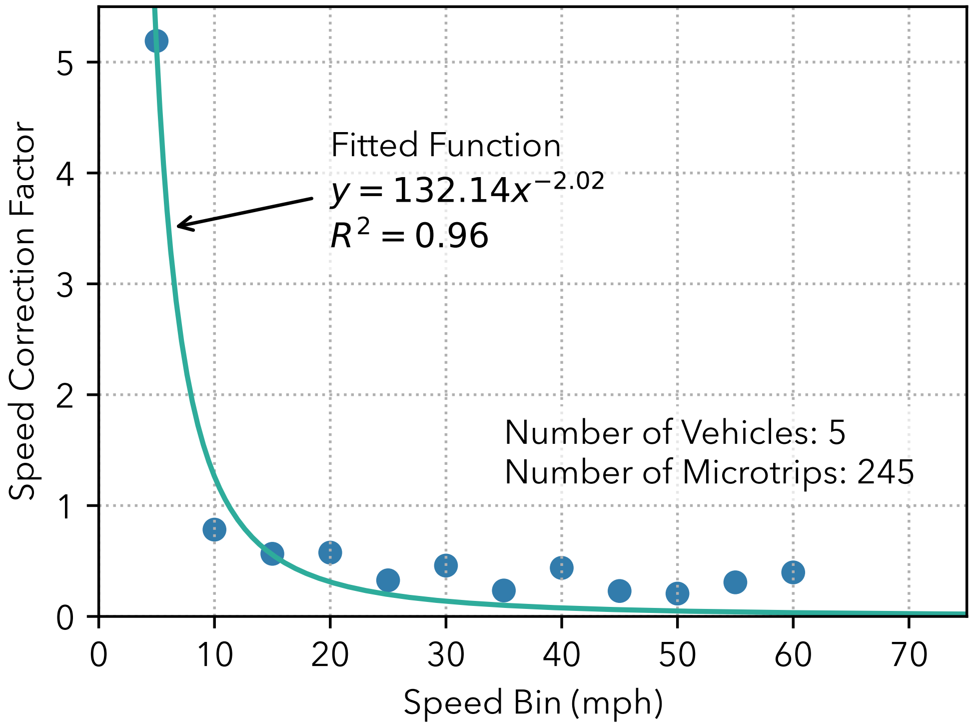


Figure 5.11: Example of a Power Function Fit Used to Calculate Speed Correction Factors for School Buses Certified to CNG 0.2 g/bhp-hr

Table 5.11 and Figure 5.12 show the resulting SCF functions for all vehicle groups. Since there were very measurements for speeds above 55 mph, CARB staff use the SCF of the 55 mph speed bin for all higher speeds. Since PEMS data for CNG 0.02 g school buses was not available, CARB staff assume the same SCFs as for CNG 0.2 g school buses. Similarly, CARB staff use the same SCFs for T6 trucks as for T7 trucks due to lack of data.

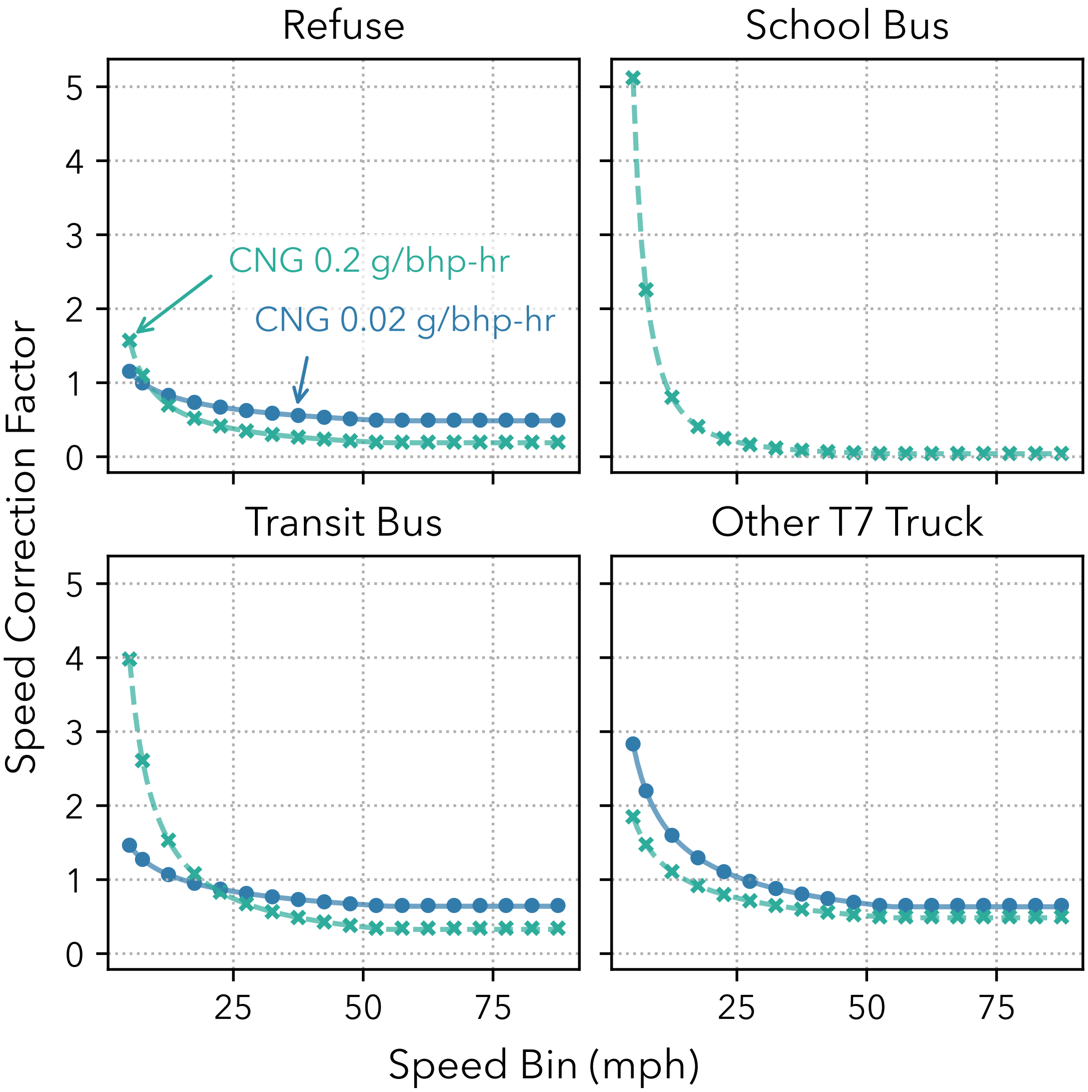


Figure 5.12: Speed Correction Factors for Natural Gas Heavy-Duty Vehicles

### 5.4.5 Start Emissions

For NG HDVs CARB staff decided not to estimate start emissions separately from running exhaust emissions. CARB staff initially attempted to define criteria to isolate start emissions similar to the new methodology used for diesel heavy-duty vehicles (Section 5.1.1). However, there appeared to be a negligible impact of start emissions on base emission rates results, regardless of the criteria used to isolate the start emissions. Other test studies also observed that the start period had a relatively low impact on total in-use $NO_x$ emissions for natural gas engines (Zhu *et al.*, 2020). This is because the three-way catalysts (TWC) in these NG vehicles warm up and activate rather quickly (on the order of 100 seconds), leading to an overall small contribution of the start emissions period despite the higher $NO_x$ emission rate on a grams per bhp-hr basis. Compared to SCR technology in diesel engines, TWCs spend much less time at temperatures below 200 °C and are less sensitive to temperature fluctuations (Zhu *et al.*, 2024, McCaffery *et al.*, 2021). Thus, CARB staff decided to treat all the data together and implicitly account for NG HDV start emissions in running exhaust emissions.

### 5.4.6 Blow-by Emissions

Blow-by processes emit pollutants in ways often not captured by tailpipe emissions. In a NG combustion chamber, methane can leak around the piston seals (“blow-by”) into the crankcase, and when the crankcase pressure accumulates, it vents into the atmosphere. Because EMFAC2021’s NG heavy-duty emissions factors are based on PEMS testing from the 200-vehicle study, which sampled from the tailpipe, blow-by emissions from NG vehicles were not measured. Blow-by emissions are only relevant for model year 2017 and earlier that were certified to the 0.2 g/bhp-hr $NO_x$ standard. For model year 2018 and later, the more stringent $NO_x$ standard led manufacturers to incorporate a closed-crankcase design, which circulates crankcase ventilation back into the engine intake.

Clark *et al.* (2016) shows that for heavy-duty NG trucks with an open-crankcase design, the methane emissions from the crankcase can be even greater than those from the tailpipe. Based on this publication, a 2.28 multiplier was added to NG methane emissions for all model year 2017 and earlier model years to account for blow-by processes in open crankcase engines.

Figure 5.13 shows a comparison between statewide EMFAC2021 and updated EMFAC2025 methane emissions from the on-road fleet. This update results in a 20% increase in methane emissions in calendar year 2025 but with a decreasing impact projected into the future as a greater proportion of the fleet turns over to model year 2018 and newer.

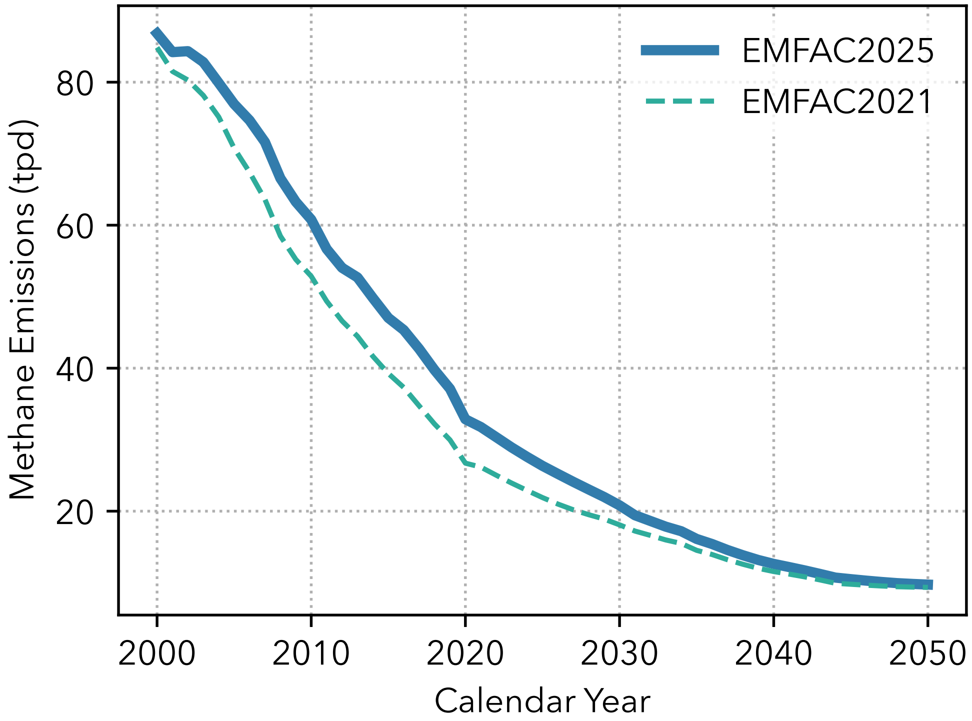


Figure 5.13: Statewide Methane Emissions from Light- and Heavy-Duty Vehicles: EMFAC2025 vs. EMFAC2021

# 6 Light-Duty Emission Rate Update

## 6.1 Base Emission Rates

Exhaust emissions from a vehicle's tailpipe, such as hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen ($NO_x$), are influenced by variations in the combustion process that depend on vehicle operating conditions. In EMFAC, two light-duty vehicle operational modes contribute to exhaust emissions: the stabilized running mode and the start mode. This section provides a brief overview of the model's handling of basic tailpipe emission rates and start emission rates. Emission rates, also referred to as emission factors, related to these sources are typically measured at standard temperature and humidity using driving cycles that mimic typical vehicle driving and operating patterns. Emission rates are ultimately combined with vehicle activity data (such as vehicle population counts and vehicle operation) to estimate vehicle emissions inventories.

EMFAC2025 retains the methodology for determining base emission rates (BER) from EMFAC2021, where the emissions characteristics of a vehicle technology group are represented by emission regimes and vehicle emissions deterioration is simulated by the movement of vehicles across regimes. The emission factors associated with each regime (i.e., regime emission factor) are then weighted using the percentage of vehicles within each regime (i.e., regime fractions). The model consists of four regimes, which are derived from certification standards (i.e., standards defined over the Federal Test Procedures – FTP) as shown in Table 6.1. These are described in detail in Section 4.3.1.1 of the EMFAC2021 Technical Documentation (CARB, 2021).

Table 6.1: Emission Regime Definitions in EMFAC2025

| Emission Regime | Emission Range |
|---|---|
| Low | 0 to 0.5 × Standard |
| Normal | 0.5 to 1.0 × Standard |
| Moderate | 1.0 to 2.0 × Standard |
| High | >2.0 × Standard |

The method for BER determination in EMFAC2025 is similar to EMFAC2021, including the test cycle (UC cycle), data sources, and the definition of technology groups. UC BERs are based on three years of new data from the U.S. EPA's In-Use Vehicle Program (IUVP) and CARB's Vehicle Surveillance Program (VSP), including running and start exhaust emission rates of HC, $NO_x$, and CO for LEV I and LEV II technology groups. New data are also used to update the ROS for the LEV III BERs, as explained in detail later in this section. In general, to update BERs, the following steps were taken:

1. Acquire the IUVP data (FTP results) for the selected tech group
2. Acquire the California sales data for each tech group from the NMOG report, if available
3. Determine the sales-weighted regime fractions and average emission rates versus odometer bins for the FTP data
4. Gather test data for the selected tech group from VSP under the FTP and UC tests
5. Classify FTP composite emission rate data into low, normal, moderate, and high regimes
6. Select vehicles tested under both the FTP and UC
7. Determine the average value of UC results for each emission regime.

LEV III technology groups (LEV160, ULEV125, SULEV30) have the same exhaust NMOG+NOx standards as LEV II technology groups (LEV, ULEV, SULEV) but with tightened durability requirements of 150,000 miles compared to 120,000 miles under LEV II. Thus, for LEV III technology groups (model years 2015 and later), EMFAC assumes that LEV160, ULEV125, and SULEV30 share the same running and start exhaust emission regressions as their respective LEV II counterparts (LEV, ULEV, SULEV). For other LEV III certification levels such as ULEV70, ULEV50, and SULEV20, a Ratio of Standards (ROS) approach is used to estimate emission rates due to limited data availability for developing technology-specific regressions. The ROS scalar is calculated as the ratio of the LEV III HC+$NO_x$ certification standard to that of the corresponding LEV II baseline, as shown in Table 6.2. This scalar is then applied to the base emission rates (BER) of the corresponding LEV II group to estimate emissions for the newer technology categories.

Table 6.2: Ratio of Standards (ROS) Scalars in EMFAC2025

| New Tech Group | Base | Ratio of Standards |
|---|---|---|
| LEV III ULEV70 | LEV II ULEV125 | 70/125 = 0.56 |
| LEV III ULEV50 | LEV II ULEV125 | 50/125 = 0.40 |
| LEV III SULEV20 | LEV II SULEV30 | 20/30 = 0.67 |

Tables 6.3 and 6.4 show sample results for IUVP and VSP data for HC emissions associated with LEV II ULEVs, respectively. U.S. EPA's IUVP data were used to determine the fractions of low, normal, moderate, and high emitters versus odometer for LEV I and LEV II vehicles. The IUVP results were weighted by the California sales of each test group. Sales data were obtained from the manufacturer non-methane organic gas (NMOG) reports to CARB. The CARB VSP program provides the UC cycle-based emission levels for the emission regimes. The emission rates are computed in terms of fraction of vehicles in an emission regime (either low, normal, moderate, or high emission, as a function of odometer), averaging the corresponding UC emission rate over odometer bins for that regime. Finally, a curve is fitted to average emission rates for each bin versus odometer.

Table 6.3: Sample of Results for IUVP Data for LEV II ULEVs Hydrocarbon (HC)

| Odometer Bin | Regime | Count | Regime Fraction | Sales Weighted Regime Fraction |
|---|---|---|---|---|
| 0–50 kmi | Low | 1330 | 0.937 | 0.902 |
| | Normal | 88 | 0.062 | 0.098 |
| | Moderate | 1 | 0.001 | 0.000 |
| | High | 1 | 0.001 | 0.000 |
| 50–100 kmi | Low | 911 | 0.686 | 0.673 |
| | Normal | 411 | 0.309 | 0.322 |
| | Moderate | 3 | 0.002 | 0.001 |
| | High | 3 | 0.002 | 0.004 |
| 100–150 kmi | Low | 105 | 0.528 | 0.511 |
| | Normal | 93 | 0.467 | 0.488 |
| | Moderate | 1 | 0.005 | 0.002 |
| | High | 0 | 0.000 | 0.000 |

Table 6.4: Sample of Results for VSP Data for LEV II ULEVs Hydrocarbon (HC)

| Odometer Bin | Regime | Count | Mean HC (g/mi) |
|---|---|---|---|
| UC Phase 1 (Cold Start) | Low | 40 | 0.385 |
| | Normal | 30 | 0.511 |
| | Moderate | 8 | 0.618 |
| | High | 0 | 0.618 |
| UC Phase 2 (Running) | Low | 40 | 0.011 |
| | Normal | 30 | 0.013 |
| | Moderate | 8 | 0.021 |
| | High | 0 | 0.021 |
| UC Phase 3 (Warm Start) | Low | 40 | 0.025 |
| | Normal | 30 | 0.033 |
| | Moderate | 8 | 0.043 |
| | High | 0 | 0.043 |

Emission rates are modeled in the form of regression equations with vehicle mileage (odometer in units of 10,000 miles) as an input to the model. To do this, staff fitted a curve to regime fractions as a function of odometer and calculated the weighted average emission rates for each phase of the UC cycle for different odometers. The resulting emission rates were again fitted with regressions as a function of odometer, and these estimated emission rates were then used in the model. Table 6.5 shows the number of vehicles added to the dataset in EMFAC2025 and the methodologies used to derive the base emission rates in each technology group.

Table 6.5: Updates to the Dataset in EMFAC2025

| Technology Group | | EMFAC2025 | EMFAC2021 |
|---|---|---|---|
| LEV I | LEV | N = 290 | N = 237 |
| | ULEV | N = 87 | N = 72 |
| LEV II | LEV160 | N = 37 | N = 33 |
| | ULEV125 | N = 78 | N = 78 |
| | SULEV30 | N = 76 | N = 49 |
| LEV III | LEV160 | Same as LEV II LEV160 | Same as LEV II LEV160 |
| | ULEV125 | Same as LEV II ULEV125 | Same as LEV II ULEV125 |
| | ULEV70 | Ratio of Standards | Ratio of Standards |
| | ULEV50 | Ratio of Standards | Ratio of Standards |
| | SULEV30 | Same as LEV II SULEV30 | Same as LEV II SULEV30 |
| | SULEV20 | Ratio of Standards | Ratio of Standards |

### 6.1.1 Hydrocarbon (HC) Base Emission Rates

Figures 6.1 to 6.8 show a comparison between EMFAC2025 and EMFAC2021 HC base emission rates. For the LEV I LEV technology group, cold start, running exhaust, and warm start emission rates for HC are higher in EMFAC2025 than in EMFAC2021, as illustrated in Figure 6.1. For the LEV I ULEV group, cold start HC emission rates are higher in EMFAC2025 compared to EMFAC2021, as shown in Figure 6.2. However, for running exhaust emissions, EMFAC2025 shows lower HC rates at lower odometer readings and higher rates at higher odometer readings compared to EMFAC2021, as illustrated in Figure 6.2. As shown in Figure 6.2, warm start HC emissions for LEV I ULEV are mostly lower in EMFAC2025. As shown in Figures 6.3 to 6.8, EMFAC2025 generally shows lower cold start HC emission rates than EMFAC2021 for LEV II and LEV III technology groups, except for LEV II LEV160 and LEV II ULEV125, which have slightly higher HC cold start emissions than EMFAC2021. Additionally, lower deterioration in HC cold start emission rates at higher odometer readings is observed in EMFAC2025, particularly for newer technology groups such as ULEV70, ULEV50, SULEV30, and SULEV20. As shown in Figures 6.3 and 6.4, LEV II LEV160 and LEV II ULEV125 technology groups exhibit higher running exhaust base emission rates and greater deterioration. In contrast, LEV III groups in EMFAC2025 generally show lower running exhaust emissions and reduced deterioration at higher odometer ranges. Higher warm start HC base emission rates and deterioration are observed in EMFAC2025 for LEV II LEV160 and LEV II ULEV125 groups compared to EMFAC2021, as shown in Figures 6.3 and 6.4. Newer LEV III groups (ULEV70, ULEV50, SULEV30, and SULEV20) exhibit lower warm start HC emission rates and reduced deterioration at high odometer readings.

Figures 6.9 to 6.11 compare cold start, running, and warm start exhaust emission rates for HC for all the technology groups in EMFAC2025.

### 6.1.2 Oxides of Nitrogen ($NO_x$) Base Emission Rates

Figures 6.12 through 6.19 present comparisons of $NO_x$ base emission rates between EMFAC2025 and EMFAC2021. For the LEV I LEV group, cold start, running exhaust, and warm start $NO_x$ emission rates are higher in EMFAC2025, as shown in Figure 6.12. Similarly, cold start $NO_x$ emission rates are higher in the LEV I ULEV group in EMFAC2025, as seen in Figure 6.13. However, for running exhaust $NO_x$ emissions in LEV I ULEV, rates are lower at lower odometer readings and higher at higher odometer readings in EMFAC2025, as shown in Figure 6.13. Warm start $NO_x$ emissions are mostly lower in EMFAC2025 than in EMFAC2021, as indicated in Figure 6.13. As shown in Figures 6.14 to 6.19, cold start $NO_x$ emission rates are lower across all LEV II and LEV III technology groups in EMFAC2025 compared to EMFAC2021, except for LEV II LEV160, for which the cold start $NO_x$ emission rates are lower at low odometer readings and higher at higher odometer readings. Figures 6.14 to 6.19 show that running exhaust $NO_x$ emissions are generally lower in EMFAC2025 across most LEV II and LEV III groups, with reduced deterioration at higher odometer readings, particularly for ULEV70, ULEV50, SULEV30, and SULEV20. The LEV160 group shows lower $NO_x$ base emission rates at low odometer readings and higher rates at higher odometer readings. The ULEV125 group shows higher $NO_x$ running exhaust rates at lower odometer readings and lower rates at higher odometer readings. Warm start $NO_x$ emission rates are also lower across all LEV II and LEV III technology groups in EMFAC2025 compared to EMFAC2021, except LEV II LEV160, as illustrated in Figures 6.14 to 6.19. The LEV II LEV160 group shows higher warm start $NO_x$ emission rates than EMFAC2021.

Figures 6.12 to 6.19 compare cold start, running, and warm start exhaust emission rates for $NO_x$ for all the technology groups in EMFAC2025.

Figures 6.20, 6.21, and 6.22 compare the cold start, running, and warm start exhaust emission rates for $NO_x$ for all the technology groups in EMFAC2025, respectively.

### 6.1.3 Base Emission Rate Regression Equations

Tables 6.6 to 6.10 provide the final regression equations utilized in EMFAC2025 for light-duty BERs. They are listed by Tech Group IDs, which are numerical identifiers for technology groups in the EMFAC model. Each technology group represents vehicles with distinct emission control technologies and similar in-use deterioration. Note that the BER for the LEV III ULEV70, LEV III ULEV50, and LEV III SULEV20 technology groups are calculated by scaling with the ROS scalar, as previously described, and share the regression equations with their corresponding LEV II base groups.

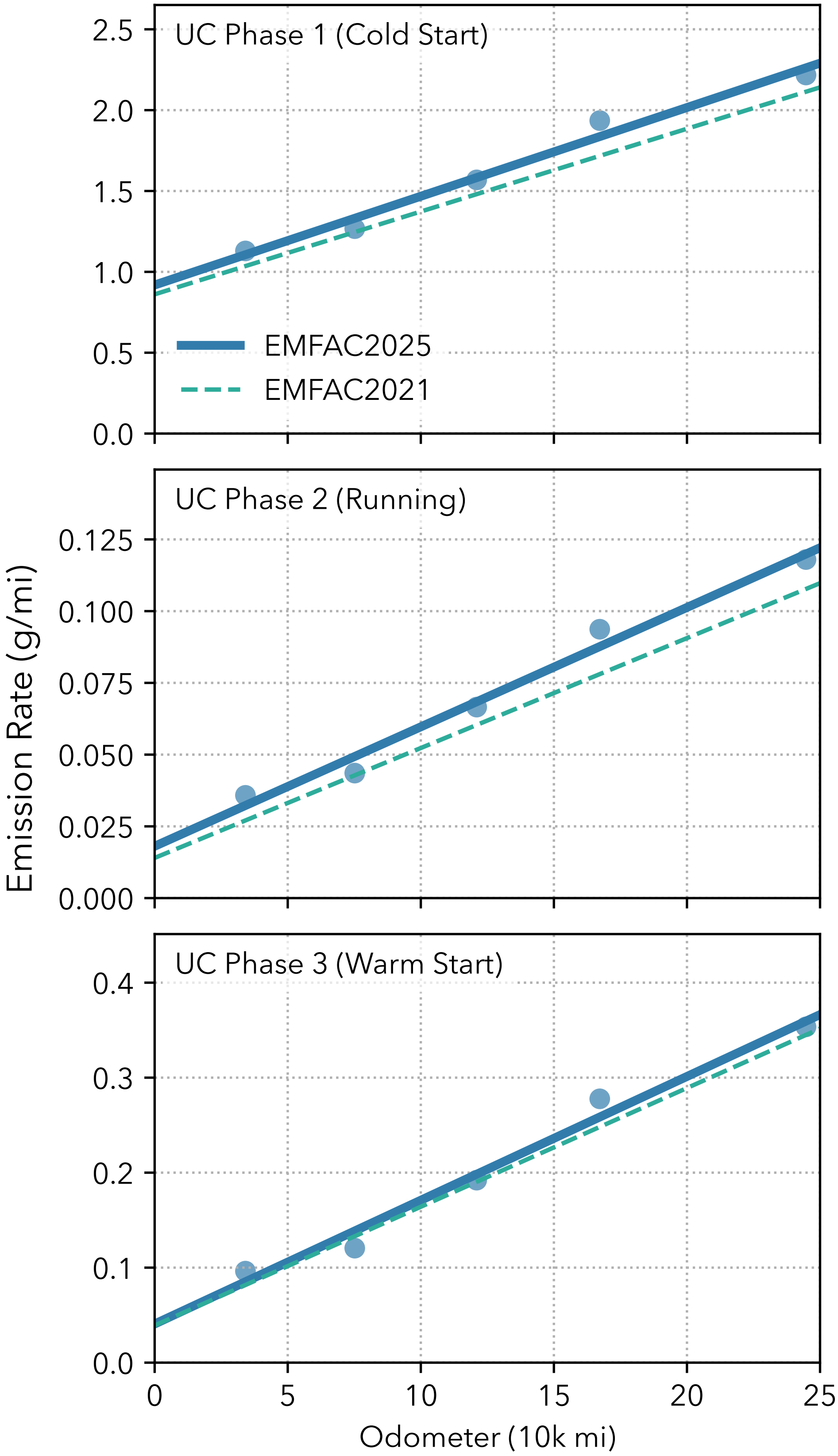


Figure 6.1: HC Emission Rates of LEV I LEV

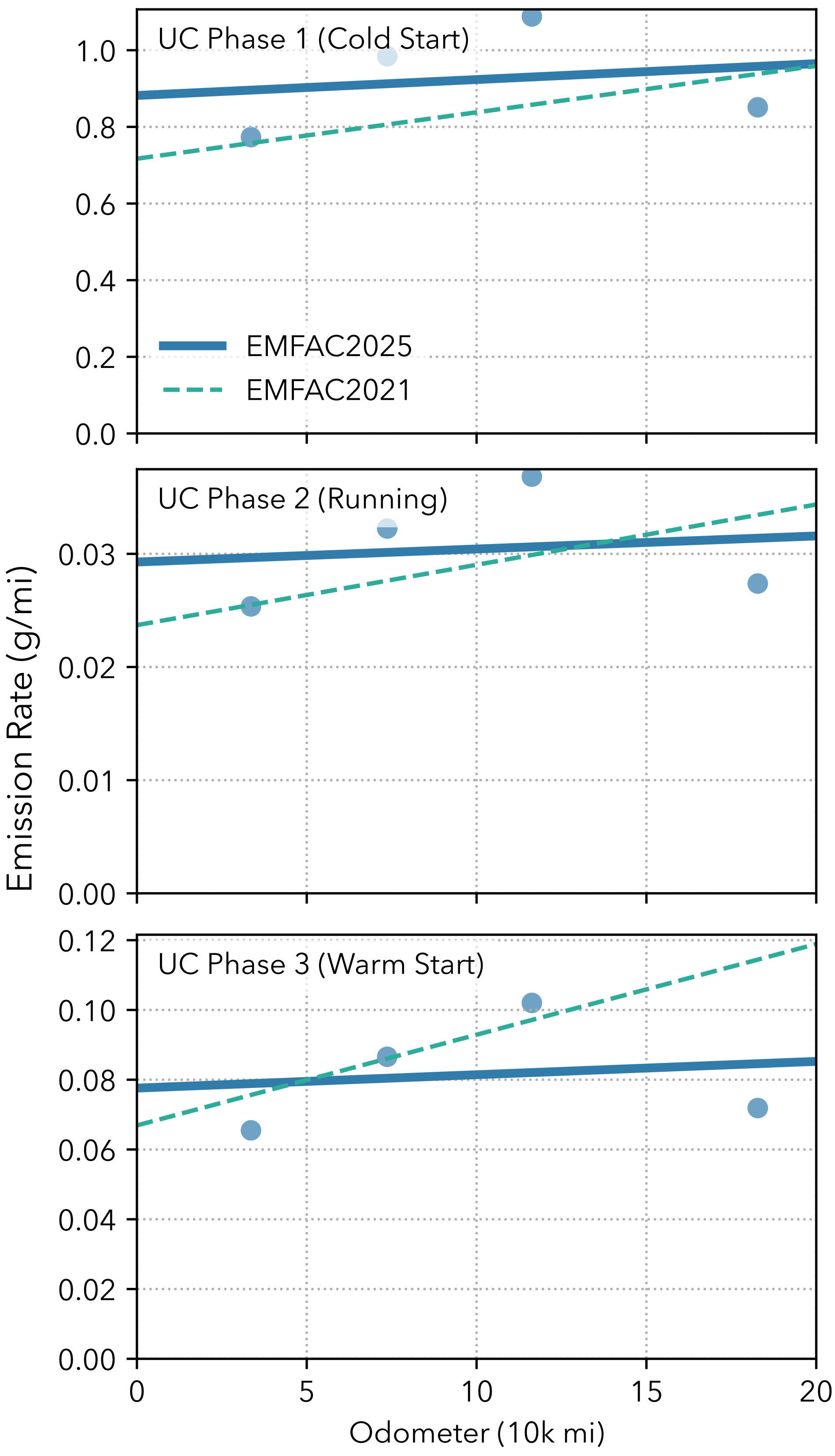


Figure 6.2: HC Emission Rates of LEV I ULEV

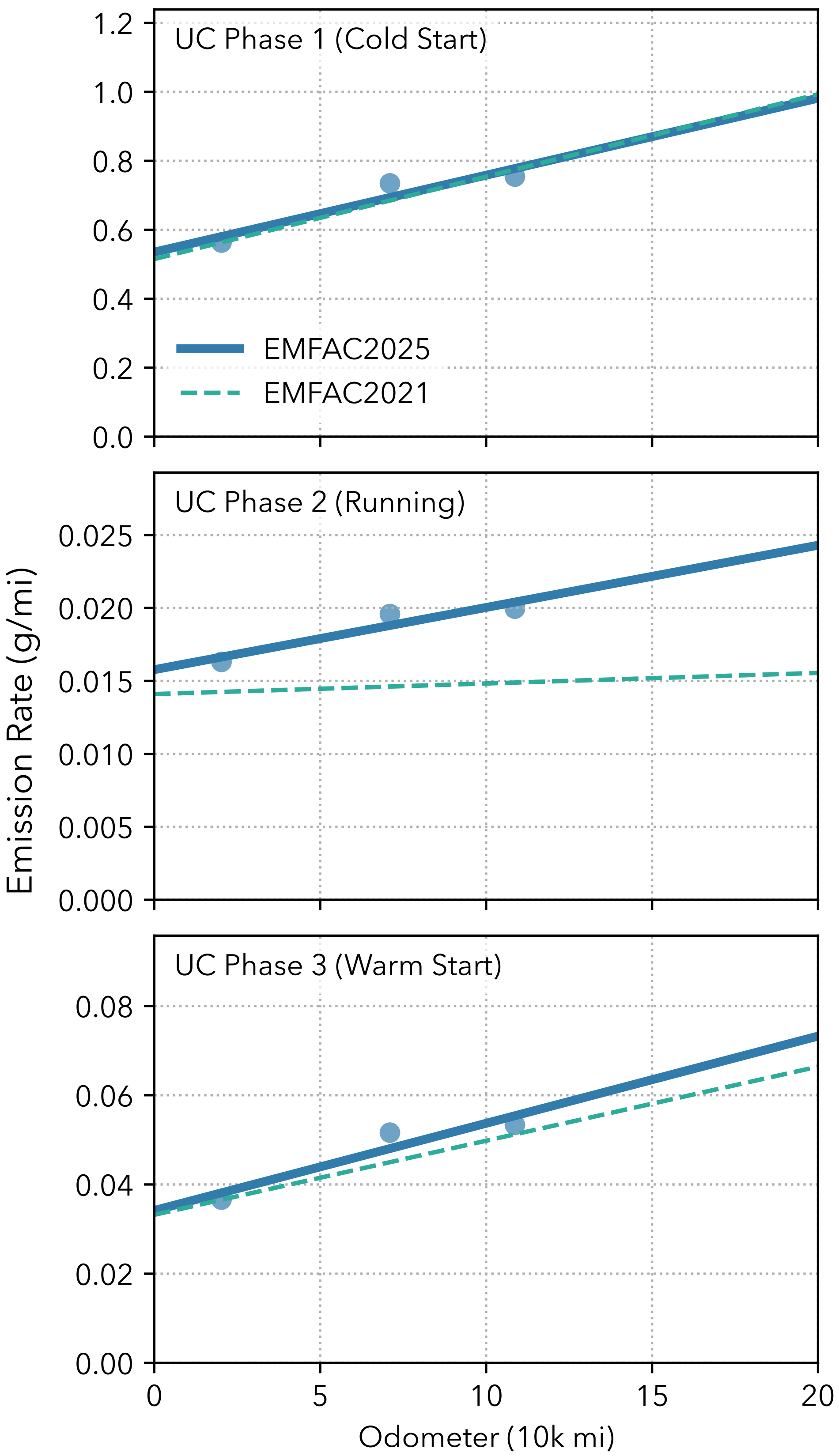


Figure 6.3: HC Emission Rates of LEV II/LEV III LEV160

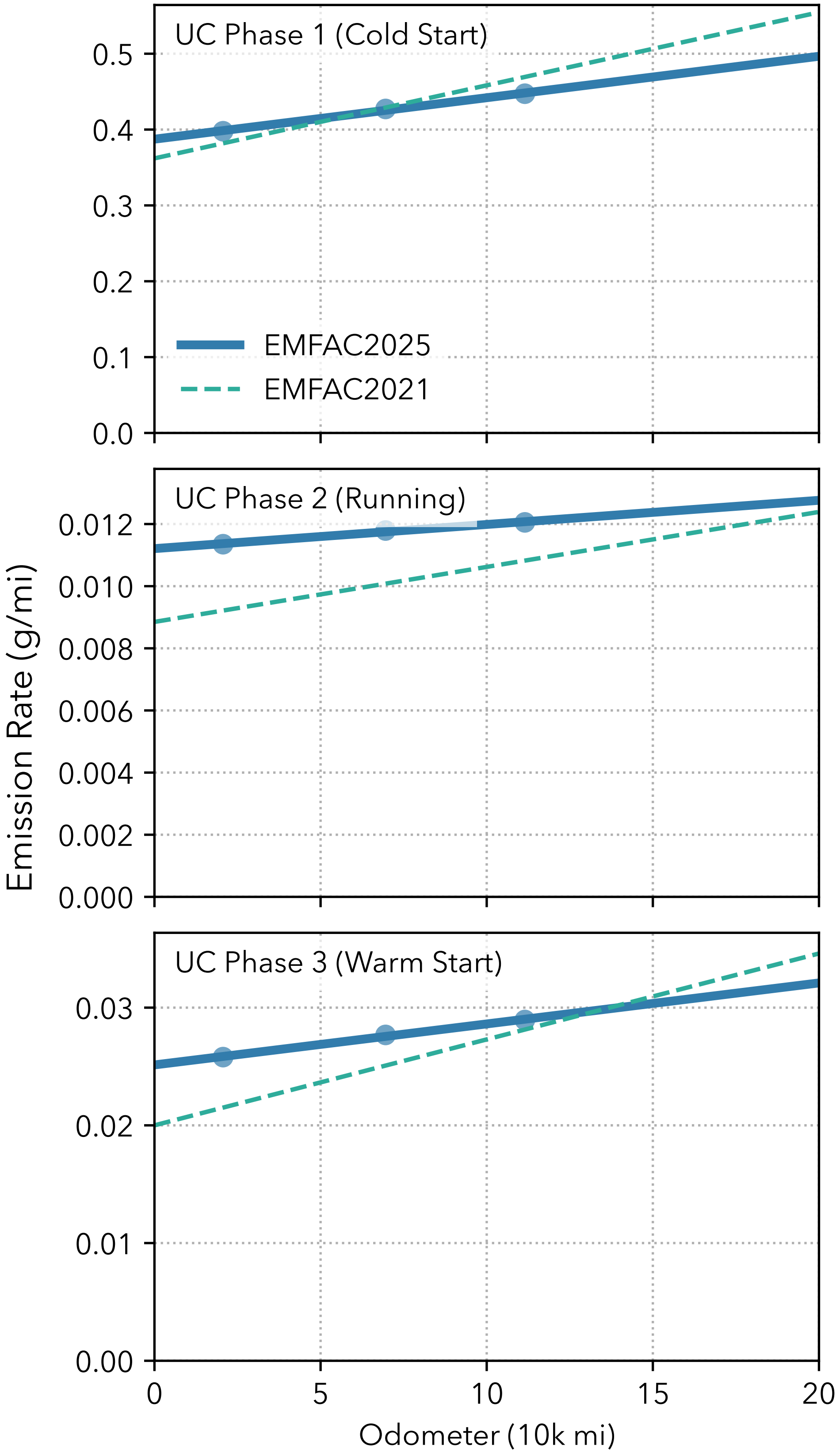


Figure 6.4: HC Emission Rates of LEV II/LEV III ULEV125

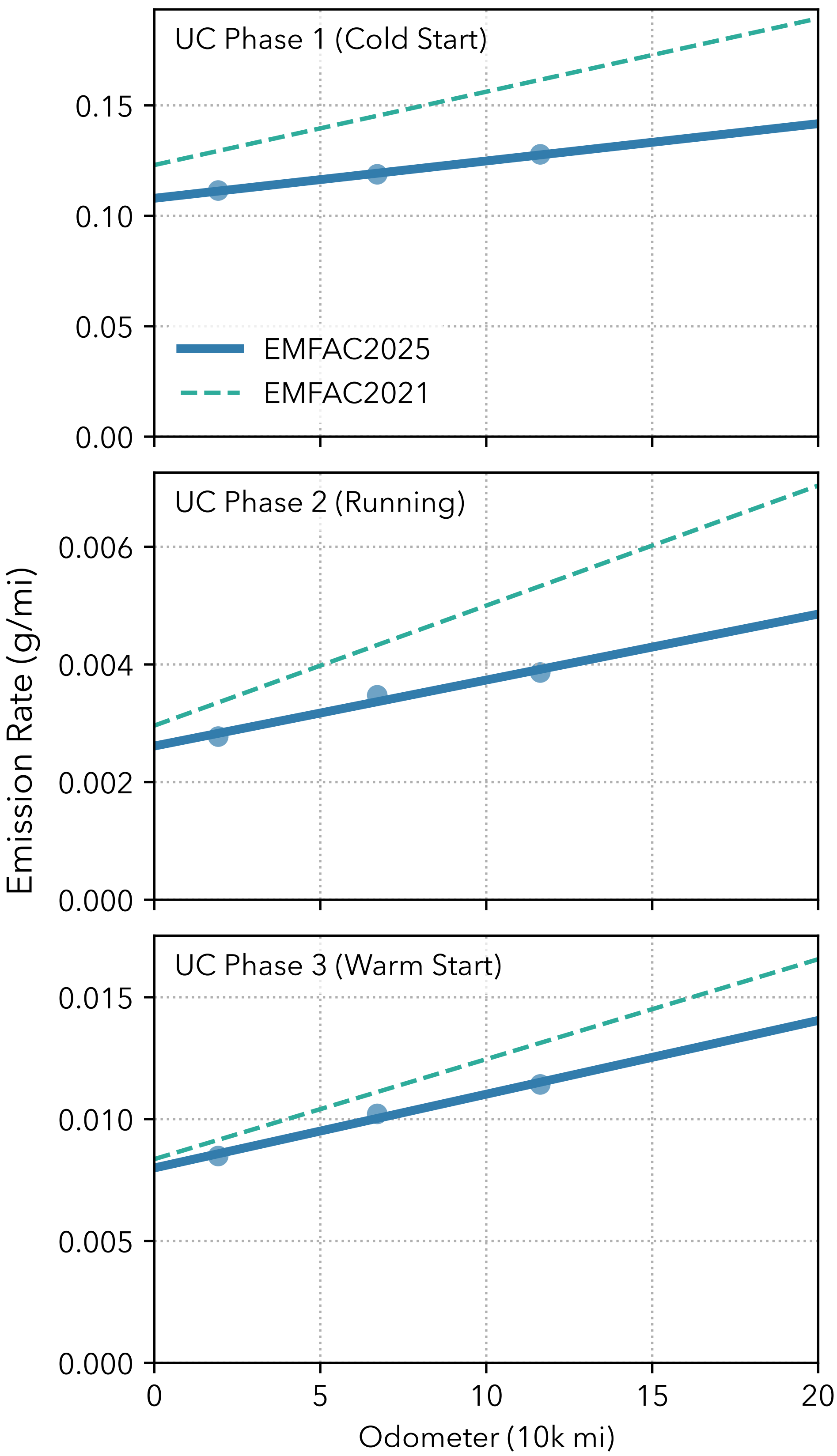


Figure 6.5: HC Emission Rates of LEV II/LEV III SULEV30

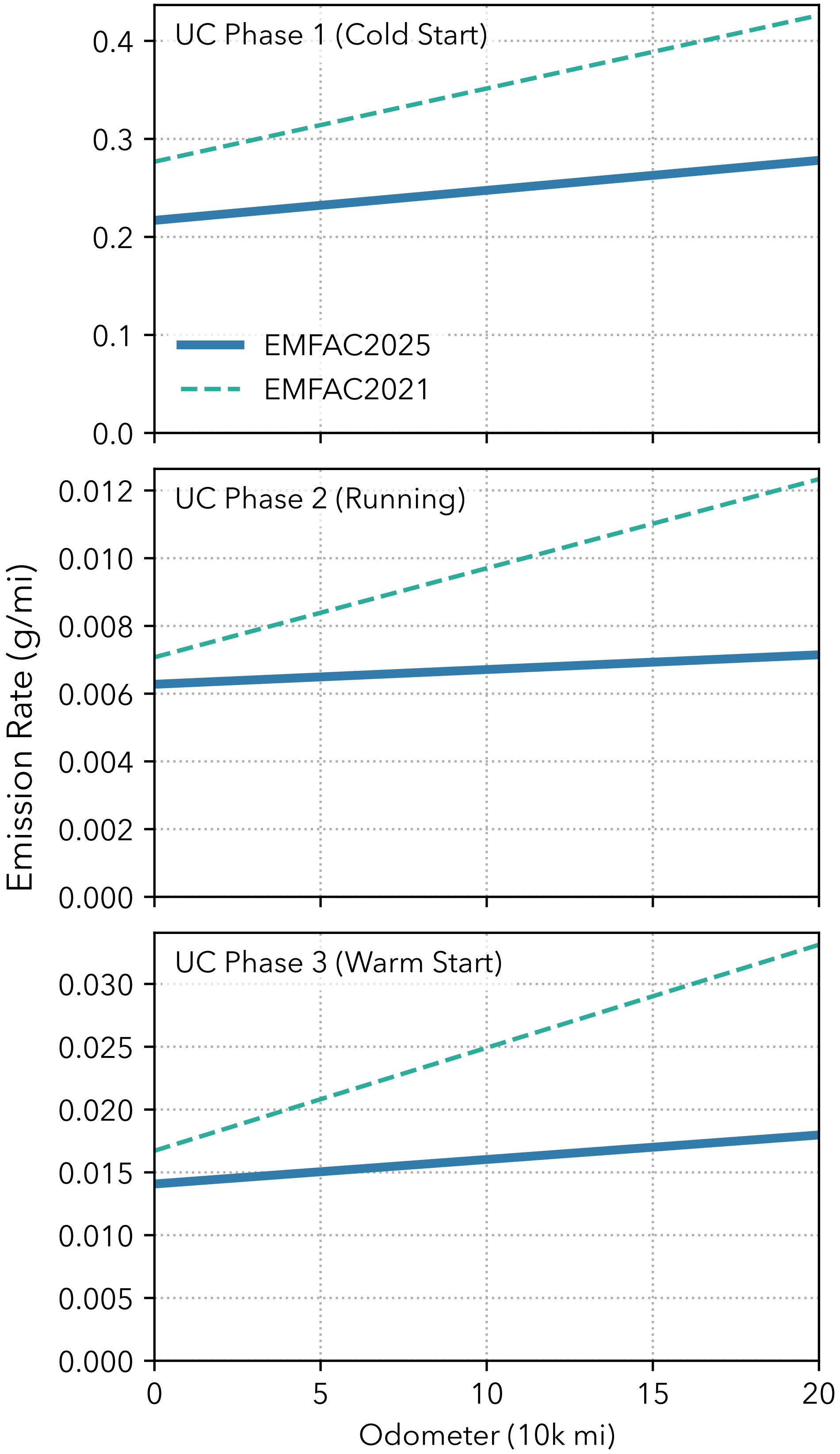


Figure 6.6: HC Emission Rates of LEV III ULEV70

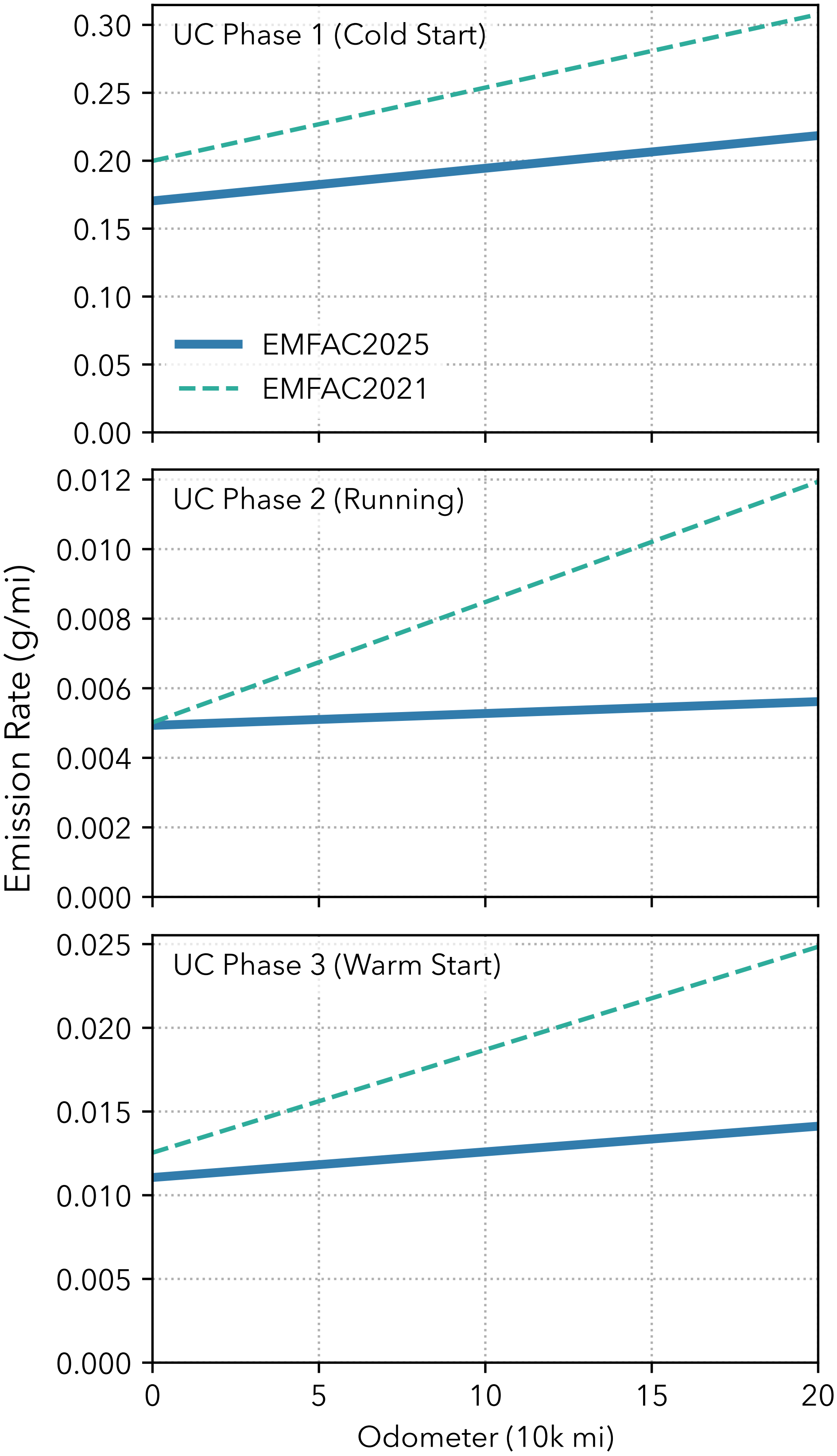


Figure 6.7: HC Emission Rates of LEV III ULEV50

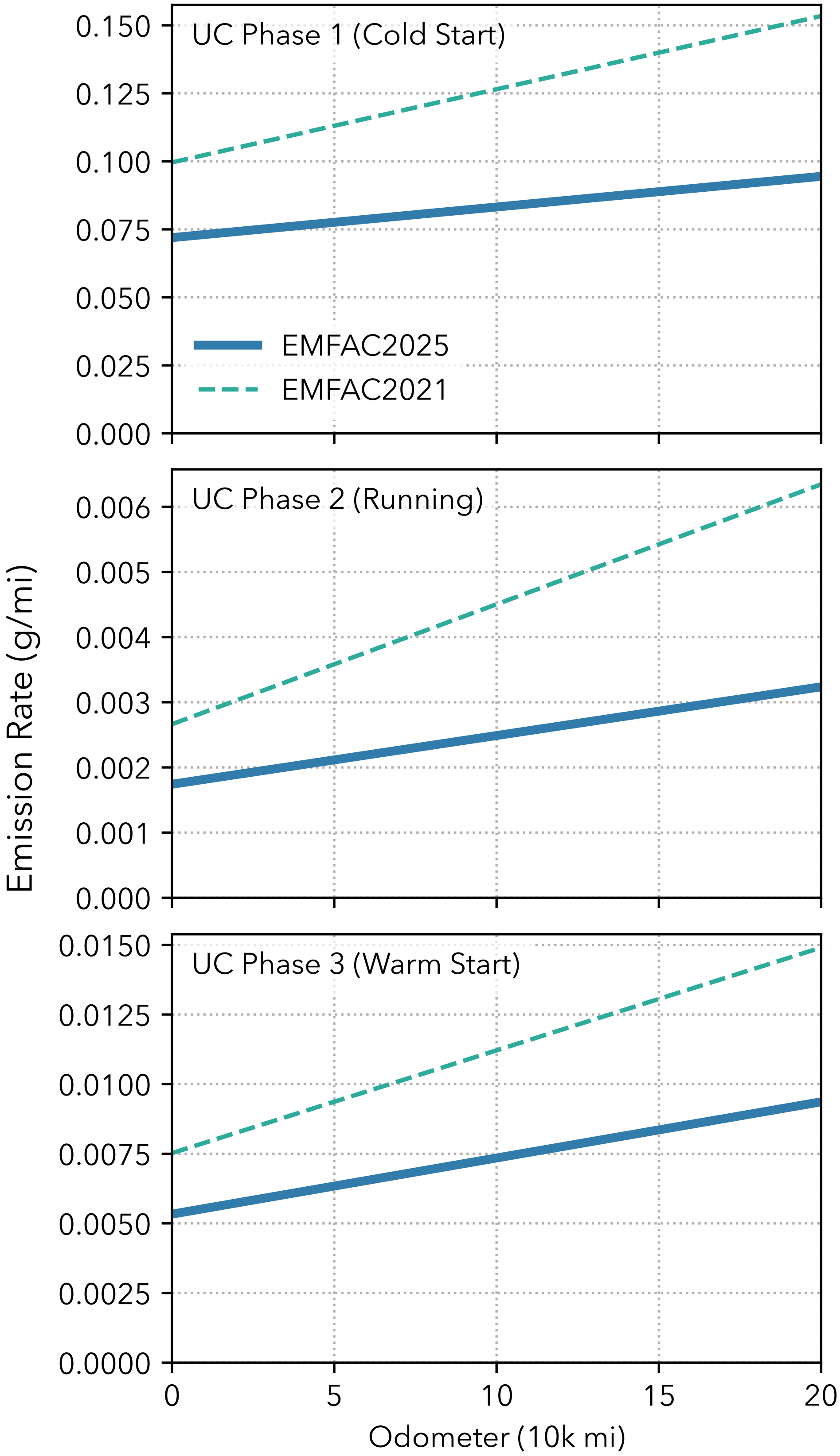


Figure 6.8: HC Emission Rates of LEV III SULEV20

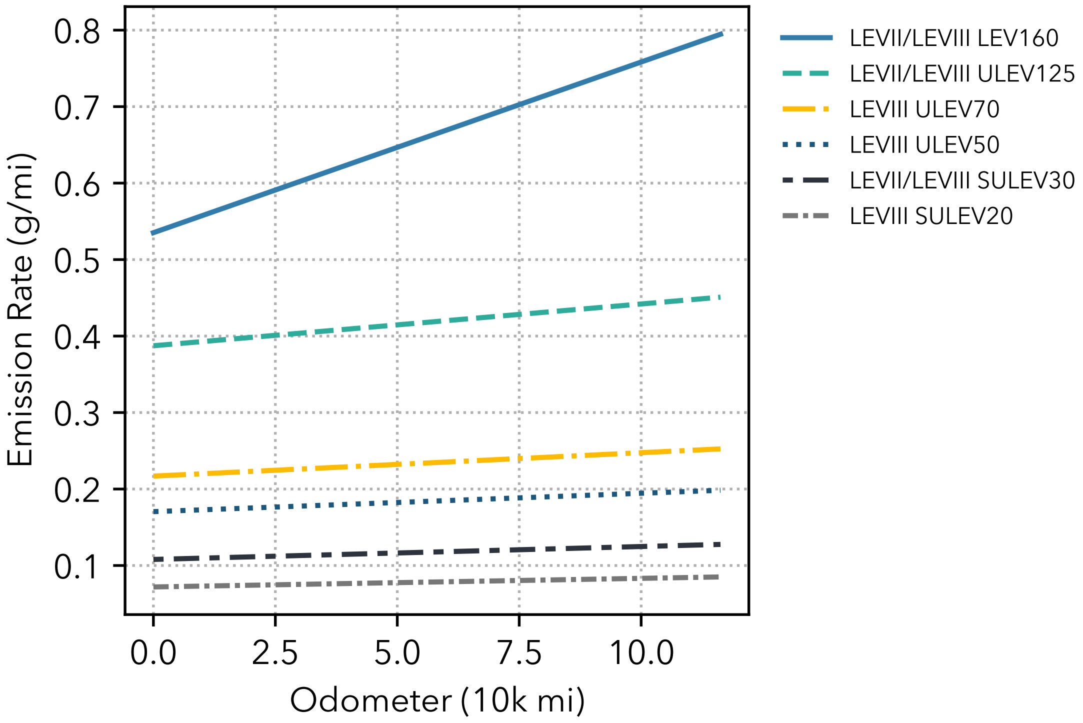


Figure 6.9: HC UC Phase 1 (Cold Start) Exhaust Emission Rates by Tech Group

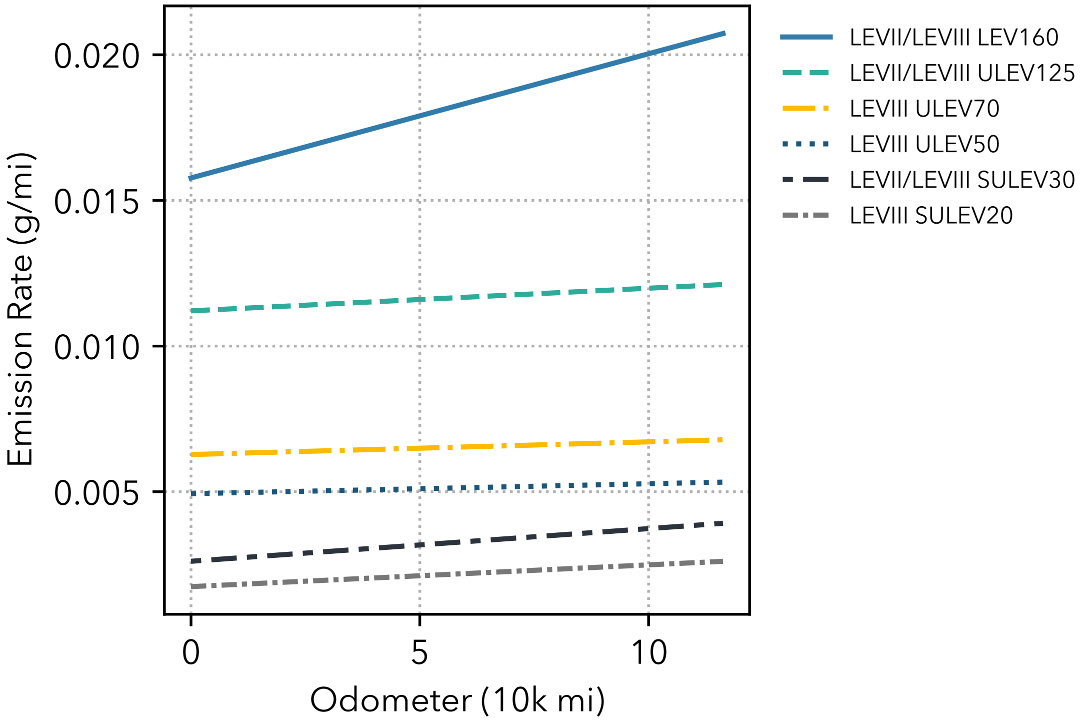


Figure 6.10: HC UC Phase 2 (Running) Exhaust Emission Rates by Tech Group

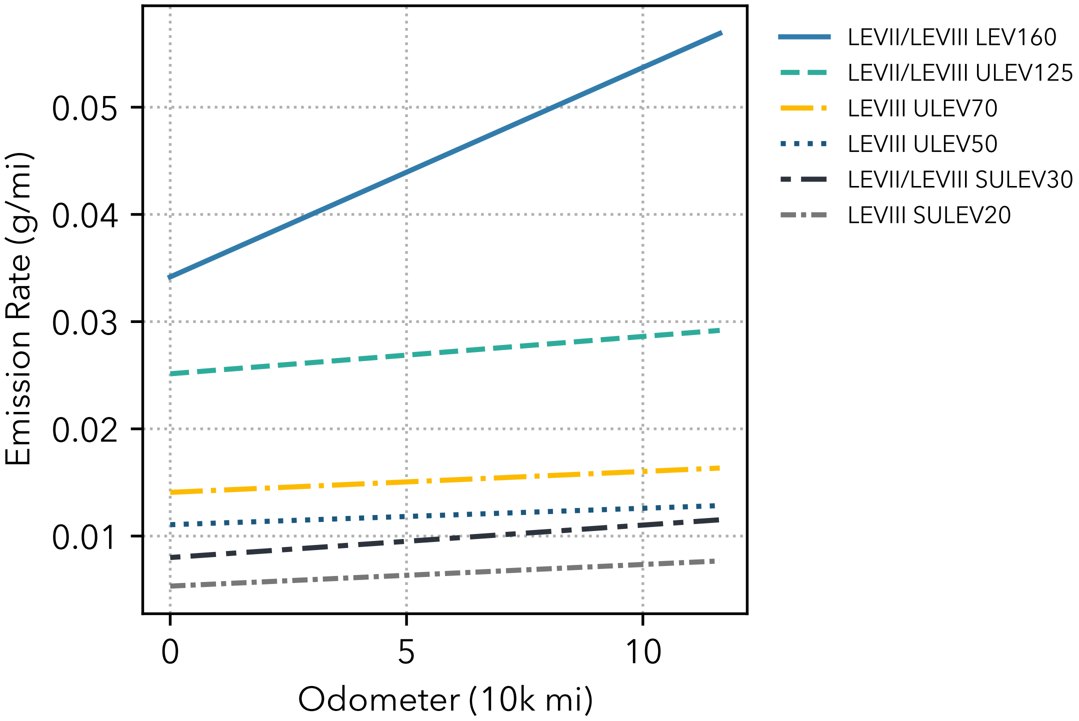


Figure 6.11: HC UC Phase 3 (Warm Start) Exhaust Emission Rates by Tech Group

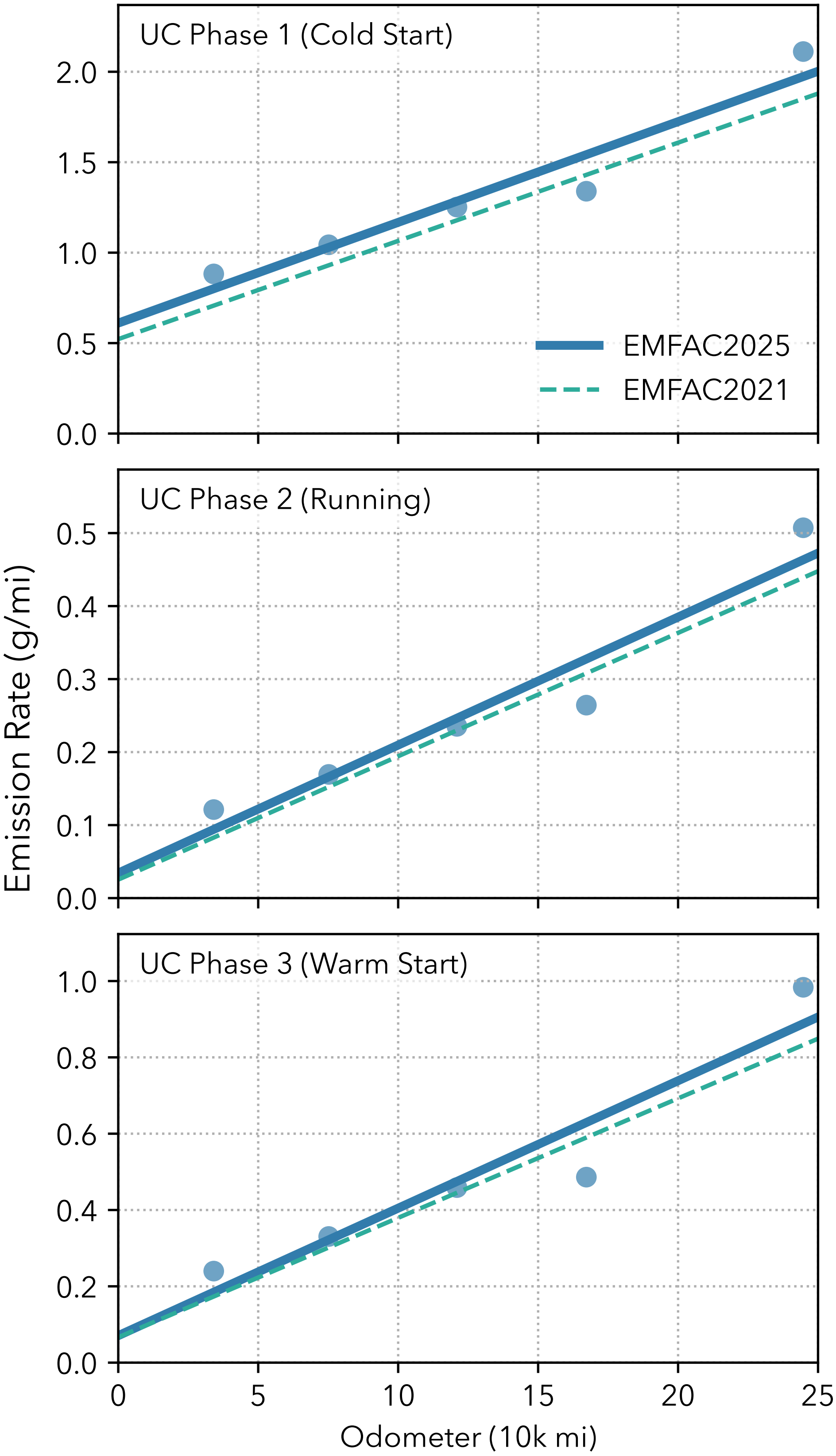


Figure 6.12: $NO_x$ Emission Rates of LEV I LEV

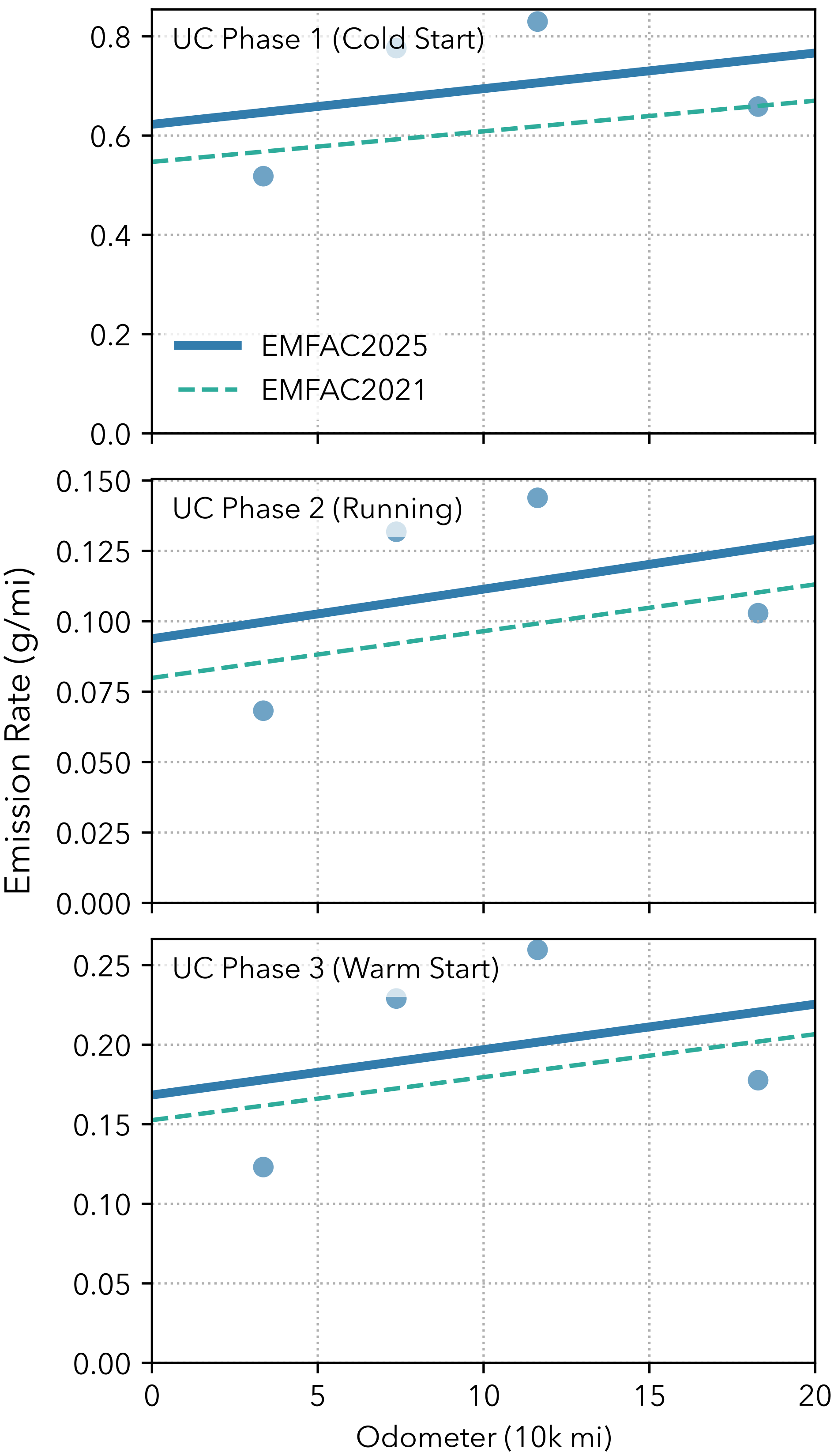


Figure 6.13: $NO_x$ Emission Rates of LEV I ULEV

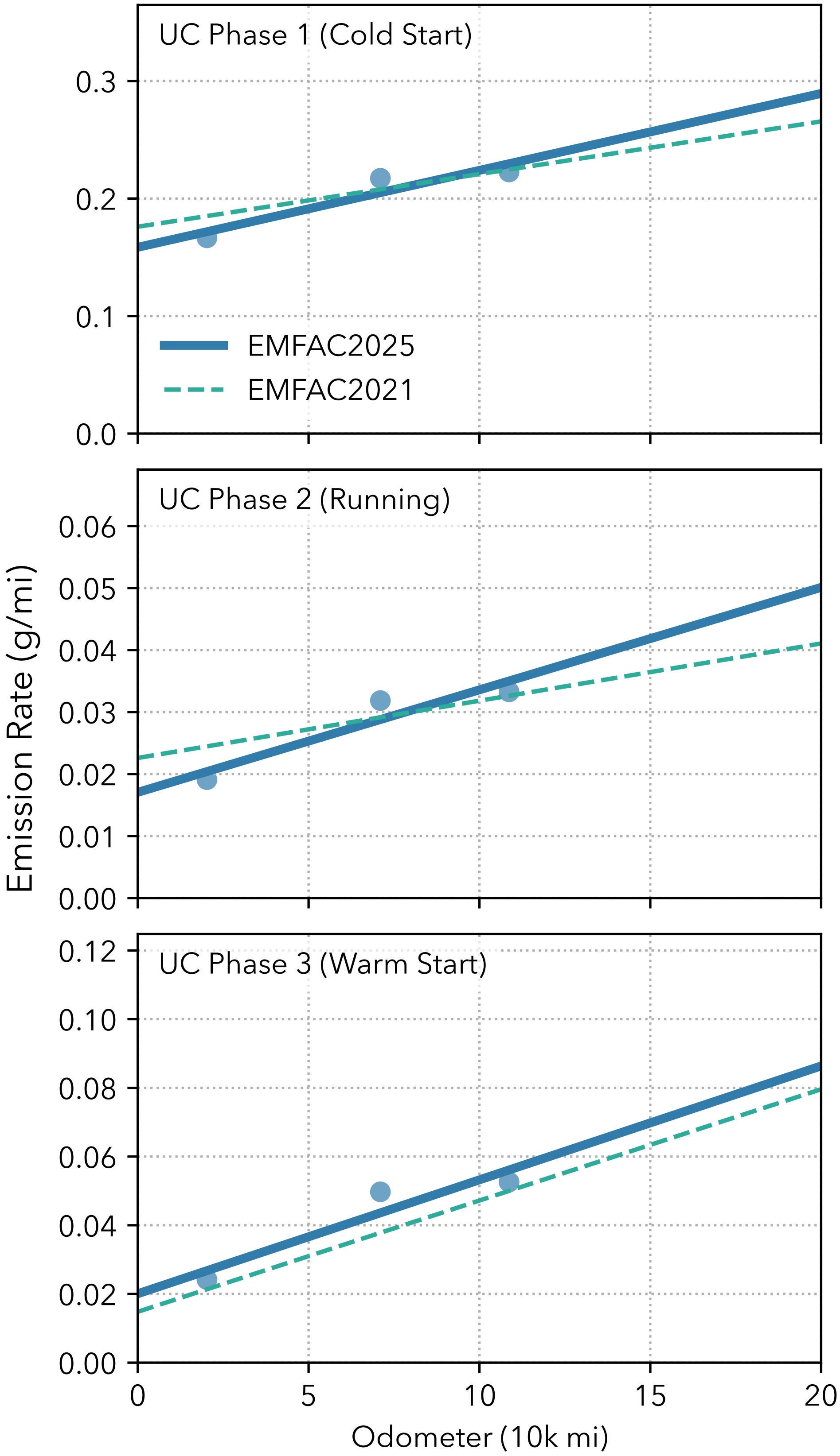


Figure 6.14: $NO_x$ Emission Rates of LEV II/LEV III LEV160

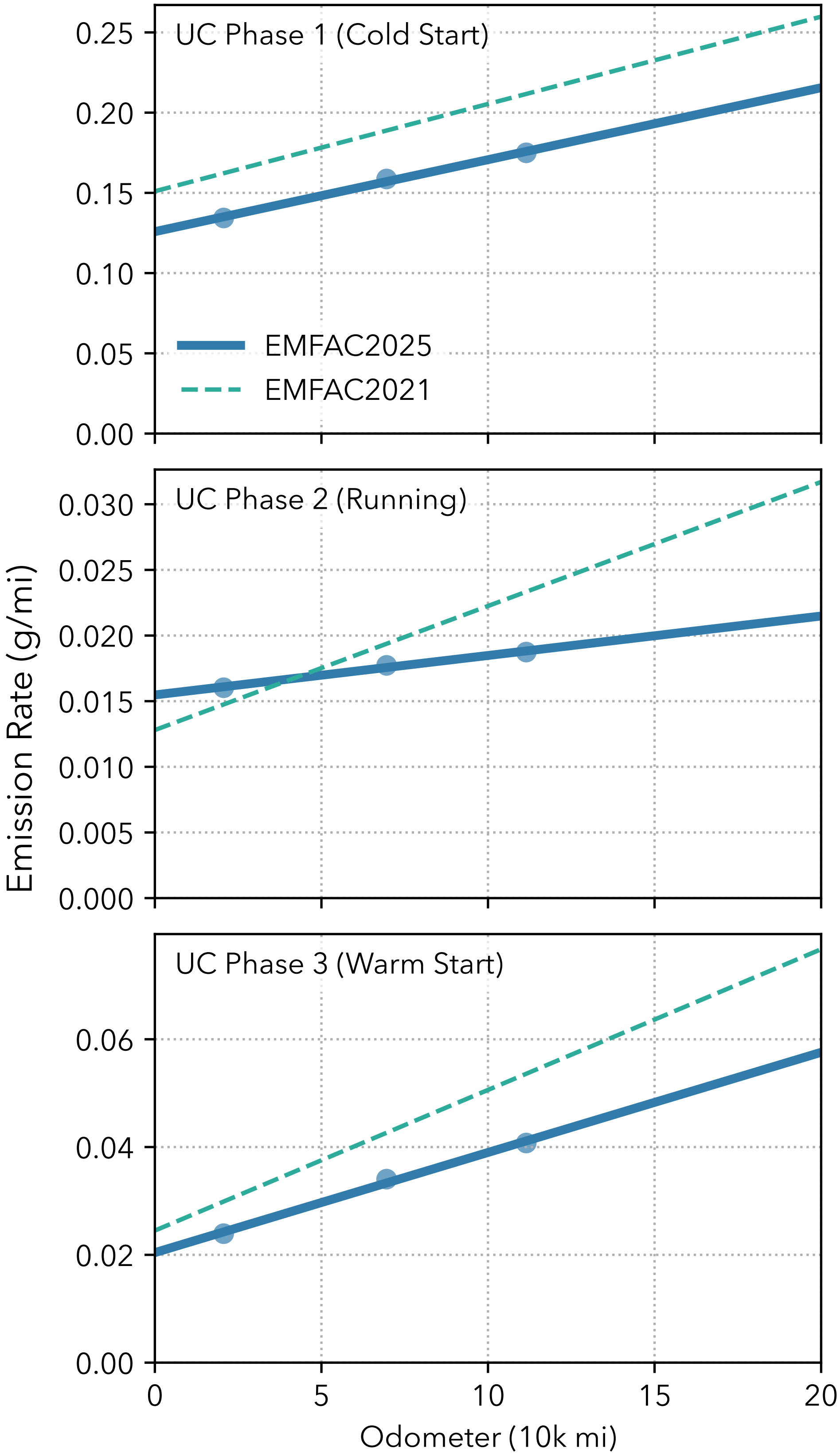


Figure 6.15: $NO_x$ Emission Rates of LEV II/LEV III ULEV125

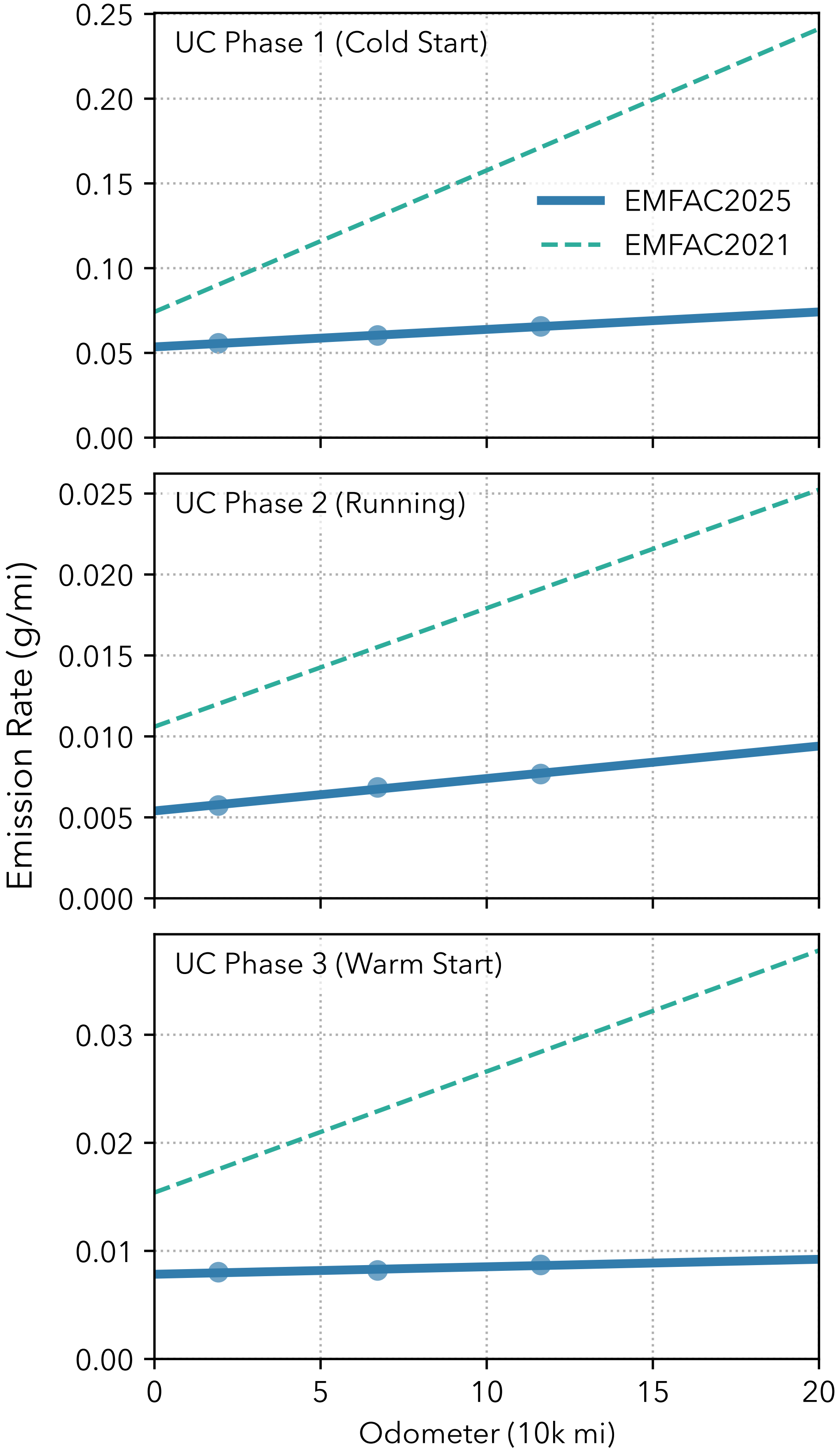


Figure 6.16: $NO_x$ Emission Rates of LEV II/LEV III SULEV30

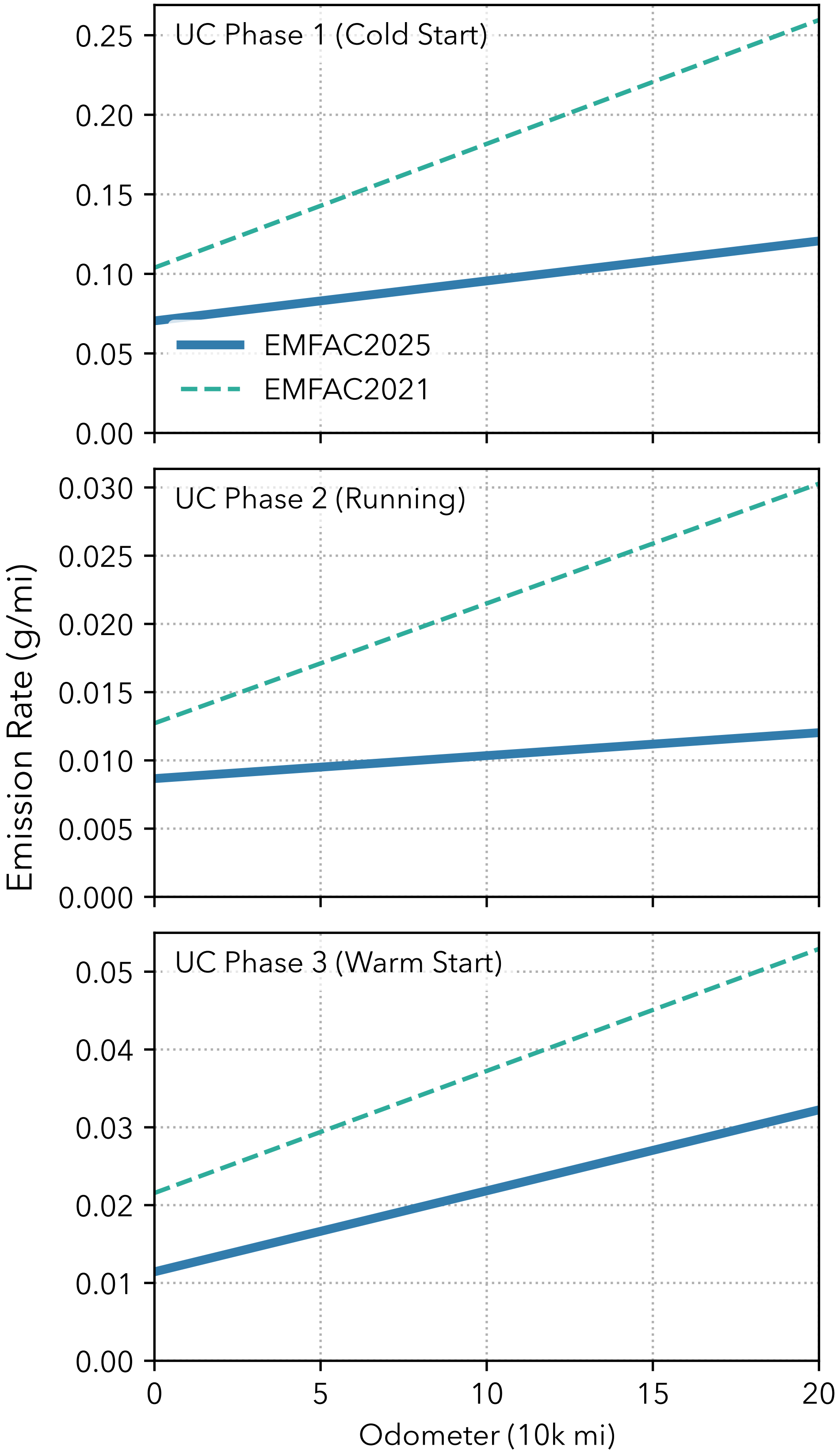


Figure 6.17: $NO_x$ Emission Rates of LEV III ULEV70

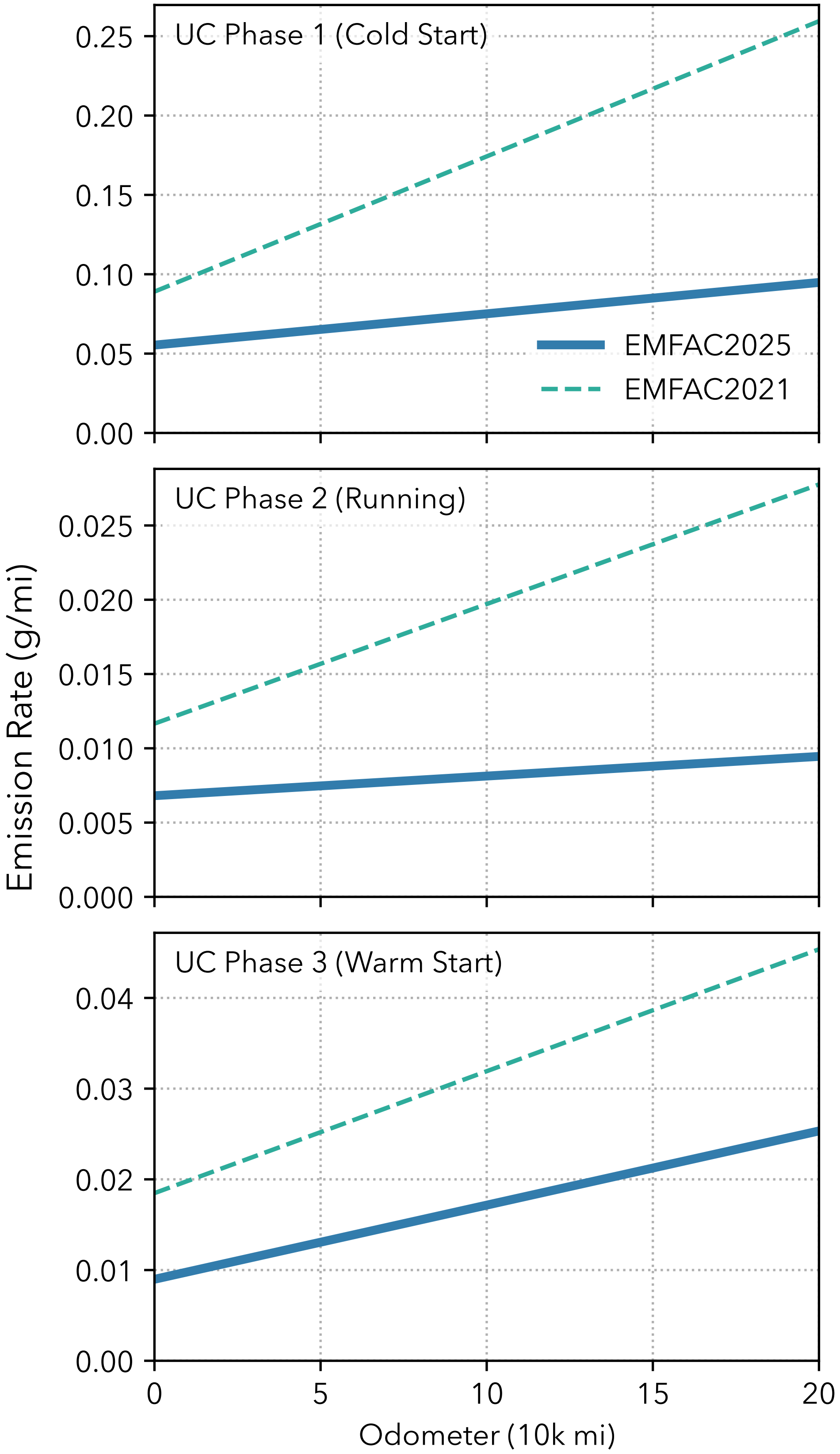


Figure 6.18: $NO_x$ Emission Rates of LEV III ULEV50

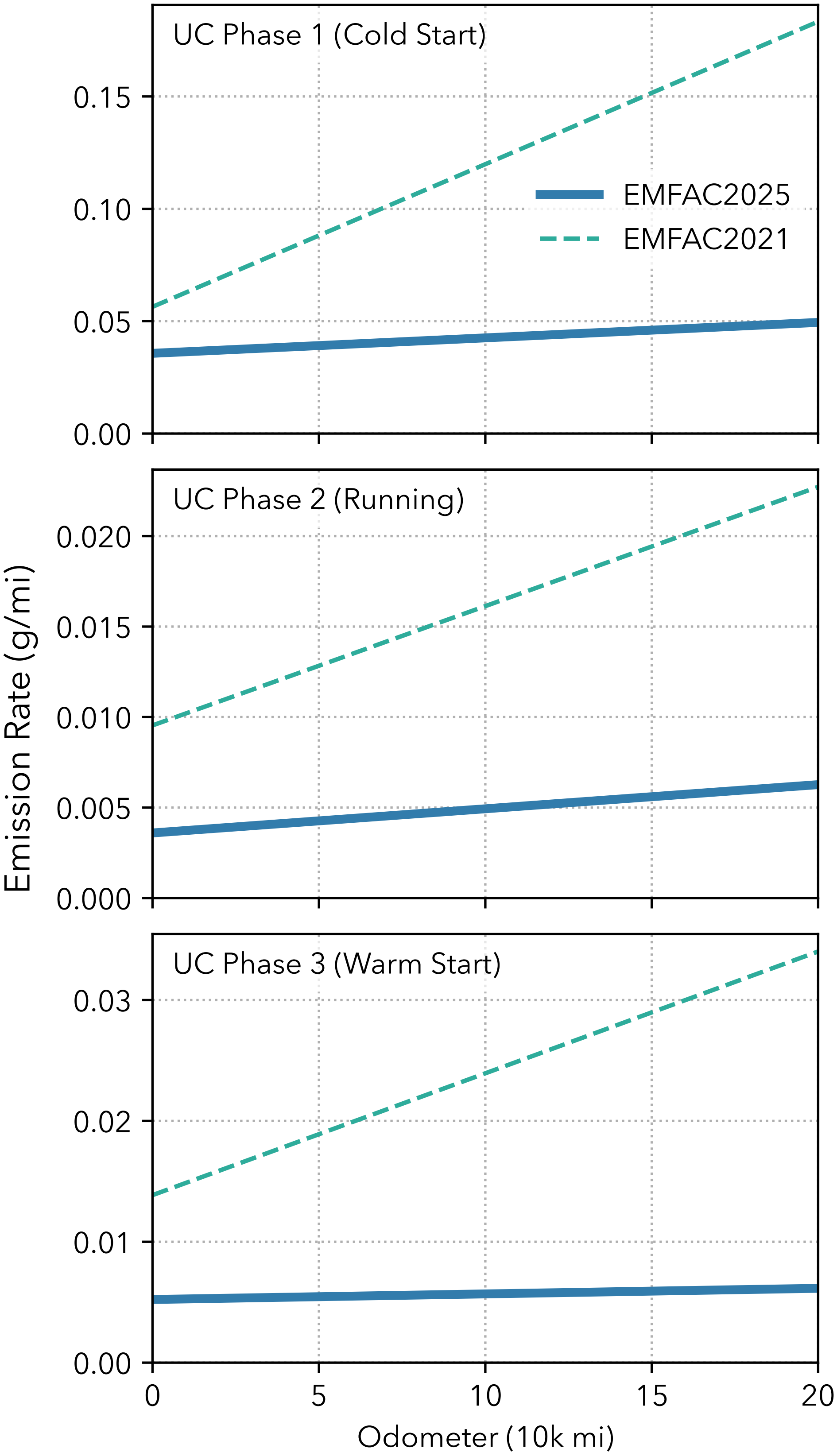


Figure 6.19: $NO_x$ Emission Rates of LEV III SULEV20

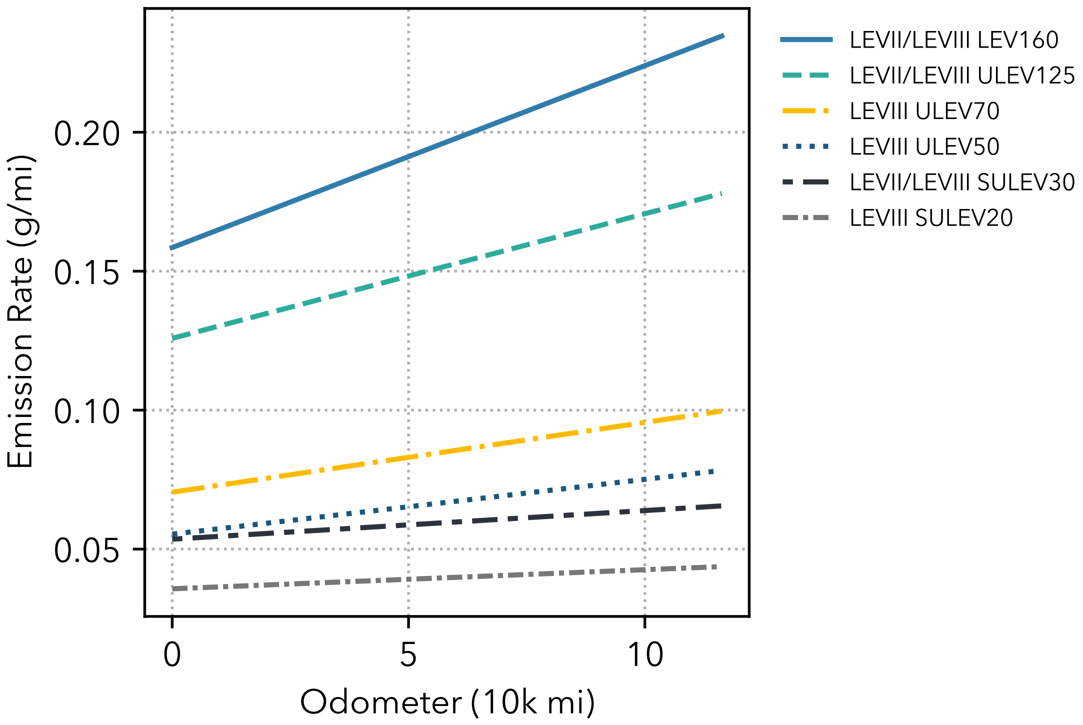


Figure 6.20: $NO_x$ UC Phase 1 (Cold Start) Exhaust Emission Rates by Tech Group

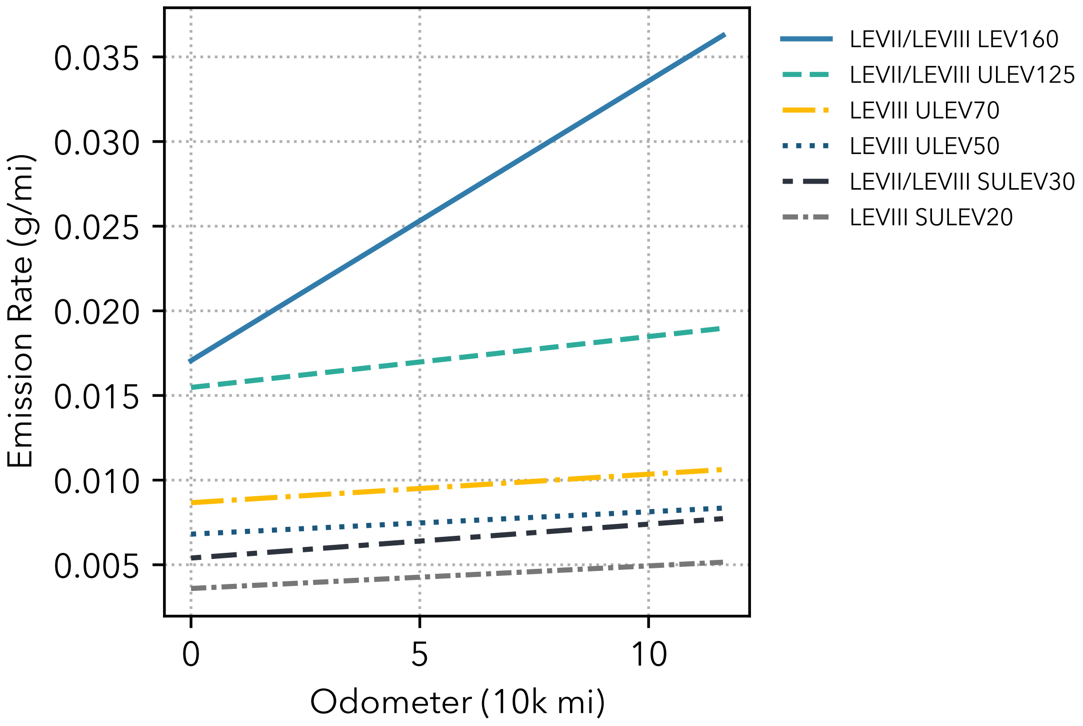


Figure 6.21: $NO_x$ UC Phase 2 (Running) Exhaust Emission Rates by Tech Group

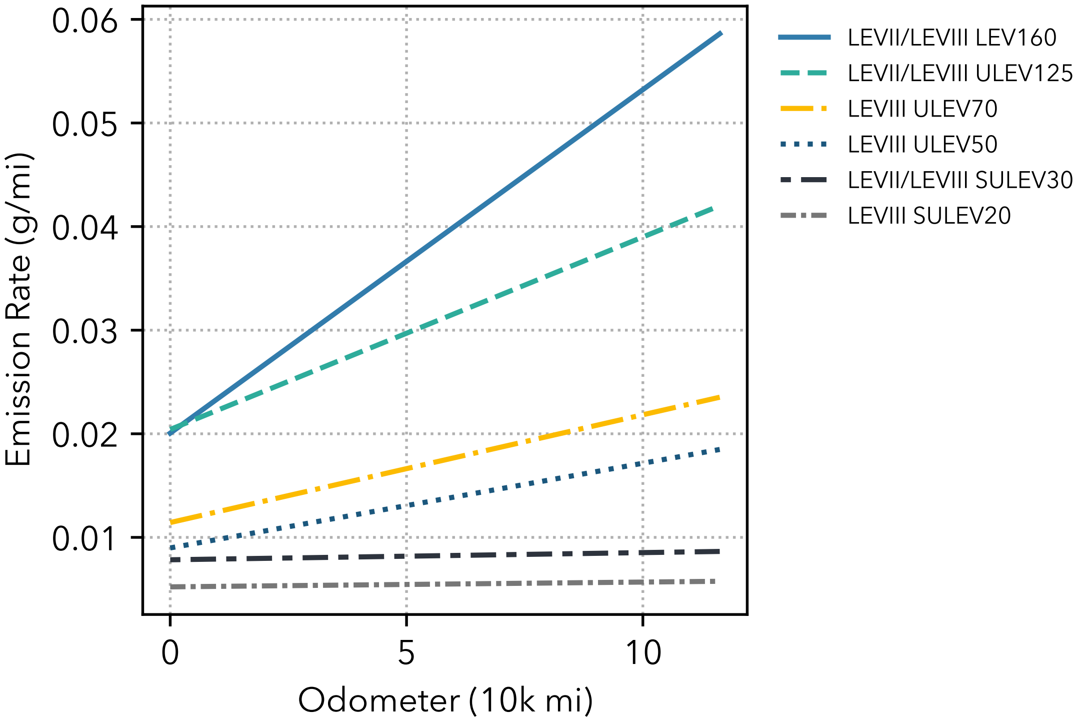


Figure 6.22: $NO_x$ UC Phase 3 (Warm Start) Exhaust Emission Rates by Tech Group

Table 6.6: LEV I LEV (Tech Group 23) Base Emission Rate Regression Equations

| Process | Pollutant | Regression Equation |
|---|---|---|
| UC Phase 1 (Cold Start) | HC | $y = 5.49 \cdot 10^{-6}x + 0.919$ |
| | CO | $y = 4.11 \cdot 10^{-5}x + 10.42$ |
| | $NO_x$ | $y = 5.56 \cdot 10^{-6}x + 0.610$ |
| UC Phase 2 (Running) | HC | $y = 4.16 \cdot 10^{-7}x + 0.018$ |
| | CO | $y = 9.22 \cdot 10^{-6}x + 1.597$ |
| | $NO_x$ | $y = 1.75 \cdot 10^{-6}x + 0.034$ |
| UC Phase 3 (Warm Start) | HC | $y = 1.30 \cdot 10^{-6}x + 0.040$ |
| | CO | $y = 1.40 \cdot 10^{-5}x + 1.178$ |
| | $NO_x$ | $y = 3.34 \cdot 10^{-6}x + 0.070$ |

Table 6.7: LEV I ULEV (Tech Group 24) Base Emission Rate Regression Equations

| Process | Pollutant | Regression Equation |
|---|---|---|
| UC Phase 1 (Cold Start) | HC | $y = 4.15 \cdot 10^{-7}x + 0.881$ |
| | CO | $y = 1.77 \cdot 10^{-5}x + 9.413$ |
| | $NO_x$ | $y = 7.18 \cdot 10^{-7}x + 0.622$ |
| UC Phase 2 (Running) | HC | $y = 1.15 \cdot 10^{-8}x + 0.029$ |
| | CO | $y = 1.35 \cdot 10^{-5}x + 0.474$ |
| | $NO_x$ | $y = 1.76 \cdot 10^{-7}x + 0.094$ |
| UC Phase 3 (Warm Start) | HC | $y = 4.77 \cdot 10^{-8}x + 0.076$ |
| | CO | $y = 0.58 \cdot e^{1.17 \cdot 10^{-5}x}$ |
| | $NO_x$ | $y = 2.85 \cdot 10^{-7}x + 0.168$ |

Table 6.8: LEV II/LEV III LEV160 (Tech Group 28) Base Emission Rate Regression Equations

| Process | Pollutant | Regression Equation |
|---|---|---|
| UC Phase 1 (Cold Start) | HC | $y = 2.23 \cdot 10^{-6}x + 0.535$ |
| | CO | $y = 3.79 \cdot 10^{-6}x + 8.051$ |
| | $NO_x$ | $y = 6.54 \cdot 10^{-7}x + 0.158$ |
| UC Phase 2 (Running) | HC | $y = 4.26 \cdot 10^{-8}x + 0.015$ |
| | CO | $y = 9.02 \cdot 10^{-7}x + 1.133$ |
| | $NO_x$ | $y = 1.65 \cdot 10^{-7}x + 0.017$ |
| UC Phase 3 (Warm Start) | HC | $y = 1.95 \cdot 10^{-7}x + 0.034$ |
| | CO | $y = 1.71 \cdot 10^{-6}x + 1.259$ |
| | $NO_x$ | $y = 3.31 \cdot 10^{-7}x + 0.020$ |

Table 6.9: LEV II/LEV III ULEV125 (Tech Group 29) Base Emission Rate Regression Equations

| Process | Pollutant | Regression Equation |
|---|---|---|
| UC Phase 1 (Cold Start) | HC | $y = 5.46 \cdot 10^{-7}x + 0.387$ |
| | CO | $y = 4.64 \cdot 10^{-6}x + 4.434$ |
| | $NO_x$ | $y = 4.48 \cdot 10^{-7}x + 0.125$ |
| UC Phase 2 (Running) | HC | $y = 7.77 \cdot 10^{-9}x + 0.011$ |
| | CO | $y = 2.61 \cdot 10^{-6}x + 0.595$ |
| | $NO_x$ | $y = 3.00 \cdot 10^{-8}x + 0.015$ |
| UC Phase 3 (Warm Start) | HC | $y = 3.48 \cdot 10^{-8}x + 0.025$ |
| | CO | $y = 2.30 \cdot 10^{-6}x + 0.675$ |
| | $NO_x$ | $y = 1.85 \cdot 10^{-7}x + 0.020$ |

Table 6.10: LEV II/LEV III SULEV30 (Tech Group 31) Base Emission Rate Regression Equations

| Process | Pollutant | Regression Equation |
|---|---|---|
| UC Phase 1 (Cold Start) | HC | $y = 1.68 \cdot 10^{-7}x + 0.107$ |
| | CO | $y = 1.13 \cdot 10^{-5}x + 1.466$ |
| | $NO_x$ | $y = 1.03 \cdot 10^{-7}x + 0.053$ |
| UC Phase 2 (Running) | HC | $y = 1.12 \cdot 10^{-8}x + 0.003$ |
| | CO | $y = 2.27 \cdot 10^{-6}x + 0.359$ |
| | $NO_x$ | $y = 2.00 \cdot 10^{-8}x + 0.005$ |
| UC Phase 3 (Warm Start) | HC | $y = 3.02 \cdot 10^{-8}x + 0.008$ |
| | CO | $y = 2.16 \cdot 10^{-6}x + 0.266$ |
| | $NO_x$ | $y = 6.92 \cdot 10^{-9}x + 0.008$ |

## 6.2 Carbon Dioxide ($CO_2$) Base Emission Rate Update

The GHG module, first introduced in EMFAC2017, was enhanced in EMFAC2021 to improve $CO_2$ emission rate estimates for vehicles from model year 2009 onward. The EMFAC2021 update used more accurate U.S. EPA 5-cycle fuel economy data and better reflected real-world driving conditions. The EMFAC2025 update retains the same methodology as EMFAC2021 but is updated using DMV registration and fuel economy data from calendar years 2020 through 2022. The methodology is described in detail in Section 4.3.3 of the EMFAC2021 Technical Documentation (CARB, 2021). In general, the following steps were taken to update the $CO_2$ emission rates:

1. The DMV registration database was queried to obtain vehicle attributes (make, model, model year, fuel type, engine size, drivetrain type, number of cylinders, and transmission type) for passenger cars (LDA and LDT1) and light-duty trucks (LDT2 and MDV) operating in California.

2. The most recent fuel economy data for the year 2022 was obtained from the U.S. DOE's fueleconomy.gov database, containing 5-cycle fuel economy ratings and detailed vehicle specifications.

3. Each vehicle in the DMV dataset was matched to the closest corresponding vehicle in the EPA database using an advanced string-matching algorithm based on detailed vehicle attributes. This algorithm is further described in Chapter 2.4 of the SB 1014 Clean Miles Standard, 2018 Base Year Emission Inventory Report (CARB, 2019).

4. Assigned 5-cycle city fuel economy values (mi/gal) were converted to $CO_2$ emission rates (g/mi) using fuel-specific conversion factors: 8,887 g $CO_2$/gal for gasoline and 10,180 g $CO_2$/gal for diesel.

5. Assuming complete combustion of fuel, the $CO_2$ emissions through model year 2022 were calculated using Equation (6.1):

$$\text{CO}_2 \text{ Emissions (g/mi)} = \frac{\text{Conversion Factor (g/gal)}}{\text{Fuel Economy (mi/gal)}} \tag{6.1}$$

6. For model years 2023 through 2032, $CO_2$ emission factors were projected using federal GHG standards and manufacturer agreements.
    a. Based on finalized $CO_2$ standards under the Final SAFE Rule, a 1.84% year-over-year (YoY) reduction was applied to gasoline passenger cars, and a 1.75% YoY reduction was applied to light trucks from 2023 to 2026.
    b. For vehicles subject to the Six Manufacturer Framework Agreement, a 2.7% YoY reduction was applied from model years 2023 to 2026 for both gasoline passenger cars and light-duty trucks.

7. Lastly, based on CARB's GHG compliance data, market share splits were assumed between framework and non-framework vehicles in California's fleet:

a. For light-duty passenger cars: 38% framework and 62% non-framework.

b. For light-duty trucks: 34% framework and 66% non-framework.

Figures 6.23 and 6.24 compare $CO_2$ emission rates between EMFAC2021 and EMFAC2025 for passenger cars and light-duty trucks for model years 2010 through 2030, respectively. $CO_2$ emissions for model years 2020 through 2022 are derived from DMV and fuel economy data, whereas $CO_2$ emission data for model years 2023 through 2030 are projected using GHG emission standards. As shown, prior to 2020, EMFAC2025 followed the same trajectory as EMFAC2021 for both vehicle categories. Minor differences emerged due to the incorporation of updated DMV and fuel economy data from 2020 to 2022. Differences in emission rates beyond 2022 reflect recalculated projections based on this updated dataset. In EMFAC2025, $CO_2$ emissions for model year 2020 were similar to those in EMFAC2021 for passenger cars but lower for light-duty trucks. However, for model years 2021 and 2022, both passenger cars and light-duty trucks show higher $CO_2$ emissions in EMFAC2025 compared to EMFAC2021. These higher emission levels are carried forward in the estimates for model years 2023 through 2026. From 2026 to 2030, $CO_2$ emissions are projected to remain steady, as regulatory standards are only projected through 2026. For passenger cars, EMFAC2025 shows moderate reduction rates of approximately 5.5 grams per model year in $CO_2$ emissions, similar to the 6.6 grams per model year reduction in EMFAC2021 for passenger cars. For light-duty trucks, however, $CO_2$ emission rates reduce at a rate of roughly 6.9 grams per model year, while EMFAC2021 reduction in $CO_2$ emission rates is approximately 12.1 grams per model year.

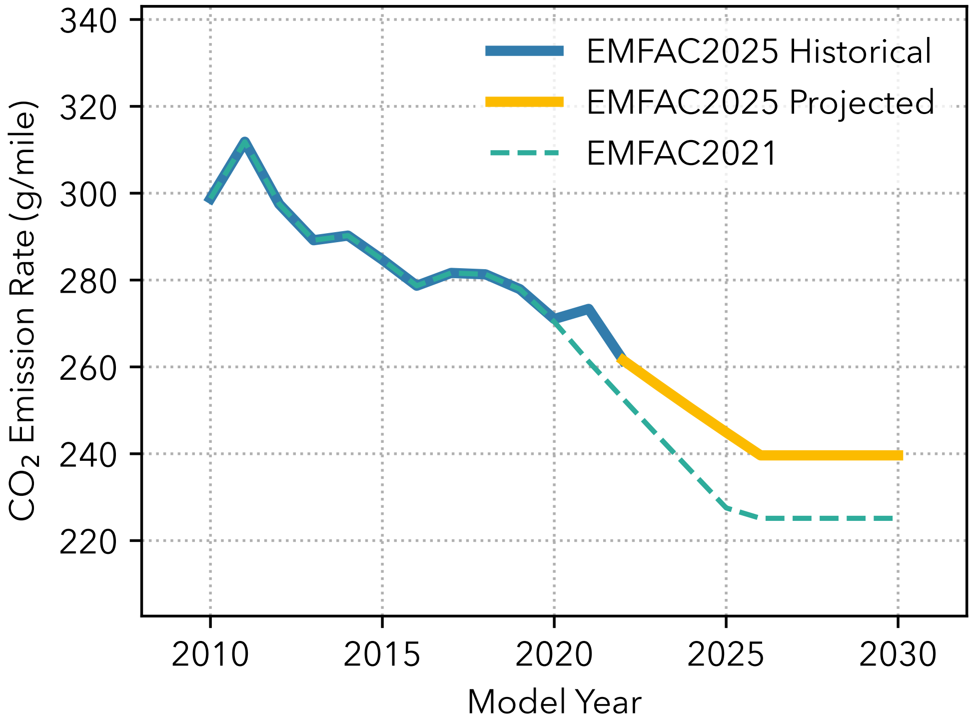


Figure 6.23: $CO_2$ Emission Rates for Passenger Cars (LDA and LDT1)

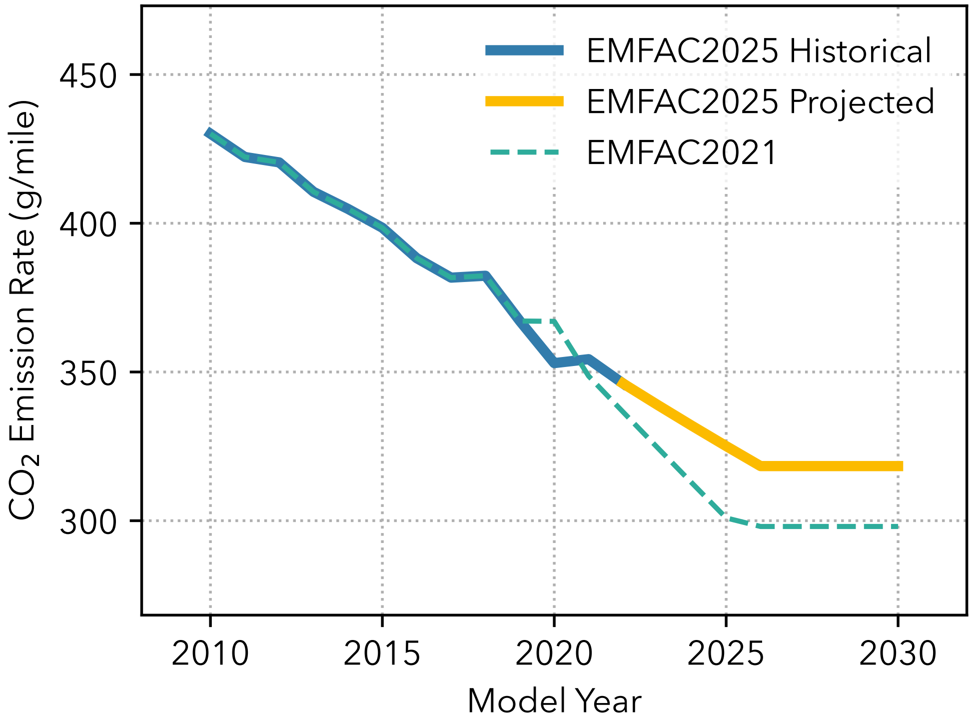


Figure 6.24: $CO_2$ Emission Rates for Light-Duty Trucks (LDT2 and MDV)

## 6.3 Light-Duty Speed Correction Factor Update

### 6.3.1 Background

The HC, CO, $CO_2$ and $NO_x$ Speed Correction Factors (SCF) used for light-duty vehicles were developed for EMFAC2000 and used in each version of the model through EMFAC2021. These SCFs were based on a set of 12 dynamometer driving cycles referred to as the Unified Correction Cycles (UCC). These 12 cycles were designed to be representative of an average trip at a given speed, where the mean speeds ranged from approximately 2.4 mph to 59.1 mph at 5 mph increments. The vehicles used in that analysis were selected from light-duty surveillance projects 2S95C1 and 2S97C1, conducted in 1995 and 1997 respectively, and from the research projects 2R9513 and 2R9811, which were conducted in 1995 and 1998.

The $CO_2$ SCFs for multiport fuel injection (MPFI) light-duty through medium-duty vehicles were updated in EMFAC2017 and are carried forward to EMFAC2025. The $CO_2$ SCFs were applied to all gasoline MPFI technology groups and for the vehicle classes of light-duty passenger vehicles through medium-duty trucks (PC, T1, T2, and T3).

To update light-duty SCFs for HC, CO and $NO_x$ in EMFAC2025, dynamometer test data collected from vehicles driven on arterial and freeway driving cycles were analyzed. These driving cycles were developed to represent real-world driving along with the Unified Cycle (UC). The arterial cycles represent surface street and arterial driving for speeds averaging between 7 and 55 mph, while the freeway cycles represent average driving conditions between 15 and 73 mph. The UCC, arterial, and freeway cycles are shown in Table 6.11.

The four arterial cycles and seven freeway cycles were implemented in light-duty Vehicle Surveillance Program Series 19 in 2012 (Project 2S11C1) and provided test data from 94 vehicles. The recent light-duty Vehicle Surveillance Program Series 21 (Project 2S22C1) is currently ongoing and has provided data from 3 test vehicles for this update.

The distribution of test vehicles by their respective technology group is shown in Table 6.12.

### 6.3.2 Analysis of LDVSP19 and LDVSP21 Test Data

The test vehicles were categorized into three groups: Pre-LEV, LEV I, and LEV II/LEV III. The number of test vehicles in each group is as follows:

- Pre-LEV: 17 vehicles
- LEV I: 42 vehicles
- LEV II/LEV III: 38 vehicles

Table 6.11: Driving Cycles Used for Speed Correction Factor Update

| Driving Cycle | Average Speed (mph) |
|---|---|
| Unified Correction Cycle (UCC) 5 | 2.5 |
| UCC 10 | 7.5 |
| UCC 15 | 12.5 |
| UCC 20 | 17.5 |
| UCC 25 | 22.5 |
| UCC 30 | 27.5 |
| UCC 35 | 32.5 |
| UCC 40 | 37.5 |
| UCC 45 | 42.5 |
| Arterial Cycle (AC) 1 | 7 |
| AC 2 | 23 |
| AC 3 | 39 |
| AC 4 | 55 |
| Freeway Cycle (FC) 1 | 15 |
| FC 2 | 25 |
| FC 3 | 33 |
| FC 4 | 46 |
| FC 5 | 57 |
| FC 6 | 65 |
| FC 7 | 73 |

Table 6.12: Test Vehicles by Technology Group Used for Speed Correction Factor Update

| Project | Tech Group | Number of Test Vehicles |
|---|---|---|
| 2S11C1 | Pre-LEV | 17 |
| | LEV I LEV | 23 |
| | LEV I ULEV | 19 |
| | LEV II LEV | 6 |
| | LEV II ULEV | 20 |
| | LEV II SULEV | 8 |
| | SULEV | 1 |
| 2S22C01 | LEV II SULEV | 2 |
| | LEV III SULEV30 | 1 |

We considered dividing the vehicles into four groups (Pre-LEV, LEV I, ULEV, and SULEV) to potentially derive more accurate SCFs. The LEV II and LEV III groups are required to be certified to the SFTP cycle, which is expected to result in lower SCFs at high speeds compared to vehicles not required to certify to the SFTP cycle. However, the sample size for some groups would be too small (e.g., only one LEV III SULEV30 vehicle). Therefore, we grouped the vehicles into three categories to ensure a larger sample size per group.

SCFs were developed for each of the three vehicle groups and for each pollutant of HC, $NO_x$, and CO. First, emission rates were averaged by speed bin for each driving cycle. Next, a best-fit equation was derived using average emission rate and average speed. Then, emission rates calculated using the derived equation were normalized to the speed of 27.4 mph by speed bin to develop SCFs.

Note that SCFs for speed bins of 75 mph and above are assumed to be the same as those of the 70-mph speed bin for pre-LEV and LEV I. For LEV II/LEV III, SCFs for speed bins of 70 mph and above were separately developed in the High-Speed Driving project, which is described in Section 2.2.3.

### 6.3.3 HC Speed Correction Factor

Figure 6.25 shows HC emission rates by average speed, which were calculated from the test data.

For each technology group, a best-fit equation was derived from the averaged data:

$$\begin{aligned} y_{\text{Pre-LEV}} &= -9.629 \cdot 10^{-6}x^3 + 1.648 \cdot 10^{-3}x^2 - 9.278 \cdot 10^{-2}x + 1.835 \\ y_{\text{LEV I}} &= -1.761 \cdot 10^{-6}x^3 + 2.926 \cdot 10^{-4}x^2 - 1.464 \cdot 10^{-2}x + 0.246 \\ y_{\text{LEV II/LEV III}} &= -3.83 \cdot 10^{-7}x^3 + 6.46 \cdot 10^{-5}x^2 - 3.20 \cdot 10^{-3}x + 5.61 \cdot 10^{-2} \end{aligned}$$

where $y$ is the HC emission rate (g/mi) and $x$ is vehicle speed (mph).

Emission rates calculated using these equations are shown in Tables 6.13 to 6.15 by speed bin. All emission rates were normalized to 27.4 mph to produce speed correction factors (SCF), as shown in Tables 6.13 to 6.15. This table also compares EMFAC2025 SCFs with those from EMFAC2021. Note SCF of each speed bin derived for its mid-point speed (e.g., SCF of 25 mph Speed Bin is derived for 22.5 mph).

Figure 6.26 presents the SCF results, with HC SCFs from EMFAC2021 also shown for comparison.

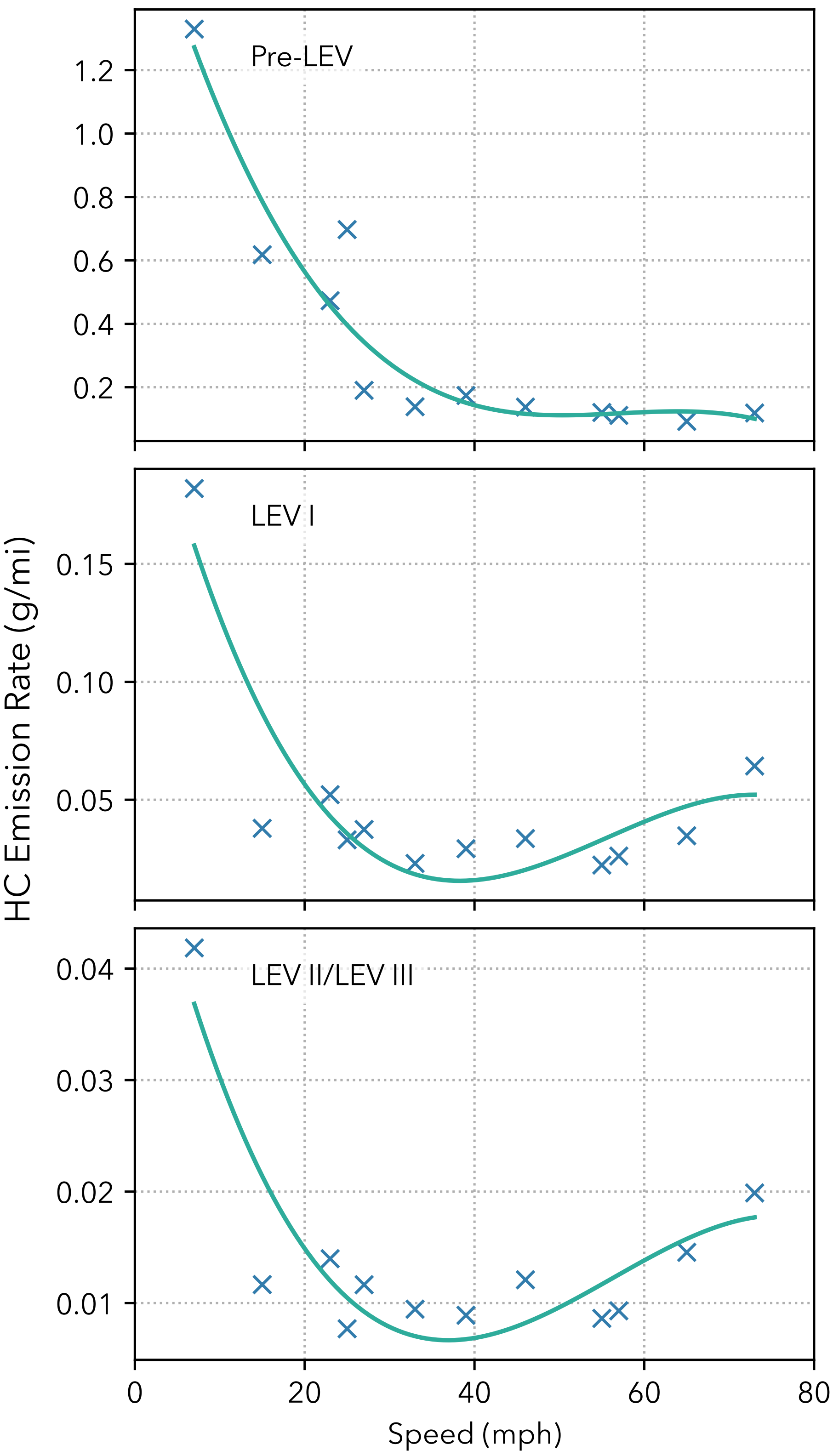


Figure 6.25: Average HC Emissions by Vehicle Speed

Table 6.13: HC Emission Rates and Speed Correction Factors (SCF): Pre-LEV

| Speed Bin | Mid-Point Speed (mph) | EMFAC2025 HC (g/mi) | EMFAC2025 HC SCF | EMFAC2021 HC SCF |
|---|---|---|---|---|
| 5 | 2.5 | 1.411 | 4.248 | 5.913 |
| 10 | 7.5 | 1.063 | 3.199 | 3.720 |
| 15 | 12.5 | 0.782 | 2.353 | 2.469 |
| 20 | 17.5 | 0.562 | 1.691 | 1.729 |
| 25 | 22.5 | 0.395 | 1.190 | 1.277 |
| 30 | 27.5 | 0.275 | 0.828 | 0.996 |
| 35 | 32.5 | 0.194 | 0.584 | 0.819 |
| 40 | 37.5 | 0.145 | 0.435 | 0.710 |
| 45 | 42.5 | 0.120 | 0.361 | 0.650 |
| 50 | 47.5 | 0.113 | 0.339 | 0.627 |
| 55 | 52.5 | 0.115 | 0.348 | 0.639 |
| 60 | 57.5 | 0.121 | 0.365 | 0.686 |
| 65 | 62.5 | 0.123 | 0.370 | 0.778 |
| 70 | 67.5 | 0.113 | 0.340 | 0.845 |
| 75* | 72.5 | 0.113 | 0.340 | 0.845 |
| 80* | 77.5 | 0.113 | 0.340 | 0.845 |
| 85* | 82.5 | 0.113 | 0.340 | 0.845 |
| 90* | 87.5 | 0.113 | 0.340 | 0.845 |

* The 70-mph speed bin values are used.

Table 6.14: HC Emission Rates and Speed Correction Factors (SCF): LEV I

| Speed Bin | Mid-Point Speed (mph) | EMFAC2025 HC (g/mi) | EMFAC2025 HC SCF | EMFAC2021 HC SCF |
|---|---|---|---|---|
| 5 | 2.5 | 0.180 | 6.335 | 5.913 |
| 10 | 7.5 | 0.127 | 4.477 | 3.720 |
| 15 | 12.5 | 0.086 | 3.041 | 2.469 |
| 20 | 17.5 | 0.056 | 1.980 | 1.729 |
| 25 | 22.5 | 0.035 | 1.248 | 1.277 |
| 30 | 27.5 | 0.023 | 0.799 | 0.996 |
| 35 | 32.5 | 0.017 | 0.585 | 0.819 |
| 40 | 37.5 | 0.016 | 0.562 | 0.710 |
| 45 | 42.5 | 0.019 | 0.681 | 0.650 |
| 50 | 47.5 | 0.025 | 0.897 | 0.627 |
| 55 | 52.5 | 0.033 | 1.163 | 0.639 |
| 60 | 57.5 | 0.041 | 1.432 | 0.686 |
| 65 | 62.5 | 0.047 | 1.659 | 0.778 |
| 70 | 67.5 | 0.051 | 1.796 | 0.845 |
| 75* | 72.5 | 0.051 | 1.796 | 0.845 |
| 80* | 77.5 | 0.051 | 1.796 | 0.845 |
| 85* | 82.5 | 0.051 | 1.796 | 0.845 |
| 90* | 87.5 | 0.051 | 1.796 | 0.845 |

* The 70-mph speed bin values are used.

Table 6.15: HC Emission Rates and Speed Correction Factors (SCF): LEV II/LEV III

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 HC (g/mi) | EMFAC2025 HC SCF | EMFAC2021 HC SCF |
|---|---|---|---|---|
| 5 | 2.5 | 0.042 | 4.630 | 5.913 |
| 10 | 7.5 | 0.030 | 3.352 | 3.720 |
| 15 | 12.5 | 0.021 | 2.370 | 2.469 |
| 20 | 17.5 | 0.015 | 1.650 | 1.729 |
| 25 | 22.5 | 0.010 | 1.162 | 1.277 |
| 30 | 27.5 | 0.008 | 0.873 | 0.996 |
| 35 | 32.5 | 0.007 | 0.751 | 0.819 |
| 40 | 37.5 | 0.007 | 0.765 | 0.710 |
| 45 | 42.5 | 0.008 | 0.882 | 0.650 |
| 50 | 47.5 | 0.010 | 1.071 | 0.627 |
| 55 | 52.5 | 0.012 | 1.300 | 0.639 |
| 60 | 57.5 | 0.014 | 1.537 | 0.686 |
| 65 | 62.5 | 0.016 | 1.750 | 0.778 |

* See Section 2.2.3.2.1 for speed correction factors of 70 to 90 mph speed bins.

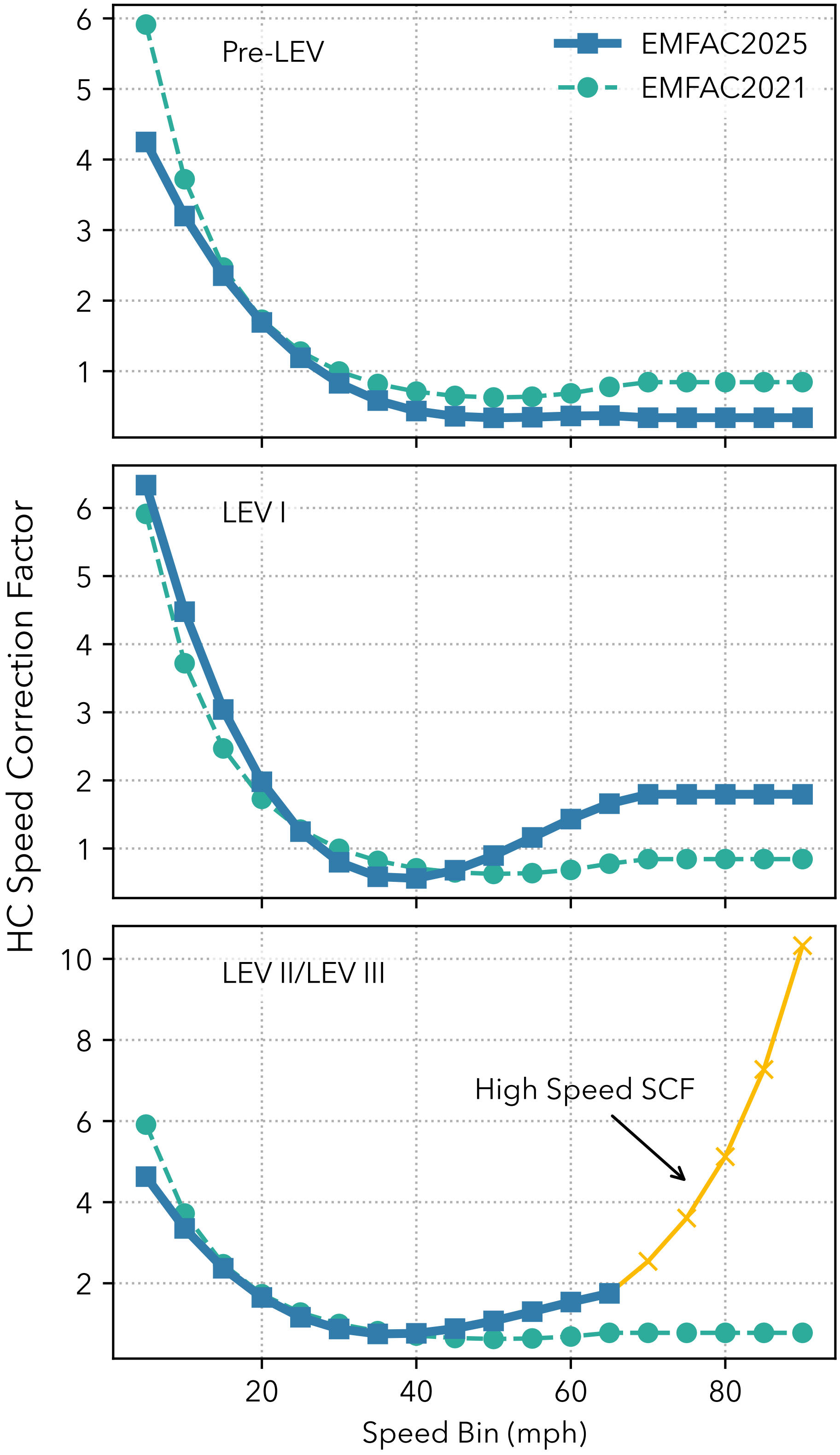


Figure 6.26: HC Speed Correction Factor: EMFAC2025 vs. EMFAC2021

### 6.3.4 NO$_x$ Speed Correction Factor

Figure 6.27 shows NO$_x$ emission rates by average speed, which were calculated from the test data.

For each technology group, a best-fit equation was derived from the averaged data:

$$\begin{aligned} y_{\text{Pre-LEV}} &= -9.027 \cdot 10^{-6}x^3 + 1.545 \cdot 10^{-3}x^2 - 7.580 \cdot 10^{-2}x + 1.727 \\ y_{\text{LEV I}} &= -2.281 \cdot 10^{-6}x^3 + 3.575 \cdot 10^{-4}x^2 - 1.647 \cdot 10^{-2}x + 0.373 \\ y_{\text{LEV II/LEV III}} &= 9.88 \cdot 10^{-9}x^3 + 4.47 \cdot 10^{-6}x^2 - 3.84 \cdot 10^{-4}x + 3.03 \cdot 10^{-2} \end{aligned}$$

where $y$ is the NO$_x$ emission rate (g/mi) and $x$ is vehicle speed (mph).

Emission rates calculated using these equations are shown in Tables 6.16 to 6.18 by speed bin. All emission rates were normalized to 27.4 mph to produce speed correction factors (SCF), as shown in Tables 6.16 to 6.18. This table also compares EMFAC2025 SCFs with those from EMFAC2021.

Figure 6.28 presents the SCF results, with NO$_x$ SCFs from EMFAC2021 also shown for comparison.

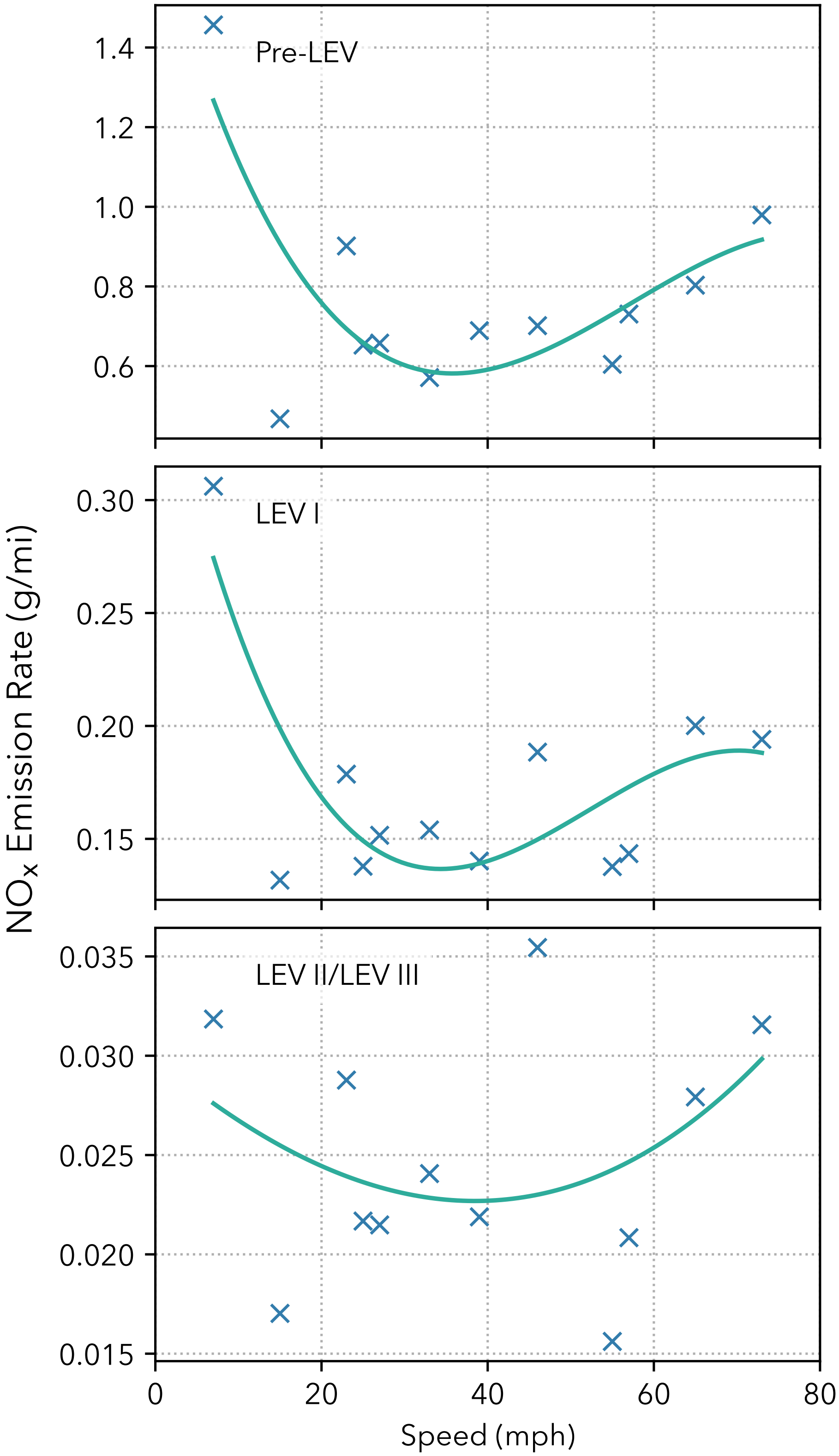


Figure 6.27: Average NO$_x$ Emissions by Vehicle Speed

Table 6.16: Pre-LEV $NO_x$ Emissions and Speed Correction Factors (SCF)

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 $NO_x$ (g/mi) | EMFAC2025 $NO_x$ SCF | EMFAC2021 $NO_x$ SCF |
|---|---|---|---|---|
| 5 | 2.5 | 1.385 | 2.219 | 1.718 |
| 10 | 7.5 | 1.114 | 1.785 | 1.493 |
| 15 | 12.5 | 0.907 | 1.453 | 1.318 |
| 20 | 17.5 | 0.757 | 1.212 | 1.182 |
| 25 | 22.5 | 0.657 | 1.052 | 1.078 |
| 30 | 27.5 | 0.600 | 0.961 | 0.999 |
| 35 | 32.5 | 0.580 | 0.928 | 0.940 |
| 40 | 37.5 | 0.589 | 0.944 | 0.899 |
| 45 | 42.5 | 0.622 | 0.996 | 0.874 |
| 50 | 47.5 | 0.671 | 1.075 | 0.863 |
| 55 | 52.5 | 0.730 | 1.169 | 0.866 |
| 60 | 57.5 | 0.791 | 1.267 | 0.883 |
| 65 | 62.5 | 0.849 | 1.359 | 0.915 |
| 70 | 67.5 | 0.895 | 1.434 | 0.937 |
| 75* | 72.5 | 0.895 | 1.434 | 0.937 |
| 80* | 77.5 | 0.895 | 1.434 | 0.937 |
| 85* | 82.5 | 0.895 | 1.434 | 0.937 |
| 90* | 87.5 | 0.895 | 1.434 | 0.937 |

* The 70-mph speed bin values are used.

Table 6.17: LEV I $NO_x$ Emissions and Speed Correction Factors (SCF)

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 $NO_x$ (g/mi) | EMFAC2025 $NO_x$ SCF | EMFAC2021 $NO_x$ SCF |
|---|---|---|---|---|
| 5 | 2.5 | 0.299 | 2.091 | 1.718 |
| 10 | 7.5 | 0.242 | 1.689 | 1.493 |
| 15 | 12.5 | 0.199 | 1.388 | 1.318 |
| 20 | 17.5 | 0.168 | 1.176 | 1.182 |
| 25 | 22.5 | 0.149 | 1.041 | 1.078 |
| 30 | 27.5 | 0.139 | 0.971 | 0.999 |
| 35 | 32.5 | 0.137 | 0.955 | 0.940 |
| 40 | 37.5 | 0.140 | 0.979 | 0.899 |
| 45 | 42.5 | 0.148 | 1.033 | 0.874 |
| 50 | 47.5 | 0.158 | 1.104 | 0.863 |
| 55 | 52.5 | 0.169 | 1.181 | 0.866 |
| 60 | 57.5 | 0.179 | 1.251 | 0.883 |
| 65 | 62.5 | 0.186 | 1.302 | 0.915 |
| 70 | 67.5 | 0.189 | 1.323 | 0.937 |
| 75* | 72.5 | 0.189 | 1.323 | 0.937 |
| 80* | 77.5 | 0.189 | 1.323 | 0.937 |
| 85* | 82.5 | 0.189 | 1.323 | 0.937 |
| 90* | 87.5 | 0.189 | 1.323 | 0.937 |

* The 70-mph speed bin values are used.

Table 6.18: LEV II/LEV III $NO_x$ Emissions and Speed Correction Factors (SCF)

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 $NO_x$ (g/mi) | EMFAC2025 $NO_x$ SCF | EMFAC2021 $NO_x$ SCF |
|---|---|---|---|---|
| 5 | 2.5 | 0.028 | 1.222 | 1.718 |
| 10 | 7.5 | 0.027 | 1.154 | 1.493 |
| 15 | 12.5 | 0.026 | 1.097 | 1.318 |
| 20 | 17.5 | 0.024 | 1.050 | 1.182 |
| 25 | 22.5 | 0.024 | 1.013 | 1.078 |
| 30 | 27.5 | 0.023 | 0.988 | 0.999 |
| 35 | 32.5 | 0.023 | 0.975 | 0.940 |
| 40 | 37.5 | 0.023 | 0.973 | 0.899 |
| 45 | 42.5 | 0.023 | 0.984 | 0.874 |
| 50 | 47.5 | 0.023 | 1.007 | 0.863 |
| 55 | 52.5 | 0.024 | 1.043 | 0.866 |
| 60 | 57.5 | 0.025 | 1.091 | 0.883 |
| 65 | 62.5 | 0.027 | 1.154 | 0.915 |

* See Section 2.2.3.2.2 for speed correction factors of 70 to 90 mph speed bins.

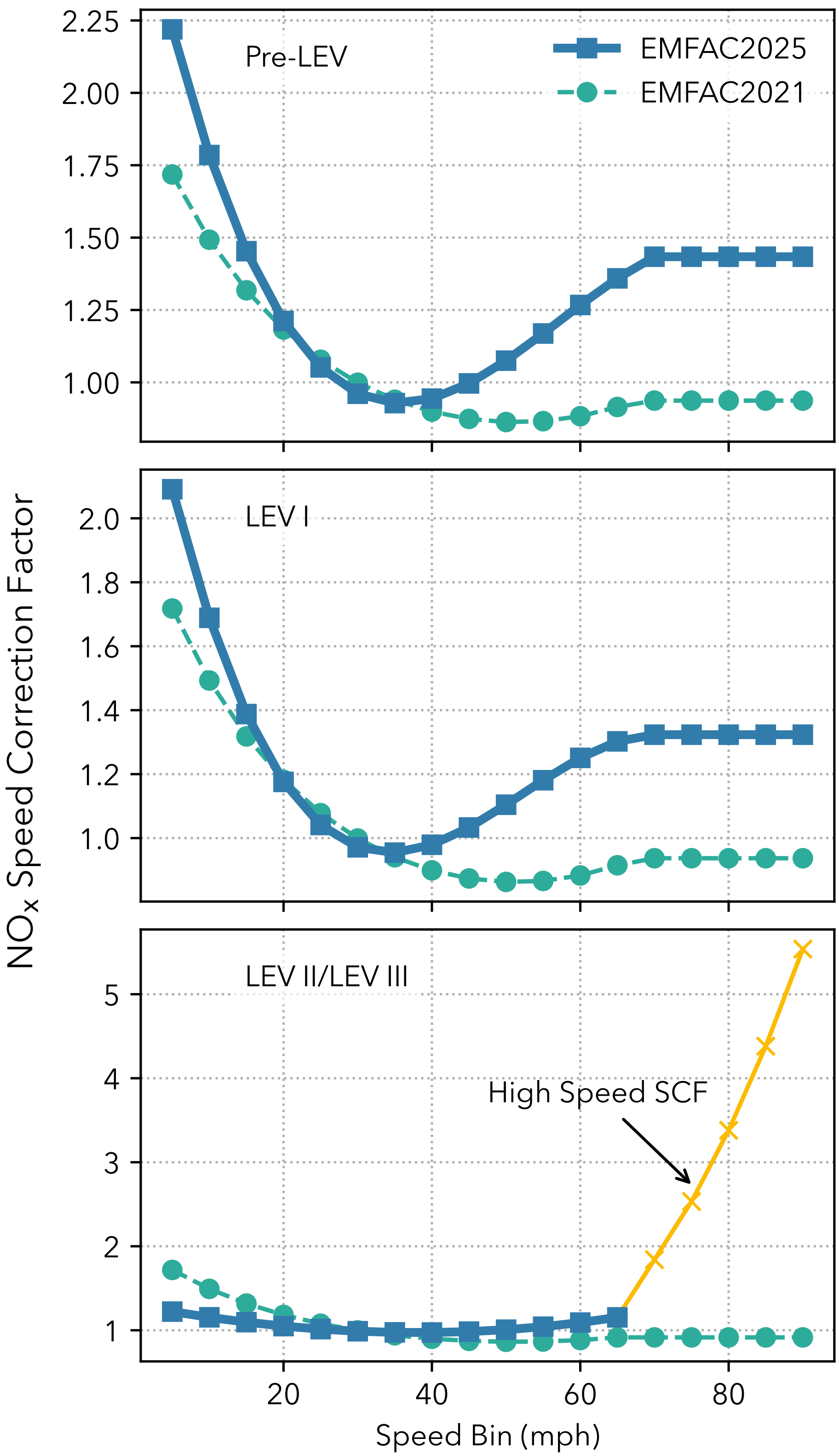


Figure 6.28: $NO_x$ Speed Correction Factor: EMFAC2025 vs. EMFAC2021

### 6.3.5 CO Speed Correction Factor

Figure 6.29 shows CO emission rates by average speed, which were calculated from the test data.

For each technology group, a best-fit equation was derived from the averaged data:

$$\begin{aligned} y_{\text{Pre-LEV}} &= -3 \cdot 10^{-6}x^3 + 0.0081x^2 - 0.5655x + 14.273 \\ y_{\text{LEV I}} &= 4.85 \cdot 10^{-5}x^3 - 2.79 \cdot 10^{-3}x^2 - 1.48 \cdot 10^{-2}x + 2.81 \\ y_{\text{LEV II/LEV III}} &= 2.06 \cdot 10^{-5}x^3 - 1.04 \cdot 10^{-3}x^2 - 1.25 \cdot 10^{-2}x + 1.41 \end{aligned}$$

where $y$ is the CO emission rate (g/mi) and $x$ is vehicle speed (mph).

Emission rates calculated using these equations are shown in Tables 6.19 to 6.21 by speed bin. All emission rates were normalized to 27.4 mph to produce speed correction factors (SCF), as shown in Tables 6.19 to 6.21. This table also compares EMFAC2025 SCFs with those from EMFAC2021.

Figure 6.30 presents the SCF results, with CO SCFs from EMFAC2021 also shown for comparison.

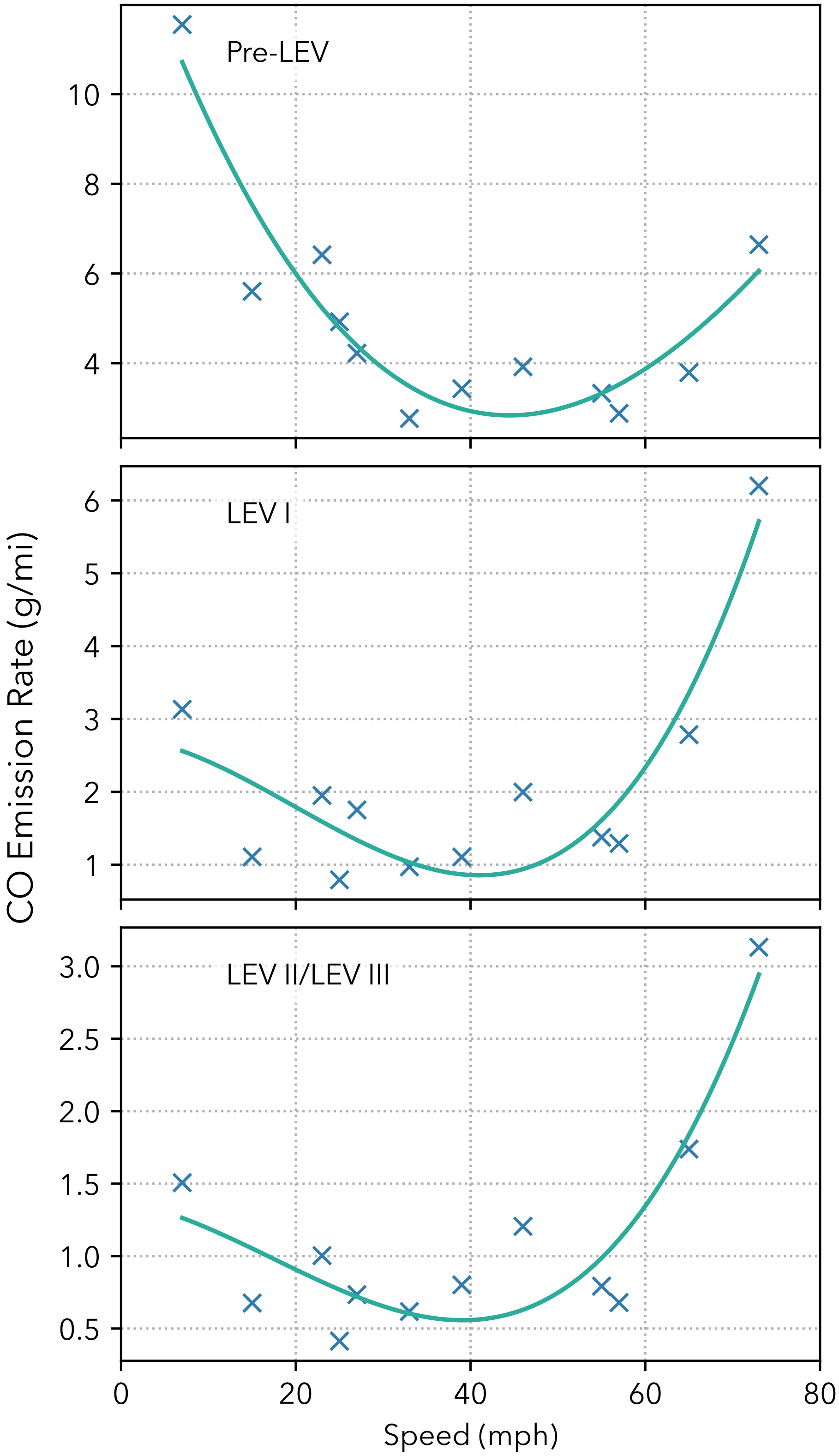


Figure 6.29: Average CO Emissions by Vehicle Speed

Table 6.19: Pre-LEV CO Emissions and Speed Correction Factors (SCF)

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 CO (g/mi) | EMFAC2025 CO SCF | EMFAC2021 CO SCF |
|---|---|---|---|---|
| 5 | 2.5 | 11.644 | 2.745 | 1.551 |
| 10 | 7.5 | 9.398 | 2.215 | 1.413 |
| 15 | 12.5 | 7.512 | 1.771 | 1.290 |
| 20 | 17.5 | 5.963 | 1.406 | 1.181 |
| 25 | 22.5 | 4.729 | 1.115 | 1.084 |
| 30 | 27.5 | 3.788 | 0.893 | 0.998 |
| 35 | 32.5 | 3.117 | 0.735 | 0.922 |
| 40 | 37.5 | 2.693 | 0.635 | 0.853 |
| 45 | 42.5 | 2.494 | 0.588 | 0.792 |
| 50 | 47.5 | 2.498 | 0.589 | 0.737 |
| 55 | 52.5 | 2.682 | 0.632 | 0.687 |
| 60 | 57.5 | 3.023 | 0.713 | 0.643 |
| 65 | 62.5 | 3.499 | 0.825 | 0.603 |
| 70 | 67.5 | 4.088 | 0.964 | 0.585 |
| 75* | 72.5 | 4.088 | 0.964 | 0.585 |
| 80* | 77.5 | 4.088 | 0.964 | 0.585 |
| 85* | 82.5 | 4.088 | 0.964 | 0.585 |
| 90* | 87.5 | 4.088 | 0.964 | 0.585 |

* The 70-mph speed bin values are used.

Table 6.20: LEV I CO Emissions and Speed Correction Factors (SCF)

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 CO (g/mi) | EMFAC2025 CO SCF | EMFAC2021 CO SCF |
|---|---|---|---|---|
| 5 | 2.5 | 2.673 | 2.044 | 1.551 |
| 10 | 7.5 | 2.433 | 1.860 | 1.413 |
| 15 | 12.5 | 2.125 | 1.625 | 1.290 |
| 20 | 17.5 | 1.787 | 1.366 | 1.181 |
| 25 | 22.5 | 1.455 | 1.112 | 1.084 |
| 30 | 27.5 | 1.165 | 0.890 | 0.998 |
| 35 | 32.5 | 0.953 | 0.729 | 0.922 |
| 40 | 37.5 | 0.857 | 0.655 | 0.853 |
| 45 | 42.5 | 0.912 | 0.697 | 0.792 |
| 50 | 47.5 | 1.155 | 0.883 | 0.737 |
| 55 | 52.5 | 1.622 | 1.240 | 0.687 |
| 60 | 57.5 | 2.349 | 1.796 | 0.643 |
| 65 | 62.5 | 3.374 | 2.580 | 0.603 |
| 70 | 67.5 | 4.732 | 3.618 | 0.585 |
| 75* | 72.5 | 4.732 | 3.618 | 0.585 |
| 80* | 77.5 | 4.732 | 3.618 | 0.585 |
| 85* | 82.5 | 4.732 | 3.618 | 0.585 |
| 90* | 87.5 | 4.732 | 3.618 | 0.585 |

* The 70-mph speed bin values are used.

Table 6.21: LEV II/LEV III CO Emissions and Speed Correction Factors (SCF)

| Speed Bin* | Mid-Point Speed (mph) | EMFAC2025 CO (g/mi) | EMFAC2025 CO SCF | EMFAC2021 CO SCF |
|---|---|---|---|---|
| 5 | 2.5 | 1.320 | 1.872 | 1.551 |
| 10 | 7.5 | 1.198 | 1.699 | 1.413 |
| 15 | 12.5 | 1.054 | 1.495 | 1.290 |
| 20 | 17.5 | 0.904 | 1.283 | 1.181 |
| 25 | 22.5 | 0.764 | 1.084 | 1.084 |
| 30 | 27.5 | 0.649 | 0.921 | 0.998 |
| 35 | 32.5 | 0.575 | 0.815 | 0.922 |
| 40 | 37.5 | 0.556 | 0.789 | 0.853 |
| 45 | 42.5 | 0.609 | 0.864 | 0.792 |
| 50 | 47.5 | 0.748 | 1.061 | 0.737 |
| 55 | 52.5 | 0.990 | 1.404 | 0.687 |
| 60 | 57.5 | 1.349 | 1.914 | 0.643 |
| 65 | 62.5 | 1.842 | 2.612 | 0.603 |

* See Section 2.2.3.2.3 for speed correction factors of 70 to 90 mph speed bins.

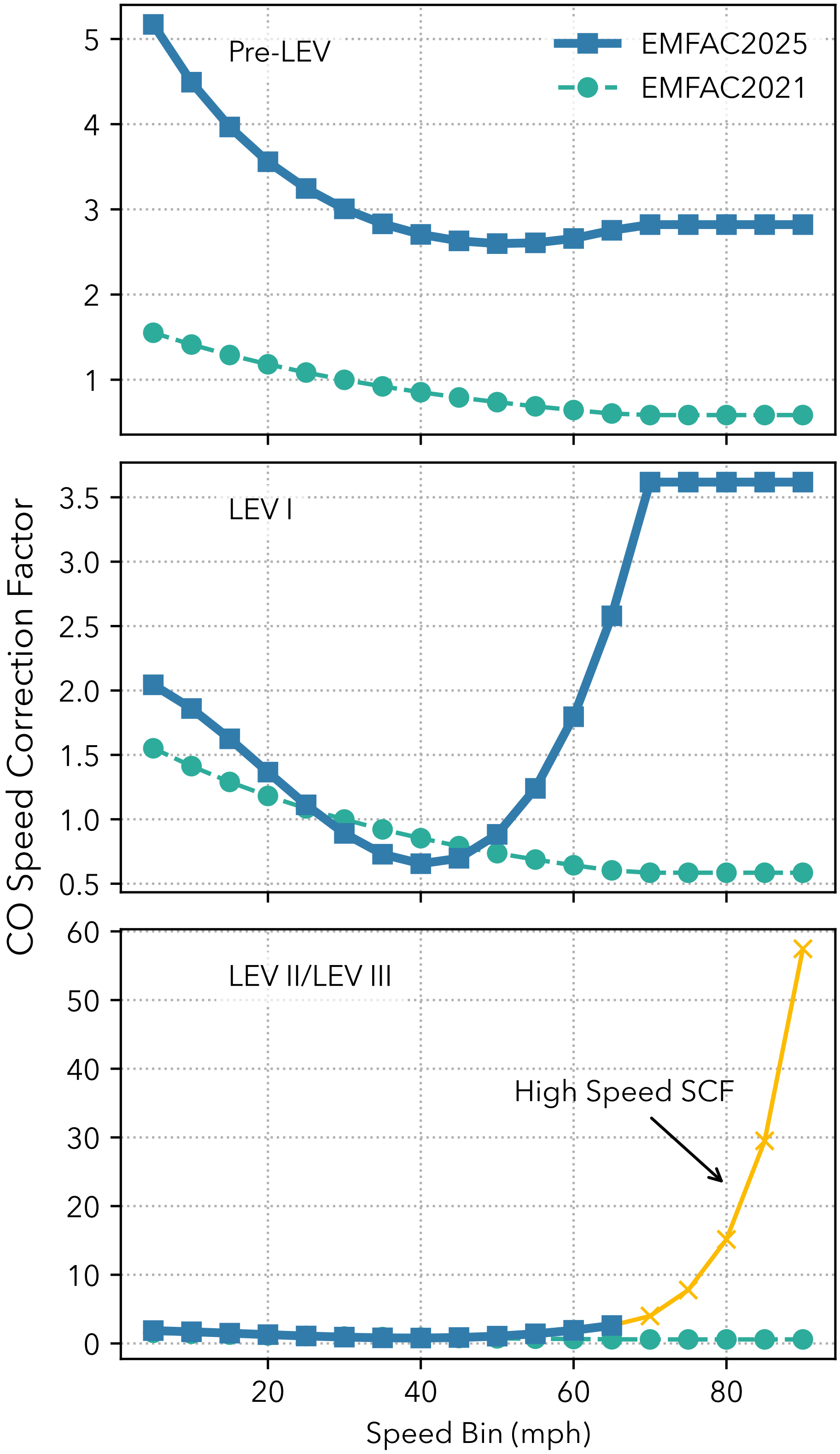


Figure 6.30: CO Speed Correction Factor: EMFAC2025 vs. EMFAC2021

## 6.4 Tire Wear Emission Rate Update

The tire wear emission rate in zero-emission fleets have been updated to incorporate the impact of their greater weight on PM emissions. Staff reviewed studies that have reported tire wear emissions in both electric vehicles and internal-combustion engine vehicles. On average, tire wear emissions are reported to be 15% higher in electric vehicles compared to their combustion counterparts, based on 40 sets of tests on different vehicles (Beddows and Harrison, 2021, Liu *et al.*, 2021, Timmers and Achten, 2016, Woo *et al.*, 2022). Therefore, LD tire wear generated by zero-emission fleets in EMFAC2025 were adjusted from 8 to 9.2 mg/mi for $PM_{10}$ and 2 to 2.3 mg/mi for $PM_{2.5}$ (increased by 15%).

It should be noted that the tire emission rate will be updated in a future version of EMFAC, based on the results of ongoing CARB research projects on non-exhaust emissions (CARB, 2025).

# 7 Fuel Properties

## 7.1 Reid Vapor Pressure Update

Reid vapor pressure (RVP) is a measure of the evaporation rate, or the volatility of gasoline, typically expressed in pounds per square inch (psi). Gasoline with higher RVP – and thus higher volatility – evaporates faster than gasoline with lower RVP at a given temperature. During winter months, higher-RVP blends of gasoline are used to promote better fuel-air mixing, aiding cold engine starts. However, to mitigate evaporative hydrocarbon emissions, CARB implemented California Phase 3 Gasoline Regulations in 2007, setting the RVP limit to 7.0 psi for oxygenated fuels and 6.9 psi for non-oxygenated fuels during summer months (CARB, 2023). It is important to note that RVP affects only evaporative emissions and not exhaust emissions.

To comply with emission targets, refineries across California switch to producing summer blend gasoline in the spring and winter blend gasoline in the fall. This seasonal switch changes the RVP of California's gasoline. California is divided into five fuel control regions, as shown in Figure 7.1. These regions represent groupings of air basins or geographic areas that follow the same transition schedules for switching between summer and winter fuel blends.

In the EMFAC model, RVP values serve as input parameters for calculating evaporative emissions, which vary by month and by air basin. These values were last comprehensively updated in EMFAC2002. For EMFAC2025, CARB has updated these values using data from recent field studies to better reflect current fuel formulations in use across California. Between 2008 and 2022, CARB's Enforcement Division collected about 15,750 data points on the RVP content of gasoline from a range of sources, including service stations, terminals, and refineries. For the EMFAC2025 update, about 6,400 data points from service stations were selected to represent real-world fuel characteristics encountered by vehicles in operation.

To observe seasonal trends, the collected RVP data were plotted across all months in Figure 7.2. In particular, data for the winter months reveal that RVP values typically exceed 8 psi, which confirms the expected characteristics of winter fuel blends in California. During summer months, RVP values were consistently observed in the range of 6.40 to 7.20 psi. This aligns with regulatory requirements that limit RVP to 7 psi during the ozone season to control evaporative emissions. To derive monthly RVP values by control region for EMFAC2025, the following steps were applied:

- Monthly averages were calculated using available service station data for each control region.
- If data for a specific month and region were missing, values were estimated by averaging RVP from neighboring regions.
- In cases where data for two consecutive months were missing, values were interpolated from the surrounding months with available data.

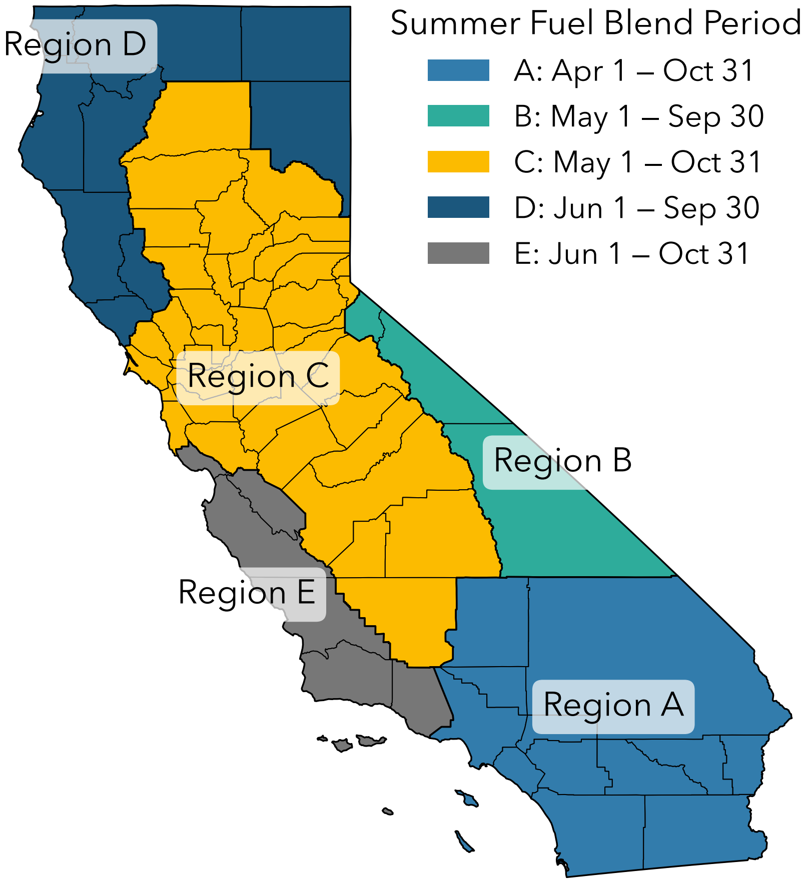


Figure 7.1: California Reid Vapor Pressure (RVP) Control Regions. The date ranges shown in the legend represent the summer fuel blend periods for each region.

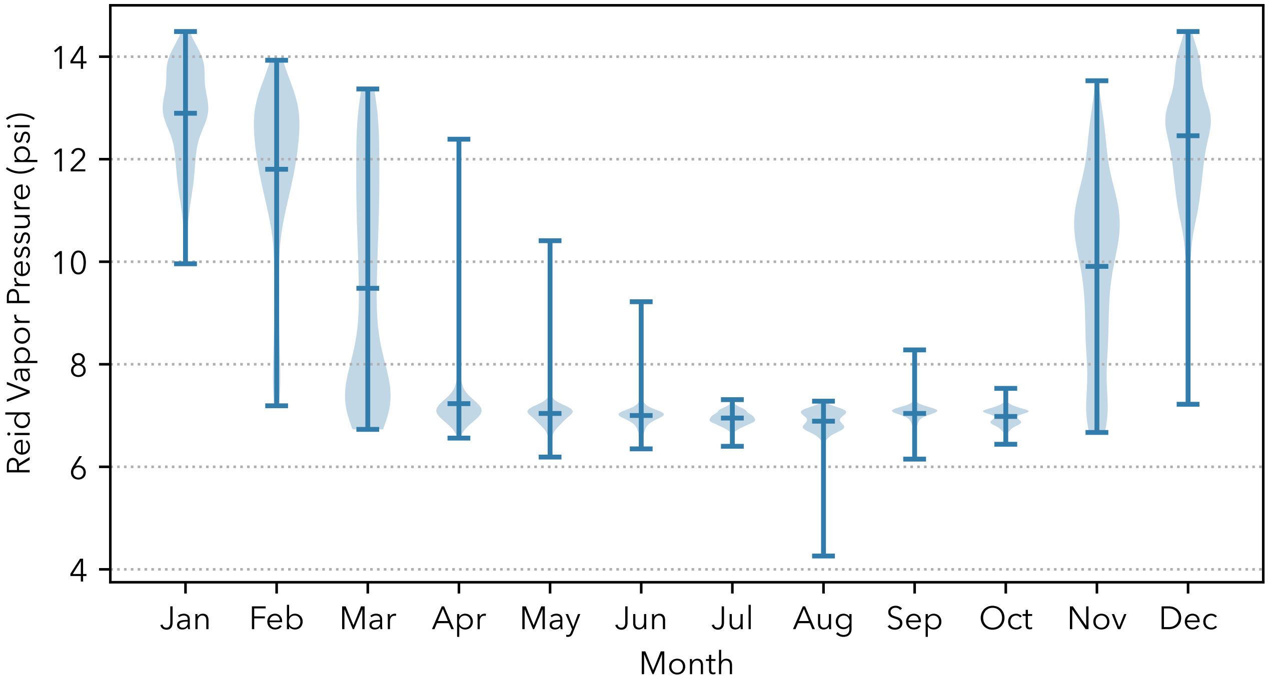
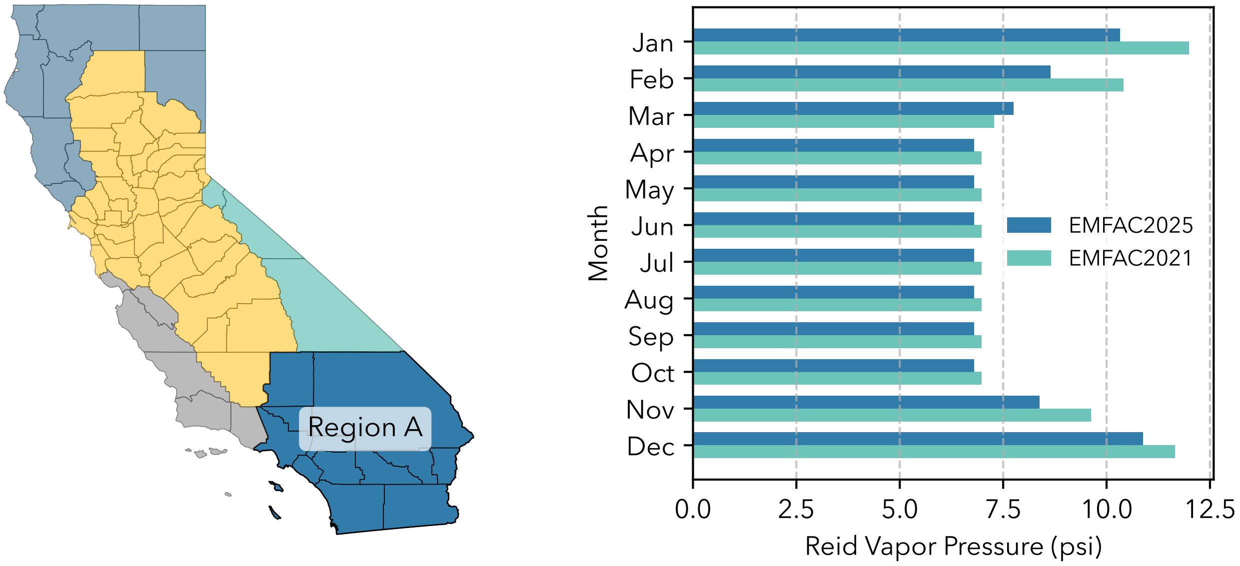


Figure 7.2: Statewide Reid Vapor Pressure (RVP) Data Collected by CARB. The top and bottom lines indicate the range of data, and the middle lines indicate mean values.

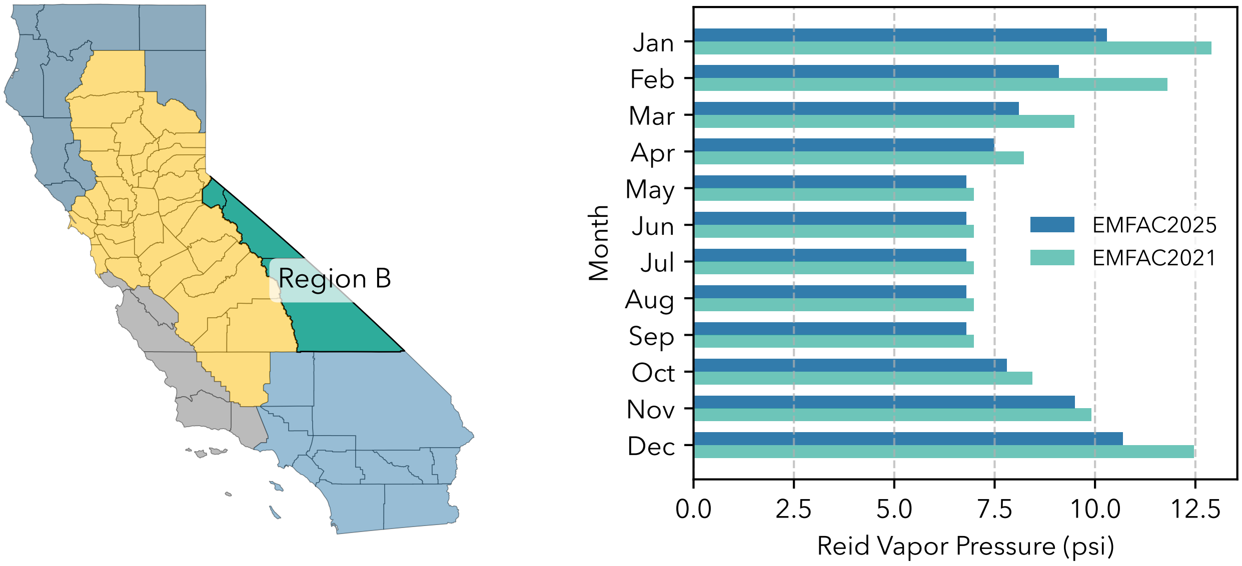
- The finalized monthly RVP values were then mapped to individual Geographic Area Indexes (GAI) based on their corresponding control regions and updated in EMFAC.

Figure 7.3 through Figure 7.7 compare the RVP values used in EMFAC2021 with those updated for EMFAC2025 for each control region.



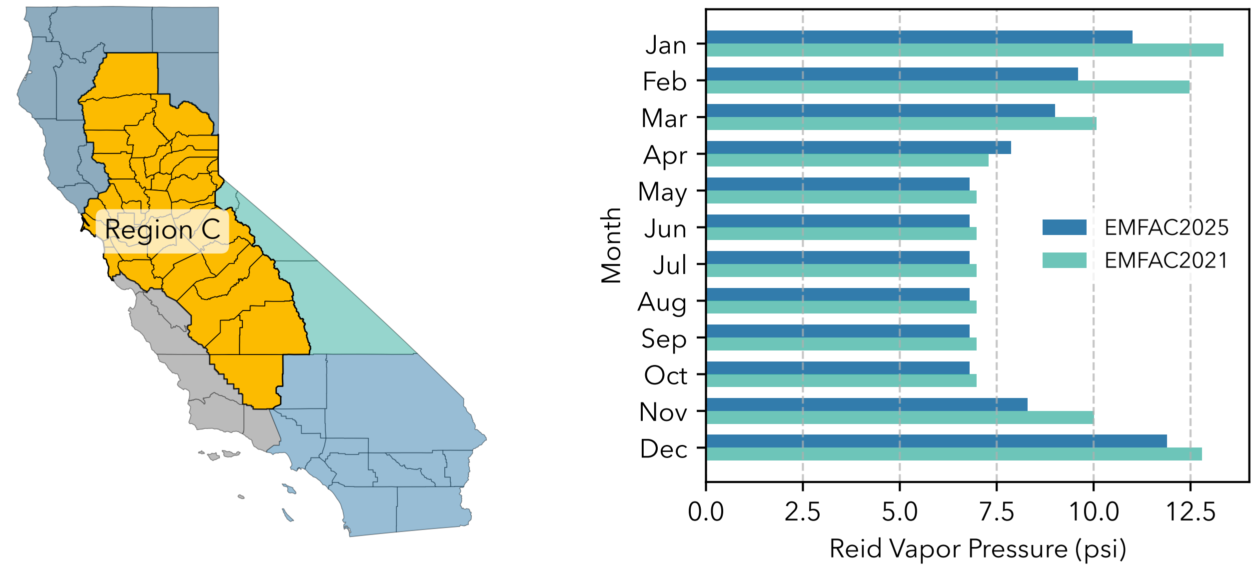
(a) Control Region A (b) Monthly Reid Vapor Pressure of Region A

Figure 7.3: Updated Reid Vapor Pressure for Control Region A



(a) Control Region B (b) Monthly Reid Vapor Pressure of Region B

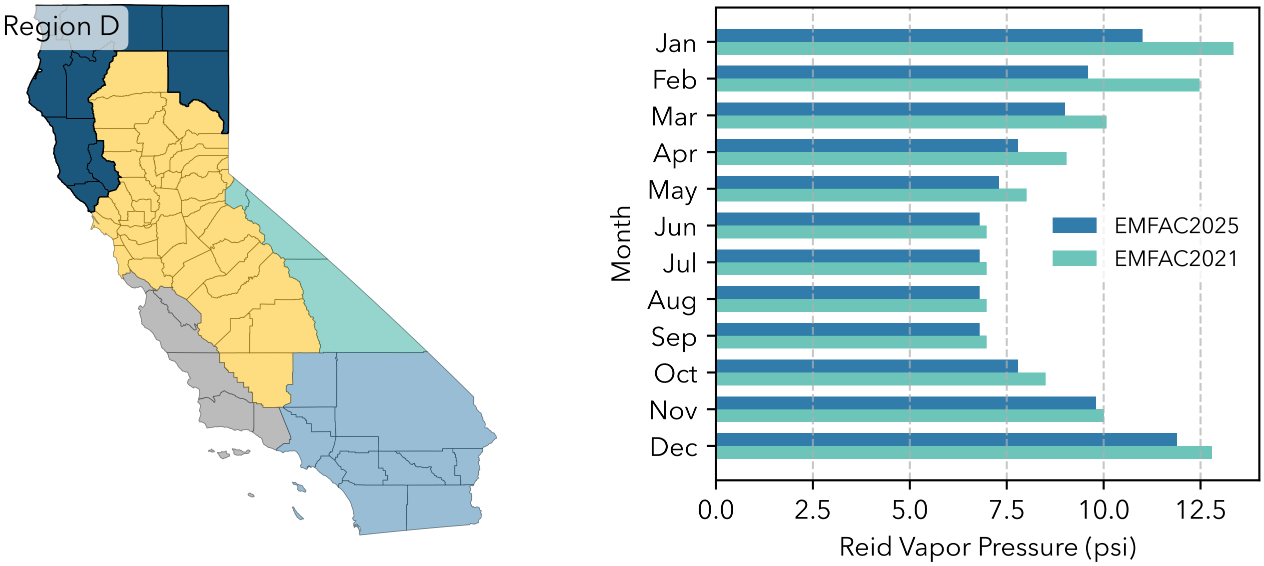
Figure 7.4: Updated Reid Vapor Pressure for Control Region B



(a) Control Region C

(b) Monthly Reid Vapor Pressure of Region C

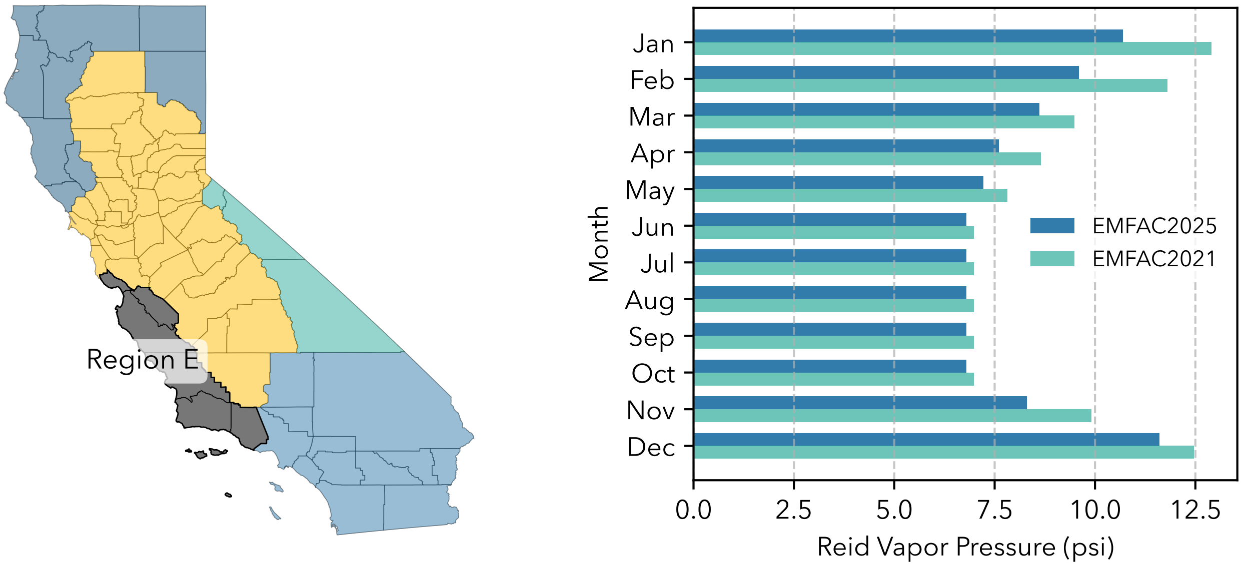
Figure 7.5: Updated Reid Vapor Pressure for Control Region C



(a) Control Region D

(b) Monthly Reid Vapor Pressure of Region D

Figure 7.6: Updated Reid Vapor Pressure for Control Region D



(a) Control Region E

(b) Monthly Reid Vapor Pressure of Region E

Figure 7.7: Updated Reid Vapor Pressure for Control Region E

## 7.2 Fuel Sulfur Content Update

In EMFAC2021, the sulfur content in fuel was assumed to be 15 ppm across all GAIs, based on values last updated in EMFAC2007 to reflect California fuel regulations in effect at that time. The EMFAC2025 update incorporates sulfur content data collected by CARB's Enforcement Division from service stations between 2008 and 2022. Figures 7.8 and 7.9 present the mean sulfur content measured for gasoline and diesel in each region, respectively. Note that the data are presented by the same control regions used for the Reid Vapor Pressure regulation (see Figure 7.2). For both gasoline and diesel fuels, statewide averages ($\bar{S}_{\text{statewide}}$) were calculated as updated fuel sulfur content values using the following equation:

$$\bar{S}_{\text{statewide}} = \frac{\sum_{i=1}^{n}(\bar{S}_i \times N_i)}{\sum_{i=1}^{n} N_i} \tag{7.1}$$

Where $\bar{S}_i$ is the mean sulfur content in region $i$ and $N_i$ is the number of samples collected in that region. The updated sulfur content in EMFAC2025 is 6.5 ppm for gasoline and 5.2 ppm for diesel.

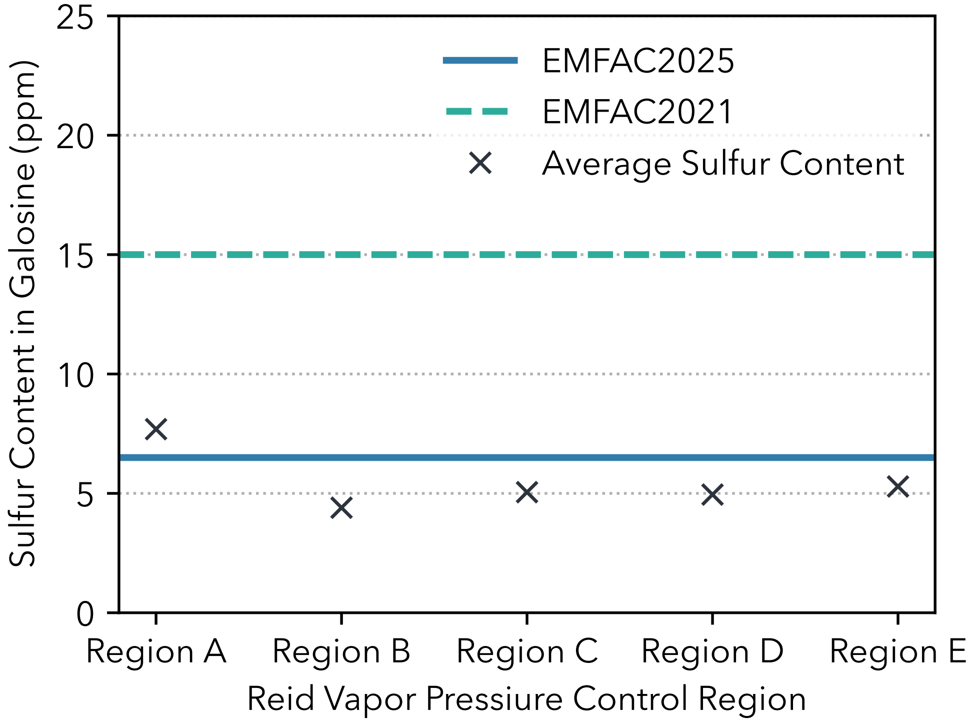


Figure 7.8: Gasoline Sulfur Content Across Reid Vapor Pressure (RVP) Control Regions

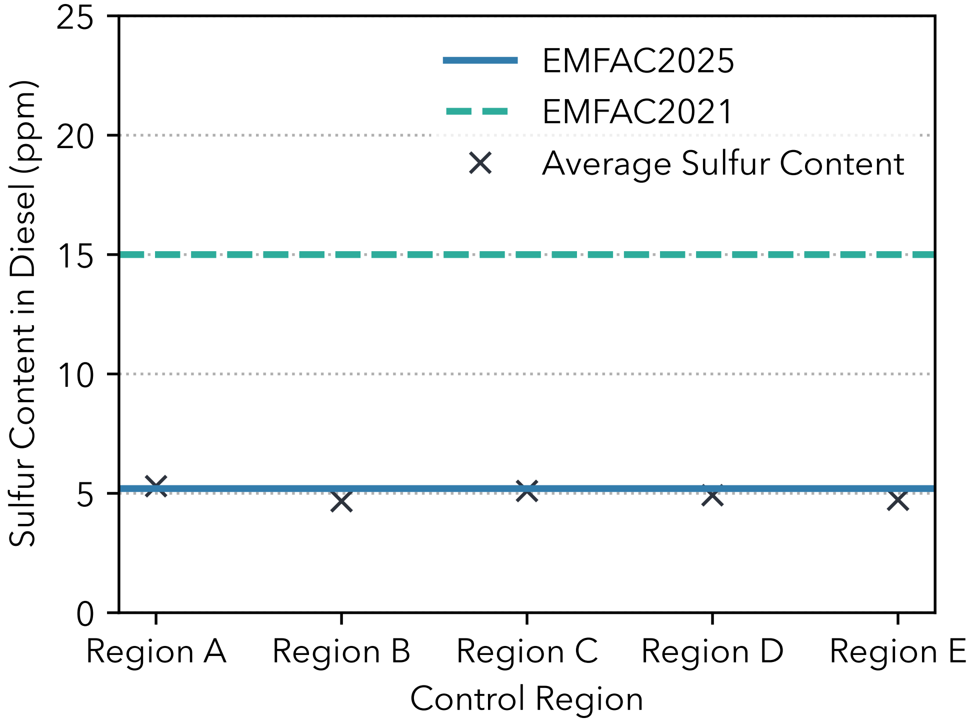


Figure 7.9: Diesel Sulfur Content Across Reid Vapor Pressure (RVP) Control Regions

## 7.3 Fuel Mix Update for Greenhouse Gas Emissions

Starting in EMFAC2017, the $CO_2$ emission rates under the GHG module are estimated based on the complete combustion of transportation fuels, consistent with the official CARB, U.S. EPA, and IPCC methodologies. Complete combustion means that a fuel is burned completely, and all carbon content of the fuel is eventually converted to $CO_2$. This approach disaggregates fuel blends into major components, and thus, $CO_2$ emissions from each of the fuel components are calculated individually. Total $CO_2$ emissions are simply the sum of those from each component. The fuel blend component approach recognizes the increasingly important role of biofuel combustion (ethanol, biodiesel, renewable diesel, etc.). It also allows for the inclusion of future emerging fuel components in a fuel blend and for tracking in upstream analysis. This aligns with the methodology used for CARB's official GHG inventory. Equation (7.2) describes how $CO_2$ from each component of a fuel blend (e.g., gasoline or diesel) is calculated. This equation also applies to natural gas vehicles, and natural gas is measured in standard cubic feet (scf) instead of gallons.

$$\begin{aligned} CO_2 = {} & \text{Fuel Consumption (gal)} \times \text{Blend Proportion (\%)} \\ & \times\ CO_2 \text{ Emission Factor (g/BTU)} \times \text{Heat Content (BTU/gal)} \end{aligned} \tag{7.2}$$

where

- $CO_2$: $CO_2$ emissions of gasoline (or diesel) vehicles for a particular vehicle type (grams).
- Fuel Consumption: Fuel consumption for a particular gasoline (or diesel) vehicle type (gallons). The fuel consumption is calculated from the emission modules in EMFAC for both light-duty and heavy-duty vehicles.
- Blend Proportion: The volumetric proportion of the component in the fuel blend (%).
- $CO_2$ Emission Factor: $CO_2$ emission factor by combustion of the fuel component, assuming complete combustion (grams $CO_2$ / BTU). The current $CO_2$ emission factors come from CARB's Mandatory Greenhouse Gas Reporting Regulation (MRR) (CARB, 2012).
- Heat Content: Heat content of the fuel component; i.e., annual average higher heating value (HHV) of the fuel component (BTU/gallon). The current heat content values come from CARB's Mandatory Greenhouse Gas Reporting Regulation (MRR) (CARB, 2012) based on the average HHV.

For fuel blend composition, the previous EMFAC versions used fuel blend information from the California Board of Equalization (BOE), which provides volume data for total gasoline blend, total diesel blend, biodiesel, and renewable diesel sold in California. In EMFAC2025, the fuel blend data were updated using the quarterly report from the Low Carbon Fuel Standard (LCFS) regulation, which was approved in 2009 and began implementation on January 1, 2011. The LCFS is designed to encourage the use of cleaner low-carbon transportation fuels in California, encourage the production of those fuels, and therefore, reduce GHG emissions and decrease petroleum dependence in the transportation sector. Under the LCFS, all regulated entities must report transportation fuel transactions and credit transfers to CARB. Specifically, the latest LCFS

Quarterly Data Summary from 2025 Q3 is used to update the fuel blend between calendar years 2011 and 2025, and the fuel blend after 2026 is carried over from 2025. With this update, two renewable fuel types were introduced as new fuel components, including renewable fuel and renewable gasoline.

Based on Figure 7.10, the proportion of renewable diesel in diesel fuel grows substantially since the LCFS start, while renewable gasoline is introduced more recently and contributes to less than 1% of gasoline fuel by 2025. The natural gas is composed of a single fuel source, and plug-in hybrid vehicles share the same fuel blend as gasoline vehicles. Therefore, those fuel types are not plotted. The growth of those alternative fuel types can have potential implications on GHG emissions and should be accounted for going forward. Moreover, the LCFS quarterly report also provided heat content for various fuel components based on lower heating values (LHVs), including renewable gasoline and diesel. Therefore, it is used to generate heat content for renewable fuels using HHV from MRR and the relative ratio between renewable fuels and their conventional counterparts. Specifically, the heat content of renewable gasoline is 2.4% higher than the conventional California gasoline blend, and the renewable diesel is 3.5% lower than distillate diesel fuels based on LCFS data. The $CO_2$ emission factors of renewable fuels are estimated from the emission factors from conventional fuels due to a lack of data, and will be updated in future versions if data becomes available.

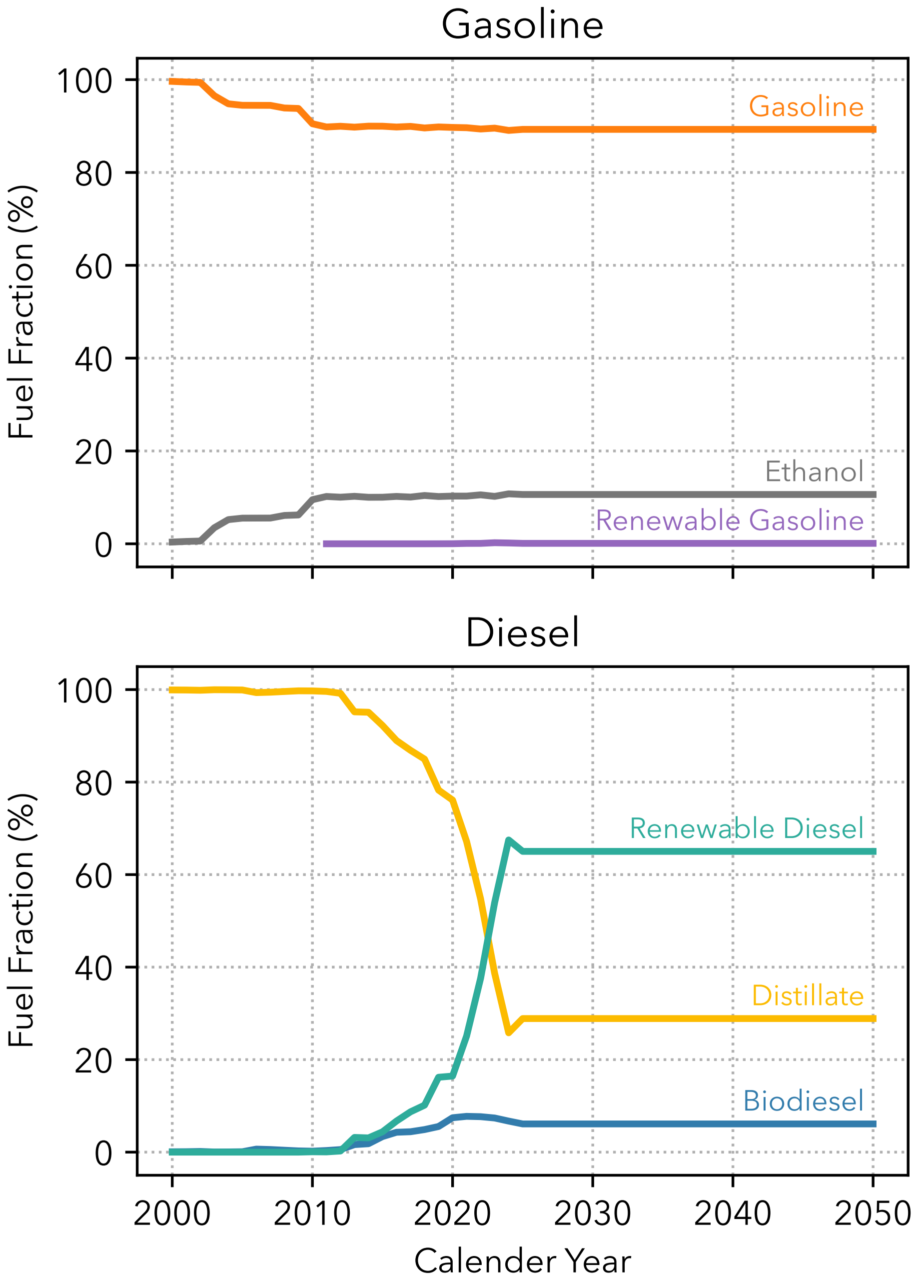


Figure 7.10: EMFAC2025 Fuel Blend by Calendar Year and Fuel Type

# 8 Electric Vehicle Energy Consumption

## 8.1 Battery-Electric Vehicles and Plug-in Hybrid Vehicles

The energy module within EMFAC estimates the total electricity consumption (kWh) needed to power the electric vehicle fleet, including both Battery-Electric Vehicles (BEV) and Plug-in Hybrid Vehicles (PHEV). The electricity consumption is determined by multiplying energy consumption rates (kWh/mi) by the electric VMT (eVMT) of each subfleet category. Such estimates and their projections into the future are valuable for infrastructure and utility planning. EMFAC estimates energy consumption for both light-duty and heavy-duty vehicle categories. This section will focus on light-duty and the following section will overview heavy-duty.

The light-duty energy module was updated using the DMV inventory of BEVs and PHEVs, data from fueleconomy.gov, and the UC Davis BEV and PHEV travel behavior study (Tal *et al.*, 2020), which are summarized in Table 8.1.

Table 8.1: Data Sources Used for BEV and PHEV Energy Consumption Updates

| Data source | Information |
|---|---|
| DMV inventory | Population of all registered cars |
| fueleconomy.gov | Fuel economy of all makes and models |
| UC Davis BEV and PHEV travel behavior study (Tal *et al.*, 2020) | Real-world energy consumption by speed bins |

The UC Davis data was generated using dataloggers that collected second-by-second data from 300 different BEV and PHEV vehicles with MYs ranging from 2012–2019. Each vehicle was logged for about one year while routinely driven on California roads by the vehicle owner and generally averaged typical accrual rates of just over 12,000 miles/year.

The UC Davis data was used to determine real-world energy efficiencies (kWh/mi) for three makes and models: the Tesla Model S (BEV), Nissan Leaf (BEV), and Chevy Volt (PHEV). The determined efficiencies were compared to the fueleconomy.gov energy efficiencies as inventory-weighted averages, which indicated that fueleconomy.gov underestimates BEV and PHEV energy consumption by 9%. The UC Davis data also showed evidence that BEVs can experience a loss of battery charge while parked, and to correctly account for this "stop-loss," another 2.3% correction was needed. Then, staff used the California DMV inventory of BEVs and PHEVs, and the comprehensive energy consumption values from fueleconomy.gov to develop inventory-weighted energy consumption for each light-duty weight class (LDA, LDT1, LDT2, and MDV), as shown below in Figure 8.1. For each category, the 9% and 2.3% corrections were applied to account for real-world driving and stop-losses, respectively. For each increasing weight class, the energy consumption rates increased, and each PHEV weight class had a higher energy consumption rate than the corresponding BEV weight class.

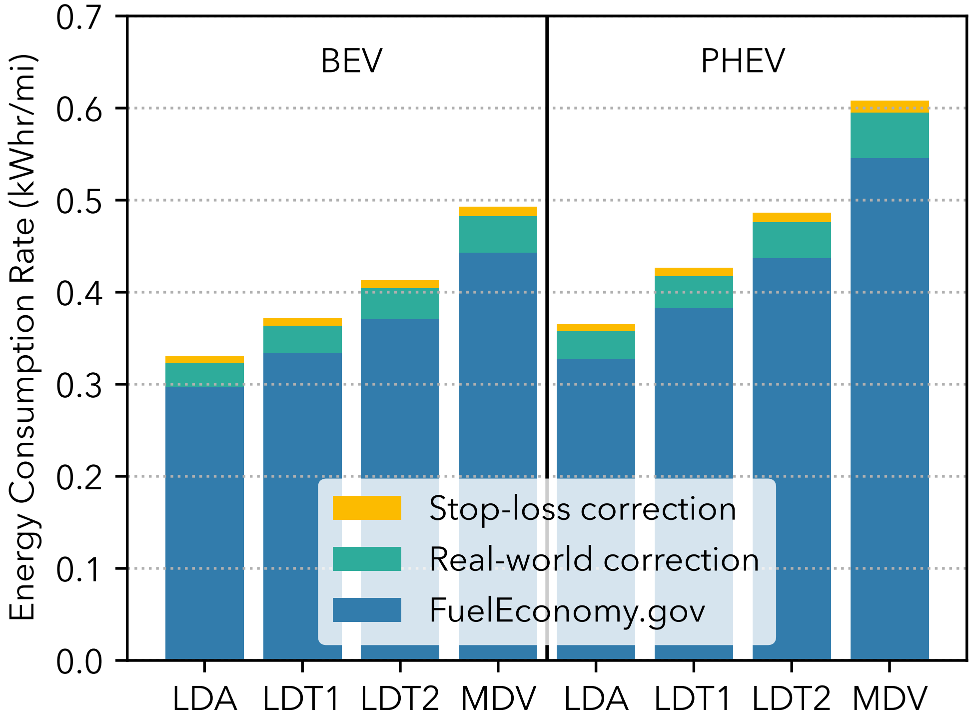


Figure 8.1: Energy Consumption Rates for Light-Duty BEV and PHEV Vehicles

Staff used the UC Davis dataset for two other purposes: to bin out the average energy consumption (as shown below) into speed-distributed energy consumption, and to determine the electric VMT (eVMT) speed distributions used within EMFAC2025. Unique distributions were generated for BEV and PHEV powertrains. The BEV eVMT and energy consumption speed distributions were based on an inventory-weighted average of the Nissan Leaf and the Tesla Model S. The PHEV distributions were based solely on the Chevrolet Volt, since all other PHEVs in the UC Davis datalogging study operated in a blended mode (e.g., Toyota Prius Prime). Blended PHEV driving data exhibited evidence that engine-on operation was impacting the calculated efficiencies, even when second-by-second data filtering methods to remove engine-on operation were applied. As a result, staff decided to only use unblended PHEVs to inform the energy model update, which limited the PHEV dataset to only the Chevrolet Volt. The result was two distinct eVMT speed distributions for BEV and PHEV models, as shown in Figure 8.2. The updated eVMT distributions shown in black are significantly higher speed than the previous eVMT distributions used in EMFAC2021.

The speed distributions of energy consumption were determined for each weight class (LDA, LDT1, LDT2, MDV) of BEV and PHEV as shown in Figure 8.3. The lowest black line on both BEV and PHEV plots is LDA, which captures the majority of all BEVs and PHEVs on the road. For both BEV and PHEV, the energy consumption rates from EMFAC2025 are higher (less efficient) than those estimated by EMFAC2021 at lower speeds, but lower (more efficient) than EMFAC2021 at higher speeds. In the case of PHEV LDT2 and MDV, the EMFAC2025 energy consumption rates exceed those of EMFAC2021 at all speeds.

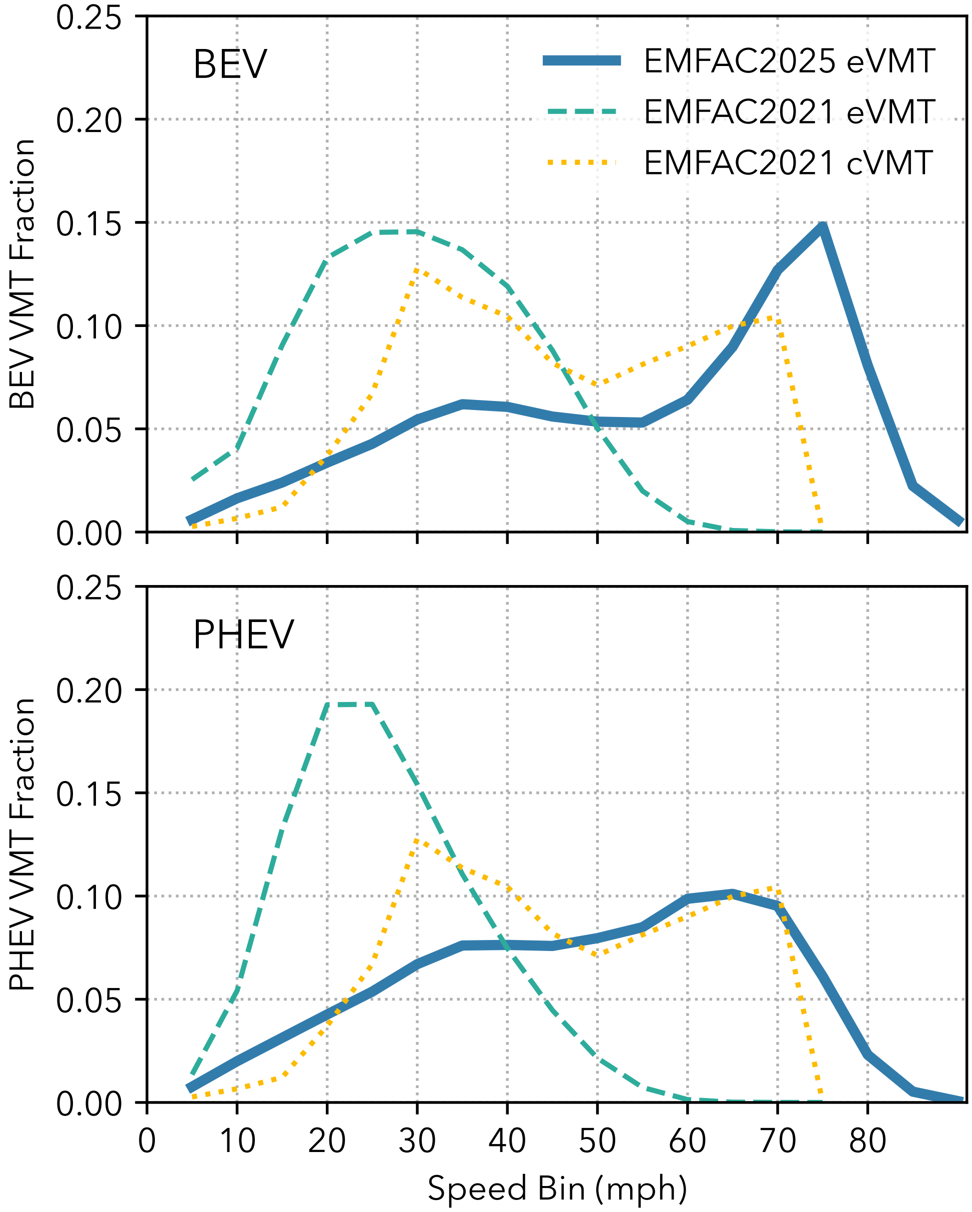
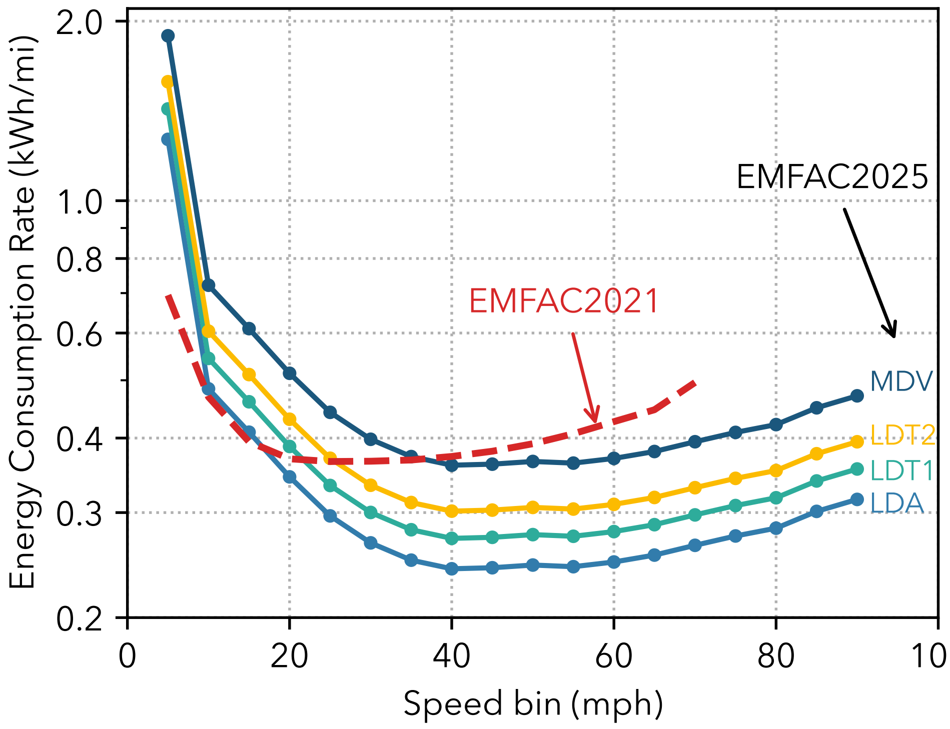
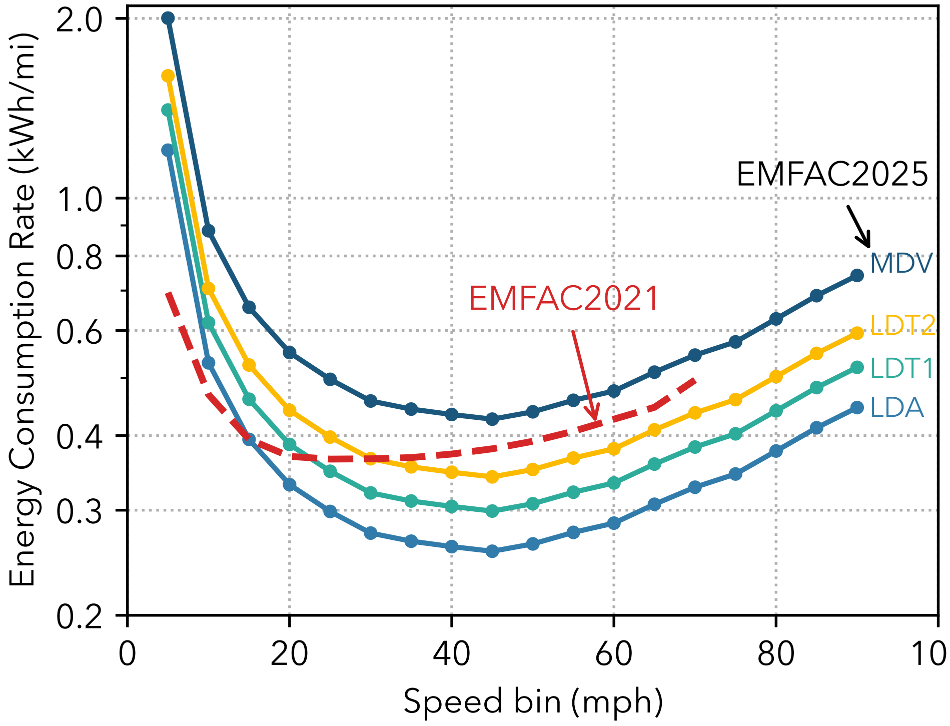


Figure 8.2: BEV and PHEV Electric Vehicle Miles Traveled (eVMT) Distributions: EMFAC2025 vs. EMFAC2021



(a) BEV



(b) PHEV

Figure 8.3: Speed Distributions of Energy Consumption Rates for Light-Duty BEV and PHEV. EMFAC2021's energy consumption rates (dashed lines) are presented for comparison.

## 8.2 Fuel Cell Electric Vehicles

### 8.2.1 Light-Duty Vehicle

As of 2023, there were 13,369 light-duty fuel cell electric vehicles (FCEV) registered in California. Staff used fuel efficiency information reported by manufacturers through an annual survey cross-referenced with active registrations of each make and model year to estimate hydrogen consumption rates from light-duty FCEVs. The fleetwide average hydrogen consumption rate using data pulled as of April 2023 was 0.0153 kg/mi. Due to lack of data, staff assumed the same hydrogen consumption rate for all speeds.

### 8.2.2 Heavy-Duty Vehicle

#### 8.2.2.1 Zero Emission Technology Mix of Heavy-Duty Vehicles

BEVs and FCEVs are the most common examples of currently available heavy-duty ZEVs. These two types of ZEVs share the goal of eliminating tailpipe emissions but differ in their underlying technologies and operation. BEVs use batteries to store energy from the electrical grid to power electric motors. FCEVs, on the other hand, use hydrogen stored on-board to generate electricity for electric motors.

As of 2022 (EMFAC2025 base year), all heavy-duty ZEVs registered with California's DMV were BEVs. Given the differing characteristics of battery and fuel cell technologies – both of which are expected to evolve as performance improves and costs decline – it was somewhat challenging to precisely predict which heavy-duty zero-emission technologies fleets would adopt to comply with ZEV requirements. During the Advanced Clean Fleets (ACF) rulemaking (CARB, 2022), based on expected manufacturer product availability and vehicle suitability analyses, heavy-duty fleets were assumed to meet their medium- and heavy-duty ZEV requirements using a combination of BEVs and FCEVs. CARB staff applied these ACF rulemaking assumptions to EMFAC2025 projections. The projected fractions of FCEVs from that analysis are shown in Table 8.2. For most heavy-duty categories, staff assumed that all purchases would be BEVs through 2026. Starting in 2027, purchases were assumed to be 90% BEV and 10% FCEV. However, higher FCEV fractions were assumed for heavy-duty long-haul applications. For example, staff assumed that 46% of T7 NNOOS Class 8 and T7 NOOS Class 8 vehicles would be FCEVs through 2026, increasing slightly to 47.5% thereafter. Additionally, purchases of heavy-duty port trucks and certain tractor categories were assumed to be 10% FCEV through 2026, increasing to 25% from 2027 onward.

Table 8.2: Fractional Distribution of BEV and FCEV Technologies in Heavy-Duty Vehicle Categories

| Vehicle Categories | Model Year Range | | | |
|---|---|---|---|---|
| | 2024–2026 | | 2027–2050 | |
| | BEV | FCEV | BEV | FCEV |
| Motor Coach | 1.000 | 0.000 | 0.900 | 0.100 |
| OBUS | 1.000 | 0.000 | 0.900 | 0.100 |
| PTO | 1.000 | 0.000 | 0.900 | 0.100 |
| SBUS | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 CAIRP Class 4 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 CAIRP Class 5 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 CAIRP Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 CAIRP Class 7 | 0.900 | 0.100 | 0.750 | 0.250 |
| T6 Instate Delivery Class 4 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Delivery Class 5 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Delivery Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Delivery Class 7 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Other Class 4 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Other Class 5 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Other Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Other Class 7 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Tractor Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Instate Tractor Class 7 | 0.900 | 0.100 | 0.750 | 0.250 |
| T6 OOS Class 4 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 OOS Class 5 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 OOS Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 OOS Class 7 | 0.900 | 0.100 | 0.750 | 0.250 |
| T6 Public Class 4 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Public Class 5 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Public Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Public Class 7 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Utility Class 5 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Utility Class 6 | 1.000 | 0.000 | 0.900 | 0.100 |
| T6 Utility Class 7 | 1.000 | 0.000 | 0.900 | 0.100 |

continues on next page

Table 8.2 – continued from previous page

| Vehicle Categories | Model Year Range | | | |
|---|---|---|---|---|
| | 2024–2026 | | 2027–2050 | |
| | BEV | FCEV | BEV | FCEV |
| T6TS | 1.000 | 0.000 | 0.900 | 0.100 |
| T7 CAIRP Class 8 | 0.620 | 0.380 | 0.575 | 0.425 |
| T7 NNOOS Class 8 | 0.540 | 0.460 | 0.525 | 0.475 |
| T7 NOOS Class 8 | 0.540 | 0.460 | 0.525 | 0.475 |
| T7 Other Port Class 8 | 0.900 | 0.100 | 0.750 | 0.250 |
| T7 POAK Class 8 | 0.900 | 0.100 | 0.750 | 0.250 |
| T7 POLA Class 8 | 0.900 | 0.100 | 0.750 | 0.250 |
| T7 Public Class 8 | 1.000 | 0.000 | 0.900 | 0.100 |
| T7 Single Dump Class 8 | 1.000 | 0.000 | 0.900 | 0.100 |
| T7 Single Concrete/Transit Mix Class 8 | 1.000 | 0.000 | 0.900 | 0.100 |
| T7 Single Other Class 8 | 1.000 | 0.000 | 0.900 | 0.100 |
| T7 SWCV Class 8 | 1.000 | 0.000 | 0.900 | 0.100 |
| T7 Tractor Class 8 | 0.892 | 0.108 | 0.745 | 0.255 |
| T7 Utility Class 8 | 1.000 | 0.000 | 0.900 | 0.100 |
| T7IS | 1.000 | 0.000 | 0.900 | 0.100 |
| UBUS | 1.000 | 0.000 | 0.900 | 0.100 |

#### 8.2.2.2 Data Source for Hydrogen Consumption Rate

Hydrogen ($H_2$) consumption rates of heavy-duty vehicle categories were collected from two CARB-funded projects: (1) The SunLine Fuel Cell Buses & Hydrogen Onsite Generation Fueling Station Pilot Commercial Deployment Project (hereafter referred to as the SunLine Project) (SunLine, 2022), and (2) The Port of Los Angeles Zero- and Near-Zero-Emission Freight Facilities "Shore to Store" Project (hereafter referred to as the Shore to Store Project) (Goldberg *et al.*, 2023).

The SunLine Project was a four-year project that deployed five new 40-foot fuel cell electric transit buses in daily service in the Coachella Valley and included an upgrade to SunLine's existing hydrogen refueling station. Operating data for the buses and stations were collected and analyzed for one year. The buses cumulatively traveled over 150,000 miles and consumed over 22,000 kg of on-site produced hydrogen.

The Shore to Store project was designed to develop and demonstrate the technical feasibility of advanced zero-emission technologies and supporting infrastructure in goods movement operation. In this project, ten Class 8 fuel cell electric trucks conducted drayage operations across four different fleet operators (UPS, TTSI, SCE, and TLS). The demonstration fleet fueled at the 'Shore to Store' hydrogen fueling stations that were installed in Ontario, California and Wilmington, California. From the 10 Class 8 FCEV trucks, nearly 22,000 miles of in-service miles and over 59,000 total miles of operational data were collected over 13 months.

CARB staff used collected data on hydrogen consumption rates across different vehicle speed ranges to develop speed-specific $H_2$ consumption rates for the UBUS and HHDT categories, as shown in Figure 8.4. These speed-specific rates were then scaled to the remaining lighter heavy-duty vehicle categories using the ratio of each category's electric energy consumption rate to that of HHDT (or UBUS). The electric energy consumption rates used in this scaling are provided in Table 8.3.

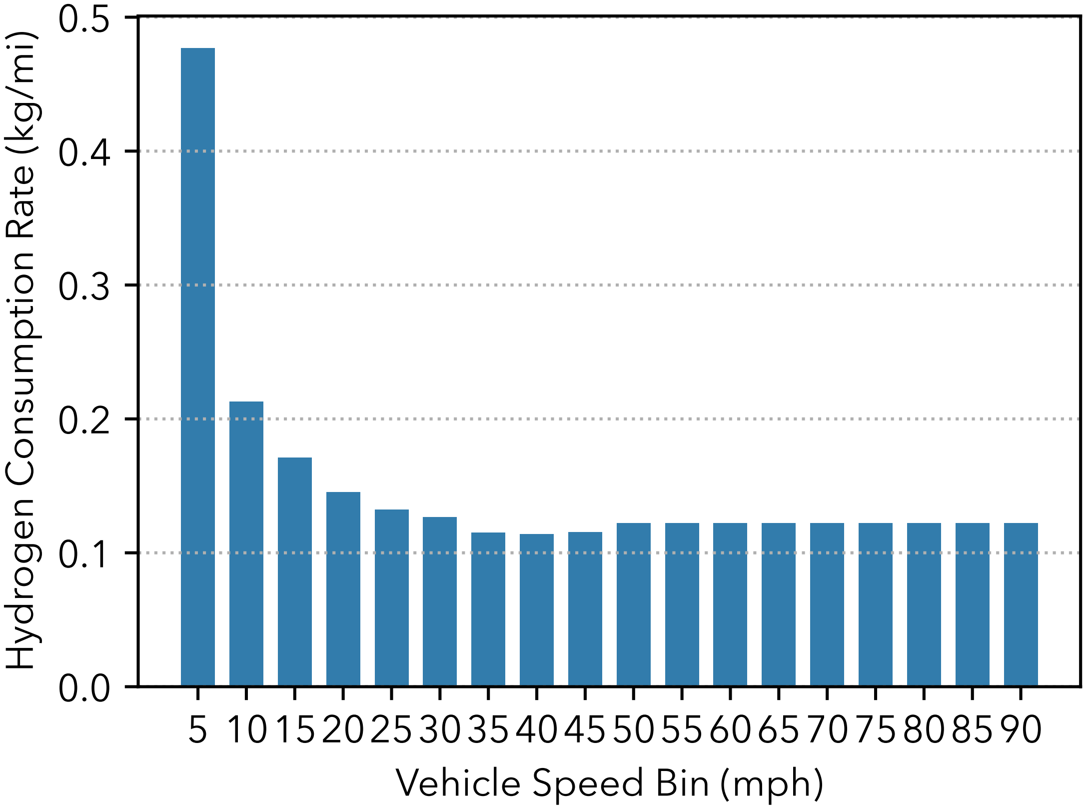


Figure 8.4: Speed-Specific Hydrogen Consumption Rates of Heavy Heavy-Duty Trucks (HHDT) and Transit Bus (UBUS) Categories

Table 8.3: Electricity Consumption Rates of EMFAC2007 Heavy-Duty Vehicle Categories

| EMFAC2007 Heavy-Duty Vehicle Categories | Electricity Consumption (kWh/mi) |
|---|---|
| Heavy Heavy-Duty Trucks (HHDT) | 2.07 |
| Light Heavy-Duty Trucks 8,501–10,000 lbs. (LHDT1) | 0.66 |
| Light Heavy-Duty Trucks 10,001–14,000 lbs. (LHDT2) | 0.66 |
| Medium Heavy-Duty Trucks (MHDT) | 1.46 |
| Other Buses (OBUS) | 1.46 |
| School Buses (SBUS) | 1.46 |
| Urban Buses (UBUS) | 2.07 |

# 9 Incorporated Regulations

EMFAC2025 v2.0.0 was officially released on May 14, 2025. Following its release, three unlawful Congressional resolutions purported to disapprove the U.S. EPA's prior actions to grant California waivers for several regulations incorporated in the model, including:

- Advanced Clean Cars II (ACC II)
- Advanced Clean Trucks (ACT)
- Zero-Emission Airport Shuttle
- Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions (Warranty Phase 1)
- Heavy-Duty Omnibus (Omnibus)

While the congressional actions are being contested, EMFAC2025 v2.1.0 has been released to reflect the current regulatory conditions. This version removes the emissions benefits of the above regulations that were included in EMFAC2025 v2.0.0. These actions also affect the emissions benefits from regulations implemented in EMFAC2021 v1.0.2; consequently, Sections 4.6.3, 4.6.4, 4.6.5, and 4.6.6 of the EMFAC2021 Technical Documentation (CARB, 2021) are no longer applicable to EMFAC2025.

Following the removal of Omnibus' emissions benefits, CARB staff assumed that California-certified engines of model year 2027 and newer would meet the Federal Clean Trucks Plan requirements, as further described in Section 9.3.

EMFAC2025 v2.1.0 also removes the Federal Phase 3 Greenhouse Gas Emissions Standards (U.S. EPA, 2024) and the Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles (U.S. EPA, 2024), both of which were repealed in February 2026.

## 9.1 Clean Truck Check

Clean Truck Check (CTC)–Heavy-Duty Inspection and Maintenance (HD I/M) Program–was approved by the California Office of Administrative Law (OAL) on October 5, 2022, and implementation began on January 1, 2023. CTC applies to all on-road, non-gasoline heavy-duty vehicles with a gross vehicle weight rating over 14,000 pounds that operate in California. This includes vehicles registered out of state and out of the country. CTC requires vehicle owners to demonstrate that their emissions control systems are properly functioning, thereby reducing excess $NO_x$ and PM emissions resulting from poor maintenance and tampering. The emission benefits from CTC in EMFAC2025 reflect lower rates of emissions-related deterioration due to induced repairs and better maintenance. The regulation requires on-board diagnostics

(OBD)-equipped vehicles to submit their OBD data periodically. Non-OBD-equipped vehicles are required to submit their opacity test periodically, and any non-compliant vehicles will receive a DMV registration hold. The program is scheduled to be implemented in four phases:

- Phase 1: Starting January 2023, high-emitter vehicles were screened with portable emissions acquisition systems (PEAQS) in the South Coast and San Joaquin Valley regions.
- Phase 2: Enforcement of compliance certification requirements began in mid-2023; the California Department of Motor Vehicles (DMV) began holding vehicle registrations of non-compliant California-registered vehicles.
- Phase 3: Starting in 2025, periodic testing is now enforced, and heavy-duty vehicles are required to have two tests per year.
- Phase 4: Starting in 2028, OBD-equipped vehicles will be required to submit their tests four times per year.

Staff developed a model to incorporate the program's different phases to calculate the emission benefit, which is described further in Appendix D of the CTC ISOR (CARB, 2021). At a high level, EMFAC2025 uses outputs from a MIL-On solver. This unit solves a series of ordinary differential equations that describe the evolution of the fraction of vehicles with their MIL lamp on, based on:

- Initial fractions at the start of the program (which depend on the EMFAC vehicle category and model year).
- Program phase, which provides inputs such as expected repair rates and test frequency.

The output of the unit is MIL ON fractions by calendar year, EMFAC vehicle category, vehicle model year, and air basin.

To reflect the emissions benefits of CTC in EMFAC2025, the baseline $NO_x$ and PM deterioration rates for applicable vehicle categories and fuel types are adjusted using the ratio of the new MIL ON fraction (after the regulation is in place) to the old MIL ON fraction (before the regulation is in place).

## 9.2 Advanced Clean Fleets

In response to the Governor's Executive Order N-79-20 (Governor of California, 2020), CARB has proposed the Advanced Clean Fleets (ACF) regulation to accelerate the use of zero-emission medium- and heavy-duty trucks through establishing fleet turnover requirements. The regulation was approved by the California Office of Administrative Law (OAL) in October 2023. However, later in January 2025, California withdrew the request for a waiver to add the ACF regulation to its emissions control program. Therefore, EMFAC2025 excludes the high priority fleets and drayage trucks requirements and only reflects the impact of the State and local government fleet turnover requirements, which do not require a federal waiver or authorization.

### 9.2.1 State and Local Government Fleet Requirements

Staff applied the ACF requirements to the population and VMT of state and local government fleets. The inventory for state and local government fleets includes Class 2b-8 heavy-duty trucks categorized under EMFAC public fleet classifications, buses, and Class 8 solid waste collection vehicles (SWCV) with exempt license plates, which were identified using the California Department of Motor Vehicles (DMV) registration database. To reflect ACF turnover requirements for state and local government fleets, staff assumed that 50% of model year 2024–2026 vehicles mentioned above are ZEVs in each calendar year. As mandated by the ACF regulation, vehicles operating in low-population counties, which generally have fewer than 125,000 residents, were exempted from this phase (CARB, 2022). For model year 2027 and newer vehicles, 100% are assumed to be ZEVs. The ZEV populations for non-public vehicle categories remain unaffected by these requirements.

## 9.3 Federal Clean Trucks Plan

On December 20, 2022, U.S. EPA adopted "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards" as part of their Clean Trucks Plan (U.S. EPA, 2023). This regulation sets stricter pollutant emission standards for federally certified heavy-duty engines with gross vehicle weight rating greater than 10,000 pounds starting in 2027. Because the vast majority (over 95%) of vehicles with GVWR of 10,000 to 14,000 pounds are chassis-certified, CARB staff assumed this regulation only applies to vehicles with GVWR greater than 14,000 pounds. Over half of heavy-duty VMT in California are driven by federal-certified trucks, so they are an important source of on-road pollutant emissions. This regulation includes:

- A tightened standard for the Federal Test Procedure (FTP),
- A new Low Load Cycle (LLC),
- Improvements to an existing heavy-duty in-use testing program,
- Improvements to the durability demonstration program,
- Lengthened warranty and useful life mileages.

Enhanced engine standards are expected to significantly reduce $NO_x$ emissions, while the lengthened warranty and useful life reduce both $NO_x$ and particulate matter (PM) emissions.

Table 9.1 lists requirements for model year 2027 and newer engines complying with Clean Trucks Plan, while Table 9.2 provides more details for off-cycle or in-use standards.

Table 9.1: Summary of Clean Trucks Plan Requirements

| Standards, Test Procedures and Elements | Engine Model Year 2027 and Newer |
|---|---|
| Federal Test Procedure (FTP) | 0.035 g $NO_x$/bhp-hr |
| Low Load Cycle (LLC) | 0.05 g $NO_x$/bhp-hr |
| Idling (in-use) | See off-cycle requirements in Table 9.2 |
| In-Use Limits | See off-cycle requirements in Table 9.2 |
| Useful Life* | 650,000/350,000/270,000/200,000 miles |
| Warranty*,† | 321,000/221,000/189,000/148,000 miles |

* The mileages shown for useful life and warranty are listed in the form of HHD/MHD/LHD/HD Otto: Diesel Class 8; GVWR > 33,000 lbs. / Diesel Class 6–7; 19,500 lbs. < GVWR ≤ 33,000 lbs. / Diesel Class 4–5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / HD Otto (gasoline).

† For warranty, the mileages shown are the average miles covered when considering the miles, years, and hours provisions within the proposed requirements.

Table 9.2: Clean Trucks Plan In-Use Testing/Off-Cycle Standards

| Weight Class* | Bin† | $NO_x$ Standard at 20 °C | $NO_x$ Standard at 5 °C |
|---|---|---|---|
| All | 1 | 10.4 g/hr | 15.4 g/hr |
| LHDE | 2 | 0.063 g/bhp-hr | 0.107 g/bhp-hr |
| MHDE and HHDE | 2 | 0.078 g/bhp-hr | 0.122 g/bhp-hr |

* Light Heavy-Duty Engines (LHDE): GVWR 14,001–19,500 lbs.; Medium Heavy-Duty Engines (MHDE): GVWR 19,501–33,000 lbs.; Heavy Heavy-Duty Engines (HHDE): GVWR > 33,000 lbs.

† Bins 1 and 2 represent idle and non-idle operation, respectively.

The in-use or off-cycle standards ensure that real-world emissions tested with portable emissions measurement systems (PEMS) are close to the certification standard and use a 2-bin moving average window (MAW). This approach evaluates emissions data from heavy-duty engines in different time segments that are classified as idle (Bin 1) or grouped as low and medium/high load (Bin 2), ensuring they meet the in-use limits in Table 9.2. Bin 2 is calculated by the weighted average of FTP and LLC (i.e., $0.75 \times FTP + 0.25 \times LLC$) as required by the regulation (U.S. EPA, 2023). The in-use or off-cycle standards in Clean Trucks Plan depend on the ambient temperature, with higher limits established at lower temperatures. To estimate the temperature-dependent in-use limits for engines meeting Clean Trucks Plan requirements operating in California, staff first calculated the annual average ambient temperature in EMFAC, weighted by heavy-duty vehicle miles traveled, to be 18.03 °C. Staff used the off-cycle standards interpolated to this average temperature. For Bin 1, the estimated temperature-weighted value is 12.14 g/hr; 0.078 g/bhp-hr for Bin 2 LHDE; and 0.093 g/bhp-hr for Bin 2 MHDE and HHDE.

To account for the impact of Clean Trucks Plan on heavy-duty emission rates, staff used similar methods as was used to reflect CARB's Heavy-Duty Omnibus (Omnibus) emissions benefits in EMFAC2021. Section 4.6.4 of the EMFAC2021 Technical Documentation (CARB, 2021) provides more details. Please note that the Omnibus regulation, which has many of the same components as Clean Trucks Plan, applies to California-certified vehicles, while Clean Trucks Plan applies to Federal-certified vehicles. To estimate running exhaust emissions from Clean Trucks Plan engines, staff used the ratio of the off-cycle standard in Bin 2 at 18.03 °C to the weighted average of the FTP and LLC certification standards (0.03875 g $NO_x$/bhp-hr). For example, the Bin 2 ratio for MHDE and HHDE is $0.093/0.03875 = 2.4$. This ratio was used to adjust the EMFAC base emission rates (at UDDS average speed of 18.9 mph) from the certification standard to the off-cycle emission rate limits for federal-certified trucks with engine model years 2027 and newer. Staff assumed that the speed correction factors that are used to adjust the base emission rate to other EMFAC speed bins for vehicles affected by Clean Trucks Plan are consistent with those applied to vehicles certified to 0.2 g/bhp-hr $NO_x$.

To estimate idle emissions rates for Clean Trucks Plan engines, staff scaled idle emission rates of 0.2 g $NO_x$/bhp-hr certified engines by applying the ratio of the interpolated Bin 2 emission rate of 12.4 g/hr to the model year 2010 standard (30 g/hr). The Bin 2 emission rate of 12.4 g $NO_x$/hr is larger than the Omnibus standard of 5.0 g/hr for engine model years 2027 and newer. Note that the idling emission rate of 2010 and newer heavy-duty engines in EMFAC depends on the season due to accessory loading (i.e., air conditioner or heater usage); the idle emission rate is 25.3 g $NO_x$/hr without accessory loading, but can go up to around 43 g $NO_x$/hr with accessory loading (CARB, 2018).

# 10 Overall Impacts

This chapter summarizes statewide differences between EMFAC2025 and EMFAC2021 for vehicle activity and emissions. It highlights how key model updates, revised activity assumptions, and regulatory changes shape projected trends through 2050, with additional context for light-duty and medium-/heavy-duty fleets where the effects differ.

As described throughout this document, EMFAC2025 retains several EMFAC2021 updates but also introduces new features and major updates. Noteworthy updates to EMFAC2025 include:

- Estimation of emissions and activity of light-duty vehicles aged 45 years and older (Section 2.1).
- Updated light-duty activity to reflect driving speeds and VMT that are more representative of real-world driving on California roads (Section 2.2.2).
- New high-speed light-duty speed correction factors to account for emissions at speeds above 70 mph (Section 2.2.3).
- Comprehensive updates to light-duty and heavy-duty emission factors (Section .5 and Section .6).
- Incorporation of a range of new regulations including the Clean Truck Check, the Advanced Clean Fleets, and the Clean Trucks Plan:
    - **Clean Truck Check (CTC)** (Section 9.1) is a comprehensive heavy-duty vehicle inspection and maintenance (HD I/M) program that ensures emissions control systems function properly when traveling on California's roadways. Implementation began in 2023. This regulation applies to heavy-duty trucks with GVWR > 14,000 lbs.
    - **Advanced Clean Fleets (ACF)** (Section 9.2) requires state and local government fleets to purchase 50% ZEVs from 2024 to 2026 and 100% ZEVs starting in 2027.
    - **Federal Clean Trucks Plan** (Section 9.3) sets stricter pollution emission standards for federally certified heavy-duty engines greater than 10,000 lbs., starting with engine model year 2027. Because the vast majority (over 95%) of vehicles below GVWR of 14,000 lbs. are chassis-certified, staff assumed this regulation only applies to vehicles with GVWR > 14,000 lbs.

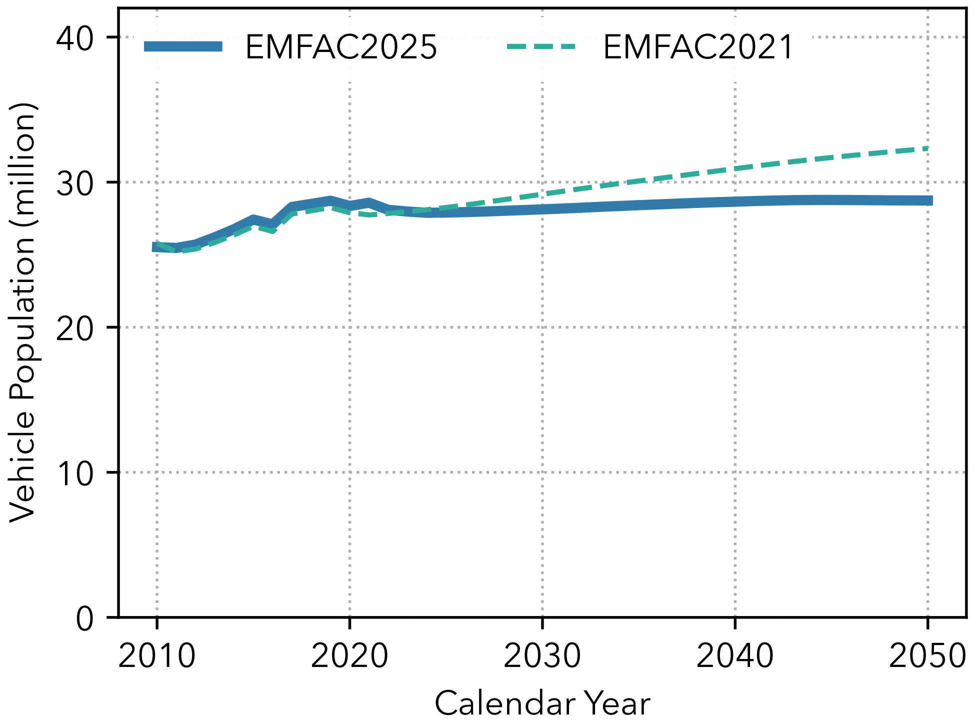
This chapter presents comparisons between emissions and activity estimates from EMFAC2021 and those estimated using EMFAC2025 at the statewide level. In addition, the comparisons include EMFAC2021 estimates adjusted for the removal of emissions benefits from the Advanced Clean Trucks (ACT), Zero-Emission Airport Shuttle, Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions (Warranty Phase 1), and Heavy-Duty Omnibus (Omnibus) regulations. These initiatives were affected by congressional resolutions that purported to disapprove of U.S. EPA decisions to grant California waivers (CARB, 2025). The adjusted EMFAC2021 estimates are referred to as “EMFAC2021 with adjustment factors” in this chapter. These adjustments provide insight into the impacts of the federal actions on EMFAC2021 projections and help isolate the effects of EMFAC2025 updates from regulatory changes.

To better illustrate the differences, comparisons for light-duty (GVWR below 8,500 lbs., including motorcycles) and medium-duty/heavy-duty (GVWR 8,501–14,000 lbs./GVWR above 14,000 lbs.) vehicles are presented alongside overall comparisons. The EMFAC results in this chapter use EMFAC’s default VMT data. Note that CARB’s SIP inventory uses VMT and speed profiles from Metropolitan Planning Organizations (MPO), which differ from EMFAC’s default VMT.

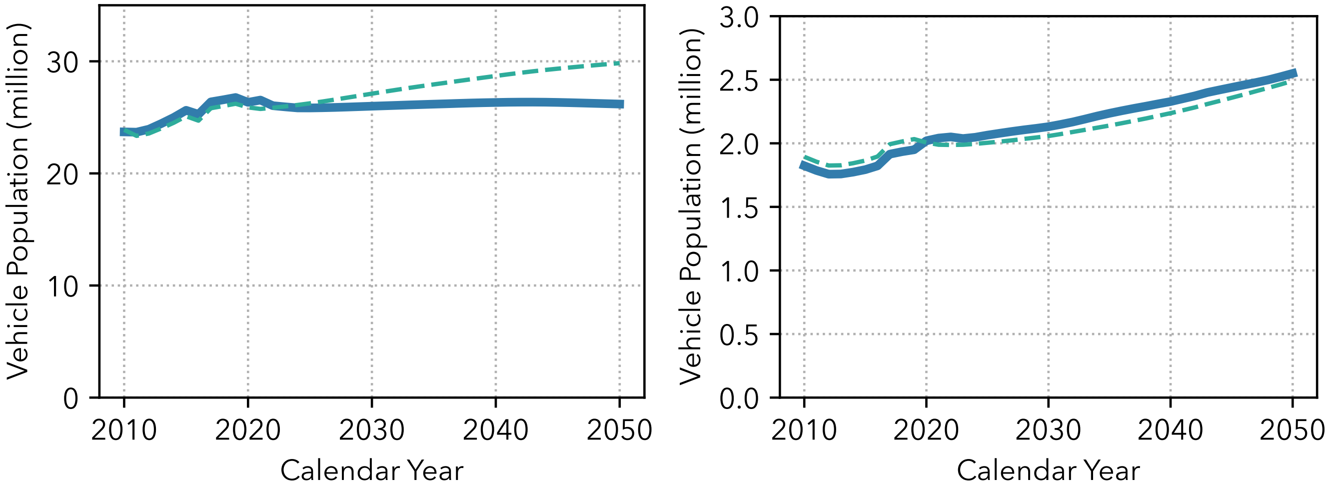
## 10.1 Vehicle Population

Figure 10.1 compares total vehicle populations of EMFAC2025 and EMFAC2021. EMFAC2025 projects about 3.6 million fewer total vehicles than EMFAC2021 by 2050. The light-duty population decline is largely attributable to decreased human population and slower economic growth projections in California.

Figure 10.2 presents statewide Zero-Emissions Vehicle (ZEV; BEV and FCEV) population for EMFAC2025 and EMFAC2021. EMFAC2021 with adjustment factors in Figure 10.2 shows ZEV population estimates from regulations removed from EMFAC2021 due to federal actions (Section .9). EMFAC2025 forecasts a significant rise in ZEV population compared to EMFAC2021, driven by consumer preference for zero-emission vehicles for light-duty vehicles and regulations including ACF for medium- and heavy-duty vehicles. Medium- and heavy-duty vehicle ZEV projections are smaller in EMFAC2025 compared to EMFAC2021 due to removing the Advanced Clean Trucks (ACT) regulation. However, medium- and heavy-duty ZEV population in EMFAC2025 is higher than in EMFAC2021 with adjustment factors, as there are ZEVs increased by ACF state and local government fleet requirements. This shift to a larger ZEV fleet is a major driver of future emission reductions.



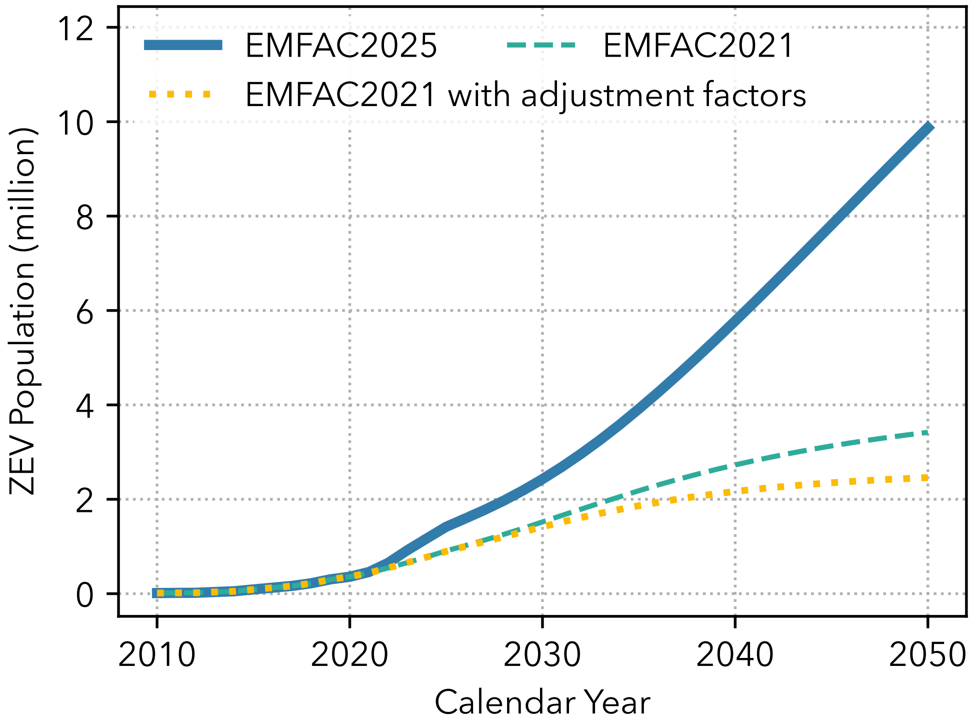
(a) All Vehicles



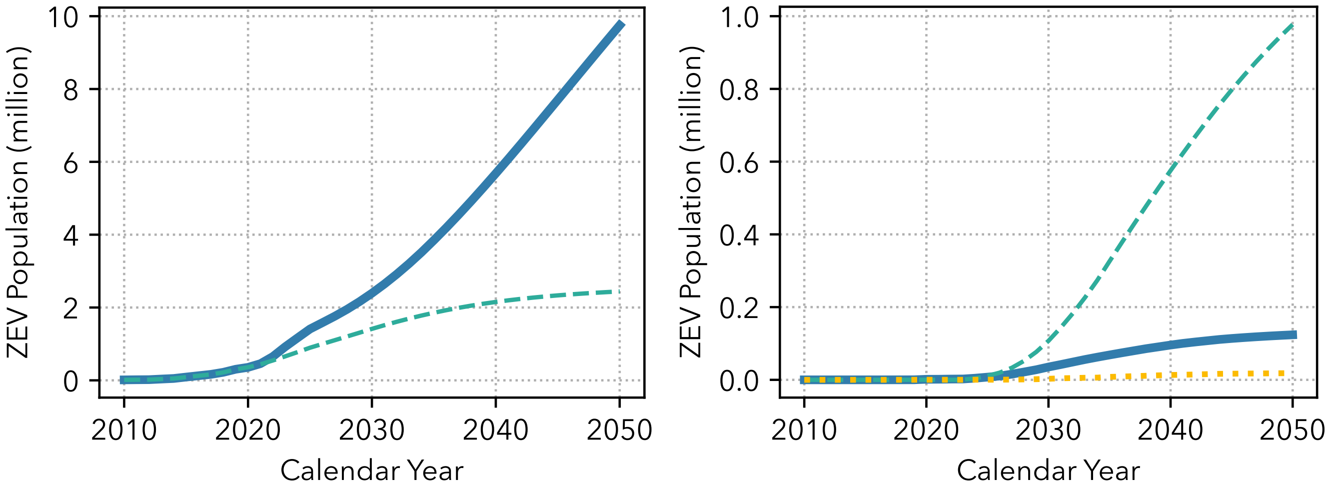
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.1: Statewide Vehicle Population: EMFAC2025 vs. EMFAC2021



(a) All Vehicles



(b) Light-Duty (GVWR ≤ 8,000 lbs.)

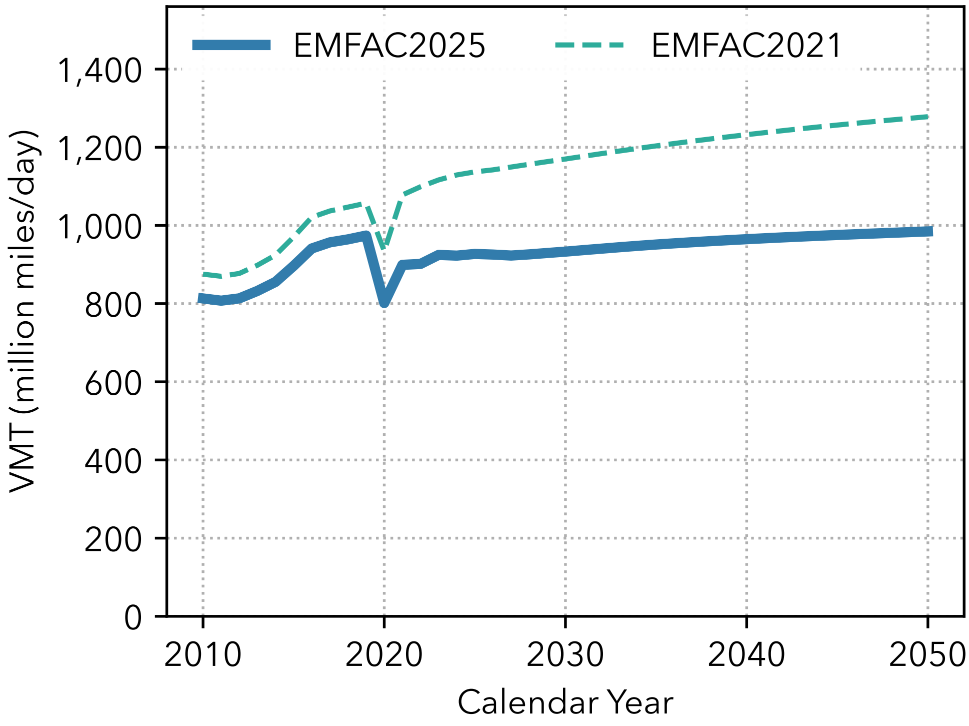
(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.2: Statewide Zero-Emissions Vehicle (ZEV) Population: EMFAC2025 vs. EMFAC2021

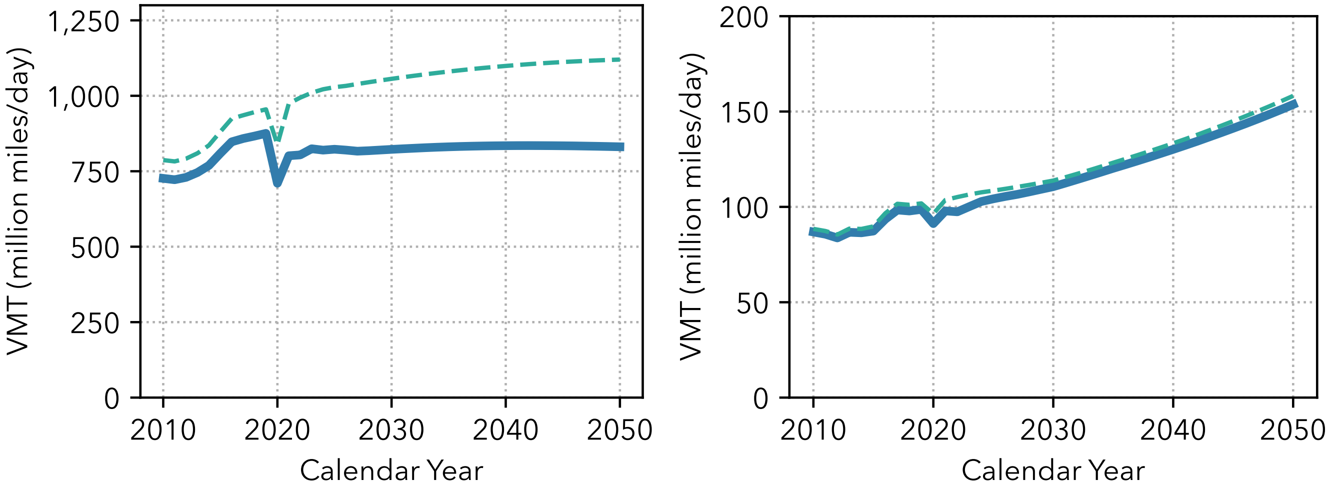
## 10.2 Vehicle Miles Traveled

Figure 10.3 compares statewide VMT from EMFAC2021 and EMFAC2025. EMFAC2025 projects lower VMT, driven primarily by the light-duty fleet, with only small differences in medium- and heavy-duty fleets. Updated speed distributions based on the NEI dataset (Section 2.2.2) shifted EMFAC2025 speeds to both lower and higher ranges, reducing fuel efficiency. Because EMFAC constrains fuel consumption to CDTFA fuel sales data, lower efficiency results in lower overall VMT in historical years. For future years, light-duty VMT decreases stem from two factors: new speed distributions and decreased human population projections in California.

Figure 10.4 presents statewide electric vehicle miles traveled (eVMT) for EMFAC2021 and EMFAC2025. The dotted yellow line shows eVMT estimates after removing federally affected regulations. Consistent with the ZEV population trends in Figure 10.2, EMFAC2025 projects substantial light-duty eVMT growth driven by accelerated ZEV and PHEV adoption from increased consumer preference. Light-duty eVMT growth is more pronounced, though medium- and heavy-duty fleets also show increases compared to EMFAC2021 with adjustment factors, EMFAC2021, showing the effect of ACF. This eVMT growth is a key driver of future emission reductions.



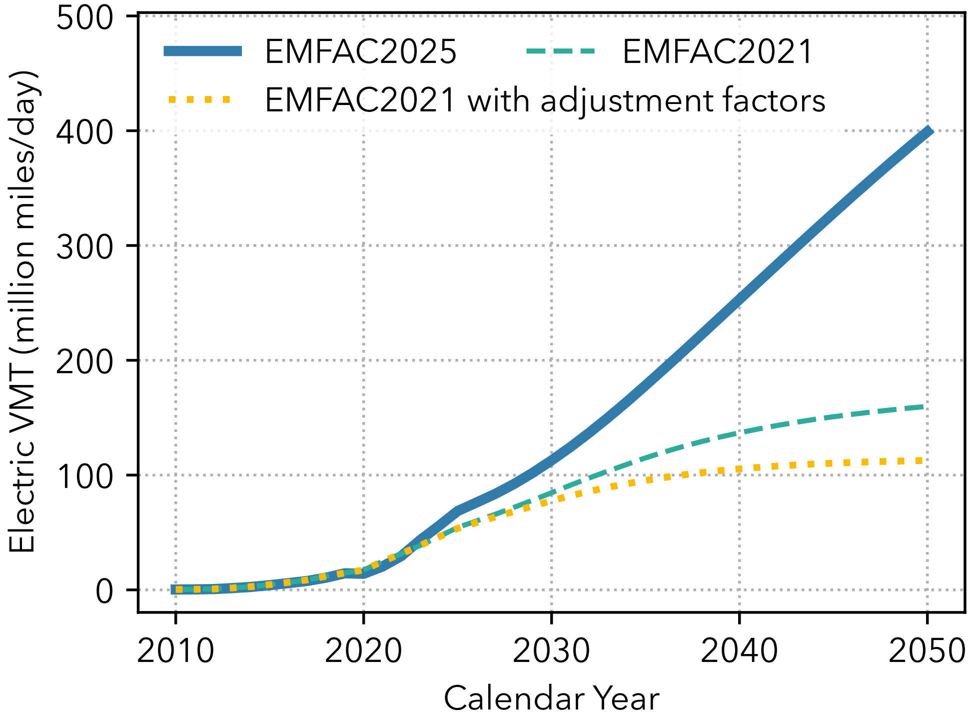
(a) All Vehicles



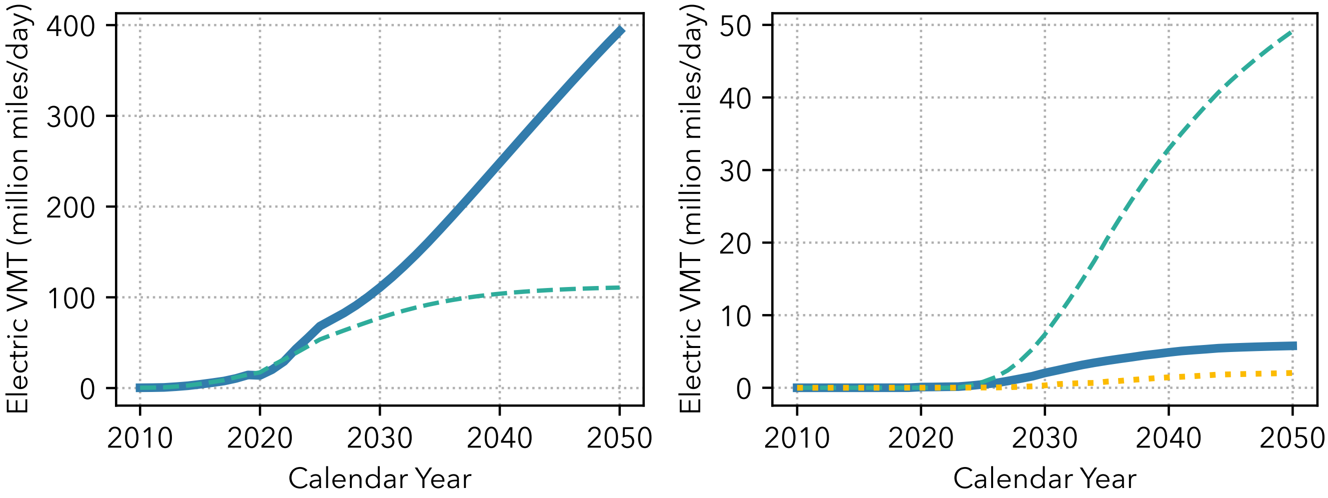
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.3: Statewide Vehicle Miles Traveled: EMFAC2025 vs. EMFAC2021



(a) All Vehicles



(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.4: Statewide Electric Vehicle Miles Traveled: EMFAC2025 vs. EMFAC2021

## 10.3 Emission Impacts

The overall emission differences between EMFAC2025 and EMFAC2021 are primarily driven by increased ZEV population projections. For light-duty vehicles, although Age45+ vehicles (Section 2.1) and improved high-speed driving characterization (Section 2.2) increase emissions, EMFAC2025 predicts lower overall emissions than EMFAC2021, especially in later years, due to increased ZEV population and lower light-duty emission factors. For medium- and heavy-duty vehicles, emission changes are driven by new regulations: the Clean Truck Check, Advanced Clean Fleets, and Federal Clean Trucks Plan.

### 10.3.1 Oxides of Nitrogen ($NO_x$)

Both EMFAC2025 and EMFAC2021 show consistent $NO_x$ emission declines over time, as shown in Figure 10.5. EMFAC2025 projects slightly higher $NO_x$ emissions than EMFAC2021 before 2025, due to updated speed correction factors and Age45+ vehicle inclusion, but lower emissions from 2025 to 2050. The post-2025 reductions reflect increased ZEV population and updated base emission rates. For medium- and heavy-duty vehicles, EMFAC2025 shows lower emissions than adjusted EMFAC2021 after 2025, reflecting new regulations.

### 10.3.2 Reactive Organic Gases (ROG)

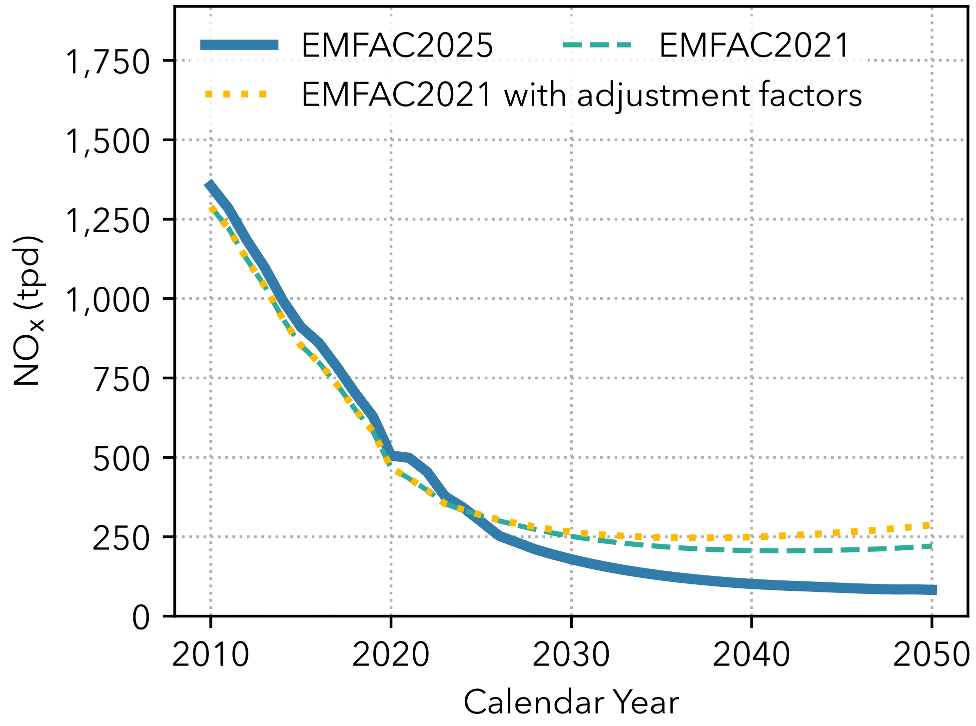
Figure 10.6 shows that both EMFAC2025 and EMFAC2021 reflect steady ROG emission declines. However, EMFAC2025 shows higher ROG emissions than EMFAC2021 from 2010 to 2042, driven by elevated light-duty emissions from Age45+ fleet and high-speed driving updates. The yellow dotted line shows the effect of the federal actions on EMFAC2021 ROG emissions.

### 10.3.3 Exhaust Particulate Matter ($PM_{2.5}$)

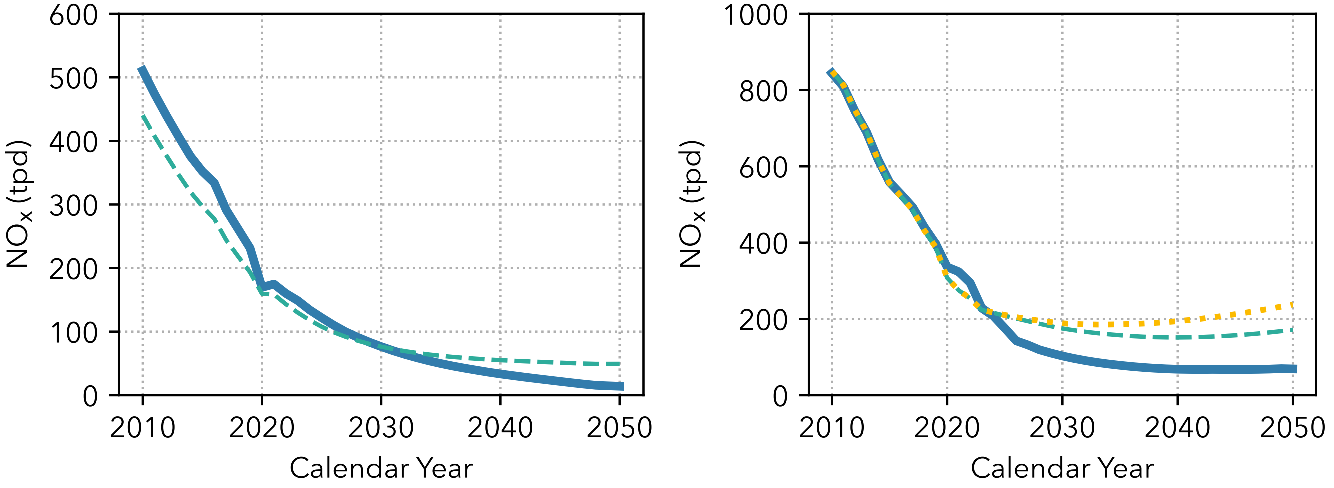
Figure 10.7 compares statewide exhaust $PM_{2.5}$ emissions. EMFAC2025 projects higher $PM_{2.5}$ emissions than EMFAC2021 for light-duty vehicles, reflecting Age45+ fleet and high-speed driving updates. This higher projection narrows over time as the light-duty ZEV population grows. For medium- and heavy-duty vehicles, EMFAC2025 estimates lower $PM_{2.5}$ emissions than EMFAC2021, reflecting the effect of new heavy-duty regulations.

### 10.3.4 Brake and Tire Wear Particulate Matter ($PM_{2.5}$)

Figure 10.8 shows lower light-duty brake and tire $PM_{2.5}$ emissions in EMFAC2025 from reduced VMT and increased regenerative braking as ZEV population grows. For medium- and heavy-duty vehicles, brake and tire wear $PM_{2.5}$ emissions in EMFAC2025 are lower than in EMFAC2021 with adjustment factors, reflecting ZEV growth driven by ACF.



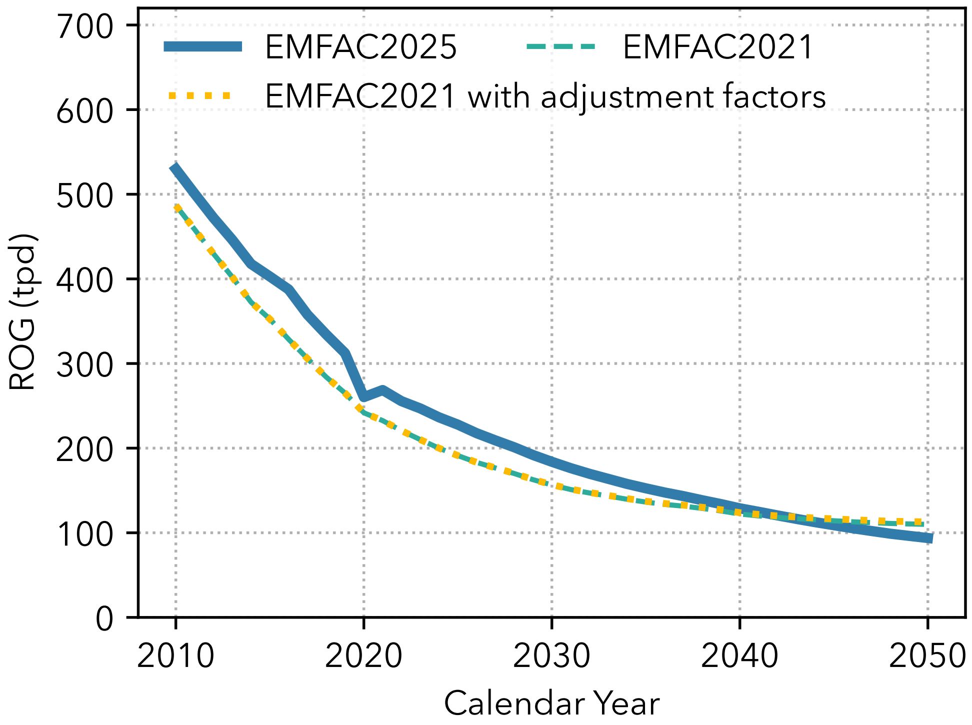
(a) All Vehicles



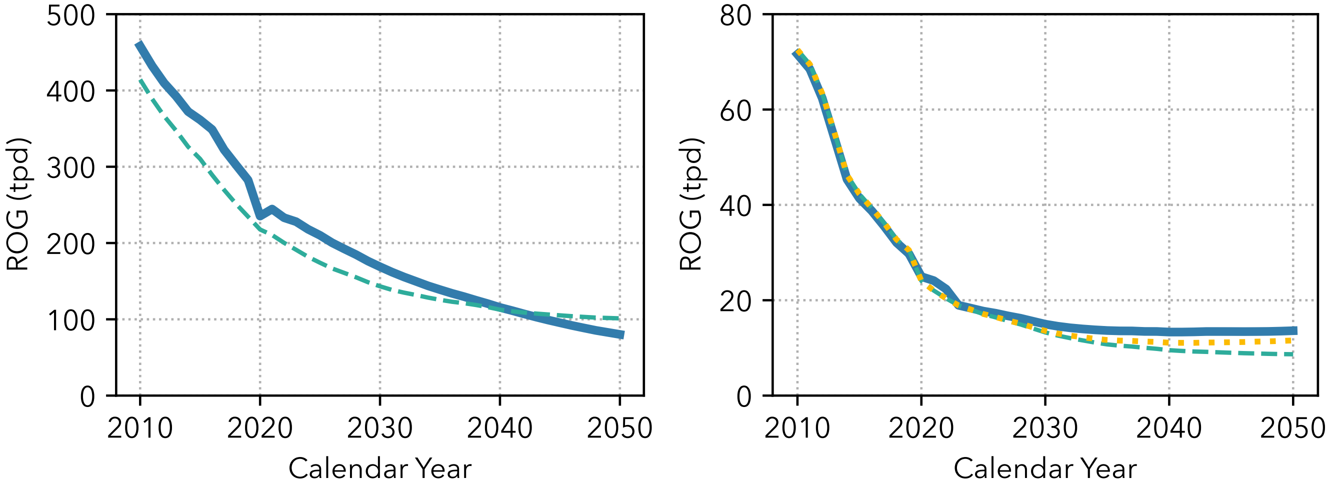
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.5: Statewide $NO_x$ Emissions: EMFAC2025 vs. EMFAC2021



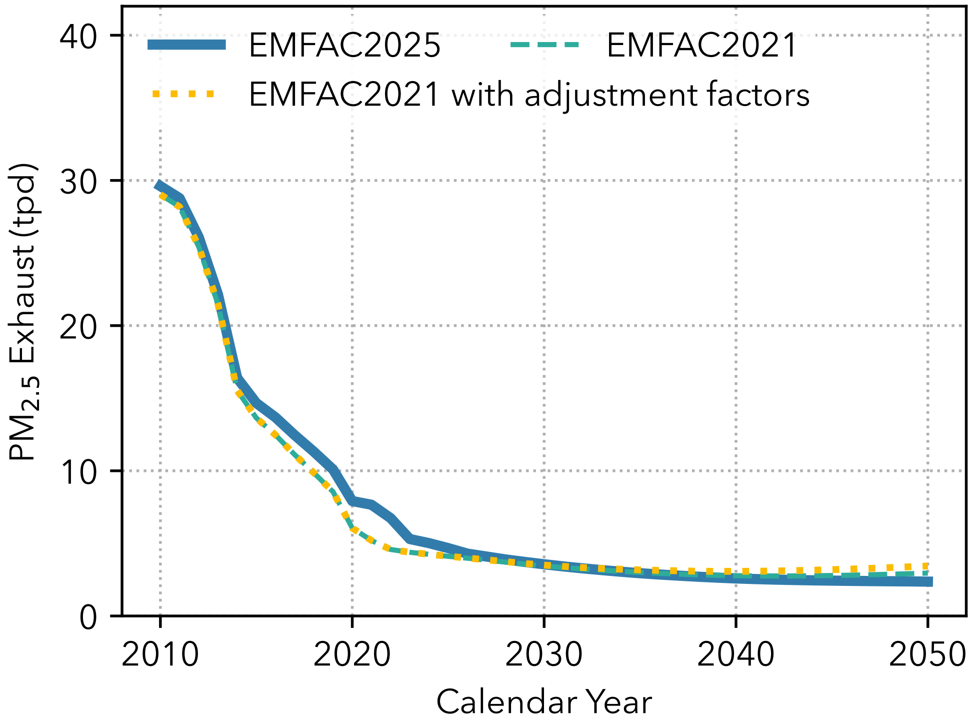
(a) All Vehicles



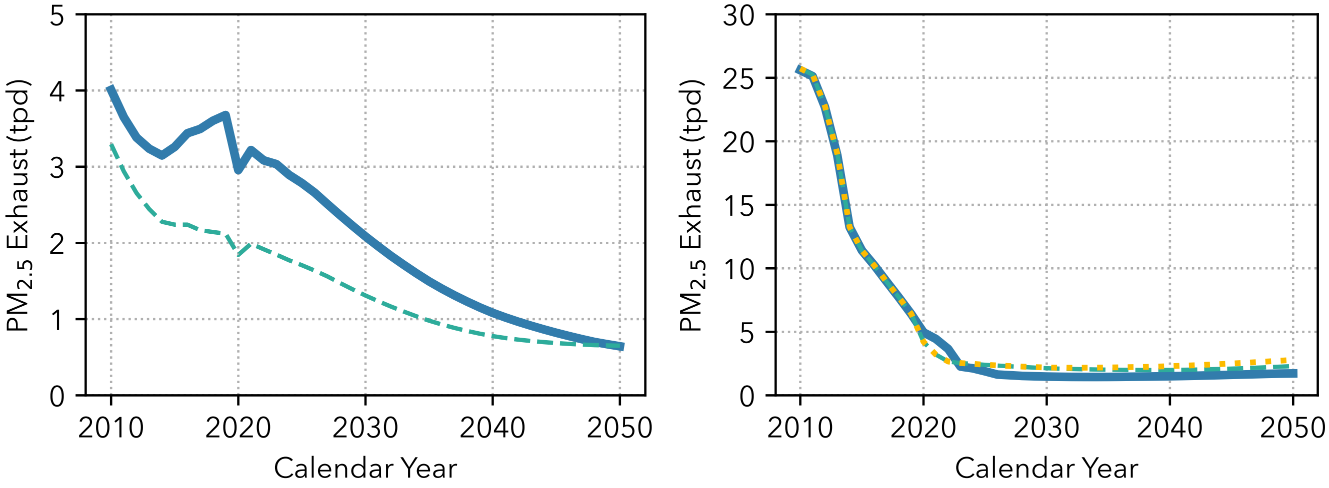
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.6: Statewide ROG Emissions: EMFAC2025 vs. EMFAC2021



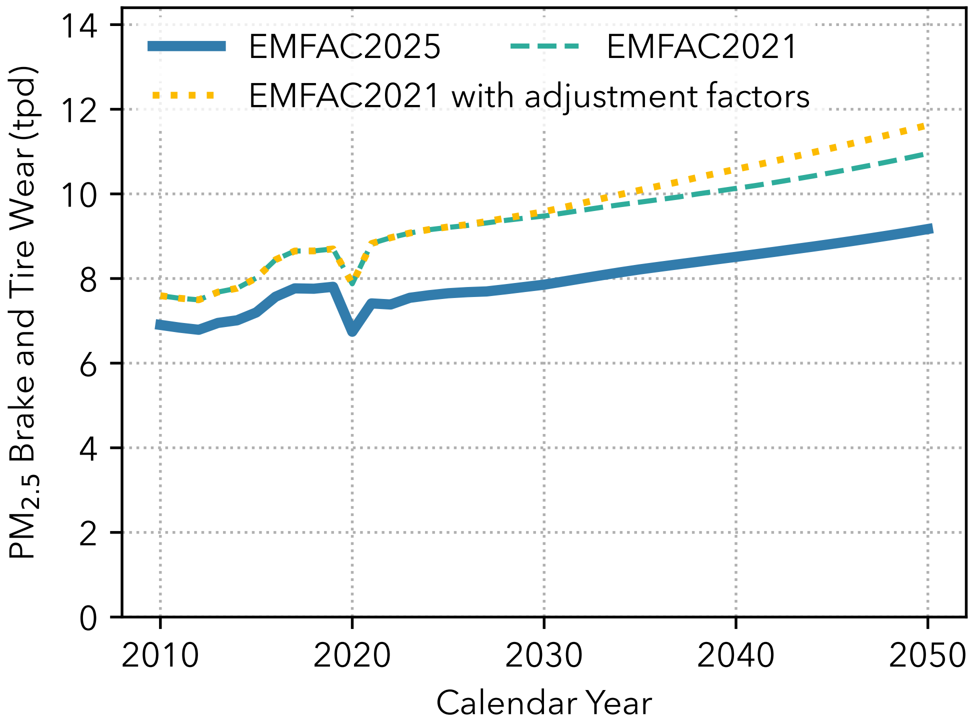
(a) All Vehicles



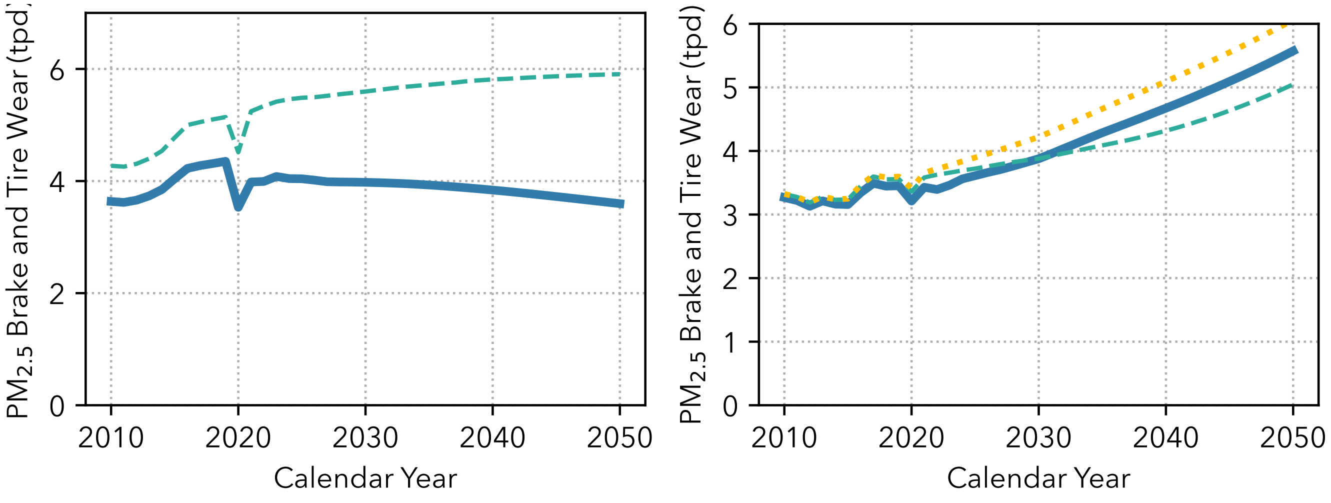
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.7: Statewide Exhaust $PM_{2.5}$ Emissions: EMFAC2025 vs. EMFAC2021



(a) All Vehicles



(b) Light-Duty (GVWR ≤ 8,000 lbs.) (c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.8: Statewide Brake and Tire Wear PM$_{2.5}$ Emissions: EMFAC2025 vs. EMFAC2021

### 10.3.5 Carbon Dioxide ($CO_2$)

Figure 10.9 presents statewide $CO_2$ emissions (tons/day) from 2010 to 2050. EMFAC2025 projects lower $CO_2$ emissions than EMFAC2021 from increased ZEV population and reduced fuel consumption. For medium- and heavy-duty sectors, EMFAC2025 shows higher $CO_2$ emissions from regulations removed by 2025 congressional resolutions, including ACT.

### 10.3.6 Carbon Monoxide (CO)

Light-duty vehicles dominate statewide CO emissions, as shown in Figure 10.10. EMFAC2025 projects higher CO emissions than EMFAC2021 from high-speed correction factors for CO and driving activity above 70 mph. Despite the increased ZEV population, CO emissions in EMFAC2025 remain higher throughout the projection period than in EMFAC2021.

### 10.3.7 Ammonia ($NH_3$)

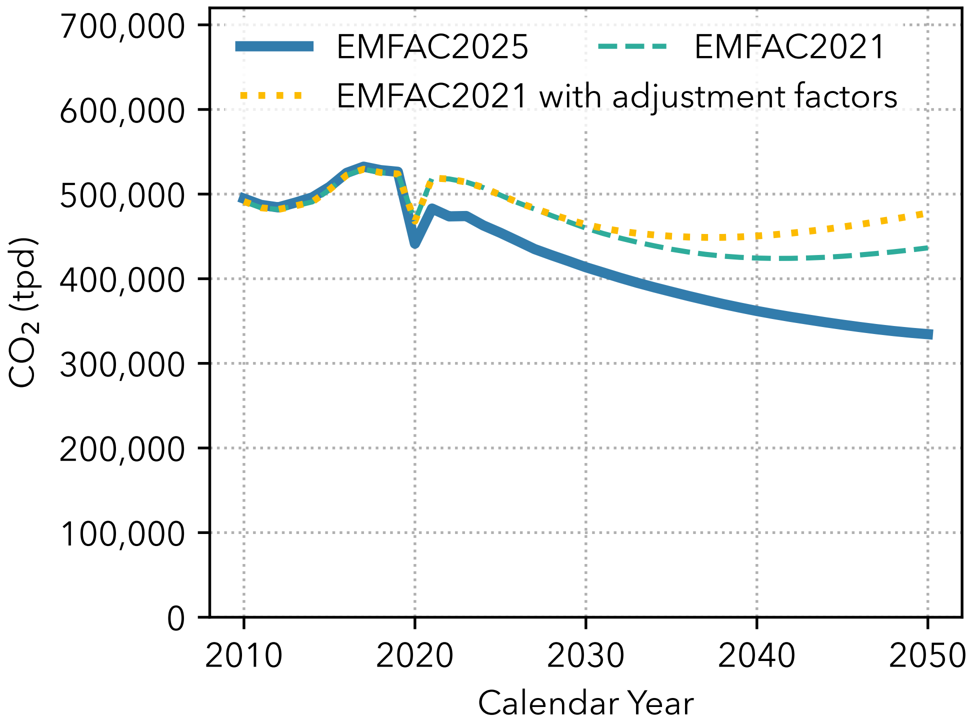
Figure 10.11 compares $NH_3$ emissions from EMFAC2025 and EMFAC2021. Light-duty $NH_3$ emissions are lower in EMFAC2025 due to lower VMT projections and increased ZEV population. Medium- and heavy-duty $NH_3$ emissions are higher in EMFAC2025 from removed regulations, but lower than adjusted EMFAC2021, reflecting the effect of ACF.

### 10.3.8 Oxides of Sulfur ($SO_x$)

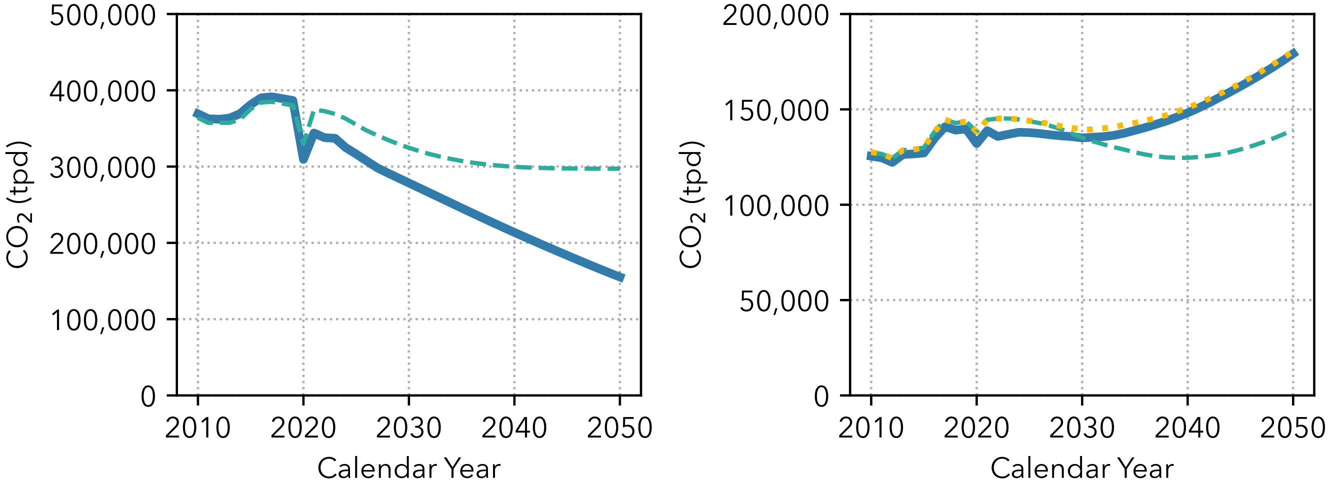
Figure 10.12 compares statewide $SO_x$ emissions (tons/day) from 2010 to 2050. Lower $SO_x$ emissions in EMFAC2025 result from lower VMT and updated sulfur content informed by a recent CARB study (See Section 7.2). This study found lower sulfur content in California fuel samples than previously estimated: 6.5 ppm for gasoline and 5.2 ppm for diesel (versus 15 ppm for both in EMFAC2021). These changes produce dramatic $SO_x$ reductions in historical years. $SO_x$ emissions decline further in future years due to the increased ZEV population.

### 10.3.9 Nitrous Oxide ($N_2O$)

Figure 10.13 compares statewide $N_2O$ emissions (tons/day) from 2010 to 2050. $N_2O$ trends are primarily driven by updates to heavy-duty emissions (Section 5.3). Pre-2011 chassis trucks show decreased $N_2O$ emissions; however, from model year 2011 onward, SCR after-treatment systems for $NO_x$ reduction cause increased $N_2O$ emissions in EMFAC2025 compared to EMFAC2021.



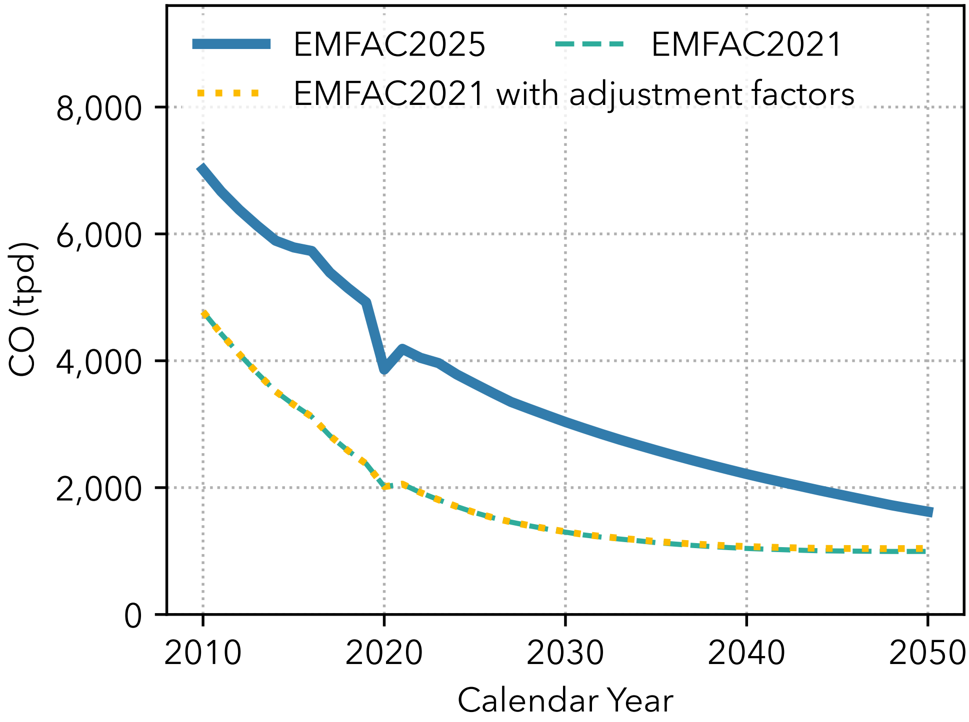
(a) All Vehicles



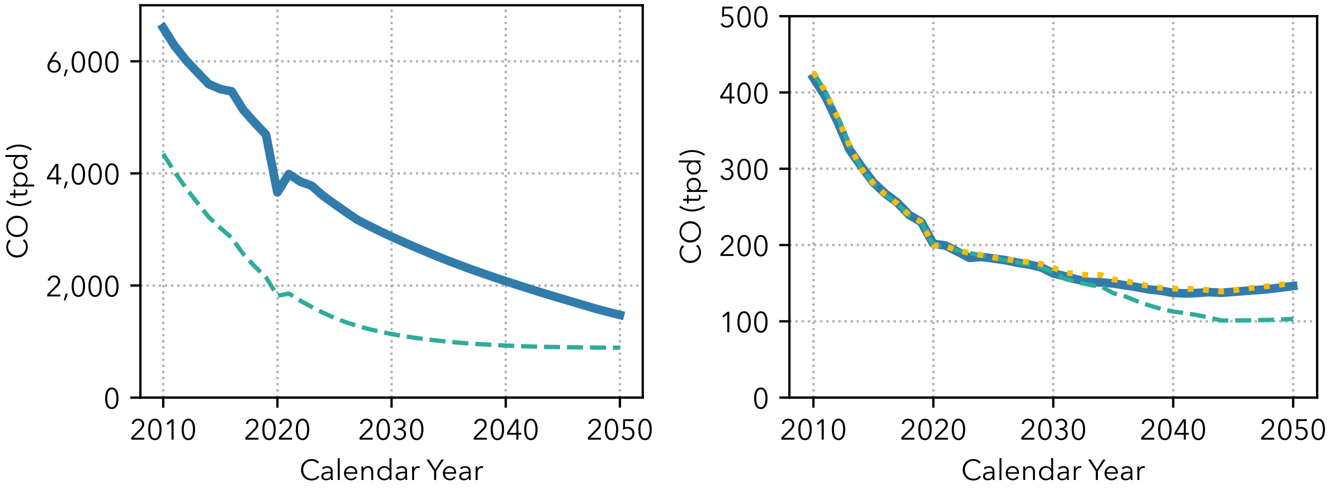
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.9: Statewide $CO_2$ Emissions: EMFAC2025 vs. EMFAC2021



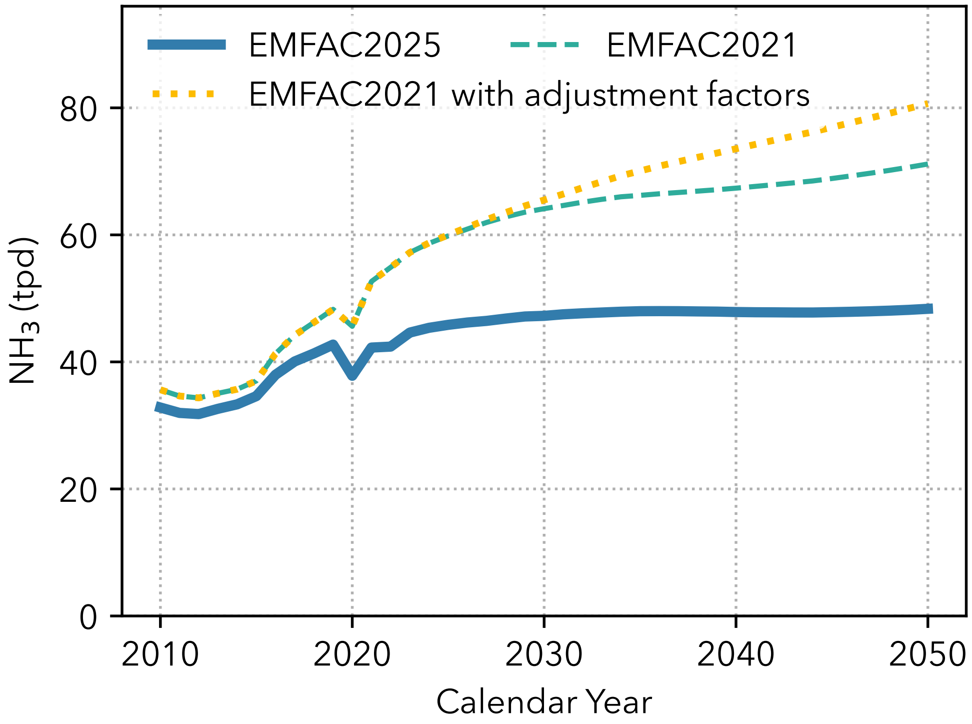
(a) All Vehicles



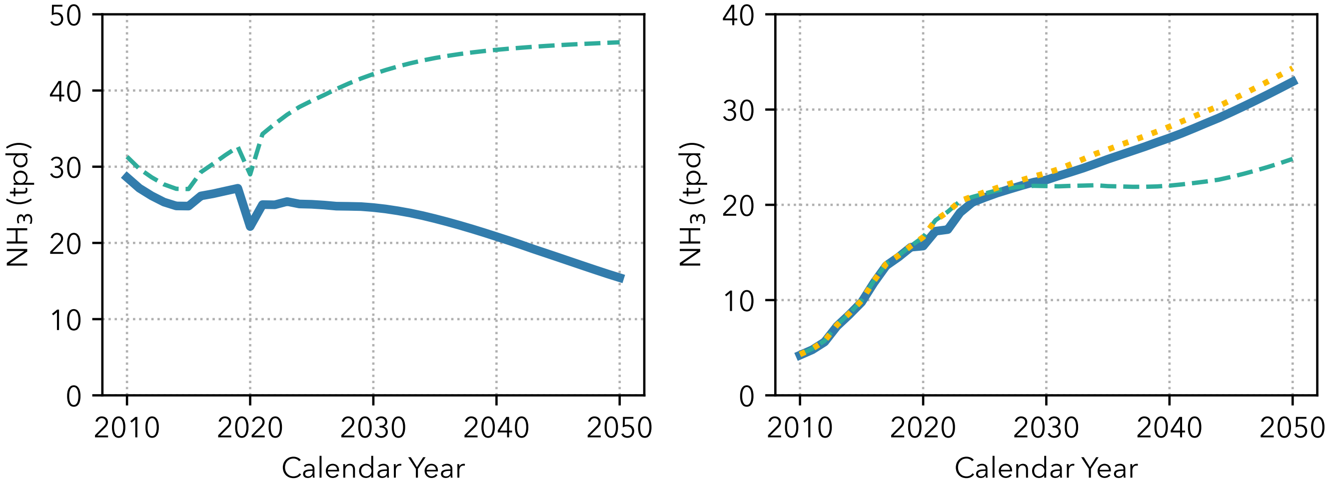
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.10: Statewide CO Emissions: EMFAC2025 vs. EMFAC2021



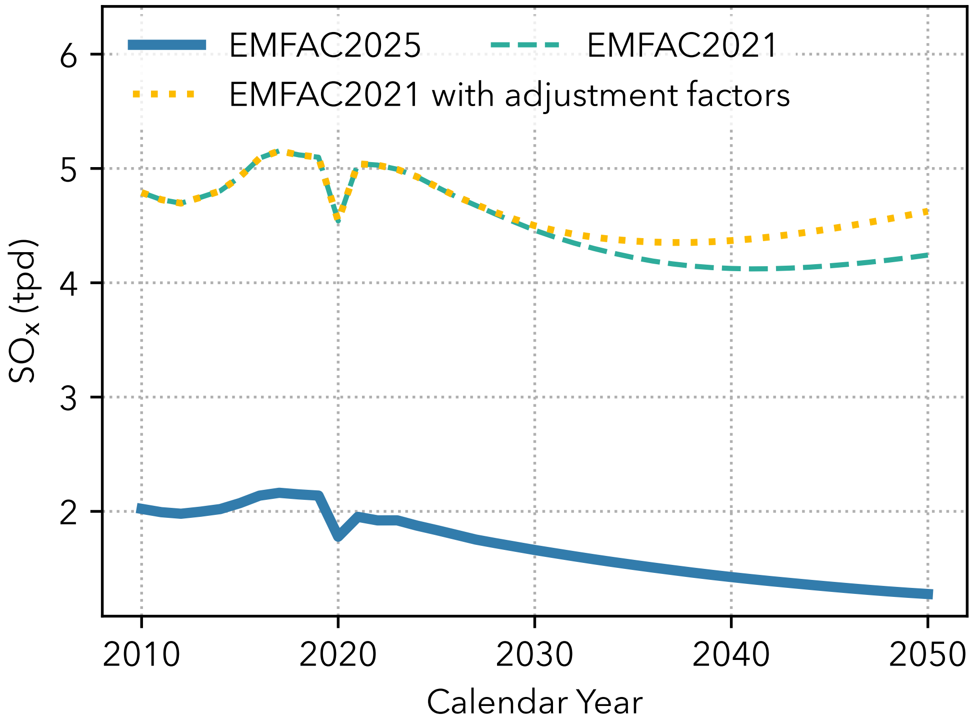
(a) All Vehicles



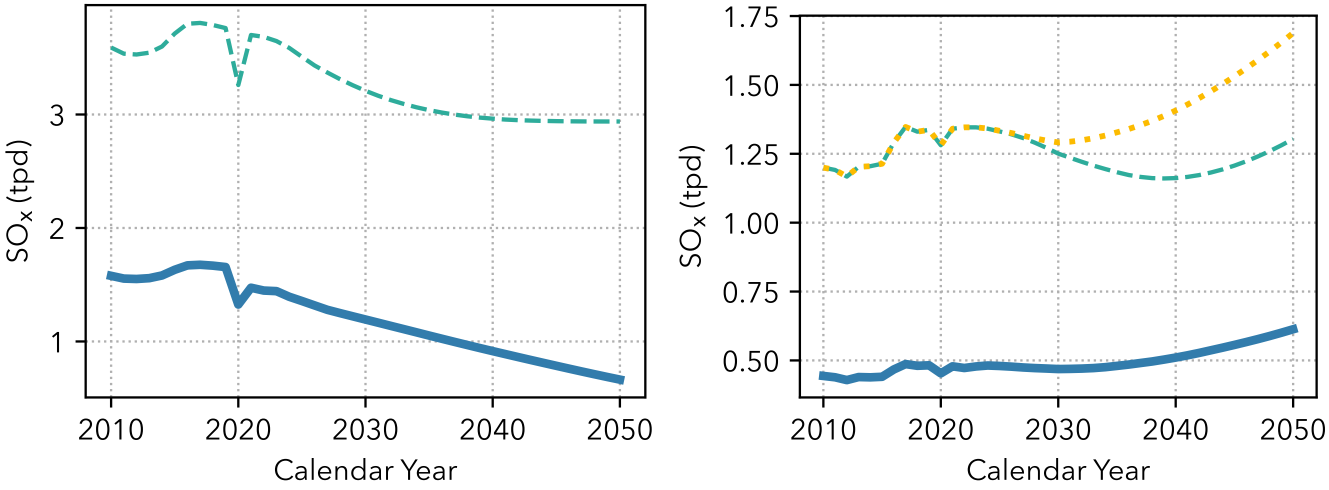
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.11: Statewide $NH_3$ Emissions: EMFAC2025 vs. EMFAC2021



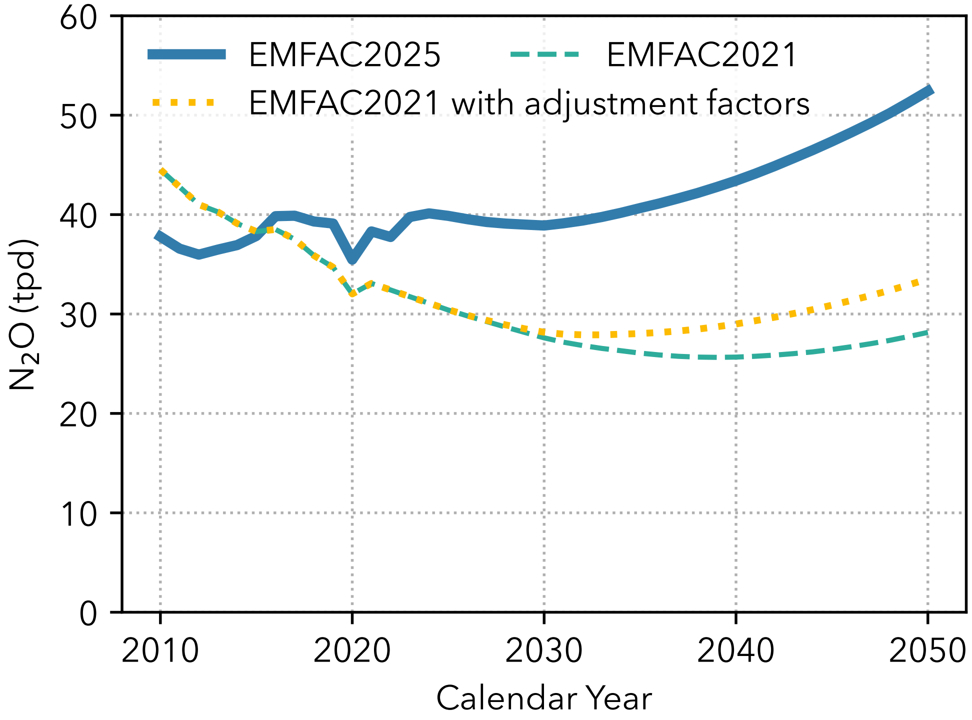
(a) All Vehicles



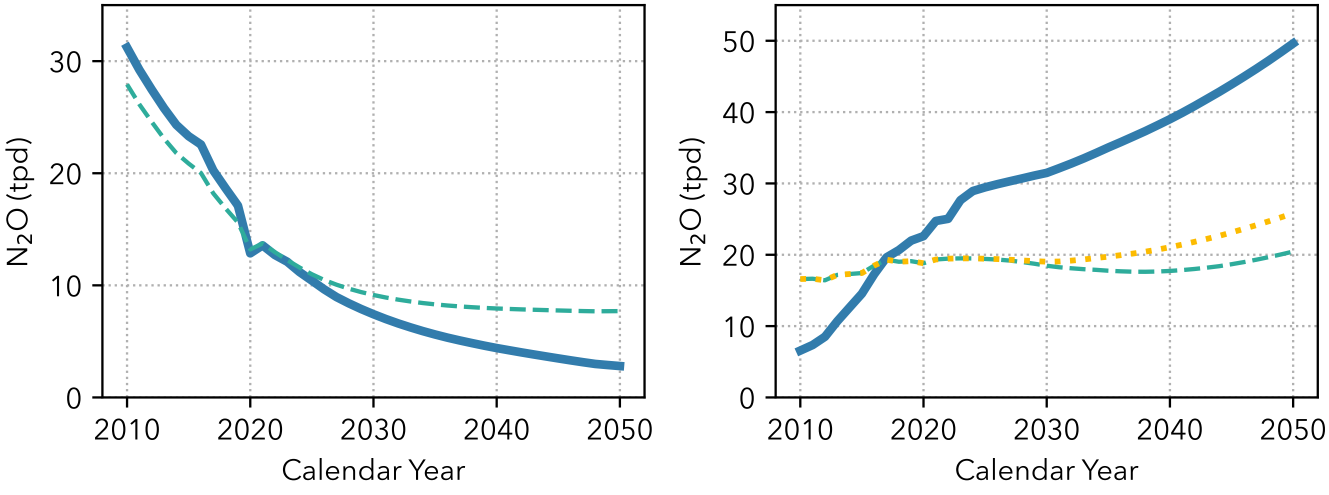
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.12: Statewide $SO_x$ Emissions: EMFAC2025 vs. EMFAC2021



(a) All Vehicles



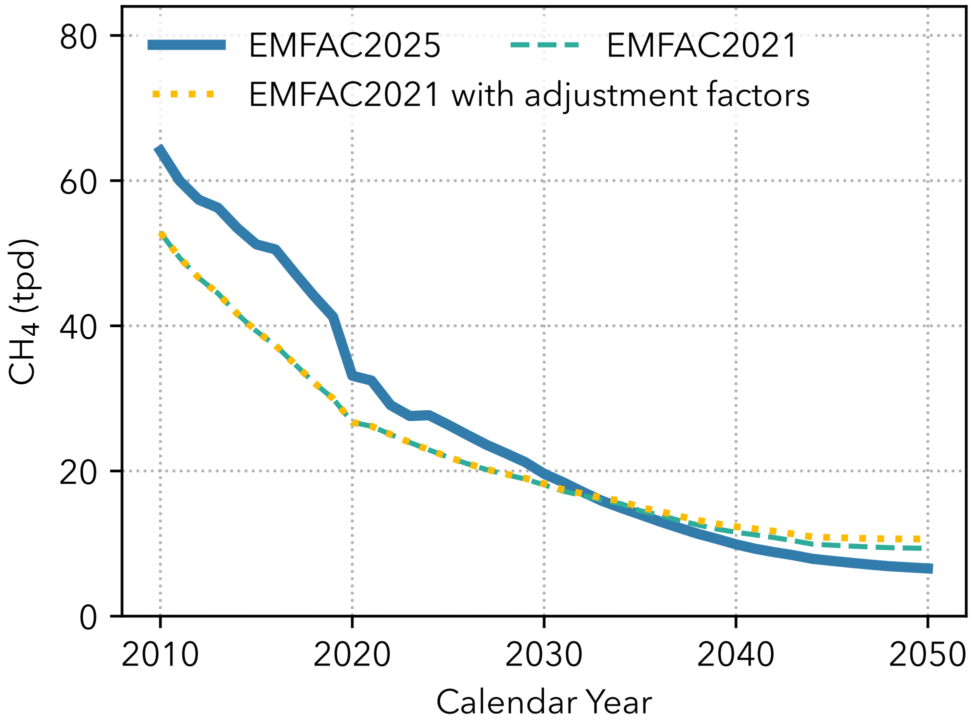
(b) Light-Duty (GVWR ≤ 8,000 lbs.)

(c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

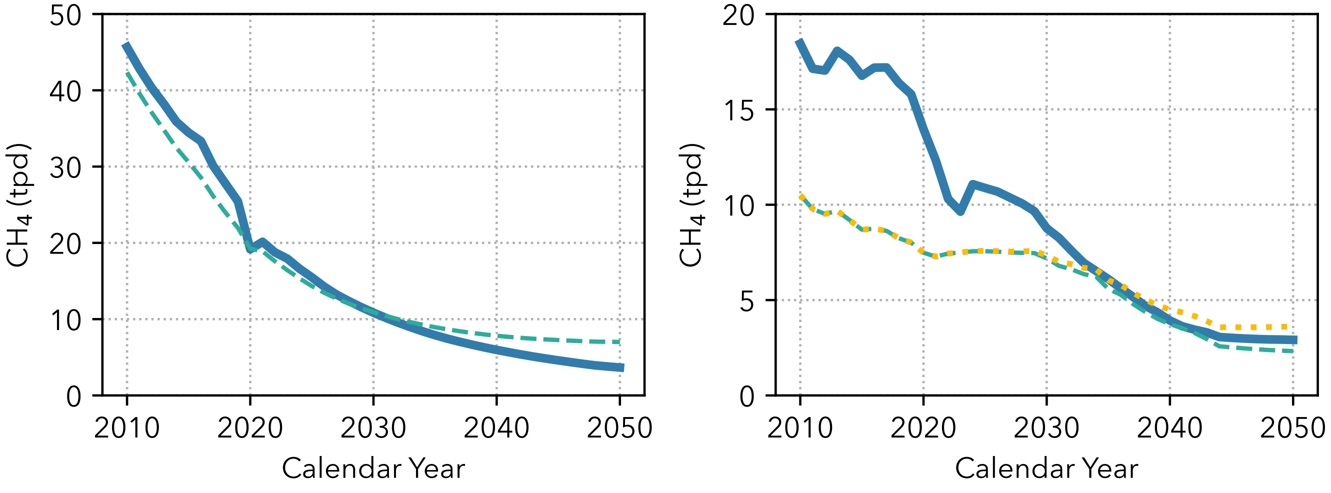
Figure 10.13: Statewide $N_2O$ Emissions: EMFAC2025 vs. EMFAC2021

### 10.3.10 Methane ($CH_4$)

Figure 10.14 compares statewide $CH_4$ emissions (tons/day) from 2010 to 2050. $CH_4$ trends are driven primarily by heavy-duty fleet updates. Added $CH_4$ crankcase emissions in heavy-duty NG trucks increase historical EMFAC2025 emissions relative to EMFAC2021. However, this update applies only to pre-2019 chassis trucks certified to 0.2 g/bhp $NO_x$ standard, so $CH_4$ emissions in the heavy-duty fleet decline sharply after 2019.



(a) All Vehicles



(b) Light-Duty (GVWR ≤ 8,000 lbs.) (c) Medium- and Heavy-Duty (GVWR > 8,000 lbs.)

Figure 10.14: Statewide $CH_4$ Emissions: EMFAC2025 vs. EMFAC2021

# Appendices

## A Acronyms and Terms

**ACC II**
Advanced Clean Cars II: A regulation adopted by CARB in 2022 to reduce emissions from new light-duty vehicles.

**ACF**
Advanced Clean Fleets: A regulation by CARB to propel the use of zero-emission medium- and heavy-duty trucks through establishing fleet purchase requirements. See Section 9.2.

**BEV**
Battery-Electric Vehicle: A vehicle that is powered entirely by an electric battery and produces no tailpipe emissions.

**CARB**
California Air Resources Board

**CDTFA**
California Department of Tax and Fee Administration

**COVID-19**
Coronavirus Disease 2019: A global pandemic that affected various sectors, including transportation and emissions.

**CTC**
Clean Truck Check: A comprehensive heavy-duty vehicle inspection and maintenance (HD I/M) regulation to ensure that vehicles' emissions control systems are properly functioning when traveling on California's roadways. See Section 9.1.

**cVMT**
Combustion Vehicle Miles Traveled: Miles driven by a conventional internal combustion engine vehicle or by using the internal combustion engine in a plug-in hybrid electric vehicle.

**DOF**
California Department of Finance

**DMV**
California Department of Motor Vehicles

**eVMT**
Electric Vehicle Miles Traveled: Miles driven using the battery in a zero-emissions vehicle or plug-in hybrid electric vehicle.

**FCEV**

Fuel Cell Electric Vehicle: A vehicle that uses a fuel cell to convert hydrogen into electricity, powering an electric motor and producing only water vapor as a byproduct.

**GVWR**

Gross Vehicle Weight Rating: Represents the maximum total safe weight of a vehicle.

**IFTA**

International Fuel Tax Agreement: An agreement among U.S. states and Canadian provinces to simplify the reporting of fuel use by motor carriers that operate in more than one jurisdiction.

**IRP**

International Registration Plan: A cooperative agreement among the contiguous United States, the District of Columbia, and Canadian provinces designed to facilitate the registration of commercial vehicles that operate across multiple jurisdictions.

**MPO**

Metropolitan Planning Organization

**MOVES**

MOtor Vehicle Emission Simulator: A model developed by the U.S. Environmental Protection Agency (EPA) to estimate emissions from mobile sources.

**NEI**

National Emissions Inventory: A comprehensive inventory of air emissions from all sources in the United States, maintained by the U.S. Environmental Protection Agency (EPA).

**NTD**

National Transit Database: A database maintained by the Federal Transit Administration that collects and reports data on public transportation systems in the U.S.

**OAL**

California Office of Administrative Law: The California state agency responsible for reviewing and approving regulations proposed by state agencies, including CARB.

**PEMS**

Portable Emissions Measurement System: An instrument typically mounted on vehicles to directly measure the emissions produced by vehicles during actual on-road operation, rather than in a laboratory setting.

**Phase 3**

Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles – Phase 3: U.S. EPA's regulation that sets stronger standards to reduce greenhouse gas emissions from heavy-duty (HD) vehicles beginning in model year (MY) 2027.

**PHEV**

Plug-in Hybrid Electric Vehicle: A vehicle that can be powered by both an internal combustion engine and an electric battery, which can be recharged by plugging into an external power source.

**RVP**

Reid Vapor Pressure: A measure of the volatility of gasoline, indicating how easily it evaporates at a given temperature.

**SCR**

Selective Catalytic Reduction: A technology used in diesel engines to reduce nitrogen oxides ($NO_x$) emissions by injecting a urea-based solution into the exhaust stream.

**SCF**

Speed Correction Factor: A factor used to adjust emission rates based on vehicle speed.

**SIP**

State Implementation Plan: A plan developed by states to demonstrate how they will achieve and maintain national air quality standards.

**SWCV**

Solid Waste Collection Vehicle: A vehicle specifically designed for collecting and transporting solid waste.

**UC**

Unified Cycle: A standardized test cycle that simulates real-world vehicle operation in a laboratory by following a specific sequence of driving conditions such as varying speeds, accelerations, and idling.

**U.S. EPA**

United States Environmental Protection Agency: The federal agency responsible for regulating air quality and enforcing environmental laws.

**VSP**

Vehicle Surveillance Program: A CARB program that collects in-use emissions data from light-duty vehicles to assess real-world emissions performance and update emissions inventories.

**ZEV**

Zero-Emissions Vehicle: Vehicles that produce no tailpipe emissions, including battery-electric vehicles (BEV) and fuel cell electric vehicles (FCEV).

# B EMFAC Vehicle Categories

Table A-1 lists the EMFAC202Y vehicle categories introduced in EMFAC2025. Table A-2 shows the relationship between EMFAC202Y vehicle categories and the corresponding vehicle categories from previous versions of EMFAC, including EMFAC202X, EMFAC2011, and EMFAC2007.

Table A-1: Definitions of EMFAC202Y Vehicle Categories

| EMFAC202Y | Description |
|---|---|
| LDA | Light-Duty Auto (Passenger Cars) |
| LDT1 | Light-Duty Trucks (GVWR <6,000 lbs. and ETW ≤3,750 lbs.) |
| LDT2 | Light-Duty Trucks (GVWR <6,000 lbs. and ETW 3,751–5,750 lbs.) |
| MDV | Medium-Duty Trucks (GVWR 6,001–8,500 lbs.) |
| MH | Motor Homes |
| MCY | Motorcycles |
| LHD1 Public | Light Heavy-Duty Public Trucks (8,501–10,000 lbs.) |
| LHD1 Other | Light Heavy-Duty Other Trucks (8,501–10,000 lbs.) |
| LHD2 Public | Light Heavy-Duty Public Trucks (10,001–14,000 lbs.) |
| LHD2 Other | Light Heavy-Duty Other Trucks (10,001–14,000 lbs.) |
| T6 Public Class 4 | Medium Heavy-Duty Public Fleet Truck (14,001–16,000 lbs.) |
| T6 Public Class 5 | Medium Heavy-Duty Public Fleet Truck (16,001–19,500 lbs.) |
| T6 Public Class 6 | Medium Heavy-Duty Public Fleet Truck (19,501–26,000 lbs.) |
| T6 Public Class 7 | Medium Heavy-Duty Public Fleet Truck (26,001–33,000 lbs.) |
| T6 Utility Class 5 | Medium Heavy-Duty Utility Fleet Truck (16,001–19,500 lbs.) |
| T6 Utility Class 6 | Medium Heavy-Duty Utility Fleet Truck (19,501–26,000 lbs.) |
| T6 Utility Class 7 | Medium Heavy-Duty Utility Fleet Truck (26,001–33,000 lbs.) |
| T6 Instate Tractor Class 6 | Medium Heavy-Duty Tractor Truck (19,501–26,000 lbs.) |
| T6 Instate Delivery Class 4 | Medium Heavy-Duty Delivery Truck (14,001–16,000 lbs.) |
| T6 Instate Delivery Class 5 | Medium Heavy-Duty Delivery Truck (16,001–19,500 lbs.) |
| T6 Instate Delivery Class 6 | Medium Heavy-Duty Delivery Truck (19,501–26,000 lbs.) |
| T6 Instate Other Class 4 | Medium Heavy-Duty Other Truck (14,001–16,000 lbs.) |
| T6 Instate Other Class 5 | Medium Heavy-Duty Other Truck (16,001–19,500 lbs.) |
| T6 Instate Other Class 6 | Medium Heavy-Duty Other Truck (19,501–26,000 lbs.) |
| T6 Instate Tractor Class 7 | Medium Heavy-Duty Tractor Truck (26,001–33,000 lbs.) |
| T6 Instate Delivery Class 7 | Medium Heavy-Duty Delivery Truck (26,001–33,000 lbs.) |
| T6 Instate Other Class 7 | Medium Heavy-Duty Other Truck (26,001–33,000 lbs.) |
| T6 CAIRP Class 4 | Medium Heavy-Duty CA International Registration Plan Truck (14,001–16,000 lbs.) |
| T6 CAIRP Class 5 | Medium Heavy-Duty CA International Registration Plan Truck (16,001–19,500 lbs.) |
| T6 CAIRP Class 6 | Medium Heavy-Duty CA International Registration Plan Truck (19,501–26,000 lbs.) |
| T6 CAIRP Class 7 | Medium Heavy-Duty CA International Registration Plan Truck (26,001–33,000 lbs.) |
| T6 OOS Class 4 | Medium Heavy-Duty Diesel Out-Of-State Truck (14,001–16,000 lbs.) |
| T6 OOS Class 5 | Medium Heavy-Duty Diesel Out-Of-State Truck (16,001–19,500 lbs.) |
| T6 OOS Class 6 | Medium Heavy-Duty Diesel Out-Of-State Truck (19,501–26,000 lbs.) |
| T6 OOS Class 7 | Medium Heavy-Duty Diesel Out-Of-State Truck (26,001–33,000 lbs.) |
| T6TS | Medium Heavy-Duty Gasoline Truck |
| T7 Public Class 8 | Heavy Heavy-Duty Diesel Public Fleet Truck |
| PTO | Power Take Off |
| T7 CAIRP Class 8 | Heavy Heavy-Duty CA International Registration Plan Truck |
| T7 Utility Class 8 | Heavy Heavy-Duty Utility Fleet Truck |
| T7 NNOOS Class 8 | Heavy Heavy-Duty Non-Neighboring Out-Of-State Truck |

continues on next page

Table A-1 – continued from previous page

| EMFAC202Y | Description |
|---|---|
| T7 NOOS Class 8 | Heavy Heavy-Duty Neighboring Out-Of-State Truck |
| T7 Other Port Class 8 | Heavy Heavy-Duty Drayage Truck at Other Facilities |
| T7 POAK Class 8 | Heavy Heavy-Duty Drayage Truck in Bay Area |
| T7 POLA Class 8 | Heavy Heavy-Duty Drayage Truck near South Coast |
| T7 Single Concrete/Transit Mix Class 8 | Heavy Heavy-Duty Single Unit Concrete/Transit Mix Truck |
| T7 Single Dump Class 8 | Heavy Heavy-Duty Single Unit Dump Truck |
| T7 Single Other Class 8 | Heavy Heavy-Duty Single Unit Other Truck |
| T7 Tractor Class 8 | Heavy Heavy-Duty Diesel Tractor Truck |
| T7 SWCV Class 8 | Heavy Heavy-Duty Solid Waste Collection Vehicle |
| T7IS | Heavy Heavy-Duty Gasoline Truck |
| SBUS | School Buses |
| UBUS | Urban Buses |
| Motor Coach | Motor Coach |
| OBUS | Other Buses |

Table A-2: Mapping of Vehicle Categories Between EMFAC202Y, EMFAC202X, EMFAC2011, and EMFAC2007

| EMFAC202Y | EMFAC202X | EMFAC2011 | EMFAC2007 |
|---|---|---|---|
| LDA | LDA | LDA | LDA |
| LDT1 | LDT1 | LDT1 | LDT1 |
| LDT2 | LDT2 | LDT2 | LDT2 |
| MDV | MDV | MDV | MDV |
| MH | MH | MH | MH |
| MCY | MCY | MCY | MCY |
| LHD1 Public | LHD1 | LHD1 | LHDT1 |
| LHD1 Other | LHD1 | LHD1 | LHDT1 |
| LHD2 Public | LHD2 | LHD2 | LHDT2 |
| LHD2 Other | LHD2 | LHD2 | LHDT2 |
| T6 Public Class 4 | T6 Public Class 4 | T6 Public | MHDT |
| T6 Public Class 5 | T6 Public Class 5 | | |
| T6 Public Class 6 | T6 Public Class 6 | | |
| T6 Public Class 7 | T6 Public Class 7 | | |
| T6 Utility Class 5 | T6 Utility Class 5 | T6 Utility | |
| T6 Utility Class 6 | T6 Utility Class 6 | | |
| T6 Utility Class 7 | T6 Utility Class 7 | | |
| T6 Instate Tractor Class 6 | T6 Instate Tractor Class 6 | T6 instate small | |
| T6 Instate Delivery Class 4 | T6 Instate Delivery Class 4 | | |
| T6 Instate Delivery Class 5 | T6 Instate Delivery Class 5 | | |
| T6 Instate Delivery Class 6 | T6 Instate Delivery Class 6 | | |
| T6 Instate Other Class 4 | T6 Instate Other Class 4 | | |
| T6 Instate Other Class 5 | T6 Instate Other Class 5 | | |
| T6 Instate Other Class 6 | T6 Instate Other Class 6 | | |
| T6 Instate Tractor Class 7 | T6 Instate Tractor Class 7 | T6 instate heavy | |
| T6 Instate Delivery Class 7 | T6 Instate Delivery Class 7 | | |
| T6 Instate Other Class 7 | T6 Instate Other Class 7 | | |
| T6 CAIRP Class 4 | T6 CAIRP Class 4 | T6 CAIRP small | |
| T6 CAIRP Class 5 | T6 CAIRP Class 5 | | |
| T6 CAIRP Class 6 | T6 CAIRP Class 6 | | |
| T6 CAIRP Class 7 | T6 CAIRP heavy | T6 CAIRP Class 7 | |
| T6 OOS Class 4 | T6 OOS small | T6 OOS Class 4 | |
| T6 OOS Class 5 | T6 OOS Class 5 | | |
| T6 OOS Class 6 | T6 OOS Class 6 | | |
| T6 OOS Class 7 | T6 OOS Class 7 | T6 OOS heavy | |
| T6TS | T6TS | T6TS | |
| T7 Public Class 8 | T7 Public Class 8 | T7 Public | HHDT |
| PTO | PTO | PTO | |

continues on next page

Table A-2 – continued from previous page

| EMFAC202Y | EMFAC202X | EMFAC2011 | EMFAC2007 |
|---|---|---|---|
| T7 CAIRP Class 8 | T7 CAIRP Class 8 | T7 CAIRP | |
| T7 Utility Class 8 | T7 Utility Class 8 | T7 Utility | |
| T7 NNOOS Class 8 | T7 NNOOS Class 8 | T7 NNOOS | |
| T7 NOOS Class 8 | T7 NOOS Class 8 | T7 NOOS | |
| T7 Other Port Class 8 | T7 Other Port Class 8 | T7 Other Port | |
| T7 POAK Class 8 | T7 POAK Class 8 | T7 POAK | |
| T7 POLA Class 8 | T7 POLA Class 8 | T7 POLA | |
| T7 Single Concrete/Transit Mix Class 8 | T7 Single Concrete/Transit Mix Class 8 | T7 Single | |
| T7 Single Dump Class 8 | T7 Single Dump Class 8 | | |
| T7 Single Other Class 8 | T7 Single Other Class 8 | | |
| T7 Tractor Class 8 | T7 Tractor Class 8 | T7 Tractor | |
| T7 SWCV Class 8 | T7 SWCV Class 8 | T7 SWCV | |
| T7IS | T7IS | T7IS | |
| SBUS | SBUS | SBUS | SBUS |
| UBUS | UBUS | UBUS | UBUS |
| Motor Coach | Motor Coach | Motor Coach | OBUS |
| OBUS | OBUS | OBUS | |
| | All Other Buses | All Other Buses | |

# C EMFAC Geographical Areas

EMFAC uses various geographical areas for modeling and reporting purposes. These include Sub-Areas, Counties, Air Basins, Air Districts, and Metropolitan Planning Organizations (MPO). Sub-Areas are defined by the combination of the boundaries of counties, air basins, and air districts. Air Basins are defined as areas with similar meteorological and geographic conditions for the purpose of managing the air resources of the State.

Table A-3 defines these geographical areas and their abbreviations as used in EMFAC. The MPO column in Table A-3 lists the Metropolitan Planning Organizations (MPO) associated with each geographical area in California:

- AMBAG: Association of Monterey Bay Area Governments
- BCAG: Butte County Association of Governments
- FCOG: Fresno Council of Governments
- KCAG: Kings County Association of Governments
- KCOG: Kern Council of Governments
- MCAG: Merced County Association of Governments
- MCTC: Madera County Transportation Commission
- MTC: Metropolitan Transportation Commission
- SACOG: Sacramento Area Council of Governments
- SANDAG: San Diego Association of Governments
- SBCAG: Santa Barbara County Association of Governments
- SCAG: Southern California Association of Governments
- SRTA: Shasta Regional Transportation Agency
- SJCOG: San Joaquin Council of Governments
- SLOCOG: San Luis Obispo Council of Governments
- StanCOG: Stanislaus Council of Governments
- TCAG: Tulare County Association of Governments
- TMPO: Tahoe Metropolitan Planning Organization (TMPO) and Tahoe Regional Planning Agency (TRPA)

Table A-3: Definition of Geographical Areas used in EMFAC

| Sub-Area | County | Air Basin | Air District | MPO |
|---|---|---|---|---|
| Alameda (SF) | Alameda | San Francisco Bay Area | Bay Area AQMD | MTC |
| Alpine (GBV) | Alpine | Great Basin Valleys | Great Basin Unified APCD | |
| Amador (MC) | Amador | Mountain Counties | Amador County APCD | |
| Butte (SV) | Butte | Sacramento Valley | Butte County AQMD | BCAG |
| Calaveras (MC) | Calaveras | Mountain Counties | Calaveras County APCD | |
| Colusa (SV) | Colusa | Sacramento Valley | Colusa County APCD | |
| Contra Costa (SF) | Contra Costa | San Francisco Bay Area | Bay Area AQMD | MTC |
| Del Norte (NC) | Del Norte | North Coast | North Coast Unified AQMD | |
| El Dorado (LT) | El Dorado | Lake Tahoe | El Dorado County AQMD | TMPO |
| El Dorado (MC) | El Dorado | Mountain Counties | El Dorado County AQMD | SACOG |
| Fresno (SJV) | Fresno | San Joaquin Valley | San Joaquin Valley APCD | FCOG |
| Glenn (SV) | Glenn | Sacramento Valley | Glenn County APCD | |
| Humboldt (NC) | Humboldt | North Coast | North Coast Unified AQMD | |
| Imperial (SS) | Imperial | Salton Sea | Imperial County APCD | SCAG |
| Inyo (GBV) | Inyo | Great Basin Valleys | Great Basin Unified APCD | |
| Kern (MD) | Kern | Mojave Desert | Eastern Kern APCD | KCOG |
| Kern (SJV) | Kern | San Joaquin Valley | San Joaquin Valley APCD | KCOG |
| Kings (SJV) | Kings | San Joaquin Valley | San Joaquin Valley APCD | KCAG |
| Lake (LC) | Lake | Lake County | Lake County AQMD | |
| Lassen (NEP) | Lassen | Northeast Plateau | Lassen County APCD | |
| Los Angeles (MD) | Los Angeles | Mojave Desert | Antelope Valley AQMD | SCAG |
| Los Angeles (SC) | Los Angeles | South Coast | South Coast AQMD | SCAG |
| Madera (SJV) | Madera | San Joaquin Valley | San Joaquin Valley APCD | MCTC |
| Marin (SF) | Marin | San Francisco Bay Area | Bay Area AQMD | MTC |
| Mariposa (MC) | Mariposa | Mountain Counties | Mariposa County APCD | |
| Mendocino (NC) | Mendocino | North Coast | Mendocino County AQMD | |
| Merced (SJV) | Merced | San Joaquin Valley | San Joaquin Valley APCD | MCAG |
| Modoc (NEP) | Modoc | Northeast Plateau | Modoc County APCD | |
| Mono (GBV) | Mono | Great Basin Valleys | Great Basin Unified APCD | |
| Monterey (NCC) | Monterey | North Central Coast | Monterey Bay Air Resources District | AMBAG |
| Napa (SF) | Napa | San Francisco Bay Area | Bay Area AQMD | MTC |
| Nevada (MC) | Nevada | Mountain Counties | Northern Sierra AQMD | |
| Orange (SC) | Orange | South Coast | South Coast AQMD | SCAG |
| Placer (LT) | Placer | Lake Tahoe | Placer County APCD | TMPO |
| Placer (MC) | Placer | Mountain Counties | Placer County APCD | SACOG |
| Placer (SV) | Placer | Sacramento Valley | Placer County APCD | SACOG |
| Plumas (MC) | Plumas | Mountain Counties | Northern Sierra AQMD | |
| Riverside (MD/MDAQMD) | Riverside | Mojave Desert | Mojave Desert AQMD | SCAG |
| Riverside (MD/SCAQMD) | Riverside | Mojave Desert | South Coast AQMD | SCAG |
| Riverside (SC) | Riverside | South Coast | South Coast AQMD | SCAG |
| Riverside (SS) | Riverside | Salton Sea | South Coast AQMD | SCAG |

continues on next page

Table A-3 – continued from previous page

| Sub-Area | County | Air Basin | Air District | MPO |
|---|---|---|---|---|
| Sacramento (SV) | Sacramento | Sacramento Valley | Sacramento Metropolitan AQMD | SACOG |
| San Benito (NCC) | San Benito | North Central Coast | Monterey Bay Air Resources District | AMBAG |
| San Bernardino (MD) | San Bernardino | Mojave Desert | Mojave Desert AQMD | SCAG |
| San Bernardino (SC) | San Bernardino | South Coast | South Coast AQMD | SCAG |
| San Diego (SD) | San Diego | San Diego | San Diego County APCD | SANDAG |
| San Francisco (SF) | San Francisco | San Francisco Bay Area | Bay Area AQMD | MTC |
| San Joaquin (SJV) | San Joaquin | San Joaquin Valley | San Joaquin Valley APCD | SJCOG |
| San Luis Obispo (SCC) | San Luis Obispo | South Central Coast | San Luis Obispo County APCD | SLOCOG |
| San Mateo (SF) | San Mateo | San Francisco Bay Area | Bay Area AQMD | MTC |
| Santa Barbara (SCC) | Santa Barbara | South Central Coast | Santa Barbara County APCD | SBCAG |
| Santa Clara (SF) | Santa Clara | San Francisco Bay Area | Bay Area AQMD | MTC |
| Santa Cruz (NCC) | Santa Cruz | North Central Coast | Monterey Bay Air Resources District | AMBAG |
| Shasta (SV) | Shasta | Sacramento Valley | Shasta County AQMD | SRTA |
| Sierra (MC) | Sierra | Mountain Counties | Northern Sierra AQMD | |
| Siskiyou (NEP) | Siskiyou | Northeast Plateau | Siskiyou County APCD | |
| Solano (SF) | Solano | San Francisco Bay Area | Bay Area AQMD | MTC |
| Solano (SV) | Solano | Sacramento Valley | Yolo-Solano AQMD | MTC |
| Sonoma (NC) | Sonoma | North Coast | Northern Sonoma County APCD | MTC |
| Sonoma (SF) | Sonoma | San Francisco Bay Area | Bay Area AQMD | MTC |
| Stanislaus (SJV) | Stanislaus | San Joaquin Valley | San Joaquin Valley APCD | StanCOG |
| Sutter (SV) | Sutter | Sacramento Valley | Feather River AQMD | SACOG |
| Tehama (SV) | Tehama | Sacramento Valley | Tehama County APCD | |
| Trinity (NC) | Trinity | North Coast | North Coast Unified AQMD | |
| Tulare (SJV) | Tulare | San Joaquin Valley | San Joaquin Valley APCD | TCAG |
| Tuolumne (MC) | Tuolumne | Mountain Counties | Tuolumne County APCD | |
| Ventura (SCC) | Ventura | South Central Coast | Ventura County APCD | SCAG |
| Yolo (SV) | Yolo | Sacramento Valley | Yolo-Solano AQMD | SACOG |
| Yuba (SV) | Yuba | Sacramento Valley | Feather River AQMD | SACOG |

# D EMFAC2025 Version Updates

This appendix summarizes changes made to EMFAC2025 since version 2.0.0 (May 2025). Each update includes a brief description and its expected impact on model outputs.

## D.1 EMFAC2025 v2.1.0, March 2026

- The Advanced Clean Cars II, Advanced Clean Trucks (ACT), Zero-Emission Airport Shuttle, Heavy-Duty Vehicle and Engine Emission Warranty and Maintenance Provisions (Warranty Phase 1), and Heavy-Duty Omnibus (Omnibus) regulations were removed in response to unlawful resolutions, which purported to disapprove U.S. EPA's prior actions to grant California waivers for these rules. As a result, emissions are higher for affected vehicle categories due to the absence of stricter emission standards and the continued operation of higher-emitting vehicles.
- Several minor bugs were corrected to improve calculation accuracy and model stability.

## D.2 EMFAC2025 v2.1.1, May 2026

- Zero-Emission Vehicle (ZEV) population estimates for light-duty vehicles (2023 to 2050) were updated to align with California Energy Commission (CEC) Integrated Energy Policy Report (IEPR) 2025 forecasts. The previous version underestimated ZEV counts and did not match the CEC projections described in Section 4.5. The update increases ZEV populations for LDA, LDT1, LDT2, and MDV, resulting in lower emissions for these categories due to a higher share of zero-emission vehicles in the fleet.
- Renewable gasoline was introduced as a fuel component for gasoline and plug-in hybrid vehicles, based on the Low Carbon Fuel Standard (LCFS) 2025 Q3 Quarterly Report. This change produces a negligible reduction (less than 0.01%) in greenhouse gas (GHG) emissions for all gasoline vehicles.

## Bibliography

CARB. EMFAC2025 User's Guide. Mobile Source Analysis Branch. Air Quality Planning & Science Division. California Air Resources Board, August 2025. URL: https://ww2.emfac.arb.ca.gov2025-model-and-documentation.

U.S. EPA and U.S. DOT. Guidance for the Use of Latest Planning Assumptions in Transportation Conformity Determinations Revision to January 18, 2001 Guidance Memorandum. EPA420-B-08-901. Transportation and Regional Programs Division. Office of Transportation and Air Quality. U.S. Environmental Protection Agency. Office of Natural and Human Environment. Federal Highway Administration. U.S. Department of Transportation. Office of Planning and Environment. Federal Transit Administration. U.S. Department of Transportation., December 2008. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/P1002RFG.PDF?Dockey=P1002RFG.pdf.

U.S. EPA. Motor Vehicle Emission Simulator: MOVES5. U.S. Environmental Protection Agency. Office of Transportation and Air Quality, November 2024. URL: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves.

Gil Tal, Seshadri Srinivasa Raghavan, Vaishnavi Chaitanya Karanam, Matthew P Favetti, Katrina May Sutton, JH Lee, C Nitta, D Chakraborty, M Nicholas, and T Turrentine. Advanced plug-in electric vehicle travel and charging behavior final report. 2020. URL: https://web.cs.ucdavis.edu/~cjnitta/pubs/2020_03.pdf.

ERG. Heavy-Duty Vehicle Accrual Rates. June 2019. URL: https://ww2.arb.ca.gov/sites/default/files/2021-02/erg_finalreport_hdv_accruals_20190614_plus_addendum.pdf.

FTA. The 2023 National Transit Database (NTD) Annual Data Products. Federal Transit Administration. U.S. Department of Transportation, December 2024. URL: https://www.transit.dot.gov/ntd.

CARB. The Innovative Clean Transit 2023 Report and Data. California Air Resources Board, November 2024. URL: https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/reporting-tool-data.

CARB. EMFAC2021 Volume III Technical Documentation Version 1.0.1. Mobile Source Analysis Branch. Air Quality Planning & Science Division. California Air Resources Board, April 2021. URL: https://ww2.arb.ca.gov/sites/default/files/2021-08/emfac2021_technical_documentation_april2021.pdf.

CARB. EMFAC Modeling Change Technical Memo: Redistribution of Heavy Heavy-Duty Diesel Truck Vehicle Miles Traveled in California. California Air Resources Board, September 2006. URL: https://ww2.arb.ca.gov/sites/default/files/2023-10/on-2006-05.pdf.

CARB. Staff Report: Initial Statement of Reasons for the Proposed Amendments to the Truck and Bus Regulation, the Drayage Truck Regulation and the Tractor-Trailer Greenhouse Gas Regulation. Appendix G: Emissions Analysis Methodology and Results. California

Air Resources Board, October 2010. URL: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2010/truckbus10/truckbusappg.pdf.

ORNL. Developing a Best Estimate of Annual Vehicle Mileage for 2009 NHTS Vehicles. Oak Ridge National Laboratory. Prepared for Federal Highway Administration National Household Travel Survey, June 2011. URL: https://nhts.ornl.gov/2009/pub/BESTMILE.pdf.

CARB. EMFAC2014 Volume III – Technical Documentation v1.0.7. Mobile Source Analysis Branch. Air Quality Planning & Science Division. California Air Resources Board, May 2015. URL: https://ww2.arb.ca.gov/sites/default/files/2023-01/emfac2014-vol3-technical-documentation-052015.pdf.

NuStats. 2010-2012 California Household Travel Survey Final Report Version 1.0. NuStats, LLC. Prepared for California Department of Transportation, June 2013. URL: http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_travel_analysis/Files/CHTS_Final_Report_June_2013.pdf.

DOF. Report P-1A: Total Population Projections, California, 2020-2060 (Baseline 2019 Population Projections; Vintage 2023 Release). Demographic Research Unit. California Department of Finance, July 2023. URL: https://dof.ca.gov/forecasting/demographics/projections/.

CEC. Transportation Fuel Price Forecasts. Revision of 27 November 2023. Transportation Energy Forecasting Unit. Demand Analysis Office. Energy Assessments Division. California Energy Commission, 2023.

CBO. The 2023 Long-Term Budget Outlook. Congressional Budget Office. Publication Number 59014, June 2023. URL: https://www.cbo.gov/publication/59014.

UCLA. Anderson Economic Forecast. California Air Resources Board Contract 21AQP003. University of California, Los Angeles, September 2023. URL: https://www.anderson.ucla.edu/about/centers/ucla-anderson-forecast.

Mark Jacobsen. Forecasting Light-Duty Vehicle New Sales and Retention Rates. Prepared for California Air Resources Board. CARB Agreement Number 21AQP018, January 2023. URL: https://ww2.arb.ca.gov/sites/default/files/2023-08/Final_Report_21AQP018_LDV_New_Sales_Retention_Rates_Forecasting.pdf.

CEC. 2025 Integrated Energy Policy Report. California Energy Commission, 2025. URL: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report-iepr/2025-integrated-energy-policy-report.

Ling Jin. Spatially Disaggregated Forecasting of ZEV Adoption in California (Contract NO. 22AQP010). Report In Preparation. California Air Resources Board, January 2023.

Ben Clark, Kiron Chatterjee, and Steve Melia. Changes in level of household car ownership: the role of life events and spatial context. *Transportation*, 43(4):565–599, 2016. URL: https://link.springer.com/article/10.1007/s11116-015-9589-y, doi:10.1007/s11116-015-9589-y.

Ling Jin, Connor Jackson, Yuhan Wang, Qianmiao Chen, Tin Ho, C. Spurlock, Aaron Brooker, Jacob Holden, Jeffrey Gonder, Mohamed Bouzaghrane, Bingrong Sun, Shivam Sharda, Venu Garikapati, Tom Wenzel, and Juan Caicedo. Technology progress and clean vehicle policies on fleet turnover and equity: insights from household vehicle fleet micro-simulations with ATLAS. Transportation Planning and Technology, May 2024. URL: https://www.tandfonline.com/doi/full/10.1080/03081060.2024.2353784.

FHWA. 2017 National Household Travel Survey. U.S. Department of Transportation. Federal Highway Administration, 2018. URL: https://www.nrel.gov/transportation/secure-transportation-data/tsdc-nhts-california.

CEC. 2019 California Vehicle Survey. California Energy Commission, 2019. URL: https://www.energy.ca.gov/data-reports/surveys/california-vehicle-survey.

FEC. Federal Elections 2016: Election Results for U.S. President, U.S. Senate, and U.S. House of Representatives. Federal Election Commission, 2016. URL: https://www.fec.gov/resources/cms-content/documents/federalelections2016.pdf.

FEC. Federal Elections 2020: Election Results for U.S. President, U.S. Senate, and U.S. House of Representatives. Federal Election Commission, 2020. URL: https://www.fec.gov/resources/cms-content/documents/federalelections2020.pdf.

CARB. EMFAC Fleet Database. California Air Resources Board, 2025. URL: https://emfac.arb.ca.gov/fleet-db/.

U.S. Census Bureau. American Community Survey (ACS) 5-Year Estimates, 2019–2023. 2024. URL: https://www.census.gov/programs-surveys/acs.html.

Andrew Owen and Brendan Murphy. Access Across America: Transit 2017 Data. Accessibility Observatory, University of Minnesota, 2018. URL: https://www.cts.umn.edu/publications/report/access-across-america-transit-2017.

CNT. Center for Neighborhood Technology, AllTransit, 2019. URL: https://alltransit.cnt.org.

Hanwei Zhu, Chengguo Li, Cavan McCaffery, Sam Cao, Kent C. Johnson, Georgios Karavalakis, and Thomas Durbin. Emissions from heavy-duty diesel, natural gas, and diesel-hybrid electric vehicles - Part 1. NOx, N2O and NH3 emissions. *Fuel*, 371:132175, 2024. URL: https://www.sciencedirect.com/science/article/pii/S0016236124013231, doi:10.1016/j.fuel.2024.132175.

Cavan McCaffery, Hanwei Zhu, Tianbo Tang, Chengguo Li, Georgios Karavalakis, Sam Cao, Adewale Oshinuga, Andrew Burnette, Kent C. Johnson, and Thomas D. Durbin. Real-world NOx emissions from heavy-duty diesel, natural gas, and diesel hybrid electric vehicles of different vocations on California roadways. *Science of The Total Environment*, 784:147224, 2021. URL: https://www.sciencedirect.com/science/article/pii/S0048969721022956, doi:10.1016/j.scitotenv.2021.147224.

CARB. Heavy Duty In-use Compliance Programs. California Air Resources Board, January 2024. URL: https://ww2.arb.ca.gov/our-work/programs/heavy-duty-in-use-compliance-programs/about.

Jonathan Leonard, Patrick Couch, Thomas D. Durbin, Kent Johnson, Arvind Thiruvengadam, Marc Besch, and Sam Cao. In-Use Emissions Testing and Activity Profiles for On-Road

Heavy-Duty Vehicles: Summary of 200 Heavy-Duty Vehicle Emissions Testing Program from the University of California, Riverside and West Virginia University. Prepared for California Energy Commission. Publication Number CEC-500-2023-002, March 2023. URL: https://www.energy.ca.gov/sites/default/files/2023-03/CEC-500-2023-002.pdf.

David C. Quiros, Jeremy Smith, Arvind Thiruvengadam, Tao Huai, and Shaohua Hu. Greenhouse gas emissions from heavy-duty natural gas, hybrid, and conventional diesel on-road trucks during freight transport. *Atmospheric Environment*, 168:36–45, 2017. URL: https://www.sciencedirect.com/science/article/pii/S1352231017305794, doi:10.1016/j.atmosenv.2017.08.066.

CARB. EMFAC2017 Volume III – Technical Documentation V1.0.2. Mobile Source Analysis Branch. Air Quality Planning & Science Division. California Air Resources Board, July 2018. URL: https://ww2.arb.ca.gov/sites/default/files/2023-01/emfac2017-volume-iii-technical-documentation.pdf.

Hanwei Zhu, Cavan McCaffery, Jiacheng Yang, Chengguo Li, Georgios Karavalakis, Kent C. Johnson, and Thomas D. Durbin. Characterizing emission rates of regulated and unregulated pollutants from two ultra-low NOx CNG heavy-duty vehicles. *Fuel*, 277:118192, 2020. URL: https://www.sciencedirect.com/science/article/pii/S0016236120311881, doi:10.1016/j.fuel.2020.118192.

Nigel N. Clark, David L. McKain, Derek R. Johnson, Scott W. Wayne, Hailin Li, Vyacheslav Akkerman, Cesar Sandoval, April N. Covington, Ronald A. Mongold, John T. Hailer, and Orlando J. Ugarte. Pump-to-Wheels Methane Emissions from the Heavy-Duty Transportation Sector. *Environmental Science & Technology*, 51:968–976, 2016. URL: https://pubs.acs.org/doi/full/10.1021/acs.est.5b06059, doi:10.1021/acs.est.5b06059.

CARB. SB 1014 Clean Miles Standard 2018 Base-year Emissions Inventory Report. California Air Resources Board, December 2019. URL: https://ww2.arb.ca.gov/sites/default/files/2019-12/SB%201014%20-%20Base%20year%20Emissions%20Inventory_December_2019.pdf.

David C.S. Beddows and Roy M. Harrison. PM10 and PM2.5 emission factors for non-exhaust particles from road vehicles: Dependence upon vehicle mass and implications for battery electric vehicles. *Atmospheric Environment*, 2021. URL: https://www.sciencedirect.com/science/article/abs/pii/S1352231020306208, doi:10.1016/j.atmosenv.2020.117886.

Ye Liu, Haibo Chen, Jianbing Gao, Ying Li, Kaushali Dave, Junyan Chen, Matteo Federici, and Guido Perricone. Comparative analysis of non-exhaust airborne particles from electric and internal combustion engine vehicles. *Journal of Hazardous Materials*, 2021. URL: https://www.sciencedirect.com/science/article/pii/S0304389421015910, doi:10.1016/j.jhazmat.2021.126626.

Victor R.J.H. Timmers and Peter A.J. Achten. Non-exhaust PM emissions from electric vehicles. *Atmospheric Environment*, 134:10–17, 2016. URL: https://www.sciencedirect.com/science/article/abs/pii/S135223101630187X, doi:10.1016/j.atmosenv.2016.03.017.

Sang-Hee Woo, Hyungjoon Jang, Seung-Bok Lee, and Seokhwan Lee. Comparison of total pm emissions emitted from electric and internal combustion engine vehicles: an experimental analysis. *Science of The Total Environment*, 2022. URL: https://www.sciencedirect.com/science/article/pii/S004896972204058X, doi:10.1016/j.scitotenv.2022.156961.

CARB. Brake and Tire Wear Emissions. California Air Resources Board, 2025. URL: https://ww2.arb.ca.gov/resources/documents/brake-tire-wear-emissions.

CARB. Gasoline Reid Vapor Pressure Requirements. California Air Resources Board, April 2023. URL: https://ww2.arb.ca.gov/resources/documents/gasoline-reid-vapor-pressure-requirements.

CARB. Threshold guidance for the regulation for the mandatory reporting of greenhouse gas emissions. California Air Resources Board, March 2012. URL: https://ww2.arb.ca.gov/sites/default/files/classic/cc/reporting/ghg-rep/guidance/fuel-threshold.pdf.

CARB. Staff Report: Initial Statement of Reasons for the Proposed Advanced Clean Fleets Regulation. California Air Resources Board, August 2022. URL: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/isor2.pdf.

SunLine. SunLine Fuel Cell Buses & Hydrogen Onsite Generation Refueling Station Final Report. SunLine Transit Agency. Prepared in fulfillment of California Air Resources Board Grant G14-LCTI-11, August 2022. URL: https://ww2.arb.ca.gov/sites/default/files/2022-07/SunLine%20AQIP%20Final%20Report%20FINAL_accessible.pdf.

Jacob Goldberg, Teresa Pisano, Laura Hunter, Lauren Dunlap, Brett Grothen, Arron Paddock, Kevin Goss, Joe Sawa, Jared Leventhal, Giles Pettifor, Cory Sigler, Andrew Kotz, Michael Lammert, Matthew Jeffers, and Jason Lustbader. The Port of Los Angeles Zero- and Near-Zero-Emission Freight Facilities "Shore to Store" Project SunLine Fuel Cell Buses & Hydrogen Onsite Generation Refueling Station Final Report. SunLine Transit Agency. Prepared for California Air Resources Board. Grant Number: G17-ZNZE-10, May 2023. URL: https://docs.nrel.gov/docs/fy24osti/89761.pdf.

U.S. EPA. Final Rule: Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles – Phase 3. U.S. Environmental Protection Agency, 2024. URL: https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-greenhouse-gas-emissions-standards-heavy-duty.

U.S. EPA. Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles. U.S. Environmental Protection Agency. Federal Register, April 2024. Document Number: 2024-06214. URL: https://www.federalregister.gov/documents/2024/02/28/2024-06214/multi-pollutant-emissions-standards-for-model-years-2027-and-later-light-duty-and-medium-duty.

CARB. Staff Report: Initial Statement of Reasons for the Proposed Heavy-Duty Inspection and Maintenance Regulation. Appendix D: Emissions Inventory Methods and Results. California Air Resources Board, October 2021. URL: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/hdim2021/appd.pdf.

Governor of California. Executive Order N-79-20. California Secretary of State, September 2020. URL: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf.

CARB. Purpose and Rationale for State and Local Government Fleet Requirements. California Air Resources Board, August 2022. URL: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/apph1.pdf.

U.S. EPA. Final Rule and Related Materials for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards. U.S. Environmental Protection Agency, 2023. URL: https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-and-related-materials-control-air-pollution.

U.S. EPA. Control of Air Pollution From New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards. U.S. Environmental Protection Agency. Federal Register, December 2023. Document Number: 2022-27957. URL: https://www.federalregister.gov/documents/2022/12/30/2022-27957/control-of-air-pollution-from-new-motor-vehicles-heavy-duty-engine-and-vehicle-standards.

CARB. EPA Approval of EMFAC2021 Off-Model Adjustment Factors. California Air Resources Board, December 2025. URL: https://content.govdelivery.com/accounts/CARB/bulletins/3fe4c52.

# Index

## State of California

## Air Resources Board

# EMFAC2025 Technical Documentation

## Version 2.1.1

June 2026

**Document Prepared By**

Mobile Source Analysis Branch
Air Quality Planning and Science Division

**For More Information**

emfac@arb.ca.gov
https://emfac.arb.ca.gov/