EMFAC2021
Volume III
Technical Document

Version 1.0.0

CALIFORNIA
AIR RESOURCES BOARD

March 31, 2021

Mobile Source Analysis Branch
Air Quality Planning and Science Division

Table of Contents

1 Executive Summary

The California Air Resources Board (CARB) officially released EMFAC2021 (v1.0.0) January 15, 2021. Used to inform and support and upcoming planning and policy development, EMFAC2021 is the latest emission inventory model that CARB developed to assess emissions from on-road motor vehicles including cars, trucks, and buses in California. This version of model reflects CARB's latest understanding of statewide and regional vehicle activities, emissions, and recently adopted regulations such as Advanced Clean Trucks (ACT) and Heavy Duty Omnibus.

Staff have also released an interactive web platform that allows EMFAC2021 users to download emissions data with default activity; produce emissions using custom activity inputs, the same as EMFAC's Custom Activity (SG[1]) mode; and generate emission factors using user-defined ambient temperature and relative humidity for project level (PL) conformity assessment.

This Technical Document provides technical details of major changes and updates in EMFAC2021 and provides an overview of differences between EMFAC2021 and the prior version of the model, EMFAC2017. For more information on how to use EMFAC2021, including how to install and navigate through its user interface, please refer to the EMFAC2021 User's Guide.[2] Please note that some of the legacy components, methodologies, data, and logic are carried over into EMFAC2021 from prior versions of the model and are not covered within this document.

1.1 Structure of This Document

The *Introduction* chapter (*Chapter 2*) provides an overview of EMission FACtors model, EMFAC2021, architecture and newly developed web platform. *Chapter 3* provides details of new modules implemented in EMFAC2021 including plug-in hybrid electric vehicles (PHEVs), energy consumption from zero-emission vehicles (ZEVs), and the ammonia modules. *Chapter 4* provides extensive information on updates to vehicle emission rates and activities in the EMFAC2021 model. *Chapter 5* presents overall impacts of EMFAC2021 on total emissions, fuel consumption, energy use, and vehicle activities and includes a comparison of model outputs between EMFAC2021 and EMFAC2017.

---

[1] Scenario Generation mode

[2] https://ww2.arb.ca.gov/sites/default/files/2021-01/EMFAC202x_Users_Guide_01112021_final.pdf

1.2 New Features

In response to stakeholders' comments on the model's design and structure, the EMFAC2021 model offers a variety of new features such as:

- *Expansion of fuel technologies to include Plug-in Hybrid Electric Vehicles (PHEV) and Natural Gas (NG) powered vehicles:* EMFAC2021 separates PHEV from conventional gasoline vehicles as a new fuel type for light-duty vehicles. PHEV-specific emission rates and activity were developed based on results from CARB's real-world emission testing and vehicle activity data collections programs. Detailed information can be found in Section 3.1. In addition, for the first time, EMFAC2021 models emissions from natural gas trucks in the default emission inventory and incorporates natural gas vehicle emission rates based on real-world emissions testing. Similar to EMFAC2017, EMFAC2021 estimates natural gas vehicle activities based on historical vehicle registration database. Detailed information on natural gas population updates can be found in Section 4.3.5.4.
- *Energy Consumption:* EMFAC2021 now includes estimates of energy consumption from light- and heavy-duty zero emission vehicles (ZEV). The significant penetration of these vehicles in the fleet for light-duty and in the future for heavy-duty vehicles has important implications for statewide energy demand. Staff used the consumer-based trip data from ZEV manufacturers to estimate energy consumption rates by speed for light-duty vehicles. For heavy-duty vehicles, staff utilized the second-by-second data from transit fleets and estimated heavy-duty energy consumption rates by speed. Detailed information can be found in Section 3.2.
- *Ammonia Emissions (Section 3.3):* For the first time, ammonia (NH3) emissions are being included in the EMFAC model. A variety of historical and new NH3 emissions studies are used to develop running exhaust emission factors. The emissions are determined by multiplying these emission rates by the vehicle miles traveled (VMT). No adjustments for speed were made in this update. The results indicate substantially higher emissions for Selective Catalytic Reduction (SCR)-equipped diesels and natural gas vehicles. These two categories show significantly higher emission rates than the historical diesel emission factors.
- *Expansion of Heavy-Duty Truck Categories (Section 4.2.2.3):* Heavy-duty truck categories in EMFAC2021 were expanded to allow for more specificity in EMFAC activity and emission rate updates and to better support future transportation policies that CARB is pursuing. The new fleet categories provide higher resolution of weight classes with additional vocation types.
- *An Updated Light-Duty Activity Forecasting Approach (Section 4.5.1):* New vehicle sales and VMT forecasting models in EMFAC2021 were updated using a new dynamic approach where a program creates an arbitrary list of economic indicators, and then evaluates the accuracy and reasonableness of the generated models. Unlike the static approach used in EMFAC2017 where a handful of

models were manually evaluated, the program goes through a large list of various combinations of economic indicators to optimize the performance of the models in predicting the historical data. These models were then evaluated by the staff for further refinement based on reasonableness of assumption. In addition to the present value of the economic indicators, EMFAC2021 considered the impacts of the lagged indicators by one or two years.

- *A New Heavy-Duty VMT Forecasting Framework (Section 4.5.2):* EMFAC2017 projected diesel heavy-duty VMT at a statewide level based on a regression model fitted to historical diesel fuel sales data. EMFAC2021 uses the California Statewide Travel Demand Model (CSTDM) that forecasts VMT by county as the primary source for the future VMT trends to better reflect the regional disparities in freight VMT growth.
- *A Novel Light-Duty ZEV Forecasting Framework (Section 4.5.3):* Unlike EMFAC2017 that projected ZEV market share based on the *most likely compliance scenario* with California's ZEV mandate, EMFAC2021 uses California Energy Commission's (CEC) vehicle choice model coupled with CARB's updated ZEV input attributes for short-term projections (2020-2030). For long-term projections (2031-2050), the ZEV market share is assumed to plateau in California, starting in 2030.

1.3 Overview of Major Changes

1.3.1 Fleet Characterization

Updates to EMFAC2021 vehicle population data using most recent Department of Motor Vehicle (DMV) registration data and other sources are as follows.

- *Multiple years of DMV data*: EMFAC2021 uses DMV populations for years 2000 through 2019. The additional three years of vehicle registration data (2017-2019) compared to EMFAC2017 reflect the most recent changes to California light- and heavy-duty fleet characteristics.
- *Expanded HD Vocational Categories (Section 4.2.2.3):* Heavy-duty truck categories in EMFAC2021 were expanded to allow for more specificity in EMFAC activity and emission rate updates to better support CARB programs. Medium Heavy-Duty Trucks (MHDT) were divided into four different weight classes (Class 4 through 7) to provide higher resolution weight classes. New fleet groups such as delivery or concrete mixers were added to provide the ability to separate trucks with specific vocational types.
- *International Registration Plan (IRP) data:* IRP Clearinghouse data is another primary source to estimate heavy-duty vehicle population. Vehicles already registered in California can be identified as interstate trucks (CA IRP fleet) or buses (motor coach fleet). 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. As part of EMFAC2021 updates, the most recent

IRP data were used. This included updated VMT for T6 OOS, T7 NNOOS and T7 NOOS categories of EMFAC2021 and their populations were back-calculated with the use of mileage accrual schedules.

- *Vehicle Data from CHP and major Ports*: List of Vehicle Identification Numbers (VIN) from California Highway Patrol (CHP) School Bus Inspections are used to identify school buses. Staff were also able to acquire list of VINs from the major Ports which were used to identify drayage trucks operating at the port of Los Angeles/Long Beach (POLA) and the port of Oakland (POAK).
- *National Transit Database (NTD) data*: Similar to EMFAC2017, NTD data was used to characterize the transit fleet. An additional four years of transit bus reporting (2016-2019) are included in this update.

1.3.2 In-Use Emissions

Light Duty Vehicles

EMFAC2021 has substantial updates regarding light-duty vehicle emission rates, including running and start exhaust emission rates for Low Emission Vehicle 1 (LEV1) through LEV3 vehicles, speed dependent PM brake wear emission rates as well as updates to motorcycle emission rates. The PHEVs are also modeled using PHEV-specific running and start exhaust emission rates that reflect the high power cold start emissions identified by CARB staff as part of the 2017 Midterm Review to the Advanced Clean Cars program[3].

In EMFAC2017, both running and start exhaust emission rates were updated for the first time since EMFAC2000 using new Federal Test Procedure (FTP) data obtained from the US EPA In-Use Verification Program (IUVP) coupled with emission test data from the CARB's Vehicle Surveillance Program (VSP). For EMFAC2021, running and start exhaust emission rates derived from the Unified Cycle (UC) test data are further assessed and updated with three years of new data from IUVP and CARB's VSP programs. The method used to determine the base emission rates are similar to EMFAC2017. However, a new "low" emission regime has been added to model deterioration at the lower end of emission levels. New test data were used to update the Ratio of Standards (ROS) and emission rate models for LEV3 vehicles. When combined together, these updates have resulted in higher NOx and ROG exhaust emissions for most of the light duty vehicles.

The PM brake-wear emission rates in previous versions of EMFAC were estimated using limited available data from 2000-2003[4] and was assumed constant across various drive cycles. For EMFAC2021, staff developed new emission factors and speed correction

---

[3] https://ww2.arb.ca.gov/sites/default/files/2020-01/appendix_h_phev_testing_ac.pdf

[4] See chapter 9 of EMFAC2011 Technical Support Document at: https://ww3.arb.ca.gov/msei/emfac2011-technical-documentation-final-updated-0712-v03.pdf

factors for PM brake wear through an extramural contract. The new emission factors incorporate the effect of modern material and composites used in disc brakes along with impacts of real-world driving patterns on them. Compared to EMFAC2017, EMFAC2021's new light-duty PM brake wear emission rates are significantly lower.

EMFAC2021 also includes updated carbon dioxide emission rates for all 2016 through 2020 model year light-duty vehicles. The updates use the latest national fuel efficiency data from *www.fueleconomy.gov*, the official U.S. government source for fuel efficiency information. Further, unlike 2-cycle fuel economies used in EMFAC2017, EMFAC2021 benefits from the more realistic 5-cycle fuel economies. Additionally, staff implemented the Final Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule phase-in schedule on GHG emissions in EMFAC2021. The final SAFE rule applies to passenger cars and light-duty trucks in California. While the previously established federal GHG emission standards and related “augural” fuel economy standards for model years 2021-2025 would have achieved yearly improvements through MY2025, the SAFE rule results in far less stringent standards and consequently higher carbon dioxide emissions.

Another area of improvement in EMFAC2021 is the on-road motorcycle emission rates. This emission category has not been updated since 2000 and staff has been conducting extensive emission testing on motorcycles using both dynamometers and Portable Emission Measurement Systems (PEMS) to better understand their emissions characteristics for the past few years. Due to the availability of emissions data in this round, EMFAC2021 is updated with new motorcycle exhaust emission rates.

Considering that PHEVs will increasingly constitute a higher fraction of California's vehicle population, EMFAC2021 adds a new fuel type specifically for PHEV. To further advance the modeling accuracy of EMFAC for this vehicle technology, staff used data collected through CARB PEMS testing and an extramural contact with University of California, Davis (UCD) to derive new emission factors and activity profiles for this vehicle technology and incorporated them into the current version of the model.

Additionally, staff updated evaporative emissions in EMFAC2021 and replicated the USEPA’s MOVES approach for modeling evaporative emissions. It brings USEPA’s extensive research on modeling evaporative emissions into EMFAC and estimates evaporative emissions with California-specific input data.

Heavy Duty Vehicles

For light heavy-duty (LHD) diesel and gasoline trucks (also referred to as medium duty vehicles in CARB LEV regulations), the running exhaust emission rates have not been revised since EMFAC2007 and the emission rates currently used in EMFAC2017 were originally derived from the test data of heavier diesel and gasoline vehicles. To address this issue, CARB has conducted an extensive emission testing program using both chassis dynamometer as well as PEMS to update emission factors for this category of vehicles.

For heavy heavy-duty (HHD) diesel trucks, the running exhaust emission rates in EMFAC2017 were based on the test data from CARB's Truck and Bus Surveillance Program (TBSP) and those from a project carried out by the Engine and Truck Manufacturers Association (EMA) and University of California Riverside (UCR). For EMFAC2017, the start emission rates for HHD diesel trucks were updated mainly based on PEMS testing data collected through CARB's TBSP and the idle emission rates for HHD diesel trucks were updated based on the idle emissions test data from both CARB and the Texas Transportation Institute (TTI) emission testing programs.

For medium heavy-duty (MHD) diesel trucks, due to a lack of test data the emission rates in EMFAC2017 for trucks equipped with after-treatment systems were estimated by applying scaling factors to the rates of HHD diesel trucks. For transit buses, the running exhaust emission rates in EMFAC2017 were updated using the emissions test data from CARB transit bus testing, the West Virginia University, and the Federal Transit Administration.

For both MHD and HHD, staff updated NOx deterioration rates for newer vehicles using data from an extramural contract. For EMFAC2021, staff has updated and developed emission rates using emissions test data from the following sources:

1. *Project 2R1702: Chassis Dynamometer and PEMS Testing of Class 2b-3 Vehicles*- This project was carried out by CARB with the objectives of understanding the in-use emission performance of newer on-road LHD diesel engines; supporting emissions inventory improvement; and addressing stakeholders' concern regarding a lack of emissions data from Class 2b-3 diesel trucks. The test data were used to update the base emission rates (BER) and speed correction factors (SCF) of LHD trucks.
2. *Truck and Bus Surveillance Program (TBSP)* – TBSP is an ongoing CARB program that is designed to collect in-use emissions data for improving the emissions inventory of heavy-duty vehicles, among other objectives. To date, the program provided test data for more than 50 HHD diesel trucks (Class 8) and the test data was used for updating the HHD diesel truck BERs and SCFs as well as start emission rates (StER).
3. *Surveillance Program for On-Road Class 4-6 Heavy-Duty Vehicles* – This program was initiated by CARB staff to provide emissions test data of in-use MHD trucks for supporting emissions inventory development as well as other CARB programs. So far, the program has tested four MHD diesel trucks and the test data from these trucks were used for updating the MHD diesel truck BERs and SCFs.
4. *In-Use Emissions Testing and Fuel Usage Profile of On-Road Heavy-Duty Vehicles* – This testing project, commonly referred to as "200-Vehicle Project", sponsored by multiple government agencies and private parties, has been carried out jointly by the University of California at Riverside and West Virginia University and many of the 200+ procured vehicles have been tested for their emissions. The emissions data from this project has provided a unique opportunity for developing and

revising the emission rates of natural gas powered HD vehicles, including BERs, SCFs, and idle emission rates (IdleER).

5. *Contract 17AQP006 to Updates Heavy-Duty Emission Deterioration in EMFAC* – Through this project, a large volume of on-board diagnostics (OBD) data were collected to improve heavy-duty vehicle deterioration assumptions in EMFAC 2021. Staff used the results of this study to update NOx deterioration rates for newer OBD-equipped (engine model year 2013 and newer) vehicles.

1.3.3 Activity

Activity profile refers to the operational characteristics that influence vehicle emissions, including mileage accrual rates, odometer schedule, speed profile, starts per day, soak time distribution, and temporal distribution of VMT and trips. EMFAC2021 implemented major updates on activity profile for both light-duty and heavy-duty vehicles using the latest vehicle data. The data sources and updates include:

The 2017 National Household Travel Survey-California Add-on: This dataset provides the most recent source for on-road motorcycle odometer mileage data in EMFAC2021. For the purpose of EMFAC update, data from 1,923 surveyed motorcycles were used to develop on-road motorcycle mileage accrual rates and the odometer schedule.

PHEV activity data from UC Davis: Through CARB project 17AQP005, "Cold Start Emission Impacts of Blended Plug-In Hybrids", UC Davis collected real-time data from164 PHEVs including date and time, accelerator pedal position, engine RPM, vehicle speed, catalyst temperature, and state of charge. The dataset was utilized to estimate PHEV starts per day, start temporal distribution, and soak time distribution[5].

2018 California Vehicle Inventory and Use Survey and Geotab Telematics Data (Section 4.4.2): This data is used to update HD mileage accrual rate and odometer schedule. HDV mileage and odometer data in EMFAC2017 were based on 2002 Vehicle In-Use Survey (VIUS), now almost 20 years old and less likely to be representative of the current trucking industry. New data has become available for updating the annual accrual rates for most of the HDV Fleet categories to reflect more current activity trends. Fleet Management Company Geotab provided aggregate data from GPS data logging for over 1.3 million GPS tracking devices in operation on HDVs. In addition, Caltrans completed the California Vehicle Inventory and Use Survey (CA-VIUS) in 2018 to update the CA portion of the discontinued national VIUS.

Portable Activity Measurement System (PAMS) from 200-Vehicle Project: Real world activity data from the 200-Vehicle Project were collected by PAMS by University of

---

[5] URL: https://ww2.arb.ca.gov/sites/default/files/2021-03/erg_finalreport_hdv_accruals_20190614_ada.pdf

California, Riverside (UCR) and West Virginia University through the "200-Vehicle Project" were analyzed to update activity profiles within the EMFAC2021 model. These data were pooled with data collected through the "90-Vehicle Project" by UCR CE-CERT in 2017[6] to update VMT distribution by hour and speed, engine starts per day, soak time distributions, and idle hours. Compared to EMFAC2017, EMFAC2021 shows that the majority of HD categories have higher percentage of VMT at higher speed, higher number of starts per day with longer soak time, and less extended idling time.

1.3.4 New Sales and VMT Forecasting

As described in EMFAC2017 [7]technical support documentation (Sections 4.5.1 and 4.5.2), EMFAC2017 uses socio-econometric regression model forecasting methods to predict new vehicle sales and VMT growth trends. These models connect the activity estimates, VMT and new vehicle sales, to state and national economic indicators such as fuel prices, disposable income, human populations, and federal interest rates.

For EMFAC2021, staff created new models for estimation of light-duty VMT and new vehicle sales. Unlike EMFAC2017, EMFAC2021 benefits from models that are created dynamically by searching through a large pool of various combinations of economic indicators, and optimizing the parameter selection based on the performance of the model in predicting the historical data. To do that, staff used the latest available socio-economic data from UCLA Anderson Forecast (UCLA), California Department of Finance (DOF), California Board of Equalization (BOE), California Energy Commission (CEC), and Federal Reserve Bank of St. Louis.

As for the light-duty ZEV market share, EMFAC2021 projects the shares based on consumer choice models rather than a most likely compliance scenario used in EMFAC2017. As a result, the future ZEV market share projected by EMFAC2021 is higher than that predicted by the EMFAC2017 model. Specifically, the ZEV market share in light-duty vehicle new sales increase from approximately 8 percent in EMFAC2017 to 12 percent of EMFAC2021 for the model year 2030 passenger vehicles.

In the heavy-duty space, EMFAC2017 forecasted statewide diesel VMT using a regression model fitted to historical diesel fuel sales. For EMFAC2021, the primary source for the future VMT trends is the CSTDM[8] forecasted VMT per county. Staff utilized county level medium and heavy duty VMT estimated by the CSTDM to determine the county specific VMT growth rates. Refer to Section 4.5.2 for more details.

---

[6] https://ww2.arb.ca.gov/sites/default/files/classic//research/apr/past/13-301.pdf

[7] EMFAC2017 Technical Documentation, URL: *https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf*

[8] https://tmip.org/content/california-statewide-freight-forecasting-model-CSTDM

1.3.5 Regulations and Policies

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

HD Warranty phase 1 (Section 4.6.5): In 2018, CARB adopted amendments to the heavy duty engine (above 14,000 lbs.) warranty regulation and further updated those warranty mileages through the CARB's HD Omnibus regulation. NOx and PM emissions reductions from these programs are incorporated into EMFAC2021.

Innovative Clean Transit (ICT) (Section 4.2.3): Adopted in 2018, ICT regulation is a program that enhance public health by improving air quality and to mitigate climate change by transforming California transit bus fleets to zero-emissions technologies. This regulation applies to all transit agencies that own, operate, or lease buses with GVWR above 14,000 lbs. It requires all public transit agencies to gradually transition to a 100% zero-emission bus fleet and encourages them to provide innovative first and last-mile connectivity and improved mobility for transit riders. The zero emissions buses introduced through this program are reflected in EMFAC2021.

Amendments to Heavy-Duty Vehicle Inspection Program (HDVIP) and Periodic Smoke Inspection Program (PSIP) (Section 4.6): CARB adopted amendments to the HDVIP and PSIP programs in 2019. This program reduces particulate matter (PM) from diesel-powered vehicles (GVWR above 14,000 lbs.) and it will be achieved through more stringent opacity limit for non-DPF and DPF-equipped vehicles. PM reductions from this program are reflected in EMFAC2021.

Zero Emission Airport Shuttle Bus: CARB adopted the zero-emission airport shuttle bus regulation in 2019 and required airport shuttle fleets to fully transition to zero emission by 2035. This regulation is not explicitly accounted for in EMFAC2021 because this category represents a very small fraction of the fleet (less than 2,000 vehicles).

Advanced Clean Truck (ACT) (Section 4.5.3): Adopted in 2020, ACT requires manufacturers of Class 2b-8 chassis or complete vehicles with combustion engines to sell zero-emission trucks as an increasing percentage of their annual California sales from 2024 to 2035. By 2035, zero-emission truck/chassis sales would need to be 55% of Class 2b – 3 truck sales, 75% of Class 4 – 8 vocational truck sales, and 40% of Class 7-8 truck tractor sales. EMFAC2021 reflects ACT by modelling heavy-duty zero emission vehicles (ZEVs) based on the sales percentage requirements for each model year and those percentages were applied to vehicles first sold or certified in California.

Heavy-Duty (HD) Omnibus (Section 4.6.4): EMFAC2021 reflects NOx emissions reductions from Heavy Duty Omnibus regulation adopted in August 2020. HD Omnibus represents a comprehensive update to heavy-duty NOx emissions standards and ensures that heavy-duty engines will emit much lower NOx emissions throughout their lifetimes.

SAFE Vehicle Rules and Actions (Section 4.6.1): In September 2019, the U.S. Environmental Protection Agency (U.S. EPA) and the National Highway Traffic Safety

Administration (NHTSA) issued the Safer Affordable Fuel-Efficient or SAFE Vehicles Rule Part One: One National Program (SAFE Part One) that revoked California's authority to set its own greenhouse gas emissions standards and ZEV mandates, 84 Fed. Reg. 51,310 (Sept. 27, 2019). In April 2020, the federal agencies issued the SAFE Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks (Final SAFE Rule) that relaxed federal greenhouse gas emissions and fuel economy standards, 85 Fed. Reg. 24,174 (Apr. 30, 2020). The Final SAFE Rule relaxed federal greenhouse gas emissions and Corporate Average Fuel Economy (CAFE) standards to increase in stringency at only about 1.5% per year from model year (MY) 2020 levels over MYs 2021–2026. CARB has updated the carbon dioxide emission factors for gasoline-fueled passenger cars and light-duty trucks in EMFAC2021 to reflect the impacts of both the SAFE Part One and the Final SAFE Rule. CARB has additionally updated EMFAC2021 model to reflect the expected impact of California's Framework Agreements on Clean Cars[9]. Automakers who voluntarily agreed to the framework agreements are BMW of North America (including Rolls Royce for purposes of the agreement), Ford, Honda, Volkswagen Group of America (including VW and Audi), and Volvo. The framework agreements are voluntary commitments that support continued annual reductions of vehicle greenhouse gas emissions through the 2026 model year, and encourage innovation to accelerate the transition to electric vehicles.

---

[9] *https://ww2.arb.ca.gov/news/framework-agreements-clean-cars*

2 Introduction

2.1 EMFAC2021

Today, the California Air Resources Board (CARB) is tasked with three key mandates: achieving health-based air quality standards for ozone, particulate matter and other air pollutants; reducing public exposure to toxic air contaminants; and leading California's efforts to fight climate change by promoting clean, energy-efficient fuels and technology. Emissions inventories are essential tools that CARB utilize in developing regulations and control strategies that helps California to achieve its air quality, climate, and toxics reduction goals.

An emissions inventory (for any source category) can be calculated, at the most basic level as the product of an emission rate, expressed in grams of a pollutant emitted per some unit of source activity, and a measure of that source's activity. The following expression illustrates this basic relationship between the emissions rate and source activity used to calculate emissions:

(Emission Factor) X (Source Activity) = Emissions

For on-road motor vehicles, emissions rates are typically expressed as mass of pollutant emitted per mile driven, per vehicle per day, or per trip made, depending on the emissions process being analyzed. An emission process for a motor vehicle is the physical mechanism that results in the emissions of a pollutant (e.g., the combustion of fuel, the evaporation of fuel, tire or brake wear, or the start of an engine).

CARB developed an EMFAC model to calculate statewide or regional emissions inventories by multiplying emissions rates with vehicle activity data from all motor vehicles, including passenger cars to heavy-duty trucks, operating on highways, freeways, and local roads in California.

Over the years, tougher emissions standards have been met with technological solutions of increasing complexity. As a result, the emissions estimation models have also grown in size and complexity. EMFAC2021 is the latest emissions inventory model that calculates emissions inventories for motor vehicles operating on California roadways. EMFAC2021 represents the next step forward in the ongoing improvement process for EMFAC, and reflects the CARB's current understanding of how vehicles travel and how much they pollute. The EMFAC2021 model is needed to support CARB's regulatory and air quality planning efforts and to meet the Federal Highway Administration's transportation planning requirements.

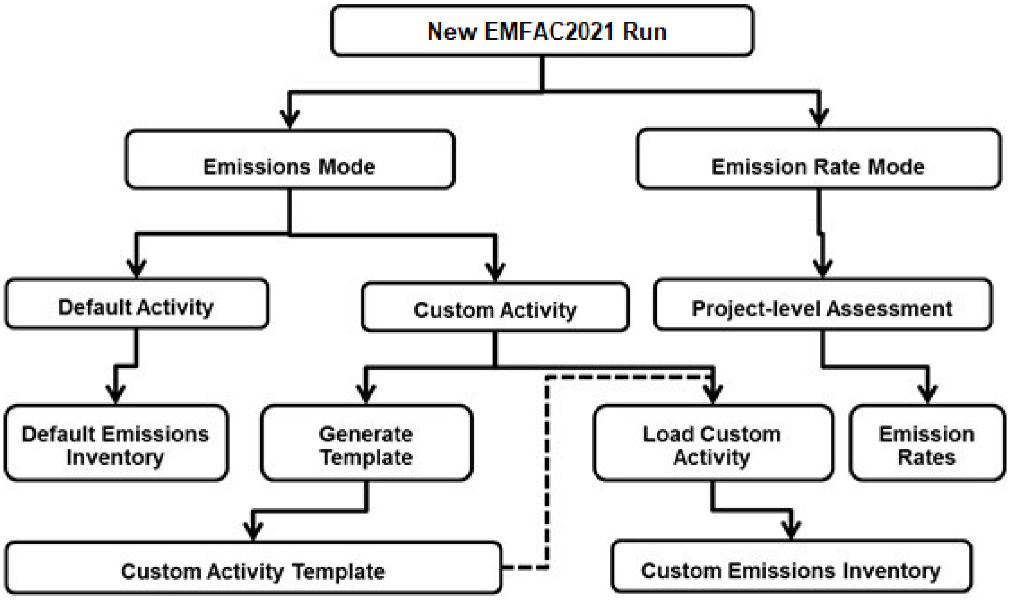
The EMFAC2021 model can be used to show how California motor vehicle emissions have changed over time and are projected to change in the future. This information helps CARB evaluate prospective control programs and determine the most effective, science-based proposals for protecting the environment. EMFAC2021 includes the latest data on California's car and truck fleets and travel activity. New forecasting methods have been incorporated for developing vehicle age distributions and estimating vehicle miles traveled. The model also reflects the emissions impact of Federal and California recent rulemakings.

2.2 Modeling Architecture

Starting from EMFAC2014, CARB staff gradually departed from using Fortran to Python and MySQL. EMFAC2014 and EMFAC2017 had a legacy Fortran module for certain emission processes. EMFAC2021 is developed completely in Python and MySQL database. While EMFAC development migrates to Python and MySQL, staff with the goal to maximize the following aspects, including user friendliness, transparency, ease of maintenance, flexibility for incorporating and supporting future regulations, improved computational efficiency, and convenience to transfer of EMFAC outputs to other services.

One major architectural change of EMFAC2021 is the ability to run the model in parallel on multiple CPU cores. Although the number of computations required for model runs has increased substantially due to many new features and updates in EMFAC2021, this parallelization allows EMFAC2021 to run significantly faster than its predecessors when deployed on high performance computing clusters. EMFAC2021 runs for multiple combinations of sub-areas and calendar years simultaneously up to a level supported by user’s computer. Since EMFAC performs most computations on its MySQL server, it is recommended to run EMFAC's MySQL server with multiple CPU cores and a high-performance storage system. Figure 2.2-1 displays a flow chart indicating the GUI selections necessary to generate the various outputs of EMFAC2021.

Figure 2.2-1. EMFAC2021 Overall Flow



Important! "Custom Activity" or Scenario Generation (SG) Mode

Similar to EMFAC2017, the SG mode in EMFAC2021 can also be used to produce emissions inventories for both conformity assessments and SB375 assessments. For conformity assessments, emissions are estimated with all current controls active. For SB375 assessments, the Advanced Clean Cars (ACC) and SAFE vehicle rules are deactivated. Because the ACC regulation has certain assumptions about vehicle usage built into it, default data in custom activity templates produced for conformity assessments will not match the default data in templates for SB375 assessments. For the same reason, estimates of GHG will also differ.

Moreover, the SG mode has been extended to provide the end users more flexibility with technology mix using the updated EMFAC2021 vehicle categories. Now users can customize the VMT with electric, plug-in hybrid, and natural gas, besides gasoline and diesel.

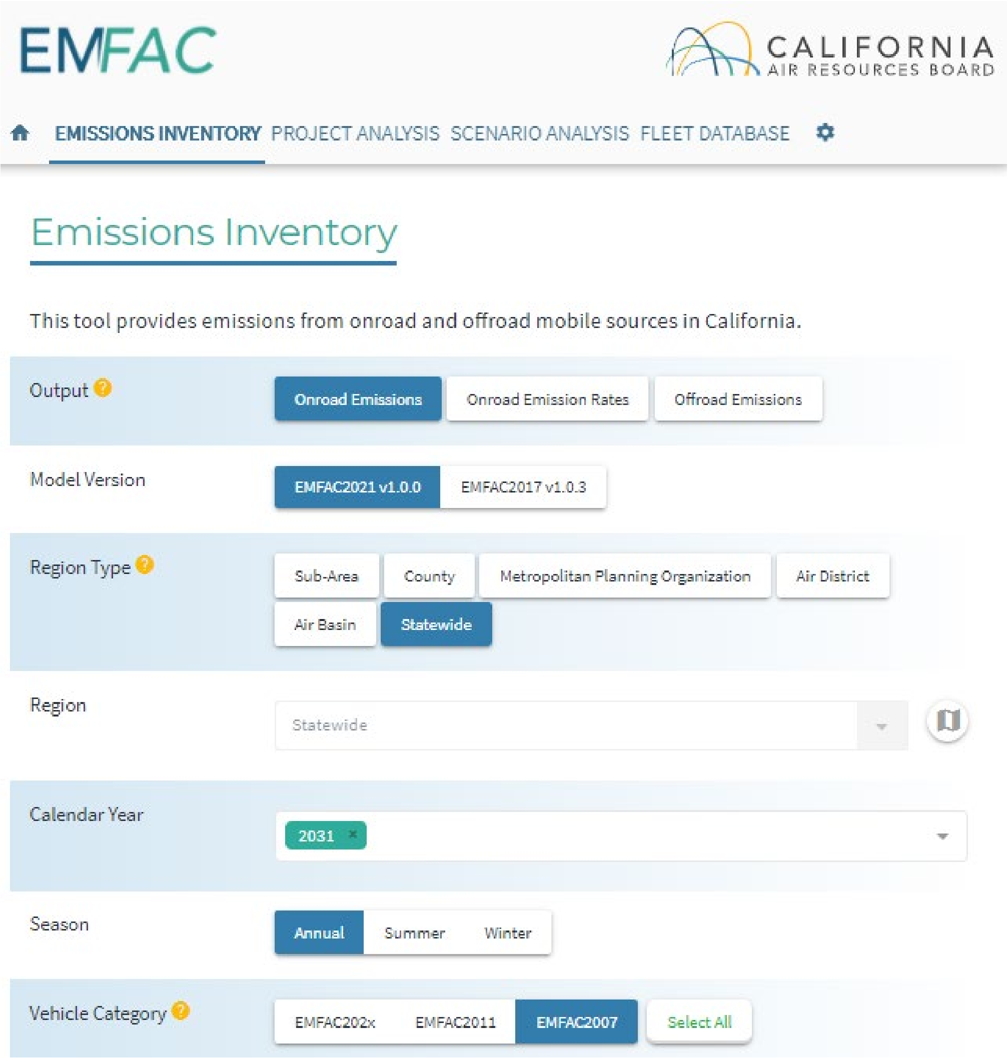
The SG mode uses total VMT as input and output cVMT and eVMT separately. Just as the previous version, end users can also use their own speed fractions by selecting the "Custom Hourly Speed Fractions" option. However, the user input speed fractions will only be used for cVMT calculation and the eVMT fraction will stay the same as default mode.

For PHEV brake wear emission calculations, the SG by hourly speed mode ignores the varying speed weighting factors by model years. For this reason, the estimates of PHEV brake wear emissions in SG mode with "Custom Hourly Speed Fractions" option will differ slightly from the default mode using user's input activity profiles.

2.3 Web Interface

Along with EMFAC2021, a new Web Platform *https://arb.ca.gov/emfac/* was developed to provide easy and quick access to all of the features provided by EMFAC2021 on the web (Figure 2.3-1). The new web interface not only provides all features of the former EMFAC Web Databases, it also provides the Project Analysis and Scenario Analysis features, which correspond to Project-Level Analysis (PL) and Scenario Generation (SG) modes in the EMFAC PC application, respectively. Compared to SG and PL modes of EMFAC PC application, the equivalent modes on the web are much faster as they are processed using preprocessed EMFAC outputs. As the new web platform provides all the functionalities of EMFAC, staff expect most EMFAC users to use the Web Platform rather than running EMFAC PC application.

Figure 2.3-1. EMFAC web application and video tutorials



Emissions Inventory

This tool provides emissions from onroad and offroad mobile sources in California.

Output: Onroad Emissions

Model Version: EMFAC2021 v1.0.0

Region Type: Statewide

Region: Statewide

Calendar Year: 2031

Season: Annual

Vehicle Category: EMFAC2007

EMFAC Web Platform Tutorial
Introduction

3 New Modules in EMFAC2021

3.1 PHEV Module

3.1.1 Background

Because of California and Federal electric vehicle incentives, Plug-in Hybrid Electric Vehicle (PHEV) sales have increased significantly in recent years. According to California DMV vehicle registration database, by the end of 2019, about 251 thousand PHEVs, including 20 makes across 42 models, are registered in California. One of the EMFAC2021's new features is to separate PHEVs from conventional light-duty gasoline vehicles and to model them in a new module, called PHEV module. As a new fuel type, the PHEV module provides emission and activity estimates of PHEV for light-duty vehicle categories.

PHEV vehicles use battery power to run an electric motor and use another fuel type, typically gasoline, to power an internal combustion engine (ICE). These vehicles have various engine operations. For example, their engine starts can occur at any time during a trip based on the vehicle's battery level and energy demand. When running on battery power alone, PHEVs do not produce tailpipe emissions; however, the engine may help power the vehicle when the battery is mostly depleted during rapid acceleration or at high speeds or when intensive heating or air conditioning is demanded. Under those circumstances, the ICE is started under high power demand. Some of these high-power demands start events may occur while the catalytic converter is cold, which could result in significantly higher emissions than a warm start. In fact, CARB's in-house test results show that the high-power cold starts from PHEV could have two to five times higher cold start emissions than traditional cold starts from conventional vehicles.

The PHEV emission factors are updated in EMFAC2021, based on new emissions data from real-world emission testing of several PHEV vehicles conducted by CARB and sec-by-sec PHEV activity data collected through CARB project 17AQ005, "Cold Start Emission Impacts of Blended Plug-In Hybrids". Eleven PHEVs across different makes and models were tested using On-road Portable Emissions Measurement System (PEMS) over various routes and different soak times throughout Southern California.

Table 3.1.1-1 shows the list of eleven PHEVs included in CARB's PEMS testing program. After post-processing and quality assurance of the test data, eight vehicles are included in the final emission analysis and these vehicles are certified under LEV2 SULEV or LEV3 SULEV30. Table 3.1.1-2 details the PEMS testing routes and characteristics. Each route was tested twice for each vehicle. Besides, through an extramural contract, CARB collaborated with UC Davis to collect activity data on 164 PHEVs over 200-300 days.

Table 3.1.1-1. List of PHEV in CARB's PEMS testing program

No.	Model Year	Make	Model	Tech Group	Type	US06 Capable	Included
1	2017	Toyota	Prius	L3 SULEV30	Blended	Yes	Yes
2	2017	Audi	A3 E-Tron	L3 SULEV30	Blended	Yes	Yes
3	2012	Chevy	Volt	L2 SULEV	Non-blended	Yes	Yes
4	2014	Ford	Fusion	L2 SULEV	Blended	No	Yes
5	2016	Ford	C-Max	L2 SULEV	Blended	No	Yes
6	2016	Hyundai	Sonata	L3 SULEV30	Blended	No	Yes
7	2017	BMW	330e	L3 ULEV125	Blended	No	No
8	2016	Porsche	Cayenne	L2 ULEV	Blended	No	No
9	2016	Mercedes	C350e	L3 SULEV30	Blended	No	Yes
10	2014	Toyota	Prius	L2 SULEV	Blended	No	Yes
11	2017	Chevy	Volt	L3 ULEV125	Blended	No	No

Table 3.1.1-2. CARB PEMS emission testing routes

Route	Distance (mile)	Travel Time (min)	Average Speed (mph)	Route Characteristics	Elevation Gain (m)
Downtown Los Angeles (DTLA)	16	60	15	Typical city driving	75
Freeway around El Monte	18	30	35-40	Freeway with higher power demand	50
Local roads in El Monte	1.3	3-6	3-6	Various soak periods	10
El Monte to Lake Pyramid	65	95	45-50	Longer arterial and freeway with high road grade	800

3.1.2 Emission Rates Analysis

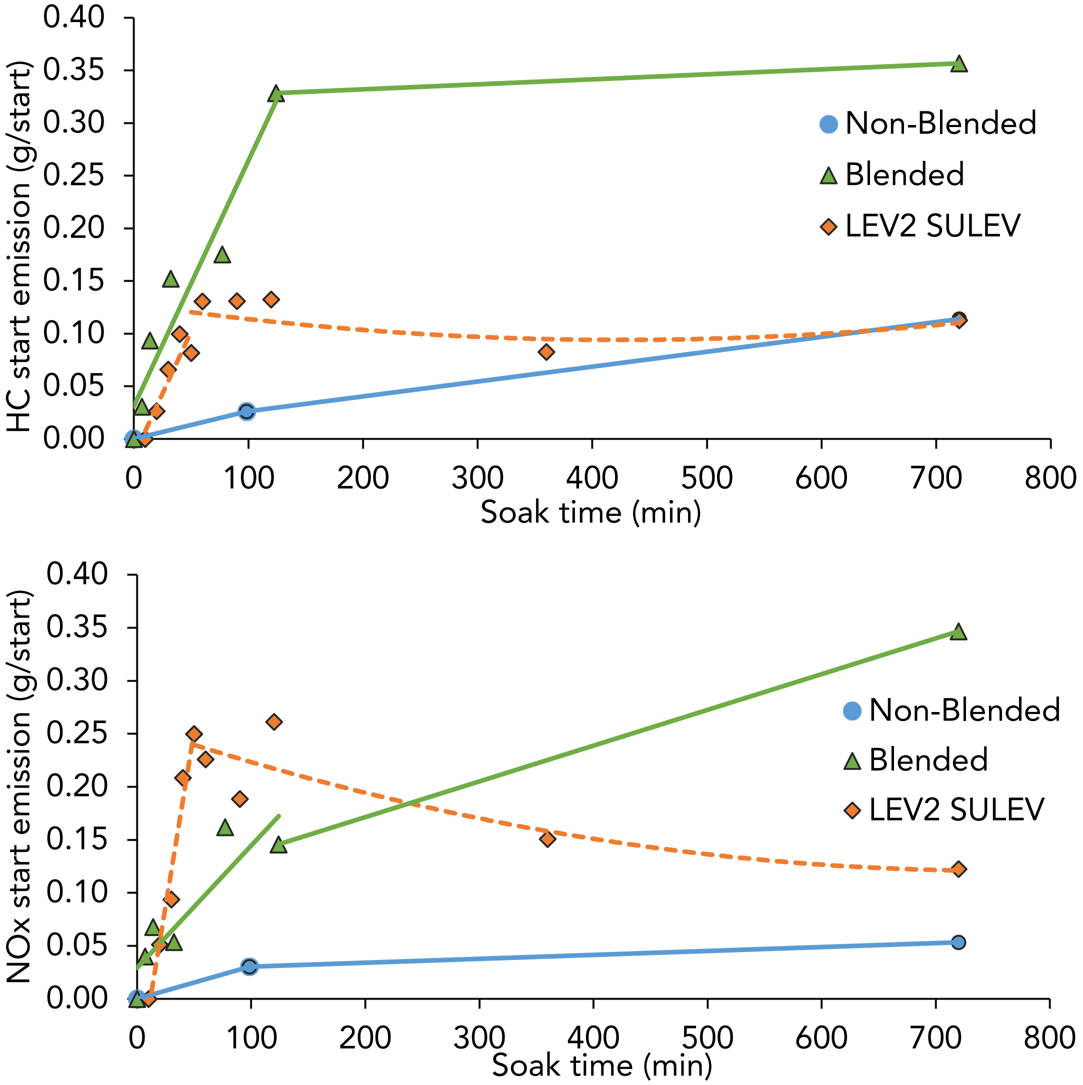
Like conventional vehicles, the PHEV start exhaust emission rates for HC, NOx, and CO are derived from PEMS testing performed by CARB. The emission rates are a function of soak time and are grouped for blended and non-blended PHEVs separately. For blended PHEVs, the engine starts and provides propulsion power when the driver's power demand is higher than what the electric powertrain and battery can provide. In contrast, for non-blended PHEVs, the electric powertrain provides propulsion regardless of the driver demand until the car switches to charge sustaining mode. At this point, the battery is maintained at a minimal level, and the engine's use is prioritized. This happens when the battery reaches a low level of charge.

Additionally, blended PHEVs typically have smaller-sized batteries and show a different starts frequency behavior than non-blended PHEVs. The US06 cycle is an aggressive test cycle with high speed or high acceleration driving behavior. Of the vehicles being tested, three out of eight vehicles are US06 capable, including one non-blended and two blended PHEVs. For the starts analysis, staff used US06 capable PHEVs for the non-blended results.

For this analysis, staff defined PHEV start as when the soak time is greater than 5 minutes, and the engine RPM is above 100 rpm while this condition lasts for more than five but less than 100 seconds. All the PHEV starts from the PEMS data were binned by EMFAC soak time bins using a piecewise linear regression.

Figure 3.1.2-1 shows a comparison between PHEV and conventional ICE vehicle starts emissions in units of grams per start for the same certification level as LEV2 SULEVs with gasoline fuel type. As shown, blended PHEVs have significantly higher start emissions when compared to conventional and non-blended PHEVs; especially with longer soaking times this is more pronounced.

Figure 3.1.2-1. Comparison of PHEV HC and NOx start emission rates in g/start by soak time in minutes with gasoline LEV2 SULEV



The PHEV running exhaust emissions data obtained through PEMS testing were analyzed using the U.S. EPA's MOVES[10] Vehicle Specific Power (VSP) modal model approach. VSP is an estimate of the power demand on the engine during driving. MOVES emission rates for running exhausts are based on 23 operating modes called OpModes, which are combinations of speed and VSP that account for different patterns of acceleration, cruising, deceleration, and average speed. Figure 3.1.2-2 presents the approach in a flow chart. All the data points from non-first starts with less than 5 minutes soaking time and beyond the 100 seconds starts duration threshold were binned into 23 MOVES

---

[10] U.S. EPA MOtor Vehicle Emission Simulator (MOVES): https://www.epa.gov/moves

OpModes based on VSP and speed. As the next step, the model average running emission rate in gram per second was calculated for all data points within an OpMode bin. Following that, sixteen CARB test cycles representing various cycle-average speeds from 2 to 71 mph were selected, and for each one, time distribution of OpModes and a time-weighted cycle-average emission rate were developed. The PHEV running exhaust emission rates were derived based on the relationship between these cycle-average emission rates versus cycle-average speed in miles per hour.

Figure 3.1.2-2. EMFAC2021 approach for estimating PHEV running exhaust emissions using MOVES modal model bins

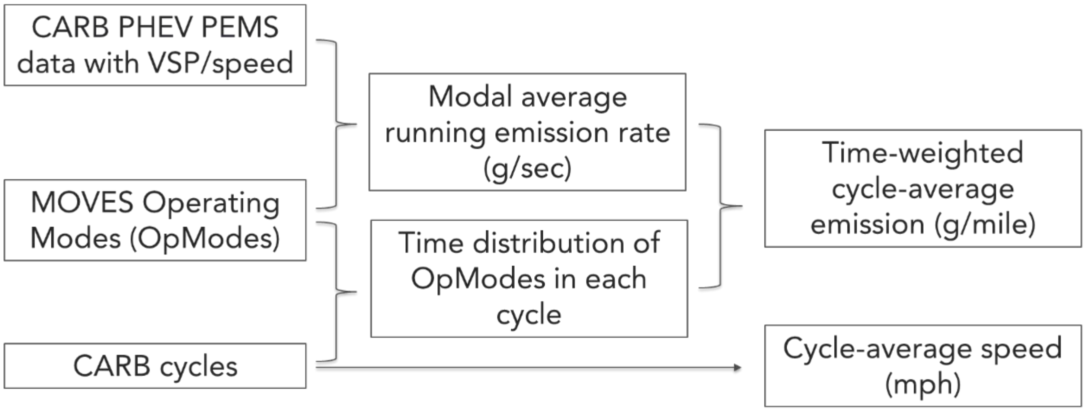
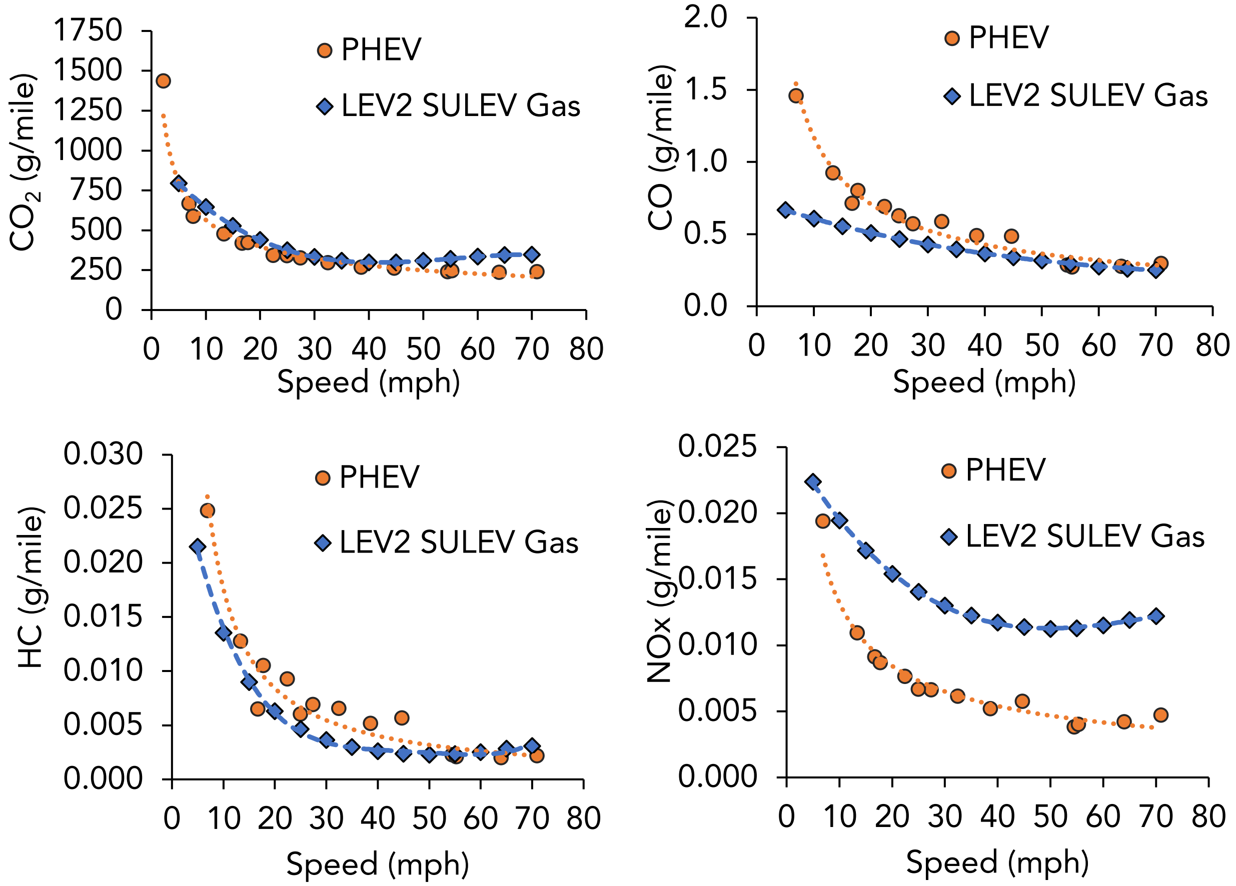


Figure 3.1.2-3 compares CO2, CO, HC, and NOx running exhaust emissions of PHEVs against those of conventional vehicles with gasoline LEV2 SULEVs. As shown, PHEV vehicles have similar CO2 emission rates per mile, higher CO emission rates at lower speeds, slightly higher HC emission rates, and lower NOx emission rates than conventional ICE vehicles certified at the same level.

Figure 3.1.2-3. Comparison of PHEV running exhaust emissions with LEV2 SULEV for CO2, CO, HC, and NOx



As a pilot study with limited emission testing data, PHEV starts and running exhaust emission rates in EMFAC2021 are assumed to be the same for different vehicle classes. For other pollutants or emission processes such as the evaporative processes where PHEV specific data was not available, EMFAC2021 is programmed to use the emission rates of conventional gasoline vehicles that are certified under the same emissions level; or to use emission rates from electric vehicles of the same vehicle class for PM brakewear emission estimation.

3.1.3 Activity Analysis

PHEV's fleet utility factor (FUF) refers to a measure of fleet-average distance driven on electricity. Specifically, it is a utility factor based on the total VMT and gives a probability that an average vehicle will be driven less than or equal to its charge depleting range during a particular driving day. Hence, FUF is particularly useful to calculate the expected fuel and electric energy consumption for a fleet of vehicles.

Due to PHEV's ability to partially substitute electricity for gasoline, FUF is particularly useful to calculate the expected fuel, electric energy consumption, and emissions for a fleet of vehicles. It is because of the effect of FUF that PHEV vehicles produce less criteria and GHG emissions compared to conventional vehicles. Table 3.1.3-1 shows the PHEV FUFs used in EMFAC2021. Pre-2018 model year FUF was derived from telematics data[11], and the rest are forecasted. More details for the forecasted data were presented in EMFAC2017 Technical Documentation Section 4.5.3.

Table 3.1.3-1. EMFAC2021 PHEV fleet utility factors

Model Year	Fleet Utility Factor (FUF)
≤ 2018	0.46
2019	0.47
2020	0.48
2021	0.50
2022	0.55
2023	0.56
2024	0.58
≥ 2025	0.59

PHEV population in EMFAC2021 for historical years are based on California DMV vehicle registration data. EMFAC2017 and earlier versions categorized PHEV as gasoline vehicles. As a result, EMFAC2021 used fractions of PHEV by model year to re-distribute PHEV population from gasoline population in historical years. The earliest available PHEV model year from the DMV database is 2010.

---

[11] https://ww2.arb.ca.gov/sites/default/files/2020-01/appendix_g_pev_in_use_and_charging_data_analysis_ac.pdf

Table 3.1.3-2 shows the fractions by vehicle class that EMFAC2021 used to re-distribute PHEV population in historical years.

Table 3.1.3-2. PHEV population fractions by vehicle class in historical years

Model Year	Vehicle Class			
	LDA	LDT1	LDT2	MDV
2010	0.00%	0.00%	0.00%	0.00%
2011	0.18%	0.00%	0.00%	0.00%
2012	1.17%	0.00%	0.00%	0.00%
2013	1.83%	0.00%	0.00%	0.00%
2014	2.63%	0.00%	0.00%	0.00%
2015	1.65%	0.00%	0.06%	0.00%
2016	1.74%	0.00%	0.15%	0.99%
2017	4.13%	0.04%	0.00%	0.80%
2018	4.08%	0.00%	0.35%	2.05%
2019	3.44%	0.00%	1.12%	0.60%

Moreover, all future year activity data is forecasted using a newly introduced ZEV forecasting framework in EMFAC2021 (Section 4.5.3). The ZEV forecasting framework uses CEC's vehicle choice models with CARB's updated ZEV input attributes for short-term projections (2020-2030). For long-term projections (2031-2050), it is assumed that California ZEV market shares will plateau starting with vehicle model year 2030.

Through an extramural contract, CARB analyzed the PHEV activity data collected by UC Davis to generate engine start activity inputs for EMFAC2021, including a starts per day distribution, start temporal distribution, and soak time distribution[12]. Staff also compared PHEV activity with conventional gasoline vehicle activity used in EMFAC.

As shown in Table 3.1.3-3, PHEVs have much higher starts frequency per day than conventional vehicles, and blended PHEVs have more first starts than non-blended PHEVs. In Figure 3.1.3-1, for all the first starts from blended PHEVs, more than 40% have a soak time less than 60 minutes. In comparison, non-blended PHEVs have higher fraction of cold starts. For the temporal distribution of engine starts, as shown in Figure

---

[12] URL: https://ww2.arb.ca.gov/sites/default/files/2021-03/erg_finalreport_hdv_accruals_20190614_ada.pdf

3.1.3-2, non-blended PHEVs have a lower fraction of starts in the morning and higher fraction in the afternoon.

Table 3.1.3-3. PHEV starts frequency per day from UC Davis Dataset

Category	Starts	First Starts	Non-First Starts > 5 mins soak
Conventional ICE	2.7 – 5.1	-	-
PHEV Non-blended	31.9	2.5	1.6
PHEV Blended	96.6	4.2	1.7

Figure 3.1.3-1. PHEV Soak time distribution for first starts from UC Davis Dataset

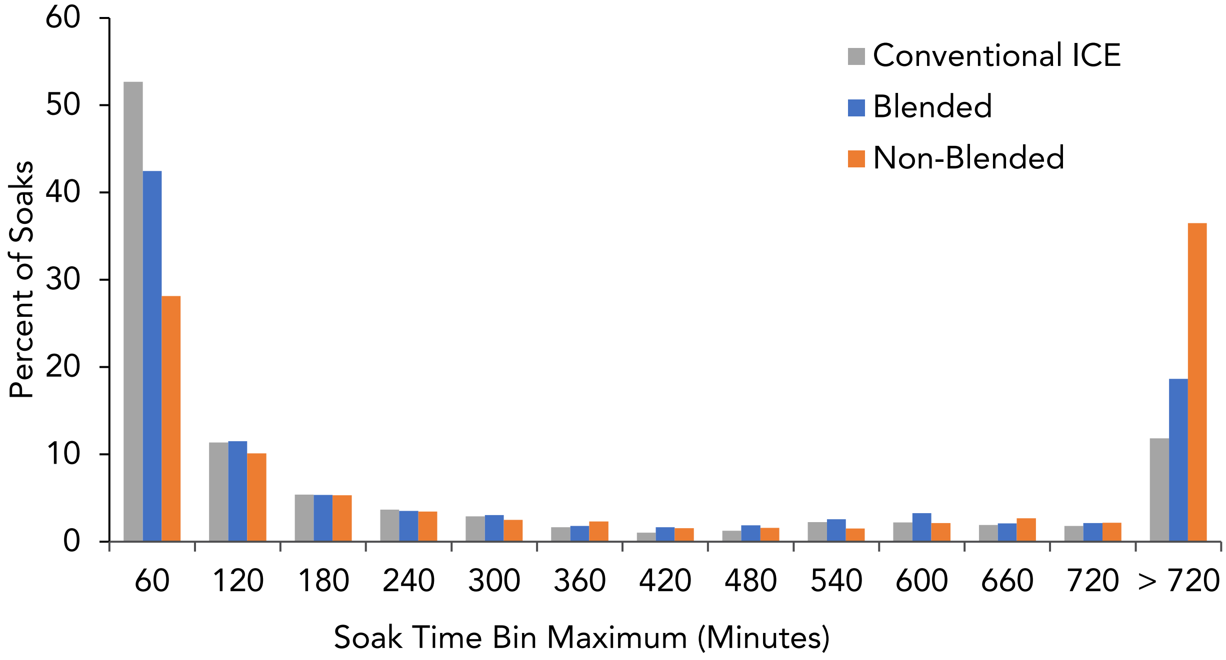
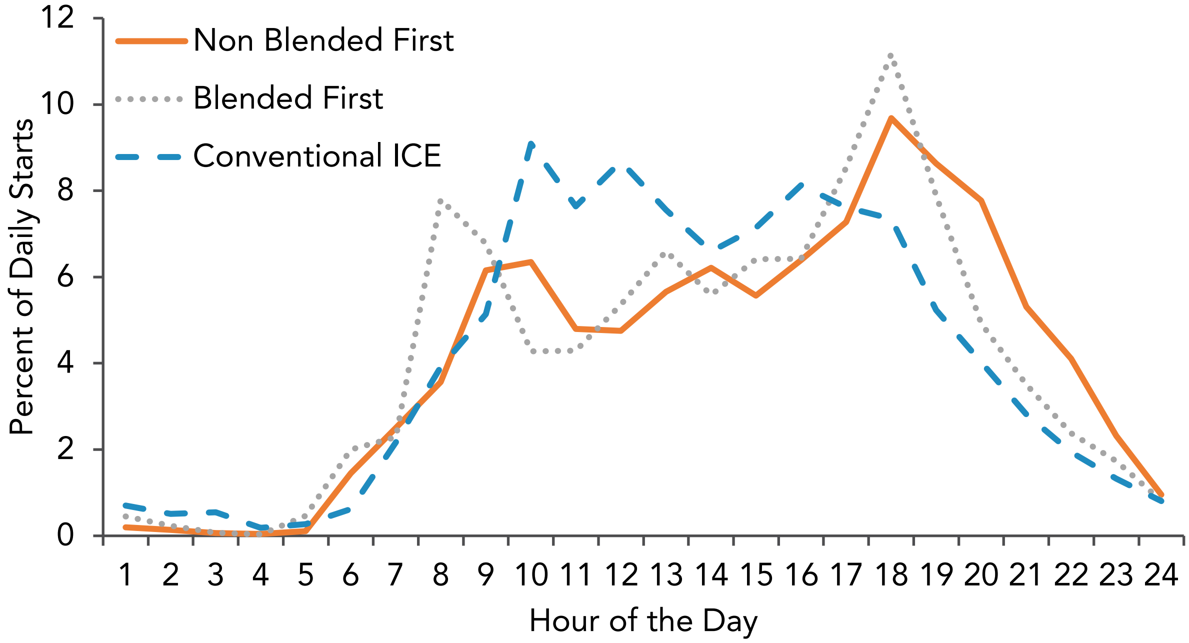


Figure 3.1.3-2. Temporal distribution of PHEV engine starts from UC David Dataset



In EMFAC2021, all these starts activity have been processed into a similar table format as conventional vehicles. EMFAC2021 assumes the PHEV fleet consists of 50% blended and 50% non-blended. PHEV trips are computed for blended and non-blended, separately, accounting for each different starts frequency and hourly distribution. Starts and running emissions are calculated in the same way as conventional vehicles by only accounting for the gasoline portion in the default emission mode. In the emission rate (project level, PL) mode, PHEV emission rates are calculated based on their total activity, including both gasoline and electric portions.

3.2 Energy Module

Meeting California's air quality and climate goals will require an ongoing transformation to cleaner technologies and fuels. As of January 2021, there are more than 800,000 light-duty zero emission and plug-in hybrid vehicles are sold in California[13]. Additionally, the adoption of Innovative Clean Transit (ICT) and Advanced Clean Truck (ACT) regulations will significantly increase the number of heavy-duty zero-emission buses and trucks in California. Therefore, it is critical to understand the energy consumption associated with these vehicles for the purpose of infrastructure planning and development as well as utility grid upgrades.

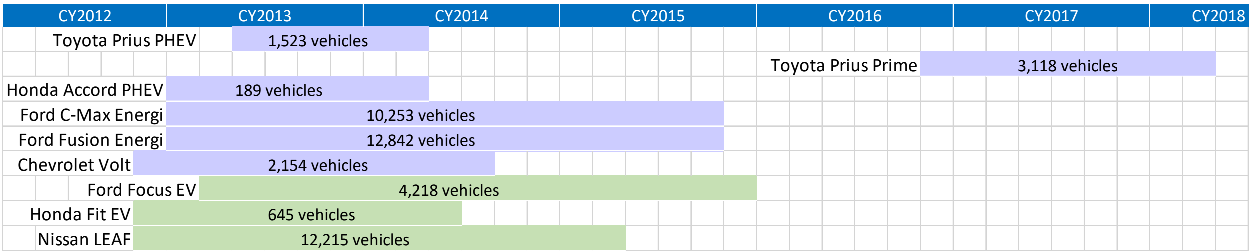
---

[13] https://www.veloz.org/sales-dashboard/

3.2.1 Light-Duty

Plug-in hybrid and electric vehicles present much higher energy efficiency as compared to conventional vehicles. However, similar to conventional vehicles, operational efficiencies of zero emission vehicles vary under different driving conditions. EMFAC2017 lacked sufficient information to accurately estimate energy consumptions associated with plug-in electric vehicles. Accurate characterization of energy consumption is particularly important because of the large recent increase in battery zero emission and plug-in hybrid vehicles in California. To collect more accurate information, real-world consumer trip information that was provided by manufacturers was analyzed for approximately 50,000 battery electric (BEV) and plug-in hybrid electric vehicles (PHEV). Trip information was collected through telematics, advanced on-board diagnostics (OBD) technologies, and mobile applications via consumer cell phones. Figure 3.2.1-1 below summarizes the sample size for each BEV and PHEV make and model analyzed, as well as the OEM sampling period.

Figure 3.2.1-1. OEM Sampling Period for Trip-by-Trip Energy Data



The electric energy consumption and average speed were estimated for each PHEV and BEV trip. Ford, Toyota, and Honda provided a direct estimate of energy consumption and, energy consumption for Chevrolet and Nissan was estimated using state of charge (SOC) and battery capacity. Energy consumption per mile was obtained by taking energy consumption and dividing it by the distance for a given trip. Average speeds were either provided directly or calculated as distance divided by time. For PHEVs, only pure electric trips during which the engine did not turn on were used. The average speeds were mapped to EMFAC speed bins. For each make and model, the average energy consumption was calculated for each speed bin. A California sales weighted average of each make and model were used to calculate an overall energy consumption curve for BEVs and PHEVs. To develop a more accurate total energy consumption, staff accounted for the energy loss that occurs during charging when power is drawn from the electrical grid from the on-board charge modules. This energy loss approximation of 20% was found using Idaho National Laboratory charging test data[14] that measured the efficiency and power quality of the on-board charge modules for 4 BEVs and 1 PHEV. To obtain

---

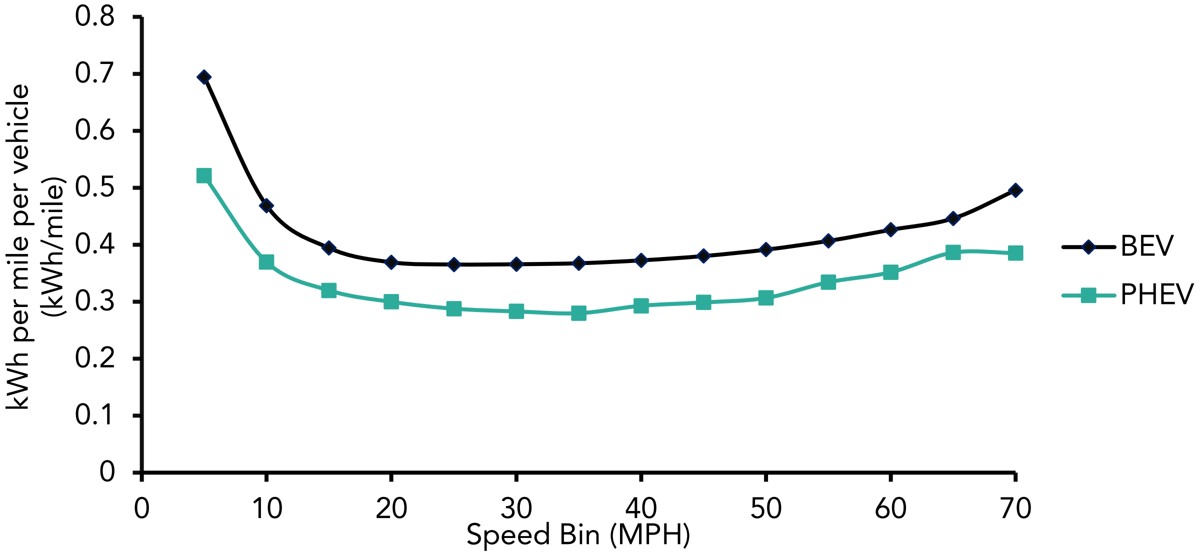
[14] https://avt.inl.gov/content/charging-system-testing/vehicle-charging-system-testing

charging losses, staff took the average of the Level 1 (110V) and the Level 2 (208-240V) charger efficiencies, which had charging efficiencies of 73% and 87%, respectively.

In addition to estimating energy consumption as a function of speed, the electric vehicle miles travelled (eVMT) fraction at each speed bin were also estimated. Here, eVMT is defined as a pure electricity powered trip. These fractions were used to allocate total eVMT at each speed for BEVs and PHEVs. In EMFAC2021, vehicle miles traveled (VMT) is split into two outputs, combustion VMT (cVMT), which corresponds to VMT that is powered by the gasoline engine, and eVMT. Note that PHEVs have a mix of eVMT and cVMT, while BEVs[15] just have eVMT.

The overall sales-weighted electric energy consumption from the grid as a function of speed are shown in Figure 3.2.1-2 for BEVs and PHEVs. Energy consumptions shown here are corrected for charging energy losses.

Figure 3.2.1-2. BEV and PHEV Electric Trip Energy Consumption-CA Sales Fleet Distribution



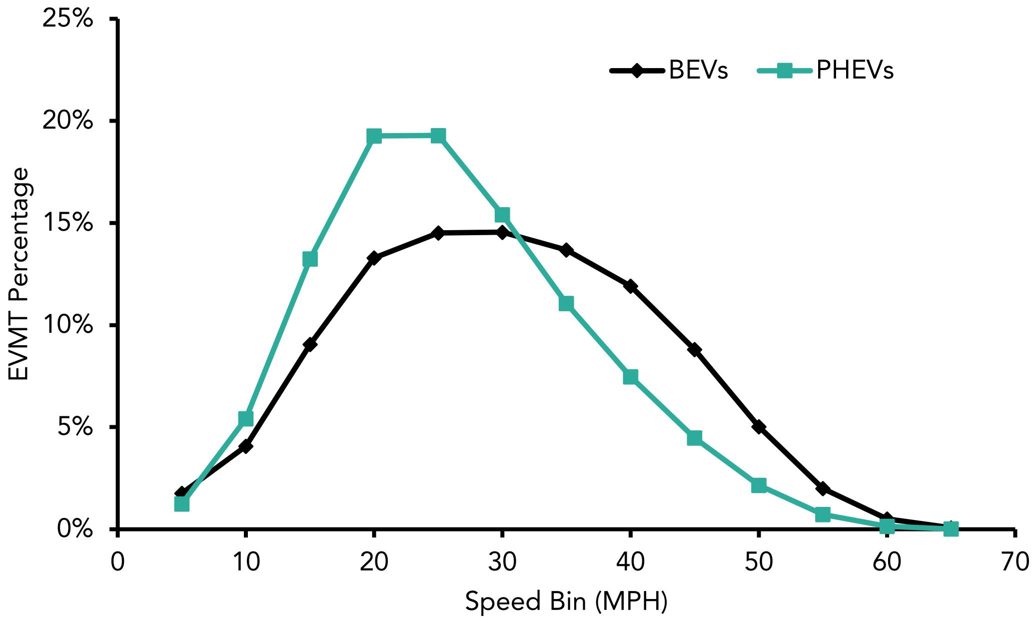
In general, BEVs and PHEVs exhibit high-energy consumption at relative low and high speed operations, while they demonstrate highest efficiency at speeds of 25-35 mph. Energy consumption is largest during low speed operation due to periods of acceleration. At faster speeds, energy consumption increases due to aerodynamic drag. Energy consumption rates reach a minimum 0.28 kWh per mile at 35 mph for PHEVs and 0.37 kWh per mile at 25 mph for BEVs. Some of this difference between BEVs and PHEVs may be due to differences in the method for estimating energy consumption. For

---

[15] Due to lack of data on FCEVs, staff use similar assumptions as in BEVs to estimate energy and emissions from FCEVs

example, estimating energy consumption from SOC and battery capacity may lead to overestimation of energy consumption, since battery capacity decreases over time. However, some makes and models, like Chevy Volt, will not have this issue because the SOC is reported as a function of usable battery capacity. Additionally, staff did not have access to trip-by-trip Tesla data, so a significant portion of the BEV market is missing from this analysis. For the next version of EMFAC staff will explore improvements in energy efficiency with model year, make and model, and refine estimates of charging losses. The eVMT distribution for BEVs and PHEVs are shown in Figure 3.2.1-3.

Figure 3.2.1-3. EVMT Speed Distribution



The eVMT peak for PHEVs occurs at 25-30 mph, while the peak for BEVs is around 25-30 mph. PHEV eVMT is skewed towards lower speeds as most of the PHEVs in this sample were not US06 capable. As mentioned above, the PHEV results are only for electric trips only, during which the engine did not turn on.

3.2.2 Heavy-Duty

CARB has conducted a study,[16] through an extramural contract, to quantify the emission reduction benefits and operational performance of the zero-emission technology vehicles compared to the current conventional vehicles, and to review commercialization

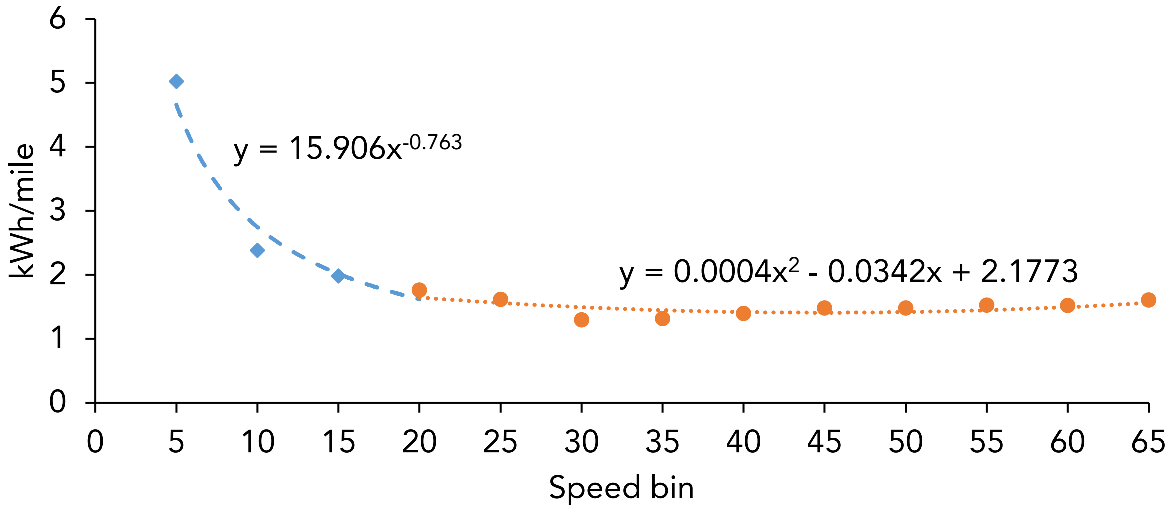
---

[16] Data Monitoring, Collection, and Analysis for Projects Granted Under Fiscal Year 14-15 Air Quality Improvements Program and Low Carbon Transportation Greenhouse Gas Reduction Fund Investments (15MSC006)

readiness of zero-emission technologies for industry adoption. The vehicle activity information was collected by HEM-supplied data loggers accessible through SAE J1962 OBD connectors. Staff analyzed real-world second-by-second vehicle activity data generated through this contract to better understand the electricity usage of heavy-duty vehicles under different driving conditions. Wheel-based vehicle speed was used to group vehicle activity by speed bin and estimate VMT. Battery pack current (Amp) and voltage (V) were used to estimate energy consumption in kWh. Subsequently, the VMT and energy consumption are aggregated by speed bin. The energy consumption per mile was obtained by taking total energy consumption and dividing it by the total distance for a given speed bin.

Until the data cutoff date of EMFAC2021 development, staff utilized data from 23 40-foot (Class 8) battery electric transit buses in five transit fleets, including San Joaquin Regional Transit District (RTD), Fresno, Visalia, Modesto, and City of Porterville. Due to the poor data quality in the initial days of data collection, data collected in 2019 was used for the former four transit agencies (15 vehicles), and data collected from April 2020 to June 2020 was used for City of Porterville (8 vehicles). To obtain energy consumption during bus operation, charging events were flagged in the dataset and removed during the analysis. Charging events were identified as a continuous segment of vehicle activity that meets three criteria: (1) opposite current to energy consumption, (2) vehicle speed less than 1 mph, and (3) the total duration of more than 1 minute. Also, idling events at 0 mph, which showed high energy consumption, were excluded. Energy consumption was averaged for 23 buses by speed bin for all transit fleets. The results are shown below in Figure 3.2.2-1.

Figure 3.2.2-1. Fitted Curves of Heavy Heavy-Duty Vehicle Energy Consumption by Speed Bins



The aggregated results were used to develop a base energy consumption at 20 mph. which was then scaled to other speed bins using speed correction factors relative to 20 mph. Considering similar weights, the energy consumption is assumed to be the same for transit bus and heavy heavy-duty vehicles (i.e. Class 8). To scale the energy consumption from transit bus to medium heavy-duty categories (e.g., medium heavy-duty trucks, school buses), the ratio (0.59) of CO2 emission rates between diesel medium heavy-duty and heavy heavy-duty in EMFAC was used. Staff also assumed an energy consumption rate of 0.56 kWh/mi for Class 2b-3 vehicles based on information from San Diego Airport Parking Company who used Class 3 Zenith Motors vans[17] in their fleet. Energy consumptions per mile were adjusted for 15% energy loss from grid to vehicle battery[17]. EMFAC2021 energy consumption inputs for heavy-duty categories are shown in Table 3.2.2-1. The assumptions align with National Renewable Energy Laboratory (NREL) measured energy use for Class 2b-8 vehicles.[18]

Note that transit bus experiences more stop-and-go than other duty cycles, yet due to lack of data, the same set of speed correction factors were used for all the heavy-duty categories to show the energy consumption variation by speed, as shown in Table 3.2.2-2, derived from fitted curve of energy consumption by speed in Figure 3.2.2-1. Also note that the numbers listed in

Table 3.2.2-1 are corrected for 15% energy loss from grid to vehicle battery. Upon availability of data, staff will continue to refine the energy consumption rates and speed correction factors for various vehicle weight class and vocations.

Table 3.2.2-1. EMFAC2021 Input Energy Consumption Rates in Kilowatt Hours per Mile at 20 mph (Including 15% Energy Loss from Grid to Vehicle Battery)

Category	Energy Consumption (kWh/mile) @ 20 mph
Light Heavy-Duty Trucks	0.66
Medium Heavy-Duty Trucks	1.45
Heavy Heavy-Duty Trucks	2.07
School Bus/All Other Buses/Other Bus	1.45
Urban Buses	2.07

---

[17] California Air Resources Board, Appendix G Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles, Staff Report of the Proposed Advanced Clean Trucks Regulation (web link: https://ww3.arb.ca.gov/regact/2019/act2019/appg.pdf, posted October, 2019)

[18] Oak Ridge National Laboratory (ORNL) and National Renewable Energy Laboratory (NREL), Medium- and Heavy-Duty Vehicle Electrification: Assessment of Technology and Knowledge Gaps (web link: https://info.ornl.gov/sites/publications/Files/Pub136575.pdf, December 2019)

Table 3.2.2-2. EMFAC2021 Speed Correction Factors for Heavy-Duty Energy Consumption Rates

Speed Bin	Speed Correction Factor	Speed Bin	Speed Correction Factor	Speed Bin	Speed Correction Factor
5	2.85	35	0.75	65	0.91
10	1.35	40	0.79		
15	1.13	45	0.84		
20	1.00	50	0.84		
25	0.92	55	0.87		
30	0.74	60	0.86		

3.3 Ammonia Module

3.3.1 Background

The EMFAC model currently does not estimate ammonia emissions from light and heavy-duty vehicles in California. In the past, such an estimate was provided using Metropolitan Planning Organization (MPO) vehicle miles travelled (VMT) combined with the latest available emission factors for ammonia. The resulting emissions inventory was then uploaded to the CEPAM database to support the State Implementation Plans (SIP). Table 3.3.1 1 and Table 3.3.1 2 detail the historical emission rates used in the 2016 State SIP strategy.

Table 3.3.1-1. Emission factors used in the 2016 SIP inventory for TWC light duty vehicles

Vehicle Category	Technology Type	EF (mg/mi)
Light Duty Vehicles (TWC)	Tier0	69
	Tier1	69
	TLEV	76
	LEV	50
	ULEV	20
	SULEV	20
	LEV II	21

Table 3.3.1-2. Emission factors used in the 2016 SIP inventory for other vehicle categories and technologies

Vehicle Category	Fuel and Catalyst Type	EF (mg/mi)
Light Duty Vehicle	Gasoline non-catalyst	5
	Gasoline oxidation catalyst	15
	Diesel	3.1

Vehicle Category	Fuel and Catalyst Type	EF (mg/mi)
Heavy Duty Vehicle	Gasoline non-catalyst	5
	Gasoline oxidation catalyst	15
	Gasoline three-way catalyst	45
	Diesel	27
Motorcycles	Gasoline non-catalyst	5
Motorcycles	Gasoline Ox cat and three-way catalyst	11

3.3.2 Data Sources

In addition to the historical data sets, staff was able to utilize NH3 data from several recent studies. These are summarized in Table 3.3.2-1 with the new data highlighted in bold.

Table 3.3.2-1. Final Emission Factors for EMFAC2017 NH3 Estimates and Data Sources

Fuel	Vehicle Class	Model Year	EF (mg/mi)	Data Source
Gasoline	Light and Medium Duty Vehicles	1965-1975	5	Historical data
		1975-1979	15	
		1980-1983	50	
		1984-1997	70	Dynamometer studies at UC Riverside and UCLA
		1998-2003	45	Caldecott tunnel study by UC Berkeley published in 2009
		2004-2015	20	Dynamometer studies at UC Riverside and UCLA
		2016+	42	CARB Light Duty Surveillance Program
	Heavy Duty Vehicles	pre-77	5	Historical data
		1977-1983	15	
		1984+	45	Caldecott tunnel study by UC Berkeley published in 2009
	Motorcycles	1965-1994	5	Historical
		1995-2007	6.4	
		2008+	9.2	
Diesel	Light and Medium Duty Vehicles	All	3.1	
	Heavy Duty Vehicles	2011+	220	CARB Truck & Bus Surveillance Program
		2007-2010	38	SCAQMD Heavy Duty Truck Emission Tests
		1965-2006	27	Historical

Fuel	Vehicle Class	Model Year	EF (mg/mi)	Data Source
CNG	Refuse	All	580	200-Vehicle Project
	Transit	All	970	
	Other	All	1060	

The major data sources that are used to update ammonia emission rates in EMFAC2021 include:

CARB Light Duty Surveillance Program: MY 2016+ light-duty gasoline updated to 42 mg/mile based upon emissions data from ten vehicles tested under CARB's light duty surveillance program. Table 3.3.2-2 summarizes these data.

Table 3.3.2-2. Updated Light Duty Emission Factors (CARB Light Duty Surveillance Program)

MY	Vehicle	Test ID	Test (phase)	Distance (mi)	NH_3 (mg)	NH_3 (mg/mi)
2018	Chevrolet Tahoe	1061931	1	1.2	58.68	48.9
		1061931	2	8.6	151.4	17.6
		1061931	3	1.2	73.44	61.2
2017	Toyota Camry	1061976	1	1.2	110.2	91.8
		1061976	2	8.6	103.2	12.0
		1061976	3	1.2	27.12	22.6
2016	Dodge Dart	1061975	1	1.2	150.1	125.1
		1061975	2	8.6	556.4	64.7
		1061975	3	1.2	76.68	63.9
2018	Jeep Wrangler	1062115	1	1.2	36.6	30.5
		1062115	2	8.6	243.4	28.3
		1062115	3	1.2	42.12	35.1
2018	Hyundai Elantra	1062116	1	1.2	61.44	51.2
		1062116	2	8.6	61.06	7.1
		1062116	3	1.2	0	0.0
2018	Nissan Altima	1062226	1	1.2	134.9	112.4
		1062226	2	8.6	411.1	47.8
		1062226	3	1.2	197.6	164.7
2017	Mercedes C300	1062227	1	1.2	90.72	75.6
		1062227	2	8.6	319.9	37.2
		1062227	3	1.2	22.68	18.9
2017	Mazda 3	1062352	1	1.2	12.72	10.6
		1062352	2	8.6	105.8	12.3
		1062352	3	1.2	14.4	12.0

MY	Vehicle	Test ID	Test (phase)	Distance (mi)	NH_3 (mg)	NH_3 (mg/mi)
2018	Ford Fusion	1062353	1	1.2	287	239.2
		1062353	2	8.6	756.8	88.0
		1062353	3	1.2	139.7	116.4
2018	BMW 430I	1062354	1	1.2	122.5	102.1
		1062354	2	8.6	200.4	23.3
		1062354	3	1.2	45	37.5
Average				110	4613.0	41.9

SCAQMD Heavy Duty Truck Emission Tests: MY 2007-2010 heavy-duty diesel vehicles are updated to 38 mg/mile (UDDS) based upon three vehicles from the South Coast Air Quality Management District (SCAQMD) testing. These are noted in Table 3.3.2-3.

Table 3.3.2-3. Pre-SCR Heavy-Duty Diesel Ammonia Emission Rates (SCAQMD Heavy Duty Truck Emission Tests)

Vehicle ID	Model Year	Manufacturer	Main Control	Cycle	NH3 (g/mi)
N12.3	2009	Navistar	Adv. EGR	UDDS	0.013
D14a	2008	DDC	DOC/DPF	UDDS	0.036
D14b	2008	DDC	DOC/DPF	UDDS	0.065

CARB Truck and Bus Surveillance Program (TBSP): MY 2011+ technology heavy-duty diesel vehicles are updated to 220 mg/mile (UDDS) based upon 21 vehicles from the CARB Truck and Bus Surveillance Program (TBSP) testing program. A summary of these data is given in Table 3.3.2-4.

Table 3.3.2-4. Updated Heavy Duty Emission Factors (MY 2011+) (CARB TBSP Testing)

Vehicle	MY	Manufacturer	Test	Repeats	NH_3 (g/mi)
18-Veh2	2015	Cummins	UDDS	3	0.28
18-Veh2	2015	Cummins	UDDS	3	1.25
18-Veh3	2014	Detroit Diesel	UDDS	3	0.13
18-Veh4	2015	Paccar	UDDS	3	0.07
19-Veh10	2016	Detroit Diesel	UDDS	3	0.00
19-Veh11	2017	Detroit Diesel	UDDS	3	0.098
19-Veh15	2019	Cummins	UDDS	3	0.980
19-Veh8	2016	Cummins	UDDS	3	0.00
19-Veh8	2016	Cummins	UDDS	3	0.024
19-Veh9	2018	Volvo	UDDS	3	0.00
20-Veh16	2017	Cummins	UDDS	3	0.008
2S19H01-4	2015	Cummins	UDDS	3	0.007
TBSP A	2010	Cummins ISB6.7	UDDS	3	0.01

Vehicle	MY	Manufacturer	Test	Repeats	NH_3 (g/mi)
TBSP A	2010	Cummins ISB6.7	UDDS	3	0.06
TBSP A	2010	Cummins ISB6.7	UDDS	3	0.00
TBSP B	2010	Cummins ISX15	UDDS	3	0.54
TBSP B	2010	Cummins ISX15	UDDS	3	0.48
TBSP C	2010	Detroit Diesel DD15	UDDS	3	0.40
TBSP C	2010	Detroit Diesel	UDDS	3	0.14
TBSP F	2011	Cummins ISX15	UDDS	3	0.46
TBSP F	2011	Cummins ISX15	UDDS	3	0.30
TBSP I	2012	Cummins ISX15	UDDS	3	0.13
TBSP J	2013	Isuzu 4HKITC	UDDS	3	0.06
TBSP L	2013	Cummins ISX15	UDDS	3	0.01
TBSP L	2013	Cummins ISX15	UDDS	3	0.04
TBSP M	2014	Volvo D13	UDDS	3	1.10
TBSP M	2014	Volvo	UDDS	3	0.01
TBSP N	2014	Detroit Diesel DD15	UDDS	3	0.14
TBSP N	2014	Detroit Diesel DD15	UDDS	3	0.03
TBSP O	2014	Cummins ISX15	UDDS	3	0.13
TBSP P	2014	Navistar	UDDS	3	0.31

200-Vehicle Project: Natural Gas (NG) data were obtained from an SCAQMD test program. These results are summarized Table 3.3.2-5.

Table 3.3.2-5. CNG Ammonia Emission Rates (200-Vehicle Project)

Engine	Vocation	Fuel	Cycle	Distance	NH3 (g)	NH3 (g/mi)
8062	Other	CNG	UDDS	5.4	1.513	0.280
8062	Other	CNG	UDDS	5.4	2.575	0.477
8062	Other	CNG	UDDS	5.4	3.123	0.578
18082	Other	CNG	UDDS	4.8	3.101	0.646
18082	Other	CNG	UDDS	5	3.858	0.772
18082	Other	CNG	UDDS	5	3.429	0.686
18045	Other	CNG	UDDS	5.4	8.307	1.538
18045	Other	CNG	UDDS	5.4	8.435	1.562
18045	Other	CNG	UDDS	5.4	8.302	1.537
8044	Other	CNG	UDDS	5.668	4.722	0.833
8044	Other	CNG	UDDS	5.424	15.53	2.864
8044	Other	CNG	UDDS	5.488	5.231	0.953
18023	Refuse	CNG	UDDS	5.5	2.85	0.518
18023	Refuse	CNG	UDDS	5.5	2.597	0.472
18023	Refuse	CNG	UDDS	5.4	2.913	0.539
8013	Refuse	CNG	UDDS	5.5	3.053	0.555

Engine	Vocation	Fuel	Cycle	Distance	NH3 (g)	NH3 (g/mi)
8013	Refuse	CNG	UDDS	5.5	3.606	0.656
8013	Refuse	CNG	UDDS	5.5	4.013	0.730
18112	Transit	CNG	UDDS	5.6	4.379	0.782
18112	Transit	CNG	UDDS	5.6	6.451	1.152
18112	Transit	CNG	UDDS	5.5	5.388	0.980

3.3.3 Results and Conclusions

Comparing Table 3.3.1-1 and Table 3.3.1-2**,** it is apparent that newer light-duty vehicles have higher emissions than those of the late 1990s and 2000s. It is not obvious whether this is a true increase from the catalyst configurations, or if it is simply differences in how the test programs were conducted. It shows that the newest SCR equipped diesels have significantly higher emissions than older diesels. Historically, emission rates from natural gas were treated the same as diesel, due to lack of data. However, the new testing data shows that they present substantially higher ammonia emissions than diesel.

4 Methodology Updates

4.1 Introduction

This chapter discusses the updates that have taken place in EMFAC2021. It can be broken up into four broad categories, including: fleet characteristics (Section 4.2), emission rate (Section 4.3), activity profile (Section 4.4), and forecasting frameworks (Section 4.5). Update to fleet characteristics include the methodology used in developing the LD and HD vehicle population and age distribution matrices used in EMFAC2021. Emission rate updates not only include changes in base emission rates, but also changes to any associated correction factors. For example, emission rates changes by speed and deteriorate as vehicle aging. Emission rates updates have been made mainly for exhaust emission process. In EMFAC2021, the particulate matter (PM) emission rates from brake wear (non-exhaust emission process) are also updated.

Activity profile updates are made to mileage accrual rates, odometer schedule, speed profile, starts per day, soak time distribution, temporal distribution of VMT and engine starts. New forecasting frameworks are adapted in EMFAC2021 to project vehicle new sales and vehicle miles traveled (VMT) for both LDV and HDV.

4.2 Fleet Characteristics

4.2.1 Light Duty Fleet Characterization

This section describes the major updates to EMFAC2021 fleet characterization and describes changes to the methodology, tools, and data sources used to characterize the vehicle population in California. It also compares the fleet vehicle counts as modeled by EMFAC2017 to that in EMFAC2021.

Starting in January 2018, DMV shared 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. EMFAC2021 uses the October data cut as the main source of data for fleet characterization, but incorporates vehicle registration status from the following April 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 the duplicate records to only keep the last record associated with each vehicle identification number (VIN). All newly acquired VINs are run through VINtelligence[19] to obtain vehicle related information that may be missing from DMV (i.e., gross vehicle weight code, model year, make name, series name, model name, body style, motive power, fuel type, displacement, battery

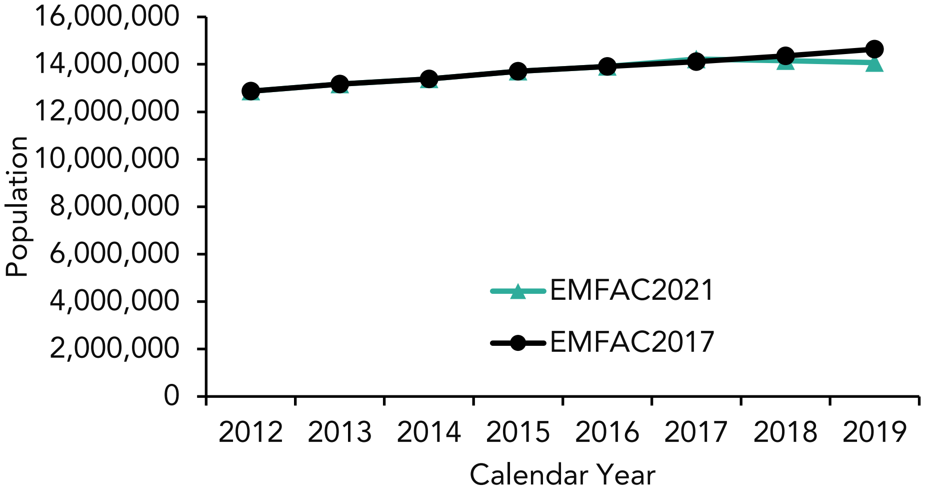
---

[19] A VIN decoder developed by IHS Markit. For more information please see: https://ihsmarkit.com/products/automotive-vin-interpretation-decoding.html

size, etc.). Only on-road vehicles in the October database are analyzed and assigned a vehicle classification. Vehicles are classified based on manufacturer certification EOs 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.

Figure 4.2.1-1 compares EMFAC2021 and EMFAC2017 vehicle populations for gasoline passenger cars (PC). Note that EMFAC2017 projected vehicle population in 2017 and onwards. As shown, EMFAC2021 has slowly declining vehicle populations of less than 1% from 2017 to 2019 compared to the previous model.

Figure 4.2.1-1. Comparison between EMFAC2021 and EMFAC2017 PC gasoline population



Similarly, Figure 4.2.1-2 displays lower counts for gasoline light-duty trucks (LDT) than predicted in EMFAC2017. EMFAC2021 does show continuous growth for the light-duty truck population, and the difference between the populations in both models is less than 3% in 2019.

Figure 4.2.1-2. Comparison between EMFAC2021 and EMFAC2017 LDT gasoline population

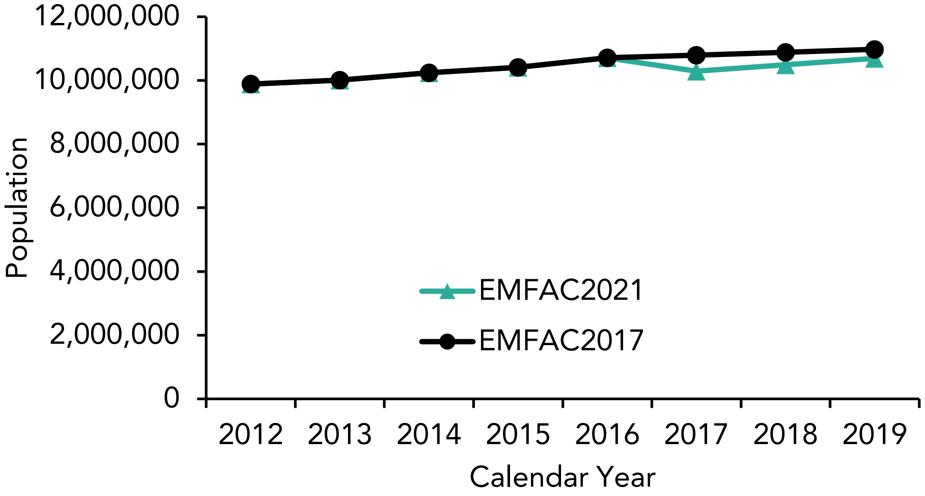


Figure 4.2.1-3 illustrates gasoline light heavy-duty truck (LHDT) populations obtained for EMFAC2021 and EMFAC2017. For this vehicle class, EMFAC2017 predicted a continuous decline in the population while actual DMV counts used in EMFAC2021 indicate substantial growth. The difference in populations show that EMFAC2017 under predicted the counts by nearly 18% for 2019.

Figure 4.2.1-3. Comparison between EMFAC2021 and EMFAC2017 LHDT gasoline population

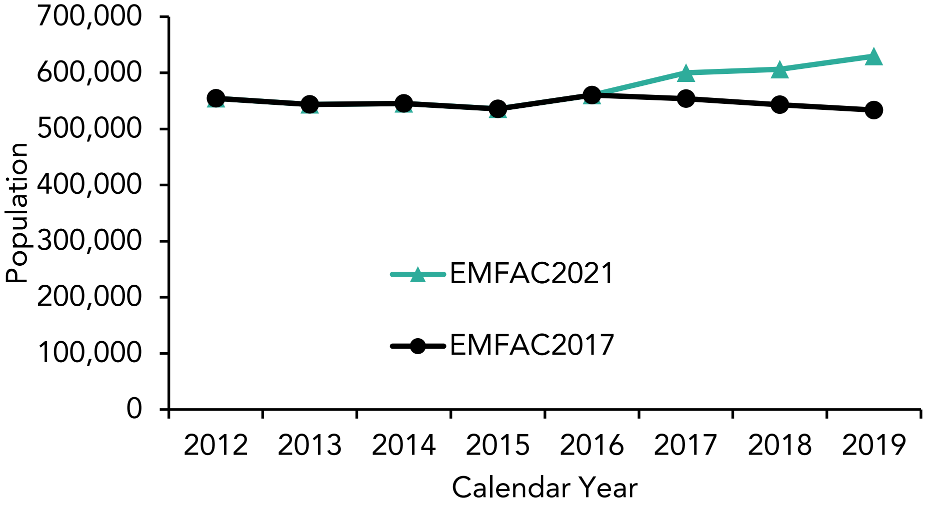
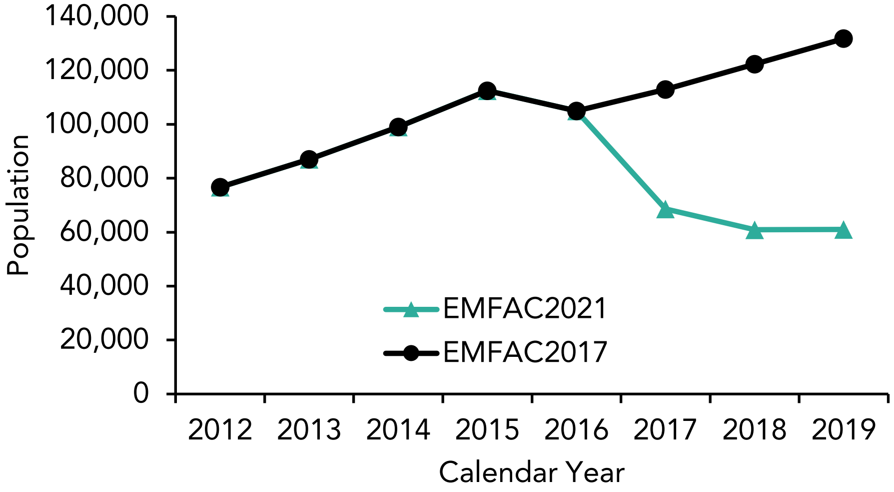


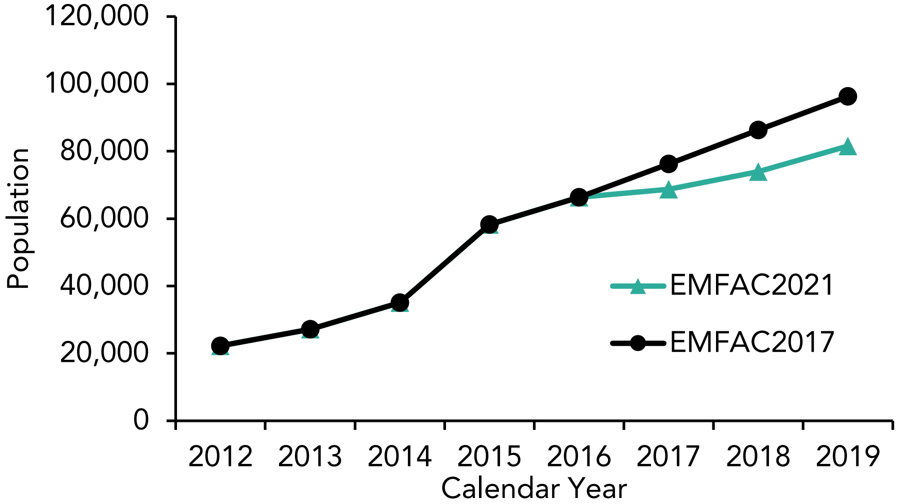
Figure 4.2.1-4 indicates a sharp drop in the number of diesel passenger cars. EMFAC2017 predicted relatively moderate growth for this category, however, EMFAC2021 counts have dropped to less than 50% of the predicted population.

Figure 4.2.1-4. Comparison between EMFAC2021 and EMFAC2017 PC diesel population



As can be seen in Figure 4.2.1-5, EMFAC2017 predicted steady growth for diesel light duty trucks (LDT). EMFAC2021 shows the growth to be significantly slower, and the difference between the two models ranges from about 10-15% lower for calendar years 2017 to 2019.

Figure 4.2.1-5. Comparison between EMFAC2021 and EMFAC2017 LDT diesel population



For diesel LHDT vehicles in Figure 4.2.1-6, there is close agreement between the estimated populations from EMFAC2017 and DMV registration counts reflected in EMFAC2021. EMFAC2021 populations have surpassed forecasted EMFAC2017 populations for this category.

Figure 4.2.1-6. Comparison between EMFAC2021 and EMFAC2017 LHDT diesel population

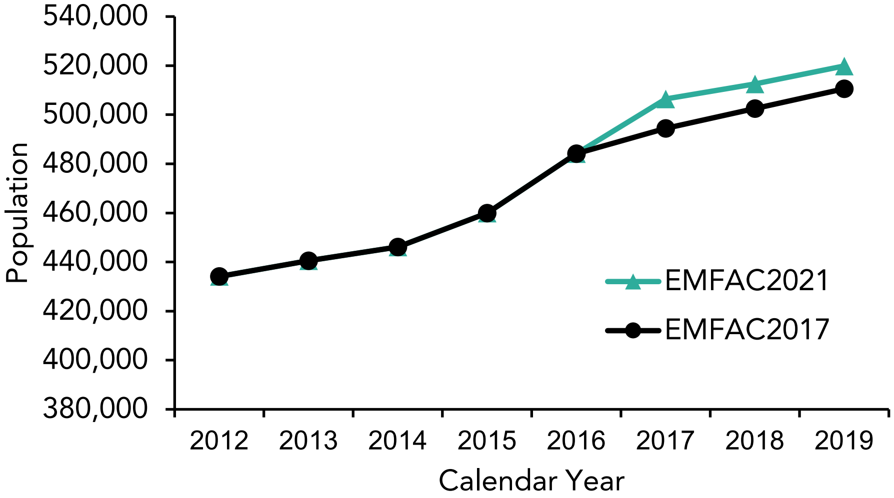
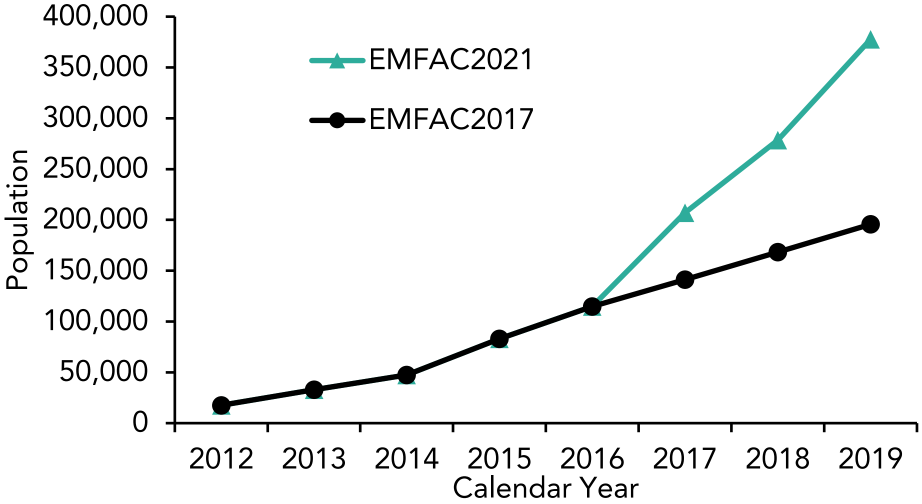


Figure 4.2.1-7 illustrates that the EMFAC2021 electric passenger car (PC) population (or electric equivalent vehicles that have the motive power of electric combined with the electric fraction of PHEVs) is substantially higher than the forecasted population of EMFAC2017. Since EMFAC2017 projected a slower growth rate for the population compared to EMFAC2021, the difference between the two models grows to nearly double the earlier number predicted for 2019. The electric PC population is expected to reach 400,000 vehicles by calendar year 2020.

Figure 4.2.1-7. Comparison between EMFAC2021 and EMFAC2017 PC electric vehicle population



According to Figure 4.2.1-8, electric LDTs have not experienced as rapid growth as their PC counterparts. As in the previous figure, these counts are for electric equivalent vehicles. While electric LDT populations grow in EMFAC2021, the increase for these alternative fuel vehicles is flatter than the rate predicted by EMFAC2017.

Figure 4.2.1-8. Comparison between EMFAC2021 and EMFAC2017 LDT electric vehicle population

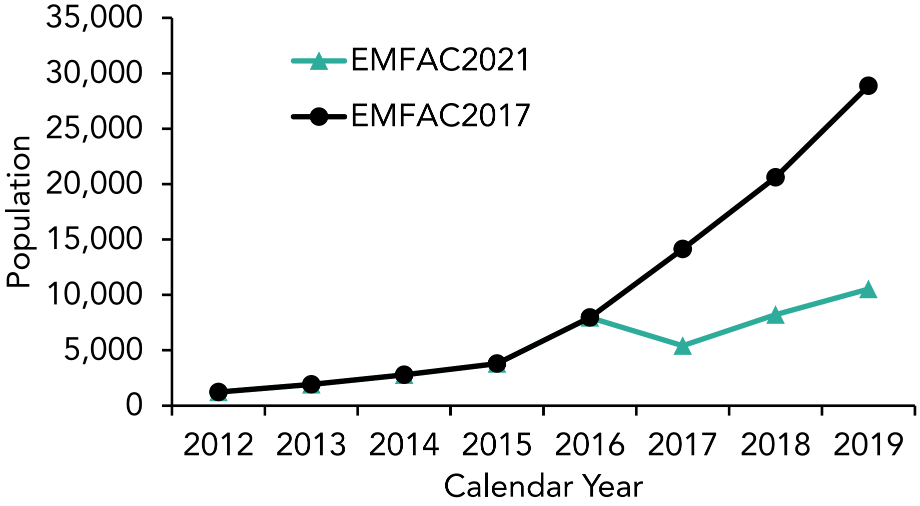


Figure 4.2.1-9 illustrate sales trends for new gasoline PCs and LDTs sold in California. While EMFAC2021 new vehicle sales projections for LDTs are consistent with those in EMFAC2017, there is a continuous decline in new vehicle sales for PCs. For calendar year 2019, the new vehicle sales counts for PC have dropped by over 400,000 vehicles.

Figure 4.2.1-9. Comparison between EMFAC2021 and EMFAC2017 New Sales by Model Year for Gasoline PC and LDT

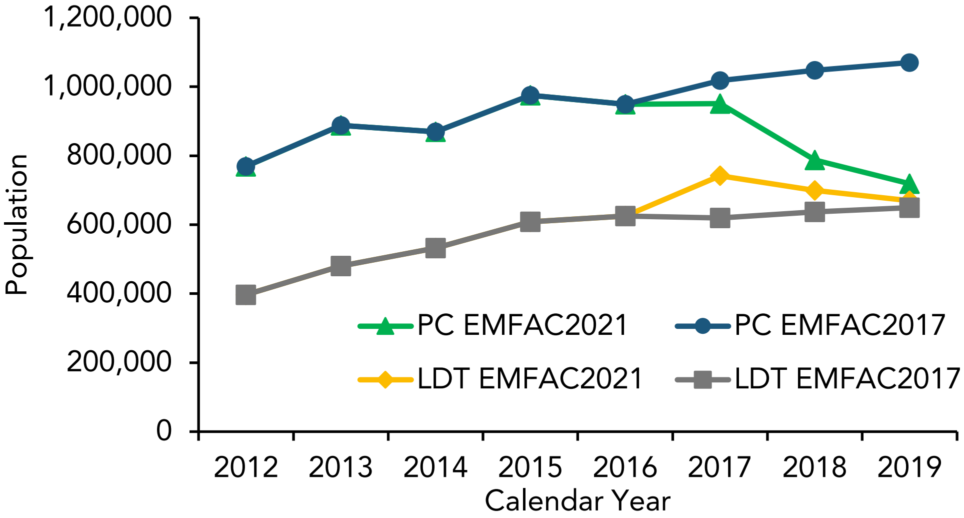


Figure 4.2.1-10 displays the diesel light-duty vehicle market sales. Both diesel PCs and LDTs have experienced major declines in recent years due in part to emissions

irregularities found by CARB and EPA. EMFAC2017 predicted modest sales increases for years 2017 to 2019, but EMFAC2021 shows that new sales have fallen short for the same period.

Figure 4.2.1-10. Comparison between EMFAC2021 and EMFAC2017 New Sales by Model Year for Diesel PC and LDT

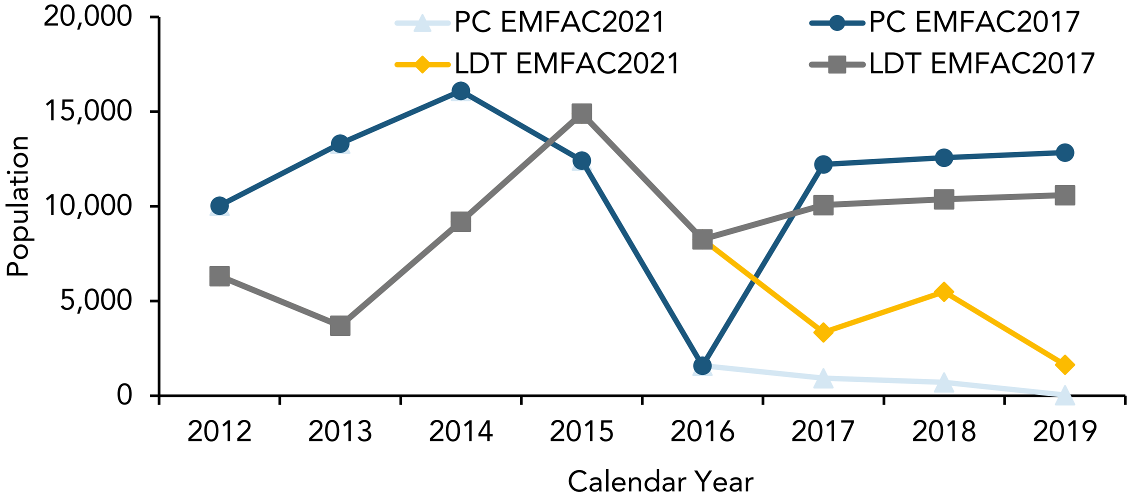


Figure 4.2.1-11 through Figure 4.2.1-13 show the distribution of vehicle population by model year for PCs, LDTs, and LHDTs for EMFAC2021 and EMFAC2017. The PC vehicle count has dropped more significantly than predicted by EMFAC2017. For LDTs and LHDTs, the reverse is true as EMFAC2021 has higher vehicle population for model years 2017 and 2018 when compared to the projected EMFAC2017 vehicle counts. Both models, however, are consistent for model year 2019 LDT and LHDT vehicle populations.

Figure 4.2.1-11. Comparison between EMFAC2021 and EMFAC2017 Model Year Distribution for PC

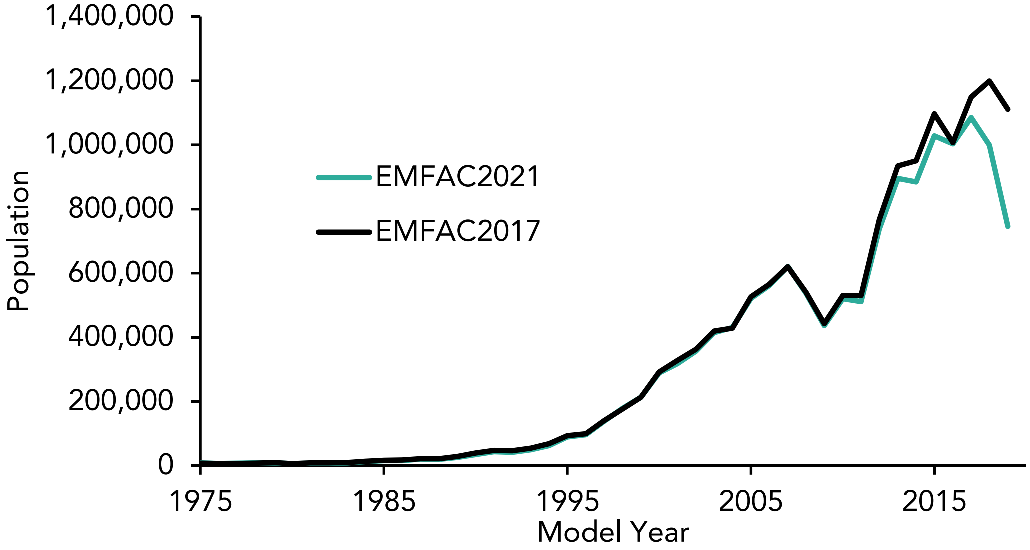


Figure 4.2.1-12. Comparison between EMFAC2021 and EMFAC2017 Model Year Distribution for LDT

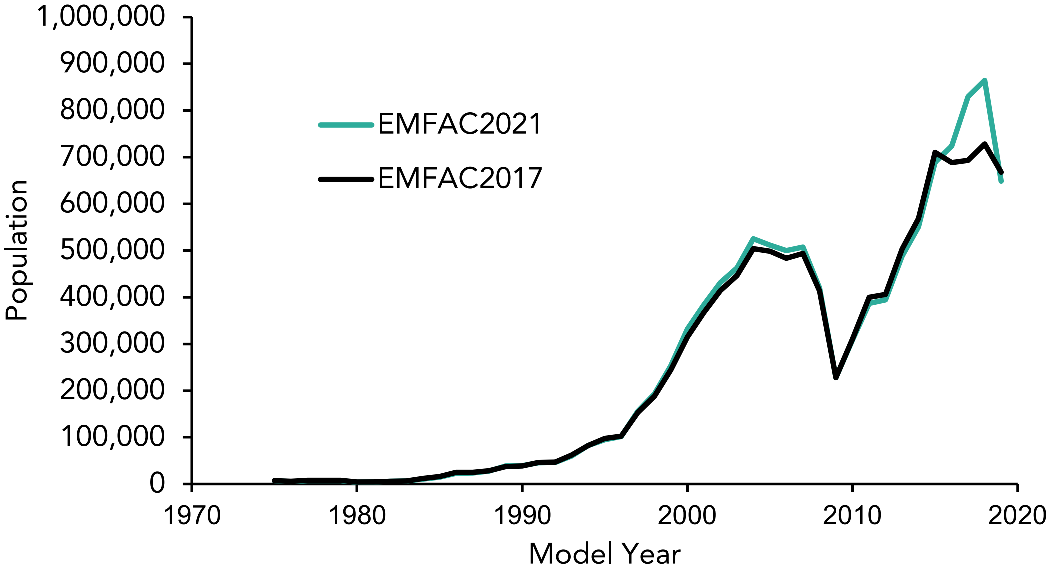
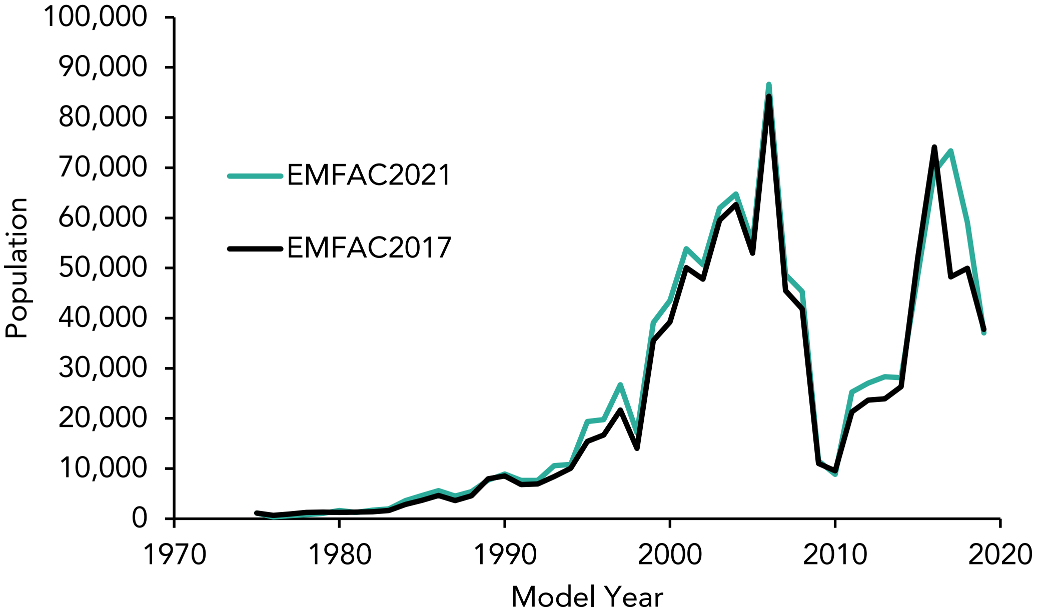


Figure 4.2.1-13. Comparison between EMFAC2021 and EMFAC2017 Model Year Distribution for LHDT



4.2.2 Heavy Duty Fleet Characterization

4.2.2.1 Introduction about HD fleet

This section focuses on the EMFAC2021 population trends for diesel and natural gas fueled medium 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 EMFAC2021 and EMFAC2017. EMFAC2017 had a base-year of 2016 while EMFAC2021 has a base-year of 2019.

4.2.2.2 Major Data Sources for Update

Major data sources used to process the heavy-duty vehicle inventory are as follows.

Processed DMV data. As discussed in the light duty vehicle section, the DMV data sets for historical years through 2019 were processed using additional inputs from various data sources to provide updated vehicle information for vehicles registered in California. DMV data field values are used to designate utility and public fleet vehicles, and to identify 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 instate 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 2019. 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 calendar years 2008 through 2018 International Fuel Tax Agreement (IFTA) mileage data, the historical ratio of VMT for out-of-state trucks as compared to VMT by CA IRP trucks was updated to 1.206 for T7 Non-Neighboring Out-of-state truck (NNOOS) and to 0.374 for T7 Neighboring Out-of-state truck (NOOS) for EMFAC2021. 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.

TRUCRS[20] data for diesel Truck and Bus Rule. Data extracted from the TRUCRS database were 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 CY2017 to CY2019 inventory. In 2019, POLA provided updated VIN lists for CY2010 to CY2019 that included details on the monthly trips per VIN and the monthly average number of trucks to use for EMFAC modeling to update the inventory for all of these years. The selected VINs to flag as POLA each year were based on having annual trips to the port above a certain threshold. Thresholds were back 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 vehicles activity and emissions calculation purposes.

---

[20] https://www.arb.ca.gov/msprog/onrdiesel/reportinginfo.htm

California Highway Patrol (CHP) School Bus Inspections.[21] The CHP provided data on School Buses that receive safety inspections that are required by law.

4.2.2.3 New HD Vocational Categories

The EMFAC2011 heavy-duty fleet categories used in EMFAC2014 and EMFAC2017 reflected MHD truck (T6) and HHD truck (T7) groupings developed to meet regulatory needs such as the Diesel Truck and Bus rule. For EMFAC2021, new fleet category updates were desirable to allow for more specificity in EMFAC activity and emission rates updates to better support future policies.

New fleet groups will assist with more focused emissions reduction programs such as freight hubs, last mile delivery, and local communities. Due to difficulties identifying construction fleet categories, they are no longer displayed as separate fleet groups. For example, 'T6 construction heavy' will now be included with 'T6 heavy', 'T7 construction tractor' will now be included with 'T7 tractor', and so on. Similarly, agricultural fleet categories which displayed vehicles claiming an approved TRUCRS exemption are now absorbed back into appropriate fleet categories such as T6 or T7 tractors, and T6 instate or T7 Single categories.

To provide further details on various weight categories, instate T6 trucks groupings have been disaggregated into weight classes 4 through 7. Exceptions include classes 4-5 for tractors and class 4 for utility trucks, both of which did not have sufficient counts for disaggregation so those small counts were rolled up into the next weight class above.

EMFAC2021 include new subgroup updates for Instate T6 trucks. The new subgroups are based on DMV body type for tractors and for delivery trucks. The remaining instate T6 trucks reside in the T6 other category. The following Table 4.2.2-1 displays the updated EMFAC2021 T6 fleet categories along with the EMFAC2017 fleet categories from which they originate.

---

[21] California Highway Patrol (CHP), School Bus Program (https://www.chp.ca.gov/Programs-Services/Programs/School-Bus-Program)

Table 4.2.2-1. EMFAC2021 T6 (14,001-33,000 lbs.) Fleet Groups

Type	EMFAC2017	EMFAC2021
T6 Truck (14,001-33,000 lbs.)	T6 CAIRP small	T6 CAIRP Class 4
	T6 CAIRP small	T6 CAIRP Class 5
	T6 CAIRP small	T6 CAIRP Class 6
	T6 CAIRP heavy	T6 CAIRP Class 7
	T6 Instate Small	T6 Instate Delivery Class 4
	T6 Instate Small	T6 Instate Delivery Class 5
	T6 Instate Small	T6 Instate Delivery Class 6
	T6 Instate Heavy	T6 Instate Delivery Class 7
	T6 Instate Small	T6 Instate Other Class 4
	T6 Instate Small	T6 Instate Other Class 5
	T6 Instate Small	T6 Instate Other Class 6
	T6 Instate Heavy	T6 Instate Other Class 7
	T6 Instate Small	T6 Instate Tractor Class 6
	T6 Instate Heavy	T6 Instate Tractor Class 7
	T6 OOS Small	T6 OOS Class 4
	T6 OOS Small	T6 OOS Class 5
	T6 OOS Small	T6 OOS Class 6
	T6 OOS Heavy	T6 OOS Class 7
	T6 Public	T6 Public Class 4
	T6 Public	T6 Public Class 5
	T6 Public	T6 Public Class 6
	T6 Public	T6 Public Class 7
	T6 utility	T6 Utility Class 5
	T6 utility	T6 Utility Class 6
	T6 utility	T6 Utility Class 7

T7 single trucks have been split into new sub-groups based on DMV body type for concrete/transit mix trucks and for dump trucks. The remaining T7 single trucks reside in the T7 other category. The following Table 4.2.2-2 displays the updated EMFAC2021 T7 fleet categories along with the EMFAC2017 fleet categories from which they originated.

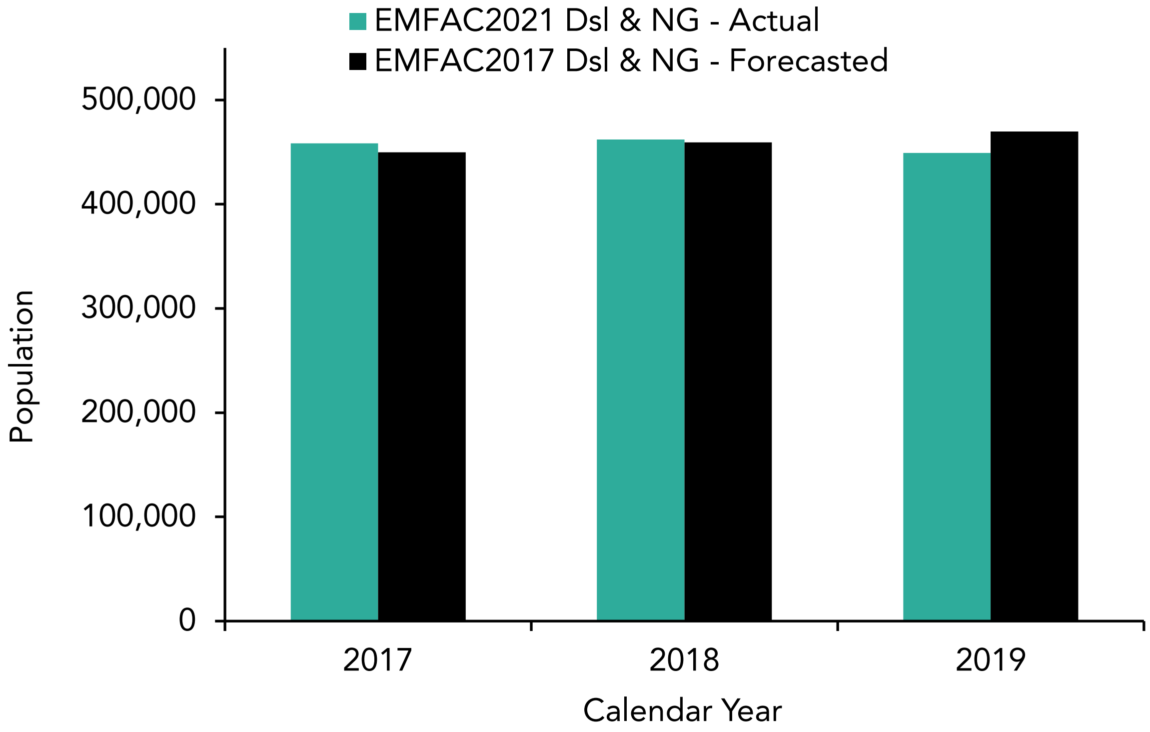
Table 4.2.2-2. EMFAC2021 T7 (>33,000 lbs.) Fleet Groups

Type	EMFAC2017	EMFAC2021
T7 Truck (>33,000 lbs.)	T7 CAIRP	T7 CAIRP Class 8
	T7 NNOOS	T7 NNOOS Class 8
	T7 NOOS	T7 NOOS Class 8
	T7 other port	T7 Other Port Class 8
	T7 POAK	T7 POAK Class 8
	T7 POLA	T7 POLA Class 8
	T7 Public	T7 Public Class 8
	T7 single	T7 Single Concrete/Transit Mix Class 8
	T7 single	T7 Single Dump Class 8
	T7 single	T7 Single Other Class 8
	T7 SWCV	T7 SWCV Class 8
	T7 Tractor	T7 Tractor Class 8
	T7 utility	T7 Utility Class 8

4.2.2.4 In-State Population

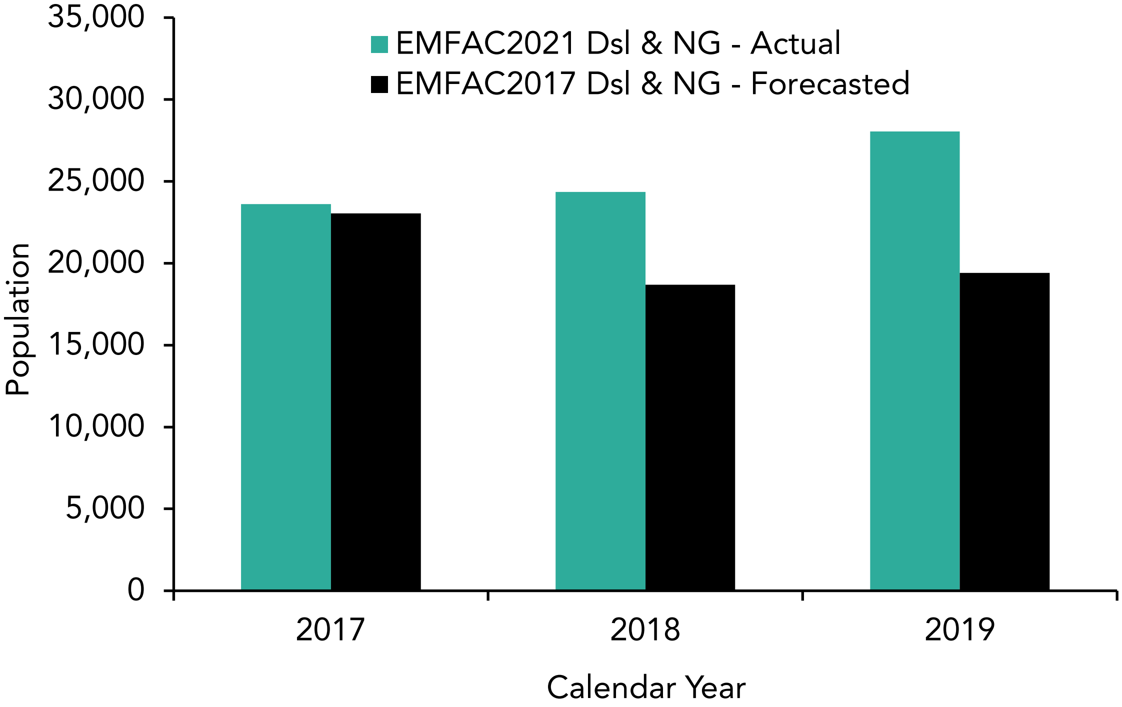
The following Figure 4.2.2-1 compares EMFAC2021 and EMFAC2017 vehicle population for heavy-duty instate trucks. Included trucks in the figure are trucks that operate within California, and those that are diesel and natural gas. Please note that estimates from EMFAC2021 are based on the DMV vehicle registration data while EMFAC2017 estimates for years 2017 and onward are projected using forecasting method described in EMFAC2014 technical support documentation. As shown below, EMFAC2021 has a higher actual vehicle population than was forecasted by EMFAC2017 for the calendar years of 2017 and 2018 while it shows lower population in 2019 when compared to EMFAC2017 projections.

Figure 4.2.2-1. Comparison between EMFAC2021 and EMFAC2017 Instate Heavy-Duty vehicle population



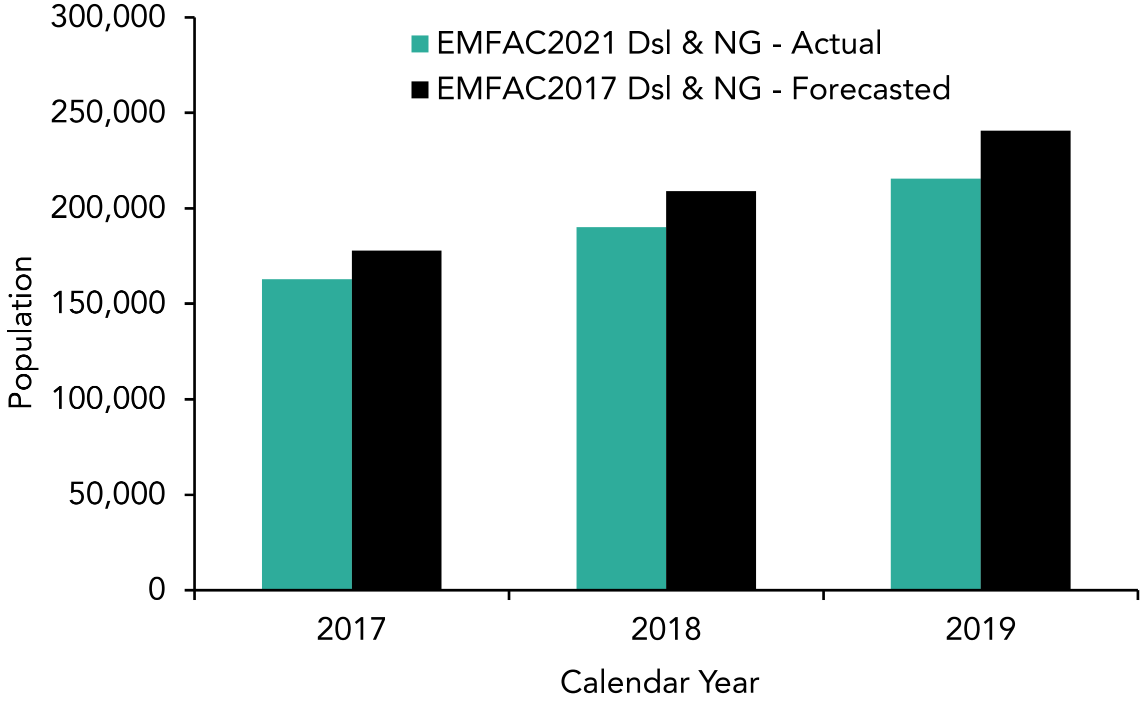
The following Figure 4.2.2-2 compares EMFAC2021 and EMFAC2017 new sales for heavy-duty instate trucks. New sales include all vehicles with chassis model years equal to or greater than the calendar year. For calendar years 2017 to 2019, the new vehicles sales exceeded the EMFAC2017 forecasts with an increase of 2.5% in 2017, 30.3% in 2018, and 44.5% in 2019.

Figure 4.2.2-2. Comparison between EMFAC2021 and EMFAC2017 Instate Heavy-Duty New Vehicle Sales



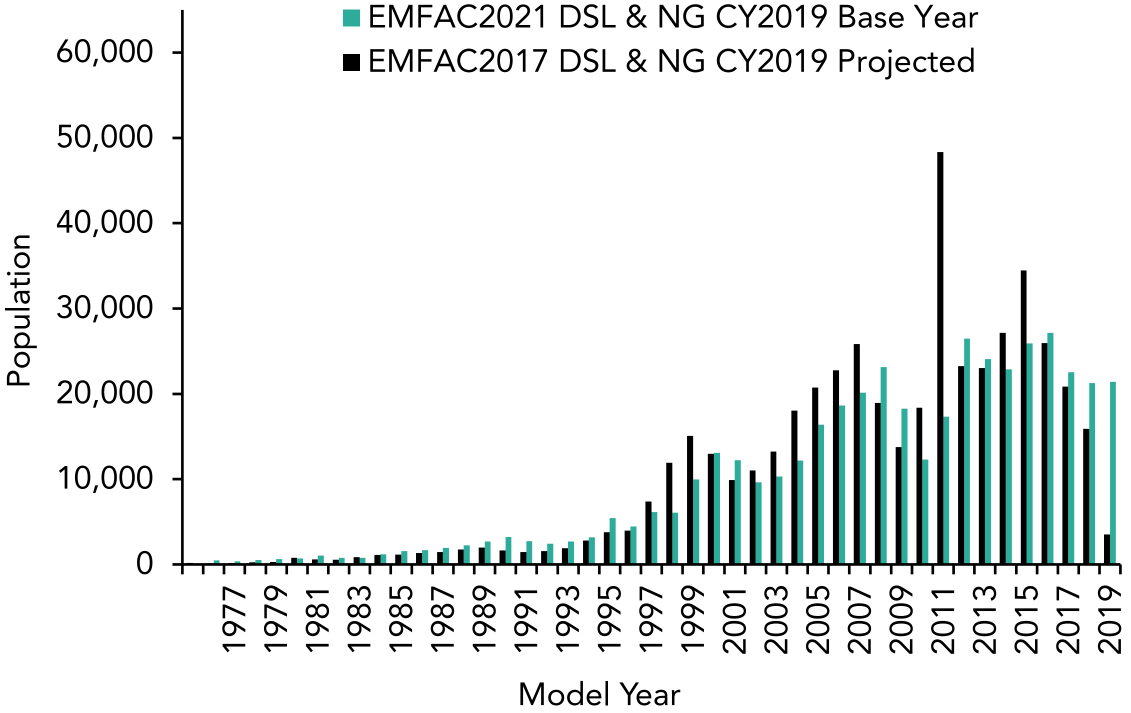
The following Figure 4.2.2-3 compares EMFAC2021 and EMFAC2017 counts of vehicles with a chassis model year of 2011 and greater which would be compliant with the Truck and Bus Rule model year 2010 engine standard requirements. For the majority of heavy-duty trucks, there is typically a one-year lag in the chassis model year from the engine model year. These population counts would include both new and used vehicle sales. The EMFAC2017 forecasted population exceeded the updated population for EMFAC2021. In calendar year 2019, EMFAC2021 showed a 10.4% decrease from the EMFAC2017 projection. EMFAC2017 Truck and Bus Rule assumptions anticipated a higher rate of model year 2010 engine compliant used vehicle sales. However, fleets have various options for achieving compliance. For example, purchasing a model year 2007 engine standard vehicle with an original equipment manufacturer (OEM) particulate filter which does not need to be replaced with a 2010 engine standard vehicle until calendar year 2023. The penetration rate for chassis model year 2011+ vehicles has been increasing over time but with a slight offset compared to what was forecasted in EMFAC2017.

Figure 4.2.2-3. Comparison between EMFAC2021 and EMFAC2017 MY2011+ Instate Heavy-Duty Vehicle Counts



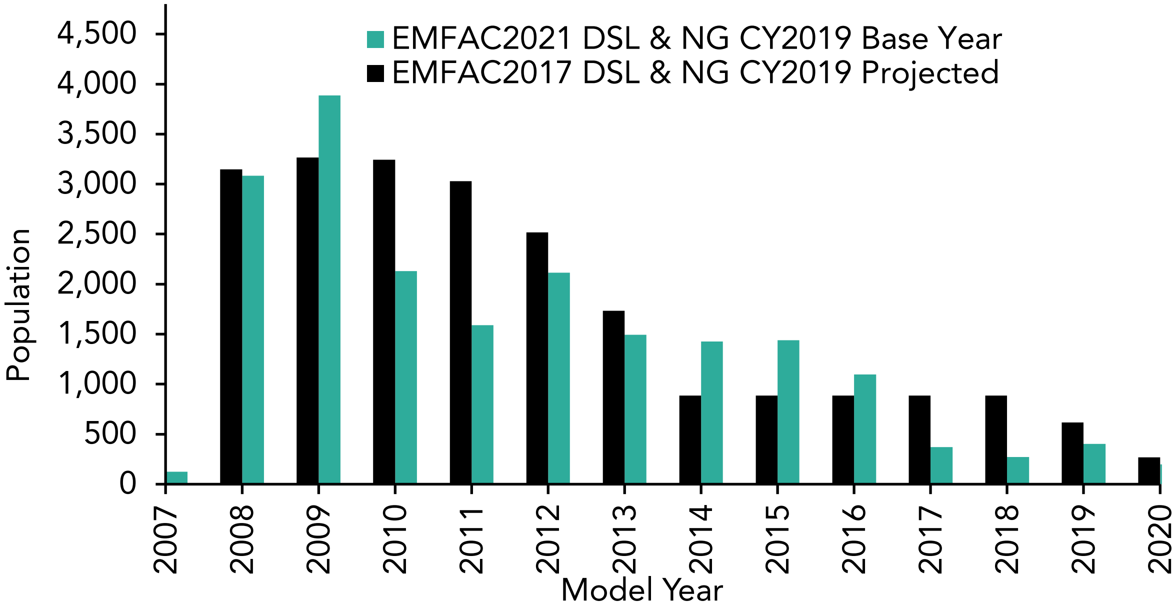
For the new base-year of 2019, EMFAC2021 reflects an average age of 10.9 for instate heavy-duty (MHD and HHD) vehicles. EMFAC2017 used calendar year 2016 as the base year with an average age of 11.2. The following Figure 4.2.2-4 provides a comparison of the age distributions for the 2019 calendar year base year in EMFAC2021 with EMFAC2017 values. As the chart indicates, the EMFAC2021 base year shows decreases in the pre-2011 model years and increases in the 2011+ model years (from both new and used vehicle purchases) as compared to the EMFAC2017 base year. EMFAC2017 shows peaks of 2012 and 2016 model years due to the Truck and Bus vehicle replacement assumptions used. EMFAC2021 modified replacement assumptions to distribute across more model years to reduce such peaks.

Figure 4.2.2-4. Comparison between EMFAC2021 and EMFAC2017 Instate Heavy-Duty Age Distributions



Port trucks had to meet the drayage rule that required MY2007 or newer engines by the beginning of calendar year 2014, which lowered the average age of this fleet group. The Port Truck population in the calendar year 2016 had an average age of 5.24. After all the drayage rule requirements in the past, no further vehicle replacements have been required so the average age increased to 7.51 in calendar year 2019 in EMFAC2021. This is slightly higher the projected average age of 7.27 for calendar year 2019 in EMFAC2017. The following Figure 4.2.2-5 provides a comparison of the age distributions for the 2019 calendar year in EMFAC2021 with EMFAC2017 values. Older chassis model years would reflect engine repowers. 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.

Figure 4.2.2-5. Comparison between EMFAC2021 and EMFAC2017 Heavy Heavy-Duty Port Truck Age Distribution



For HHD instate tractors, the EMFAC2017 base year of calendar year 2016 had an average age of 9.4 which has decreased to 8.0 in the updated EMFAC2021 base year of calendar year 2019. This is similar to the average age of 8.8 years that EMFAC2017 projected for year 2019. A comparison of the age distributions for the 2019 calendar year in EMFAC2021 with EMFAC2017 values for heavy heavy-duty instate tractors is shown in Figure 4.2.2-6.

Figure 4.2.2-6. Comparison between EMFAC2021 and EMFAC2017 Base Year Heavy Heavy-Duty Instate Tractor Age Distribution

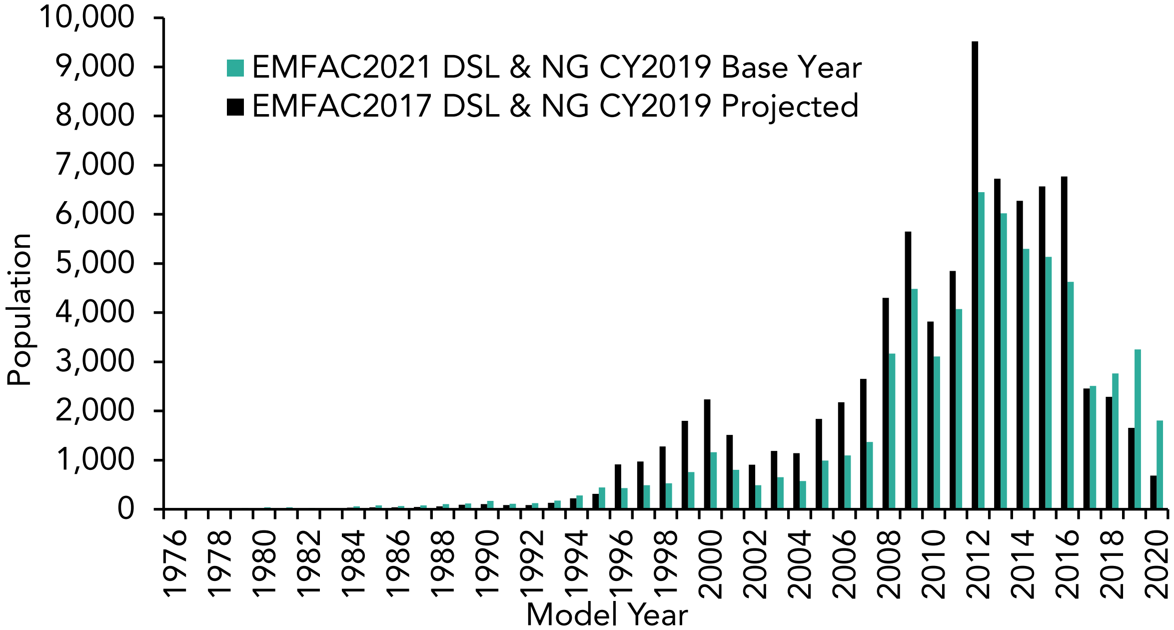


Figure 4.2.2-7 displays a comparison of the updated 2019 calendar year base year in EMFAC2021 with EMFAC2017 values for heavy heavy-duty instate singles. For HHD instate singles, the EMFAC2017 calendar year 2016 base year had an average age of 12.0, which has decreased to 10.6 in the updated EMFAC2021 calendar year 2019 base year. This is slightly lower than the 11.2 average age that EMFAC2017 projected for year 2019.

Figure 4.2.2-7. Comparison between EMFAC2021 and EMFAC2017 Base Year Heavy Heavy-Duty Instate Single Age Distribution

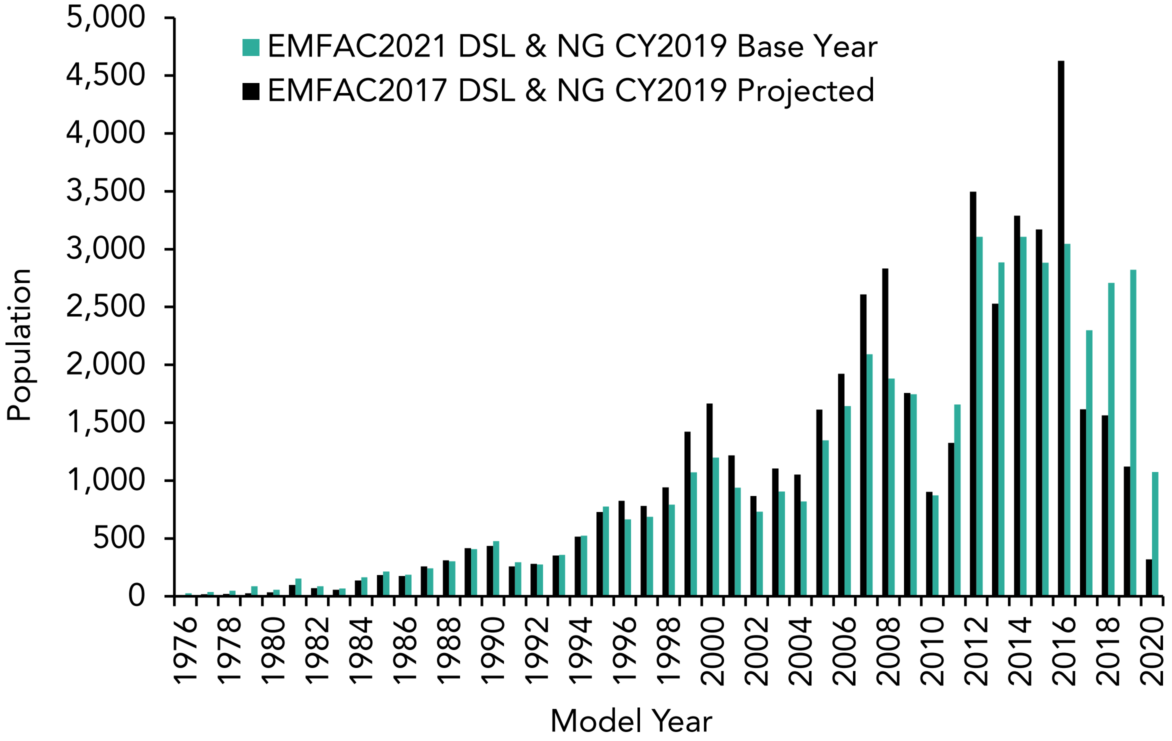
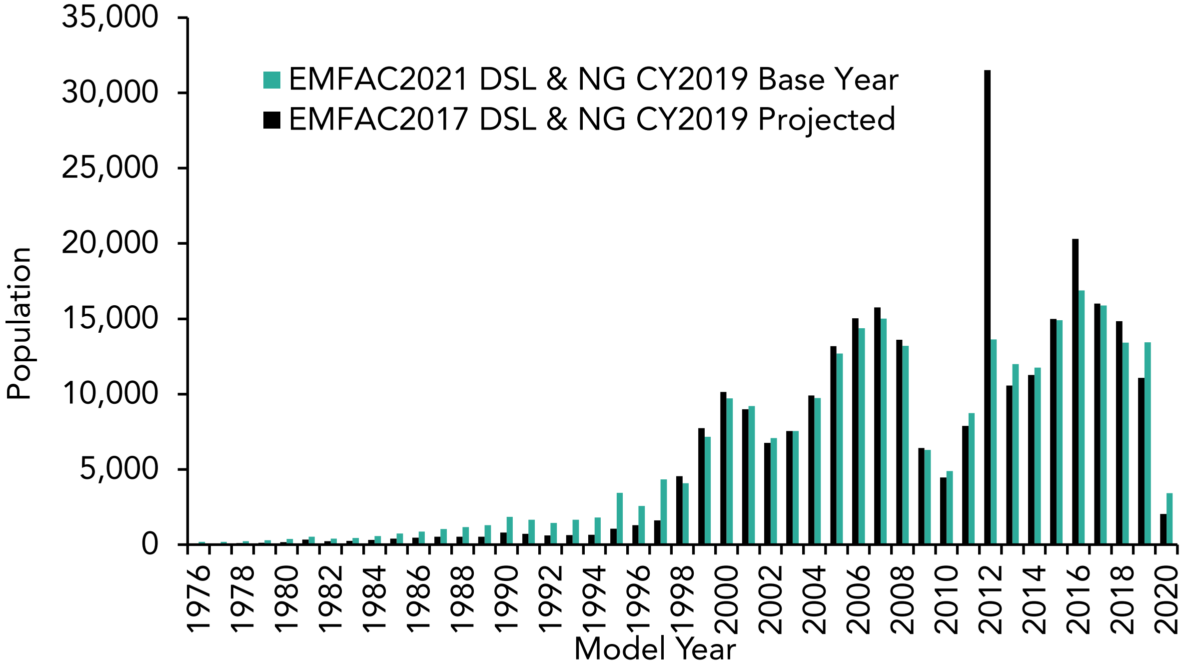


Figure 4.2.2-8 displays a comparison of the updated 2019 calendar year base year in EMFAC2021 with EMFAC2017 values for medium heavy-duty instate vehicles. The EMFAC2017 base year of calendar year 2016 had an average age of 11.3, which has decreased slightly to 11.1 in the updated EMFAC2021 base year of calendar year 2019. This is higher than the average age of 9.8 years that EMFAC2017 projected for calendar year 2019.

Figure 4.2.2-8. Comparison between EMFAC2017 and EMFAC2021 Medium Heavy-Duty Instate Age Distribution

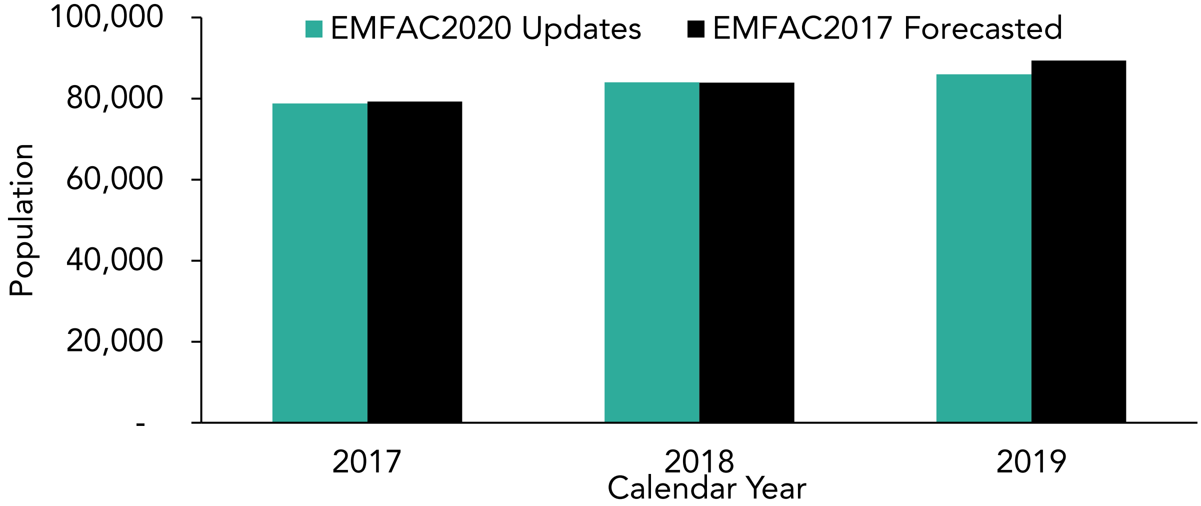


4.2.2.5 California Interstate (CAIRP) Heavy-Duty Fleet Population

The following figure compares EMFAC2021 and EMFAC2017 vehicle population for heavy-duty Interstate trucks that report into the International Registration Plan (CAIRP) with fleet's base jurisdiction designated as California. These trucks are authorized to operate within California and within other states or provinces. As shown in ehicle population by EMFAC2017.

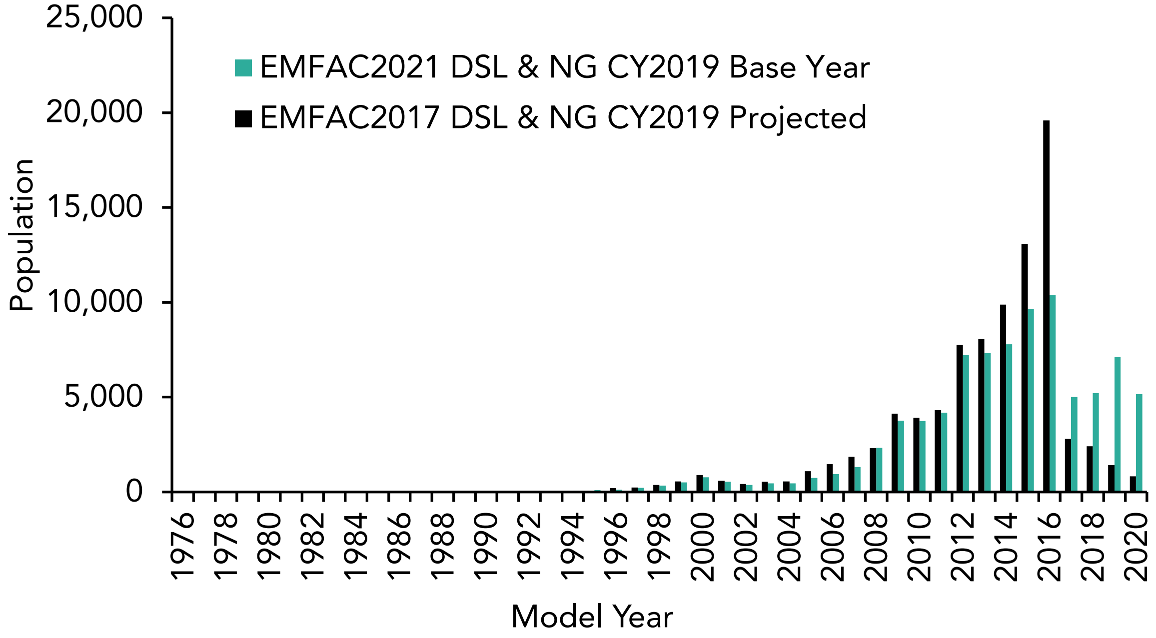
Figure 4.2.2-9, EMFAC2021 shows similar counts in calendar year 2018 and a 3.8% decrease in the counts for calendar year 2019 relative to the forecasted vehicle population by EMFAC2017.

Figure 4.2.2-9. Comparison between EMFAC2021 and EMFAC2017 CAIRP Heavy-Duty vehicle population



For the heavy heavy-duty CAIRP, the calendar year 2016 EMFAC2017 base-year had an average age of 5.8, which has decreased to 5.4 in 2019 updated base-year for EMFAC2021. This is a lower than the 6.1 average age that EMFAC2017 projected for calendar year 2019. A comparison is shown in Figure 4.2.2-10.

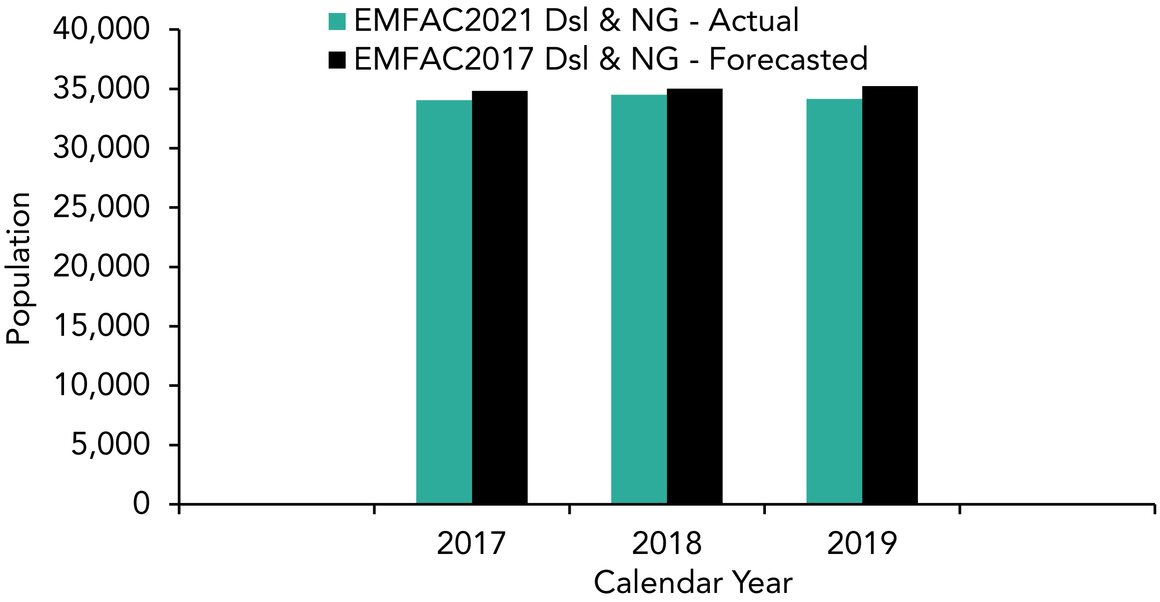
Figure 4.2.2-10. Comparison between EMFAC2021 and EMFAC2017 Heavy Heavy-Duty CAIRP Age Distribution



4.2.2.6 Bus Fleet Population

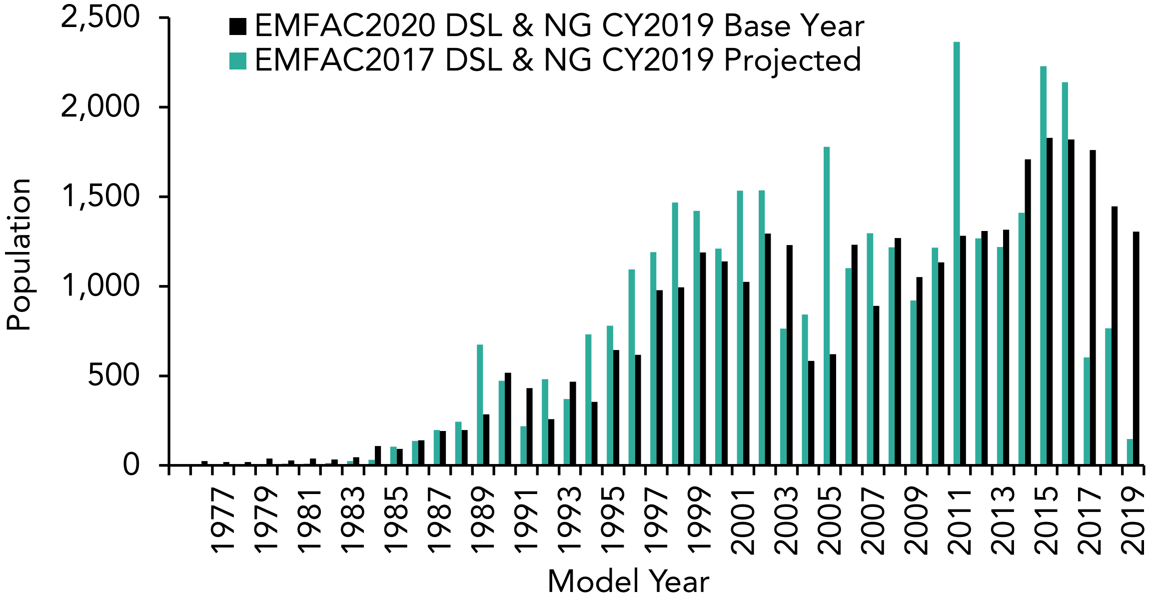
Bus fleet types presented in this section include school buses, transit buses, motor coaches and other buses. Urban transit bus inventory has a separate module that began with EMFAC2017 and is discussed separately. Figure 4.2.1-11 displays the updated heavy-duty bus population for EMFAC2021 new base-year of calendar year 2019 with a comparison to EMFAC2017 values.

Figure 4.2.2-11.Comparison between EMFAC2017 and EMFAC2021 Heavy-Duty Bus vehicle population (excluding Urban Transit Buses)



EMFAC2021 continues to make use of California Highway Patrol inspection reports to flag vehicles in DMV as school buses. The flagged DMV school bus population is then scaled up to reflect the CHP list of total vehicle counts. The scaling process might have resulted in some buses that are less than 14,000 pounds being presented as heavy-duty buses. Figure 4.2.2-12 reflects a positive trend in EMFAC2021 2019 with decreased counts of pre-2011 model years and increased counts of MY2011+ buses.

Figure 4.2.2-12. Comparison between EMFAC2021 and EMFAC2017 Heavy-Duty Bus Age Distribution



4.2.2.7 Updates for Diesel In-Use Fleet Rules

EMFAC2014 and EMFAC2017 incorporated regulatory changes for diesel In-Use Fleet Rules[22] using assumptions regarding the selection of the most likely compliance path options. For EMFAC2021, compliance assumptions had to be updated starting with the new calendar year 2019 base-year inventory and applying updated compliance assumptions as appropriate. Replacement model year (MY) selections for EMFAC2021 spread replaced vehicles across several model years to avoid large spikes in a single model year grouping.

Compliance assumptions for EMFAC2021 reflect the changes in actual inventory with the new calendar year 2019 base-year and updated compliance path options for fleets to meet the diesel In-Use Fleet Rules. The following sections present the updated Retrofit/Replacement assumptions. In 2018, finalized Court decisions voided 2014 amendments to the Truck and Bus Rule[23,24] as discussed in the relevant sections below. As in EMFAC2017, EMFAC2021 assumes a delay in the engine technology standards as compared to the chassis model year for modeling purposes. Thus, a chassis model year

---

[22] https://ww3.arb.ca.gov/msprog/truckstop/truckstop.htm

[23] https://ww3.arb.ca.gov/msprog/truckstop/tb/truckbus.htm

[24] California Air Resources Board (CARB), CTA/Lawson Lawsuit: 2014 Truck & Bus Regulation Amendments Affected (https://ww3.arb.ca.gov/msprog/truckstop/azregs/flexoptions.htm)

of 2008 (MY2008) and newer are assumed to have OEM DPFs and MY2012 and newer vehicles are assumed to meet 2010 engine standards.

EMFAC2014 assumed 100% compliance with the Truck and Bus Rule. EMFAC2017 did not assume 100% compliance each year but did assume achievement of full compliance by calendar year 2023. On April 28, 2017, Governor Brown signed the Road Repair and Accountability Act of 2017 (SB 1). The bill includes a provision that modified the Vehicle Code to prohibit DMV from registering or renewing the registration of medium and heavy-duty diesel trucks unless the truck owner can demonstrate full compliance with applicable emission requirements. Beginning in 2020, DMV has started implementing their vehicle registration hold system[25] therefore EMFAC2021 assumes full compliance beginning in 2020.

The assumption tables below list the "Action", which is either retrofitting with diesel particulate filters (DPF), or replacing an older vehicle with a newer vehicle (turnover). The "DPF" in the "Action" column designates a retrofit requirement for a pre-2008 vehicle not equipped with OEM filters. The numbers (such as 2008, 2012, 2013, etc.) in the "Action" column designate the model year of the replacement vehicles. EMFAC2017 assumptions began for January 1, 2017. EMFAC2021 assumptions begin for January 1, 2020 as vehicle inventory has been updated through calendar year 2019.

Low Use Vehicle[26]

A low-use vehicle is one that operates less than 1,000 miles per calendar year within California's borders. To qualify for this permanent exemption, vehicles must report annual odometer readings into TRUCRS and maintain records that are subject to CARB audits. In EMFAC2017, low-use vehicles also included vehicles that travel less than 5,000 total miles per calendar year and assumed that all pre-2012 low use vehicles (with less than 5,000 miles per year) would be replaced with MY2012 vehicles by January 1, 2020. However, court decisions voided the 5,000 mile per year 2014 amendment and thus EMFAC2021 is no longer reflecting this provision.

Low-Mileage Construction Truck Extension[27]

The Work Truck Phase-in Option is no longer available for EMFAC2021 as this provision was also a voided 2014 amendment. The remaining provision is now the Low-Mileage

---

[25] California Air Resources Board (CARB), DMV Compliance Verification (https://ww3.arb.ca.gov/msprog/truckstop/azregs/dmvreg.htm)

[26] California Air Resources Board (CARB), Truck and Bus Regulation Low-Use Vehicle Exempt (https://www.arb.ca.gov/msprog/onrdiesel/documents/fsLowuse.pdf, last updated September 2019)

[27] California Air Resource Board (CARB), Truck and Bus Regulation Low Mileage Construction Truck Phase-in Option (https://www.arb.ca.gov/msprog/onrdiesel/documents/faqconstructiontrucks.pdf, last updated November 2018)

Construction Truck Extension, which required 100% DPF installations by 2018, and that owners must meet eligibility requirements and complete annual reporting into TRUCRS. Low-mileage construction trucks must operate less than 15,000 miles per year; however, dump trucks can operate up to 20,000 miles per year. At the time of this modeling, the counts for vehicles approved to use this provision in TRUCRS were too low to include in the modeling compliance assumptions. For EMFAC2014 and EMFAC2017, construction truck categories provided separated estimates for the sole purpose of applying Truck and Bus provisions. EMFAC2021x no longer provides the construction categories as a separate fleet category.

Specialty and Limited Mileage Agricultural Truck Provisions[28]

Agricultural truck provisions provided extensions for vehicles that applied in TRUCRS as having eligible specialty equipment or that operated within limited mileage thresholds. EMFAC2017 assumed the limited mileage vehicles above 10,000 miles/year and less than 15,000 miles/year would have 25% of the vehicles replaced with MY2012 vehicles by 2017, 50% by 2020, and 100% by 2023. By 2023, EMFAC2017 assumed that all of the specialty equipment and the limited mileage vehicles of less than 10,000 miles/year would be replaced with 2012 MY trucks. However, the voided 2014 amendments eliminated the mileage limit steps of 15,000 miles per year from January 1, 2017 to January 1, 2020 and the 10,000 miles per year from January 1, 2020 to January 1, 2023.

For EMFAC2021, the specialty vehicle definition that had no mileage restrictions has already expired as of January 1, 2017. Agricultural vehicles that have not exceeded 10,000 miles per year between January 1, 2011 and January 1, 2017 would continue to be exempt until 2023 as long as they do not exceed the 10,000 miles per year and meet annual reporting requirements. At the time of this modeling, the remaining counts for vehicles approved to use this provision in TRUCRS were too low to include in the modeling compliance assumptions. EMFAC2014 and EMFAC2017 provided separate vehicle counts for agricultural fleet groups to apply the Truck and Bus provisions based on reported TRUCR vehicle counts claiming the agricultural exemption compliance options. At the time of this modeling, the counts for vehicles approved to continue to use remaining agricultural provisions in TRUCRS were too low to include in the modeling compliance assumptions and EMFAC2020 no longer displays agricultural fleet categories separately.

Small Fleet Rule Compliance (>26,000 lbs. GVWR)[29]

The Small Fleet Option allowed small fleets to delay vehicle replacements until January 1, 2020 or later for heavier trucks with a gross vehicle weight rating (GVWR) greater than

---

[28] https://www.arb.ca.gov/regact/2014/truckbus14/tbfrooal.pdf

[29] https://ww3.arb.ca.gov/msprog/onrdiesel/documents/tbfinalreg.pdf?_ga=2.99117590.966000508.1577125908-182099193.1574357539

26,000 lbs. To use this option, owners must have reported their fleet information by January 31, 2014, demonstrated they had at least one PM filter no later than July 1, 2014 and report fleet information each January. Table 4.2.2-3 below lists the EMFAC2020 modeling assumptions for small fleet trucks with GVWR above 26,000 lbs. (including single-unit, tractor and interstate IRP trucks).

Table 4.2.2-3. Retrofit/Replacement Assumptions for >26,000 GVWR Trucks in Small Fleets

By Jan 1	Vehicle Model Year	1st Truck Action	2nd Truck Action	3rd Truck Action
2014	1996-2007	100% DPF		
2017	1996-2007		100% DPF	
2018	1996-2007			100% DPF
2020	Pre-2001	40% 2011, 40% 2012, 20% 2013	40% 2011, 40% 2012, 20% 2013	40% 2011, 40% 2012, 20% 2013
2021	2001-2005	40% 2012, 40% 2013, 20% 2014	40% 2012, 40% 2013, 20% 2014	40% 2012, 40% 2013, 20% 2014
2022	2006-2007	40% 2013, 40% 2014, 20% 2015	40% 2013, 40% 2014, 20% 2015	40% 2013, 40% 2014, 20% 2015
2023	2008-2010	40% 2014, 40% 2015, 20% 2016	40% 2014, 40% 2015, 20% 2016	40% 2014, 40% 2015, 20% 2016

Large Fleet Rule Compliance (>26,000 lbs. GVWR)[30]

Heavier trucks and buses with a GVWR greater than 26,000 pounds must comply with a schedule by engine model year. For EMFAC2017, staff assumed that by January 1, 2014, only a portion of pre-2008 trucks within this category were retrofitted with DPFs based on the number of pre-2008 model year trucks in the 2016 DMV registration data and the number of retrofits that were sold in California (excluding those retrofits that were used for fleets to meet PAU, Transit, and SWCV rules). EMFAC2021 continues to use similar assumptions for the portion of pre-2008 trucks retrofitted with DPFs by January 1, 2014. The EMFAC2021 modeling assumptions for large fleets are shown below in Table 4.2.2-4 4.2.2-5 through 4.2.2-9.

Table 4.2.2-4. Replacement Assumptions for >26,000 GVWR Out of State Trucks (Large Fleets)

By Jan 1	Vehicle Model Year	Fleet Action (Turnover to)
2012	1996-1999	15% DPF
2013	2000-2004	15% DPF
2014	2005-2007	15% DPF
2020	Pre-2001	2018

---

[30] https://www.arb.ca.gov/msprog/onrdiesel/documents/FSRegSum.pdf

By Jan 1	Vehicle Model Year	Fleet Action (Turnover to)
2021	2001-2005	2019
2022	2006-2007	2020
2023	2008-2010	2021

Table 4.2.2-5. Replacement Assumptions for >26,000 GVWR Tractors (Large Fleets)

By Jan 1	Vehicle Model Year	Fleet Action (Turnover to)
2012	1996-1999	15% DPF
2013	2000-2004	15% DPF
2014	2005-2007	15% DPF
2020	Pre-1997	40% 2011, 40% 2012, 20% 2013
2020	1997-2000	40% 2014, 40% 2015, 20% 2016
2021	2001-2005	40% 2015, 40% 2016, 20% 2017
2022	2006-2007	40% 2016, 40% 2017, 20% 2018
2023	2008-2010	40% 2016, 40% 2017, 20% 2018

Table 4.2.2-6. Replacement Assumptions for >26,000 GVWR Single Unit Trucks (Large Fleets)

By Jan 1	Vehicle Model Year	Fleet Action (Turnover to)
2012	1996-1999	15% DPF
2013	2000-2004	15% DPF
2014	2005-2007	15% DPF
2020	Pre-1997	40% 2011, 40% 2012, 20% 2013
2020	1997-2000	40% 2012, 40% 2013, 20% 2014
2021	2001-2005	40% 2013, 40% 2014, 20% 2015
2022	2006-2007	40% 2014, 40% 2015, 20% 2016
2023	2008-2010	40% 2014, 40% 2015, 20% 2016

NOx Exempt Area Extensions[31]

The NOx Exempt Area Extension only applies to vehicles that travel exclusively within specified NOx exempt areas, and excludes school buses. Regions of the state added in the 2014 amendments are no longer applicable for these NOx provisions due to court decisions. Only vehicles in the remaining regions of the state are qualified to make use of this provision. Qualified vehicles that met the delayed schedule PM filter requirements do not need to be replaced.

---

[31] https://www.arb.ca.gov/msprog/onrdiesel/documents/fsnoxexempt.pdf

Table 4.2.2-7. Retrofit Assumptions for >26,000 GVWR Trucks in the NOx Exempt Areas

By Jan 1	Vehicle Model Year	Large Fleets	% of Small Fleet Trucks that must have DPF		
		Fleets with>3 Trucks	1 Truck Fleet	2 Truck Fleet	3 Truck Fleet
2019	Pre-2008	85% must have DPF	100%	100%	100%
2020	Pre-2008	100% must have DPF	100%	100%	100%

Table 4.2.2-8. Retrofit Assumptions for <=26,000 GVWR Trucks in the NOx Exempt Areas

By Jan 1	Vehicle Model Year	All Fleets (Both Large and Small Fleets have the same requirements)
2019	Pre-2001	100% of these must have DPF
2020	2001-2004	100% of these must have DPF
2021	2005-2007	100% of these must have DPF

Assumptions for Trucks <= 26,000 GVWR[32]

This section discusses compliance requirements and options that are available to lighter vehicles. Lighter vehicles are those with a gross vehicle weight rating (GVWR) of 14,001 to 26,000 lbs. These requirements and options do not apply to school buses. Table 4.2.2-9 illustrated EMFAC2021 assumptions on most likely compliance path for these vehicles.

Table 4.2.2-9. Replacement Assumptions for <=26,000 GVWR Trucks

By Jan 1	Vehicle Model Year	Fleet Action (Turnover to)
2020	2000-2004	40% 2012, 40% 2013, 20% 2014
2021	2005-2007	40% 2015, 40% 2016, 20% 2017
2023	2008-2010	40% 2016, 40% 2017, 20% 2018

School Bus Provision

Diesel-fueled school buses with a gross vehicle weight rating (GVWR) over 14,000 lbs. are subject to the Truck and Bus Regulation. Owners needed to retire school buses manufactured before April 1, 1977 by calendar year 2012 and DPFs were required to be installed according to a phase-in schedule that was to be completed by CY2014. All 2-stroke engine buses were being replaced by January 1, 2018.

---

[32] https://ww3.arb.ca.gov/msprog/onrdiesel/documents/fsregsum.pdf

Public/Utility/Solid Waste Collection Vehicles[33,34]

CARB approved a regulation in 2003 that required diesel-fueled solid waste collection vehicles (SWCV) use CARB verified control technology according to a phase-in schedule completed by 2010. EMFAC2021 assumes all pre-2008 diesel SWCV installed DPFs by January 1, 2012. In 2005, CARB approved a regulation to reduce diesel particulate matter (PM) emissions from fleets operated by public agencies and utilities (PAU). EMFAC2021 assumes all pre-2008 diesel public vehicles operating in higher population regions installed DPFs by January 1, 2013, and by January 1, 2018 for those operating in lower population regions. For utility trucks, EMFAC2021 assumes DPF retrofits were completed by January 1, 2011 and that all pre-2012 utility vehicles will be replaced with 40% MY2012, 40% MY2013 and 20% MY2014 vehicles by January 1, 2021.

4.2.3 Transit Bus Population

The National Transit Database (NTD) is used as the primary source of information to obtain population and activity for urban transit buses (UBUS) in EMFAC. The NTD was established as required by Congress to be the nation's primary source of information and statistics on the transit systems. The State requires transit agencies to report their activity to NTD annually if they receive or benefit from federal grants[35, 36]. NTD reports provide rich and detailed accounts of transit fleet activity data for emission modeling purposes. Examples of data provided include vehicle make, model year, fuel type, capacity, number of active vehicles, VMT for each transit agency, and service mode. The most recent NTD report, 2019, is used as the base year to project the urban buses' activity and population for EMFAC2021.

In EMFA2017, staff processed the 2000-2015 annual NTD revenue inventory data to generate the most recent historical transit bus population and VMT data for urban buses. In EMFAC2021, staff further processed the 2016-2019 annual NTD data. Depending on the funding sources that urban and rural transit agencies use, they have different reporting requirements and structure. Staff include both urban and rural reports in their analyses in order to obtain the UBUS activities.

The future population and VMT are forecasted at the regional level using specific growth rates estimated for each subarea or region. For areas governed by MPOs, transit growth rates extracted from the Regional Transportation Plan/Sustainable Communities Strategy

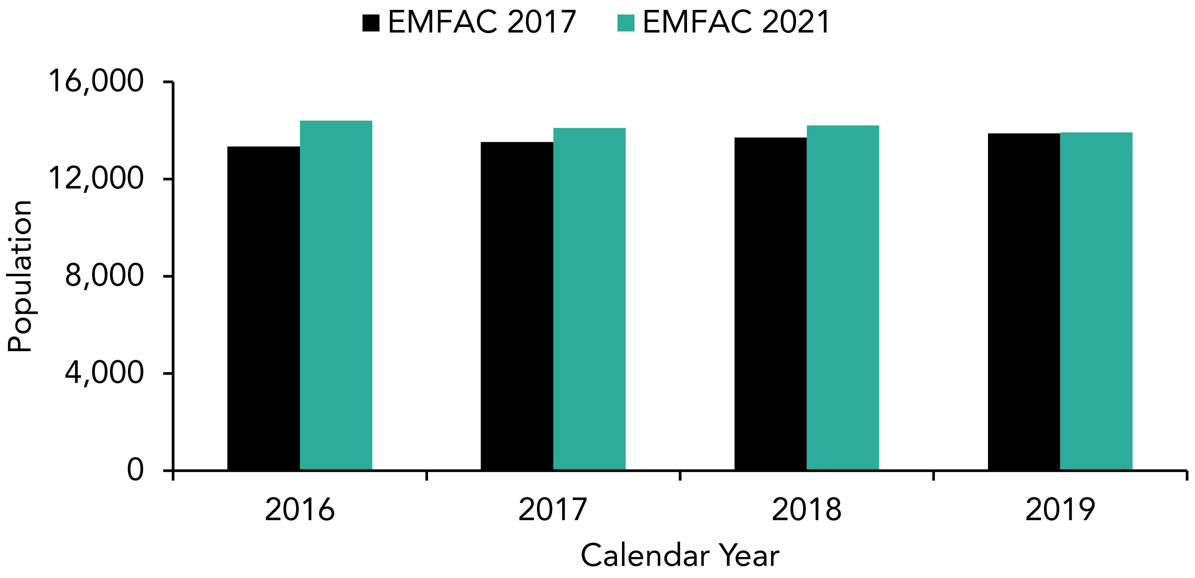
---

[33] https://www.arb.ca.gov/msprog/publicfleets/publicfleetsfactsheet.pdf
[34] https://www.arb.ca.gov/msprog/swcv/trashtruck.pdf
[35] https://www.transit.dot.gov/funding/grants/urbanized-area-formula-grants-5307
[36] https://www.transit.dot.gov/rural-formula-grants-5311

(RTP/SCS)[37] were used. For areas that are not covered by an MPO, or where local MPOs do not forecast transit growth, the county-level human population growth rate published by the Department of Finance were used as a surrogate for the transit growth.[38] Where human population growth was negative, EMFAC2021 assumed a zero growth rate for transit VMT in that region (i.e., the VMT neither increases nor decreases).

Similar to EMFAC2017, EMFAC2021 assumes transit buses have a fixed life span and will be removed from the service after their useful life. For lighter vehicles with GVWR less than 14,000 lbs., the useful life is assumed to be 10 years, and for the rest of the vehicles, the useful life is assumed to be 14 years. Figure 4.2.3-1 compares the projected population from EMFAC2017 with the most recent processed NTD in EMFAC2021.

Figure 4.2.3-1. EMFAC 2017 Transit Bus population compared to processed NTD 2016-2019



CARB's Board adopted the Innovative Clean Transit (ICT) regulation in December 2018. This regulation intends to enhance public health by improving air quality and to mitigate climate change by transforming California transit bus fleets to zero-emissions technologies. The ICT regulation will achieve its electrification goal by gradually increasing the fraction of zero-emission buses (ZEBs) purchased and the number of engines with low NOx emissions purchased in early years, if available, to replace the

---

[37] Regional Plans and Evaluations (https://ww2.arb.ca.gov/our-work/programs/sustainable-communities-program/regional-plans-evaluations)

[38] California Department of Finance (DOF), Population Projections (baseline 2019), P-2A Total Population for California and Counties (https://www.dof.ca.gov/Forecasting/Demographics/Projections/)

existing conventional internal combustion engine buses. This regulation applies to all transit agencies that own, operate, or lease buses with GVWR larger than 14,000 lbs.

Starting 2023, large agencies are required to have a certain percentage of their new purchases as ZEB. For small agencies, this requirement starts in 2025. By the year 2030, all new purchases are required to be ZEB for both small and large agencies. Table 4.2.3-1 shows the general phase-in schedule of ZEBs for standard buses in large and small agencies. The purchase requirements for cutaways and other types of buses will start in 2026 or later. The detailed assumptions and methods for modeling the ICT regulation can be found in the Appendix L of ICT staff report. [39, 40]

Table 4.2.3-1. ZEB phase in based on ICT scheduling

	ZEB % of Total New Bus Purchase	
Year	Large Transit Agency	Small Transit Agency
2023	25%	-
2024	25%	-
2025	25%	-
2026	50%	25%
2027	50%	25%
2028	50%	25%
2029 and after	100%	100%

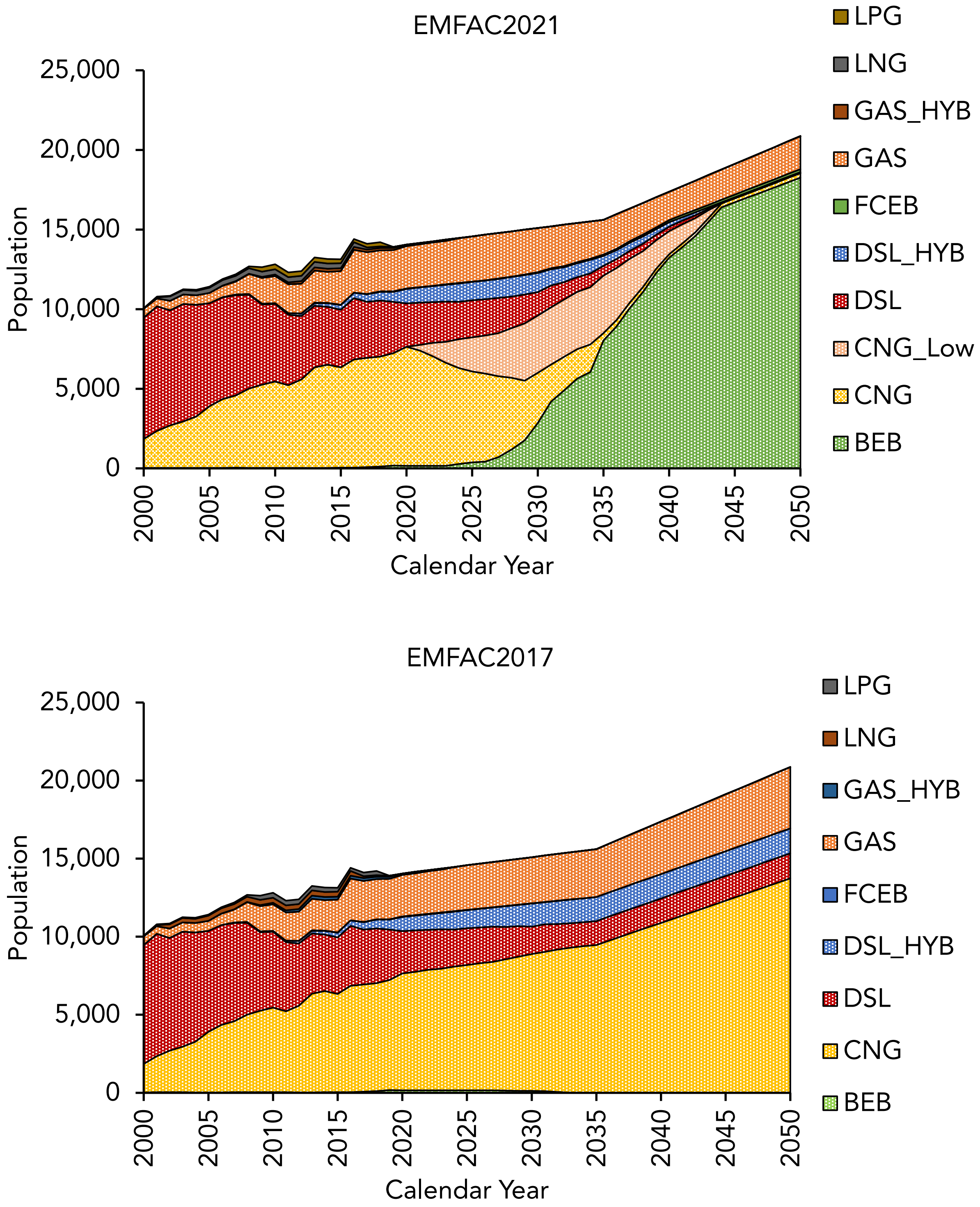
Figure 4.2.3-2 illustrates the population of the urban buses by fuel type. As shown, ZEB population gradually increases over time starting from 2023 according to the ICT schedule.

---

[39] CARB (2018). Appendix L: Emission Inventory Methods and Results for the Proposed Innovative Clean Transit Regulation, https://ww3.arb.ca.gov/regact/2018/ict2018/appl.pdf?_ga=2.215362455.1626164022.1612202484-1307567751.1567730621)

[40] CARB (2018). Attachment C: Updates to the Emission Inventory Methods and Results for the Proposed Innovative Clean Transit Regulation (https://ww2.arb.ca.gov/rulemaking/2018/innovative-clean-transit-2018)

Figure 4.2.3-2. Technology mixture for urban buses based on ICT regulation.



4.2.4 Natural Gas Population

In previous EMFAC models, only emissions from natural gas transit buses and refuse trucks were modeled explicitly. Starting in EMFAC2017, a module was developed to estimate natural gas truck population based on the fraction of natural gas vehicles among heavy-duty truck population at the air district level. However, due to limited emission test data for natural gas powered vehicles, this module treated emission rates from natural gas trucks the same as their diesel counterpart. Besides, it was kept as an optional selection for end users, and the estimated natural gas population or emissions were not included as parts of the default emission inventory output. With the availability of emission tests for a wide variety of natural gas vehicles (Section 4.3.5.4), EMFAC2021 updated the natural gas truck population and modeled emissions from these trucks explicitly in the default emission inventory.

EMFAC2021 followed similar method to EMFAC2017 estimate natural gas truck population, yet incorporated more recent vehicle registration data to expand the coverage of vehicle categories and model years. EMFAC2017 used the model years of 2011 as the cut-off point for estimating the natural gas population, while EMFAC2021 tracked back to model year 2008. As compared to EMFAC2017, EMFAC2021 reduced the natural gas penetration fraction prediction classes to a flat average and a linear regression class. The flat average class assumes that a constant fraction of natural gas penetration, while the linear regression class assumes that natural gas fraction increases as a function of model year until it reaches 100%. Details of natural gas truck penetration fraction at each air district is provided in Appendix 6.4.

Moreover, EMFAC2021 treated the historical natural gas vehicle fraction differently. EMFAC2017 used the model predicted values even for the historical years, while EMFAC2021 applied fractions obtained from the DMV directly. Figure 4.2.4-1 shows two examples of natural gas truck prediction classes for heavy heavy-duty public trucks: linear for South Coast AQMD and flat-averaged for San Joaquin Valley Unified APCD.

Figure 4.2.4-1. Natural gas fractions for heavy heavy-duty public trucks based on two different prediction classes

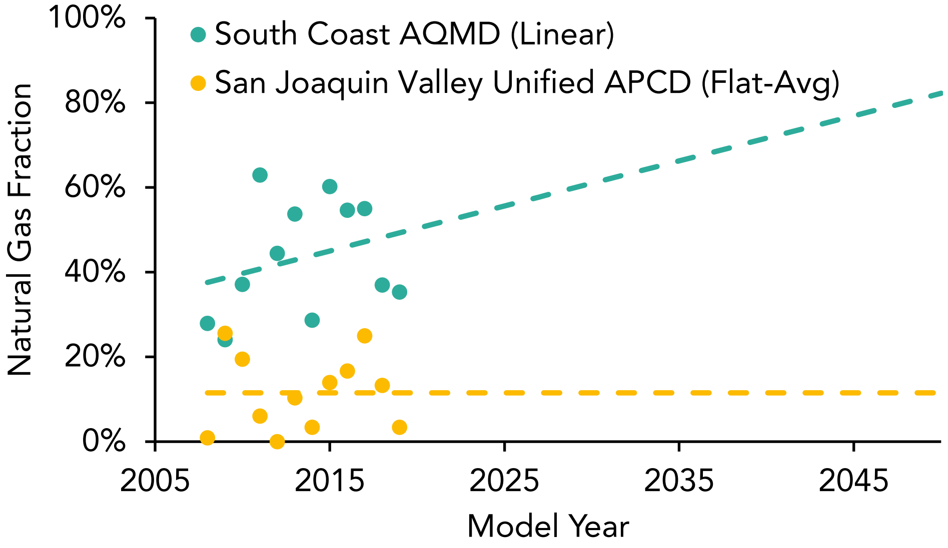
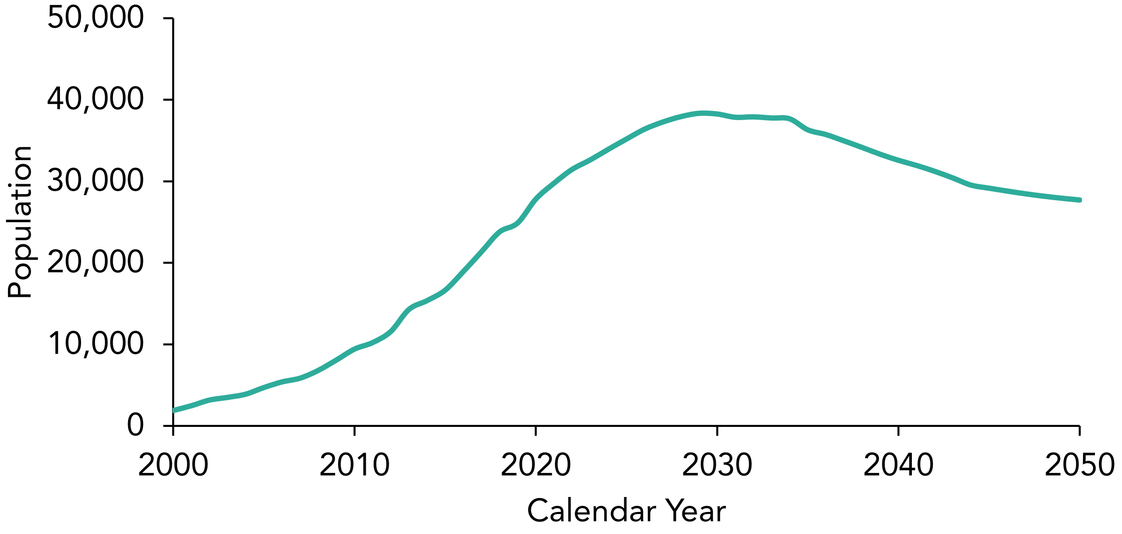


Figure 4.2.4-2 illustrates the statewide population of natural gas heavy-duty trucks from 2000-2050. Please note that this chart also includes population of natural gas powered transit buses that were discussed in Section 4.2.3. It is worth mentioning that refuse trucks are a major portion of the natural gas truck population. The decrease in number of natural gas trucks is caused by the ACT regulation, which generally reduces the population of trucks with internal combustion engines.

Figure 4.2.4-2. Statewide natural gas vehicle population based on EMFAC2021



In 2013, California established optional low-NOx standards with the most aggressive being 0.02 g/bhp-hr, which is 90% below the current standard. As a result, since 2016, a number of natural gas- and propane-fueled Otto-cycle engine families have been certified to the optional low NOx standards of 0.02 g/bhp-hr.[41] The analysis of sales volume of CARB certified heavy-duty natural gas engines shows that engines certified to 0.02 g/bhp-hr NOx are roughly 50% starting from model year 2017 and approximately 100% for the model year 2018 and newer. Therefore, the emission rates for natural gas engines have been adjusted accordingly to these fractions. Detailed discussion about natural gas truck and bus emission rates can be found in Section 4.3.5.4.

4.3 Emission Rates

4.3.1 Light Duty Emission Rates

Emissions that emanate from the vehicle's tailpipe are called exhaust emissions. Incomplete combustion of the fuel is the primary cause of hydrocarbon (HC), carbon monoxide (CO), and particulate matter (PM) emissions. These emissions occur at all times but are more intense when the air-to-fuel ratio is richer than stoichiometric (14.7-to-1) conditions, such as during hard acceleration. Oxides of nitrogen (NOx) emissions are produced during combustion at high temperatures and pressures and can be enhanced under lean air-to-fuel ratio conditions. Properly working catalysts reduce tailpipe emissions from gasoline vehicles by over 90 percent when combined with electronic systems that monitor the air-to-fuel ratio. Due to higher combustion temperatures, excess air, and high pressures, a diesel-fueled vehicle emits comparatively more NOx than a gasoline-fueled vehicle. The lean overall air-to-fuel ratios used by diesel vehicles precluded the use of conventional reduction catalysts for emissions control systems. Combustion engine vehicles also emit carbon dioxide (CO2) and contribute to statewide greenhouse gas (GHG) emissions. It should be noted that EMFAC uses measured CO2 emissions data to predict CO2 emissions and emission rates.

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 mimicking typical vehicle driving and operating patterns. Emission rates are ultimately combined with vehicle activity data (such as vehicle population counts) to estimate vehicle emissions inventories.

In EMFAC2017, the base emission rates (BER) used to compute the running and the starts emission rates were updated for the first time since EMFAC2000. In EMFAC2021,

---

[41] CARB (2020). Optional Low NOx Certified Heavy-Duty Engines (https://ww2.arb.ca.gov/sites/default/files/classic//msprog/onroad/optionnox/optional_low_nox_certified_hd_engines.pdf)

those BERs are further evaluated and updated based on three years of new data from the US EPA's In-Use Vehicle Program (IUVP) and CARB's Vehicle Surveillance Program (VSP). The method to determine BERs are similar to EMFAC2017, but a new "low" emission regime has been added to model deterioration at lower emission levels. The new test data are also used to update the Ratio of Standards (ROS) for characterizing technology groups (i.e., new certification levels) lacking sufficient test data.

As described in the EMFAC2017 technical documentation, see Section 4.3.1.1.3, the light-duty vehicle fleet can be categorized into unique "technology groups."[42] Each technology group represents vehicles with distinct emission control technologies with similar in-use deterioration rates and response to repairs. Further, vehicles in each technology group can be sub-divided into "emission regimes" defined by certification standards (i.e., Standards defined over the Federal Test Procedures –FTP). In order to calculate the fleet average emission rates (i.e., Base Emission Rate – BER), emission factors associated with each regime (i.e., Regime emission factor) are weighted using the percent of vehicles within each regime (i.e., regime fractions).

In EMFAC2017, staff included three emission regimes, including normal, moderate, and high. In EMFAC2021, a new "low" regime is separated from the normal regime to model deterioration at lower emission levels (Table 4.3.1-1). The low regime's emission factor is the average FTP emissions of vehicles that have emissions less than 0.5 times of the standard. The emission factor for the revised normal regime is the average emissions of vehicles that have emissions between 0.5 and 1 times the standard.

Table 4.3.1-1. Emission regime definitions in EMFAC2021 model

Emission Regime	Emission Range
Low	0 to 0.5 x Standard
Normal	0.5 to 1.0 x Standard
Moderate	1.0 to 2.0 x Standard
High	> 2.0 x Standard

Other than adding the new "low" emission regime, the method of BER determination in EMFAC2021 is similar to EMFAC2017, including the test cycle (UC cycle), data sources (IUVP and VSP), and the definition of technology groups. These are described in detail in Section 4.3.1.1 of EMFAC2017 Technical Documentation.

For EMFAC2021, UC BERs are updated with the past three years of new data from the IUVP and VSP programs, including running and start exhaust emission rates of HC, NOx, and CO for LEV1 and LEV2 technology groups. The new data are also used to update the Ratio of Standards (ROS) for the LEV3 BERs. In general, to update BERs, the following steps were taken:

---

[42] See appendix 6.2

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 tests data for the selected tech group from VSP under the FTP and UC tests
5. Classify FTP composite emission rate data by 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.

Table 4.3.1-2 shows a sample of results for HC emissions associated with LEV2 LEVs. The U.S. EPA's IUVP data were used to determine the fractions of low, normal, moderate and high emitters versus odometer for LEV1 and LEV2 vehicles. The IUVP results were weighted by the California sales of each test group. Sales data were obtained from the manufacturers' non-methane organic gas (NMOG) reports to CARB. The CARB's 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 bin for that regime. Finally, a curve is fitted to average emission rates for each bin versus odometer.

Table 4.3.1-2. Sample of Results for LEV2 LEVs Hydrocarbon (HC)

IUVP Data

Odometer Bin	Regime	Count	Regime Fraction	Sales Weighted Regime Fraction
0-50 kmi	Low	214	0.88	0.80
	Normal	27	0.11	0.19
	Moderate	2	0.01	0.01
	High	0	0.00	0.00
50-100 kmi	Low	190	0.56	0.39
	Normal	138	0.41	0.57
	Moderate	8	0.02	0.03
	High	1	0.00	0.00
100-150 kmi	Low	26	0.48	0.39
	Normal	26	0.48	0.59
	Moderate	2	0.04	0.02
	High	0	0.00	0.00

VSP Data:

UC Bag	Regime	Count	UC Phase	Mean HC (g/mile)
UC_{P1}	Low	12	1	0.440
	Normal	13	1	0.927
	Moderate	5	1	1.045
	High	1	1	2.080
UC_{P2}	Low	12	2	0.014
	Normal	13	2	0.014
	Moderate	5	2	0.037
	High	1	2	0.037
UC_{P3}	Low	12	3	0.028
	Normal	13	3	0.062
	Moderate	5	3	0.076
	High	1	3	0.076

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.

Figure 4.3.1-1 to Figure 4.3.1-5 show comparison between EMFAC2021 and EMFAC2017 emission rates. Both running and start exhaust emission rates for HC and NOx for LEV1 LEV and LEV1 ULEV showed higher rates in EMFAC2021 when compared to EMFAC2017, especially for high odometer regimes. For LEV2 technology groups, EMFAC2021 shows lower HC emissions for LEV2 ULEV. However, HC emission rates are slightly higher for LEV2 LEV in high odometer ranges and significantly higher for LEV2 SULEV in EMFAC2021 than EMFAC2017. The NOx running exhaust emission rates of LEV2 LEV and LEV2 ULEV are higher in EMFAC2021 with an increased odometer reading, although LEV2 SULEV is mostly closer to EMFAC2017 values. For HC and NOx start exhaust emission rates, all LEV2 technology groups showed higher emissions in EMFAC2021 than in EMFAC2017.

For LEV3 technology groups (MY from 2015), EMFAC assumes LEV160, ULEV125, and SULEV30 share the same running and start exhaust emission regressions with LEV2 LEV, LEV2 ULEV, and LEV2 SULEV, separately. For other LEV3 certification levels such as ULEV70, ULEV50, and SULEV20, a Ratio of Standards (ROS) approach is used from EMFAC2014 to estimate future technologies' emission rates since there are limited available data to accurately develop their own emission regressions. Previously, the ROS were derived from the ratio of emission standards between the LEV3 HC+NOx certification and its LEV2 base. Despite that, staff concluded that based on the most recent CARB VSP test results, applying the same ROS to all test phases might not be appropriate. Therefore, in EMFAC2021, the ROS for LEV3 tech groups were further assessed and updated based on the latest VSP or FTP test data, available EPA fuel economy test data, and staff engineering judgment. Figure 4.3.1-6 to Figure 4.3.1-8 compare the UC bag emission rates for various technology groups in EMFAC2021.

Figure 4.3.1-1. UC Bags 1-3 HC and NOx emission rates (g/mi) for LEV1 LEVs – EMFAC2021 vs. EMFAC2017

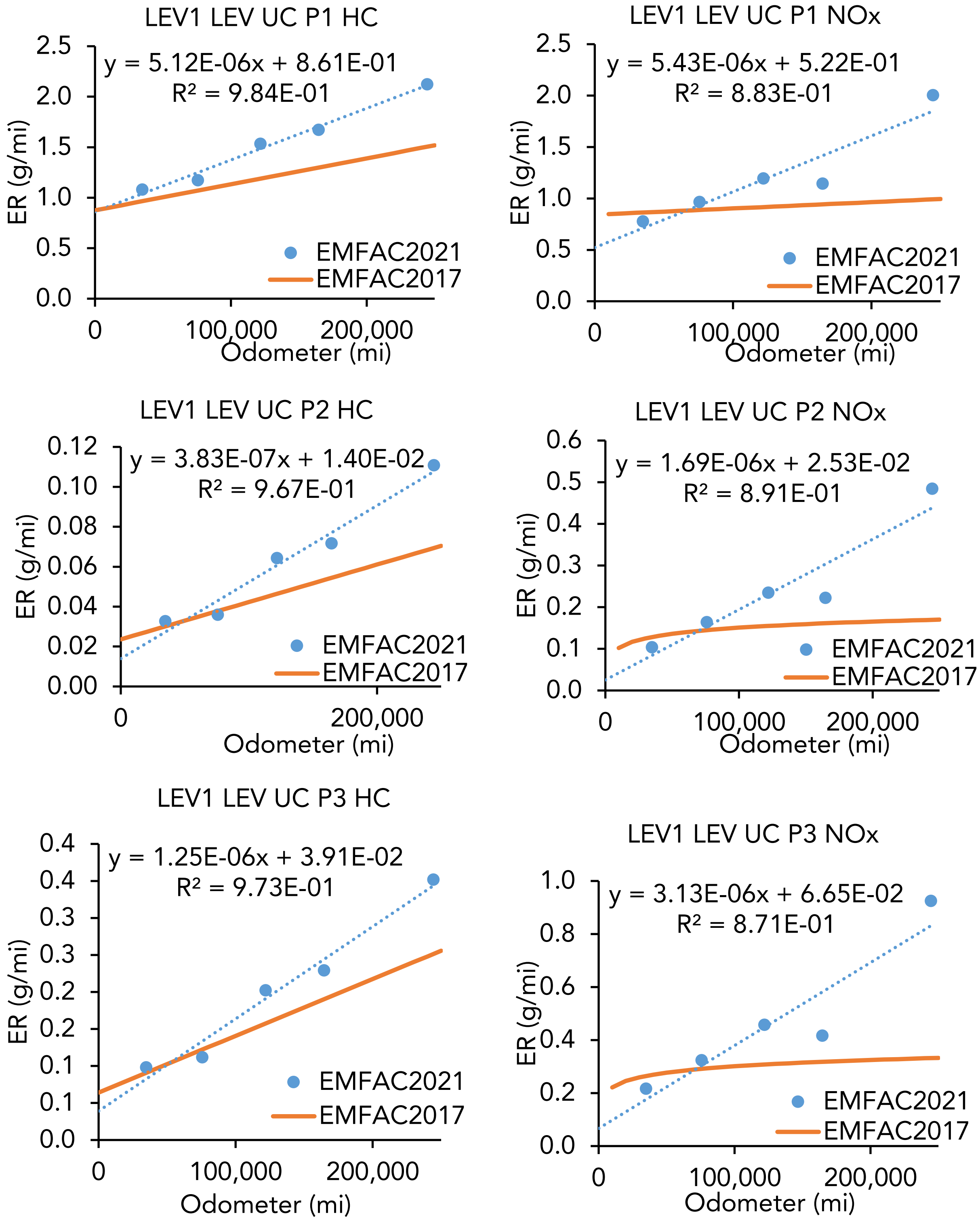


Figure 4.3.1-2. UC Bags 1-3 HC and NOx emission rates (g/mi) for LEV1 ULEVs – EMFAC2021 vs. EMFAC2017

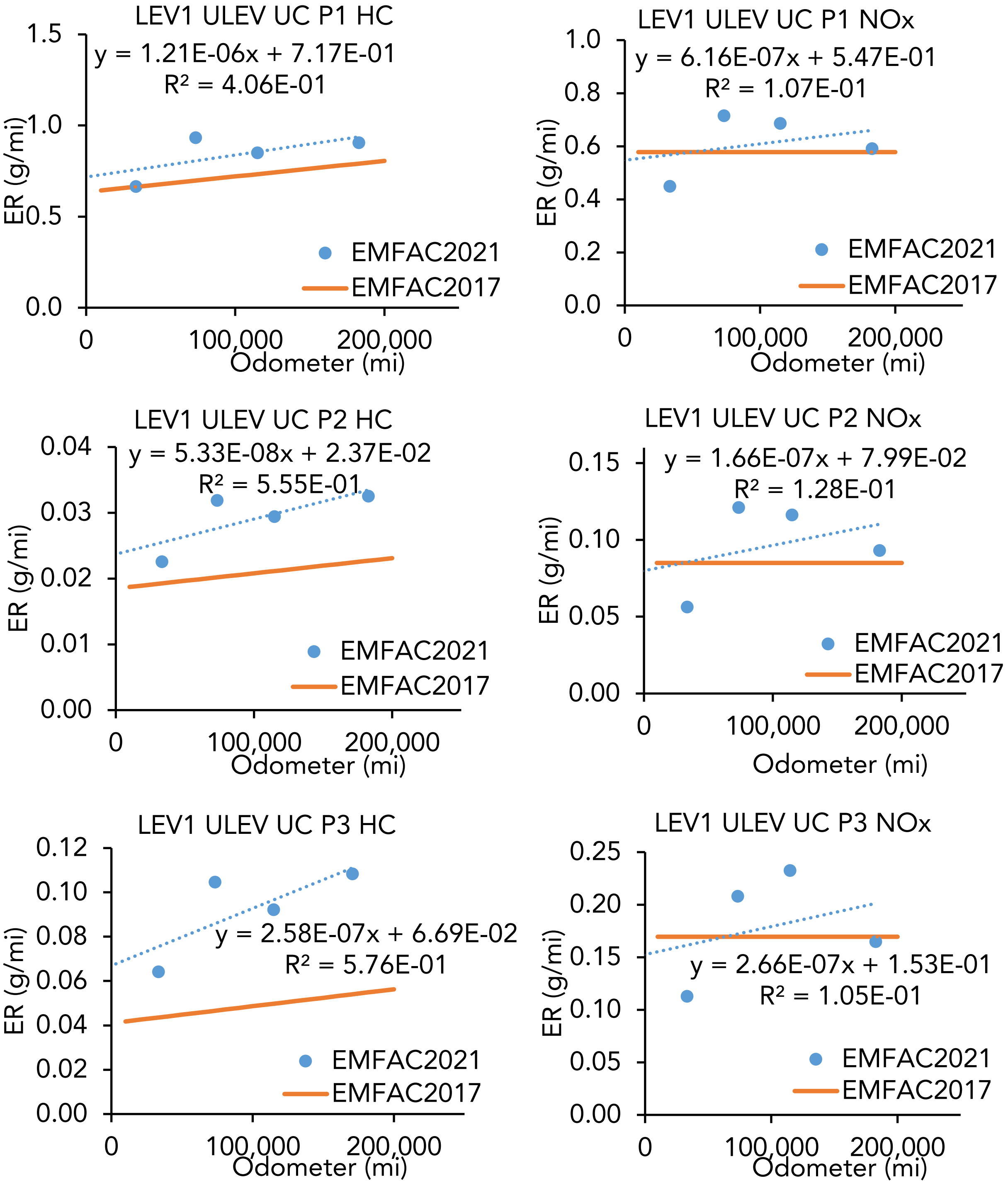


Figure 4.3.1-3. UC Bags 1-3 HC and NOx emission rates (g/mi) for LEV2 LEVs – EMFAC2021 vs. EMFAC2017

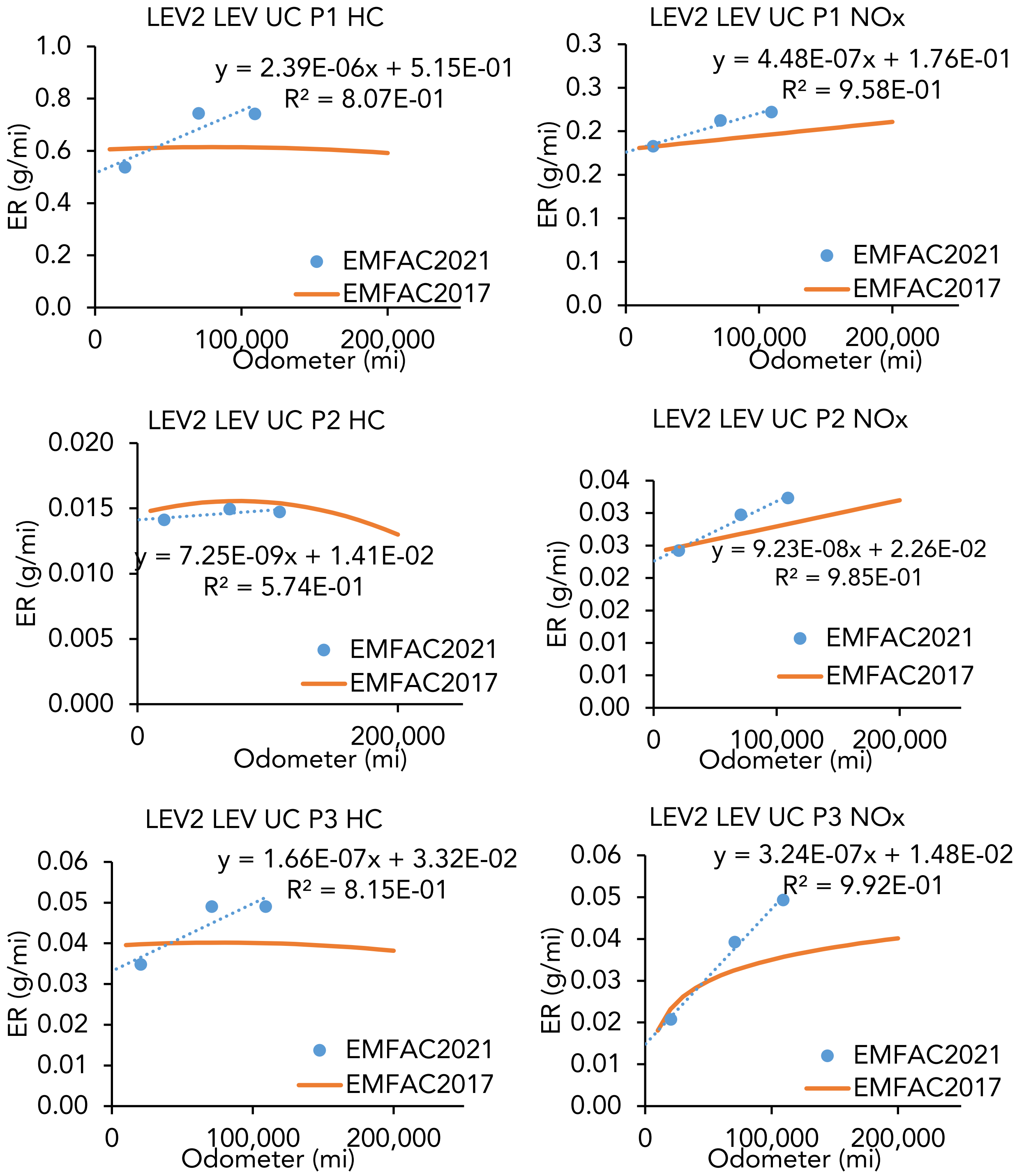


Figure 4.3.1-4. UC Bags 1-3 HC and NOx emission rates (g/mi) for LEV2 ULEVs – EMFAC2021 vs. EMFAC2017

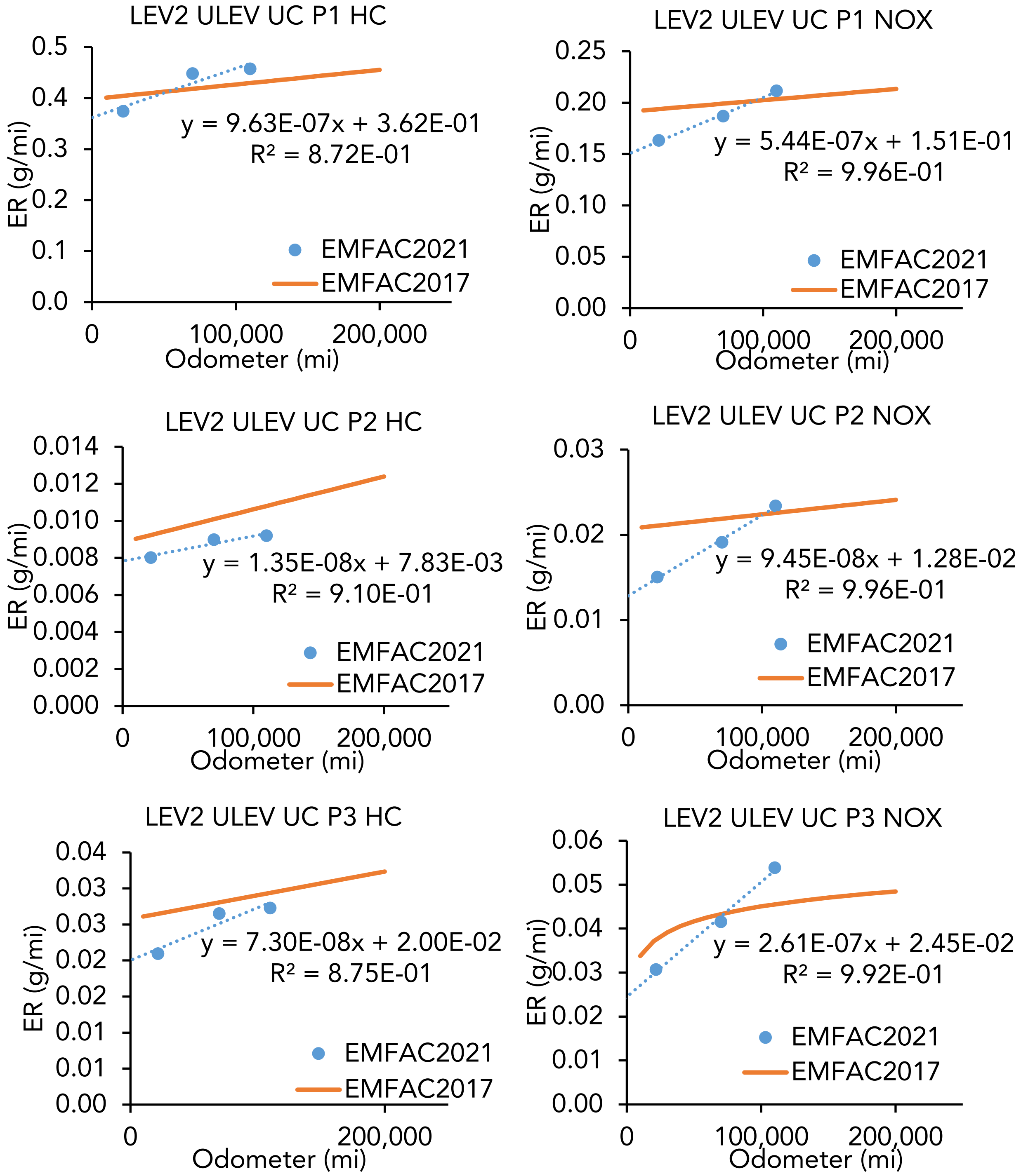


Figure 4.3.1-5. UC Bags 1-3 HC and NOx emission rates (g/mi) for LEV2 SULEVs – EMFAC2021 vs. EMFAC2017

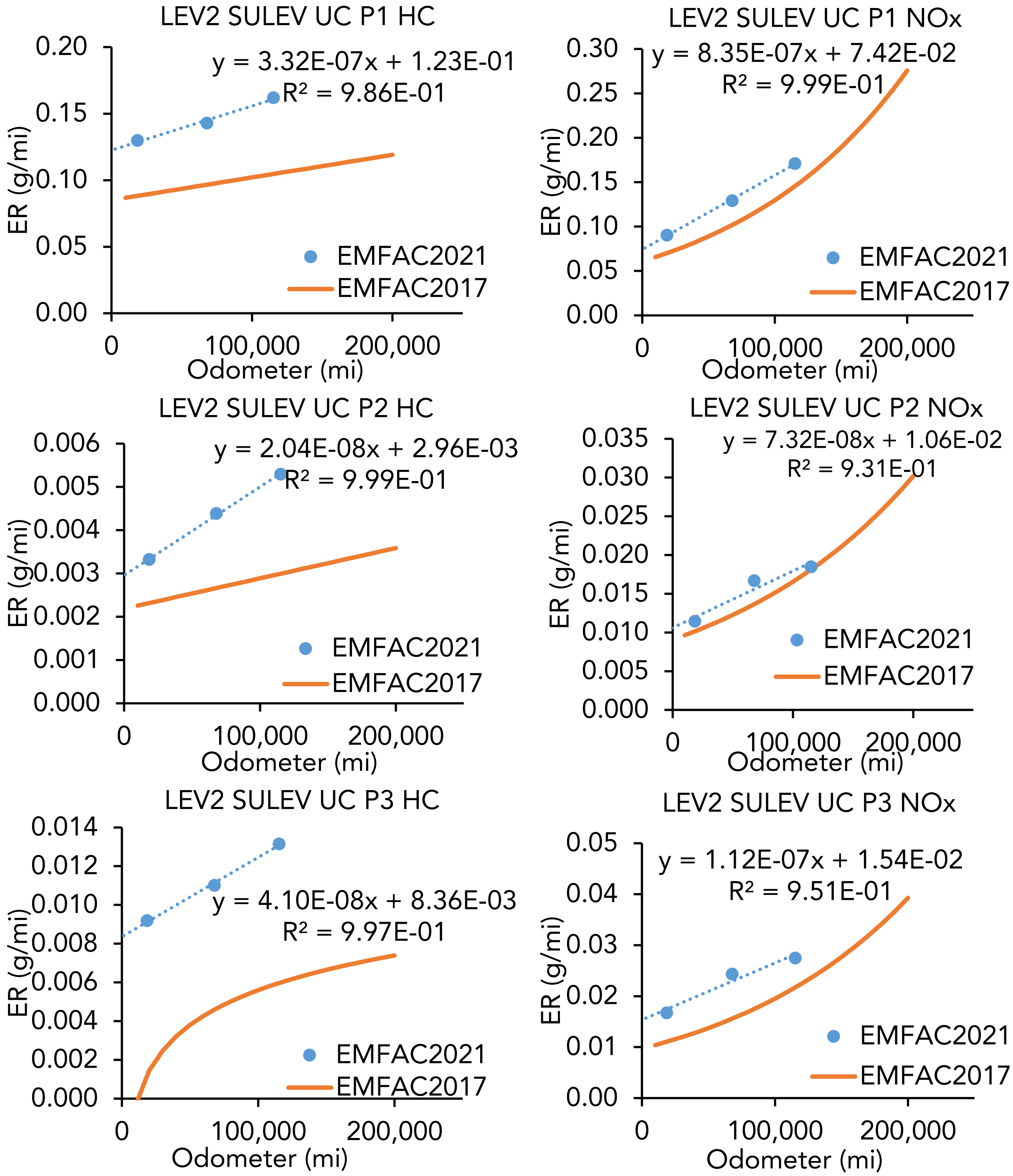
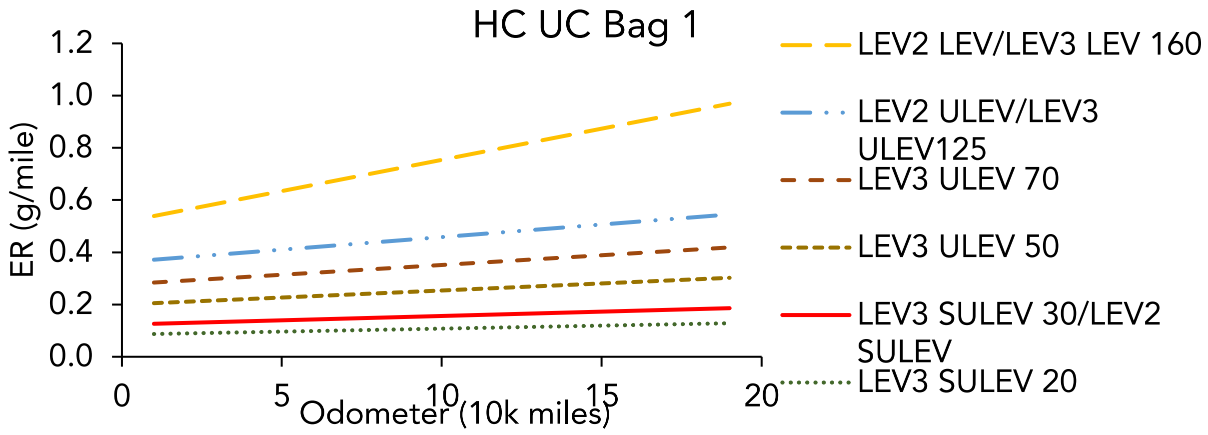


Figure 4.3.1-6. EMFAC2021 HC and NOx Cold Start Exhaust (UC_{P1}) Emission Rates by Tech Group



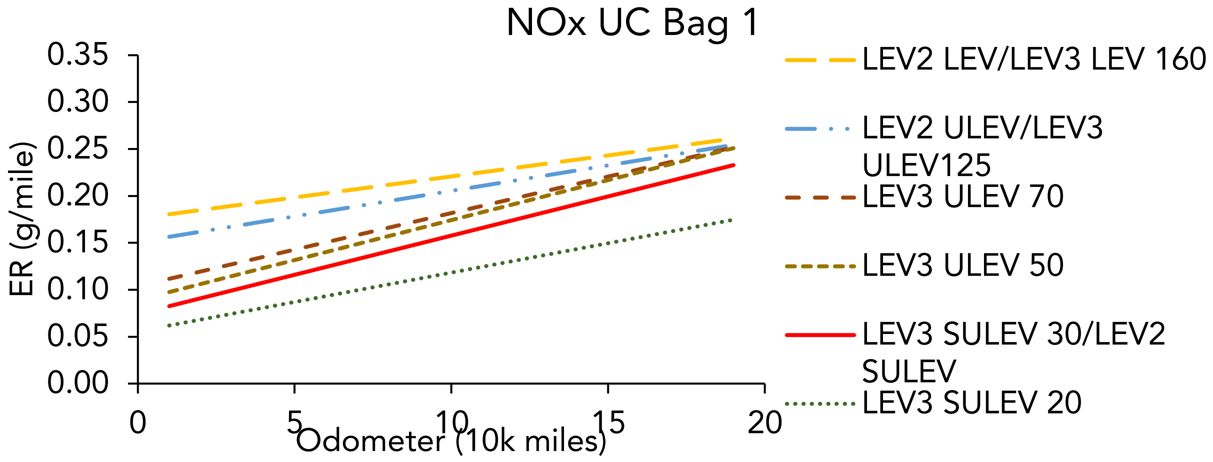
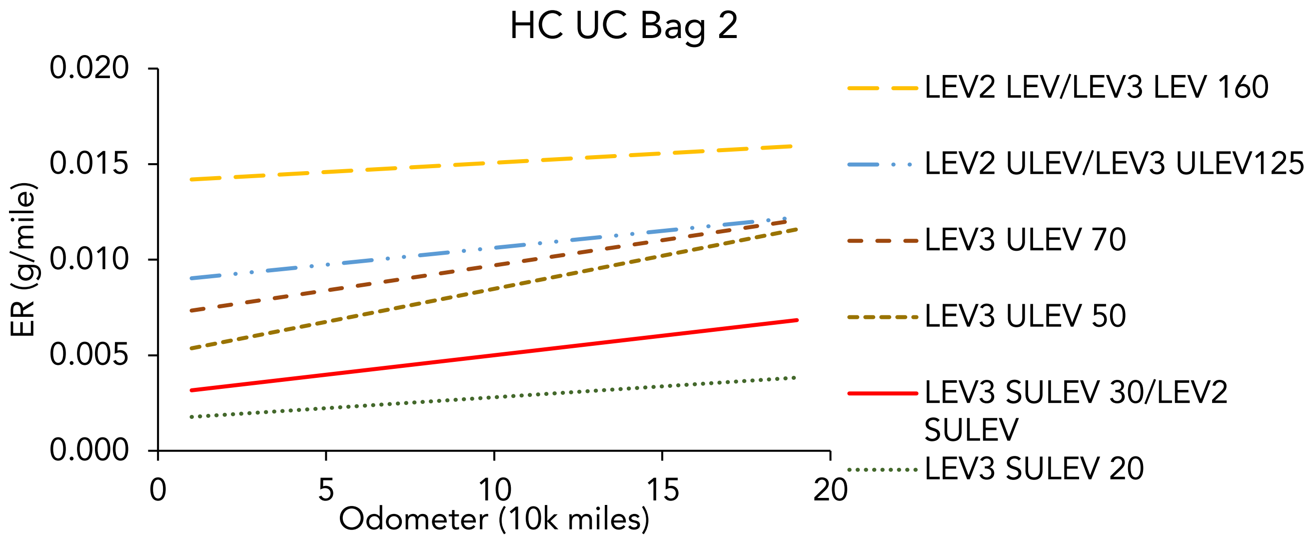


Figure 4.3.1-7. EMFAC2021 HC and NOx Running Exhaust (UC_{P2}) Emission Rates by Tech Group



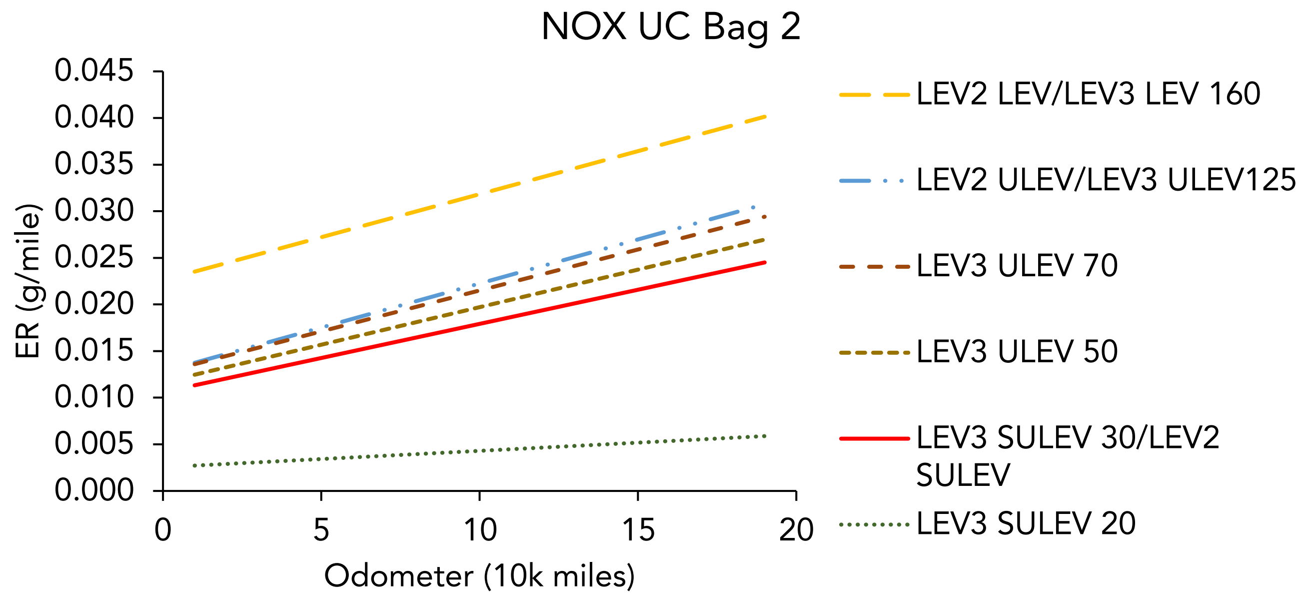


Figure 4.3.1-8. EMFAC2021 HC and NOx Running Exhaust (UC_{P3}) Emission Rates by Tech Group

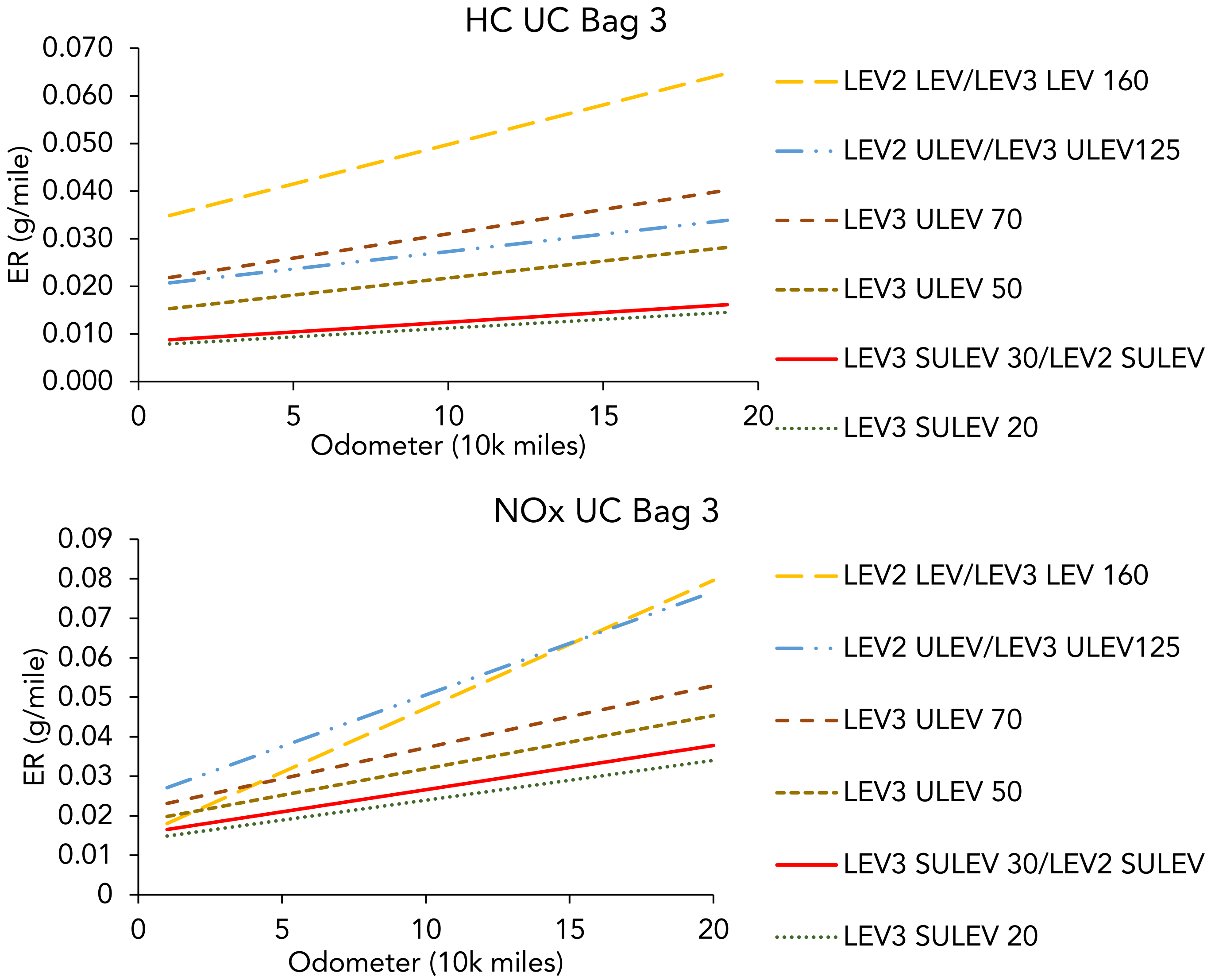


Table 4.3.1-3 to Table 4.3.1-13 provide the final regression equations utilized in EMFAC2021 for LD Base Emission Rates (BERs). They are listed by Tech Group IDs – Numerical identifiers for technology groups in the EMFAC model. Each technology group represents vehicles with distinct emission control technologies with similar in-use deterioration. The correlations are in units of g/mi for pollutants and 10 kmi for odometer readings.

Table 4.3.1-3. Tech Group 23 (LEV1 LEV) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.861	0.0512	Linear
	NOx	0.522	0.0543	Linear
	CO	10.7	0.262	Linear
UC2	HC	0.014	0.00383	Linear
	NOx	0.0253	0.0169	Linear
	CO	1.59	0.0832	Linear
UC3	HC	0.0391	0.0125	Linear
	NOx	0.0665	0.0313	Linear
	CO	1.39	0.127	Linear

Table 4.3.1-4. Tech Group 24 (LEV1 ULEV) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.717	0.0121	Linear
	NOx	0.547	0.00616	Linear
	CO	6.59	0.293	Linear
UC2	HC	0.0237	0.000533	Linear
	NOx	0.0799	0.00166	Linear
	CO	0.31	0.142	Linear
UC3	HC	0.0669	0.0026	Linear
	NOx	0.1526	0.0027	Linear
	CO	0.131	0.5255	Exponential

Table 4.3.1-5. Tech Group 28 (LEV2 LEV) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.515	0.0239	Linear
	NOx	0.176	0.00448	Linear
	CO	11.1	0.0569	Linear
UC2	HC	0.0141	0.0000725	Linear
	NOx	0.0226	0.000923	Linear
	CO	1.4	0.0303	Linear
UC3	HC	0.0332	0.00166	Linear
	NOx	0.0148	0.00324	Linear
	CO	1.49	0.0283	Linear

Table 4.3.1-6. Tech Group 29 (LEV2 ULEV) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.362	0.00963	Linear
	NOx	0.151	0.00544	Linear
	CO	4.71	0.0449	Linear
UC2	HC	0.00885	0.000177	Linear
	NOx	0.0128	0.000945	Linear
	CO	0.6513	0.0115	Linear
UC3	HC	0.02	0.00073	Linear
	NOx	0.0245	0.00261	Linear
	CO	0.789	0.0187	Linear

Table 4.3.1-7. Tech Group 31 (LEV2 SULEV) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.123	0.00332	Linear
	NOx	0.0742	0.00835	Linear
	CO	1.3	0.0585	Linear
UC2	HC	0.00296	0.000204	Linear
	NOx	0.0106	0.000732	Linear
	CO	0.324	0.032	Linear
UC3	HC	0.00836	0.00041	Linear
	NOx	0.0154	0.00112	Linear
	CO	0.19	0.0214	Linear

Table 4.3.1-8. Tech Group 38 (LEV3 SULEV20) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.09963	0.002689	Linear
	NOx	0.056392	0.006346	Linear
	CO	1.868	0.0252	Linear
UC2	HC	0.002664	0.000184	Linear
	NOx	0.00954	0.000659	Linear
	CO	0.4134	0.003373	Linear
UC3	HC	0.007524	0.000369	Linear
	NOx	0.01386	0.001008	Linear
	CO	0.3601	0.01292	Linear

Table 4.3.1-9. Tech Group 39 (LEV3 ULEV50) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.199875	0.005395	Linear
	NOx	0.08904	0.00852	Linear
	CO	3.812857	0.036348	Linear
UC2	HC	0.005017	0.000346	Linear
	NOx	0.01166	0.000805	Linear
	CO	0.527243	0.00931	Linear
UC3	HC	0.01254	0.000615	Linear
	NOx	0.01848	0.001344	Linear
	CO	0.638714	0.015138	Linear

Table 4.3.1-10. Tech Group 44 (LEV3 ULEV70) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.27675	0.00747	Linear
	NOx	0.10388	0.007784	Linear
	CO	3.812857	0.036348	Linear
UC2	HC	0.007074	0.000263	Linear
	NOx	0.01272	0.000878	Linear
	CO	0.527243	0.00931	Linear
UC3	HC	0.01672	0.00082	Linear
	NOx	0.02156	0.001568	Linear
	CO	0.638714	0.015138	Linear

Table 4.3.1-11. Tech Group 45 (LEV3 SULEV30) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.123	0.00332	Linear
	NOx	0.0742	0.00835	Linear
	CO	1.3	0.0585	Linear
UC2	HC	0.00296	0.000204	Linear
	NOx	0.0106	0.000732	Linear
	CO	0.324	0.032	Linear
UC3	HC	0.00836	0.00041	Linear
	NOx	0.0154	0.00112	Linear
	CO	0.19	0.0214	Linear

Table 4.3.1-12. Tech Group 55 (LEV3 ULEV125) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.362	0.00963	Linear
	NOx	0.151	0.00544	Linear
	CO	4.71	0.0449	Linear
UC2	HC	0.00885	0.000177	Linear
	NOx	0.0128	0.000945	Linear
	CO	0.6513	0.0115	Linear
UC3	HC	0.02	0.00073	Linear
	NOx	0.0245	0.00261	Linear
	CO	0.789	0.0187	Linear

Table 4.3.1-13. Tech Group 56 (LEV3 LEV160) BER Correlation Coefficients

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC1	HC	0.515	0.0239	Linear
	NOx	0.176	0.00448	Linear
	CO	11.1	0.0569	Linear
UC2	HC	0.0141	0.0000725	Linear
	NOx	0.0226	0.000923	Linear
	CO	1.4	0.0303	Linear
UC3	HC	0.0332	0.00166	Linear
	NOx	0.0148	0.00324	Linear
	CO	1.49	0.0283	Linear

4.3.2 Evaporative Emissions Module

EMFAC2021 has updated the evaporative module to estimate evaporative emissions from gasoline vehicles, which are the major sources of gaseous hydrocarbon pollutants.[43] This updated module in EMFAC2021 models physical processes that are involved in generation of evaporative emissions, while EMFAC2017 and earlier versions modeled the certification processes of evaporative emissions. This update is implemented mainly by adopting the same method as used by the U.S. EPA's MOVES3 model to estimate

---

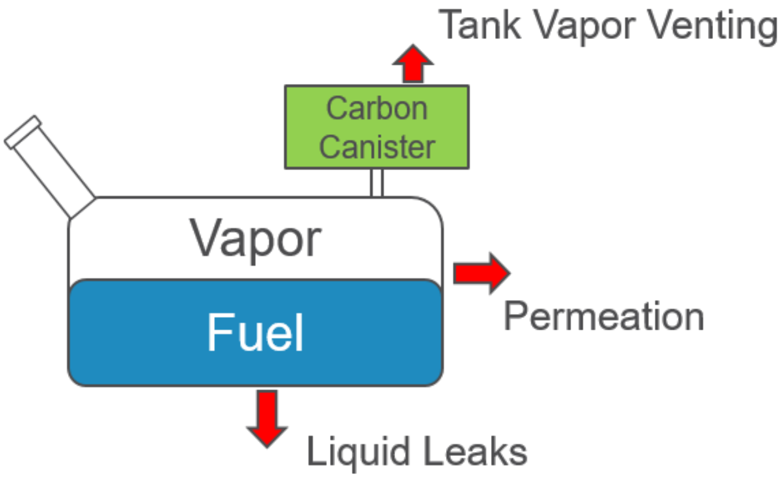
[43] Evaporative emissions are generated as gasoline fuels evaporate and escape from the vehicle's fuel system.

evaporative emissions.[44] Additionally, CARB staff customized the new method for the state of California by using California specific meteorological data, vehicle activity data, and fuel information.

The evaporative emissions module in previous versions of EMFAC estimated emissions using an empirical method based on certification processes, which are a) diurnal and resting loss (DIURN and RESTLOSS), b) running loss (RUNLOSS), and c) hot soak (HOTSOAK).[45] Following the MOVES3 model, EMFAC2021 takes a different approach of modeling three physical evaporative emission processes, namely, tank vapor venting, permeation, and liquid leak. Each physical process is modelled for three modes of activity: cold soak (or diurnal), running, and hot soak modes. The three processes are illustrated in Figure 4.3.2-1 and defined as follows:

1. Tank vapor venting is a process of fuel vapors escaping from the fuel tank when the carbon canister is saturated (or the amount of fuel vapor is larger than the capacity of the carbon canister).
2. Permeation happens when fuel escapes through materials in the system such as tank walls, hoses, and seals.
3. Liquid leak indicates non-vapor form emissions of fuel escaping the fuel system such as dripping fuel, which ultimately evaporates into the atmosphere.

Figure 4.3.2-1. An illustration of evaporative processes of tank vapor venting, permeation, and liquid leaks as modeled in EMFAC2021



---

[44] USEPA (2020). "Evaporative Emissions from Onroad Vehicles in MOVES3" Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency. EPA-420-R-20-012 (web link: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010M0C.pdf, November 2020)

[45] California Air Resources Board (CARB), Chapter 5 of Technical Support Document for EMFAC2000 (web link: https://ww3.arb.ca.gov/msei/onroad/downloads/tsd/emfac2000-emissions.pdf, May 2000)

The evaporative emission module in EMFAC2021 not only incorporate U.S.EPA’s latest research findings, but also provides a platform for further development of EMFAC through refinement of model parameters and updates of its input data based on results from new emissions testing and data collection efforts. CARB staff is tentatively considering to update the module in the following areas in the future: (1) designing and conducting new emission test methods to better characterize emission rates for permeation and tank vapor venting processes; (2) more accurate speciation profiles for LEV 2 and LEV 3 technologies, and advanced vehicle technologies such as plug-in hybrids; (3) better quantification method for liquid leaks; and (4) more refined characterization of fuels used in California.

Compared to MOVES' implementation of evaporative emissions, EMFAC2021 is implemented differently in several areas to improve the module's computational efficiency and to customize the module for use in California. First of all, EMFAC2021 and MOVES have different sets of vehicle classes. Staff matched vehicle classes used in EMFAC2021 to the most equivalent vehicle classes used in the MOVES model. The matched pairs are listed in Table 4.3.2-1.

Table 4.3.2-1 EMFAC vehicle classes and their equivalent MOVES regulatory classes and source types used in the evaporative emission module

EMFAC2021 EMFAC202x Vehicle Category	MOVES3	
	Regulatory Class	Source Type
MCY	MC	Motorcycle
LDA	LDV	Passenger Car
LDT1	LDT	Passenger Truck
LDT2	LDT	Passenger Truck
MDV	LDT	Passenger Truck
LHDT1	LHD ≤ 10k	Light Commercial Truck
LHDT2	LHD ≤ 14k	Single Unit Short-haul Truck
MH	LHD ≤ 14k	Single Unit Short-haul Truck
OBUS	LHD45	Transit Bus
UBUS	LHD45	Transit Bus
SBUS	LHD45	Transit Bus
T6TS	MHD67	Single Unit Long-haul Truck
T7IS	HHD8	Combination Short-haul Truck

Second, EMFAC2021 uses California-specific meteorology inputs, vehicle activity, and fuel information. Instead of using meteorological data used in the MOVES database, staff used meteorological data that are specifically developed for use in EMFAC.[46,47] Additionally, as EMFAC's spatial resolution of sub-areas is finer than MOVES' county-level resolution, this allows EMFAC to use more accurate meteorological input at the finer sub-area level. Besides, staff used vehicle trip data including vehicle starts, trips, and parking activities from the California Household Travel Survey (CHTS)[48] to estimate vehicle activity values for evaporative emissions (e.g., vehicle operation hours, cold-soak hours, and hot-soak hours). Rather than using MOVES default values, staff ran MOVES with the CHTS data to pre-generate data as an input to the updated module to estimate the activity values. In addition, rather than using those used by MOVES, staff used the sub-area specific gasoline volatility (or Reid vapor pressure) values used in EMFAC2017 to better represent fuels used in California.

Third, EMFAC2021 does not generate temperature profiles of fuel tanks during model runs but utilize tank temperature profiles preprocessed using MOVES. The fuel tank temperature is an important parameter used in the calculation of evaporative emission rates. MOVES has a module that estimates tank temperatures numerically based on meteorological inputs and vehicle trip information. To reduce the computational cost of generating the temperature profile in the module and simplify the module implementation, staff pre-generated tank temperature values using MOVES with aforementioned California-specific meteorological inputs and vehicle trip information and used the generated values as input data to the new module.

Lastly, EMFAC2021 still outputs evaporative emissions by activity modes (i.e., DIURN, HOTSOAK, and RUNLOSS). Note that unlike previous versions of EMFAC, RESTLOSS is no longer produced as a separate process and that DIURN in EMFAC2021 includes RESTLOSS. Like the MOVES model, EMFAC2021 models internally each of the three physical evaporative emission processes (tank vapor venting, permeation, and liquid leaks) for the three modes of vehicle activities (diurnal, running, and hot soak). While MOVES aggregates resulting emissions in the three physical processes, EMFAC2021 does the same thing in the three modes of vehicle activity to provide more consistent outputs with previous versions.

Besides these differences, staff incorporated the same method and data implemented in the MOVES3 model. Please refer to U.S.EPA MOVES (2020) for detailed description of the algorithms of estimating evaporative emissions.

---

[46] California Air Resources Board (2000). On-Road Emission Model Methodology Documentation, Section 7.8 County-Specific Diurnal Temperature Profiles

[47] California Air Resources Board (2006). An Update to Summer Temperature and Relative Humidity Profiles for the EMFAC2007 On-road Emissions Model

[48] California Department of Transportation. (2013) 2010-2012 California Household Travel Survey Final Report Version 1.0

In order to illustrate the difference between EMFAC's new and old evaporative modules, comparisons of statewide evaporative emissions for several calendar years estimated by EMFAC2021 and EMFAC2017 are presented in Figure 4.3.2-2. Despite the substantial change in the modeling method, EMFAC2021 shows a similar magnitude and trend of evaporative emissions than EMFAC2017. EMFAC2021 estimates higher diurnal emissions than EMFAC2017, while EMFAC2021's running loss emissions are somewhat smaller than EMFAC2017's. As shown, EMFAC2021's hot soak emissions are similar to EMFAC2017's.

In addition, Figure 4.3.2-3 shows a comparison between EMFAC2021 and MOVES3 for evaporative emissions from passenger cars (LDA) in Los Angeles county. The comparison was made in terms of a per-vehicle emission basis to exclude the effects of different future population forecasts of the two models. The emissions from EMFAC2021 are aggregated by MOVES3 output categories for the comparison. The evaporative emissions from both models show similar trends and magnitudes. As described earlier, EMFAC2021 uses California-specific inputs (meteorology, vehicle activity, and fuel information) and assumes model year distributions that are different from MOVES3. These are some of the major reasons for the differences between EMFAC2021 and MOVES3 emission outputs.

Figure 4.3.2-2. Comparison of statewide evaporative emissions between EMFAC2021 and EMFAC2017. EMFAC2017's RESTLOSS is included in DIURN for the comparison.

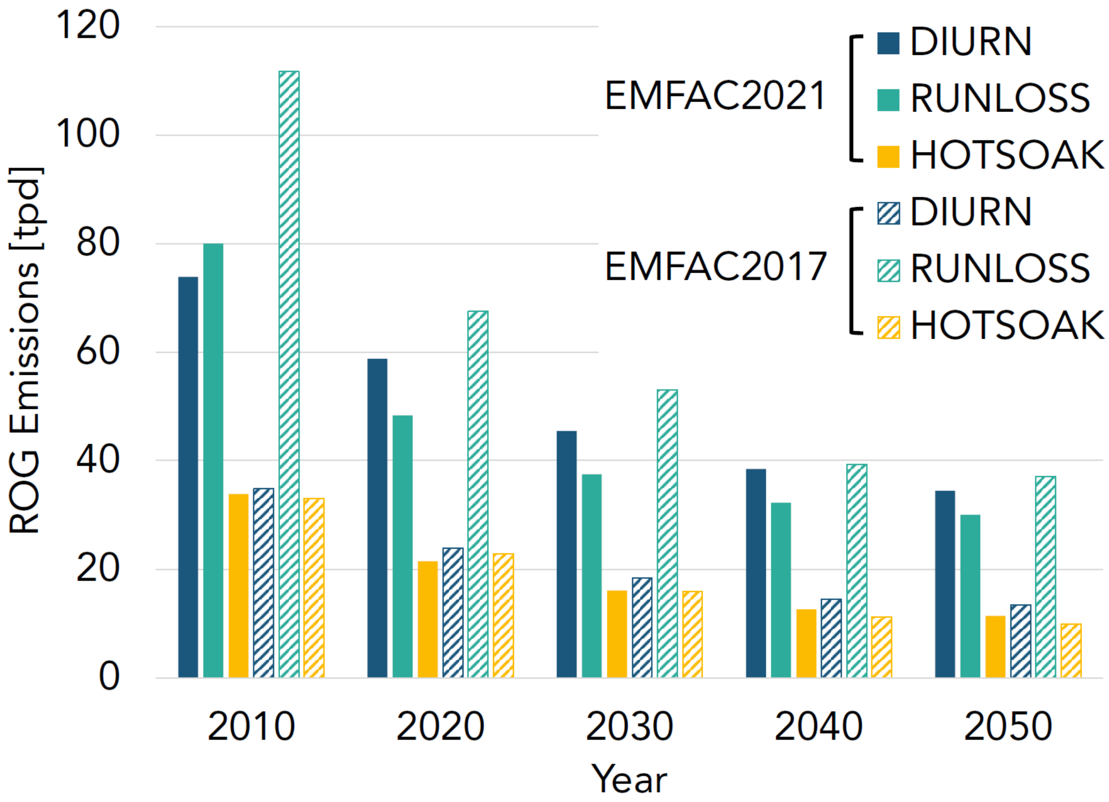
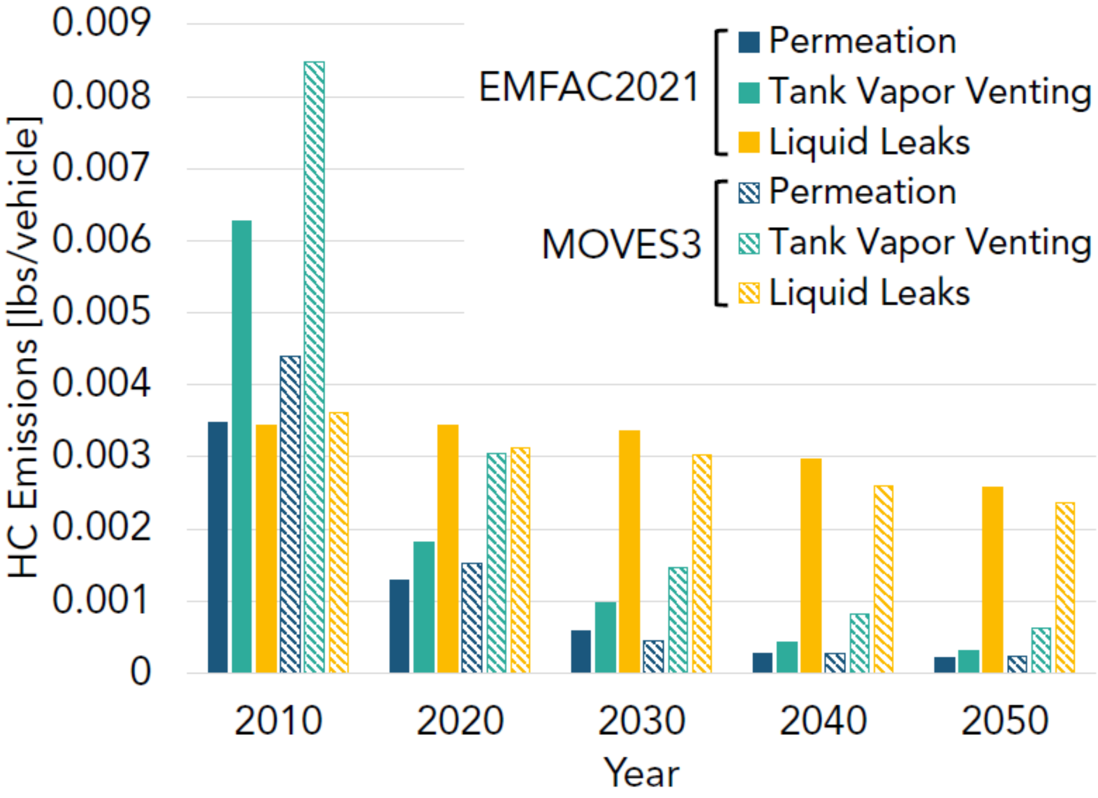


Figure 4.3.2-3. Comparison of evaporative emissions of Passenger Cars (LDA) in Los Angeles county between EMFAC2021 and MOVES3.



4.3.3 Light Duty CO2 Emission Rates

The GHG module was first introduced in EMFAC2017 and staff have further updated fuel efficiency assumptions in the model through the EMFAC2021 update. The current update to GHG module improved the accuracy of CO2 emission rates and provided new emission rates for CO2 for all model year vehicles as old as 2009. The new approach entails using U.S. EPA 5-cycle fuel economy ratings for motor vehicles to estimate the total CO2 emissions.

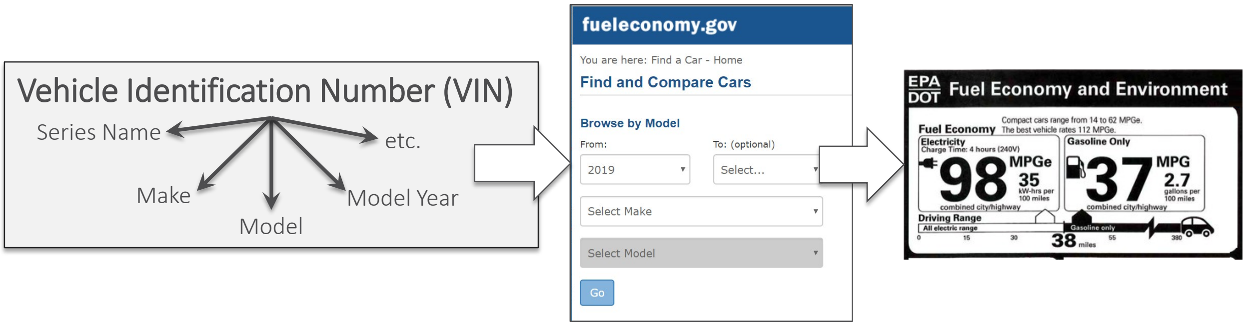
EMFAC2021 is developed assuming complete combustion of fuel, similar to EMFAC2017, and consistent with the official CARB, U.S. EPA, and IPCC methodologies. Complete combustion of fuel means that 100% of carbon in the fuel is converted to CO2. Additionally, EMFAC2021 assumes that using EPA fuel economy ratings provides an acceptable basis for estimation of amount of burned fuel.

Moreover, EMFAC2017 used EPA 2-cycle fuel economy ratings, while EMFAC2021 takes advantage of 5-cycle ratings. 5-cycle fuel economy ratings are more representative of real-world condition due to accounting for effects of air conditioning and more frequent vehicle acceleration events. Hence, the resulting CO2 emissions are assumed to be more representative of California driving style.

In order to obtain a fuel economy rating for each vehicle that operates in California, DMV registration database was first queried and a list containing all vehicle VINs associated with passenger and light duty trucks operating in California was obtained. The queries, other than VIN, provided other vehicle characteristics such as model name, series name, model year, and fuel type. More detailed vehicle characteristics such as engine size, drive train type, and number of cylinders were obtained from Polk/IHS VINtelligence service and were appended to the DMV vehicle records as shown in Figure 4.3.3-1.

Next, the latest copy of EPA fuel economy data was obtained from EPA fueleconomy.gov, and was queried for each of the vehicle records from the previous step. Using the collected vehicle characteristics for each vehicle in the DMV database (including parameters extracted from the VINtelligence), EPA fueleconomy.gov data base was then queried using an advanced string-matching algorithm to link the most similar vehicles in terms of their vehicle characteristics. This algorithm is further described in Chapter 2.4 of SB 1014 Clean Miles Standard, 2018 Base Year Emission Inventory Report.[49] Subsequently, the 5-cycle city MPGs of the most similar matches/vehicles from EPA fueleconomy.gov were assigned to the input VINs for all vehicles. The analysis was also quality checked to ensure that correct 5-cycle fuel economy values are assigned to each vehicle. Details of the data processing flow in illustrated in Figure 4.3.3 2. The 5-cycle fuel economy values were then converted to CO2 emission rates (g CO2/mile) using a fuel specific conversion factor of 8,887 grams CO2 per gallon of gasoline, and 10,180 grams CO2 per gallon of diesel.[50]

Figure 4.3.3-1. Flow chart to show how each DMV vehicle record a fuel economy rating was obtained

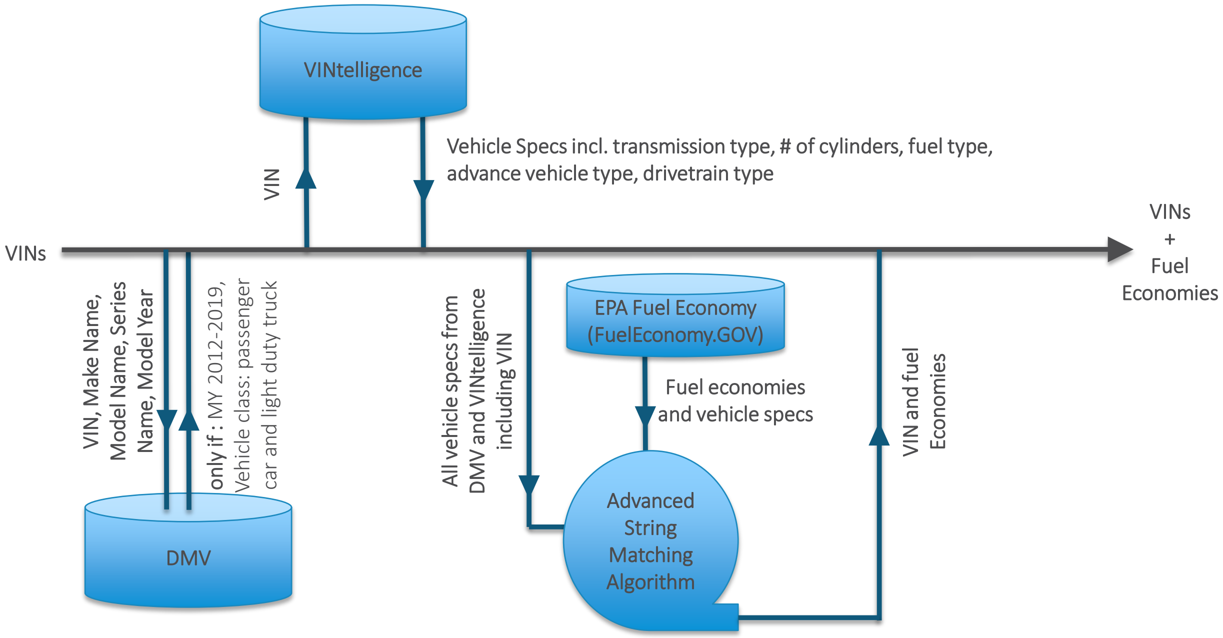


---

[49] SB1014 Base Year Emissions Inventory https://ww2.arb.ca.gov/sites/default/files/2019-12/SB%201014%20-%20Base%20year%20Emissions%20Inventory_December_2019.pdf

[50] U.S. EPA website, https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculatorcalculations-and-references

Figure 4.3.3-2. Data processing flow chart to determine fuel economy ratings for the DMV vehicle fleet



EMFAC2017 CO2 emissions were calculated using the 2-cycle (i.e., unadjusted) U.S. EPA city fuel as opposed to the 5-cycle (i.e., adjusted) fuel economies. For 5-cycle fuel economies, EPA added three additional cycles (cold FTP, US06, and SC03) to the 2-cycle fuel economy tests to further reflect real world condition that impact fuel efficiency of light duty vehicles. This was done by considering a wider range of driving conditions such as more frequent acceleration events, impact of air conditioning and heater usage, and hot and cold temperatures. The results from the five cycle tests are then combined to derive the adjusted 5-cycle fuel economy rating.

Moreover, EMFAC models CO2 running exhaust emissions using Phase 2 of UC cycle. Considering that the FTP composite CO2 emissions are highly correlated with the UC Phase 2 CO2 emissions,[51] EMFAC2017 used a combination of 2-cycle city and highway fuel economy ratings to calculate CO2 emission rates. In contrast, to account for more city-like driving behavior in California, EMFAC2021 uses the adjusted 5-cycle city fuel economies to derive CO2 emissions. This method now ensures that the EMFAC's estimate of CO2 emissions for different model year vehicles accounts for real world conditions impacting them.

---

[51] Use of 2-cycle fuel economies and correlation between FTP composite and UC cycle is thoroughly discussed in SB 1014 Clean Miles Standard, 2018 Base Year Emission Inventory Report. See page 29. Download https://ww2.arb.ca.gov/sites/default/files/2019-12/SB%201014%20-%20Base%20year%20Emissions%20Inventory_December_2019.pdf

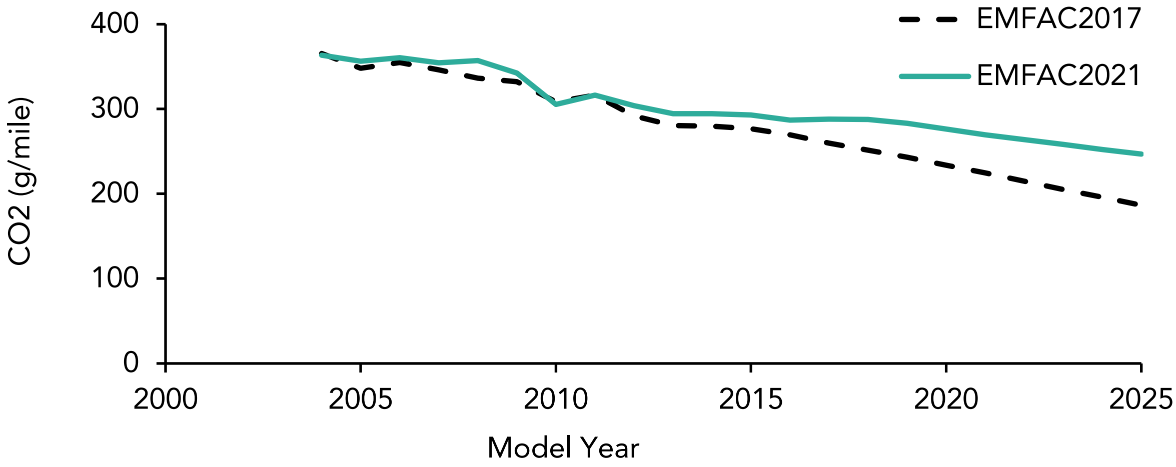
Comparison of emissions between EMFAC2017 and EMFAC2021 CO2 emission rates for years 2008 through 2026 for passenger cars (a) and light duty trucks (b) is shown in Figure 4.3.3 3. Please note that CO2 emission data for model year 2020 through 2026 are projected using the GHG emission standards. As can be seen prior to 2019, EMFAC2017 was on a different trajectory as compared to EMFAC2021 for both passenger cars and light duty trucks. This is mainly due to the latest methodology updates that included the use of 5-cycle fuel economy values versus previously using 2-cycle data, and improvements made by using the advanced string matching algorithm, and specially adjusting the CO2 rates for the differences between the certification fuel (E0) versus commercially available fuel which is assumed to be E10. Although, the impact of these updates and improvements extends into the future, the final SAFE rule and six manufacturer Framework Agreement on Clean Cars account for the major difference in CO2 emission rates of EMFAC2017 and EMFAC2021 post 2020.

For passenger cars, EMFAC2021 shows a more moderate reduction rates of approximately 6.6 grams per model year in CO2 emissions as compared to 8.34 grams per model year of EMFAC2017 for passenger cars. For light duty trucks, however, CO2 emission rates reduce at a rate of roughly 13.2 grams per model year, while EMFAC2021 reduction in CO2 emission rates is approximately 12.1 grams per model year.

In terms of fuel economy, as shown in Figure 4.3.3-3, for passenger cars, EMFAC2021 average fleet fuel economy by model year increases at a slower pace of approximately 0.8 mpg per model year as compared to roughly 1.1 mpg per model year for EMFAC2017 for passenger cars. For light duty trucks, however, EMFAC2017 fuel economies grow 0.89 mpg per model year, while EMFAC2021 growth rate of fuel economy is approximately 0.84 mpg per model year.

Figure 4.3.3-3. CO2 emission factors by vehicle model year for (a) passenger cars and (b) light duty trucks for EMFAC2017 and EMFAC2021

a) Passenger Cars



b) Light Duty Trucks

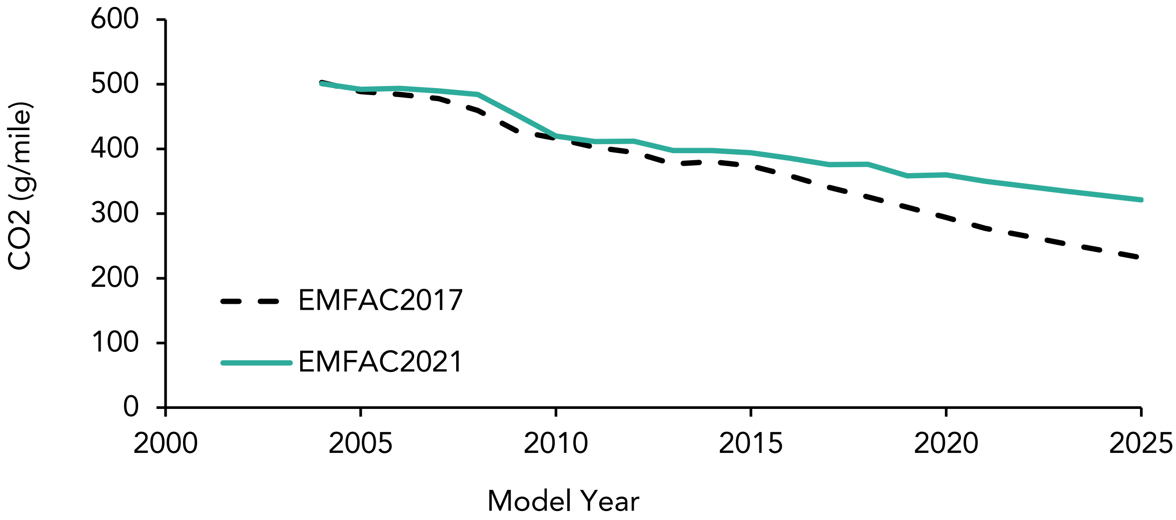
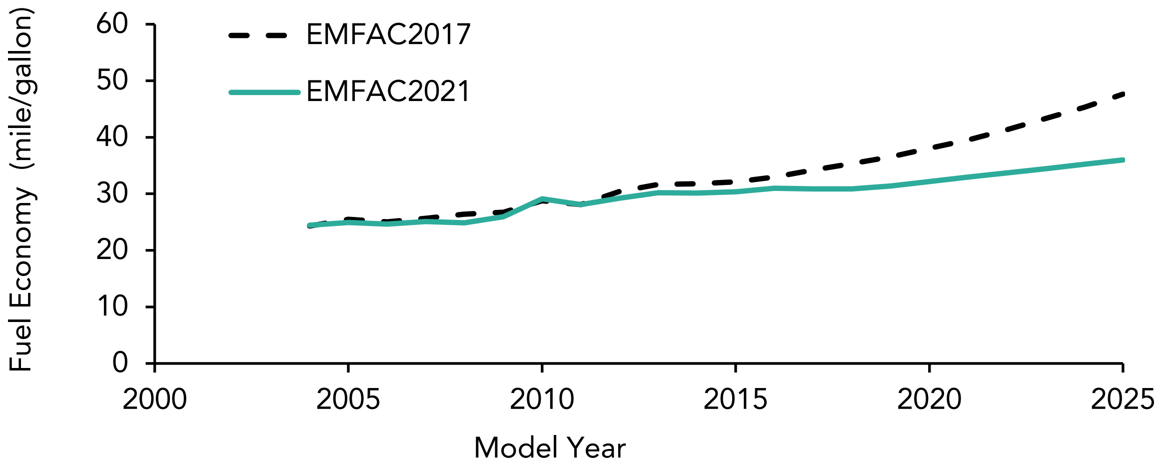
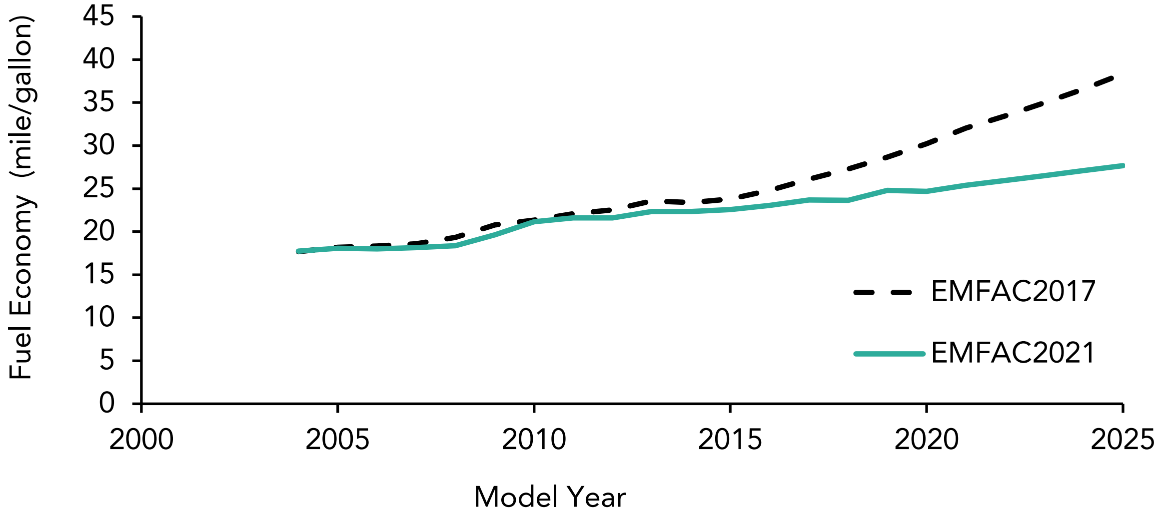


Figure 4.3.3-4. Fuel Economy by vehicle model year for (a) passenger cars and (b) light duty trucks for EMFAC2017 and EMFAC2021

a) Passenger Cars



b) Light Duty Trucks



The Final 2020 SAFE Rule modified the tailpipe carbon dioxide (CO2) emission targets for passenger cars (PC) and light trucks (LT) for the 2021 to 2026 model years. Actual fleet CO2 targets are based on current fleet average footprints (FP) of 46.2 ft^2 for PC and 53.8 ft^2 for LT vehicles. These targets were subsequently used to derive year-over-year (YoY) % reductions in CO2 targets for model years 2021-2026 in the PC and LT fleets. Under the Final SAFE Rule, a 1.5% YoY improvement in fuel economy in the CAFE standards was finalized which translates to a slightly different YoY reduction in CO2 space (e.g., grams of CO2 emitted/mile which is more akin to the inverse of fuel economy (e.g., miles/gallon). Derived from the finalized CO2 standards rather than the finalized CAFE standards, a 1.84% YoY reduction from 2020 to 2026 for the CO2 emission factor (EF) values of gasoline passenger cars were applied. For light trucks, a 1.75% YoY reduction was applied. EMFAC2021 also accounts for the six manufacturer Framework Agreements on Clean Cars on reducing CO2 emissions more stringently than those in the SAFE Rule. Specifically, these manufacturers have agreed to meet CO2 emission targets for model years 2022 through 2026 that collectively represent a 3.7% YoY reduction between 2021 and 2026. In addition, these manufacturers are allowed to meet up to 1.0% of those reductions using ZEV credits. As a result, a 2.7% YoY reduction was applied from model years2022 to 2026 for the CO2 emission factor values of gasoline passenger cars and light duty trucks subject to the framework. Based on the CARB 2018 GHG compliance data, 38% and 62% of sales splits are assumed between the six manufacturer framework and the non-framework gasoline vehicles in the California fleet for light duty passenger cars, respectively; and 34% versus 66% for the light trucks categories, are assumed to be the split between framework and non-framework vehicles respectively.

As mentioned above, EMFAC2021 incorporated EPA rated 5-cylce fuel economy. The accuracy of 5-cycle fuel economy is further evaluated against real-world fuel economy data. Following the On Board Diagnostic (OBD) II regulation updates that were adopted by the Board in 2016, the OBD systems on new vehicles (starting from model year 2019) are expected to record fuel consumption and distance traveled, with a phase-in schedule of 30% in MY2019, 60% in MY2020, and 100% in MY2021[52]. Staff was able to extract the OBD data for a total of 73,000 vehicles of model years 2019 and 2020 from California's Bureau of Automotive Repair (BAR) Smog Check database. Data with known issues, duplicate records, and vehicles that travelled less than 6000 km were removed, resulting in a dataset of 41,000 vehicles.

The fuel economy matching was done in two steps. First, for each vehicle, the OBD real-world fuel economy was calculated as lifetime miles travelled divided by lifetime gallons of fuel consumed. As part of the second step, staff matched EPA rated 5-cycle combined fuel economy to vehicles in the OBD dataset using VINtelligence[53], a VIN decoder, and did manual corrections based on vehicle specifications and EPA Fuel Economy Guide[54]. This step resulted in a sample size of approximately 34,000 gasoline vehicles. Finally, the EPA rated fuel economy of 34,000 gasoline light-duty vehicles were evaluated against OBD real-world fuel economy. .

---

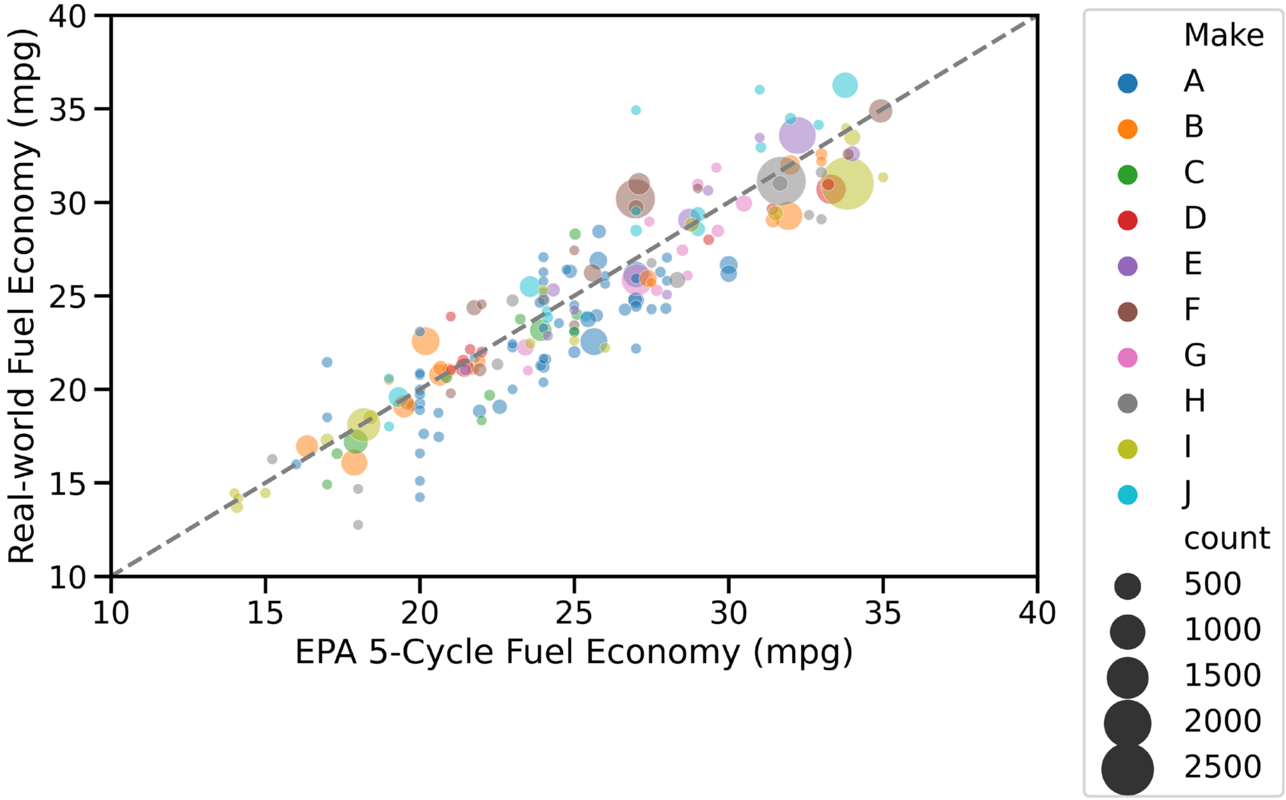
[52] https://ww3.arb.ca.gov/regact/2015/obdii2015/finalregorder2.pdf?_ga=2.6318005.628219904.1607613641-982443962.1602979098

[53] https://ihsmarkit.com/products/automotive-vin-interpretation-decoding.html

[54] https://www.fueleconomy.gov/

Figure 4.3.3-5 shows a bubble plot for the comparison of real-world fuel economy versus EPA 5-cycle fuel economy of 10 major manufacturers with number of data points in the OBD dataset greater than 1,000. Interestingly, the current data demonstrated that the EPA 5-cycle fuel economy is close to real-world fuel economy. Furthermore, the analysis showed significant correlation with an R-square value of 0.84. While there are over-performing and underperforming models, the average difference between EPA rated fuel economy (27.35 mpg) and OBD real-world fuel economy (26.90 mpg) is only 0.45 mpg for these datasets. Therefore, this analysis justifies that EPA 5-cycle fuel economy is a better representation of real-world fuel efficiency as compared to the EPA 2-cycle fuel economy.

Figure 4.3.3-5. A Comparison of real-world fuel economy versus EPA 5-cycle fuel economy[55].



---

[55] Each bubble represents a model in the model year 2019 or 2020. Different colors denote manufacturers A-J. The sizes of the bubbles represent the number of vehicles in the OBD dataset. The dash line is the line for 1:1 ratio.

4.3.4 Motorcycle Emission Rates

The motorcycle emission rates currently in EMFAC2017 have not been updated since 2000. Since EMFAC2000, the model had used emission rates resulting from analysis of FTP and UC dynamometer test data from about 125 model year 1998 and older motorcycles tested in calendar year 1999. Additionally, the evaporative emission factors used in EMFAC2017 and previous models were based on light-duty automobiles. To provide updated motorcycle emission rates for EMFAC2021, CARB conducted an internal study in 2019 at the Haagen-Smit Laboratory (HSL) in El Monte to test current model motorcycles. The test plan intended to procure and test up to 18 motorcycles from the in-use fleet (model years 2010-2018) and test 7 state-owned bikes (3 MY2019, 3 MY2008, and 1 MY2006) for exhaust and evaporative emissions. The dynamometer exhaust tests included the UC, FTP, and the World Motorcycle Test Cycle (WMTC). For EMFAC, the UC test data is used to analyze and update the model for motorcycles of MY2008 and newer (fuel injected with catalyst). The evaporative tests included a 1-hour hot soak test and a 3-day diurnal test. Due to COVID-19, the laboratory was closed in March 2020, resulting in the partial completion of CARB’s motorcycle test plan. However, dynamometer test data from 13 motorcycles were collected and analyzed to estimate exhaust emission rates used to update EMFAC2021. Of these motorcycles, one was tested in stock condition and tampered configuration (without catalyst), one was tested in tampered condition only, while the remaining motorcycles were all tested in stock condition.

Table 4.3.4-1 lists the 13 motorcycles tested in non-tampered stock condition with corresponding engine size and odometer at the time of testing.

Table 4.3.4-2 lists two motorcycles tested in the tampered configuration. Note that MCY1 was tested in both stock and tampered configurations. The state-owned motorcycles were of model year 2008, 2018, 2019, and 2020. The motorcycle of model year 2013 and 2016 were procured from private owners from the in-use fleet.

Table 4.3.4-1. CARB Motorcycle List (Non-Tempered Stock Condition)

MCY	MY	Make	Model	Displ cc	Odo
1	2008	Honda	CBR600RR	600	10,466
2	2019	Harley Davidson	Street Bob	1746	632
3	2016	Kawasaki	NINJA 650	650	27,302
4	2018	Suzuki	GSX R1000	1000	1,013
5	2019	Yamaha	MT09	847	1,180
6	2013	Honda	CBR250R	250	29,300
7	2020	Triumph	Street Triple	765	596
8	2014	Triumph	Daytona 675	675	5,052
10	2014	Yamaha	Bolt	950	16,787
11	2015	Honda	VT750	750	7,486
12	2015	Yamaha	FZ-07	690	8,117
13	2011	BMW	S1000RR	1000	11,115

Table 4.3.4-2. CARB Motorcycle List (Tampered Configuration)

MCY	MY	Make	Model	Displ cc	Odo
1	2008	Honda	CBR600RR	600	10,178
9	2008	Harley Davidson	FXDWG	1584	3,437

For EMFAC, the results of UC dynamometer tests were used for analysis. Each motorcycle was tested twice over the UC, and the results were averaged by each test phase (UC Bag 1, Bag 2, Bag 3). The non-tampered motorcycles from dynamometer tests were binned by odometer reading. The averaged emission rates (grams per mile) were then compiled by bag and pollutant, as shown in the following tables. Similarly, the average emission rates from the tampered motorcycles from were compiled for each UC bag.

Table 4.3.4-3. Non-Tampered MCY UC Bag 1 Emission Rates by Bin

Process	Bin	Pollutant	ER (g/mile)	Average Odometer
UC Bag 1	2500	HC	0.725	855.25
		NOx	0.119	
		CO	3.29	
		CO2	306.93	
	7500	HC	1.74	7780.25
		NOx	0.329	
		CO	8.52	
		CO2	239.19	
	12500	HC	2.08	11115
		NOx	0.145	
		CO	10.71	
		CO2	359.13	
	17500	HC	2.07	16787
		NOx	0.327	
		CO	12.67	
		CO2	238.04	
	22500	HC	1.83	28301
		NOx	0.253	
		CO	18.00	
		CO2	186.77	

Table 4.3.4-4. Average Tampered MCY UC Bag 1 Emission Rates

Process	Pollutant	ER (g/mile)
UC Bag 1	HC	5.32
	NOx	0.533
	CO	47.85
	CO2	276.60

Table 4.3.4-5. Non-Tampered MCY UC Bag 2 Emission Rates by Bin

Process	Bin	Pollutant	ER (g/mile)	Average Odometer
UC Bag 2	2500	HC	0.067	855.25
		NOx	0.036	
		CO	0.491	
		CO2	201.87	
	7500	HC	0.432	7780.25
		NOx	0.367	
		CO	3.76	
		CO2	167.00	
	12500	HC	0.188	11115
		NOx	0.118	
		CO	0.829	
		CO2	236.36	
	17500	HC	0.351	16787
		NOx	0.108	
		CO	3.72	
		CO2	162.06	
	22500	HC	0.609	28301
		NOx	0.299	
		CO	12.38	
		CO2	133.11	

Table 4.3.4-6. Average Tampered MCY UC Bag 2 Emission Rates

Process	Pollutant	ER (g/mile)
UC Bag 2	HC	2.67
	NOx	0.823
	CO	27.27
	CO2	171.81

Table 4.3.4-7. Non-Tampered MCY UC Bag 3 Emission Rates by Bin

Process	Bin	Pollutant	ER (g/mile)	Average Odometer
UC Bag 3	2500	HC	0.294	855.25
		NOx	0.056	
		CO	0.564	
		CO2	261.67	
	7500	HC	0.789	7780.25
		NOx	0.260	
		CO	2.99	
		CO2	210.07	
	12500	HC	0.486	11115
		NOx	0.166	
		CO	0.755	
		CO2	308.59	
	17500	HC	0.952	16787
		NOx	0.193	
		CO	6.14	
		CO2	195.94	
	22500	HC	0.832	28301
		NOx	0.201	
		CO	10.82	
		CO2	160.55	

Table 4.3.4-8. Average Tampered MCY UC Bag 3 Emission Rates

Process	Pollutant	ER (g/mile)
UC Bag 3	HC	4.34
	NOx	0.527
	CO	34.96
	CO2	235.35

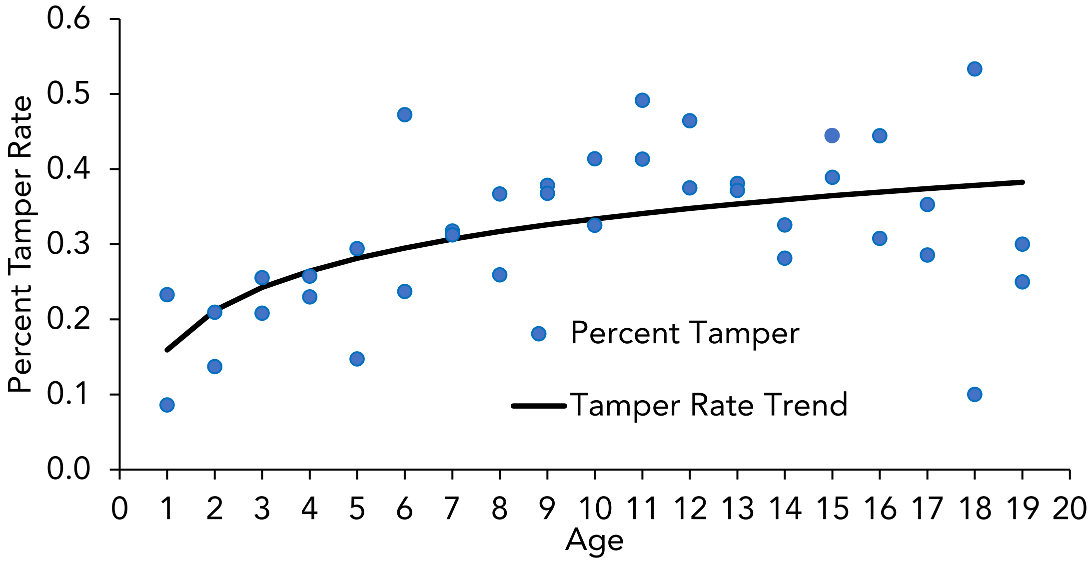
For non-tampered motorcycles, by UC bag, each pollutant was plotted by odometer bin to determine a best fit trend to represent non-tampered emission rates by mileage. The analysis of the CO2 UC test results yielded no significant trend in emission rates, so the average of emission rates between the binned non-tampered motorcycles and the tampered motorcycles was calculated. Table 4.3.4-9 below shows the regression equations that are used in EMFAC2021 to calculate emissions of HC, NOx, CO, and CO2 for motorcycles.

Table 4.3.4-9. Regression equations of HC, NOx, CO and CO2 emissions for motorcycle

Process	Pollutant	A (X0)	B (X1)	Regression Type
UC Bag1	HC	-3.5865	0.5741	Log Linear
	NOx	-0.3103	0.0593	Log Linear
	CO	-43.841	5.9258	Log Linear
	CO2	271.309	0	Flat
UC Bag 2	HC	-1.3164	0.179	Log Linear
	NOx	-0.3883	0.0625	Log Linear
	CO	-28.869	3.6008	Log Linear
	CO2	175.95	0	Flat
UC Bag 3	HC	-1.5668	0.2434	Log Linear
	NOx	-0.3391	0.056	Log Linear
	CO	-29.44	3.6649	Log Linear
	CO2	231.364	0	Flat

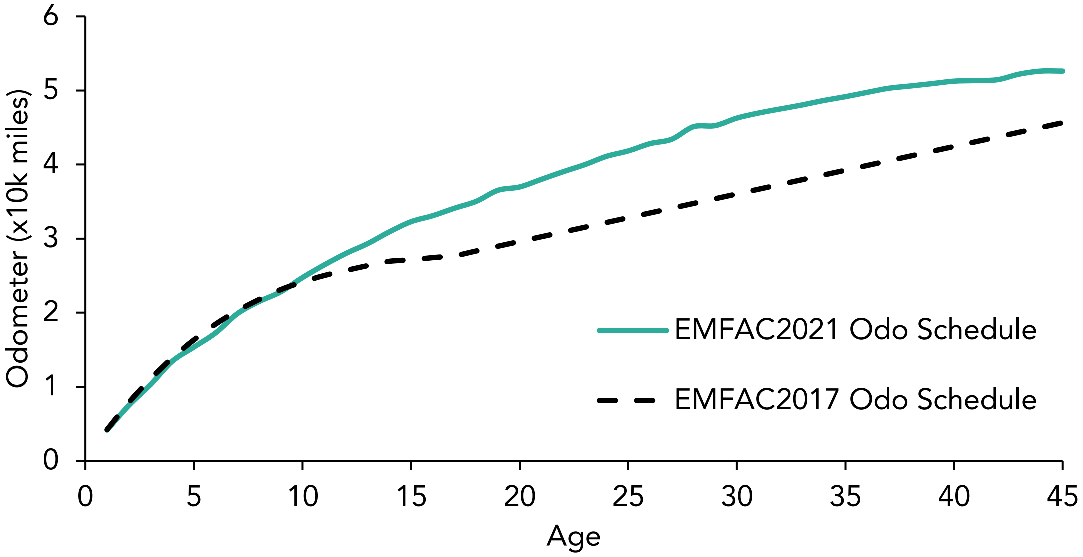
Two other data sources were examined to supplement the analysis for updated emission rates-one to provide information on tampering rates and the other to provide an updated motorcycle odometer schedule. The first source involves two recent CARB online studies of 2000 sales advertisements of motorcycles and their tampered components (August 2016 to February 2017 and September 2019 to January 2020). This study provided information to determine tamper rates by motorcycle age. By combining the two studies, staff determined the percentage of tampered motorcycles by age. Figure 4.3.4-1 shows the two tamper studies through age 20, and the best fit trend line to represent tamper percentages by age.

Figure 4.3.4-1 road Motorcycle Tamper Percentage by Age



The second source of information is the 2017 National Household Travel Survey-California Add-on (NHTS CA), which provides motorcycle odometer mileage data to create an odometer schedule by age. This data source contains a vehicle subset of 1,923 motorcycles surveyed for odometer information by age.[56] Figure 4.3.4-2 illustrates staff analysis of the 2017 NHTS data results as compared to the odometer schedule used in EMFAC2017. The updated odometer schedule for EMFAC2021 continues at a slightly higher trend after age 10 than estimated by EMFAC2017.

Figure 4.3.4-2 Updated Motorcycle Odometer Schedule



In order to calculate the weighted emission rates by age, the tamper rates were used to calculate weighted average emission rates using the non-tampered and tampered emission factors presented earlier. The equation to calculate the weighted emission rate by bag is shown below.

Wt. ER = (Bag Non-Tamp*(1-Tamp Rate)) + (Bag Tamp*Tamp Rate) (Eq. 4.3.4-1)

Furthermore, regression equations were developed to model the weighted average emissions rates as a function of odometer. These regressions are provided in the following tables.

---

[56] https://www.nrel.gov/transportation/secure-transportation-data/tsdc-nhts-california.html

Table 4.3.4-10. On-road Motorcycle Weighted Emission Rates (g/mile) vs odometer (10k miles)

UC Bag 1	Regression Type	Equation
HC	Log Linear	y = 0.6919ln(Odometer) + 2.588
NOx	Log Linear	y = 0.0646ln(Odometer) + 0.3085
CO	Log Linear	y = 7.1147ln(Odometer) + 19.817
CO2	Flat	y = 271.3

UC Bag 2	Regression Type	Equation
HC	Log Linear	y = 0.3247ln(Odometer) + 0.9094
NOx	Log Linear	y = 0.097ln(Odometer) + 0.3438
CO	Log Linear	y = 4.3618ln(Odometer) + 9.9189
CO2	Flat	y=175.95

UC Bag 3	Regression Type	Equation
HC	Log Linear	y = 0.4848ln(Odometer) + 1.5789
NOx	Log Linear	y = 0.0672ln(Odometer) + 0.2625
CO	Log Linear	y = 5.091ln(Odometer) + 11.835
CO2	Flat	y=231.3640

Overall, the new motorcycle emission rates embedded in EMFAC2017 are lower for HC and NOx, and higher for CO and CO2.

4.3.5 HD Emission Rates

4.3.5.1 Light Heavy-Duty Diesel and Gasoline Vehicle Running Exhaust Emission Rates

In EMFAC, LHD trucks are defined as vehicles with a gross vehicle weight rating (GVWR) of 8,501-14,000 lbs. and further divided into LHDT1 (LHD trucks with GVWR 8,501-10,000 lbs.) and LHDT2 (LHD trucks with GVWR 10,001-14,000 lbs.). Unlike the HD vehicles with GVWR greater than 14,000 lbs., these vehicles are unique in terms of their emission compliance. Some of these vehicles comply with emission regulations through certification of their engines but others through chassis certification. In either case, they must meet the respective engine or chassis emission standards. When chassis certified, they are also referred to as medium duty vehicles 4 and 5 (MDV4 and MDV5) under California Low Emission Vehicle (LEV) regulations. Chassis standards are considered to be comparable in stringency to the corresponding engine standards, and in EMFAC all vehicles with GVWR of 8,501-14,000 lbs. are modeled under LHD trucks whether they are engine or chassis certified.

The emission rates for LHD trucks have not been updated since EMFAC2007. In recent years, there have been increased interest in the emissions of criteria pollutants as well as greenhouse gases (GHG) from these vehicles; therefore, it is desirable to have a better understanding of their emission levels and their emissions impact on the overall on-road emissions inventory. To support CARB regulatory programs and better serve stakeholders' needs, staff carried out a project to test in-use LHD trucks and collect emissions data from the test vehicles. This section discusses the analysis of the emission test data from the project and present revised emission factors based on the results of test data analysis.

4.3.5.1.1 Emissions Test Data

CARB staff has completed an emissions testing project (Project 2R1702) to obtain emission data from in-use LHD trucks. A total of 10 diesel and 2 gasoline LHD trucks of several model years (MY) were tested. Each test vehicle was tested on dynamometer over eight test cycles (Table 4.3.5-1) and emissions of THC, CO, NOx, PM, and CO2 were measured following the standard light-duty vehicle testing procedures.

Table 4.3.5-1. Test cycles used for dynamometer testing in CARB Project 2R1702

Test Cycle/Mode	Average Speed (mph)	Duration (sec)	Length (mi)
FTP-75	21.2	1,877	11.04
UC	22.92	1,735	11.04
MAC1	6.8	798	1.50
MAC3	39	823	8.92
MFC5	57	517	8.14
MFC6	65	502	9.12
MFC7	73	515	10.45
HWFET	48.3	765	10.26

Table 4.3.5-2 lists the vehicles procured for emissions testing, and dynamometer test results are listed in Appendix 6.5.

Table 4.3.5-2. Test Vehicles for Project 2R1702

Manufacturer	Model	MY	Fuel	Odometer	Emissions STD	Weight Class
FCA U.S.	Dodge Ram 2500	2015	Diesel	51,380	LEV3 ULEV340	LHDT1 / MDV4
Daimler AG	Sprinter 2500	2017	Diesel	22,860	LEV2 ULEV	LHDT1 / MDV4
General Motors	Silverado 2500	2015	Diesel	64,600	LEV2 ULEV	LHDT1 / MDV4
Ford	F250	2015	Diesel	30,460	LEV2 ULEV	LHDT1 / MDV4
Ford	F350	2015	Diesel	70,630	LEV2 ULEV	LHDT2 / MDV5
Daimler AG	Sprinter 3500	2017	Diesel	8,630	LEV2 ULEV	LHDT2 / MDV5
FCA U.S.	Dodge Ram 3500	2015	Diesel	139,340	LEV3 ULEV570	LHDT2 / MDV5
General Motors	Silverado 2500	2015	Gasoline	42,400	LEV3 LEV395	LHDT1 / MDV4
General Motors	Sierra 2500	2015	Gasoline	43,110	LEV3 LEV395	LHDT1 / MDV4
General Motors	Silverado 3500	2015	Diesel	24,570	LEV2 ULEV	LHDT2 / MDV5
Ford	F350	2006	Diesel	73,800	ULEV	LHDT1 / MDV4
General Motors	Silverado 2500	2006	Diesel	120,810	ULEV	LHDT1 / MDV4

4.3.5.1.2 Running Exhaust Emission Rate

The emission rates of 2007+ MY LHD diesel trucks (USEPA 2007 standards) were updated using the test data of six 2015 MY and two 2017 MY diesel test vehicles (Table 4.3.5-2). Plots of emission rates versus odometer readings of these test vehicles show that it is not possible to use a regression method to develop meaningful zero mile rates (ZMR) and deterioration rates (DR), and therefore the average emission rates of all test vehicles were used to scale the ZMRs and DRs of LHD diesel trucks in EMFAC2017 to obtain the new ZMRs and DRs, as described below in detail.

Additionally, as the eight test vehicles include four tested LHDT1 trucks and four LHDT2 trucks, the ZMRs and DRs calculated from the test data of all eight vehicles were further split into two separate sets of ZMRs and DRs using the average CO2 emission rates of the four LHDT1 trucks and four LHDT2 trucks. This is based on an assumption that to some degree the emissions of criteria pollutants from a fleet tend to be positively related to the amount of fuel consumed, which in turn is correlated with the CO2 emissions.

The following discusses staff updates to ZMRs and DRs of UC Bag 1 and Bag 2 for LHD trucks.

<u>UC Bag 1.</u> First, for each pollutant, the UC bag 1 (B1) emissions test data of the eight vehicles were averaged to obtain the pollutant's UC B1 emission rate (UCB1ER*). Next, as the average of the odometer readings of the eight vehicles is 54,700 miles, the pollutant's UC B1 emission rate at 54,700 mi (UCB1ER) was calculated from the B1 ZMR

and DR of 2007+ MY LHD diesel trucks in EMFAC2017. Finally, the ratio between UCB1ER* and UCB1ER was used to scale the pollutant's ZMR and DR of 2007+ MY LHD diesel trucks in EMFAC2017 to obtain a new ZMR and a new DR. Using this method, new ZMRs and DRs for all pollutants were calculated.

In addition, two weighting factors were calculated from the UC B1 CO2 emission rates of the four tested LHDT1 trucks and four LHDT2 trucks, respectively, and the two factors were then applied to the new ZMRs and DRs for all pollutants to obtain separate sets of ZMRs and DRs for LHDT1 and LHDT2. Table 4.3.5-3 and Table 4.3.5-4 show the revised ZMRs and DRs for 2007+ MY diesel LHDT1 and LHDT2, respectively, as well as the corresponding ZMRs and DRs for LHDT1 and LHDT2 in EMFAC2017.

Table 4.3.5-3. UC Bag1 ZMR and DR of 2007+ MY diesel LHDT1

Pollutant	EMFAC2017		EMFAC2021	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.038	0.0080	0.14	0.031
CO	0.28	0.055	0.86	0.18
NOx	4.43	0.011	1.30	0.033
PM	0.10	0.0023	0.0048	0.0012
CO2	745	0.0	1,085	0.0

Table 4.3.5-4. UC Bag1 ZMR & DR of 2007+ MY diesel LHDT2

Pollutant	EMFAC2017		EMFAC2021	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.038	0.0080	0.15	0.035
CO	0.28	0.055	0.97	0.21
NOx	4.43	0.011	1.46	0.038
PM	0.10	0.0023	0.0054	0.0013
CO2	745	0.0	1,222	0.0

UC Bag 2 The UC Bag 2 (B2) ZMRs and DRs of all pollutants for 2007+ MY were revised in the same way as described above, and the results are shown in Table 4.3.5-5 and Table 4.3.5-6.

Table 4.3.5-5. UC Bag2 ZMR and DR of 2007+ MY diesel LHDT1

Pollutant	EMFAC2017		EMFAC2021	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.11	0.0022	0.066	0.0014
CO	0.23	0.045	0.088	0.017
NOx	0.19	0.011	0.44	0.025
PM	0.071	0.0017	0.0069	0.0017
CO2	642	0.0	932	0.0

Table 4.3.5-6. UC Bag2 ZMR and DR of 2007+ MY diesel LHDT2

Pollutant	EMFAC2017		EMFAC2021	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.10	0.0022	0.076	0.0016
CO	0.23	0.045	0.10	0.020
NOx	0.19	0.010	0.51	0.029
PM	0.071	0.0017	0.0080	0.0019
CO2	642	0.0	1,082	0.0

The emission rates of 2004-2009 MY LHD diesel trucks (or ULEV) were updated using the test data of two 2006 MY diesel test vehicles (Table 4.3.5-2). Similar to the revision of emission rates of 2007+ MY diesel LHDT1 and LHDT2, the ZMRs and DRs of 2004-2009 MY diesel LHDT1 and LHDT2 were revised by scaling the corresponding ZMRs and DRs in EMFAC2017 using the test data of the two 2006 MY test vehicles. No attempt was made to calculate separate sets of ZMRs and DRs for LHDT1 and LHDT2 and therefore the obtained ZMRs and DRs apply to both these two LHD truck categories. Table 4.3.5-7 show the revised B1 ZMRs and DRs and Table 4.3.5-8 shows the revised B2 ZMRs and DRs for the 2004-2009 MY diesel LHDT1 and LHDT2.

Table 4.3.5-7. UC Bag1 ZMR and DR of 2004-2009 MY diesel LHDT1 & LHDT2

Pollutant	EMFAC2017		EMFAC2021	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.14	0.0075	0.31	0.017
CO	1.00	0.055	1.84	0.10
NOx	4.43	0.011	7.85	0.019
PM	0.0999	0.0023	0.19	0.0043
CO2	745	0.0	1,137	0.0

Table 4.3.5-8. UC Bag2 ZMR and DR of 2004-2009 MY diesel LHDT1 & LHDT2

Pollutant	EMFAC2017		EMFAC2021	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.12	0.0066	0.23	0.012
CO	0.82	0.045	0.73	0.040
NOx	4.33	0.010	3.69	0.0089
PM	0.071	0.0017	0.15	0.0036
CO2	642	0.0	687	0.0

As shown in Table 4.3.5-5 to Table 4.3.5-8, compared to EMFAC2017, NOx emission rates for MY2007+ have increased while those for MY2004-2009 LHD diesels have decreased. In terms of diesel PM, the 2004-2009 model year LHD vehicles show significantly higher PM emissions (~2x higher) than what was assumed in EMFAC2017 model.

The emission rates of 2008+ MY LHD gasoline trucks were revised using the test data of two 2015 MY gasoline test vehicles (Table 4.3.5-2). Again, as with the emission rate revision for 2007+ MY diesel LHDT1 and LHDT2, the ZMRs and DRs of 2008+ MY gasoline LHDT1 and LHDT2 were revised by scaling the corresponding ZMRs and DRs in EMFAC2017 using the test data. The obtained ZMRs and DRs apply to both LHDT1 and LHDT2. Table 4.3.5-9, Table 4.3.5-10, and Table 4.3.5-11 show the revised ZMRs and DRs of UC B1, B2, and B3, respectively, for the 2004-2009 MY gasoline LHDT1 and LHDT2.

Table 4.3.5-9. UC Bag1 ZMR and DR of 2008+MY gasoline LHDT1 & LHDT2

Pollutant	EMFAC2021		EMFAC2017	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.50	0.081	0.30	0.047
CO	16.2	1.07	7.17	0.47
NOx	0.30	0.053	0.39	0.068
PM	0.0028	0.0	0.023	0.0
CO2	1,128	0.0	810	0.0

Table 4.3.5-10. UC Bag2 ZMR and DR of 2008+MY gasoline LHDT1 & LHDT2

Pollutant	EMFAC2021		EMFAC2017	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.0105	0.0010	0.015	0.0014
CO	0.631	0.019	0.15	0.0046
NOx	0.011	0.0020	0.034	0.0066
PM	0.0016	0.0	0.0040	0.0
CO2	707	0.0	873	0.0

Table 4.3.5-11. UC Bag3 ZMR and DR of 2008+MY gasoline LHDT1 and LHDT2

Pollutant	EMFAC2021		EMFAC2017	
	ZMR (g/mi)	DR (g/mi/10K mi)	ZMR (g/mi)	DR (g/mi/10K mi)
HC	0.017	0.0026	0.027	0.0040
CO	1.60	0.11	0.10	0.0066
NOx	0.0086	0.0017	0.13	0.026
PM	0.0020	0.0	0.020	0.0
CO2	1,020	0.0	799	0.0

As shown, EMFAC2021 is showing lower NOx emissions for gasoline LHD vehicles as compared to EMFAC2017.

4.3.5.1.3 Speed Correction Factors

EMFAC calculates vehicle running exhaust emissions by multiplying emission rate in g/mi by vehicle mile travelled (VMT). Since VMTs are distributed across the entire spectrum of vehicle driving speeds, emission rates at different speeds are needed to match the VMTs at different speeds. Emission rates of a pollutant at various speeds are calculated by applying SCFs to the BERs of that pollutant. An SCF for a pollutant is developed from the pollutant's emission rates measured over several dynamometer test cycles with different average speeds.

For LHD trucks, all vehicles were tested over the FTP cycle as well as several other test cycles with average speeds either lower or higher than that of the FTP. A pollutant's emission rates from all the test cycles were first plotted as a function of speed, and regression curves were then fitted to find equations best representing the data. Data fitting shows that for all pollutants, quadratic polynomials could best represent the variations of emission rate with speed. For each pollutant, the emission rates calculated from the polynomial for various speeds were then normalized to 16.0 mph (the average speed of FTP Bag 2) to yield SCFs for the pollutant. The following equation can be used to calculate the SCFs for all the pollutants:

$$\boldsymbol{SCF = A \cdot speed^2 + B \cdot speed + C} \qquad \text{(Eq. 4.3.5-1)}$$

where a, b, and c are coefficients of the polynomials. The numerical values of these coefficients for all pollutants and respective MY groups are provided in Table 4.3.5-12.

Table 4.3.5-12. Coefficients speed correction factor equations for light heavy-duty diesel trucks

Pollutant	Model Year	Fuel Type	A	B	C
HC	2007+	Diesel	$1.37\text{x}10^{-4}$	$-3.12\text{x}10^{-2}$	1.71
HC	2004-2009	Diesel	$5.76\text{x}10^{-4}$	$-6.36\text{x}10^{-2}$	2.09
HC	2008+	Gasoline	$2.69\text{x}10^{-3}$	-0.260	6.50
CO	2007+	Diesel	$1.43\text{x}10^{-3}$	-0.168	5.26
CO	2004-2009	Diesel	$6.96\text{x}10^{-4}$	$-7.67\text{x}10^{-2}$	2.31
CO	2008+	Gasoline	$4.64\text{x}10^{-2}$	-0.366	85.3
NOx	2007+	Diesel	$1.73\text{x}10^{-3}$	-0.164	4.93
NOx	2004-2009	Diesel	$3.52\text{x}10^{-4}$	$-3.84\text{x}10^{-2}$	1.74
NOx	2008+	Gasoline	$4.32\text{x}10^{-4}$	$-2.73\text{x}10^{-2}$	1.27
PM	2007+	Diesel	$4.04\text{x}10^{-4}$	$-4.66\text{x}10^{-2}$	1.78
PM	2004-2009	Diesel	$9.35\text{x}10^{-4}$	$-9.79\text{x}10^{-2}$	3.12
PM	2008+	Gasoline	$3.14\text{x}10^{-3}$	-0.265	8.56
CO2	2007+	Diesel	$5.21\text{x}10^{-4}$	$-5.22\text{x}10^{-2}$	1.97
CO2	2004-2009	Diesel	$6.00\text{x}10^{-4}$	$-6.08\text{x}10^{-2}$	2.13
CO2	2008+	Gasoline	$5.55\text{x}10^{-4}$	$-5.69\text{x}10^{-2}$	2.04

4.3.5.2 Heavy Heavy-Duty and Medium Heavy-Duty Diesel Truck Running Exhaust Emission Rates and Speed Correction Factors

In EMFAC2017, staff updated the BERs of running exhaust emissions and SCFs for 2010+ MY HHD (T7) diesel trucks using emissions test data from CARB TBSP and emissions testing of late model diesel trucks by CARB and EMA (Engine and Truck Manufacturer Association)[57]. However, due to a lack of test data, the BERs for 2010+ MY MHD (T6) diesel trucks were estimated by scaling the rates of HHD diesel trucks and the SCFs of HHD diesel trucks were assumed to be also applicable to MHD diesel trucks.

Since the release of EMFAC2017, additional late model HHD diesel trucks were tested in TBSP. Following a pilot phase, TBSP has become a regular ongoing truck emissions surveillance program. It primarily performs testing of Class 8 trucks (HHD trucks) and large buses but also conducts some testing of Class 6 or Class 7 trucks as needed. To better serve the needs of CARB programs and regulations, staff has recently developed a new surveillance program, Class 4-6 SP, to focus on the testing of MHD diesel trucks. The program has started producing valuable emissions data for modeling the emissions of MHD trucks in EMFAC.

4.3.5.2.1 Emissions Test Data

All new emissions test data of HHD diesel trucks came from TBSP. To date, emissions data from an additional twenty-six 2013+ MY HHD diesel trucks were obtained from the program. All 26 trucks were tested on dynamometer over six test cycles for the emissions of THC, CO, NOx, PM, and CO2 among some other species. The key parameters of the six test cycles are shown in Table 4.3.5-13, and all test vehicle information and measured emissions of five pollutants are listed in Appendix 6.6.

Table 4.3.5-13. Test cycles for dynamometer testing in CARB TBSP

Test Cycle/Mode	Average Speed (mph)	Duration (sec)	Length (mi)
UDDS	18.8	1060	5.54
Creep	1.8	253	0.12
Near Dock Drayage	6.6	3,046	5.59
Local Drayage	9.3	3,362	8.70
HHDT Cruise	39.9	2,083	23.1
Modified HS Cruise	47.9	1,560	20.8

The new emissions test data of MHD diesel trucks came from both CARB's Class 4-6 SP and TBSP, with each contributing data for four of the eight tested trucks, all of which had an engine of 2013 or later MY. The MHD diesel truck testing in Class 4-6 SP were carried out on a dynamometer over seven test cycles and emissions of THC, CO, NOx, PM, and CO2, among other species, were measured. Key parameters for the seven test cycle are shown in Table 4.3.5-14, and the test vehicle information and the measured emission rates of the five pollutants are listed in Appendix 6.7.

---

[57] https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf

Table 4.3.5-14. Test cycles for dynamometer testing in CARB Class 4-6 Program

Test Cycle/Mode	Average Speed (mph)	Duration (sec)	Length (mi)
UDDS	18.8	1,060	5.54
Creep	1.8	253	0.124
Parcel Delivery	10.1	2,552	7.09
Transient	15.4	668	2.85
Local	32.6	1,690	15.3
HDDT Cruise	39.9	2,083	23.1
Modified HS Cruise	47.9	1,560	20.8

4.3.5.2.2 HHD and MHD Running Exhaust Emission Rates

In EMFAC2021, except for NOX, the BER of running exhaust emissions for a given model year of heavy-duty trucks can be calculated using the following equation:

$$BER = (ZMR + DR \times Odo) \qquad \text{(Eq. 4.3.5-2)}$$

where Odo is the average odometer of all trucks within that model year.

ZMR and DR are typically developed on a model year group basis, with each group including several consecutive model years that usually share the same emission standards and/or emission control technology. An average emission rate (ER_{avg}) of all tested trucks in a given MY group and an average odometer (Odo_{avg}) of these trucks are first calculated, and from these two averages the ZMR and DR for that MY group can be calculated using an HD emissions deterioration model.

4.3.5.2.3 HHD Diesel Truck ZMR and DR

Considering that the additional 26 HHD trucks tested in TBSP since the release of EMFAC2017 were 2013 MY or newer, staff decided to only revise the running exhaust emission rates of 2013+ MY. For EMFAC2017, there were eighteen 2013+ MY HHD trucks that provided test data for emission rate update. Therefore, dynamometer test data from the twenty-six 2013+ MY newly tested HHD trucks in TBSP were merged with the data from the eighteen 2013+ MY HHD trucks in EMFAC2017 updating to form a 44-truck dataset for EMFAC2021 updating.

On the basis of engine model year, these 44 trucks were divided into two MY groups: a 2013-2015 MY group and a 2016+ MY group. This grouping is aligned with the HD OBD requirements, with the phase-in period for 2013-2015 MY and full implementation for 2016 and later MY[58]. For each group, the UDDS emission rates of all tested trucks as well as their odometer readings were averaged to obtain the ER_{avg} and Odo_{avg}.

---

[58] https://ww3.arb.ca.gov/regact/2012/hdobd12/hdobdiiisor.pdf

For NOx, staff revised the deterioration model used in EMFAC2017 based on the OBD data obtained from a CARB sponsored study, and a non-linear model was developed from the data to determine NOx ZMR and DR for NOx. Details are provided in Section 4.3.6 of this document.

For THC, CO, and PM, the HD diesel truck emissions deterioration model of EMFAC2017 was used to calculate the ZMRs and DRs for these pollutants using the equations below:

$$ZMR = ER_{avg} \,/\, (1 + EIR \cdot Odo_{avg}) \qquad \text{(Eq. 4.3.5-3)}$$

$$DR = (ER_{avg} - ZMR)/Odo_{avg} \qquad \text{(Eq. 4.3.5-4)}$$

where EIR is emission impact rate, which is used in EMFAC to quantify the emission deterioration of HD trucks. Unlike NOx, for THC, CO, and PM, separate sets of ZMRs and DRs were calculated for the 2013-2015 MY group and 2016+ MY group. Table 4.3.5-15 shows the revised ZMR and DR for 2013+ MY HHD diesel trucks. For comparison, the corresponding ZMRs and DRs are also shown in the table.

Table 4.3.5-15. Revised ZMRs (g/mi) and DRs (g/mi/10K mi) for heavy heavy-duty diesel trucks

EMFAC Model	Model Year	HC		CO		NOx		PM	
		ZMR	DR	ZMR	DR	ZMR	DR	ZMR	DR
EMFAC2021	2013-15	0.013	0.00012	0.20	0.0017	0.6	n/a*	0.0041	0.00015
	2016+	0.011	0.00010	0.13	0.0011			0.0029	0.00011
EMFAC2017	2013-14	0.019	0.00025	0.28	0.003	2.67	0.050	0.0025	0.00011
	2015+	0.019	0.00021	0.28	0.003	2.68	0.046	0.0025	0.00010

*See Section 4.3.6 for details on NOx deterioration

4.3.5.2.4 MHD Diesel Truck ZMR and DR

As discussed earlier, the eight MHD diesel trucks had engines with model years ranging from 2013 to 2017. In addition, an examination of the test data suggested that it was more appropriate to analyze all these trucks as a single 2013+ MY group. Thus, for this EMFAC update staff developed the ZMRs and DRs of MHD diesel trucks for a 2013+ MY group only and left these rates for 2010-2012 unchanged from EMFAC2017.

Similar to the calculations for HHD diesel trucks, the UDDS emission rates of the eight tested trucks and their odometer readings were averaged to obtain the ER_{avg} and Odo_{avg}. The calculations of ZMRs and DRs of all gaseous pollutants and PM for MHD diesel trucks are the same as those used for HHD trucks. Table 4.3.5-16 shows the revised ZMRs and DRs for 2013+ MY MHD diesel trucks. For comparison, also include in the table are the ZMRs and DRs of EMFAC2017.

Table 4.3.5-16. Revised ZMRs (g/mi) and DRs (g/mi/10K mi) for medium heavy-duty diesel Trucks

EMFAC Model	Model Year	HC		CO		NOx		PM	
		ZMR	DR	ZMR	DR	ZMR	DR	ZMR	DR
EMFAC2021	2013+	0.0044	0.00017	0.039	0.0015	0.15	N/A*	0.0016	0.00010
EMFAC2017	2013-14	0.0088	0.00025	0.12	0.0025	1.52	0.070	0.0014	0.00015
	2015+	0.0088	0.00023	0.12	0.0020	1.48	0.065	0.0014	0.00012

* See Section 4.3.6 for details on NOx deterioration

4.3.5.2.5 HHD and MHD Diesel Truck Speed Correction Factors

As described earlier, the running exhaust emissions is calculated by multiplying BER in g/mi by VMT, and emission rate at a specific speed is obtained by applying an SCF to the BER calculated from the emission rate at the UDDS speed (18.8 mph). HHD trucks typically are tested over the UDDS as well as a several other cycles that have an average speed either lower or higher than the UDDS speed. The emission rates of all the cycles are normalized to the UDDS rate to yield SCF.

For this EMFAC update, the SCFs of HC, CO, NOx, PM, and CO2 for HHD diesel trucks were developed using the emissions test data from 41 of the 44 trucks used for running exhaust emission rate calculations. Three of the trucks were from the testing by CARB and EMA (see earlier), which used a set of testing cycles different from that used in TBSP. As discussed earlier, staff had to combine the 2013-2015 MY and 2016+ MY group into a single 2013+ MY group in calculating NOx running exhaust emission rate but used the two separate MY groups for the emission rates of other pollutants; therefore, the SCF for NOx was also calculated for a single 2013+ MY group and the SCFs for the other pollutants for a 2013-2015 MY group and a 2016+ MY group.

For a given MY group, a pollutant’s emission rates of all test cycles were first plotted versus the cycles’ speeds. Curves were then fitted to find the equations best representing the data. In finding the empirical curves that best relates the emission rates to speeds, a two-segment curve was used in order to reasonably fit all the data points. Based on data fitting, it was found that for all pollutants Eq. 4.3.4-5 should be used to calculate SCFs for speeds below 18.8 mph and Eq. 4.3.4-6 for speed between 18.8 and 65 mph.

$$\boldsymbol{SCF = A \cdot Speed^{b}} \qquad \text{(Eq. 4.3.5-5)}$$

$$SCF = C + D \cdot speed + E \cdot speed^2 \qquad \text{(Eq. 4.3.5-6)}$$

where *a*, *b*, *c*, *d,* and *e* are coefficients for the respective equations, and Table 4.3.5-17 lists the numeric values of these coefficients for calculating the SCF of NOx for 2013+ MY group and the SCFs of other 4 pollutants for 2013-2015 and 2016+ MY groups.

Table 4.3.5-17. Coefficients of speed correction factor equations for heavy heavy-duty diesel trucks

Pollutant	Model Year	5-18.8 mph		18.8-65 mph		
		A	B	C	D	E
THC	2013-15	60.3	-1.40	4.83×10^{-4}	-5.02×10^{-2}	1.77
	2016+	89.1	-1.53	8.92×10^{-4}	-7.70×10^{-2}	2.13
CO	2013-15	31.2	-1.17	5.06×10^{-4}	-6.02×10^{-2}	1.95
	2016+	33.2	-1.19	5.07×10^{-4}	-6.12×10^{-2}	1.97
NOx	2013+	13.0	-0.874	8.94×10^{-4}	-8.69×10^{-2}	2.32
PM	2013-15	2.05	-0.244	2.27×10^{-3}	-8.84×10^{-2}	1.86
	2016+	4.63	-0.525	3.70×10^{-3}	-0.182	3.11
CO2	2013-15	3.05	-0.380	2.92×10^{-4}	-2.81×10^{-2}	1.43
	2016+	2.96	-0.370	2.85×10^{-4}	-2.59×10^{-2}	1.39

The data analysis for SCFs of MHD diesel trucks is the same as that for HHD diesel trucks. As is the case with the BER, SCFs of MHD diesel trucks were developed for only a single 2013+ MY group due to the small number of trucks tested. The two equations (Eq. 4.3.5-5 and Eq. 4.3.5-6) used for HHD diesel trucks are also applicable for MHD diesel trucks. Table 4.3.5-18 lists the numeric values of these coefficients for calculating the SCFs of THC, CO, NOx, PM, and CO2 for 2013+ MY group of MHD diesel trucks.

Table 4.3.5-18. Coefficients of speed correction factor equations for medium heavy-duty diesel trucks

Pollutant	Model Year Group	5-18.8 mph		18.8-65 mph		
		A	B	C	D	E
THC	2013+	172	-1.75	1.05×10^{-3}	-8.62×10^{-2}	2.25
CO	2013+	19.3	-1.01	4.04×10^{-4}	-4.58×10^{-2}	1.72
NOx	2013+	23.6	-1.08	8.78×10^{-4}	-8.30×10^{-2}	2.25
PM	2013+	6.90	-0.659	2.59×10^{-3}	-0.144	2.78
CO2	2013+	4.02	-0.474	3.59×10^{-4}	-3.09×10^{-2}	1.46

4.3.5.3 Heavy Heavy-Duty Diesel Truck Start Emission Rates

In EMFAC2017, StER of NOx for HD trucks were developed based on the emissions data collected from CARB Project 2R1406 (*In-Use Testing of Heavy-Duty Vehicles Certified to Applicable 2010 Emission Standards).* In the project, four trucks with 2011-2014 engine MY were tested at CARB Depot Park facility using PEMS for the emissions of gaseous pollutants. In this project staff performed testing on a route called DPTODP, which is an uninterrupted round trip starting from Depot Park and covering a distance of about 15 miles before ending at Depot Park. For each test vehicle, start emission test was conducted following soak times of 5, 10, 15, 30, 60, 120, 240, and 720 minutes.

In CARB's TBSP, 11 HD diesel trucks of 2013+ engine model years were tested using PEMS to collect start emissions data. Staff made two modifications to the testing procedures of CARB Project 2R1406 based on the analysis of the project's test data. First, it was found that for all the test vehicles, the start emissions occurred within the first 20 minutes of the runs, and thus a shortened version of the DPTODP route was used for all the test runs in order to reduce testing time. Second, the 4 soak times between 5 and 30 minutes did not contribute a great deal of information in terms of establishing the relationship between the soak time and start emissions (i.e., soak time curve); therefore, for each vehicle only a 20-min soak time run was performed instead of the 4 runs done in Project 2R1406 and a 480-min soak time run was added to better define the soak time curve at that point.

Since the engines of all 11 trucks tested in CARB TBSP were 2013 or newer model year engines, staff merged the start emission data of these 11 trucks with the data of three trucks with 2013-2014 model year engines from Project 2R1406 to form a larger dataset for updating the StERs of 2013+ engine model years. As mentioned earlier, the three Project 2R1406 trucks were tested with a different set of soak times; as a result, a soak time curve was first fit using each truck's actual test data and then emissions at the re-defined five soak times were then calculated from the curve for merging with the TBSP data.

The method for analyzing start emission data is the same as that used in the EMFAC2014 and EMFAC2017 updates. Briefly, the NOx 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, for a test run, the StER is obtained by subtracting the NOx emission rate of the running phase from the emission rate of the start phase. A detailed discussion of the StER calculation method can be found in Section 3.2.3.6 of EMFAC2014 technical documentation[59].

It should be mentioned that in previous EMFAC StER updates, SCR temperatures of a test run was used to determine the duration of the start phase. However, for this update SCR temperature data are available for only three of the 11 tested trucks. As a result, staff had to use the exhaust temperature as a surrogate for SCR temperature using the exhaust-SCR temperature relationship of the three trucks for which the SCR temperatures were recorded.

As in EMFAC2017 update, start emissions were only found for NOx in the test data of the 11 trucks with SCR engines but no incremental emissions increases were identified for THC, CO, and CO2. Thus, staff assumes no start emissions for THC, CO, and CO2. PM emissions data were not measured in the PEMS testing of these 11 trucks, but the dynamometer test data of these trucks show PM levels mostly near or at detection limit.

---

[59] https://ww3.arb.ca.gov/msei/downloads/emfac2014/emfac2014-vol3-technical-documentation-052015.pdf

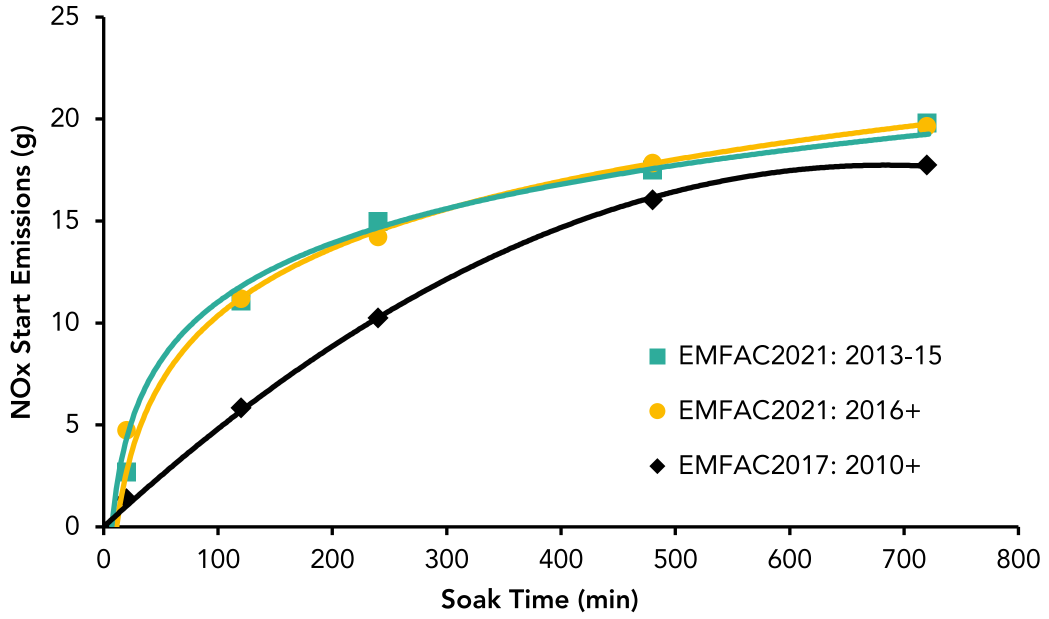
Since all these trucks were equipped with a DPF system, it is assumed that there were no start emissions for PM.

The StERs of NOx by soak time for the four HD diesel trucks were determined for all test runs and the results are provided in Table 4.3.5-19. In Figure 4.3.5-1 the calculated NOx StERs are plotted as a function of soak time. EMFAC2017 StER data are also provided for comparison.

Table 4.3.5-19. Heavy heavy-duty diesel truck NOx start emission rates by soak time

EMFAC Model	Model Year	Start Emission Rate (g/hr)				
		20 min	120 min	240 min	480 min	720 min
EMFAC20201	2013-15	2.67	11.1	15.0	17.5	19.8
	2016+	4.74	11.2	14.2	17.8	19.6
EMFAC2017	2013+	1.38	5.84	10.2	16.0	17.7

Figure 4.3.5-1. NOx start emissions as a function of soak time for heavy heavy-duty diesel trucks: EMFAC2021 vs EMFAC2017



As can be seen in Figure 4.3.5-1, compared to the EMFAC2017 curve, the two revised curves for EMFAC2021 both show higher NOx start emissions especially for soak times less than 400 minutes. This indicates that NOx start emissions would be higher for EMFAC2021 if the soak times of EMFAC2017 were unchanged.

4.3.5.4 Natural Gas Emission Rate Updates

In previous EMFAC models, only emissions from natural gas (NG) transit buses and NG refuse trucks were modeled explicitly using emissions data compiled from CARB internal testing, published papers, and testing project reports. The data used were all obtained from dynamometer testing and covered engines of both pre-2007 MY non-TWC and 2007+ MY TWC control technologies. Emissions from other categories of NG vehicles such as NG HD trucks were implicitly accounted for by treating them as diesel vehicles.

In EMFAC2014, staff developed the running exhaust emission rates for 2007+ MY NG transit buses (engines certified to 0.2 g/bhp-hr NOx or 0.2-g engines) and 2010+ MY refuse (also 0.2-g engines)[60]. The analysis was based on dynamometer test data from one 2008 MY three-way catalyst (TWC) NG refuse truck one 2008 MY TWC engine, both of which were tested in a project carried out by South Coast Air Quality Management District (SCAQMD). In EMFAC2017, staff further updated running exhaust emission rates of NG transit buses using emissions data from multiple data sources that included NG transit buses ranging from 2008 to 2015 MY[61].

In the 200-Vehicle Project, nearly one hundred HD vehicles were tested using PEMS and about half of these were NG vehicles. Each test vehicle was instrumented with a PEMS unit, and the PEMS continuously measured the vehicle's emissions of gaseous pollutants for a typical day of operation. PEMS data from 46 NG HD vehicles were obtained, and Table 4.3.5-20 shows the distribution of the data among four categories of vehicles.

Table 4.3.5-20. Natural gas vehicles tested in 200-Vehicle Project

Technology	Transit Bus	School Bus	Refuse Truck	Goods Movement Truck	Delivery Truck
0.2g TWC	6	5	6	9	3
0.02g TWC	4	--	5	8	--

It should be noted EMFAC does not have a goods movement truck category and a delivery truck category, and these trucks were together treated as NG HD trucks in the emission rate analysis.

As each PEMS testing run in the 200-Vehicle Project was basically the vehicle's operation of a typical working day, the test data consisted of emissions produced under various driving conditions. A simple average of all the data points in a test run would not only mask many unique emission features of the test vehicles but also make a meaningful comparison difficult among vehicles in a vehicle category as well as between two different vehicle categories. As a result, an emissions vs speed relationship needs to first established for each of the NG vehicle categories from their PEMS data. This relationship in essence is a speed correction curve, and from such a curve a BER can be calculated using the cycle speed of a dynamometer test cycle commonly used for a vehicle category. Table 4.3.5-21 lists the test cycles chosen for the four NG vehicle categories.

---

[60] https://ww3.arb.ca.gov/msei/downloads/emfac2014/emfac2014-vol3-technical-documentation-052015.pdf
[61] https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf

Table 4.3.5-21. Cycle speeds for estimating base emission rates of natural gas vehicles

	Transit Bus	School Bus	Refuse Truck	Goods Movement Truck	Delivery Truck
Standard Cycle	OCBC	AQMD-SB	AQMD RTC	UDDS	UDDS
Cycle Speed (mph)	12.1	12.3	7.31	18.8	18.8

With the analysis approach outlined above, the PEMS data collected from a daily operation of a test vehicle was first grouped into 10-mph speed bins based on the speeds of the data points to form seven speed bins, with the middle point speed representing the speed for each speed bin. A preliminary data analysis has showed that there are very few data points for speeds higher than 70 mph, and therefore all such data points are included in the 65-mph bin. Table 4.3.5-22 lists the speed ranges of the seven speed bins.

Table 4.3.5-22. Middle Speed Point of the seven speed bin ranges

Speed	Speed Bin						
Middle Speed Point	5-mph	15-mph	25-mph	35-mph	45-mph	55-mph	65-mph
Speed Range (mph)	<10	10-<20	20-<30	30-<40	40-<50	50-<60	≥60

For each vehicle, all data points in a speed bin were averaged to yield an average emission rate for that bin. The average emission rates of a given speed bin (e.g., 25-mph bin) of all test vehicles in a vehicle category (e.g., transit bus) were then averaged to obtain a final bin average emission rate.

Not all test runs have data in all seven bins. Among the tested transit buses, none has data in the 65-mph bin and several even lack data in the 45-mph bin. The tested refuse trucks have top speed bins ranging from 45-mph to 65-mph. Since individual test vehicles show very different overall emission levels, if emission rates of all the speed bins in a category of vehicles had been averaged, it would have resulted in a distorted relationship between emissions and speed at the higher speed end. Therefore, in constructing emission rate vs speed curves, an engineering judgement was made to decide how many speed bins would be used.

<u>PM emission rate.</u> No PM emissions data were collected during the PEMS testing. However, in the 200-Vehicle Project, selected test vehicles were also tested on dynamometer and for many of these vehicles total PM emissions were quantified using gravimetrical method. Using the dynamometer PM data, staff estimated PM running exhaust emission rates for all NG vehicle categories. It should be noted that PM emissions of all the NG vehicles tested on dynamometer were very low and thus these estimated PM emission rates should be viewed as an indication of the overall levels of PM emissions.

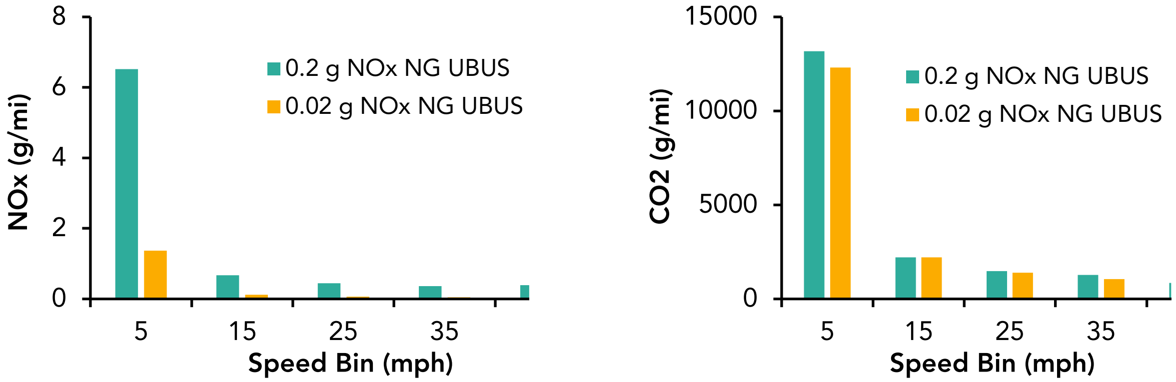
<u>Emission deterioration.</u> In previous EMFAC, no emission deterioration was applied to NG transit buses and NG refuse trucks mainly based on the assumption that these vehicles,

being operated by public agencies or large companies, would undergo regular maintenance, thus greatly reducing the occurrence of control component tampering and/or failures. The dataset of NG vehicle PEMS testing from the 200-Vehicle Project, although relatively large, does not seem to be sufficient for an analysis of emission deterioration. Therefore, the average emission rates of all four categories of NG vehicles are used for all odometers of the fleets (i.e., emission rates do not change with mileages). While this does not explicitly provide an estimate of emission deterioration, the effect of any emission deterioration that has occurred is implicitly reflected in the average emission rates.

Idle emissions In EMFAC, continuous operation of a heavy-duty vehicles for >5 minutes at speed <5 mph is defined as extended idle and emissions from such operation is specifically modeled as idle emissions. As with HD diesel vehicles, IdleERs were determined for NG refuse trucks and NG HD trucks. No separate idle emissions were determined for NG transit buses and school buses; for these buses all idle operations were considered to be part of the normal trips. To calculate the IdleER of a test run, all PEMS data points were first flagged as either idle or non-idle based on the EMFAC criteria for extended idle. All data points flagged as idle were then averaged to yield an IdleER. All the non-idle data points were processed for the vehicle's running exhaust emission rate by following the same procedures as described above.

Results of the speed bin analysis of the PEMS data of urban transit buses (UBUS) are displayed in Figure 4.3.5-2 for NOx and CO2, two key contributors from HD vehicles in terms of emissions inventory.

Figure 4.3.5-2. NOx and CO2 running exhaust emission rates of natural gas urban transit bus by speed bin



NOx emission results show that compared to 0.2-g UBUS, 0.02-g UBUS can achieve significant emissions reduction under all operating conditions. As will be seen later, this is also the case for NG refuse trucks and NG HD trucks although the degree of NOx reduction varies. Also note the notably high CO2 rates for the 5-mph speed bin relative to other higher speed bins. As mentioned earlier, for UBUS the vehicle operations that could be characterized as idle according to the EMFAC definition of extended idle were considered to be part of the normal trips of buses, and thus all the data points belong to such operations were counted in the 5-mph speed bin. The operations below 5 mph contribute fair amount of emissions but little distance, resulting in much higher emission rate in g/mi.

As discussed earlier, for the running exhaust emissions of NG vehicles, a BER can be obtained from its emission rate vs speed curve established based on the PEMS test data. For UBUS, the commonly used dynamometer test cycle is OCBC (Orange County Bus Cycle), which has a cycle speed of 12.1 mph. From the emission rate vs speed curves established for UBUS, the BERs for THC, CO, NOx, and CO2 were calculated at the OCBC speed. The BER for PM was calculated based on the dynamometer test results of one 0.2-g and two 0.02-g NG UBUS from the 200-Vehicle Project. Table 4.3.5-23 shows the BER of THC, CO, NOx, PM, and CO2 for two MY groups of UBUS. Also included in the table are the BERs for the corresponding MY groups of UBUS in EMFAC2017.

Table 4.3.5-23. Base emission rates of natural gas urban transit buses

EMFAC Model	Model Year	Base Emission Rate (g/mi) @ OCBC Speed (12.1 mph)				
		THC	CO	NOx	PM	CO2
EMFAC2021	2007-2017*	2.95	50.9	1.44	0.00037	3,801
	2018+**	1.70	22.1	0.23	0.00071	3,507
EMFAC2017	2007	21.0	0.833	17.1	0.015	2,048
	2008+	8.17	58.0	0.61	0.0050	2,237

*The vast majority of 2007-2017 MY engines were certified to 0.2 g/bhp-hr NOx with TWC as the primary control but some 2007 engines were also certified to 1.8-1.0 g/bhp-hr NOx with OxyCat and some 2017 engines were certified to 0.1-0.02 g/bhp-hr NOx with TWC.

**Starting 2018 MY, engines have been certified to 0.02 g/bhp-hr NOx with TWC as the primary control but some 2018-2019 MY engines were also certified to 0.1-0.05 g/bhp-hr NOx with TWC.

From the calculated BERs, emission rates at other speeds can be obtained by applying SCFs. The SCFs for NG UBUS were calculated by normalizing the rates of all speed bins to the BERs at the OCBC speed. Table 4.3.5-24 gives the equations for calculating SCFs for the five pollutants.

Table 4.3.5-24. Speed correction factor equations for natural gas urban transit buses

Pollutant	Model Year	Speed*	SCF Equation	A	B	C
THC	2007-2017	5-45	$A\ (Speed)^B$	13.5	-1.04	
	2018+	5-45	$A\ exp^{B\ (Speed)}$	3.95	-0.112	
CO	2007-2017	5-45	$A\ (Speed)^B$	10.9	-0.953	
	2018+	5-45	$A\ exp^{B\ (Speed)}$	3.41	-0.100	
NOx	2007-2017	5-45	$A\ (Speed)^B$	27.7	-1.32	
	2018+	5-45	$A\ (Speed)^B$	89.2	-1.79	
PM	2007+	5-65	$A\ (speed)^2 + B\ (speed) + C$	$5.90\text{x}10^{-4}$	$-5.73\ \text{x}10^{-2}$	1.62
CO2	2007-2017	5-45	$A\ (Speed)^B$	20.8	-1.21	
	2018+	5-45	$A\ (Speed)^B$	26.3	-1.30	

* For speeds >45 mph, SCF equal to values at 45 mph

The above discussion is pertinent to the heavier urban transit buses or heavy heavy-duty buses, as all NG transit buses tested in the 200-Vehicle Project had a GVWR > 33,000 lbs. Since EMFAC also includes many lighter transit buses or medium heavy-duty buses, emission rates were estimated for these buses from T7 buses using scaling factors.

In estimating the emission rates of T6 buses, an assumption was made that, everything else being equal, emission rates of buses would generally relate to the vehicle weight. Thus, the ratios of BERs of medium heavy-duty and heavy heavy-duty diesel trucks were used as scaling factors and were applied to the BERs of heavy heavy-duty NG buses to obtain the BERs of medium heavy-duty NG buses. As the BERs of MHD and HHD diesel trucks were calculated at the UDDS speed (18.8 mph), the scaling factors based on MHD and HHD diesel trucks were further adjusted to the OCBC speed (12.1 mph) using SCFs of MHD and HHD diesel trucks. Table 4.3.5-25 shows the estimated BERs for T6 NG UBUS.

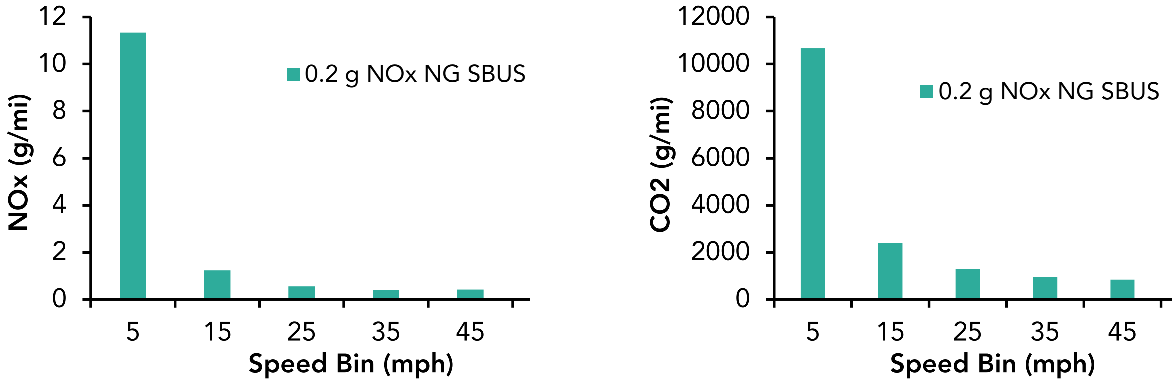
Table 4.3.5-25. Estimated base emission rates for T6 natural gas urban buses

EMFAC Model	Model Year	Base Emission Rate (g/mi) @ OCBC Speed (12.1 mph)				
		THC	CO	NOx	PM	CO2
EMFAC2021	2007-2017	1.34	11.2	0.43	0.0001	2,335
	2018+	0.96	7.91	0.070	0.0004	2,232

As no medium heavy-duty transit bus test data is available from the 200-Vehicle Project for determining speed-emissions relationship, the SCFs of heavy heavy-duty NG UBUS (Table 4.3.5-24) were used for medium heavy-duty NG UBUS.

For this EMFAC update, staff also developed emission rates for NG school buses (SBUS) using the PEMS data from the 200-Vehicle Project. Results of the SBUS PEMS analysis are displayed in Figure 4.3.5-3 for NOx and CO2.

Figure 4.3.5-3. NOx and CO2 running exhaust emission rates of natural gas school bus by speed bin



A test cycle, SCAQMD-SB Cycle, was used in the 200-Vehicle Project for school buses being tested on chassis dynamometer. This cycle was developed based on telemetry activity of school buses operating in Southern California and has a cycle speed of 12.3 mph. From the rate-speed curves determined for SBUS, the BERs for THC, CO, NOx, and CO2 were calculated at 12.3 mph, the average speed of SCAQMD-SB Cycle. The BER for PM was calculated based on the dynamometer test results of one 0.2g NG school bus from the 200-Vehicle Project. No emissions data for school buses with 0.02-g engines are available from the 200-Vehicle Project, and therefore the BERs for 0.02-g SBUS were estimated by scaling the BERs of 0.2-g SBUS using the ratios of BERs of 0.2-g UBUS and 0.02-g UBUS. Table 4.3.5-26 shows the BERs of THC, CO, NOx, PM, and CO2 for the 2007-2017 MY and 2018+ MY NG SBUS.

Table 4.3.5-26. Base emission rates of natural gas school buses

Model Year	Rate @ School Bus Cycle Speed (12.3 mph)				
	THC	CO	NOx	PM*	CO2
2007-2017*	11.0	39.8	2.23	0.0102	3,402
2018+**	6.36	17.3	0.363	0.0102	3,139

* Most of 2007-2017 MY engines were certified to 0.2 g/bhp-hr NOx with TWC as the primary control.

** Rates were estimated based on ratio of NG transit bus rates and applied to engines certified to 0.02 g/bhp-hr NOx.

Similar to UBUS, SCFs were developed for SBUS using the PEMS data. Equations for calculating SCFs of the five pollutants are listed in Table 4.3.5-27. It is assumed that the SCFs based on 0.2-g SBUS are also applicable to 0.02-g SBUS.

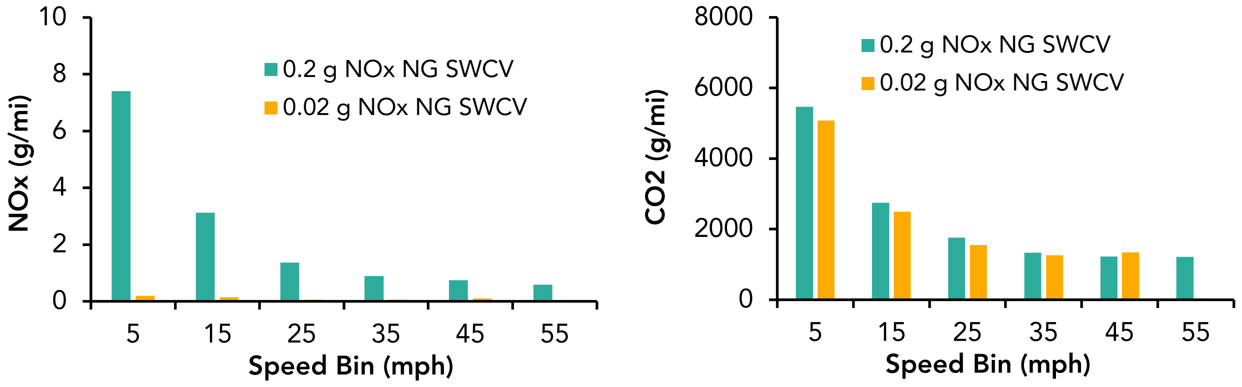
Table 4.3.5-27. Speed correction factor equations for natural gas school buses

Pollutant	MY	SCF Equation	Speed*	A	B	C
THC	2007+	$A\ (Speed)^{B}$	0-55	20.4	-1.20	
CO	2007+	$A\ (Speed)^{B}$	0-55	24.7	-1.28	
NOx	2007+	$A\ (Speed)^{B}$	0-55	46.2	-1.53	
PM	2007+	$A\ (speed)^{2} + B\ (speed) + C$	0-55	$5.90\text{x}10^{-4}$	$-5.73\text{x}10^{-2}$	1.62
CO2	2007+	$A\ (Speed)^{B}$	0-55	16.2	-1.11	

* For speeds >45 mph; SCF equals to values at 45 mph

For this version of EMFAC model, staff also updated emissions rates for solid waste collection vehicles (SWCV). Results of the speed bin analysis of the PEMS data for SWCV (refuse trucks) are displayed in Figure 4.3.5-4 for NOx and CO2.

Figure 4.3.5-4. NOx and CO2 running exhaust emission rates of natural gas solid waste collection vehicles by speed bin



In recent years, dynamometer testing of refuse trucks have been using a cycle developed by WVU for SCAQMD and consists of the refuse truck operation (SCAQMD-RTC) and operation/compaction (SCAQMD-RCC) cycles to simulate typical transportation and curbside pick-up mode operations. The emissions from the RCC are integrated into the emissions from the RTC. The RTC has an average speed of 7.31 mph.

From the rate-speed curves determined for SWCV, the BERs for THC, CO, NOx, and CO2 were calculated at the RTC speed of 7.31 mph. Again, the BER for PM was calculated based on the dynamometer test results of one 0.2-g and one 0.02-g NG refuse trucks from the 200-Vehicle Project. Table 4.3.5-28 shows the BERs of THC, CO, NOx, PM, and CO2 for two MY groups of SWCV. Also included in the table are the BERs for the corresponding MY groups of SWCV in EMFAC2017.

Table 4.3.5-28. Base emission rates of natural gas solid waste collection vehicles

EMFAC Model	Model Year	Base Emission Rate (g/mi) @ OCBC Speed (12.1 mph)				
		THC	CO	NOx	PM	CO2
EMFAC2021	2007-2017*	21.6	112	7.90	0.0017	4,559
	2018+*	0.54	33.8	0.169	0.0034	4,197
EMFAC2017	2007-2009	22.8	18.5	18.8	0.0044	5,404
	2010+	10.1	36.6	0.879	0.0044	5,077

* 2007-2017 MY: mostly 0.2 g/bhp-hr NOx engines; 2018+ MY: mostly 0.02 g/bhp-hr NOx engines. See Table 4.3.5-23 notes for more details.

From the calculated BER, emission rates at other speeds can be obtained by applying the SCFs. The SCFs for NG SWCV were calculated by normalizing the rates of all speed bins to the BER at the RTC speed. Table 4.3.5-29 lists the equations for calculating the SCFs of NG SWCV for all the pollutants.

Table 4.3.5-29. Speed correction factor equations for natural gas school buses

Pollutant	MY	SCF Equation	Speed*	A	B	C
THC	2007-2017	$A\,(Speed)^B$	0-55	6.51	-0.942	
	2018+	$A\,(Speed)^B$	0-55	22.7	-1.57	
CO	2007-2017	$A\,(Speed)^B$	0-55	8.52	-1.08	
	2018+	$A\,(Speed)^B$	0-55	7.99	-1.05	
NOx	2007-2017	$A\,(Speed)^B$	0-55	8.31	-1.06	
	2018+	$A\,(Speed)^B$	0-55	2.92	-0.539	
PM	2007-2017	$A\,(speed)^2 + B\,(speed) + C$	0-55	$4.80\text{x}10^{-4}$	$-4.67\text{x}10^{-2}$	1.32
CO2	2007-2017	$A\,(Speed)^B$	0-55	4.18	-0.719	
	2018+	$A\,(Speed)^B$	0-55	4.14	-0.714	

* SCF values for speeds >55 = SCF at 55 mph.

As discussed earlier, in addition to running exhaust emission rate a separate IdleER for each pollutant was also determined for NG SWCV. IdleERs were calculated for SWCV following the method described above, and the obtained rates are shown in Table 4.3.5-30.

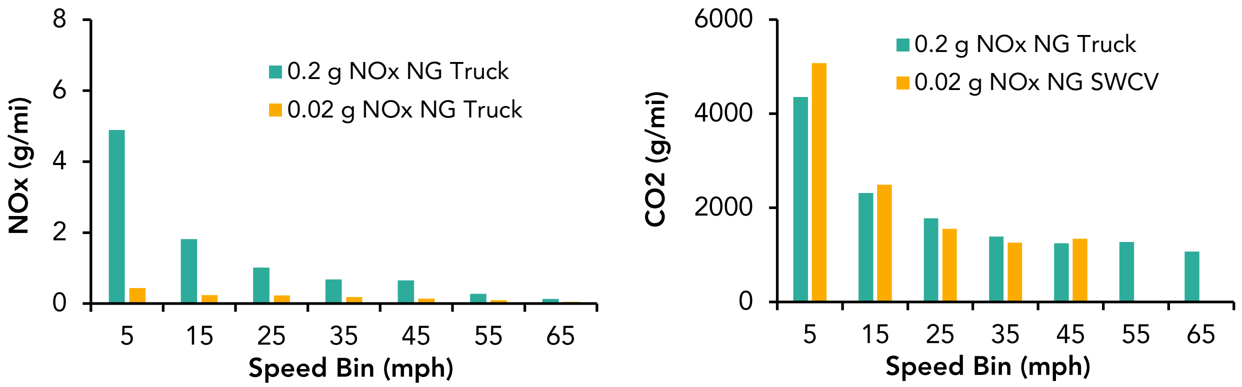
Table 4.3.5-30. Idle emission rates of natural gas solid waste collection vehicles

Model Year	Idle Emission Rate (g/hr)				
	THC	CO	NOx	PM	CO2
2007-2017*	38.8	136	17.8	0.00090	12,350
2018+*	3.38	58.9	0.227	0.0029	13,991

* 2007-2017 MY: mostly 0.2 g/bhp-hr NOx engines; 2018+ MY: mostly 0.02 g/bhp-hr NOx engines. See Table 4.3.5-23 notes for more details.

In previous EMFAC, heavy-duty NG trucks has been treated as heavy-duty diesel trucks in emissions inventory calculations. In EMFAC2021 update, staff was able develop emission rates for HHD (T7) NG trucks based on PEMS test data from the 200-Vehicle Project. For HHD NG trucks, the method of data analysis has been described earlier and results for NOx and CO2 are displayed in Figure 4.3.5-5.

Figure 4.3.5-5. NOx and CO2 running exhaust emission rates of heavy heavy-duty diesel trucks by speed bin



Although two dynamometer test cycles – Goods Movement Truck Cycle and Delivery Truck Cycle – were developed in the 200-Vehicle Project, staff decided to use the UDDS as the cycle to determine the running exhaust emission rates of these trucks as they are re-characterized as HHD NG trucks. Thus, BERs of HHD NG trucks were calculated at 18.8 mph from the rate-speed curve developed from the PEMS data. Table 4.3.5-31 shows the calculated BERs of THC, CO, NOx, PM, and CO2 of HHD NG trucks.

Table 4.3.5-31. Base emission rates of heavy heavy-duty natural gas trucks

Model Year	**Base Emission Rate (g/mi) @ UDDS Speed (18.8 mph)**				
	THC	**CO**	**NOx**	**PM**	**CO2**
2007-2017*	2.43	16.9	1.28	0.0033	2075
2018+*	2.18	14.1	0.24	0.0062	2193

* 2007-2017 MY: mostly 0.2 g/bhp-hr NOx engines; 2018+ MY: mostly 0.02 g/bhp-hr NOx engines. See Table 4.3.5-23 notes for more details.

Emission rates at other speeds can be obtained using SCF. The SCFs for NG HHD trucks were calculated by normalizing the rates of all speed bins to the BER at the UDDS speed and regression equations were then obtained for all gaseous pollutants. The SCF for PM was derived by re-normalizing the EMFAC2017 PM SCF for NG vehicles to the UDDS speed. Table 4.3.5-32 presents the equations for calculating SCFs of NG HHD trucks.

Table 4.3.5-32. Speed correction factor equations for heavy heavy-duty natural gas trucks

Pollutant	MY	SCF Equation	Speed	A	B	C
THC	2007-2017	$A\ (Speed)^B$	0-65	26.8	-1.12	
	2018+	$A\ (Speed)^B$	0-65	14.7	-0.917	
CO	2007-2017	$A\ (speed)^2 + B\ (speed) + C$	0-65	4.37×10^{-4}	-4.43×10^{-2}	1.68
	2018+	$A\ (speed)^2 + B\ (speed) + C$	0-65	4.13×10^{-4}	-5.50×10^{-2}	1.89
NOx	2007-2017	$A\ (Speed)^B$	0-65	24.7	-1.09	
	2018+	$A\ (Speed)^B$	0-65	5.25	-0.565	
PM	2007-2017	$A\ (speed)^2 + B\ (speed) + C$	0-65	7.94×10^{-4}	-7.72×10^{-2}	2.18
CO2	2007-2017	$A\ (Speed)^B$	0-65	5.16	-0.559	
	2018+	$A\ (Speed)^B$	0-65	4.91	-0.542	

Similar to NG refuse trucks, separate IdleERs were also developed for HHD NG trucks. Same analysis method was used to calculate the IdleERs of gaseous pollutants and the PM rate was estimated based on the dynamometer test data of one delivery truck (0.2-g engine) and 3 goods movement trucks (one 0.2-g and two 0.02-g engines). Table 4.3.5-33 shows the IdleERs of THC, CO, NOx, PM, and CO2 of HHD NG trucks.

Table 4.3.5-33. Idle emission rates of natural gas heavy-duty trucks

Model Year	Idle Emission Rate (g/hr)				
	THC	CO	NOx	PM	CO2
2007-2017*	48.2	48.0	15.5	0.033	11,224
2018+*	33.9	109	14.4	0.066	14,164

* 2007-2017 MY: mostly 0.2 g/bhp-hr NOx engines; 2018+ MY: mostly 0.02 g/bhp-hr NOx engines. See Table 4.3.5-23 notes for more details.

4.3.5.5 CO2 Emission Rate

To align with the Federal Phase 1 and Phase 2 programs, CARB adopted California Phase 1 and Phase 2 GHG regulations in 2013 and 2018, respectively. These two regulations allowed CARB to enforce its own GHG regulations. It also allowed CARB to certify the heavy-duty manufacturers in California. Phase 1 covers engines and three vehicle categories, including tractors (Class 7-8), vocational vehicles (Class 2b-8), and pickup trucks and vans (Class 2b-3). Phase 2 covers trailers along with the engines and the three-vehicle categories covered in Phase 1, and it is expected to lower CO2 emissions beyond Phase 1 levels by an additional 13 percent in 2030, and by 2050, those reductions will increase to roughly 24 percent.

To account for the impacts of CARB Phase 1 and Phase 2 GHG regulations, the percentage reductions in CO2 emission rates with respect to 2010 are estimated to adjust CO2 emissions by vehicle type, model year, and fuel type. The details of CO2 emission reduction percentage can be found under Section 4.3.3.1 in EMFAC2017 technical documentation and Appendix F[62] of Proposed California Greenhouse Gas Emissions Standards for Medium- and Heavy-Duty Engines and Vehicles (i.e., CA Phase 2 staff report).

For EMFAC2021, staff further evaluated the impact of Phase 1 regulation implementation using CARB certified subfamily CO2 Family Emission Level (FEL) along with their production volume from 2016 through 2019. To evaluate the CO2 emission reduction rate, composite baselines for model year 2010 in gram per mile are established for medium heavy-duty and heavy heavy-duty vehicles based on baseline vehicle performance[63] and California certified production volumes, as shown in Table 4.3.5-34 and Table 4.3.5-35.

Table 4.3.5-34. Composite CO2 baseline for Medium Heavy-Duty Vehicles

Medium Heavy-Duty Vehicles	Vocational		Tractor
	Class 4-5	Class 6-7	Class 7
CO2 baseline (gCO2/ton-mile)	408	247	236
Payload (tons)	2.85	5.6	12.5
CO2 baseline (gCO2/mile)	1163	1383	2950
Production Volume Share (%)	33%	63%	4%
Composite CO2 baseline (gCO2/mile)	1375		

Table 4.3.5-35. Composite CO2 baseline for Heavy Heavy-Duty Vehicles

Heavy Heavy-Duty Vehicles	Vocational	Tractor	
	Class 8	Class 8 Day-Cabs	Class 8 Sleeper-Berth
CO2 baseline (gCO2/ton-mile)	236	95	93
Payload (tons)	7.5	19	19
CO2 baseline (gCO2/mile)	1770	1798	1758
Production Volume Share (%)	38.7%	28.3%	33.0%
Composite CO2 baseline (gCO2/mile)	1774		

---

[62] California Air Resources Board, Appendix F-Emissions Inventory Analysis and Results, Staff Report of Proposed California Greenhouse Gas Emissions Standards for Medium- and Heavy-Duty Engines and Vehicles (web link: https://ww3.arb.ca.gov/regact/2018/phase2/appf.pdf?_ga=2.133493582.1354806717.1613440332-1307567751.1567730621, posted December, 2017)

[63] U.S.EPA, Federal Register Volume 76 Number 179 57106-57513 (http://www.gpo.gov/fdsys/pkg/FR-2011-09-15/pdf/2011- 20740.pdf, published September 15, 2011)

CO2 FEL and production volumes by subfamily, vehicle classification, model year are collected from nine major manufacturers[64] for this analysis. The manufacturers account for 76% of the total heavy-duty vehicle market from 2016 through 2019. The production volume weighted average CO2 FEL in gram per mile is calculated for medium heavy-duty and heavy heavy-duty vehicles, respectively. Results from this analysis are presented in Table 4.3.5-36 and Table 4.3.5-37. The analysis of California heavy-duty vehicle certification data shows that the production volume weighted average CO2 FEL achieved similar or even more CO2 emission reductions than the composite Phase 1 requirements in EMFAC2017. The CO2 emission rates for heavy heavy-duty vehicles from the TBSP also showed similar reduction trend. Therefore, the same Phase 1 CO2 emission reduction factors from EMFAC2017 are used in EMFAC2021. To avoid double accounting of Phase 1 impacts, the CO2 emission rates for model year 2014 and newer are estimated as baseline emission rate for model year 2010 (2,350 g/mile for heavy heavy-duty vehicles, and 1,413 g/mile for medium heavy-duty vehicles) multiplied by CO2 reduction factors. According to emissions test data, the baseline emission rate is 2,350 g/mile for heavy heavy-duty vehicles and 1413 g/mile for medium heavy-duty vehicles. The baseline CO2 emission rates for medium heavy-duty vehicles is scaled from heavy heavy-duty ones, since there is no testing data available for model year 2010.

Table 4.3.5-36. Phase 1 CO2 Ratios to the Baseline for Medium Heavy-Duty Vehicle

Model Year	Medium Heavy-Duty Vehicle		
	California Certificates		Phase 1 in EMFAC2017
	Production weighted average CO2 FEL (gCO2/mile)	Ratio to Baseline	
2010	1375	100%	100%
2014	No Data	No Data	95%
2015	No Data	No Data	95%
2016	1233	90%	95%
2017	1230	89%	91%
2018	1184	86%	91%
2019	1142	83%	91%
2020	No Data	No Data	91%

---

[64] Daimler, Paccar, Ford, Isuzu, Volvo, FCA, Hino, Navistar, and Gillig

Table 4.3.5-37. Phase 1 CO2 Ratios to the Baseline for Heavy-Heavy Duty Vehicle

Model Year	Heavy Heavy-Duty Vehicle				
	California Certificate		TBSP Testing		Phase 1 in EMFAC2017
	Production weighted average CO2 FEL (gCO2/mile)	Ratio to Baseline	Average Emission Rate (g/mil)	Ratio to Baseline	
2010	1774	100%	2350	100%	100%
2014	No Data	No Data	2215	88%	87%
2015	No Data	No Data	2209	85%	87%
2016	1538	87%	2074	84%	87%
2017	1507	85%	2063	82%	85%
2018	1509	85%	1992	87%	85%
2019	1493	84%	1976	85%	85%
2020	No Data	No Data	No Data	No Data	85%

ZEVs produced by manufacturers to meet the Advanced Clean Truck (ACT) regulation can also be used to meet the Phase 2 GHG requirements. As such, corrections were made to the Phase 2 CO2 reduction factors for vehicles originally sold in California to ensure that emissions reductions are not double counted with ACT. The adjusted Phase 2 CO2 emission rate ratio to the baseline by model year for California certified trucks after phase-in of ACT are estimated with the equation below and should not exceed 100%.

$$ACT\ Adjusted\ Phase\ 2\ CO_2\ Ratio\ to\ Baseline\ = \frac{Original\ Phase2\ CO_2\ Ratio\ to\ Baseline}{1 - ZEV\ \%\ by\ ACT}$$

However, once the Phase 2 CO2 ratios to baseline reaches a minimum, they were assumed to stay constant for subsequent model years. In other words, staff assumed that Phase 2 fuel efficiency gains would not be reversed through overlap with ACT. The original and adjusted Phase 2 CO2 reduction percentage are shown in Table 4.3.5-38, Table 4.3.5-39, Table 4.3.5-40. Note that the adjusted Phase 2 factors are used for vehicles originally sold in California, while original Phase 2 reduction factors are applied to vehicles originally sold out-of-state.

Table 4.3.5-38. LHD1 and LHD2 Phase 1 and Phase 2 Original and Adjusted CO2 Reduction Percentage

Model Year	Gasoline LHD1 and LHD2			Diesel LHD1 and LHD2		
	ACT (% ZEV Sales)	Phase 1 and Phase 2 CO2 Ratio to Baseline	Phase 2 Adjusted for ACT	ACT (% ZEV Sales)	Phase 1 and Phase 2 CO2 Ratio to Baseline	Phase 2 Adjusted for ACT
2014	0%	99%	99%	0%	98%	98%
2015	0%	98%	98%	0%	97%	97%
2016	0%	96%	96%	0%	94%	94%
2017	0%	94%	94%	0%	91%	91%
2018	0%	90%	90%	0%	85%	85%
2019	0%	90%	90%	0%	85%	85%
2020	0%	90%	90%	0%	85%	85%
2021	0%	88%	88%	0%	83%	83%
2022	0%	86%	86%	0%	81%	81%
2023	0%	83%	83%	0%	79%	79%
2024	5%	81%	83%	5%	77%	79%
2025	7%	79%	83%	7%	75%	79%
2026	10%	77%	83%	10%	73%	79%
2027	15%	75%	83%	15%	71%	79%
2028	20%	75%	83%	20%	71%	79%
2029	25%	75%	83%	25%	71%	79%
2030+	30%	75%	83%	30%	71%	79%

Table 4.3.5-39. Medium Heavy-Duty Vocational Trucks and Buses, and Tractors Phase 1 and Phase 2 Original and Adjusted CO2 Reduction Percentage

Model Year	MHD Vocational Trucks and Buses			MHD Tractors		
	ACT (% ZEV Sales)	Phase 1 and Phase 2 CO2 Ratio to Baseline	Phase 2 Adjusted for ACT	ACT (% ZEV Sales)	Phase 1 and Phase 2 CO2 Ratio to Baseline	Phase 2 Adjusted for ACT
2014	0%	95%	95%	0%	95%	95%
2015	0%	95%	95%	0%	95%	95%
2016	0%	95%	95%	0%	95%	95%
2017	0%	91%	91%	0%	91%	91%
2018	0%	91%	91%	0%	91%	91%
2019	0%	91%	91%	0%	91%	91%
2020	0%	91%	91%	0%	91%	91%
2021	0%	82%	82%	0%	82%	82%
2022	0%	82%	82%	0%	82%	82%
2023	0%	82%	82%	0%	82%	82%

2024	9%	76%	82%	5%	76%	80%
2025	11%	76%	82%	7%	76%	80%
2026	13%	76%	82%	10%	76%	80%
2027	20%	73%	82%	15%	73%	80%
2028	30%	73%	82%	20%	73%	80%
2029	40%	73%	82%	25%	73%	80%
2030 +	50%	73%	82%	30%	73%	80%

Table 4.3.5-40. Heavy Heavy-Duty Vocational and Tractor Trucks Phase 1 and Phase 2 Original and Adjusted CO2 Reduction Percentage

Model Year	HHD Vocational Trucks			HHD Tractors		
	ACT (% ZEV Sales)	Phase 1 and Phase 2 CO2 Ratio to Baseline	Phase 2 Adjusted for ACT	ACT (% ZEV Sales)	Phase 1 and Phase 2 CO2 Ratio to Baseline	Phase 2 Adjusted for ACT
2014	0%	87%	87%	0%	87%	87%
2015	0%	87%	87%	0%	87%	87%
2016	0%	87%	87%	0%	87%	87%
2017	0%	85%	85%	0%	85%	85%
2018	0%	85%	85%	0%	85%	85%
2019	0%	85%	85%	0%	85%	85%
2020	0%	85%	85%	0%	85%	85%
2021	0%	74%	74%	0%	74%	74%
2022	0%	74%	74%	0%	74%	74%
2023	0%	74%	74%	0%	74%	74%
2024	9%	69%	74%	5%	69%	72%
2025	11%	69%	74%	7%	69%	72%
2026	13%	69%	74%	10%	69%	72%
2027	20%	65%	74%	15%	65%	72%
2028	30%	65%	74%	20%	65%	72%
2029	40%	65%	74%	25%	65%	72%
2030+	50%	65%	74%	30%	65%	72%

4.3.6 Heavy Duty NOx Deterioration Rates

In EMFAC2017, heavy-duty (HD) vehicle base emission rates (BER) were calculated by model year group using the following equation:

$$\mathrm{BER}_{\mathrm{odo}}\left(\frac{\mathrm{g}}{\mathrm{mile}}\right) = (\mathrm{ZMR} + \mathrm{DR} \times \mathrm{Odometer}) \times \mathrm{SCF} \qquad \text{(Eq. 4.3.6-1)}$$

where ZMR is the zero-mile rate, DR is the deterioration rate, and SCF is the speed correction factor. A basic assumption in assessing emission deterioration of HD trucks is that emissions from engines remain stable in the absence of tampering, mal-maintenance, and malfunction (TM&M). As the heavy-duty fleet ages and accrues mileage, EMFAC models a greater fraction of the fleet having an engine or emissions after-treatment malfunction. The DR represents the slope of this increase. ZMR and DR are typically developed on a model year group basis. Each group includes several consecutive model years that usually share the same emission standards and/or emission control technology. DRs are calculated as follows.

$$\text{DR (gmile}^{-1}\text{ per 10,000 miles)} = (\text{ZMR}\times\text{EIR})/100 \qquad \text{(Eq. 4.3.6-2)}$$

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

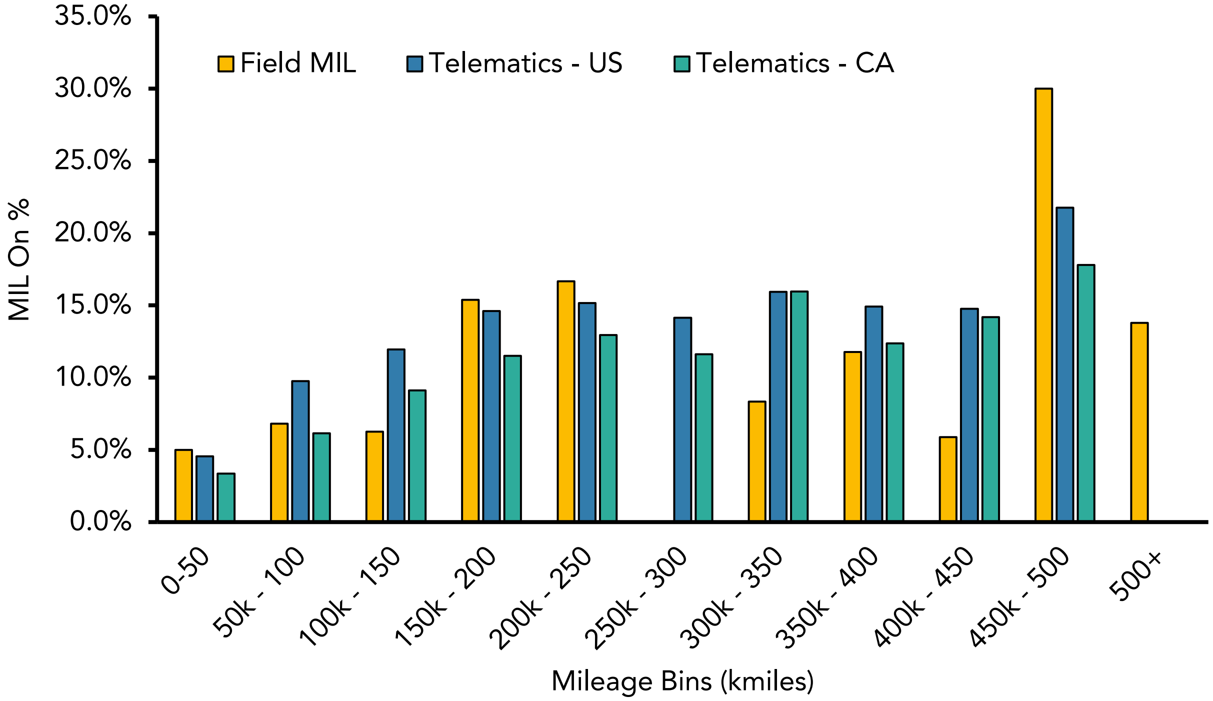
EMFAC2017 uses a framework for calculating EIR that was originally developed in EMFAC 2000. To estimate the emission impact of TM&M, this method identifies several specific types of TM&M affecting the average emissions of a truck fleet. The EIR is the product of the frequency of occurrence of TM&M, and the emission increases over the baseline level caused by the TM&M.

In EMFAC2017, there were some revisions to these TM&M frequencies for engine model years 2010 and newer for vehicles with extended warranties. Furthermore, engine model year 2013+ vehicles that are equipped with OBD systems were assumed to have 33% reduction in TM&M frequencies for all categories (e.g., DPF filter issues). More details can be found in section 4.3.2.1.2 of the EMFAC2017 technical documentation. When EMFAC2017 was released, there was very limited information available for engine model year 2013 and newer deterioration rates. With more and more engine model year 2013 and newer phase-in, there is a need to improve EMFAC modeling related to failure frequencies associated with the engine and after-treatment components in the EMFAC model for newer, OBD-equipped vehicles, especially to assess potential costs and emission benefits of heavy-duty inspection and maintenance program. To better understand heavy-duty in-use performance, EMFAC2021 utilized 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.

Through Contract 17AQP006, CARB collected OBD data in the field, like the Port of LA and Truck Stops, and through telematics companies allowing fleets to track data (e.g., GPS) on all of their vehicles. Overall, OBD data was collected from 457 vehicles from the field locations, and 24,555 and 180,892 California-operating and US-operating vehicles, respectively, from telematics data sources.

Figure 4.3.6-1 shows the malfunction indicator lamp (MIL) rates for field and telematics data. Here “MIL On” represents the percentage of vehicles with an illuminated MIL and thus are assumed to have an emissions-related engine or after-treatment malfunction. Overall, US-operating vehicles have slightly higher MIL On, and there was no systematic difference between field and telematics MIL rates. Notably, the observed MIL On percentage was as large as 5% for low mileage vehicles (i.e., 0-50 kmiles), which indicates that vehicles have emissions-related issues early in their life.

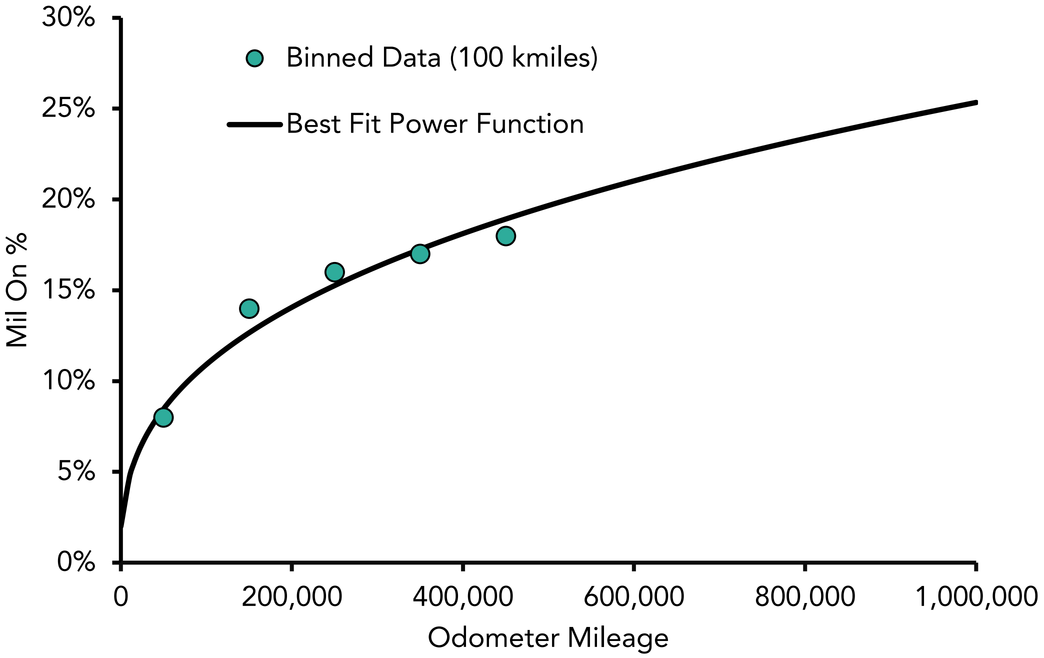
Figure 4.3.6-1. Percentage of Vehicles with MIL On as a Function of Odometer



For EMFAC2021, US-operating telematics dataset was selected to model the deterioration rate due its high sample size. It is also noteworthy to mention that out-of-state registered heavy-duty vehicles that travel to California are responsible for a large fraction of heavy-duty vehicle miles traveled in the State.

A combination of MIL On frequency from this contract and in-use emission rate data were used to develop new deterioration rates for engine model year 2013 and newer in EMFAC2021. In-use test data was provided through CARB's Truck and Bus Surveillance Program and the EMA/UCR Testing Projects. In a nutshell, in-use test data determines the magnitude of deterioration, while the MIL On function determines the shape of deterioration rate. First, the MIL On frequency (binned by 100 kMi) as a function of odometer was fit to a power function, as shown in Figure 4.3.6-2.

Figure 4.3.6-2. Power Function Fit to MIL On as a Function of Odometer



The fitted equation for MIL On frequency is

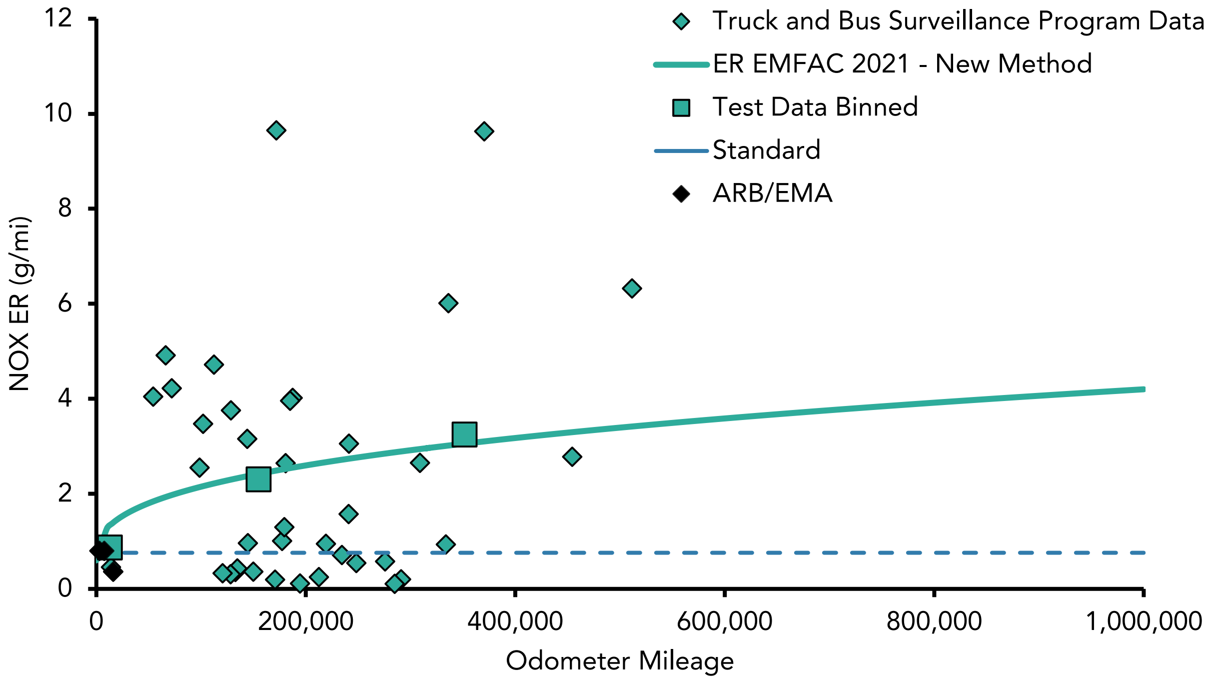
$$\mathbf{MIL\ On} = \mathbf{0.016} \times \mathbf{Odometer}^{\mathbf{0.37}} \qquad \text{(Eq. 4.3.6-3)}$$

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 an EIR and ZMR at 90,249 miles, the average odometer of the US-wide data set
- _Step 2._ Scale EIR to other odometers using the MIL On function
    - EIR (odometer) = MIL On (odometer)^b/MIL On (90,249)^b
- _Step 3._ Use EIRs to determine odometer-dependent emission rates
    - ER (odometer) = ZMR + ZMR * EIR (odometer)
- _Step 4._ Calculate root mean square error (RMSE) between binned in-use NOx emission rates and the modelled values
- _Step 5._ Update ZMR and EIR until the RMSE reaches a minimum

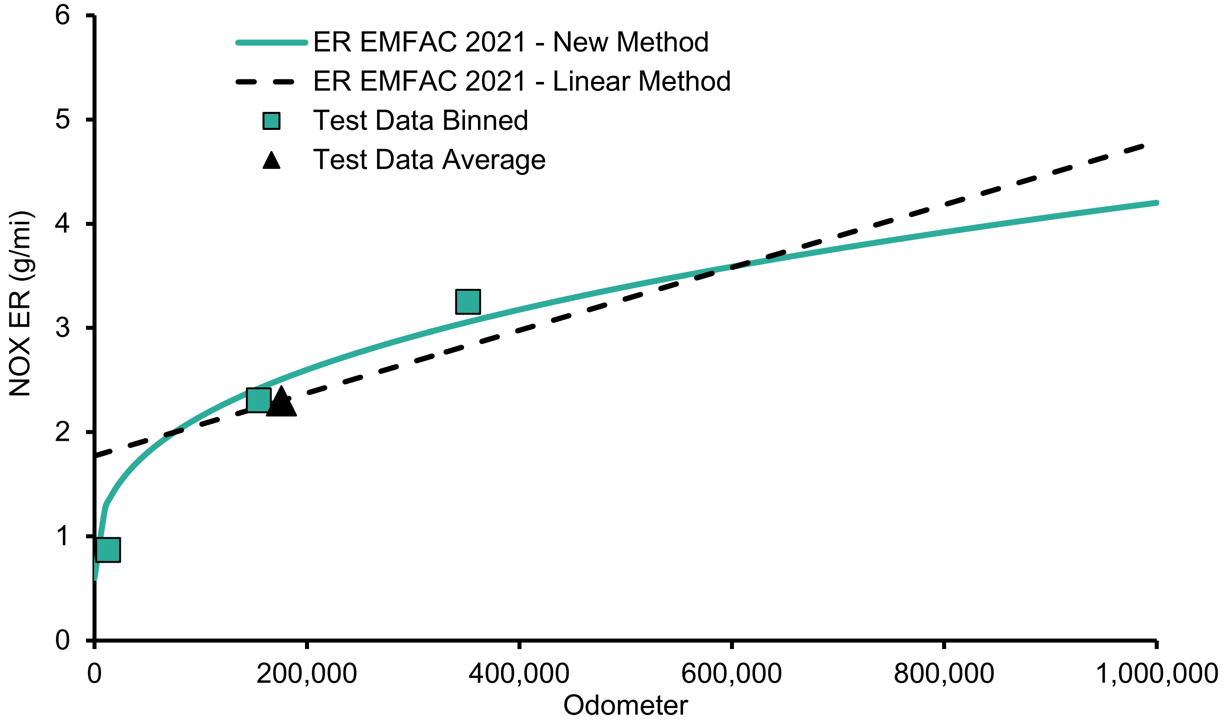
With the above method, the best fit EIR was 249% and a ZMR of 0.6 g/mile of NOx emissions for vehicles with engine model year 2013 and newer; the resulting best fit emission rate equation for heavy heavy-duty vehicles is shown in Figure 4.3.6-3. A ZMR of 0.6 g/mile aligns well with the TBSP and EMA test data for vehicles with odometer mileage less than 50,000 miles. Note that, unlike the linear model that was used previously, the base EIR is at 90,249 miles instead of 1,000,000 miles.

Figure 4.3.6-3. Modelled and Observed NOx Emission Rates



For comparison, the linear method used for the previous versions of EMFAC is shown. This linear method uses an average emission rate for all test data, as shown as the black triangle in Figure 4.3.6-4. Then, the ZMR is back-calculated using an EIR of 170% at 1,000,000 miles. In general, the new method based on MIL On leads to higher emission rates from 100,000 to 600,000 odometer mileage, but lower emission rates beyond 600,000 miles. Note that the OBD-based method is used for NOx, but not for PM due to the lack of vehicles with high PM emissions in the in-use dataset. As described in Section 4.3.5.2, for PM, EMFAC2021 uses similar method as in EMFAC2017.

Figure 4.3.6-4. Comparison of New Deterioration Model to that derived from a Linear Method



4.3.7 Break Wear Emissions

The current EMFAC brake wear emission factors rely on data from 2000-2003. Both light and heavy-duty brake wear emission rates have been updated with recently collected data using dynamometer-based testing methods.

4.3.7.1 Light-Duty Brake wear

During EMFAC2021 development, CARB staff worked closely with U.S. EPA and Caltrans to conduct a comprehensive brake wear testing using the European Commission Joint Research Committee (JRC) protocol/procedure. Specifically, measuring emissions with a brake dynamometer simulating real-world conditions. The testing would look at the most popular brake configurations, and would address regenerative braking.

The testing was conducted under ARB contract 17RD016. This study utilized a LINK Engineering (LINK) single wheel brake dynamometer for the measurement of PM emissions over a prescribed driving cycle. The vehicles were driven on a representative driving cycle (California Brake Driving Cycle or CBDC) developed from the 2010-2012 Caltrans Household Travel Survey. Brake temperatures were monitored, and temperature profiles were controlled accordingly on the break dynamometer. Six vehicles were tested, one of which used a regenerative braking system. PM was measured using both particulate filters and in real time with a quartz crystal micro-balance (QCM). Figure 4.3.7-1 presents the vehicle-level results for each of the 6 tested models by three different pad materials: Original Equipment Service non-asbestos organic (OES-NAO), aftermarket NAO, and aftermarket Low-Metallic (LM). The F-150 and Sienna were also tested with higher vehicle loads.

Figure 4.3.7-1. Whole Vehicle Braking Emissions by Model and Material

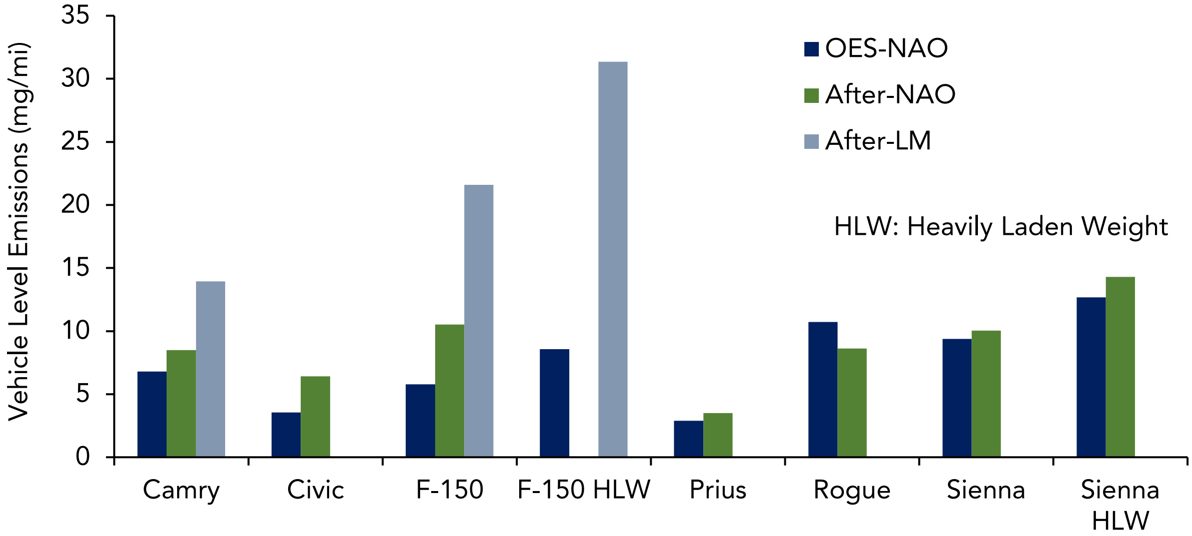


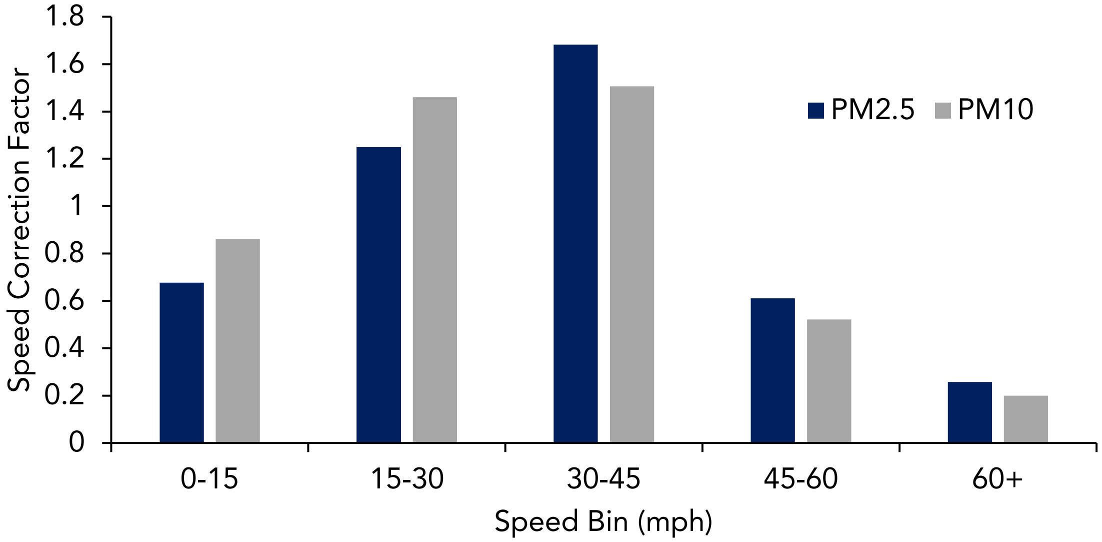
Table 4.3.7-1 breaks out the emission rate results as a function of vehicle type. The light trucks are slightly higher than the passenger vehicles because of a different distribution of braking materials, especially in the rear axle. The Toyota Prius with the regenerative braking have the lowest emission rates.

Table 4.3.7-1. Whole Vehicle Braking Emissions by Vehicle Class

Vehicle Type	PM2.5 BER (mg/mi)	PM10 BER (mg/mi)
Conventional Passenger	1.55	7.65
Light Truck	1.81	8.38
Regenerative-equipped	0.93	3.30

Figure 4.3.7-2 illustrates the relationship with respect to speed. The speed correction factors are used in conjunction with the BERs to determine emissions at a given speed.

Figure 4.3.7-2. Speed Correction Factors for PM2.5 and PM10



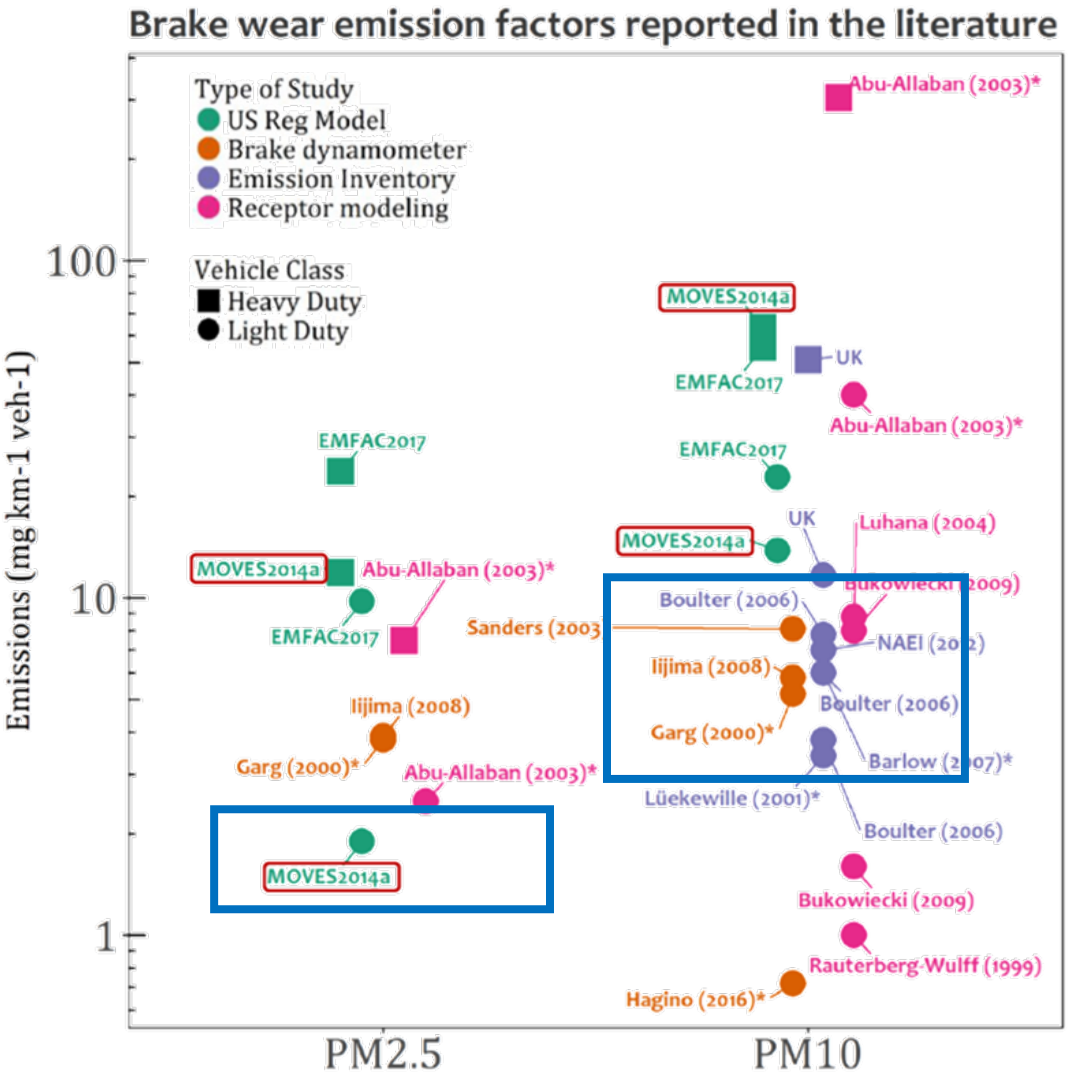
Interestingly, the study also found a form of deterioration to the basic emission rates. This is not deterioration in the classical sense, but more of a representation of how there is a switch from OEM equipment to aftermarket equipment as the vehicle ages. Therefore, emission rates in the form of a linear regression were determined. The adjusted emission rates and deterioration rates are given in Table 4.3.7-2

Table 4.3.7-2. Estimated PM10 Deterioration Rates and New-Vehicle Estimated Emission Rates based on Friction Material Trend with Vehicle Age

Vehicle Type	Deterioration Rate (mg/10K mi)	New vehicle estimated emission rate (mg/mi)
Conventional Passenger Car	0.0492	7.65
Light Truck	0.1825	8.38
Regenerative-Equipped	0.0047	3.30

Figure 4.3.7-3 presents a comparison with past studies of brake wear emission rates of PM2.5 and PM10 for light- and heavy-duty vehicles. The rectangles represent the range of light duty emission rates determined in CARB’s recent study (i.e., contract 17RD016). The squares represent heavy-duty vehicles and circles represent light-duty vehicles. The findings from this light-duty study are lower in both PM2.5 and PM10 than values currently in EMFAC2017, but reasonably close to most other studies.

Figure 4.3.7-3. Various literature values for brake emissions, with the ranges from this study overlaid for comparison



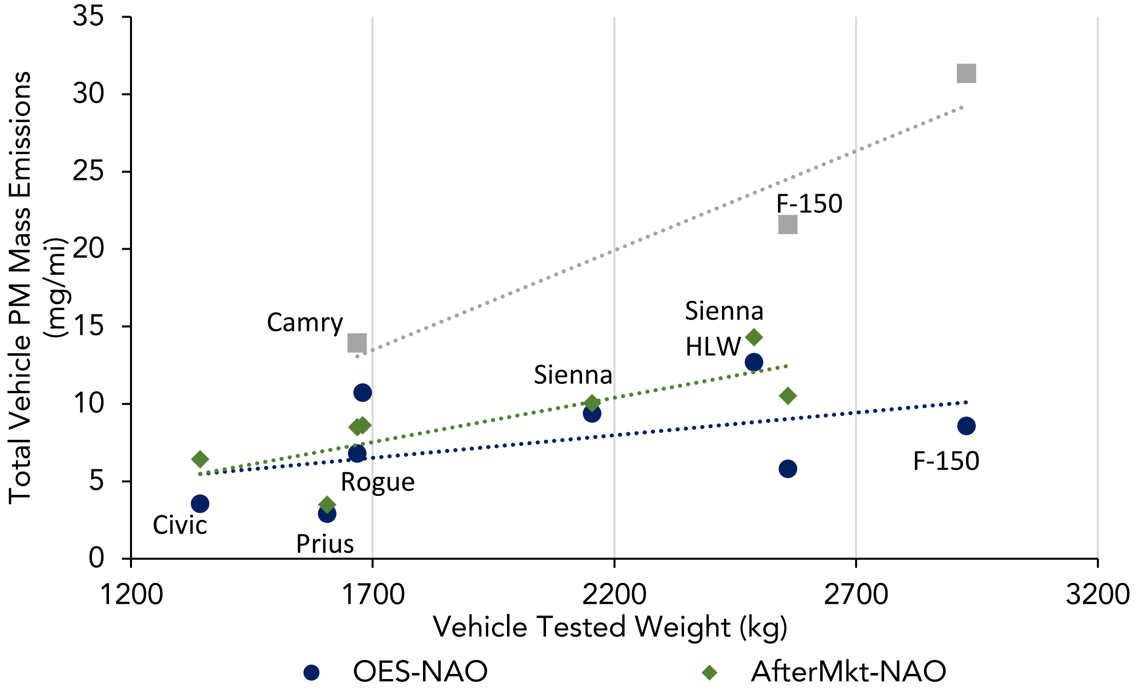
The study further revealed that:

- Front brakes emit more PM than rear brakes-since most of the braking occurs in the front of the vehicle, the brakes seem to experience much higher temperatures and emit significant higher PM.
- Non Asbestos Organic (NAO) friction material brakes emit less PM than Low Metallic (LM) brakes-as vehicles age, the owners are more likely to replace the brakes with low metallic materials resulting in higher emission rates as the vehicles age.
- Speed effects are not monotonic as implied in previous versions of EMFAC-the data suggest that brake wear emissions are highest at moderate speeds. At lower

speeds the braking events tend to be frequent but mild, and at high speeds braking is relatively infrequent.

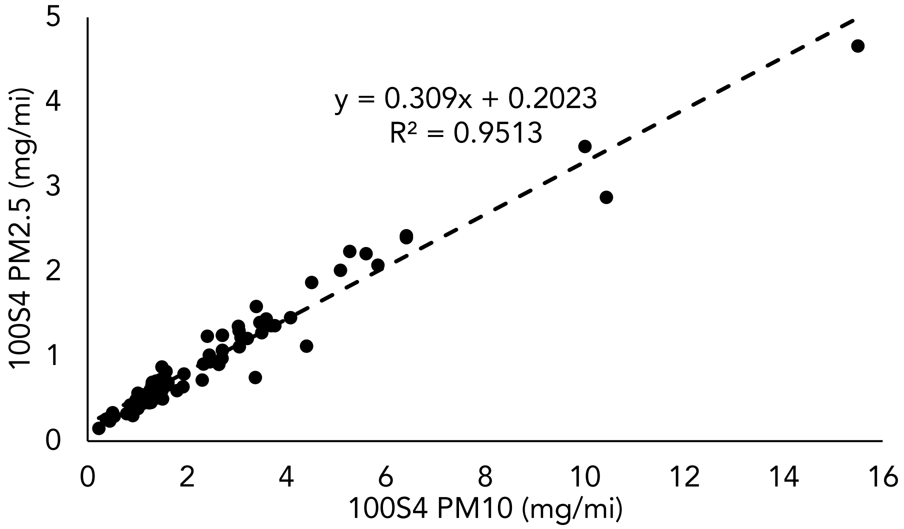
- There appears to be a correlation to weight as indicated in Figure 4.3.7-4. Although beyond the scope of this update, it is possible that future updates may want to address the vehicles load in use.

Figure 4.3.7-4. Total vehicle test cycle PM mass emissions vs simulated vehicle test weight, categorized by pad material.



The updated emission rates in EMFAC2021 are significantly lower than EMFAC2017. The results indicate that emissions are approximately 75% lower than previous estimates. Vehicles with regenerative braking may be 50% or less than those of conventional vehicles. As illustrated in Figure 4.3.7-5, PM 2.5 shows a strong correlation with PM10. Therefore, staff modeled PM10 and treat PM 2.5 as a fraction of the PM10. The ratio of PM2.5/PM10 was found to be 0.35.

Figure 4.3.7-5. PM2.5 mass emission rate vs. PM10 mass emission rate with linear trend line as measured by 100S4



4.3.7.2 Heavy-Duty Brake wear

Heavy-duty brake wear emission rates in EMFAC2021 were updated using dynamometer test data from a Caltrans contract 65A0703.[65] Previous estimates relied on outdated data and did not account for speed effects. Brake emissions tests were performed on LINK Engineering (LINK)'s single wheel brake dynamometer for several heavy-duty brake wear configurations, including Class 8 (GVWR > 33,000 lbs.) drum, Class 8 air disc, refuse truck air disc, bus air disc, and hydraulic disc. Within these brake configurations, tests were completed for different hardware configurations. steer, drive, and trailer axles (Class 8 only).

Table 4.3.7-3 shows the test matrix for HD brake wear tests for Class 8 (heavy heavy-duty) vehicles with drum and disc brakes, medium heavy-duty (hydraulic disc; test weight of 26,000 lbs.), as well as refuse, and urban bus with disc brakes. Various vocational cycles with different average speeds, developed through the UC Riverside heavy-duty activity study,[66] were used to characterize how brake wear emission rates vary by speed heavy heavy-duty and medium heavy-duty truck tests. The UC Riverside study developed vocational cycles using second-by-second activity data from 90 heavy-duty vehicles operating in California, which were grouped into various vocations (e.g. line haul). Briefly, "Drayage N" are drayage trucks operating in Northern California, "Cement" are cement

---

[65] Link to final report once it's released

[66] Boriboonsomsin et al. 2017 Collection of Activity Data from On-Road Heavy Duty Vehicles, Final Report for ARB Agreement 13-301, May 2017.
https://ww2.arb.ca.gov/sites/default/files/classic//research/apr/past/13-301.pdf

mixers, "LH OOS" are long-haul trucks that are registered out-of-state, "Refuse" are garbage trucks, "Urban Buses" are urban or transit buses, "Beverage" are beverage distribution trucks, and "Local Moving" are vehicles that do pick-up and delivery.

Table 4.3.7-3. Test Matrix for HD PM Brake Wear Emissions

Test Fixture	Cycle 1	Cycle 2	Cycle 3
Class 8 Drum Steer Loaded	Drayage – Northern California (N)	Cement	Long-haul out-of-state (LH OOS)
Class 8 Drum Drive Unloaded	Drayage N	Cement	LH OOS
Class 8 Drum Drive Loaded	Drayage N	Cement	LH OOS
Class 8 Drum Trailer Unloaded	Drayage N	Cement	LH OOS
Class 8 Drum Trailer Loaded	Drayage N	Cement	LH OOS
Class 8 Disc Steer Loaded	Drayage N	Cement	LH OOS
Class 8 Disc Drive Unloaded	Drayage N	Cement	LH OOS
Class 8 Disc Drive Loaded	Drayage N	Cement	LH OOS
Refuse Truck ADisc Steer	Refuse		
Refuse Truck ADisc Drive	Refuse		
Urban Bus ADisc Steer	Urban Bus		
Urban Bus ADisc Drive	Urban Bus		
Hydraulic Disc Steer	Beverage	Local Moving	
Hydraulic Disc Drive	Beverage	Local Moving	

The test matrix was constructed with brake types, axle types, vocational cycle, equipment, and loading:

- **Urban Bus:** one vehicle x 2 axle types (steer and drive) x 2 equipment types (OE and AM), single test
- **Refuse:** one vehicle x 2 axle types x 2 equipment types, single test
- **Medium Heavy-Duty:** one vehicle x 2 axle types x 2 vocations x 2 equipment types, single test
- **Heavy Heavy-Duty:** two vehicles (drum and disc brakes) x 3 axle types (including trailer) x 3 vocations x 2 equipment types. Subset loaded and unloaded. Single test with repeats on subset of trailer tests

Table 4.3.7-4 shows the average speeds of the vocational cycles listed above. Cycles with smaller average speeds (e.g., drayage) generally have larger brake power densities. Three vocational cycles were selected for heavy heavy-duty vehicles; the drayage cycle represents lower speed operation (e.g., at a port) and therefore more frequent braking, while the long-haul OOS cycle covers higher speeds (e.g., driving on the freeway) and therefore less frequent braking. Finally, medium speed operation was best represented by the cement cycle. Medium heavy-duty vehicles were tested on two vocational cycles, one for lower speed operation (e.g., stop-and-go delivery) and one for medium speeds (e.g., operating on city streets).

Table 4.3.7-4. Average vocational cycle speeds for medium heavy-duty and heavy heavy-duty brake wear tests

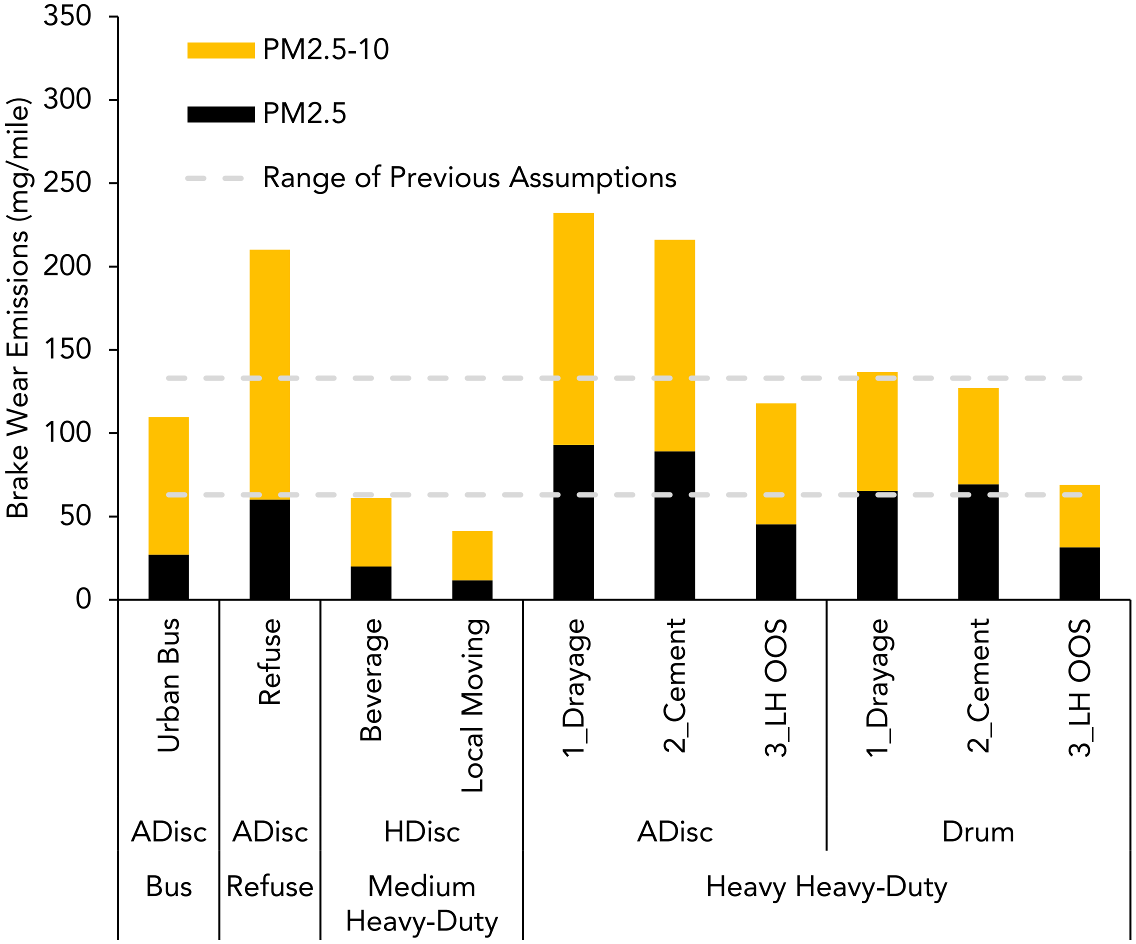
Class	Vocation	Average Speed (mph)
Heavy Heavy-Duty	Drayage N	11.9
	Cement	28.1
	Long Haul OOS	48.6
Medium Heavy-Duty	Beverage	14.2
	Local Moving	32.6
Refuse	Refuse	11.1
Urban Bus	Urban Bus	14.9

For HD trucks, raw filter results from single wheel dynamometer testing were transformed to full vehicle EMFAC2021 emission rates. Brake wear ZMRs in EMFAC are expressed as grams per vehicle-mile traveled (grams/mile). Transforming single wheel dynamometer results to represent full-truck gram/mile rates required accounting for load, axle, and speed factors designed into the emission test matrix, primarily for heavy heavy-duty trucks. In rolling up single-wheel ZMR, the following factors were accounted for:

- The mix of loaded and unloaded operation (heavy heavy-duty trucks only);
- The number of steers, drive, and (if applicable) trailer brakes per truck;
- The fraction of particles dispersing to the environment vs. residing within brake housing (airborne fraction);
- The mix of drum and air disc brakes by model year range; (heavy heavy-duty trucks only);
- Differences in PM emissions from original and aftermarket friction material, which would form the basis of deterioration rates
- Vocation cycle results

Figure 4.3.7-6 shows a comparison between processed PM2.5 and PM10 brake wear emission rates and the range of previous EMFAC assumptions, which represent PM10 emission rates for medium heavy-duty (133 mg/mile) and heavy heavy-duty (63 mg/mile). These results are for full trucks and account for the list of factors above. Overall, the updated results are similar to previous assumptions. Heavy heavy-duty vehicle emission rates at lower speeds are higher than EMFAC2017 rates, especially for disc brake systems. Refuse or solid waste collection vehicle emission rates were underestimated by previous assumptions. T6 or medium-heavy trucks and bus emission rates are also substantially smaller than the previously assumed emission rate of 133 mg/mile.

Figure 4.3.7-6. Heavy-Duty Full Truck Brake Wear ZMRs



Heavy heavy-duty disc and drum emission rates were combined into one factor by model year groups. These groups reflect the shift from brakes to disc brakes due to NHTSA's Reduced Stopping Distance rules (NHTSA 2009[67]). Market surveys indicate that this shift has been slow, with currently 15% disc market penetration estimated for 2010-2025. Trailer brakes will likely continue using drum brakes because tractors with discs can pull older drum-equipped tractors. In the future, the percentage of disc brakes is expected to increase. Table 4.3.7-5 lists the splits between drum and disc brakes used to develop heavy heavy-duty brake wear emission rates by model year.

---

[67] https://www.federalregister.gov/documents/2013/02/11/2013-02987/federal-motor-vehicle-safety-standards-air-brake-systems

Table 4.3.7-5. T7 Drum vs. Disc by Model Year Range

	Pre 2010	2010-2025	2026+
Drum	100%	85%	50%
Disc	0%	15%	50%

Table 4.3.7-6 provides a mapping between EMFAC 2021 categories and the brake wear categories and Table 4.3.7-7 provides ZMRs by model year. Unlike the light-duty brake wear update, there was no significant deterioration (i.e., emission rate increases due to aftermarket parts). Emission rate tests with aftermarket brake pads did not differ significantly from OEM brake pads. Though this finding differed from LD vehicles, this is consistent with market trends. In the U.S., the majority of commercial vehicle brake components are supplied by only a few companies, which provide both original and aftermarket parts. The friction material formulations do not vary significantly between original and aftermarket, unlike the light vehicle market, where many aftermarket-only suppliers produce many varieties of pads. The EMFAC 2021 brake wear emission rates are assumed to be 50% lower for zero emission heavy-duty vehicles due to regenerative braking.

Table 4.3.7-6. EMFAC2021 Brake Wear Category Mapping

Brake Wear Category	EMFAC2021 Categories
Heavy Heavy-Duty	All T7 truck categories (except T7 SWCV Class 8), Motor Coach
Medium Heavy-Duty	All T6 truck categories, SBUS, OBUS, All Other Buses
Refuse	T7 SWCV Class 8
Urban Bus	UBUS

Table 4.3.7-7. EMFAC 2021 Input PM10 ZMRs by Vehicle Category

Model Year Range	PM10 ZMR (g/mile)			
	Refuse	Medium Heavy-Duty	Heavy Heavy-Duty	UBUS
Pre2010	0.21	0.047	0.129	0.11
2010-2025	0.21	0.047	0.096	0.11
2026+	0.21	0.047	0.106	0.11

To estimate the SCFs, full truck emission rates calculated as described for each vocation cycle were mapped to speed bins based on closest cycle average speed. Emissions for speed bins between the average speeds of two vocation cycles were interpolated based on speed bin midpoint. Table 4.3.7-8 lists all the updated SCFs for heavy heavy-duty and medium heavy-duty categories.

Table 4.3.7-8. EMFAC 2021 Brake Wear PM Speed Correction Factors (SCFs)

Speed Bin	PM SCF	
	Medium Heavy-Duty	Heavy Heavy-Duty
5	1.31	1.43
10	1.31	1.43
15	1.31	1.41
20	1.29	1.38
25	1.06	1.35
30	0.94	1.33
35	0.88	1.12
40	0.88	0.98
45	0.88	0.83
50+	0.88	0.72

Aggregate HD PM10 and PM2.5 ZMRs were then calculated as a weighted average of truck category ZMRs using EMFAC VMT fraction for heavy heavy-duty (0.42), medium heavy-duty (0.27), refuse (0.18) and urban bus (0.13) categories. PM2.5 fraction was then calculated as aggregate HD PM2.5 ZMR divided by aggregate HD PM10 ZMR. The result was 0.35, which matches the light-duty PM2.5 fraction for brake wear. This is lower than the previously assumed value in EMFAC2017 of 0.42.

4.4 Activity Profiles

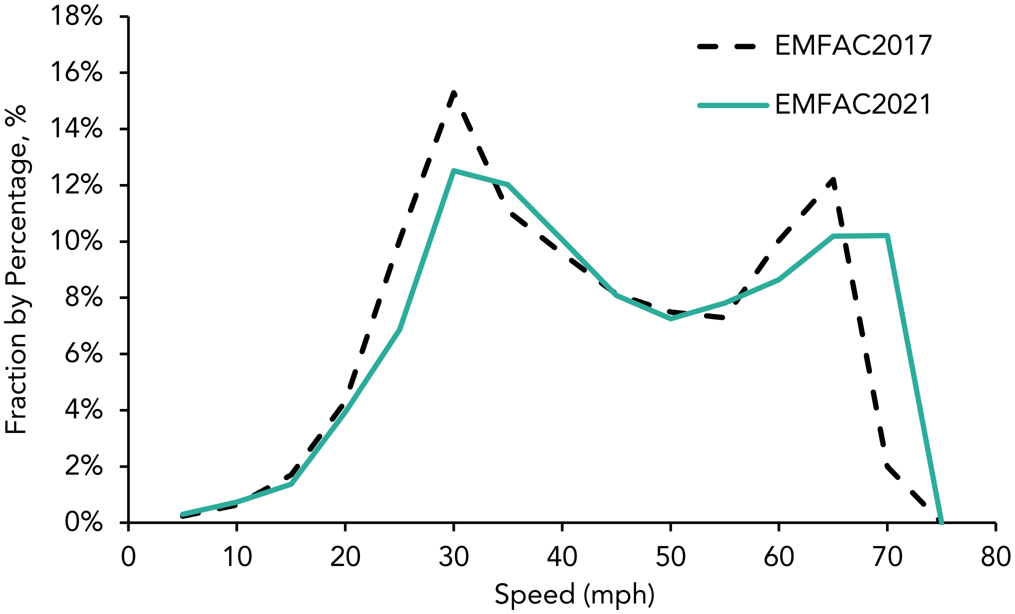
4.4.1 Light Duty Activity Profiles

VMT distribution by speed. The VMT speed distributions by speed for LDV in EMFAC2021 have been updated based on the most recent activity profiles from Metropolitan planning organizations (MPOs) at the time of release and shown below.[68] Compared to the previous version, LDV activity profiles for more calendar years and sub-areas are included in EMFAC2021. Figure 4.4.1-1 illustrates updates to light duty vehicle speed distribution as compared to the one used by EMFAC2017.

---

[68] Internal communication with CARB's Sustainable Transportation and Communities Division. MPO009 is used in EMFAC2021. This version of MPO data is reflective of latest data submittals to CARB as of December 2020 and include SCAG's 2020 RTP known as Connect SoCal.

Figure 4.4.1-1 Light Duty Vehicle Speed Distribution Comparison between EMFAC2017 and EMFAC2021



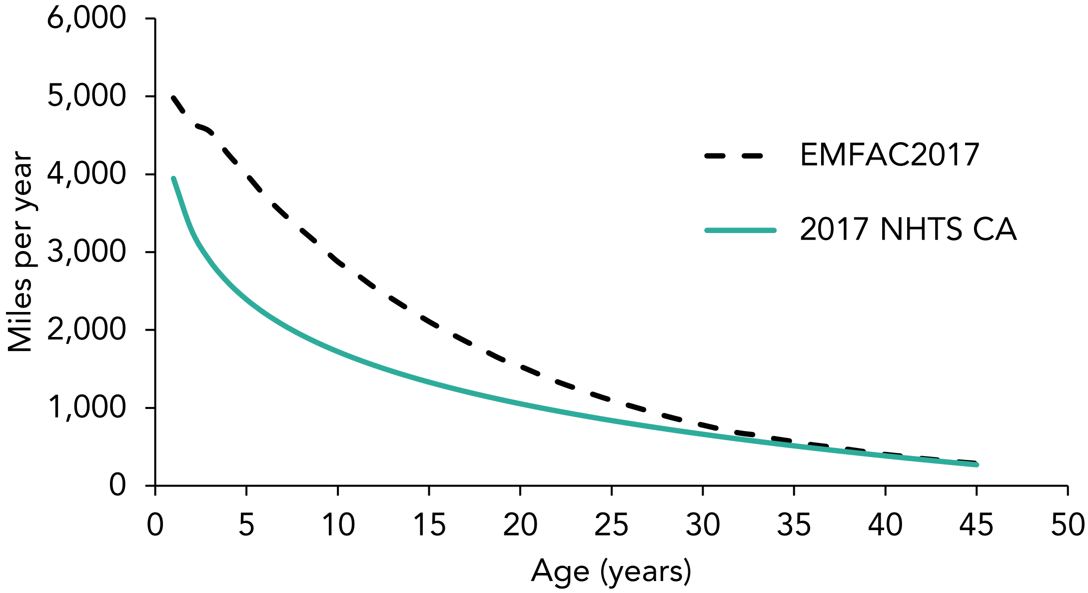
<u>Updates to Motorcycles Accrual rates.</u> For EMFAC2000, on-road motorcycle accrual rates were estimated using data from the Motorcycle Industry Council's (MIC) survey in 1990. For EMFAC2017, accrual rates were estimated for each GAI of the state. From the EMFAC2017 model output, the statewide yearly mileage accrual rate can be determined by model year using the VMT and population up to 45 years.

As a recent source of motorcycle mileage data, the 2017 National Household Travel Survey-California Add-on (NHTS-CA) provided a vehicle subset of 1,923 motorcycles surveyed for odometer information by age.[69] Figure 4.4.1-2 shows the comparison of the mileage accrual rates by age from both EMFAC2017 and the 2017 NHTS-CA survey. As shown in the figure, the accrual rates trend line from the 2017 NHTS-CA survey is lower, which results in the reduction of total emissions in the EMFAC2021 model.

---

[69] https://www.nrel.gov/transportation/secure-transportation-data/tsdc-nhts-california.html

Figure 4.4.1-2 On-road Motorcycle Accrual Rates – EMFAC2017 vs. 2017 NHTS-CA Add-on



4.4.2 Heavy Duty Activity Profiles

Similar to light duty vehicles, heavy-duty vehicle's activity profiles have significant effects on the emissions produced from these vehicles. Starting from EMFAC2017, utilization of Portable Activity Measurement Systems (PAMS) data has enabled accurate characterization of HD vehicle activity in the real world, which is critical to nowadays HDV emission inventory development. In the development of EMFAC2021, more PAMS data are collected and used for HD activity updates.

In total, PAMS data from 174 HD vehicles collected by UCR and West Virginia University were utilized. Vehicle location and activity information were collected by Global Positioning System (GPS) and electronic control unit (ECU) data loggers at 1 Hz resolution. Activity information includes timestamp, vehicle instantaneous speed, engine speed, etc. Data cleaning procedures were performed to remove any vehicle sample with overly short sampling duration (i.e., less than 24 hours), low quality data, too many missing data, abnormal behavior (e.g., too many engine starts, too slow speed). Finally, 168 vehicle samples are used for EMFAC2021 updates. These samples are pooled with 90 vehicle samples inherited from EMFAC2017 and together make a total sample size of 258 vehicles.

In EMFAC2017, the 90 sample vehicles from UCR CE-CERT study[70] were assigned vehicle categories based on their vocations. EMFAC2021 adopts a new vehicle category schema: EMFAC202x vehicle class. Hence the assignment of vehicle categories is re-done through the following steps: 1) if the vehicle has VIN information, it is searched in DMV and IRP dataset to find a matched record and corresponding EMFAC2021 vehicle class; 2) if the vehicle does not have VIN, vocation and weight class are used to identify the vehicle's category as detailed in Table 4.4.2-1; 3) vocation and GPS records are used to validate VIN identification results. For example, a truck is identified as T7 CAIRP based on VIN in DMV but its vocation is assigned by the contractor as a line-haul in-state tractor. By checking its GPS trajectory, it is known that the truck only has activities within a city boundary in California, therefore this truck is more representative of an in-state tractors and assigned as T7 Tractor in EMFAC.

Table 4.4.2-1. Sample sizes and vocation-category mapping used for EMFAC2021 HDV activity updates

EMFAC2021 Vehicle Categories	Number of samples inherited from EMFAC2017	Number of new samples acquired from 200-Vehicle Project	Updated in EMFAC2021?
Not Found	8	0	Do not exist in EMFAC2021
All Other Buses	10	0	No
T6 CAIRP, T6 OOS, T7 CAIRP, T7 NNOOS, T7 NOOS, Motor Coach	5	18	Yes
SBUS	0	27	Yes
T6 Instate Delivery	2	2	Yes
T6 Instate Tractor/Others	4	7	Yes
T7 POLA/POAK/Other Port	4	37	Yes
T6/T7 Public	22	1	No
T7 Single Concrete/Transit Mix, T7 Single Dump, T7 Single Other	11	4	Yes
T7 SWCV	6	27	Yes
T7 Tractor	8	35	Yes
T6/T7 Utility	2	0	No
UBUS	5	10	Yes

It should be noted that not all EMFAC202x HD vehicle categories' activity profiles are updated in EMFAC2021. For example, T6/T7 Public, T6/T7 Utility, All Other Buses are

---

[70] Boriboonsomsin, K., Johnson, K., Scora, G., Sandez, D., Vu, A., Durbin, T., & Jiang, Y. (2017) Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles. Available at https://www.arb.ca.gov/research/apr/past/13-301.pdf

not updated in this version due to lack of samples in the new acquired PAMS dataset. In addition, no significant difference was observed across fuel types. As a result, HD activity updates are applied to EMFAC202x vehicle categories regardless of fuel types. Sample size by region is too small to be representative, so HD activity updates are done to all regions the same way, except for SCAG regions which have their own vehicle activity profiles estimated by SCAG Truck model[71]. Since EMFAC is designed to estimate emissions on an average weekday, results were generated using weekday data, i.e., abandoning all activity data on weekends before analyses.

VMT distribution. Two dimensions of VMT distribution are modeled in EMFAC: by hour and by speed. The hourly VMT distribution refers to when vehicles are active/inactive on an average day, measured by VMT in each hour of the day. The speed distribution for HD vehicles refer to the fractions of VMT in each speed bin. While EMFAC2017 updated VMT distribution by speed but not by hour due to limited sample size, EMFAC2021 updated both. Similar to EMFAC2017, VMT distributions in EMFAC2021 are developed for each vehicle category.

VMT distribution by hour. In general, VMT distribution by hour in EMFAC2021 shows similar trends with EMFAC2017. Some vehicle categories' by-hour distribution curve is smoother and more continuous than EMFAC2017, for example out-of-state HD vehicles, school bus, heavy-heavy duty port trucks, heavy-heavy duty tractors. School bus is updated using real-world data for the first time. Out-of-state trucks, medium-duty in-state tractor/other shows higher VMT early in the morning, while heavy heavy-duty port trucks, heavy-heavy duty single trucks show higher VMT during work hours instead of late night. Heavy-heavy duty solid waste collecting vehicle shows higher VMT in the afternoon than EMFAC2017. Heavy heavy-duty tractors show higher VMT during night time than day time compared to EMFAC2017, which can be contributed by the long-haul travel patterns. Please see detailed VMT distribution by hour figures and comparison with EMFAC2017 in Appendix 6.10.

VMT distribution by speed. In general, VMT distribution by speed trends are similar to EMFAC2017. Some HD vehicle categories show higher VMT at higher speed (> 55mph), for example out-of-state HD vehicles (including T6 CAIRP, T6 OOS, T7 CAIRP, T7 NOOS, T7 NNOOS, Motor Coach due to their across-state-border traveling patterns), medium-heavy duty in-state tractor/other, heavy-heavy duty port trucks, and heavy-heavy duty single trucks. In EMFAC2021, school bus has lower VMT at high speed compared to EMFAC2017, with majority of VMT around 40 mph, which is closer to real-world situation since school buses operate a lot on local roads. Medium-heavy duty in-state delivery truck has much lower activity at high speed compared to EMFAC2017, with majority of the VMT at around 35-40 mph, possibly due to mostly traveling locally compared to tractors. Urban bus has higher VMT around 35 mph, compared to EMFAC2017 at 20 mph. Prior to EMFAC2021, urban bus did not use real-world data to model its VMT

---

[71] https://scag.ca.gov/heavy-duty-truck-model

distribution. Heavy-heavy duty solid waste collecting vehicle and heavy-heavy duty tractor have very similar VMT distribution by speed to EMFAC2017. Please see detailed VMT distribution by speed and comparison with EMFAC2017 in Appendix 6.10.

Starts and soak time distribution. Number of engine starts are directly related to start emissions. On top of that, temperature of engine at the time of engine start, which is often determined by time interval since last engine off (i.e. soak time), plays an important role in affecting efficacy of pollutants removed through catalyst converters. Therefore, both number of engine starts per weekday, and engine starts distribution by soak time are critical information to estimate start emissions. As discussed earlier for VMT distribution, selected EMFAC2021 vehicle category are mapped to available tested groups, and then average starts per weekday and distributions by soak time were applied to EMFAC2021 vehicle categories using the same mapping as in Table 4.4.2-1. Similar to EMFAC2017, number of engine starts in EMFAC2021 are developed for each vehicle category. All individual vehicle samples within each vehicle category are treated the same.

Following the staff analysis, the average starts per weekday is provided in Table 4.4.2-2. After including more vehicle samples, most vehicle categories have similar engine starts per weekday compared to EMFAC2017, with an increasing trend in general. Out-of-state (long-distance line hauls) trucks have the highest number of starts per day, while refuse trucks and public fleets remain the lowest numbers. These align with those observed in EMFAC2017.

Table 4.4.2-2. Engine starts per weekday of HDV in EMFAC2021 and EMFAC2017

EMFAC2021 Vehicle Categories	Number of engine starts in EMFAC2021	Number of engine starts in EMFAC2017	Updated in EMFAC2021?
All Other Buses	8.9	8.9	No
T6 Instate Delivery	14.27	11.54	Yes
T6 Instate Tractor	11.56	11.54	Yes
T7 POLA	16.36	7.6	Yes
T7 Single Other	9.42	11.54	Yes
T7 SWCV	4.60	3.9	Yes
T7 Tractor	14.53	12.7	Yes
OOS	22.98	14.6	Yes
SBUS	14.48	11.54	Yes
T6/T7 Public	3.0	3.0	No
T6/T7 Utility	11.5	11.5	No

The soak time distribution is defined as the fraction of starts with preceding soak time in one of the 19 soak time bins at a specific hour of the day. The average starts with soak time ≥ 2 hours per weekday is provided in Table 4.4.2-3. Similar to total number of starts per weekday, starts with longer soak time (≥2hr) in EMFAC2021 have a slight increase compared to EMFAC2017. For most vocations, the soak time distribution is dominated by short soaking events of less than 5 minutes. The starts distributions by soak time and by hour are provided in Appendices 6.11 and 6.12.

Table 4.4.2-3. Engine starts with soak time >= 2hr per weekday of HDV in EMFAC2021 and EMFAC2017

EMFAC2021 Vehicle Categories	Number of engine starts in EMFAC2021	Number of engine starts in EMFAC2017
All Other Buses	0.22	0.22
T6 Instate Delivery	3.10	2.78
T6 Instate Tractor	3.38	2.78
T7 POLA	1.41	0.56
T7 Single Other	1.05	2.78
T7 SWCV	1.35	1.19
T7 Tractor	2.15	1.11
OOS	1.59	1.47
SBUS	2.06	2.78
T6/T7 Public	0.30	0.30
T6/T7 Utility	0.20	0.20

Idling hours. The HD idling hours refers to time spent in extended idling activity that usually occur at trip origins and destinations such as work site, or at rest stops. Duration of idling events have a direct effect on idling emissions. In EMFAC2021, an HD Extended Idling Event is defined as a continuous segment of vehicle activity that meets 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. Adopting the same method used in EMFAC2017, number of extended idling hours per weekday in EMFAC2021 are developed for each vehicle category. All individual vehicle samples within each vehicle category are treated the same. For all HDV except Heavy-heavy duty CAIRP trucks, Heavy-heavy duty Out-of-state trucks, Heavy-heavy duty Single trucks, Heavy-heavy duty Tractor, the extended idle hours per day is a set value depending only on vehicle category, as presented in Table 4.4.2-4. For vehicle categories updated in EMFAC2021, extended idling hours per weekday are longer compared to EMFAC2017. School buses have the longest idling hours, while T6 Instate Delivery trucks and Tractors have the shortest idling periods. These trends are observed in both EMFAC2021 and EMFAC2017.

Table 4.4.2-4. Extended idling hours per weekday of HDV (except Heavy-heavy duty Out-of-state trucks, Single trucks, and Tractors) in EMFAC2021 and EMFAC2017

EMFAC2021 Vehicle Categories	Extended idling hours in EMFAC2021	Extended idling hours in EMFAC2017	Updated in EMFAC2021
All Other Buses (OB)	0.098	0.098	No
T6 Instate Delivery	0.33	0.098	Yes
T6 Instate Tractor	0.35	0.098	Yes

EMFAC2021 Vehicle Categories	Extended idling hours in EMFAC2021	Extended idling hours in EMFAC2017	Updated in EMFAC2021
T7 POLA	1.44	1.38	Yes
T7 SWCV	0.58	0.63	Yes
SBUS (SB)	2.06	2.78	Yes
MCH	1.69	1.69	No
Public	0.51	0.51	No
Utility	0.27	0.27	No

Under the California truck idling regulation, heavy heavy-duty diesel trucks' (HHDT) idling requirements vary by both calendar year and model year, as presented in Table 4.4.2-5. Newly acquired vehicle samples are all collected after year 2008 and for vehicle of model year 2008 or newer. Therefore, only heavy heavy-duty single trucks and tractors in calendar year later than 2008 and model year later than 2008 get updated in EMFAC2021. For the rest of the HD fleets, or fleet of pre-2008 model year, EMFAC2017 assumptions were applied. Please note that for long-distance line hauls (T7 CAIRP and T7 OOS), the updated PAMS analysis results are significantly different than those historically assumed in EMFAC. Due to lack of representative sample size and supporting evidences from other empirical data, the idling hours for these two vehicle categories are not updated in EMFAC2021 and remained the same as previous versions of the EMFAC model.

Table 4.4.2-5. Extended idling hours per weekday of HHDT in EMFAC2021 and EMFAC2017

EMFAC2021 Vehicle Categories	Calendar Year Range	Model Year Range	Extended idling hours in EMFAC2021	Extended idling hours in EMFAC2017	Updated in EMFAC2021?
T7 CAIRP	2005-2007	2008+	4.28	4.28	No
T7 CAIRP	2005-2007	pre 2008	4.28	4.28	No
T7 CAIRP	2008+	2008+	0.97	4.41	No
T7 CAIRP	2008+	pre 2008	0.22	0.22	No
T7 CAIRP	pre 2005	pre 2008	4.41	4.41	No
T7 OOS	2005-2007	2008+	5.42	5.42	No
T7 OOS	2005-2007	pre 2008	5.42	5.42	No
T7 OOS	2008+	2008+	0.97	5.47	No
T7 OOS	2008+	pre 2008	0.21	0.21	No
T7 OOS	pre 2005	pre 2008	5.47	5.47	No
T7 Single	2005-2007	2008+	0.36	0.36	No
T7 Single	2005-2007	pre 2008	0.36	0.36	No
T7 Single	2008+	2008+	0.79	0.92	Yes
T7 Single	2008+	pre 2008	0.25	0.25	No
T7 Single	pre 2005	pre 2008	0.79	0.79	No
T7 tractor	2005-2007	2008+	0.36	0.36	No

EMFAC2021 Vehicle Categories	Calendar Year Range	Model Year Range	Extended idling hours in EMFAC2021	Extended idling hours in EMFAC2017	Updated in EMFAC2021?
T7 tractor	2005-2007	pre 2008	0.36	0.36	No
T7 tractor	2008+	2008+	1.46	0.79	Yes
T7 tractor	2008+	pre 2008	0.25	0.25	No
T7 tractor	pre 2005	pre 2008	0.79	0.79	No

HD accrual rates

HDV mileage accrual rates in EMFAC2017[72] were similar to those used in EMFAC2014 and EMFAC2011. HDV mileage accrual rates in EMFAC2011 primarily relied on data from the 2002 Vehicle Inventory and Use Survey (VIUS)[73] supplemented with CARB survey data as documented in the 2008 Truck and Bus (T&B) Technical Appendix.[74]

Updated EMFAC2021 HDV mileage accrual rates reflect new data that recently become available for use. Caltrans completed a CalVIUS survey that had questions designed to obtain annual freight truck activities specific to California as was discussed in the Caltrans' California Transportation Plan 2040 (CTP 2040)[75]. The CalVIUS survey was developed to fill the gap created by the discontinuance of the federal VIUS survey process after 2002. Additionally, CARB's contract to examine potential sources of HDV accrual rate data for designated fleet types based on vocations and weight classes was completed through an extramural contract[76]. In addition to the CalVIUS survey data, CARB utilized logged vehicle data provided by a telematics service provider with over 1.3 million tracking devices deployed on heavy-duty vehicles. The updated HDV mileage accrual rates reflect the processed CalVIUS and telematics data results. The American Transportation Research Institute 2019 Report on the Operational Costs of Trucking[77] indicated the average miles driven per year per truck was 91,506 in 2018 with an average age of 4.4 for the trucks. The updated VMT in EMFAC2021 for long haul Class 8 trucks agreed with these results, reflecting an average weighted annual mileage of 91,876 with an average truck age between 4 to 5 years.

The updated annual accrual rates in EMFAC2021 will reflect more current activity trends. EMFAC2017 underestimated annual accrual rates for some fleets, including Interstate Tractors, Public/Utility Trucks and Solid Waste Collection Vehicles, while it overestimated

---

[72] EMFAC2017 Technical Documentation at https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-modeling-tools-emfac

[73] https://www.census.gov/econ/overview/se0501.html

[74] Table 1 in http://www.arb.ca.gov/regact/2008/truckbus08/appg.pdf cites sources used to derive mileage accrual rates.

[75] https://dot.ca.gov/-/media/dot-media/programs/legislative-affairs/documents/f0004899-ctp2040-a11y.pdf

[76] https://ww2.arb.ca.gov/sites/default/files/2021-01/erg_finalreport_hdv_accruals_20190614.pdf

[77] Page 30 of https://truckingresearch.org/wp-content/uploads/2019/11/ATRI-Operational-Costs-of-Trucking-2019-1.pdf

annual accrual rates for other fleets such as T7 Tractors, T6 Heavy Instate Other and T7 Single Other Vehicles and School Buses.

The following figures display the updated EMFAC2021 accrual rates based on the CA-VIUS and Geotab data with the EMFAC2017 accrual for comparison. Figure 4.4.2-1 through Figure 4.4.2-3 display accrual for the Interstate long-haul tractors based in California (CAIRP), based in near states/provinces (NOOS) and in not near states/provinces (NNOOS). Figure 4.4.2-4 and Figure 4.4.2-5 display the accrual for Class 8 and Class 7 Instate tractors. Figure 4.4.2-6 and Figure 4.4.2-7 display accrual for Delivery Vehicles which are a new vehicle category, and as such there is no EMFAC2017 accrual to display.

Figure 4.4.2-1. Interstate Accrual Rate for Class 7&8 CAIRP Tractors (N=1,382)

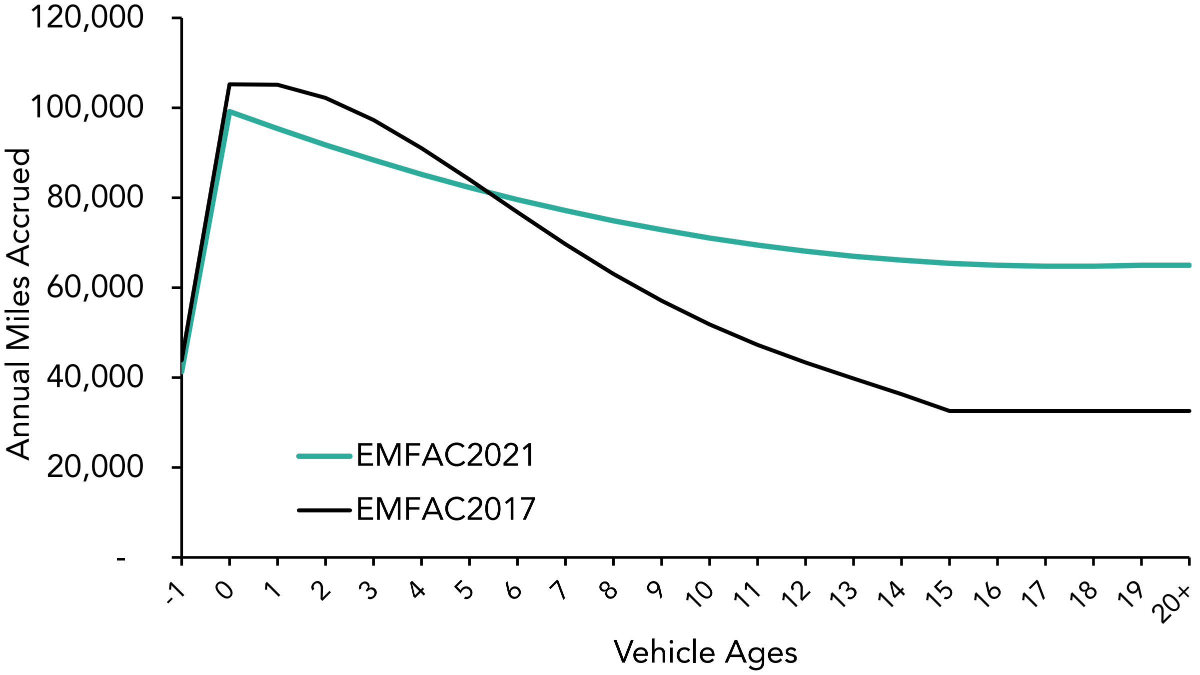


Figure 4.4.2-2. Interstate Accrual Rate for Class 7&8 NOOS Tractors (N=6,874)

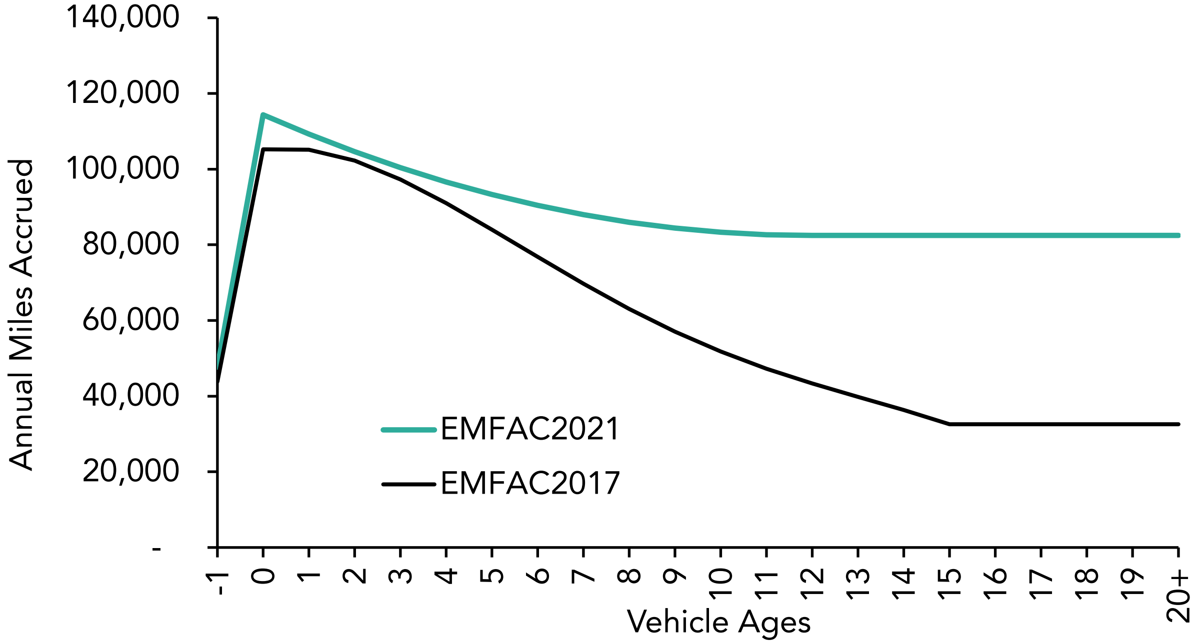


Figure 4.4.2-3. Interstate Accrual Rate for Class 7&8 NNOOS Tractors (N= 1,424)

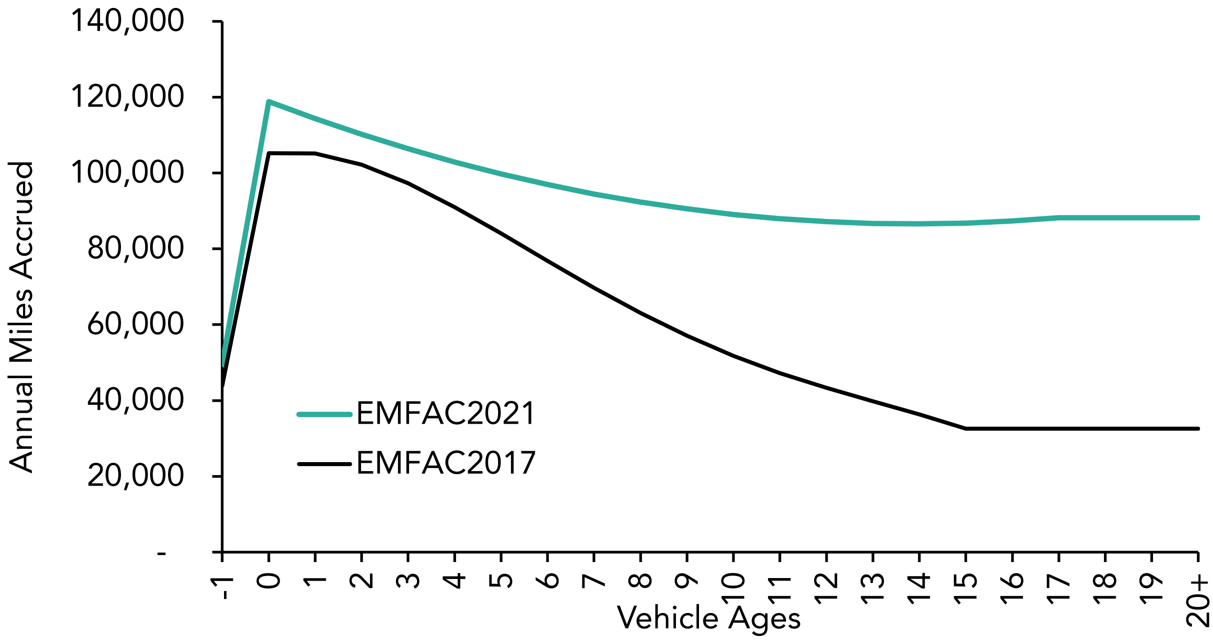


Figure 4.4.2-4. Instate Accrual Rate for Class 8 Tractors (N=5,551)

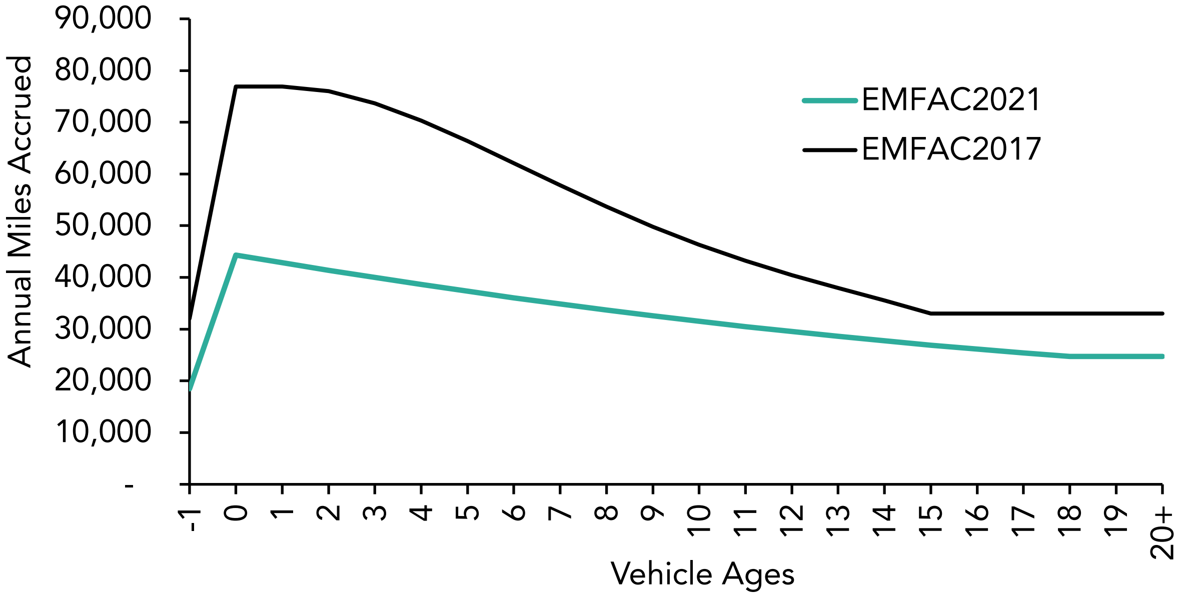


Figure 4.4.2-5. Instate Accrual Rate for Class 7 Tractors (N=456)

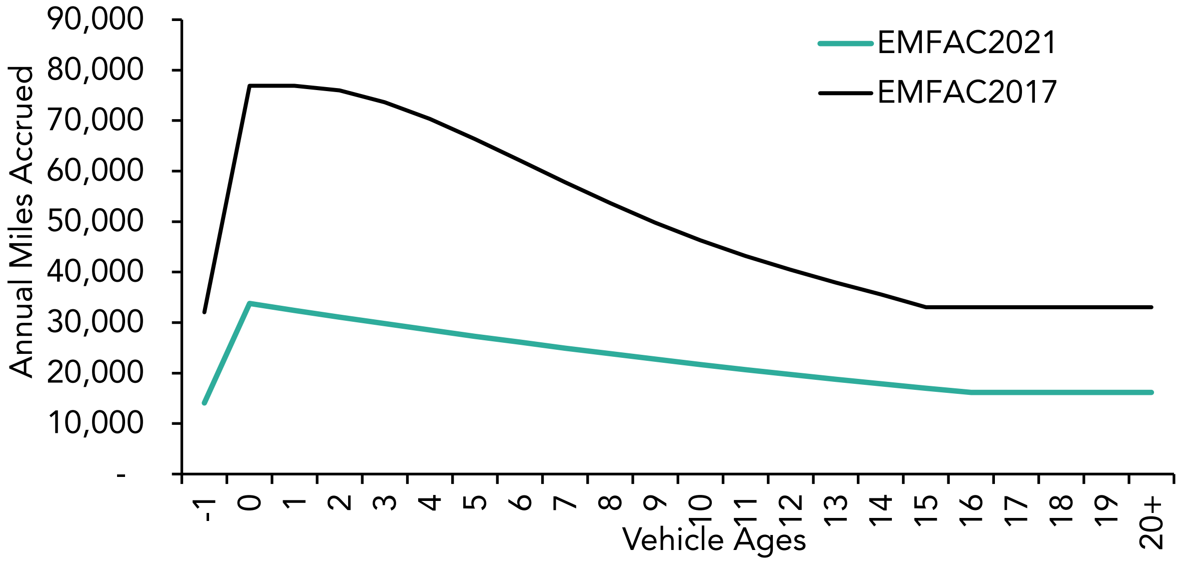


Figure 4.4.2-6. Instate Accrual Rate for Class 7 Delivery Vehicles (N=392)

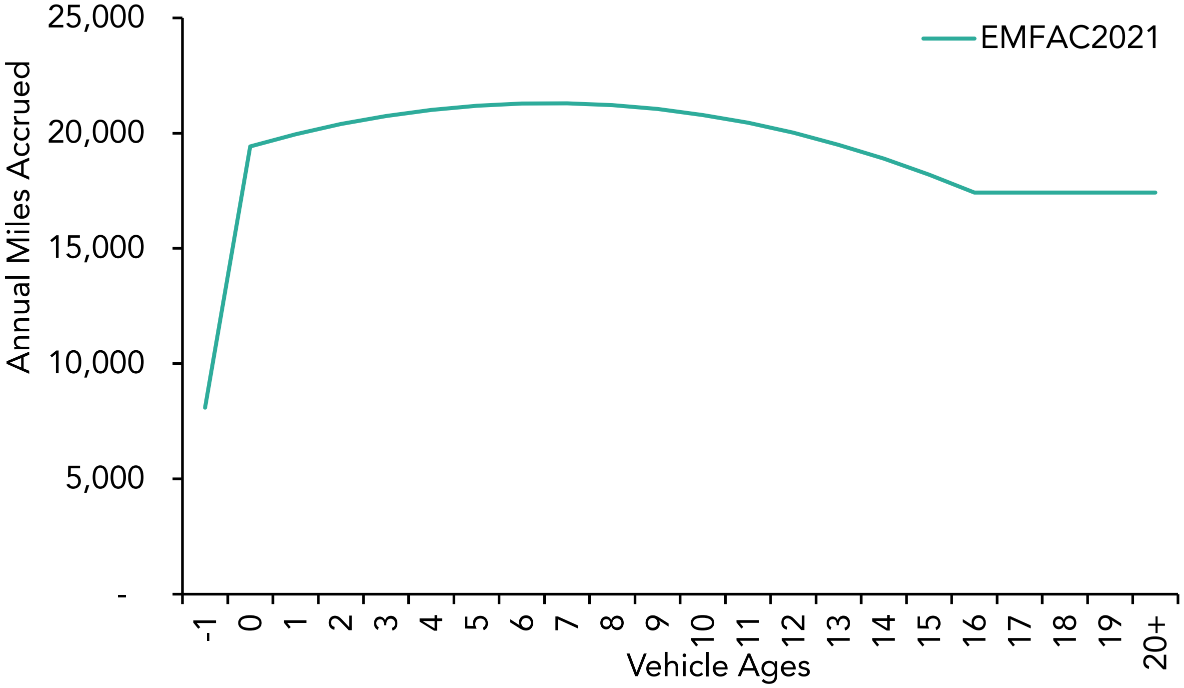
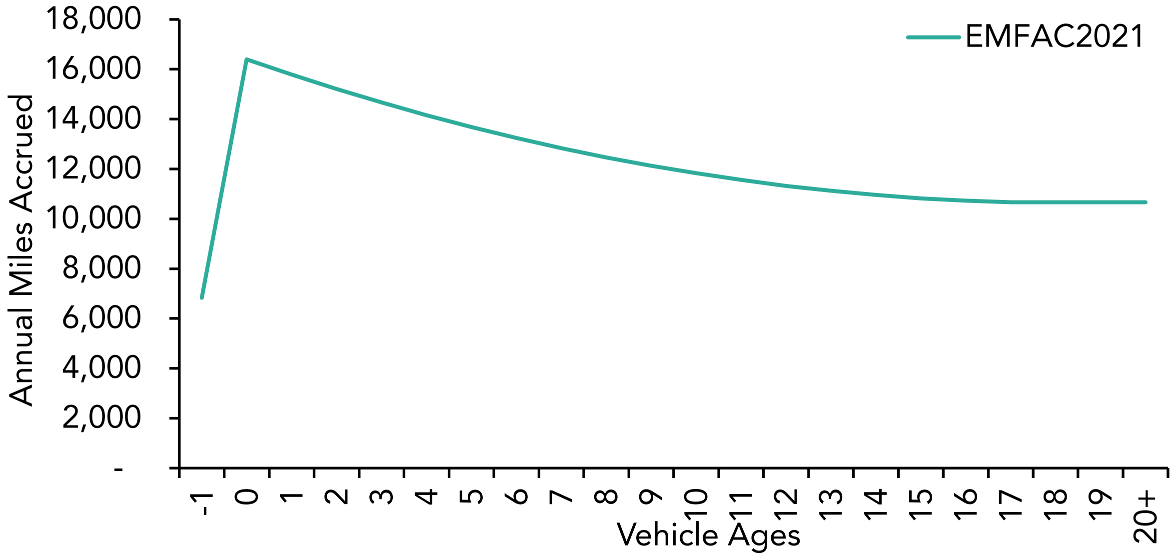


Figure 4.4.2-7. Instate Accrual Rate for Class 4-6 Delivery Vehicles (N=1,335)



HD odometer schedule

EMFAC uses odometer schedules to model increases in the emission rate due to deterioration. In EMFAC2017, odometer schedules relied on the 2002 Federal Vehicle Inventory and Use Survey (VIUS). In EMFAC2021, odometer schedules by age for heavy-duty trucks were updated using the 2018 California Inventory and Use Survey (CAVIUS) data. In EMFAC2021, odometer schedules were updated for heavy heavy-duty and medium heavy-duty trucks, including T7 Interstate Registration Plan (IRP), T7 out-of-state (OOS) registered, T7 in-state tractor T7 single-unit trucks, T6 classes 4-6 (GVWR 14,001 – 26,000), and T6 class 7 (GVWR 26,001 – 33,000 lbs.). Following a basics data cleaning, (e.g., removing unrealistically large odometer mileages), average odometers by age were calculated for each weight class and vehicle type. The average odometers as a function of vehicle age were then fit to a polynomial function. The EMFAC 2021 odometer schedules matches the polynomial fit at younger ages. At older ages, once the odometer mileage hits a maximum value, the odometer mileage is assumed to be constant at the maximum value of the fit.

Figures 4.4.2-8 through Figure 4.4.2-13 show the new odometer schedules, the EMFAC2017 schedules, and the fitted CAVIUS data. Compared to EMFAC2017, EMFAC2021 odometer schedules are larger for T7 OOS and IRP, leading to higher deterioration-related emissions. On the other hand, odometer schedules are smaller for T7 in-state tractors, T7 single unit trucks, and T6 trucks, leading to less deterioration-related emissions.

Figure 4.4.2-8. T7 OOS Odometer Schedule

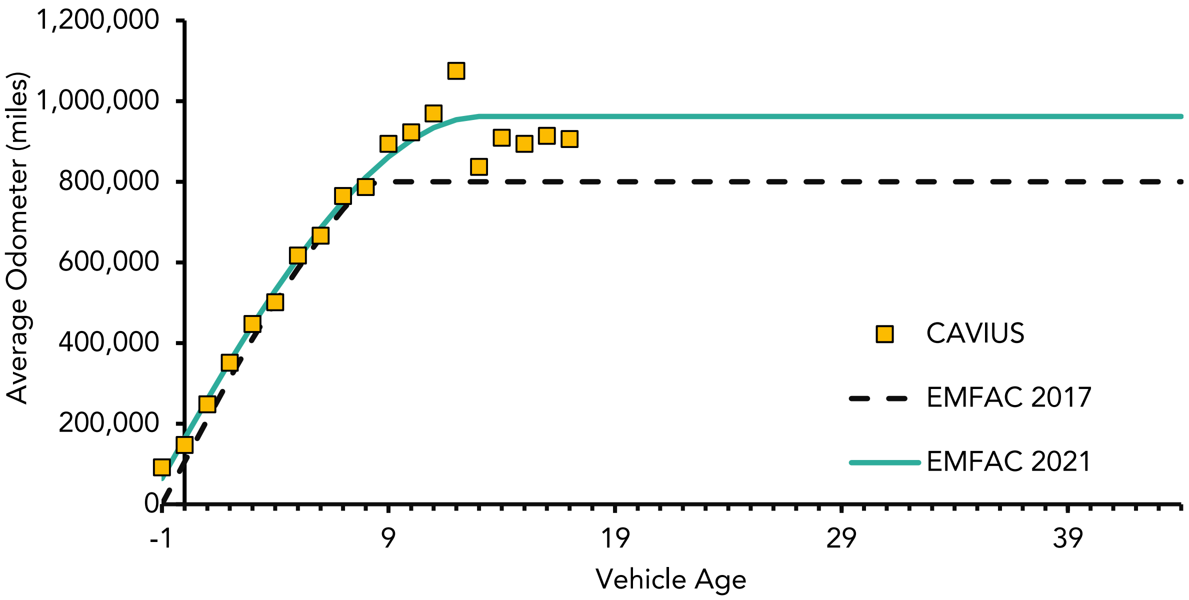


Figure 4.4.2-9. Updated T7 IRP Odometer Schedule

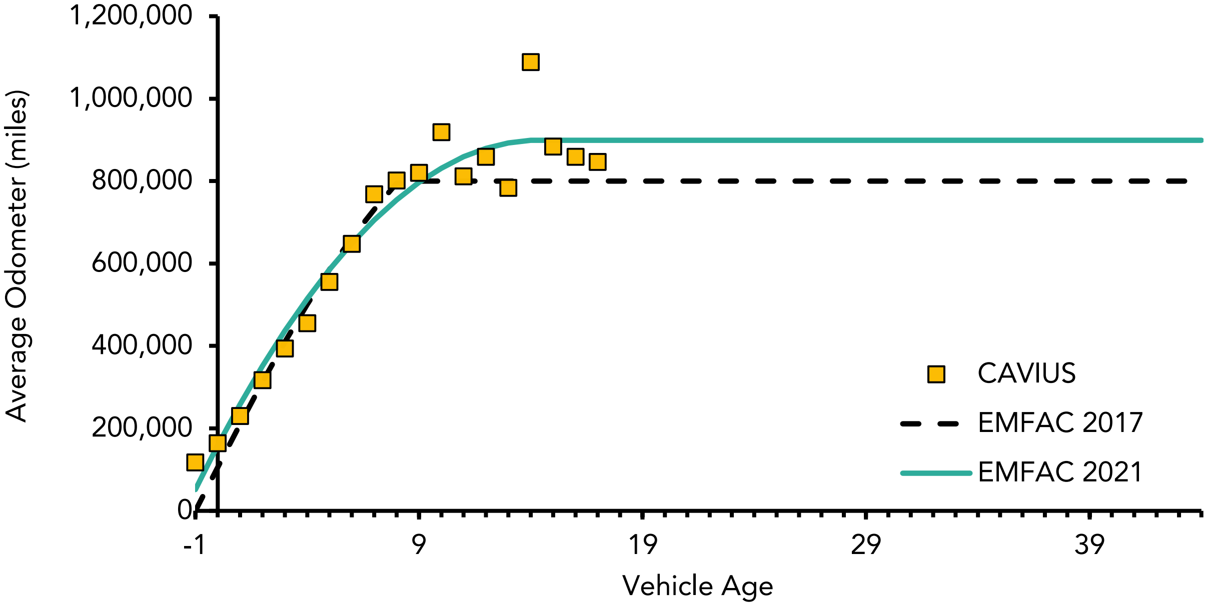


Figure 4.4.2-10. Updated T7 Single Odometer Schedule

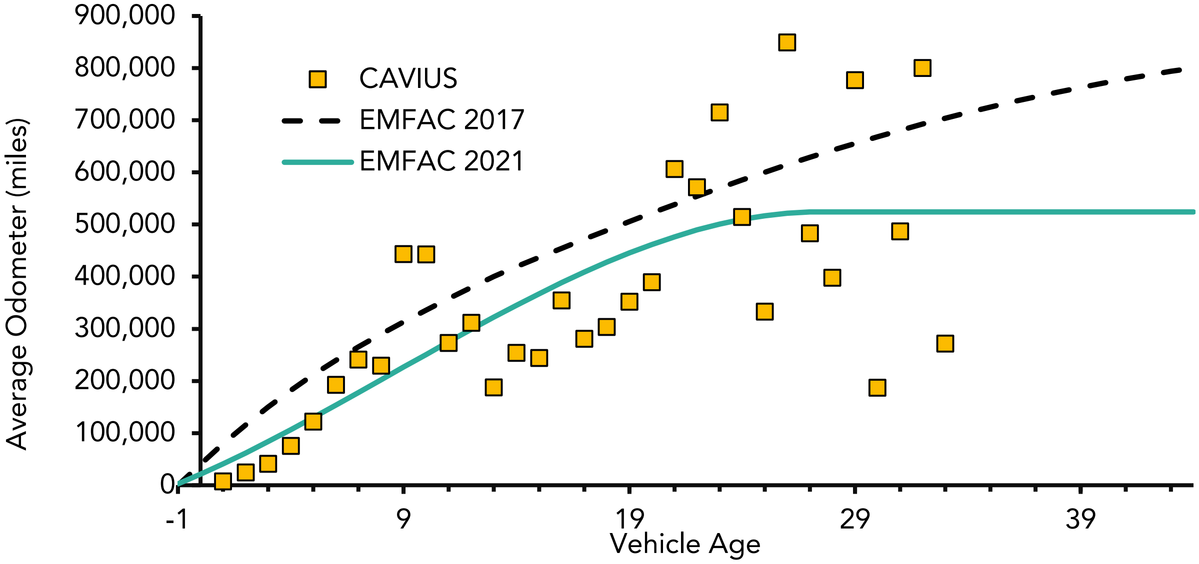


Figure 4.4.2-11. Updated T7 Tractor Odometer Schedule

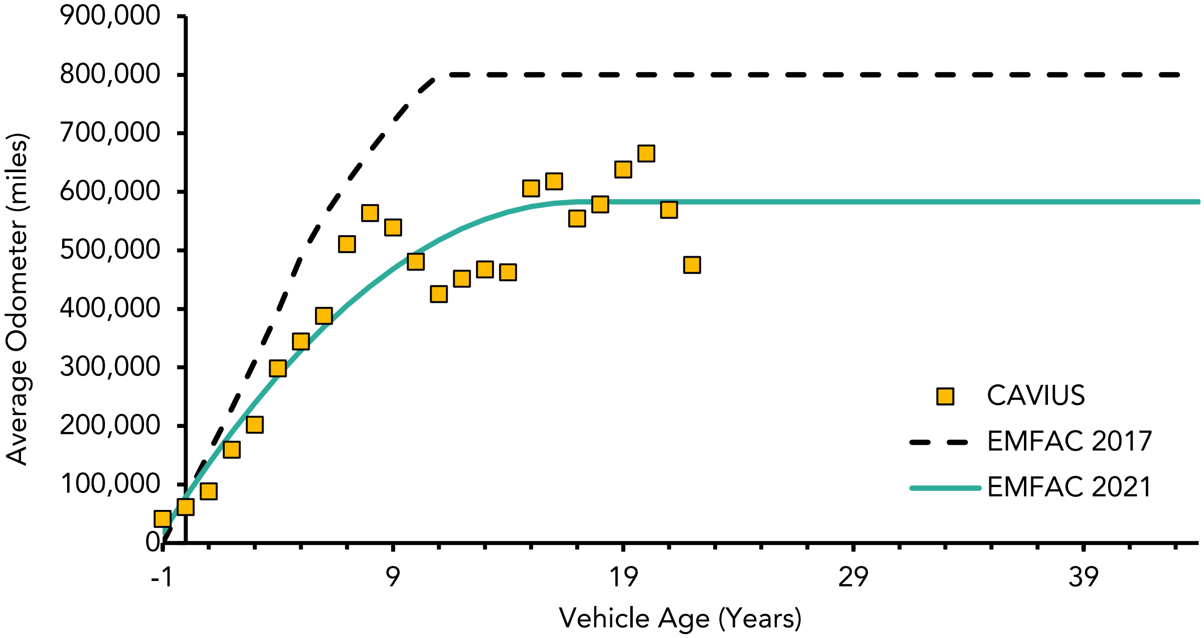


Figure 4.4.2-12. Updated T6 Class 4-6 Odometer Schedule

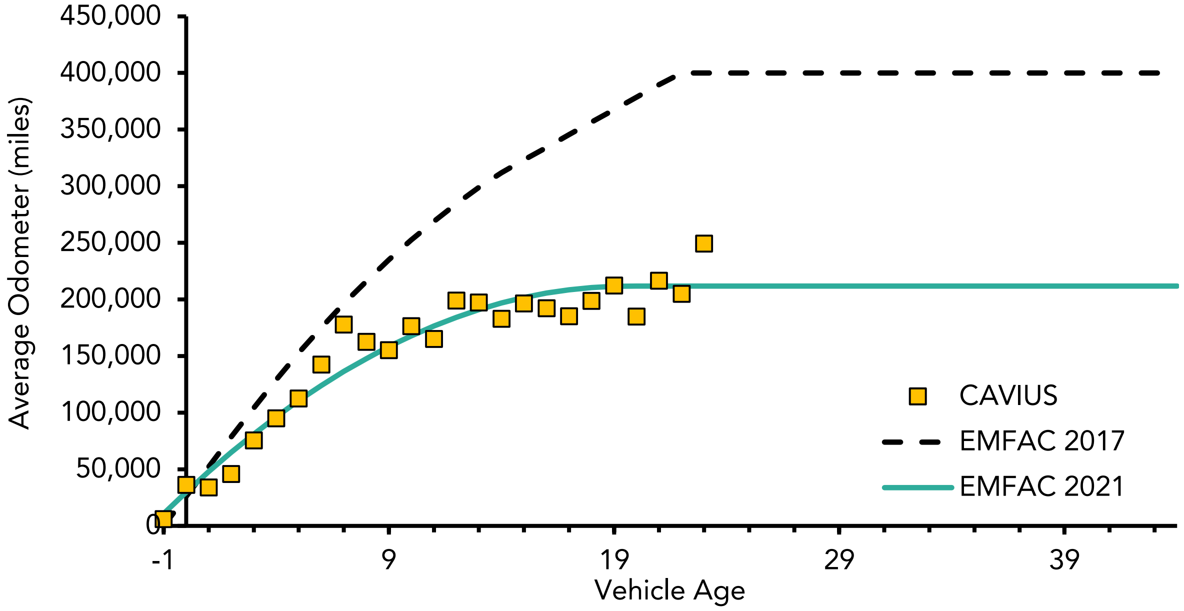
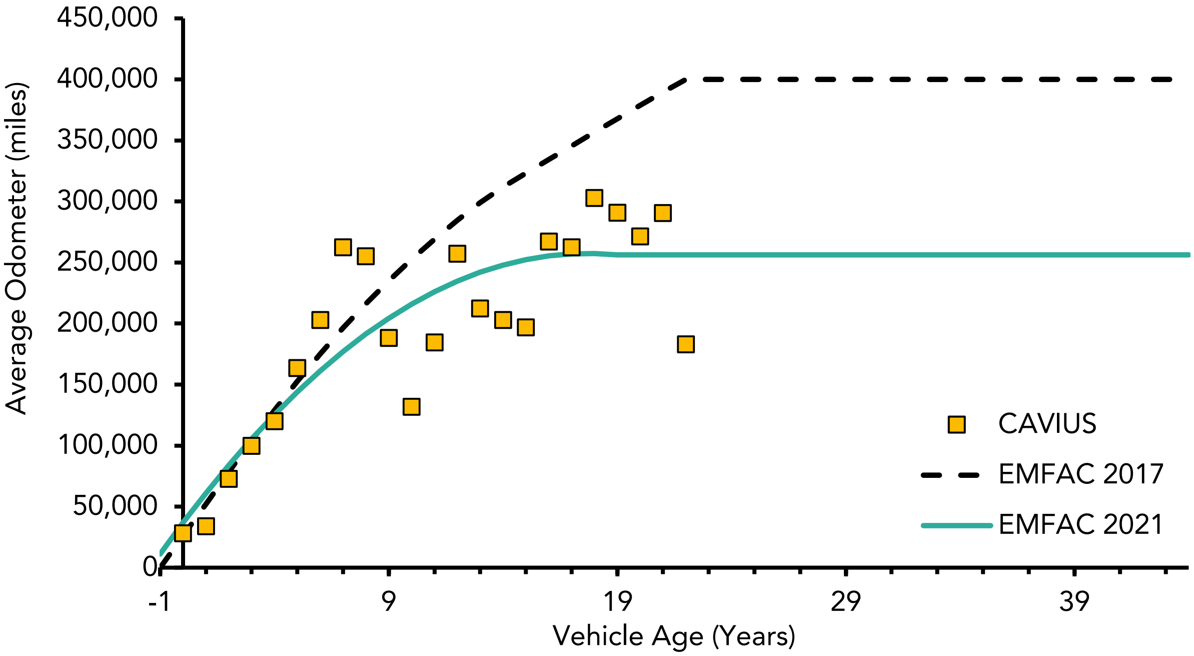


Figure 4.4.2-13. Updated T6 Class 7 Odometer Schedule



4.5 Forecasting

4.5.1 Light Duty New Sales and VMT Forecasting

New Vehicle Sales

In EMFAC2021, the annual vehicle population is comprised of vehicles retained from the prior calendar years, plus new vehicle sales. The count of retained vehicles is calculated by counting how many vehicles existed in California for prior calendar years. To forecast new vehicle sales, first the statewide new vehicle sales need to be estimated and then it is disaggregated to regional level new sales. In EMFAC2017, the forecasting equation for statewide new sales of LD vehicles, for all fuel types, was developed using a multivariate regression analysis based on historical socio-econometric time-series data from 2000 – 2016. To do the econometric modeling, the selection of variables aimed to be consistent with microeconomic theory which dictates that attention must be paid to the reasonableness of coefficient magnitudes and signs. Hence, the goodness of fit and significance criteria (such as t-statistic) from potential models, using different variable combinations, was considered.

While CARB staff used the same socio-econometric modeling approach for development of the new vehicle sales model for EMFAC2021, the current update included a dynamic modeling approach where staff utilized an optimization methodology choose the best socio-economic indicators that describe historical data and create a set of candidate models for further assessment. As the next step, staff picked the best model that was more consistent with past and future socioeconomic situation for use in EMFAC2021. The same criteria for statistical modeling were applied to other regression analysis efforts, including new vehicle sales, LDV VMT growth trends as discussed in subsequent sections.

The primary data sources used for this analysis included UCLA Anderson Forecast (UCLA), California Department of Finance (DOF), and DMV. Table 4.5.1-1 shows a more detailed list for the sources used in this regression development, spanning the years 2003 – 2019, and in the forecasting equations, starting in 2020. All data variables used were on a statewide, annual basis.

Table 4.5.1-1. Primary data sources used for EMFAC2021 new vehicle sales forecasting.

Data	Source
New vehicle sales	Historical DMV data and UCLA Anderson Report, 2020
Human population and GDP	DOF, Jan 2020
Gas price, unemployment rate, housing starts, disposable income	UCLA Anderson Report, 2020
Gas price	CEC Fuel Prices-2019 Forecasts
Federal Rates	Federal Reserve Bank of St. Louis, 2019

To do the modeling, staff looked at seven different econometric indictors. To evaluate whether any of the parameters listed have any delayed impact on new vehicle sales, all the selected parameters were lagged by one year. The multivariate regression analyses was then performed on all the socio-econometric parameters along with their lagged counterparts.

For the modeling, a large number of models were created using ordinary least square (OLS) method, including an array of two to seven variable models. Since it is impractical to look at all available combination of the given parameters, a computer program was developed to create random n-variable models using a random combination of the given parameters such as housing starts and unemployment rate; the program then sieved through the models to keep only the best ones.

The models were created based on historical socio-econometric data obtained for calendar years 2003 through 2019; and projection or forecast for new vehicle sales was developed for calendar years 2020 through 2050. Moreover, evaluation of each created model based a set of automated reasonableness criteria – described below – allowed the computer program to pick a handful of best models.

To further test the reasonableness of each model manually, a number of statistical indicators including R^2 value and t-statistic value or p-value were calculated and evaluated for each of the computer-selected best models. R^2 value measured the correlation between the given data and the modeled ones, and p-value provided the degree of significance of each parameter in the model. Other than these two measure, the staff checked the sign validity for each model, and ensured that the coefficients of the parameters of each model have the correct sign. Staff then evaluated parameter coherency along with the overall impact of the model on forecasts up to 2050. This exercise boiled down the available models to the best model for new vehicle sales as shown below.

$$\begin{aligned} N\text{ew vehicle sales per capita} \\ &= 0.05744068 \\ &- 0.004672403 \text{ x UR} \\ &+ 0.00271036 \text{ x L1\_UR} \end{aligned} \qquad \text{Eq. 4.5.1-1}$$

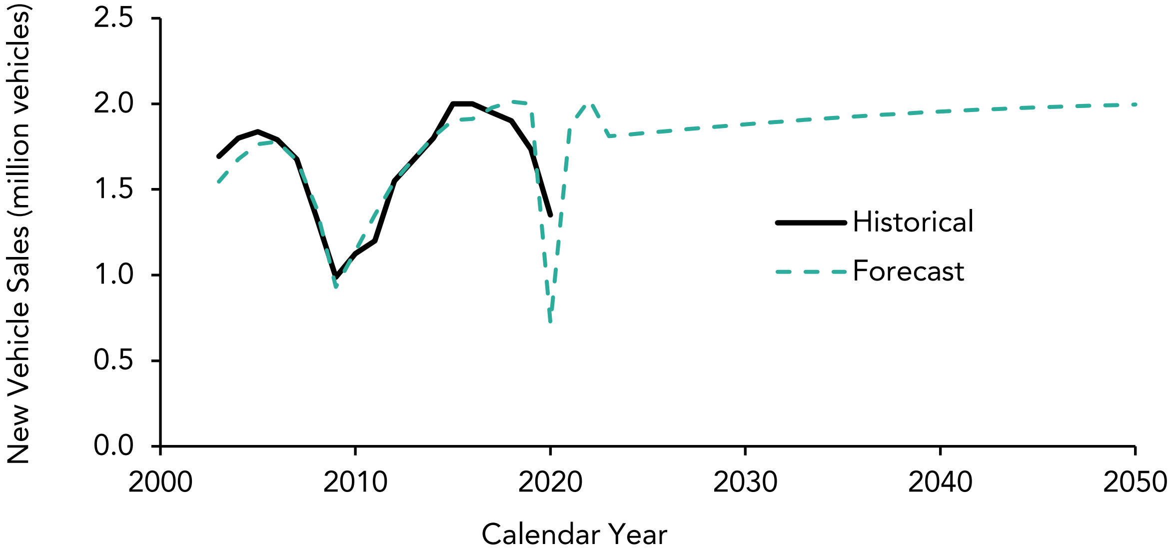
where UR is unemployment rate in percentage and L1_UR is 1-year lagged unemployment rate. As shown, the count of new vehicles sold in California per capita is a function of only unemployment rate and the 1-year lagged unemployment rate. The select model has a high correlation coefficient of 0.89, and less than 0.05 p-values illustrating the significance of the selected parameters. These values are shown in Table 4.5.1-2.

Table 4.5.1-2. Statistics pertaining to the choice of parameters for the updated vehicles sales per capita model for EMFAC2021

p-Value			R2
Intercept	**Unemployment Rate (UR)**	**1-year lagged Unemployment Rate (L1_ UR)**	
$2.7\text{x}10^{-8}$	$4.17\text{x}10^{-7}$	$2.29\text{x}10^{-4}$	89%

A comparison between historical new vehicle vehicles sales and the new model forecasts is provided in Figure 4.5.1-1. It is noteworthy to mention that an estimated new vehicles for year 2020 based on the sales fata from California New Car Dealers Association[78] (CNCDA) was used to reflect the impact of COVID-19 pandemic on light duty vehicle sales in year 2020. For years 2021 and onward, the model used the forecasted new vehicles sales from the regression model described earlier.

Figure 4.5.1-1 Comparison between historical new vehicle sales and estimated new sales by the regression model



As described above, EMFAC2021 is updated using a new vehicle sales model. The new model predicts that the count of new vehicles sold in California solely depends on unemployment rate and 1-year lagged unemployment rate along with population. It should be noted that the current model is only capable of representing business-as-usual conditions and is made using the best available data, and factors such as COVID-19 introduce both short- and long-range uncertainties in the ability of the model to accurately forecast future trends.

---

[78] https://www.cncda.org/wp-content/uploads/Cal-Covering-4Q-20.pdf

Vehicle Miles Travelled (VMT)

Similar to the new vehicles sales, VMT of light duty vehicles at the statewide level is forecasted using multivariate regression analysis based on historical time-series data from 2003-2019. Practices described above such as using a computer program to sieve through automatically generated models and testing the reasonableness of the models by first the computer program and then the staff were implemented to develop forecasting models for light duty VMT. For this econometric modeling, it was assumed that historical light duty vehicles VMT has followed similar trend as statewide gasoline consumptions after discounting the impact of fuel efficiency improvements. Therefore, in the absence of any future fuel efficiency improvement, the growth in the motor vehicle gasoline consumptions should be directly correlated to the growth in the light duty vehicle VMT. It needs to be noted that light duty vehicles in California are the major consumers of motor vehicle gasoline.

The primary data sources used for this analysis included economic data from UCLA Anderson forecasts along with those from Department of Finance (DOF), and fuel sales data from the California Department of Tax and Fee Administration (CDTFA). Table 4.5.1-3 below shows a more detailed list for the sources used in this regression development, spanning years 2003 through 2019, and in the forecasting equations, starting in 2020. All data variables used were on a statewide, annual basis.

Table 4.5.1-3. Primary data sources used for EMFAC2021 new vehicle sales forecasting.

Data	Source
New vehicle sales	UCLA Anderson Report, 2020
Human population and GDP	DOF, Jan 2020
Gas price, unemployment rate, housing starts, disposable income	UCLA Anderson Report, 2020
Gas price	CEC Fuel Prices-2019 Forecasts
Federal Rates	Federal Reserve Bank of St. Louis, 2019
Fuel Usage	California Department of Tax and Fee Administration (CDTFA), 2019 Motor Vehicle Fuel Tax (MVF)

The chosen regression model for annual VMT of light duty vehicles at the statewide level is:

$$\begin{aligned} Vehicle\ Miles\ Travelled\ (VMT) \\ &= -381.4848092 \\ &- 13.74702754 \times GASP \\ &+ 18.91130716 \times POP \\ &+ 0.024905874 \times L1HST \end{aligned} \qquad \text{Eq. 4.5.1-2.}$$

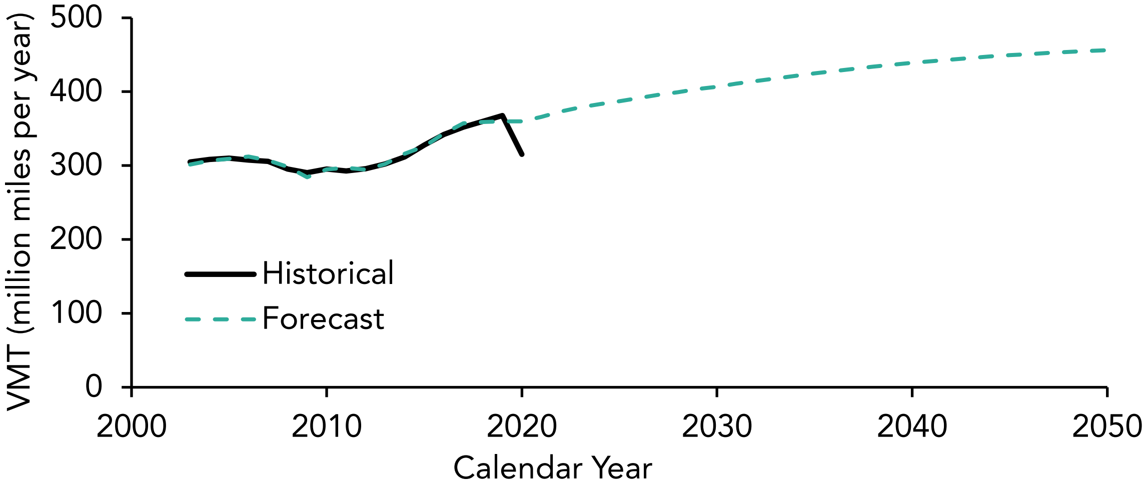
where GASP is gas price in dollars, POP is human population in millions, and L1HST is the 1-year lagged national housing starts in thousand units. The chosen model has a high correlation coefficient of 0.98, and less than 0.05 p-values illustrating the significance of the selected parameters. These values are shown in Table 4.5.1-4.

Table 4.5.1-4. Statistics pertaining to the choice of parameters for the updated VMT model for EMFAC2021

	p-Value			**R2**
Intercept	**Gas price (GASP)**	**Human population (POP)**	**1-year lagged national housing starts (L1HST)**	
2.7×10^{-8}	1.1×10^{-5}	~0.0	9.3×10^{-7}	98%

A comparison of historical VMT data and those estimated from the new model is shown in Figure 4.5.1-2. It is noteworthy to mention that an estimated VMT for year 2020 based on the CDTFA taxable fuel sales data was used to reflect the impact of COVID-19 pandemic on light duty vehicle VMT in year 2020. For years 2021 and onward, the model used the forecasted VMT from the regression model described earlier.

Figure 4.5.1-2. Comparison between historical VMT data and estimates from the VMT regression model



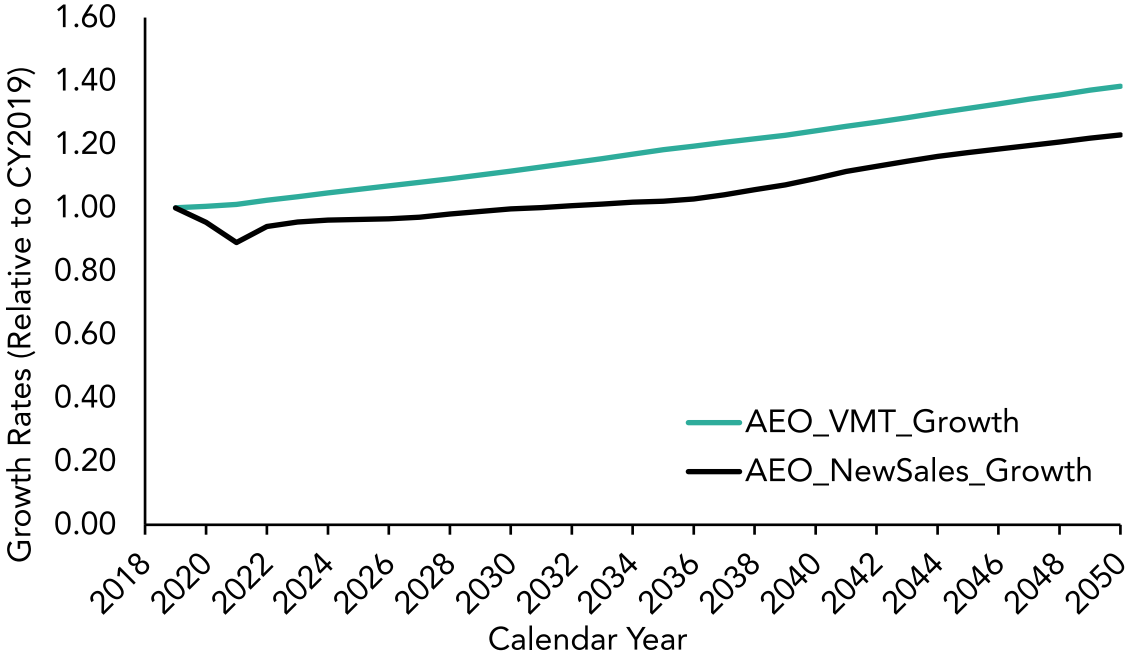
4.5.2 Heavy Duty New Sales and VMT Forecasting

New Vehicle Sales

EMFAC2021 continues to use the heavy-duty new vehicle sales forecasting method used in EMFAC2014 and EMFAC2017 (refer to Section 3.3.4.1.2.1 of the EMFAC2014

Technical Documentation)[79]. The forecasting method begins with the national HD new vehicle sales growth trend, which is obtained from the Annual Energy Outlook (AEO) report[80] of the U.S. Energy Information Administration (EIA). The national growth trend is translated to California's specific new HD vehicle sales growth trend by applying the ratio between the national VMT growth based on AEO and California's VMT growth. For more details, please refer to Section 4.5.3 of the EMFAC2017 technical documentation[81]. While EMFAC2017used 2005 as the base year for new sales growth, EMFAC2021 uses 2019 as base year. The national VMT and growth trends are displayed in Figure 4.5.2-1 . For more details, please refer to Section 4.5.3 of the EMFAC2017 technical documentation[82].

Figure 4.5.2-1. National Heavy-Duty VMT and New Sales Growth Trend Reported by AEO (Relative to 2019)



In EMFAC2021, except for CA IRP, out-of-state, and Class 8 in-state tractors[83], the rest of HD categories needs a sales adjustment process to ensure that the forecasted new HD

---

[79] https://ww3.arb.ca.gov/msei/downloads/emfac2014/emfac2014-vol3-technical-documentation-052015.pdf

[80] https://www.eia.gov/outlooks/aeo/

[81] https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf

[82] https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf

[83] Including T6 CAIRP Class 4, T6 CAIRP Class 5, T6 CAIRP Class 6, T6 CAIRP Class 7, T6 OOS Class 4, T6 OOS Class 5, T6 OOS Class 6, T6 OOS Class 7, T7 CAIRP Class 8, 7 NNOOS Class 8, T7 NOOS Class 8, T7 Single Other Class 8, and T7 Tractor Class 8.

sales from the above process will meet the forecasted VMT target. The new vehicle sales for these categories are estimated in such a way that VMT estimated by forecasted population and accrual rate meets the target VMT determined by base year VMT and growth rates. Therefore, the number of new vehicle sales for these categories was determined based on how much VMT were needed to match the target VMT. Details can be found in Section 3.3.4.1.2.1 of the EMFAC2014 technical documentation.

VMT forecasting

For years 2000-2016, EMFAC2017 used historical data on taxable diesel fuel sales to normalize the statewide HD VMT rates, so that fuel usage results would match actual fuel sales results.[84] For EMFAC2021, historical taxable diesel fuel sales continue to be used to normalize the statewide VMT rates such that fuel usage results match the actual historical fuel sales for 2000-2019. However, fuel sales data used to be obtained from the Board of Equalization but now resides with the California Department of Tax and Fee Administration.[85]

EMFAC2017 forecasted future statewide level on-road diesel consumption using an econometric regression model based on historical time-series data. This method was based on the assumption that historical diesel consumption in California was directly correlated to VMT associated with heavy-duty vehicle VMT (the major consumer of taxable diesel in California), and that in the absence of any diesel fuel efficiency improvement, the growth in future diesel fuel consumption should be directly correlated with heavy-duty vehicle VMT. Statewide diesel fuel growth rates from the regression model were used in EMFAC2017 to forecast the statewide diesel VMT for years 2017-2050.

EMFAC2021 has improved HD VMT forecasting method. County level VMT growth rates extracted from the California Statewide Travel Demand Model (CSTDM) [86] is used to forecast future VMT from 2020 to 2050. CSTDM utilizes a commodity-based model which forecasts future freight flows by mode on the transportation network under various policy scenarios. The major benefits of using CSTDM freight projections as HD VMT surrogates include:

- It helps create consistent forecasting methods across CARB's freight inventory sectors. Freight movement drives the growth in shipments by HD vehicles, ocean going vessels (OGVs), locomotives, as well as activities in cargo handling equipment (CHE) sectors. CARB's OGV and CHE model primarily use Freight Analysis Framework (FAF) projections, along with other freight forecasts. Using freight flows as surrogates for forecasting HD VMT growth will ensure consistency of CARB's inventory projections in the main freight sectors.

---

[84] refer to Section 4.5.3 in the EMFAC2017 Technical Documentation

[85] https://www.cdtfa.ca.gov/taxes-and-fees/spftrpts.htm

[86] https://dot.ca.gov/programs/transportation-planning/multi-modal-system-planning/statewide-modeling

- It allows VMT forecasting by truck class at regional level, in contrast to the previous uniform statewide growth rate with the socio-economic regression model. CSTDM forecasts freight activity by light, medium, and heavy duty trucks. The CSTDM model projects freight flows among over 5000 zones in California.
- Finally, using CSTDM allows potential future explorations of HD VMT and emissions under different policy scenarios, such as mode shifts, carbon tax, alternative spatial development, change in infrastructure, etc.

The CSTDM county level VMT for the calendar years 2015, 2020, 2030 and 2040 were used to predict the values between these years and 2030 – 2040 values were used to predict VMT for 2041-2050. The CSTDM county level VMT growth rates were calculated separately for the heavy heavy-duty vehicles (above33,000 lbs.) and the medium heavy-duty vehicles (14,001-33,000 lbs.). Summary results are displayed in the following Figure 4.5.2-2 through Figure 4.5.2-4 for Statewide, South Coast, and San Joaquin Valley Air Basins.

Figure 4.5.2-2. CSTDM HD VMT Growth Rates – Statewide

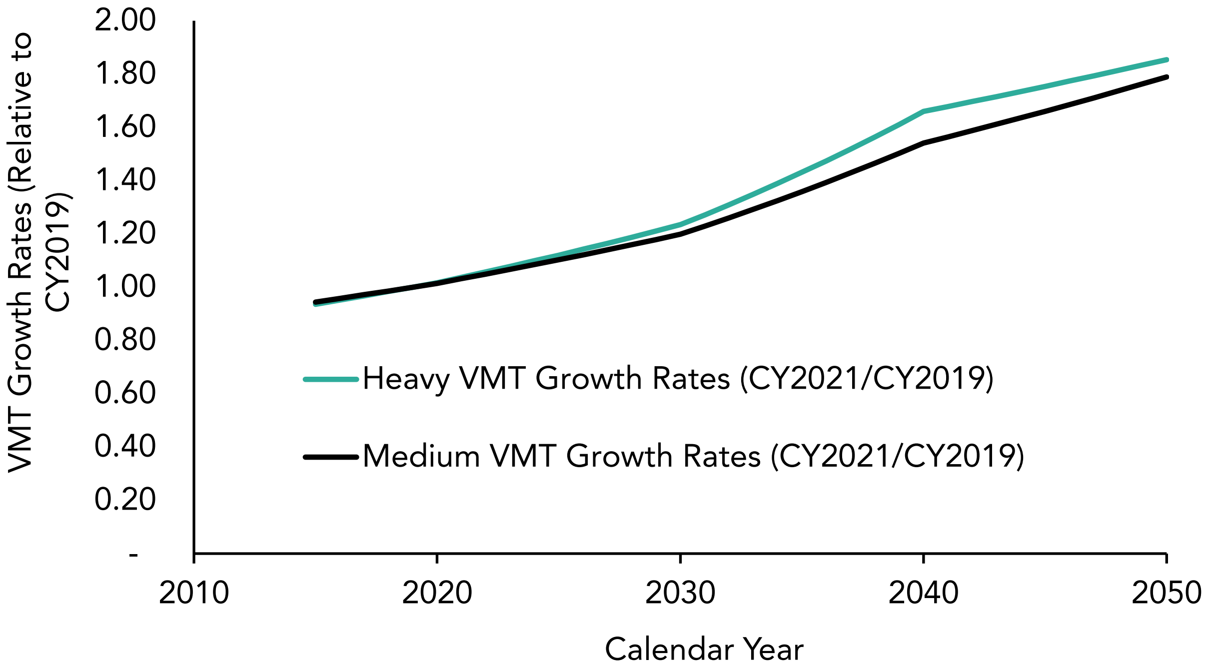


Figure 4.5.2-3. CSTDM HD VMT Growth Rates-South Coast Air Basin

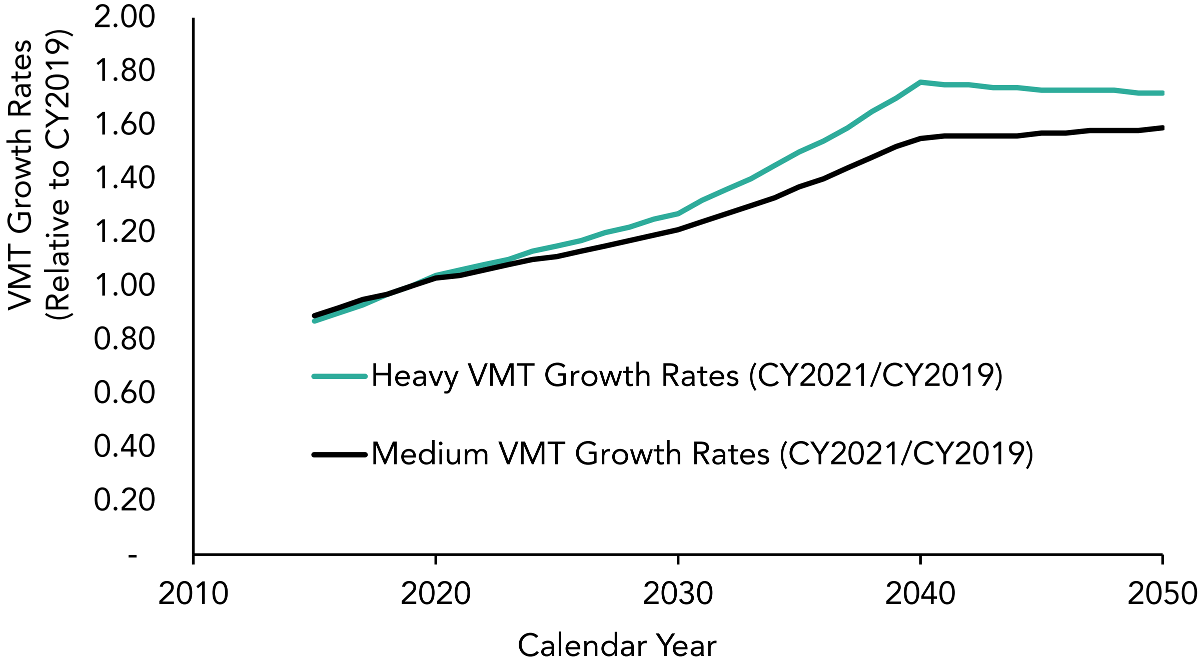
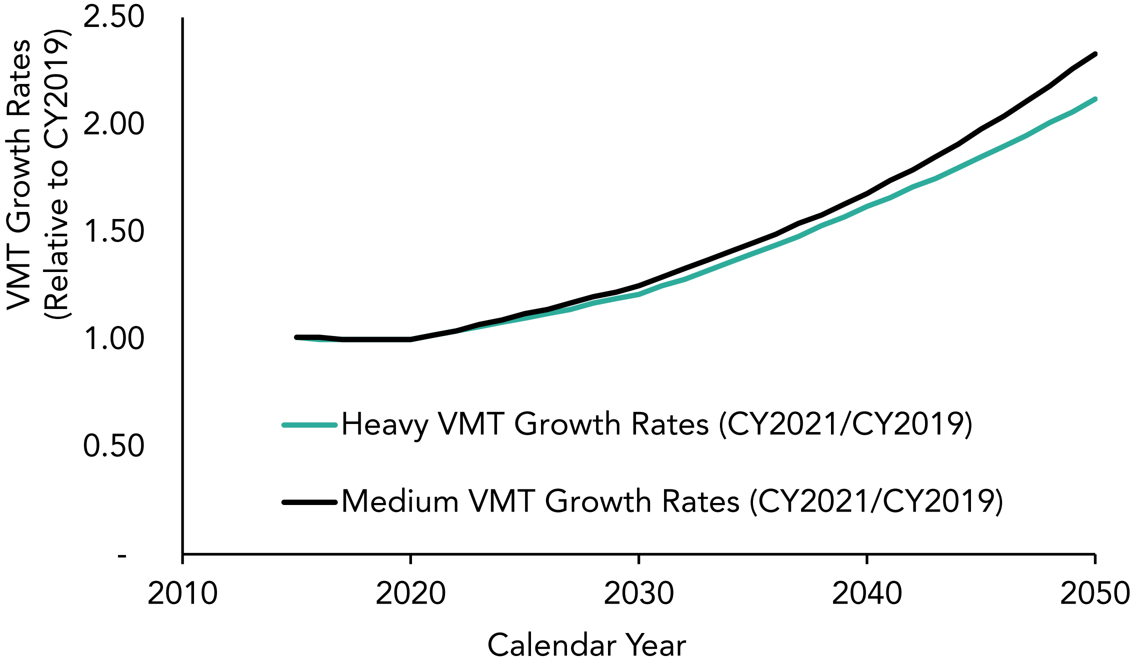


Figure 4.5.2-4. CSTDM HD VMT Growth Rates-San Joaquin Air Basin



Drayage Trucks

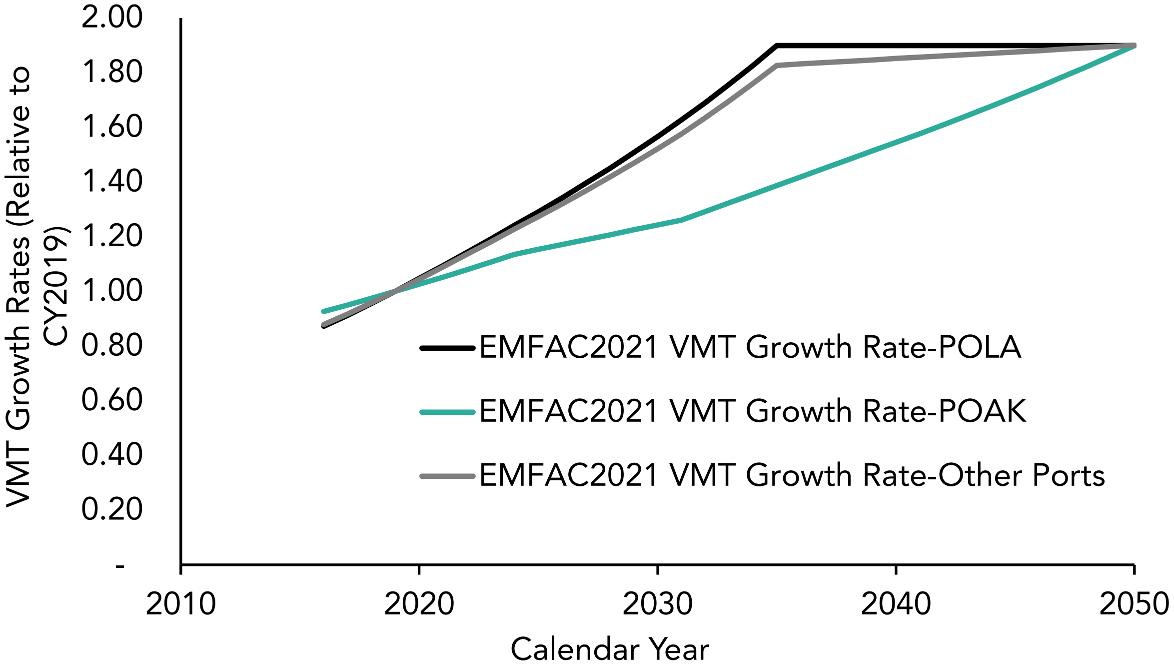
As in EMFAC2014 and EMFAC2017, EMFAC2021 keeps using the activity growth rates from CARB's Ocean-Going Vessel (OGV) model as a surrogate for future drayage truck VMT growth for the Port of Los Angeles (POLA) and the Port of Long Beach (POLB). Mercator International Forecast from 2016[87] is used to project drayage truck VMT growth operating at the POLA and POLB. It should be noted that POLA and POLB will reach their combined capacity limit by 2035. At that point, the estimated growth rate is zero. CARB staff applied this capacity limit. As a result, post-2035 growth rate is assumed to be zero for POLA and POLB. For the Port of Oakland, the growth rates used for EMFAC2021 are based on the moderate growth rate scenario described in the 2019-2050 Bay Area Seaport Forecast report, which is prepared for the SF Bay Conservation and Development Commission by the Tioga Group.[88] For the "Other Ports" drayage truck category, EMFAC2021 assumes that VMT grows similar to the Port of Los Angeles/Long Beach and Port of Oakland growth rates adjusted by Twenty-foot Equivalent Unit (TEU) proportions. Figure 4.5.2-5 shows the VMT growth rates used in EMFAC2021 for drayage trucks.

---

[87] https://ww3.arb.ca.gov/msei/offroad/pubs/2019_OGV_Inv_Methodology.pdf

[88] The Tioga Group, 2019-2050 Bay Area Seaport Forecast, Prepared for SF Bay Conservation and Development Commission (https://www.bcdc.ca.gov/seaport/2019-2050-Bay-Area-Seaport-Forecast-Draft.pdf, April 2020)

Figure 4.5.2-5. VMT Growth Trend for Drayage Trucks



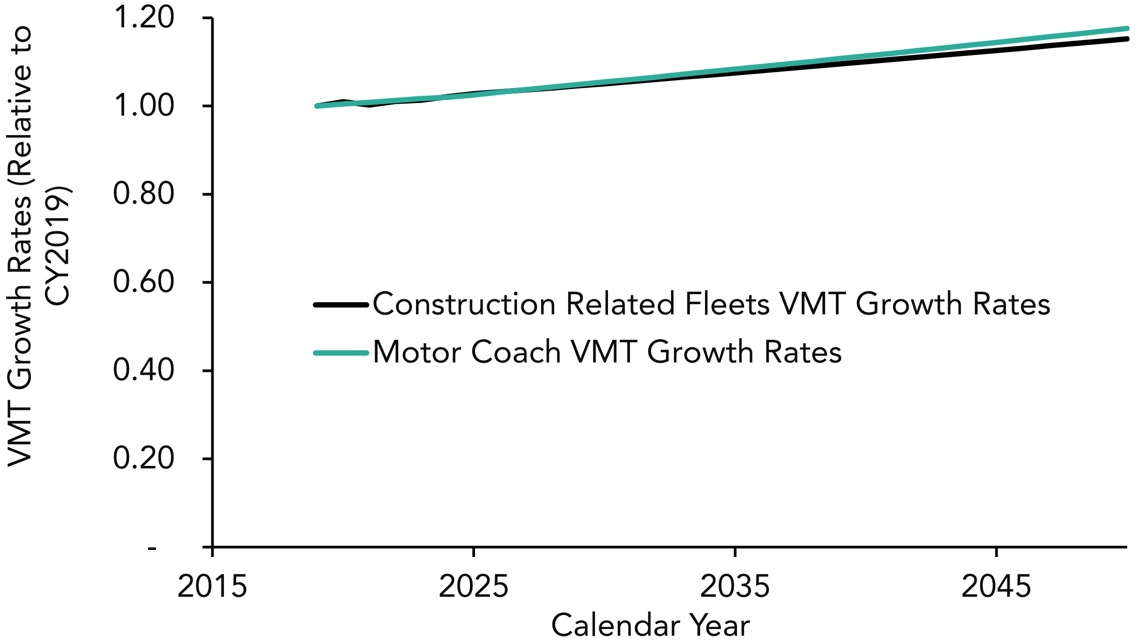
Construction and Motor Coach Buses

The VMT growth rates for Construction and Motor Coach Buses in EMFAC2021 (Figure 4.5.2-6) are based on 10 years of projected employment from the June 2018 UCLA Anderson Annual Economic Forecast[89]. 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.

---

[89] https://www.anderson.ucla.edu/centers/ucla-anderson-forecast

Figure 4.5.2-6. VMT Growth Trend for Construction Trucks and Motor Coaches



NOTE: CY2028 Annual Growth Rates were held constant from CY2029 through CY2050

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

Similar to EMFAC2017, the VMT of Public, Utility and Solid Waste Collection Vehicles (SWCV) and the All Other Bus fleet in EMFAC2021 is assumed to follow the same activity growth trend as the DOF based statewide human population[90] displays. The School Bus growth rates to forecast VMT are set at 1.0 (as it was in EMFAC2017), reflecting no growth.

4.5.3 Zero Emission Vehicle Forecasting

LDV ZEV sales

EMFAC2017 predicted the sales of new light-duty ZEV vehicles based on a most likely compliance scenario that was dictated by ZEV mandates outlined in the Appendix A of Advanced Clean Car Regulation (ACC) Mid-term Review[91]. The comparison between ZEV sales projected by EMFAC2017 and DMV data indicates that EMFAC2017 underestimated the new vehicle sales of light-duty ZEV vehicles in California in recent years (shown in Figure 4.5.3-3). This shows the important role of consumer preference

---

[90] http://www.dof.ca.gov/Forecasting/Demographics/Projections/

[91] https://ww2.arb.ca.gov/sites/default/files/2020-01/appendix_a_minimum_zev_regulation_compliance_scenarios_formatted_ac.pdf

that promotes ZEV sales beyond the existing ZEV mandate. Therefore, EMFAC2021 updates its methodology for projecting ZEV market shares using California Energy Commission (CEC)'s light-duty vehicle choice models, coupled with CARB's customized input variable projections for the state incentives and vehicle attributes.

For short-term projection, California Energy Commission (CEC)'s consumer vehicle choice models along with CARB's updated input assumptions for projecting ZEV market share from 2020 to 2030 are used. The models used for short-term projection are the personal vehicle choice (PVC) model for vehicles owned by residents and the commercial vehicle choice (CVC) model for vehicles owned by businesses in California. In addition, light-duty vehicles and zero-emission vehicle sales in the rental and governmental sectors follow CEC's Integrated Energy Policy Report (IEPR) 2020[92] projections, which are made based on economic growth and guidelines established by the current requirements for California state government's vehicle fleet. For long-term projections, ZEV market share is assumed to plateau in California starting 2030.

CEC has developed and has been updating the PVC and CVC models since 1983. These models are important components for policymaking in California, such as predicting demand for alternative fuel vehicles, forecasting future transportation energy consumption, and performing analysis under various scenarios. California specific data from the California Vehicle Survey[93] provide the foundation of the PVC and CVC models and are used to derive model coefficients. The survey represents households and businesses' geographic distribution across California and collects thousands of responses from residents and businesses, including hundreds of plug-in electric vehicle owners.

Based on CEC's 2017 Staff report,[94] PVC is a dynamic model that forecasts the mix of light-duty vehicles. The model starts forecasting using base year data on the mix of vehicles by fuel type, age, and vehicle class. Forecasts of vehicle mix are conducted year by year, with the vehicle mix in the next year based on the current year's vehicle mix. For each projected year, the models need the following inputs:

1. Vehicle attributes including price, fuel economy, range, the number of available makes and models
2. Demographic and economic information such as household population and income
3. Incentives from both the federal government and the California government (e.g., HOV lane access, federal tax credit)
4. Other variables such as fuel price

---

[92] CEC IEPR website: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report

[93] California Travel Survey: https://www.energy.ca.gov/data-reports/surveys/california-vehicle-survey

[94] CEC Staff report (2017): *https://efiling.energy.ca.gov/GetDocument.aspx?tn=223241&DocumentContentId=28845*

With these input projections, the PVC model predicts the changes in the number of households with zero, one, two, and three or more vehicles. These changes determine the number of households adding or dropping vehicles. Furthermore, the model estimates the probability of a household replacing previously owned vehicles. The model then calculates households' probability of purchasing and dropping vehicles of particular fuel types, classes, and model years. To do so, the model considers the competitiveness of the vehicle attributes and the degree to which certain vehicles appear attractive to the consumers. Finally, the model projects statewide vehicle stock and new sales for different fuel types, model years, and vehicle classes. Similarly, the CVC model can be used to estimate the new sales of business-owned vehicles. CEC calibrated their vehicle choice models to 2019 DMV data.

CARB conducted a sensitivity analysis of the PVC model to determine the input variables that are most important to output results. These variables include vehicle price, fuel economy, range, and CVRP rebate for BEV and PHEV. Staff further updated input data used for these variables using the latest available information.

Projected battery electric vehicles' (BEV) and plug-in hybrid electric vehicles (PHEV) 's attributes including fuel economy, price, and range are projected as described in the following steps:

- *Step 1* base-year (2019) vehicle attributes are calculated based on the best available data, listed below.
    1. EPA’s fueleconomy.gov[95] providing fuel economy, tank size, and range
    2. WARDS INTELLIGENCE[96] providing vehicle price
    3. IHS/POLK[97] providing the sales of different makes and models

Using the above data sources, sales-weighted average of vehicle attributes across all models for each vehicle class is calculated.

- *Step 2* Assumptions are developed as to how these attributes will change in the future using projections obtained from a white paper published by ICCT[98] and by consulting with CARB’s regulatory teams. Details are as follows.

---

[95] EPA fuel economy data download page: https://www.fueleconomy.gov/feg/download.shtml
[96] WARDS INTELLIGENCE website: https://wardsintelligence.informa.com/datacenter
[97] https://ihsmarkit.com/btp/polk.html
[98] The International Council on Clean Transportation (ICCT) (2019). Update on electric vehicle costs in the United States through 2030. Available at: https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

Fuel economy. The fuel economy of BEV is assumed to grow by 0.7% every year, according to the ICCT report. For PHEV, the fuel economy of electric motors are assumed to grow 0.7% every year; the fuel economy of gas engines follows the 2020 SAFE Vehicle rules, hence, increasing 1.5% per year from 2021 to 2026 and flattening in 2026. Then the composite fuel economy of PHEV is calculated using the weighted average of fuel economy of electric motor and gas engine, based on utility factor, which is a function of e-range defined in SAE paper.[99]

Range. The range of BEV is assumed to reach 300 miles, and the e-range of PHEV is assumed to reach 60 miles in 2030, according to the ICCT report. The ranges for years between 2019 and 2030 are interpolated. The gasoline range of PHEV is calculated based on the projection of the gasoline engines' fuel economy, assuming gasoline tank size will stay the same over the years.

Vehicle price. Vehicle price is calculated as the sum of the base-year non-battery price, the change in non-battery cost, and the future battery cost. Battery cost is calculated by multiplying battery cost per kWh and battery size (kWh). The battery size is estimated based on the range and the fuel economy. The battery cost per kWh is projected to decrease 7% per year, according to the ICCT White Paper. Non-battery cost is assumed to change following the trend of indirect costs (i.e., depreciation, amortization, research and development, administration, and warranty) projected by ICCT: a downward trend for BEV and a slight upward trend for PHEV.

For vehicle classes that do not have available PHEV and BEV models in the base year and fuel cell electric vehicle (FCEV), CEC's IEPR2020 projections are used for their vehicle attributes.[100]

CVRP Rebate. Staff also updated the projection of California’s Clean Vehicle Rebate Program (CVRP) rebate and HOV lane policy from CEC’s IEPR2019 projection. Staff’s projections were adopted by CEC when IEPR2019 was updated to IEPR2020 projections. California’s CVRP program promotes clean vehicle adoption by giving rebates for purchasing new ZEV. The amount of CVRP rebate vary by income levels: high-income individuals are not eligible for the rebate of BEV and PHEV, while low-income individuals receive additional rebate. To project CVRP rebate averaged for all Californians of different income levels, the following data sources are used: CVRP dashboard[101] provides the number of applications and the amount of rebate given to each application. BEV and

---

[99] SAE International (2009). Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data J2841_201009. Available at: https://www.sae.org/standards/content/j2841_201009/

[100] CEC IEPR website: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report

[101] CVRP dashboard: https://cleanvehiclerebate.org/eng/rebate-statistics

PHEV new sales are obtained from the California New Car Dealers Association (CNCDA)'s website[102].

Using these two data sources, the percentage of BEV and PHEV purchasers who did not apply for the CVRP rebate is estimated as the total number of applications divided by total ZEV sales in 2019. All FCEVs are assumed to be funded by CVRP because there is no restriction on income. It is assumed that the individuals who did not apply for CVRP rebates (due to high income or other reasons) get zero CVRP rebates. Among the other individuals, the percentage of CVRP rebates given to low-income individuals is calculated based on the CVRP dashboard database. These individuals receive higher CVRP rebate. Lastly, the weighted average CVRP rebate for all individuals in California are calculated. The resulting CVRP rebate projection for BEV, PHEV, and FCEV are $1023, $481, and $4823 from 2020 to 2025, respectively; CVRP rebate is assumed to end in 2025, following suggestions from CARB's CVRP team.

HOV lane policy Following the California Vehicle Code (CVC) §§5205.5 and 21655.9[103], HOV lane access to ZEVs is projected to end in 2025.

CEC models output sales by CEC vehicle classes, so the data are post-processed to the input information that EMFAC can utilize. Accordingly, CEC's 18 vehicle classes (e.g., Car-Compact and Cross/Ut-midsize) are mapped to EMFAC vehicle classes (i.e., LDA, LDT1, LDT2, and MDV), utilizing 2019 DMV registration data as well as EMFAC and CEC's classification guides. Appendix 6.8 summarizes the results of the mapping.

CEC models output sales for all fuel types, including BEV, PHEV, and FCEV. The sum of BEV and FCEV in total LDV new sales is inputted as the market share of "electric" fuel type to EMFAC. The fraction of PHEV in new sales of CEC output is inputted as the market share of "PHEV" fuel type to EMFAC. EMFAC2021 uses the ZEV market shares for different EMFAC light-duty vehicle classes and new vehicle sales forecasting to calculate ZEV new sales.

The market shares of different EMFAC light-duty vehicle classes are summarized in Table 4.5.3-1 for electric vehicles and Table 4.5.3-2 for PHEV. Figure 4.5.3-1 and Figure 4.5.3-2 show the electric and PHEV market shares in total LDV sales (LDA, LDT1, LDT2, and MDV) in EMFAC2021, respectively. EMFAC2021 projects that BEV and PHEV market share in new sales to reach 9% and 3%, respectively. The comparison of light-duty ZEV market share of EMFAC2021 and EMFAC2017 are shown in Figure 4.5.3-3. EMFAC2021 projects ZEV market share in LDV new sales in 2030 to be 12%, which is significantly higher than that in EMFAC2017 (~6%). Both EMFAC2017 and EMFAC2021 project higher ZEV market share in 2030 than the base year. Note that the decrease in ZEV

---

[102] CNCDA California Auto Outlook: https://www.cncda.org/news/auto-outlook-2019-q4/

[103] https://codes.findlaw.com/ca/vehicle-code/veh-sect-21655-9.html

market share from 2025 to 2026 in the EMFAC2021 projection can be attributed to the projected end of the HOV lane policy and CVRP rebate in 2025.

Figure 4.5.3-1. The Market Share of Electric Vehicles (BEV+FCEV) in New Sales

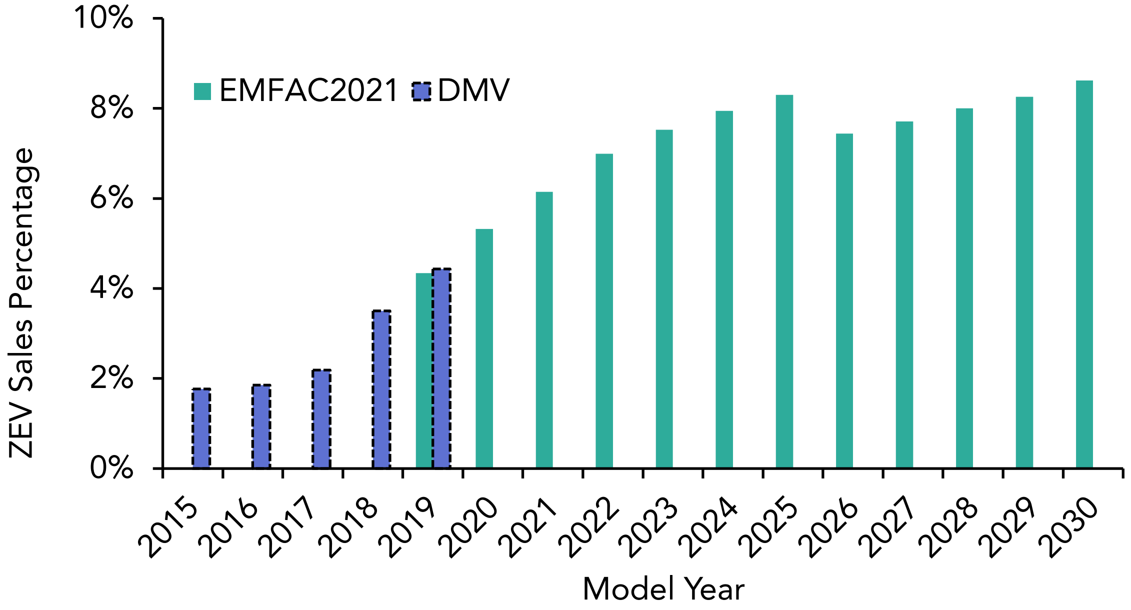


Figure 4.5.3-2. The Market Share of PHEV in New Sales

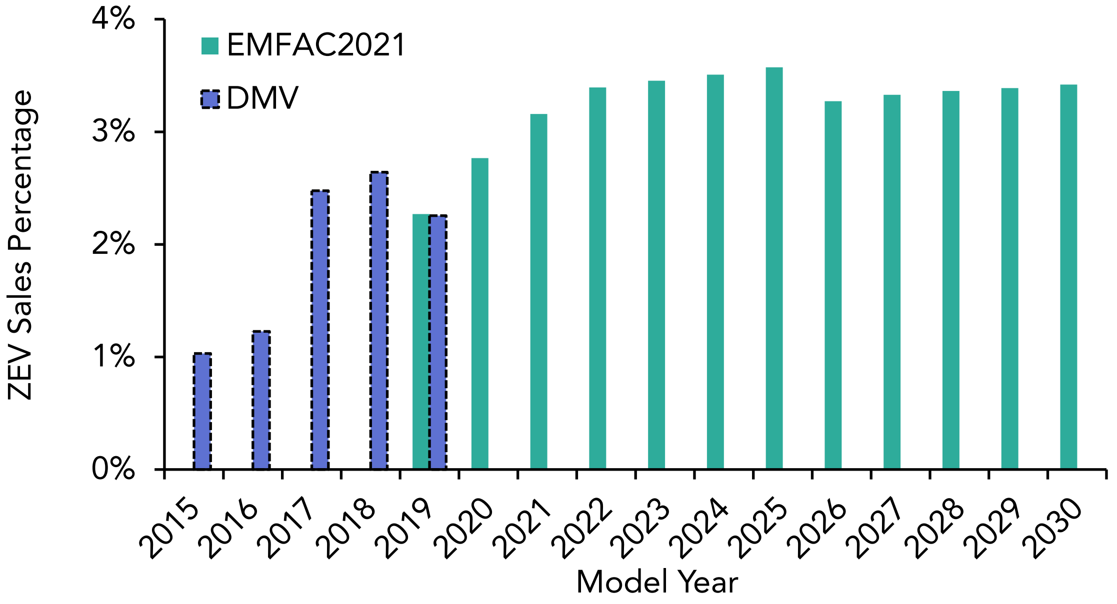


Figure 4.5.3-3. The Market Share of ZEV in New Sales

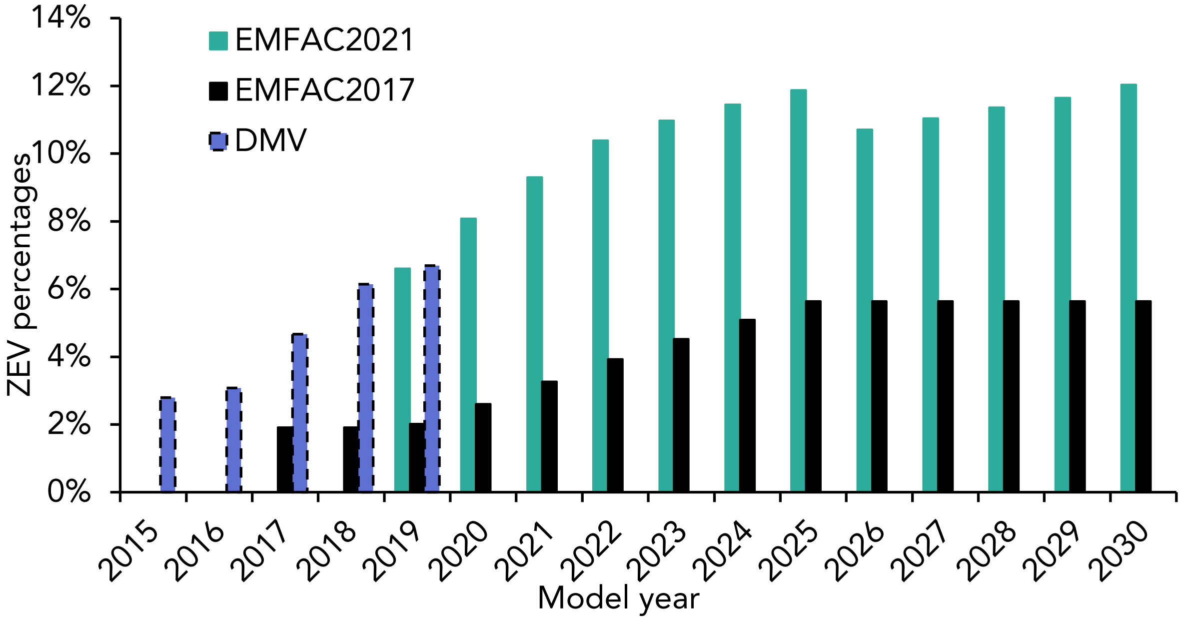


Table 4.5.3-1. The Market Share of Electric Vehicles in New LDV Sales

MY	LDA	LDT1	LDT2	MDV
2020	9.4%	0.1%	0.2%	1.0%
2021	10.2%	0.2%	1.2%	1.9%
2022	10.9%	0.6%	2.0%	3.5%
2023	11.4%	0.9%	2.3%	4.6%
2024	11.9%	1.2%	2.6%	4.9%
2025	12.3%	1.5%	2.9%	5.3%
2026	10.8%	1.8%	2.8%	5.0%
2027	11.0%	2.1%	3.1%	5.3%
2028	11.3%	2.5%	3.4%	5.6%
2029	11.6%	2.9%	3.7%	5.9%
2030+	11.9%	3.3%	4.0%	6.2%

Table 4.5.3-2. The Market Share of PHEV in New LDV Sales

MY	LDA	LDT1	LDT2	MDV
2020	4.2%	0.2%	1.3%	0.9%
2021	4.5%	0.4%	2.0%	1.0%
2022	4.7%	0.7%	2.1%	1.7%
2023	4.7%	0.9%	2.3%	1.8%
2024	4.6%	1.2%	2.2%	2.5%
2025	4.6%	1.4%	2.3%	2.7%
2026	4.1%	1.5%	2.2%	2.5%
2027	4.1%	1.8%	2.3%	2.6%
2028	4.1%	2.0%	2.4%	2.7%
2029	4.0%	2.2%	2.6%	2.8%
2030+	4.0%	2.5%	2.7%	2.9%

HDV ZEV sales

For the first time EMFAC2021 now includes heavy-duty zero-emission truck and bus population projections. The phase-in of heavy-duty ZEVs is driven by CARB’s recently adopted regulations, including Innovative Clean Transit (ICT), Zero-Emission Airport Shuttle Bus, and Advanced Clean Truck (ACT). Zero-emission transit bus forecasting based on ICT is provided in Section 4.2.3. Zero-emission airport shuttle bus was not explicitly accounted for in EMFAC2021 since this category represents a very small fraction of the fleet.

The ACT regulation approved on June 25, 2020[104] is a measure to improve air quality and to mitigate climate change by transforming the California heavy-duty vehicle fleet to zero-emissions technologies. The ACT regulation will achieve its electrification goal by gradually increasing the fraction of zero-emission vehicles (ZEVs) sold in California starting with model year (MY) 2024 vehicles. The rule applies different sales requirement fractions to Class 2b-3 (8,501- 14,000 lbs. GVWR), Class 4-8 (>14,000 lbs. GVWR) Vocational and Class 7-8 (>26,000 lbs. GVWR) Tractors. The Class 2b-3 vehicle inventory is comprised of two EMFAC vehicle categories: LHDT1 (light heavy-duty trucks with GVWR 8,501-10,000 lbs.) and LHDT2 (light heavy-duty trucks with GVWR 10.001-14,000 lbs.). The class 4-8 vocational vehicles included instate buses, instate non-tractor class 7 and 8 heavy trucks (>26,000 lbs.), and instate class 4 – 6 trucks (14,001-26,000 lbs.). The bus inventory was adjusted to account for light duty vehicles that are included in this EMFAC vehicle category and to exclude transit and shuttle buses, which already have to meet the ICT[105] or Zero-Emission Airport Shuttle Bus [106] regulations. Instate vehicles include vehicles that are registered by International Registration Plan (IRP) as well as California Department of Motor Vehicles (DMV). The detailed assumptions and methods of emission benefit analysis for the ACT regulation shown in the Appendix F of its ISOR.[107,108]

The ACT requirements only apply to vehicles that are originally sold in California (hereinafter, we refer to them as *First Sold in CA*). To estimate the portion of new vehicle sales specific to California, staff reviewed the *First Sold* data field values in the California DMV vehicle registration data from 2014 through 2017. The *First Sold* data field identifies the year for vehicles that were first sold in California. The International Registration Program (IRP) vehicles are not required to have this field populated in the DMV data sets and they were excluded from this analysis. The average percentages of vehicles first sold in California from DMV data from 2014-2017 were used to develop trends to estimate future new sales by vehicle type. The estimated first sold percentages (as shown in Table 4.5.3-3) were then applied to the total new sales forecasted by EMFAC2021. For instate buses and vehicles below 14,001 lbs., it was assumed that the rate of first sold in California is 100%.

---

[104] https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks

[105] California Air Resources Board, Innovative Clean Transit (web link: https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit, Last accessed June, 2019)

[106] California Air Resources Board, Zero-Emission Airport Shuttle (web link: https://ww2.arb.ca.gov/our-work/programs/zero-emission-airport-shuttle, Last accessed June, 2019)

[107] California Air Resources Board, Appendix F: Emissions Inventory Methods and Results for the Proposed Advanced Clean Trucks (web link: Regulation https://ww3.arb.ca.gov/regact/2019/act2019/appf.pdf, posted October, 2019)

[108] California Air Resources Board, Attachment D Emissions Inventory Methods and Results for the Proposed Advanced Clean Trucks Regulation Proposed Modifications (web link: https://ww3.arb.ca.gov/regact/2019/act2019/30dayattd.pdf, May, 2020)

Table 4.5.3-3. Average Percentages for First Sold in California by Vehicle Type

Age	Class 8 Tractor	Class 8 Vocational	Class 7 Tractor	Class 7 Vocational	Class 4-6 Vocational
-1 or 0	89.00%	89.78%	84.31%	85.01%	90.97%
1	86.61%	85.80%	82.10%	80.35%	88.38%
2	79.17%	81.86%	76.91%	76.22%	85.68%
3	68.61%	78.34%	69.92%	72.74%	83.07%
4	56.87%	75.59%	62.30%	70.02%	80.74%
5	45.87%	74.00%	55.25%	68.18%	78.90%
6	37.55%	73.92%	49.92%	67.35%	77.76%
7	33.85%	73.92%	47.51%	67.35%	77.50%
8	33.85%	73.92%	47.51%	67.35%	77.50%
9+	33.85%	73.92%	47.51%	67.35%	77.50%

In EMFAC2021, different heavy-duty vehicle categories are mapped to tractor and vocational groups, as shown in Table 4.5.3-4. As already noted, the ACT regulation requires an increasing percentage of new vehicle sales in California to be ZEVs beginning with model year 2024.

Table 4.5.3-5 provides a summary of the ZEV sales requirements for new vehicle sales in California.

Table 4.5.3-4. Heavy Duty Vehicle Classes Mapped to ACT First Sold Classes

First Sold Class	EMFAC2021 HD Category
Class 2b-3	LHD1; LHD2
Class 4 -6 Vocational	T6TS; T6 Public Class 4; T6 Public Class 5; T6 Public Class 6; T6 Utility Class 5; T6 Utility Class 6; T6 Utility Class 7; T6 Instate Tractor Class 6;T6 Instate Delivery Class 4; T6 Instate Delivery Class 5; T6 Instate Delivery Class 6; T6 Instate Other Class 4; T6 Instate Other Class 5; T6 Instate Other Class 6; T6 CAIRP Class 4; T6 CAIRP Class 5; T6 CAIRP Class 6
Class 7 Vocational	T6 Public Class 7; T6 Instate Delivery Class 7; T6 Instate Other Class 7
Class 7 Tractor	T6 Instate Tractor Class 7; T6 CAIRP Class 7
Class 8 Vocational	T7 Public Class 8; PTO; T7 Single Concrete/Transit Mix Class 8; T7 Single Dump Class 8; T7 Single Other Class 8; T7 SWCV Class 8
Class 8 Tractor	T7 CAIRP Class 8; T7 Other Port Class 8; T7 POAK Class 8; T7 POLA Class 8; T7 Tractor Class 8
SBUS	SBUS
OBUS	OBUS

Table 4.5.3-5. ZEV Sales Requirements Under the ACT Regulation

Model Year	Class 2b-3	Class 4-8* Vocational	Class 7-8 Tractors
2024	5%	9%	5%
2025	7%	11%	7%
2026	10%	13%	10%
2027	15%	20%	15%
2028	20%	30%	20%
2029	25%	40%	25%
2030	30%	50%	30%
2031	35%	55%	35%
2032	40%	60%	40%
2033	45%	65%	40%
2034	50%	70%	40%
2035+	55%	75%	40%

*Excludes Class 7-8 Tractors

4.6 Regulations and Policies

4.6.1 SAFE Rule

In September 2019, the U.S. Environmental Protection Agency (U.S. EPA) and the National Highway Traffic Safety Administration (NHTSA) issued the Safer Affordable Fuel-Efficient or SAFE Vehicles Rule Part One: One National Program (SAFE Part One) that revoked California’s authority to set its own greenhouse gas emissions standards and zero-emission vehicle (ZEV) mandates in California, 84 Fed. Reg. 51,310 (Sept. 27, 2019). In April 2020, the federal agencies issued the SAFE Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks (Final SAFE Rule) that relaxed federal greenhouse gas emissions and fuel economy standards, 85 Fed. Reg. 24,174 (Apr. 30, 2020). The Final SAFE Rule then relaxed federal greenhouse gas emissions and Corporate Average Fuel Economy (CAFE) standards to increase in stringency at only about 1.5% per year from model year (MY) 2020 levels over MYs 2021–2026. In 2020, CARB finalized with six participating automakers to reach a Framework Agreements on Clean Cars to meet a more stringent CO2 reduction targets than the SAFE Rule. Automakers who voluntarily agreed to the framework agreements are BMW of North America (including Rolls Royce for purposes of the agreement), Ford, Honda, Volkswagen Group of America (including VW and Audi), and Volvo. The six manufacturer Framework Agreements on Clean Cars will collectively represent a 3.7% YoY reduction in CO2 emissions from MY 2022 to 2026. In addition, these manufacturers are allowed to meet up to 1.0% of those reductions using ZEV credits. To comply with this rule, the assumption in EMFAC2021 for CO2 emission factor were updated for gasoline passenger cars and light trucks. This is further described in section 4.3.3.

4.6.2 Innovative Clean Transit

The Innovative Clean Transit (ICT) regulation was adopted by CARB in 2019 and targets reductions in transit fleets by requiring transit agencies to gradually transition their buses to zero-emission technologies. ICT has helped to advance heavy-duty ZEV deployment, with buses acting as a beachhead in the heavy-duty sector. Based on the size of the transit agencies, they are categorized as small and large agencies. Starting calendar year 2023, large agencies follow the phase-in schedule to have a certain percentage of their new purchases as ZEB. For the small agencies, the start calendar year will be 2025. By 2030, all the agencies need to have 100% of their new purchases as ZEB[109]. More details can be found in section 4.2.3.

4.6.3 Zero-Emission Airport Shuttle Bus

CARB adopted the zero-emission airport shuttle bus regulation in 2019 and required airport shuttle fleets to fully transition to zero emission by 2035. This regulation is not explicitly accounted for in EMFAC2021 since this category represents a very small fraction of California fleet (<2,000 vehicles).

4.6.4 HD Omnibus

CARB adopted the Heavy-Duty Omnibus regulation in August 2020, which applies to engine-certified vehicles with GVWR > 10,000 lbs. that are first sold or certified in California (see Section 4.5.3). Note that the majority (> 95%) of vehicles with GVWR 10,001-14,000 lbs. are chassis-certified and thus are excluded from HD Omnibus standards in EMFAC 2021. This program represents a comprehensive update to heavy-duty NOx emissions standards and ensures that heavy-duty engines will emit much lower NOx emissions throughout their lifetimes. This regulation includes

- A tightened standard on the Federal Test Procedure (FTP),
- A new low-load certification cycle (LLC),
- Improvements to the existing heavy-duty in-use testing (HDIUT) program,
- Improvements to the durability demonstration program (DDP),
- Lengthened warranty and useful life (UL) mileages, and
- Amendments to the emission warranty information reporting (EWIR) program and corrective action procedures.

More details on each program element listed above, as well as emissions benefits methodology can be found in Appendix D of the HD Omnibus ISOR.[110] The full requirements of the HD Omnibus program are shown in Table 4.6.4-1.

---

[109] https://ww3.arb.ca.gov/regact/2018/ict2018/isor.pdf

[110] https://ww3.arb.ca.gov/regact/2020/hdomnibuslownox/appd.pdf

Table 4.6.4-1. HD Omnibus Requirements by Engine Model Year Groups

Standards, Test Procedures and Elements	Units	Engine MY2024-26	Engine MY2027-30	Engine MY2031 & Newer
FTP	g/bhp-hr	0.05	0.02	0.02
LLC	g/bhp-hr	0.2	0.04	0.04
Idling	g/hr	10	5	5
HDIUT Method	g/bhp-hr	Binned MAW 1.5x Standards	Binned MAW w/ Cold Start 1.5x Standards	Binned MAW w/ Cold Start 1.5x Standards
DDP	NA	100% UL aging	100% UL aging	100% UL aging
UL[3]	10^3×miles	435/185/110/110*	600/270/190/155*	800/350/270/200*
Warranty	See Section 4.6.5	See Section 4.6.5	See Section 4.6.5	See Section 4.6.5
EWIR*	--	Modified EWIR	Modified EWIR	Modified EWIR

Note: DDP= Durability Demonstration Program, EWIR= Emission Warranty Information Reporting and corrective actions, FTP= Federal Test Procedure, HDIUT= Heavy-Duty In-Use Testing, LLC= Low Load Cycle, MAW= Moving Average Window, MY=Model Year, NTE= Not-to-Exceed, UL= Useful Life

Units: g/bhp-hr= Grams Per Brake Horsepower-Hour, g/hr= Grams Per Hour.

* Diesel Class 8; GVWR >33,000 lbs. / Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /Diesel Class 4-5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / HD Otto (gasoline).

Staff modelled reductions in the zero-mile emission rate (ZMR) as part of the HD Omnibus emissions inventory analysis. These reductions reflect the tightened Federal Test Procedure (FTP) standard, which is 75% (engine model year 2024-2026) to 90% (engine model year 2027 and newer) lower than the 0.2 g/bhp-hr baseline standard. They also reflect improvements to heavy-duty in-use testing program to ensure that real-world emission rates are closer to the standard. Staff developed scaling factors for HD Omnibus ZMRs that were derived from the rulemaking analysis, specifically 0.44 g/mile for engine model year 2024-26 and 0.12 g/mile for 2027 and newer, divided by the new baseline ZMR of 0.6 g/mile (derived in Section 4.3.6). The same scaling factors were used at all speeds. Tightening the FTP standard results in emissions reductions across the full range of speeds. In the rulemaking analysis, tightening the LLC to less than 2X the FTP standard resulted in additional benefits relative to just an FTP standard. However, since the LLC standards in Table 4.6.4-1.

are at least 2X the FTP, no additional benefits for LLC were modelled and speed correction factors (SCFs) were assumed to be the same as 0.2 g/bhp-hr engines. However, in reality, an LLC standard will ensure that FTP standard results in significant reductions at lower speeds.

Idle emissions for HD vehicles are also adjusted in EMFAC2021 using the ratio of the new standards and the baseline standard of 30 g/hr for engine model year groups 2024-26 and 2027 and newer HD deterioration rates (DR) are adjusted to account for HD Omnibus warranty and durability requirements. More details can be found in Section 4.6. Please note that the HD Omnibus regulation only applies to vehicles that are first sold or certified in California. However, a portion of the California-certified pool of MY 2024 and newer heavy-duty vehicles are assumed to be converted to ZEVs as required by Advanced Clean Trucks (see Section 4.6.2.5). Therefore, the first sold fractions were adjusted, such that HD Omnibus only applied to combustion vehicles remaining after ACT.

4.6.5 Warranty

The Heavy-Duty Engine Warranty Amendments were adopted in 2018. This regulation is designed to reduce emissions of nitrogen oxides (NOx) and particulate matter (PM) from heavy-duty vehicles by requiring manufacturers to lengthen the warranty mileages of heavy-duty vehicles that are first sold or certified in California. In addition, the Heavy-Duty Omnibus regulation (see Section 4.6.2.5) further lengthened warranty mileages in two steps: for engine model years 2027-2030 and lengthened further for 2031 and newer.

Lengthened warranty requirements in 2018 HD Warranty Amendments and 2020 HD Omnibus are expected to decrease the PM and NOx deterioration rates of heavy-duty vehicles by decreasing the frequency of malfunction of after-treatment system and engine components. To model the impact of lengthened warranty on deterioration rates, the emission impact rate (EIR) at the lengthened warranty mileage was assumed to be the same as the previous warranty mileage. Figure 4.6.5-1 shows an example of NOx emission rates with a lengthened warranty in black and the baseline warranty in blue. The red squares mark the original warranty mileage for the baseline case and the new warranty mileage for the lengthened warranty case. The emission rate for the lengthened warranty case at 400,000 miles is the same as that for the baseline case at 200,000 miles because the assumed EIRs are equivalent. For example, to adjust the NOx deterioration rate of OBD-equipped, the following equation was used

$$EIR_{@\ odometer\ mileage} \times \frac{Baseline\ Warranty\ Mileage^{b}}{Lengthened\ Warranty\ Mileage^{b}} \qquad \text{(Eq. 4.6.5-1)}$$

where ZMR is the zero mile rate, EIR is the emission impact rate at a given odometer mileage, and b is the fitted power function coefficient (see Section 4.3.6). Warranty mileages used in EMFAC2021 are shown in Table 4.6.5-1.

Figure 4.6.5-1. The Impact of Lengthened Warranty on HD NOx Emission Rates

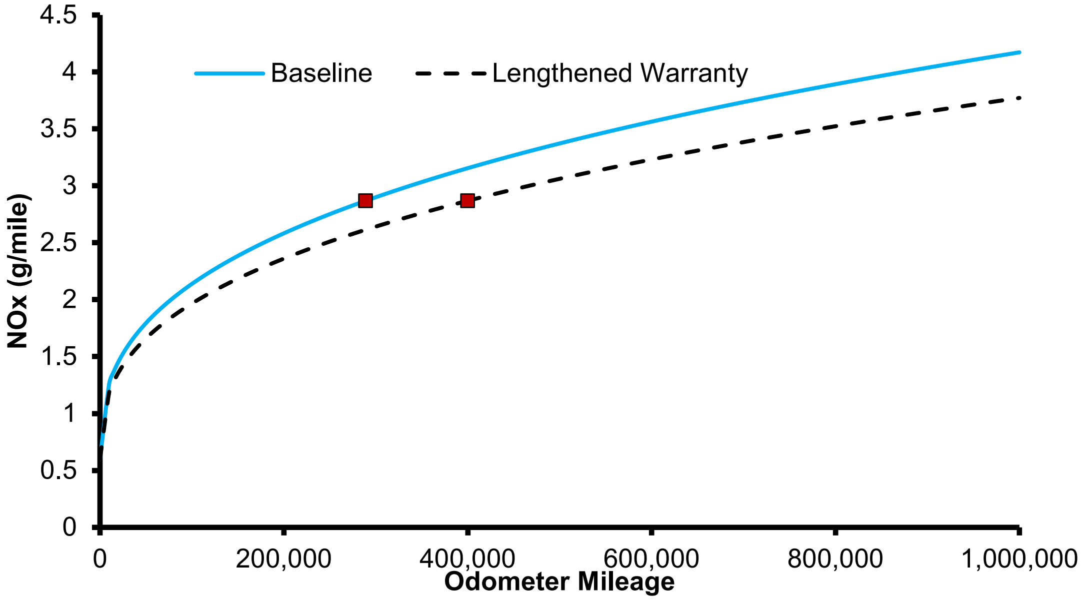


Table 4.6.5-1. Baseline and Warranty Mileages Adjusted for Year Limits

Regulation/Engine Model Year	LHDD*	MHDD*	HHDD*
Baseline	100,000	100,000	100,000
June 2018 Step 1 Warranty 2022-2026	103,000	139,000	289,000
HD Omnibus 2027-2030	135,000	172,000	308,000
HD Omnibus 2031 and Newer	189,000	221,000	400,000

* HHDD: Diesel Class 8; GVWR >33,000 lbs. / MHDD: Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /LHDD: Diesel Class 4-5.

Although the current emission warranty requirements for classes 4 to 8 trucks is 100,000 miles, a recent CARB sponsored survey indicates that 40% of these trucks carry extended warranties to their respective useful lives (110,000 miles for classes 4 & 5, 185,000 miles for classes 5 & 6, and 435,000 miles for class 8).[111] In addition, according to data and information from manufacturers as well as other sources, ~75% of the remaining 60% of class 8 trucks have an extended warranty of 250,000 miles. As such, the baseline mileages were adjusted for vehicle classes with warranties larger than the baseline. The warranty mileages shown in Table 4.6.5-1 represent average miles covered when considering the miles, years, and hours provisions within the proposed requirements. For example, using the 2022 Step 1 warranty requirements for HHD, manufacturers must cover emissions warranty to 350,000 miles or 5 years, whichever comes first. On average,

---

[111] https://ww3.arb.ca.gov/regact/2018/hdwarranty18/appf.pdf

HHD vehicles reach 289,000 miles before they reach 5 years of age, so the table shows "289,000 miles" for HHD.

4.6.6 Advanced Clean Trucks

CARB's Advanced Clean Trucks (ACT) regulation was adopted by the Board in June 2020. EMFAC2021 reflects ACT by modelling heavy-duty zero emission vehicles (ZEVs) based on the sales percentage requirements for each model year and those percentages were applied to vehicles first sold or certified in California. More details can be found in Section4.5.3. ZEVs produced by truck manufacturers to meet the ACT regulation can also be used to meet the Phase 2 GHG regulation. For heavy-duty vehicles first sold or certified in California, the Phase 2 reduction factors had to be adjusted to account for overlap with ACT. More details can be found in Section 4.3.5.5

4.6.7 Opacity

The Amendments to the Heavy-Duty Vehicle Inspection Program (HDVIP) and Periodic Smoke Inspection Program (PSIP) are designed to reduce emissions of particulate matter (PM) from diesel powered heavy-duty vehicles (HDV) powered by diesel engines. Emission reductions would primarily result from heavy-duty diesel (HDD) trucks, which include heavy heavy-duty diesel trucks (above 33,000 lbs. GVWR) and medium heavy-duty diesel trucks (14,001-33,000 lbs. GVWR).

The amendments to the HDVIP and PSIP regulation require diesel powered trucks and buses that are found to exceed i) the 20-40% opacity limit for non-DPF vehicles to repair their engines and ii) 5% opacity limit for DPF-equipped engines to either repair or replace their DPFs in order to reduce the opacity below the respective limits. The PM emissions benefits are the result of such repairs or replacement. EMFAC2021 assumed that repaired engines have equivalent PM emissions to a new vehicle, i.e., the emission rate would equal the zero-mile rate, ZMR.

These assumptions were incorporated into Appendix C of the Proposed Amendments of the Heavy-Duty Vehicle Inspection Program and Periodic Smoke Inspection Program Staff Report.[112] Briefly, repair effectiveness values were calculated for calendar years 2019 and 2025. This repair effectiveness was translated to reductions in TM&M frequency, i.e., the frequency of malfunction, which reduces the deterioration rate, DR. To implement these changes into the model, scalars were developed for calendar years 2019 through 2025 for different model year groups (e.g., engine model years 2007-2009). These scalars are shown in Table 4.6.7-1. Below is an example of how PM deterioration rates are applied in EMFAC 2021.

---

[112] https://ww2.arb.ca.gov/rulemaking/2018/heavy-duty-vehicle-inspection-program-and-periodic-smoke-inspection-program

$$\text{PM Emission Rate} = \text{ZMR} + \text{PM Deterioration Scalar} \times \text{DR} \times \frac{\text{Odometer}}{10{,}000} \qquad \text{(Eq. 4.6.7-1)}$$

Table 4.6.7-1 PM Deterioration Rate Scalars developed for EMFAC2021

Engine Model Year Range	**PM Deterioration Scalar by Calendar Year**						
	2019	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Pre1993	1	1	1	1	1	1	1
1993-02	0.92	0.88	0.87	0.87	0.86	0.86	0.85
2003-06	0.88	0.8	0.79	0.78	0.78	0.77	0.76
2007-09	0.82	0.71	0.7	0.69	0.67	0.66	0.65
2010-12	0.86	0.78	0.76	0.75	0.74	0.73	0.72
2013+	0.85	0.77	0.76	0.75	0.73	0.72	0.71

5 Overall Impacts

As described earlier in this document, EMFAC2021 retains some of the EMFAC2017 updates but also has some unique additions and new features. Some of the noteworthy updates to the EMFAC2021 include:

- Extended fuel technologies to PHEV and natural gas vehicles
- Estimation of energy consumption from BEV and PHEV vehicles as well as heavy-duty vehicles
- Development of an ammonia module for running exhaust emissions based on various historical and new studies
- Expansion of heavy-duty truck categories to include vocational categories for more emission characterization specificity
- Adaption of new light-duty ZEV market share and heavy-duty VMT forecasting frameworks

To examine the impact of these updates, this section presents charts of vehicle populations, VMT, emissions, fuel and energy consumptions. A comparison is made between emission and activity estimates from EMFAC2017 and those estimated using EMFAC2021, at the statewide level. In order to better explain the differences, separate comparisons are made for LD (GVWR below 8,500 lbs. and including motorcycles) and HD (GVWR above 8,500 lbs.) vehicles. The EMFAC2021 results presented in this section were generated using default VMT data. Please note that CARB's SIP inventory is based on VMT and speed profiles provided by Metropolitan Planning Organizations (MPOs), which might be different from EMFAC default VMT.

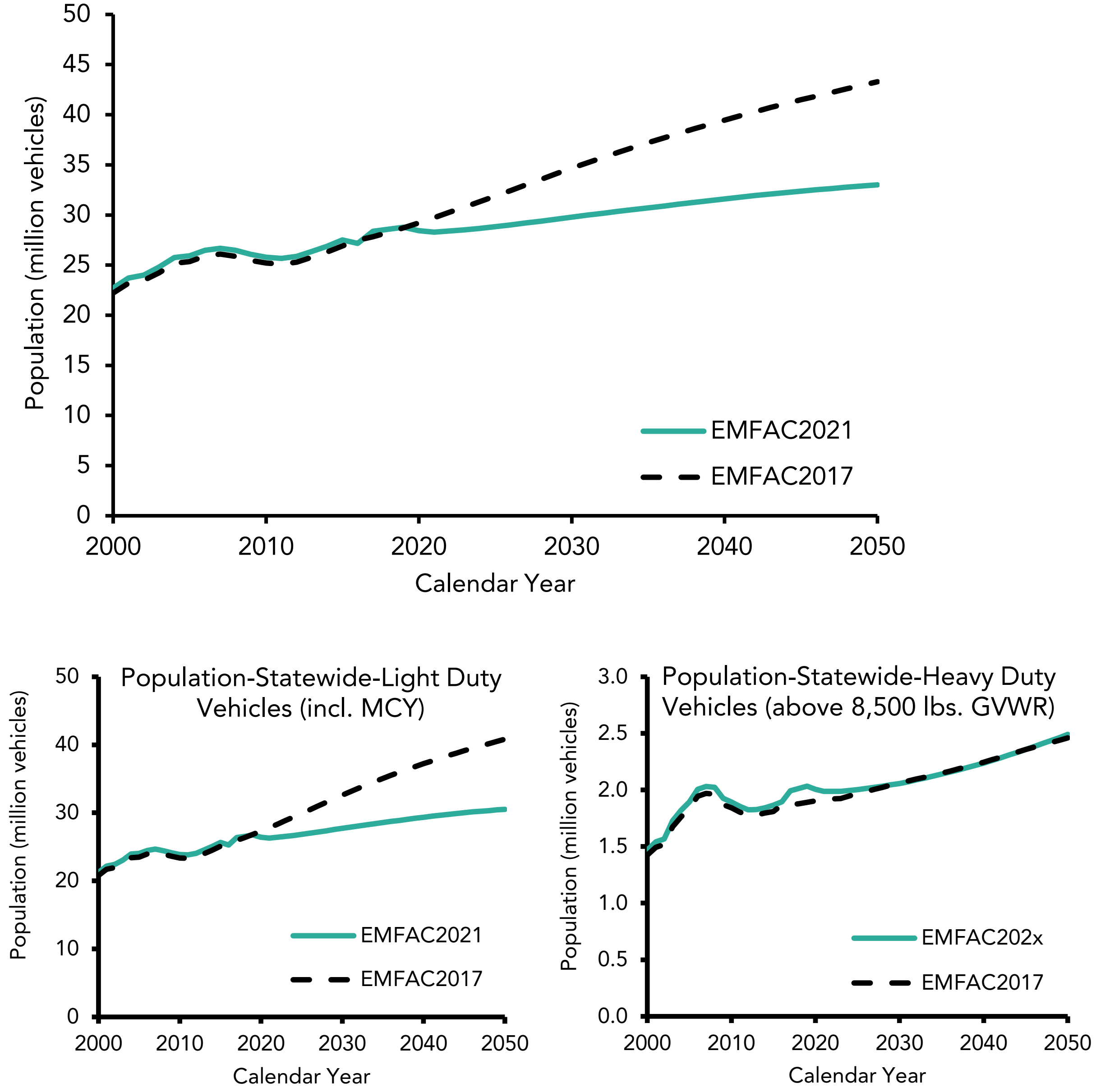
Similar comparisons have been performed for the South Coast and San Joaquin Valley sub areas; and, the explanations provided for the statewide results also apply to these regions. The charts for these regional comparisons are not presented in this section, but are provided in Appendix 6.3.

This section compares the statewide results of EMFAC2021 with EMFAC2017 for vehicle populations (in millions), VMT (in million miles per day), emissions (in tons per day), fuel consumption (million gallons), and energy consumption (giga watts-hour). Differences in the results between the two model versions are discussed below.

5.1 Vehicle Population

The panels of figure below compare EMFAC2021 and EMFAC2017 total HD and LD vehicle populations. The EMFAC2021 total vehicle population, which is dominated by LD vehicles, is about 10 million lower than in EMFAC2017 by the year of 2050. EMFAC2021 accounts for the COVID-19 related restrictions and incorporated a new LD new vehicle sales forecasting for future years. The statewide HD populations are slightly higher than EMFAC 2017 since staff accounted for light-heavy categories, i.e., LHD1 and LHD2 with registration addresses outside of California in EMFAC2021, as shown in Figure 5.1-1.

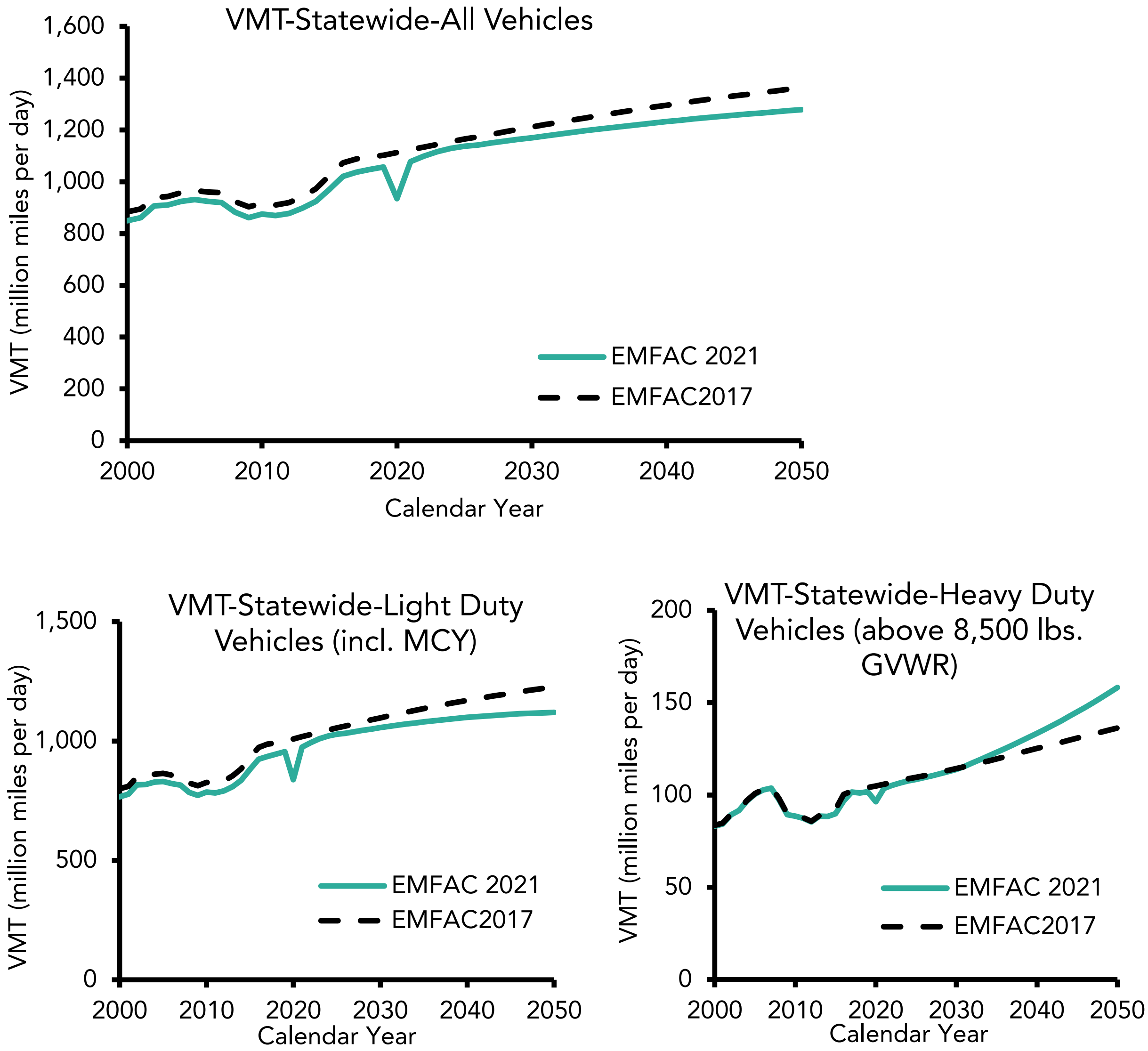
Figure 5.1-1. Comparison of Vehicle Population between EMFAC2021 and EMFAC2017



5.2 Vehicle Miles Traveled (VMT)

Figure 5.2-1 shows a comparison of statewide VMT from EMFAC2021 and EMFAC2017 in million miles per day. EMFAC2021 shows a lower VMT as compared to EMFAC2017 for all vehicles statewide. The lower LD VMT in historical years is because EMFAC2021 further subtracted off-road gas usage from the total fuel consumption. The COVID-19 pandemic also restricted LD VMT to some extent. For future years, EMFAC2021 reflected the adjusted human population forecast from DOF in its LD VMT estimates. HD VMT in EMFAC2021 is higher than EMFAC 2017 in the long-term because of higher assumed VMT growth rates from the Caltrans CSTDM model.

Figure 5.2-1. Comparison of VMT between EMFAC2021 and EMFAC2017

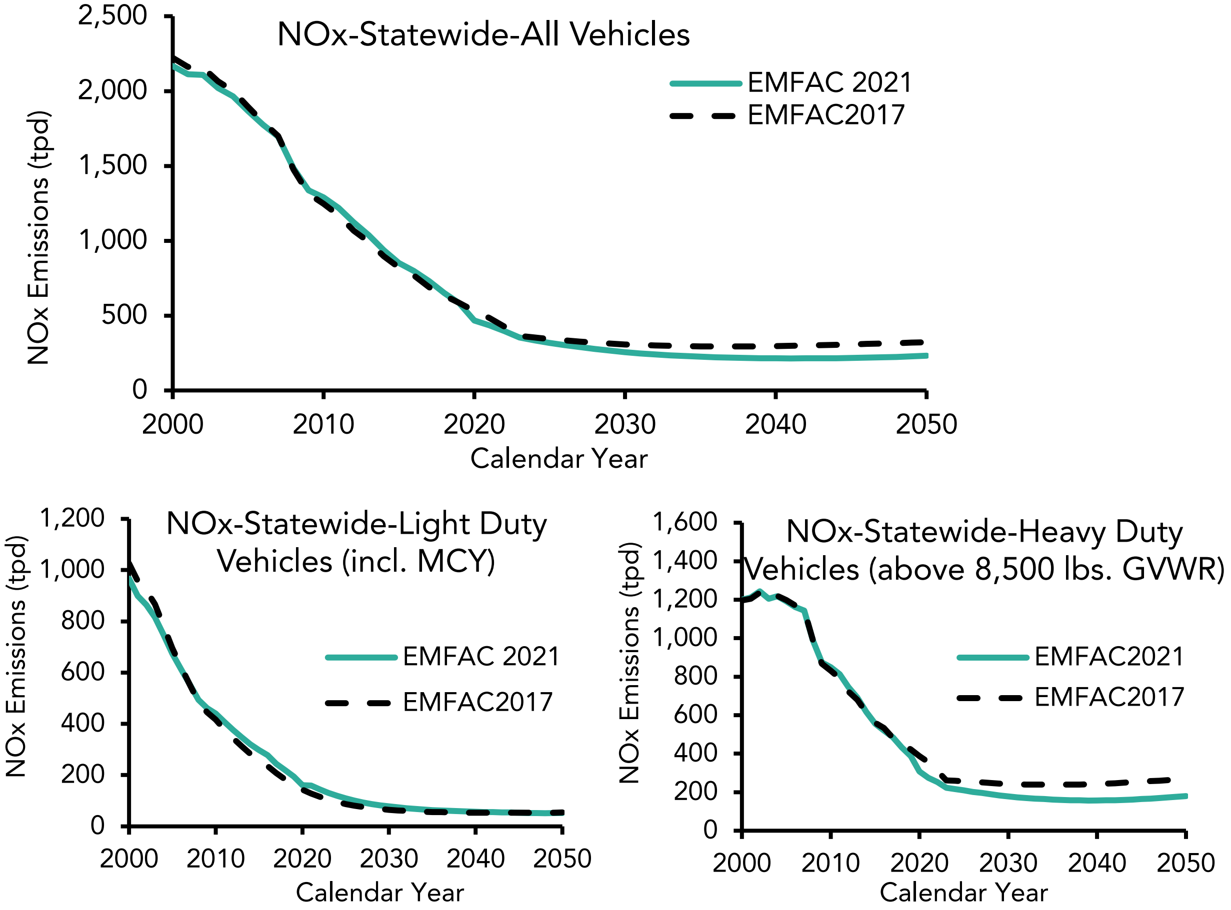


5.3 Emissions

Oxides of Nitrogen (NOx)

The following figure shows the comparison of estimates of statewide NOx emissions between EMFAC2021 and EMFAC2017, in tons per day. EMFAC2021 results shows slightly higher NOx emissions in historical years but lower emissions in future years. This is because of LD updated NOx emission rates for LEV 1, LEV 2, and LEV 3 vehicles, which resulted higher emission rates in historical years. On the other hand, higher compliance due to CARB's enforcement actions and SB 1 DMV registration holds was modelled in EMFAC2021 for HD, which resulted in lower NOx emissions between 2020 and 2023 compared to EMFAC2017. In the long-term, ACT, HD Warranty, and HD Omnibus resulted in lower NOx emissions in EMFAC 2021 relative to EMFAC 2017, but these reductions are somewhat offset by the higher VMT growth rate.

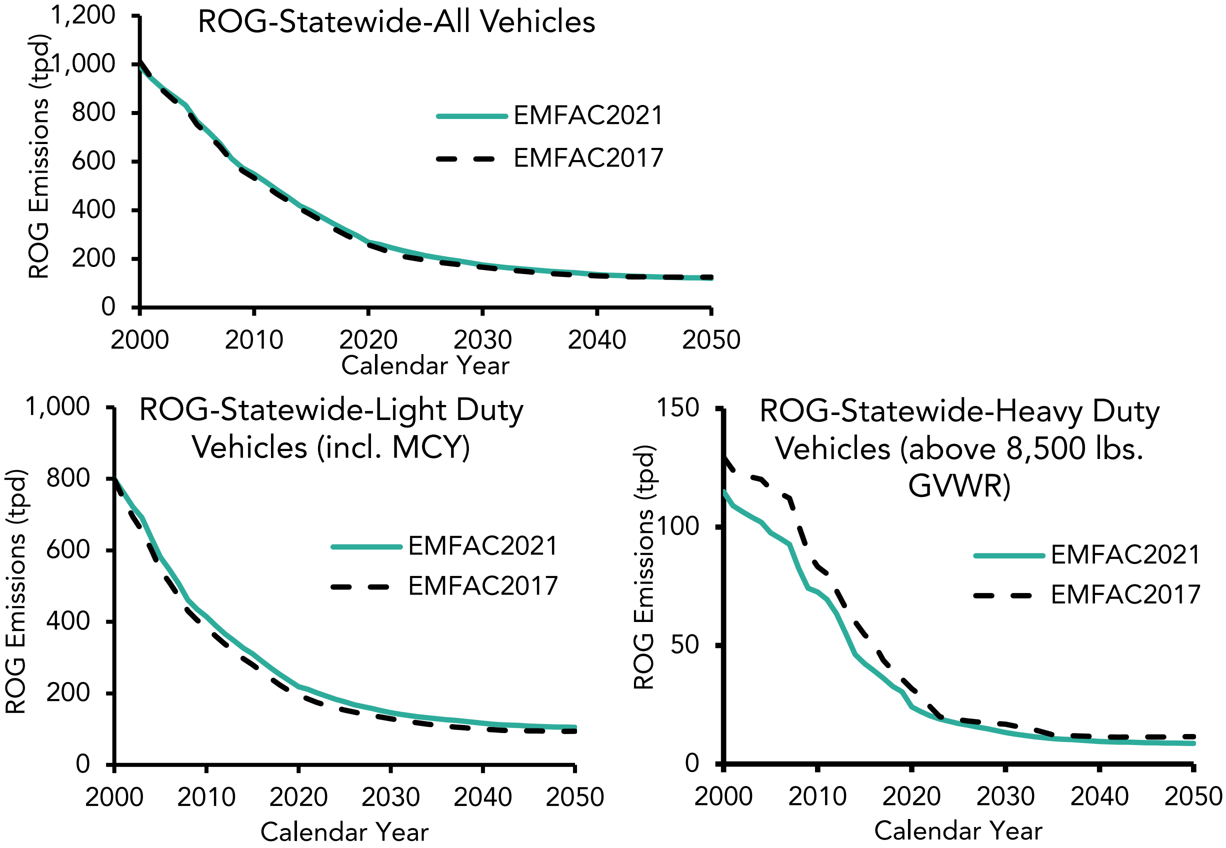
Figure 5.3-1. Comparison of NOx emissions between EMFAC2021 and EMFAC2017



Reactive Organic Gases (ROG)

The following figure shows a comparison of EMFAC2021 and EMFAC2017 estimates of statewide ROG emissions. ROG is dominated by LD vehicles. EMFAC2021 assumes higher emission rates for LEV 1, LEV 2, and LEV 3 LD vehicles, and higher LD evaporative emissions. HD ROG emissions decreased across all years for heavy-duty due to mileage accrual updates for certain EMFAC 2021 categories, notably the T7 Tractor Class 8 category.

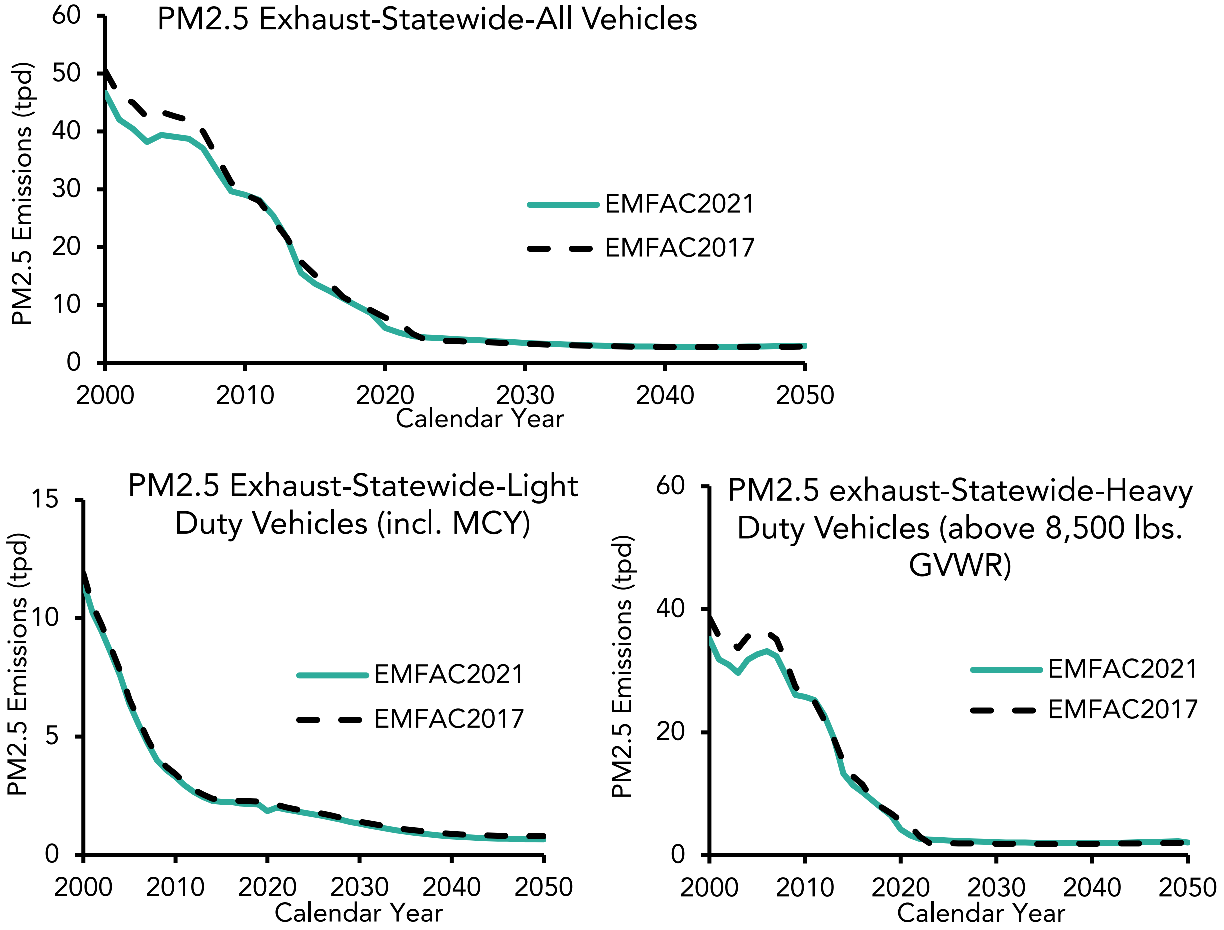
Figure 5.3-2. Comparison of ROG emissions between EMFAC2021 and EMFAC2017



Particulate Matter (PM2.5)

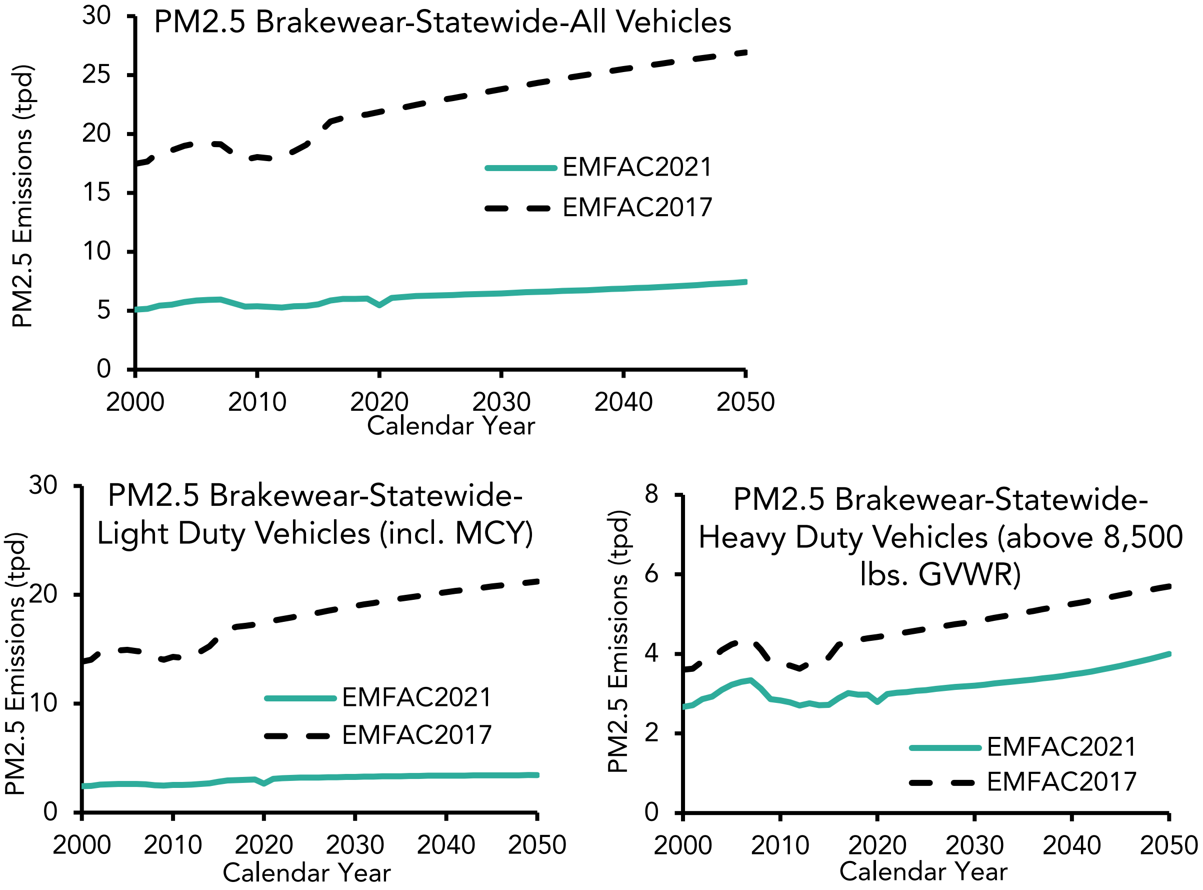
PM2.5 emissions include both tailpipe exhaust emissions and brake wear emissions. Figure 5.3-3 shows the comparison of estimates of statewide total tailpipe PM2.5 exhaust emissions between EMFAC2021 and EMFAC2017. There is not much difference in LD PM2.5 exhaust emissions, but EMFAC2021 HD PM2.5 exhaust emissions are lower in the historical years compared to EMFAC2017. Mileage accrual for certain EMFAC categories, like T7 Tractor Class 8, was lower than previously assumed in EMFAC2017 (see Section 4.4.2). This decrease in mileage accrual for these categories led to a decrease in emissions. In the longer-term, emissions are larger because of updated emission rates for model years 2014 and newer. In addition, the larger assumed VMT growth rates in EMFAC2021 also led to an increase in PM emissions over time, but these increases were somewhat offset by PSIP amendments, HD Warranty, ICT, and ACT regulations.

Figure 5.3-3. Comparison of tailpipe PM2.5 emissions between EMFAC2021 and EMFAC2017



The following figure shows a comparison of statewide PM2.5 brake wear emissions between EMFAC2021 and EMFAC2017. As described in in Section 4.3.7, both LD and HD PM brake wear emission rates were updated based on new data and resulted in substantially lower PM brake wear emissions in EMFAC2021. The smaller PM2.5/Total PM fraction of 35% in EMFAC2021 compared to 42% in EMFAC2017 also resulted in substantially lower PM2.5 emissions overall. In addition, zero emission heavy-duty vehicles required by ICT and ACT were assumed to have 50% lower brake wear emissions through regenerative braking.

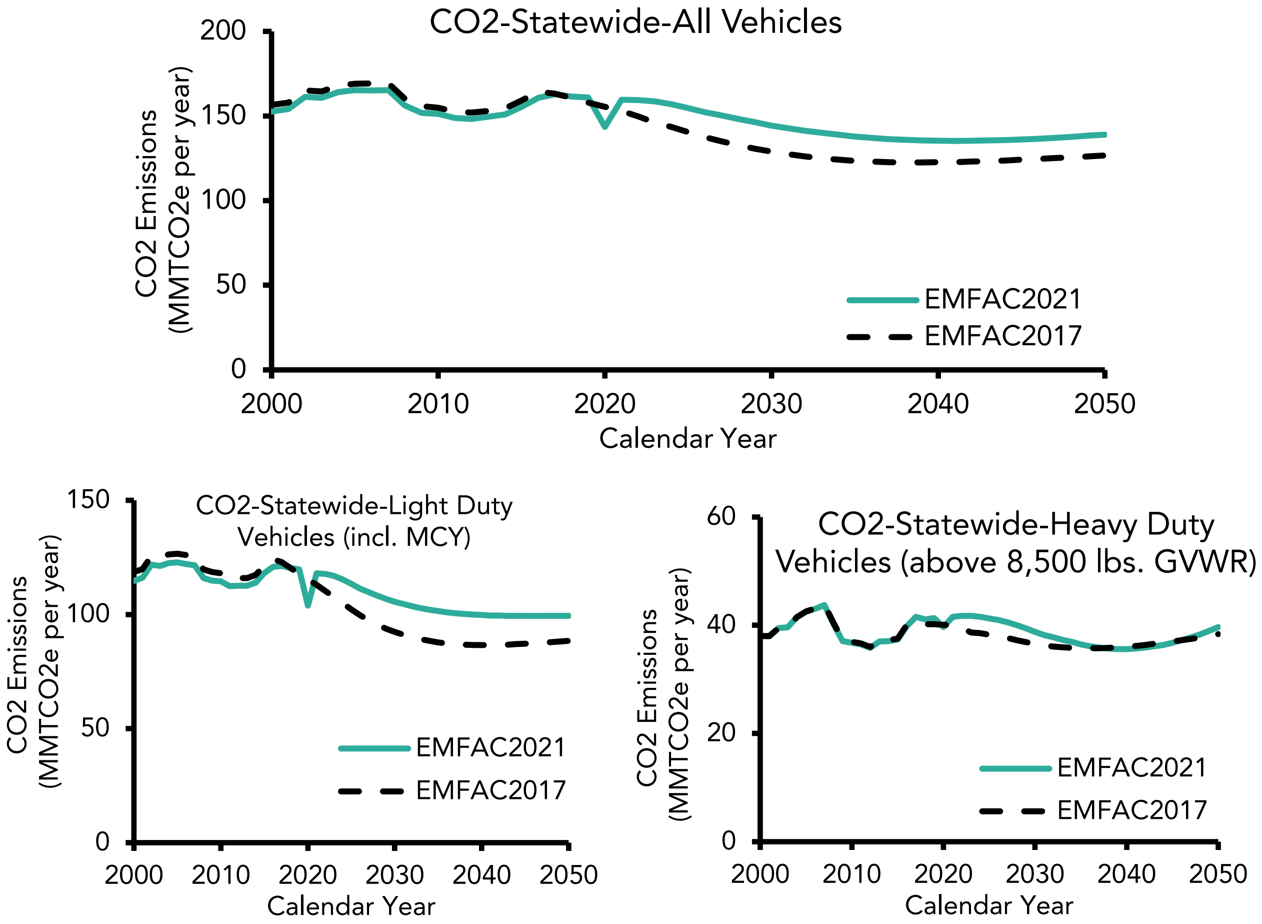
Figure 5.3-4. Comparison of PM2.5 brake wear emissions between EMFAC2021 and EMFAC2017



Carbon Dioxide (CO2)

Figure 5.3-5 shows a comparison of CO2 emissions between EMFAC2021 and EMFAC2017. The lower CO2 emissions in historical years is mainly due to the subtraction of taxable gasoline being used in the off-road section for LD. Higher LD CO2 emissions for future years attributes to the updated fuel economy analysis and the incorporation of the U.S. EPA's Final SAFE Rule in EMFAC2021. For HD, the emission rates in EMFAC2021 are calculated so that once they are corrected for Phase 1 GHG standards, they match the in-use emission data from TBSP. Compared to EMFAC2017, HD emission rates in EMFAC2021 are slightly higher for MY2014 and newer. In the long-term, emissions begin to increase due a higher VMT growth rate, but this increase is somewhat offset by the incorporation of the ACT regulation. As described earlier, staff accounted for the potential overlap between the ACT and Phase 2 regulations when determining the fleet average CO2 emissions for heavy duty vehicles.

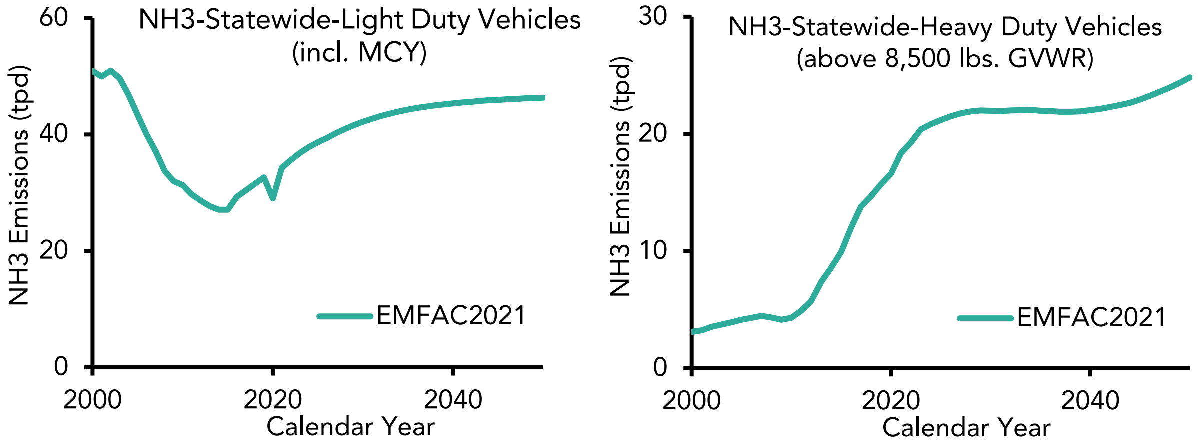
Figure 5.3-5. Comparison of CO2 emissions between EMFAC2021 and EMFAC2017



Ammonia

Ammonia (NH_3) is modeled for the first time in EMFAC2021 and the following figure shows the trend of estimated NH_3 emissions. The increase of NH_3 emissions in future years is because EMFAC2021 assumes newer LD vehicles have higher NH3 emissions. HD NH_3 emissions increase due to the increasing fraction of SCR-equipped vehicles (i.e. 2010-certified). These vehicles produce NH_3 emissions via NH_3 slip from their SCR catalysts.

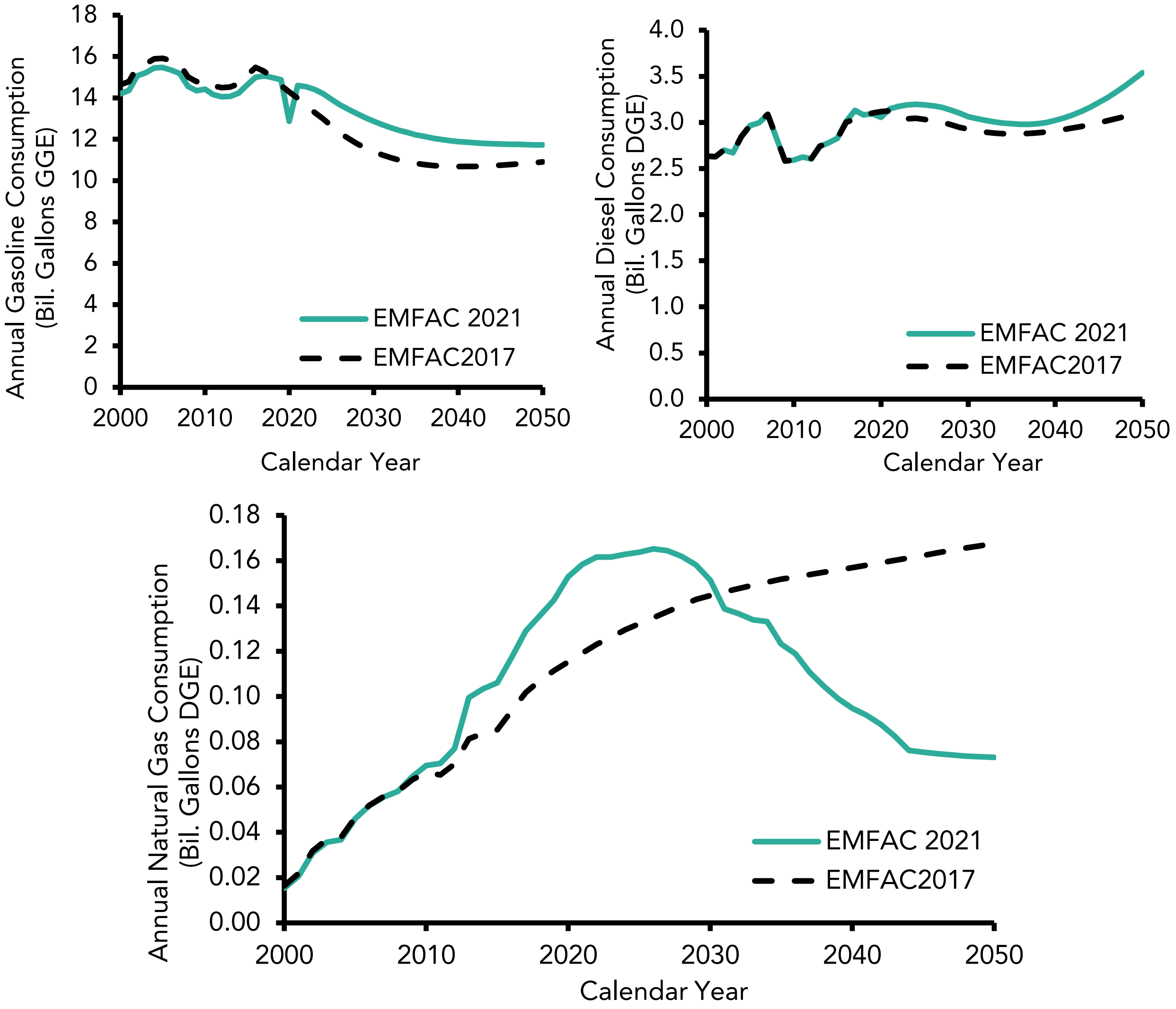
Figure 5.3-6. NH$_3$ emissions in EMFAC2021



Fuel Consumptions

Figure 5.3-7 shows a comparison of gasoline, diesel, and natural gas fuel consumptions between EMFAC2021 and EMFAC2017. The higher estimates of gasoline consumption in future years is mainly due to higher LD CO2 emission rates from the impact of the Final SAFE Rule (section 4.3.3). Diesel fuel consumption in EMFAC2021 is larger in the near-term starting in 2019 due to updated fuel consumption data from CDTFA. In the longer-term, fuel consumption increases due to larger projected HD VMT growth rates from CSTDM. To some extent, these increases in fuel consumption are mitigated by the ACT regulation, however, the regulatory impact of ACT is somewhat limited by its overlap with Phase 2 (see more details in Section 4.3.5.5). Natural gas (NG) consumption in EMFAC2021 is larger than EMFAC2017 between 2012 and 2030 because the separation of NG trucks from diesel ones. The decline in NG consumption starting in 2030 is driven by the ICT and ACT regulations. Transit buses comprises a significant portion of NG vehicles, and ICT directly affects the population of combustion buses by turning them into zero-emission ones. Therefore, starting 2030, which is the first year of 100% ICT implementation, the NG population and fuel consumption starts decreasing.

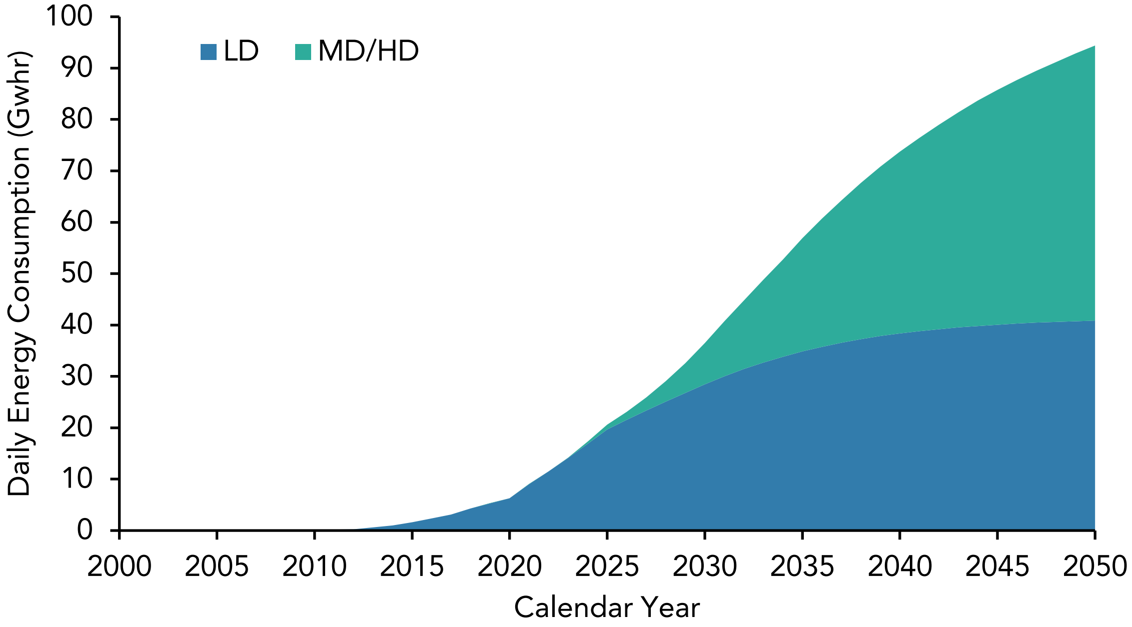
Figure 5.3-7. Comparison of annual fuel consumption (in billion gallons) between EMFAC201 and EMFAC2017



Energy Consumption

Figure 5.3-8 shows EMFAC2021 estimated California statewide energy consumption from on-road sections. LD BEV and PHEV energy consumption increases over time, as they make up a greater fraction of the fleet. Energy consumption for MD and HD starts when ACT is implemented in 2024 and continues to grow as MD and HD electric vehicles further penetrate the fleet. In 2050, MD and HD are responsible for gigawatt hours (GWhr) per day, which is larger than the LD energy consumption of 40.9 GWhr per day. Although there are a larger number of LD BEVs and PHEVs of 2.4 million compared to 1 million MD and HD ZEVs, energy consumption per mile for HD and MD electric vehicles are significantly higher than LD ones. Overall, the total energy consumption in 2050 is 94.4 GWhr per day.

Figure 5.3-8. Statewide Energy Consumption (Gigawatt Hours)



6 Appendices

6.1 Vehicle Class Categorization

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
LDA-Dsl	LDA	Passenger Cars	LDA	LDA
LDA-Gas				
LDA-Elec				
LDA-Phe				
LDT1-Dsl	LDT1	Light-Duty Trucks (GVWR* <6000 lbs. and ETW** <= 3750 lbs.)	LDT1	LDT1
LDT1- Gas				
LDT1-Elec				
LDT1-Phe				
LDT2-Dsl	LDT2	Light-Duty Trucks (GVWR <6000 lbs. and ETW 3751-5750 lbs.)	LDT2	LDT2
LDT2-Gas				
LDT2-Elec				
LDT2-Phe				
MDV-Dsl	MDV	Medium-Duty Trucks (GVWR 5751-8500 lbs.)	MDV	MDV
MDV-Gas				
MDV-Elec				
MDV-Phe				
MH-Dsl	MH	Motor Homes	MH	MH
MH-Gas				
MCY-Gas	MCY	Motorcycles	MCY	MCY
LHD1 – Dsl	LHD1	Light-Heavy-Duty Trucks (GVWR 8501-10000 lbs.)	LHDT1	LHDT1
LHD1-Gas				
LHD1-Elec				
LHD2 – Dsl	LHD2	Light-Heavy-Duty Trucks (GVWR 10001-14000 lbs.)	LHDT2	LHDT2
LHD2-Gas				
LHD2-Elec				
T6 Public Class 4-Dsl	T6 Public Class 4		T6 Public	MHDT

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
T6 Public Class 4-Elec		Medium-Heavy Duty Public Fleet Truck (GVWR 14001-16000 lbs.)		
T6 Public Class 4-NG				
T6 Public Class 5-Dsl	T6 Public Class 5	Medium-Heavy Duty Public Fleet Truck (GVWR 16001-19500 lbs.)	T6 Public	MHDT
T6 Public Class 5-Elec				
T6 Public Class 5-NG				
T6 Public Class 6-Dsl	T6 Public Class 6	Medium-Heavy Duty Public Fleet Truck (GVWR 19501-26000 lbs.)	T6 Public	MHDT
T6 Public Class 6-Elec				
T6 Public Class 6-NG				
T6 Public Class 7-Dsl	T6 Public Class 7	Medium-Heavy Duty Public Fleet Truck (GVWR 26001-33000 lbs.)	T6 Public	MHDT
T6 Public Class 7-Elec				
T6 Public Class 7-NG				
T6 Utility Class 5-Dsl	T6 Utility Class 5	Medium-Heavy Duty Utility Fleet Truck (GVWR 16001-19500 lbs.)	T6 Utility	MHDT
T6 Utility Class 5-Elec				
T6 Utility Class 5-NG				
T6 Utility Class 6-Dsl	T6 Utility Class 6	Medium-Heavy Duty Utility Fleet Truck (GVWR 19501-26000 lbs.)	T6 Utility	MHDT
T6 Utility Class 6-Elec				
T6 Utility Class 6-NG				
T6 Utility Class 7-Dsl	T6 Utility Class 7	Medium-Heavy Duty Utility Fleet Truck (GVWR 26001-33000 lbs.)	T6 Utility	MHDT
T6 Utility Class 7-Elec				
T6 Utility Class 7-NG				
T6 Instate Tractor Class 6-Dsl	T6 Instate Tractor Class 6	Medium-Heavy Duty Tractor Truck (GVWR 19501-26000 lbs.)	T6 Instate small	MHDT
T6 Instate Tractor Class 6-Elec				
T6 Instate Tractor Class 6-NG				
T6 Instate Delivery Class 4-Dsl	T6 Instate Delivery Class 4		T6 Instate small	MHDT
T6 Instate Delivery Class 4-Elec				

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
T6 Instate Delivery Class 4-NG		Medium-Heavy Duty Delivery Truck (GVWR 14001-16000 lbs.)		
T6 Instate Delivery Class 5-Dsl	T6 Instate Delivery Class 5	Medium-Heavy Duty Delivery Truck (GVWR 16001-19500 lbs.)	T6 Instate small	MHDT
T6 Instate Delivery Class 5-Elec				
T6 Instate Delivery Class 5-NG				
T6 Instate Delivery Class 6-Dsl	T6 Instate Delivery Class 6	Medium-Heavy Duty Delivery Truck (GVWR 19501-26000 lbs.)	T6 Instate small	MHDT
T6 Instate Delivery Class 6-Elec				
T6 Instate Delivery Class 6-NG				
T6 Instate Other Class 4-Dsl	T6 Instate Other Class 4	Medium-Heavy Duty Other Truck (GVWR 14001-16000 lbs.)	T6 Instate small	MHDT
T6 Instate Other Class 4-Elec				
T6 Instate Other Class 4-NG				
T6 Instate Other Class 5 -Dsl	T6 Instate Other Class 5	Medium-Heavy Duty Other Truck (GVWR 16001-19500 lbs.)	T6 Instate small	MHDT
T6 Instate Other Class 5-Elec				
T6 Instate Other Class 5-NG				
T6 Instate Other Class 6 – Dsl	T6 Instate Other Class 6	Medium-Heavy Duty Other Truck (GVWR 19501-26000 lbs.)	T6 Instate small	MHDT
T6 Instate Other Class 6-Elec				
T6 Instate Other Class 6-NG				
T6 Instate Tractor Class 7-Dsl	T6 Instate Tractor Class 7	Medium-Heavy Duty Tractor Truck (GVWR 26001-33000 lbs.)	T6 Instate heavy	MHDT
T6 Instate Tractor Class 7 –Elec				
T6 Instate Tractor Class 7-NG				
T6 Instate Delivery Class 7 -Dsl	T6 Instate Delivery Class 7	Medium-Heavy Duty Delivery Truck (GVWR 26001-33000 lbs.)	T6 Instate heavy	MHDT
T6 Instate Delivery Class 7 -Elec				
T6 Instate Delivery Class 7 -NG				
T6 Instate Other Class 7-Dsl	T6 Instate Other Class 7	Medium-Heavy Duty Other Truck (GVWR 26001-33000 lbs.)	T6 Instate heavy	MHDT
T6 Instate Other Class 7-Elec				
T6 Instate Other Class 7-NG				
T6 CAIRP Class 4-Dsl	T6 CAIRP Class 4		T6 CAIRP small	MHDT

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
T6 CAIRP Class 4-Elec		Medium-Heavy Duty CA International Registration Plan Truck (GVWR 14001-16000 lbs.)		
T6 CAIRP Class 5-Dsl	T6 CAIRP Class 5	Medium-Heavy Duty CA International Registration Plan Truck (GVWR 16001-19500 lbs.)	T6 CAIRP small	MHDT
T6 CAIRP Class 5-Elec				
T6 CAIRP Class 6-Dsl	T6 CAIRP Class 6	Medium-Heavy Duty CA International Registration Plan Truck (GVWR 19501-26000 lbs.)	T6 CAIRP small	MHDT
T6 CAIRP Class 6-Elec				
T6 CAIRP Class 7- Dsl	T6 CAIRP Class 7	Medium-Heavy Duty CA International Registration Plan Truck (GVWR 26001-33000 lbs.)	T6 CAIRP heavy	MHDT
T6 CAIRP Class 7-Elec				
T6 CAIRP Class 7-NG				
T6 OOS Class 4-Dsl	T6 OOS Class 4	Medium-Heavy Duty Out-of-state Truck (GVWR 14001-16000 lbs.)	T6 OOS small	MHDT
T6 OOS Class 5-Dsl	T6 OOS Class 5	Medium-Heavy Duty Out-of-state Truck (GVWR 16001-19500 lbs.)		MHDT
T6 OOS Class 6-Dsl	T6 OOS Class 6	Medium-Heavy Duty Out-of-state Truck (GVWR 19501-26000 lbs.)		MHDT
T6 OOS Class 7-Dsl	T6 OOS Class 7	Medium-Heavy Duty Out-of-state Truck (GVWR 26001-33000 lbs.)	T6 OOS heavy	MHDT

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
T6TS-Gas	T6TS	Medium-Heavy Duty Truck	T6TS	MHDT
T6TS-Elec				
T7 Public Class 8-Dsl	T7 Public Class 8	Heavy-Heavy Duty Public Fleet Truck (GVWR 33001 lbs. and over)	T7 Public	HHDT
T7 Public Class 8-Elec				
T7 Public Class 8-NG				
T7 CAIRP Class 8-Dsl	T7 CAIRP Class 8	Heavy-Heavy Duty CA International Registration Plan Truck (GVWR 33001 lbs. and over)	T7 CAIRP	HHDT
T7 CAIRP Class 8-Elec				
T7 CAIRP Class 8-NG				
T7 Utility Class 8-Dsl	T7 Utility Class 8	Heavy-Heavy Duty Utility Fleet Truck (GVWR 33001 lbs. and over)	T7 Utility	HHDT
T7 Utility Class 8-Elec				
T7 NNOOS Class 8-Dsl	T7 NNOOS Class 8	Heavy-Heavy Duty Non-Neighboring Out-of-state Truck (GVWR 33001 lbs. and over)	T7 NNOOS	HHDT
T7 NOOS Class 8-Dsl	T7 NOOS Class 8	Heavy-Heavy Duty Neighboring Out-of-state Truck (GVWR 33001 lbs. and over)	T7 NOOS	HHDT
T7 Other Port Class 8-Dsl	T7 Other Port Class 8	Heavy-Heavy Duty Drayage Truck at Other Facilities (GVWR 33001 lbs. and over)	T7 Other Port	HHDT
T7 Other Port Class 8-Elec				
T7 POAK Class 8-Dsl	T7 POAK Class 8	Heavy-Heavy Duty Drayage Truck in Bay Area (GVWR 33001 lbs. and over)	T7 POAK	HHDT
T7 POAK Class 8-Elec				
T7 POAK Class 8-NG				
T7 POLA Class 8-Dsl	T7 POLA Class 8	Heavy-Heavy Duty Drayage Truck near	T7 POLA	HHDT
T7 POLA Class 8-Elec				

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
T7 POLA Class 8-NG		South Coast (GVWR 33001 lbs. and over)		
T7 Single Concrete/Transit Mix Class 8-Dsl	T7 Single Concrete/Transit Mix Class 8	Heavy-Heavy Duty Single Unit Concrete/Transit Mix Truck (GVWR 33001 lbs and over)	T7 Single	HHDT
T7 Single Concrete/Transit Mix Class 8-Elec				
T7 Single Concrete/Transit Mix Class 8-NG				
T7 Single Dump Class 8-Dsl	T7 Single Dump Class 8	Heavy-Heavy Duty Single Unit Dump Truck (GVWR 33001 lbs. and over)	T7 Single	HHDT
T7 Single Dump Class 8-Elec				
T7 Single Dump Class 8-NG				
T7 Single Other Class 8-Dsl	T7 Single Other Class 8	Heavy-Heavy Duty Single Unit Other Truck (GVWR 33001 lbs. and over)	T7 Single	HHDT
T7 Single Other Class 8-Elec				
T7 Single Other Class 8-NG				
T7 Tractor Class 8-Dsl	T7 Tractor Class 8	Heavy-Heavy Duty Tractor Truck (GVWR 33001 lbs. and over)	T7 Tractor	HHDT
T7 Tractor Class 8-Elec				
T7 Tractor Class 8-NG				
T7 SWCV Class 8-Dsl	T7 SWCV Class 8	Heavy-Heavy Duty Solid Waste Collection Truck (GVWR 33001 lbs. and over)	T7 SWCV	HHDT
T7 SWCV Class 8-Elec				
T7 SWCV Class 8-NG				
T7IS-Gas	T7IS	Heavy-Heavy Duty Truck	T7IS	HHDT
T7IS-Elec				
PTO-Dsl	PTO	Power Take Off	PTO	HHDT
PTO-Elec				
SBUS-Gas	SBUS	School Buses	SBUS	SBUS
SBUS-Dsl				
SBUS-Elec				
SBUS-NG				
UBUS-Dsl	UBUS	Urban Buses	UBUS	UBUS
UBUS-Gas				

EMFAC202x Vehicle & Fuel	EMFAC202x Vehicle Class	Description	EMFAC2011 Vehicle Class	EMFAC2007 Vehicle Class
UBUS-Elec				
UBUS-NG				
Motor Coach-Dsl	Motor Coach	Motor Coach	Motor Coach	OBUS
Motor Coach-Elec				
OBUS-Gas	OBUS	Other Buses	OBUS	OBUS
OBUS-Elec				
All Other Buses-NG	All Other Buses	All Other Buses	All Other Buses	OBUS
All Other Buses-Dsl				

6.2 Exhaust Technology Groups

Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
1	1965-1974	LDA-LDT-MDV	GAS	NonCat	Carb	Pre-1975, no secondary air
2	1966-1974	LDA-LDT-MDV	GAS	NonCat	Carb	Pre-1975, with secondary air
3	1975-1979	LDA-LDT-MDV	GAS	NonCat	Carb	1975+
4	1975-1976	LDA-LDT-MDV	GAS	OxCat	Carb	1975-76, with secondary air
5	1975-1979	LDA-LDT-MDV	GAS	OxCat	Carb	1975-79, no secondary air
6	1980-1981	LDA-LDT-MDV	GAS	OxCat	Carb	1980+, no secondary air
7	1977-1984	LDA-LDT-MDV	GAS	OxCat	Carb	1977+, with secondary air
8	1978-1979	LDA-LDT-MDV	GAS	TWC	TBI / Carb	1978-79
9	1981-1984	LDA	GAS	TWC	TBI / Carb	1981-84, 0.7 NOx std.
10	1985-1993	LDA-LDT-MDV	GAS	TWC	TBI / Carb	1985+, 0.7 NOx std.
11	1977-1980	LDA	GAS	TWC	MPFI	1977-80,
12	1981-1985	LDA-LDT-MDV	GAS	TWC	MPFI	1981-85, 0.7 NOx std.
13	1986-1993	LDA-LDT-MDV	GAS	TWC	MPFI	1986+, 0.7 NOx std.
14	1989-1994	LDA-LDT-MDV	GAS	TWC	TBI / Carb	1989+, 0.4 NOx std.
15	1989-1994	LDA-LDT	GAS	TWC	MPFI	1989+, 0.4 NOx std.

Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
16	1980	LDA-LDT-MDV	GAS	TWC	TBI / Carb	1980,
17	1993-1995	LDA-LDT	GAS	TWC	TBI / Carb	1993+, 0.25 HC std.
18	1993-1995	LDA-LDT	GAS	TWC	MPFI	1993+, 0.25 HC std.
19	1996-1999	LDA-LDT	GAS	TWC	TBI / Carb	1996+, 0.25 HC std, OBD2
20	1996-1999	LDA-LDT	GAS	TWC	MPFI	1996+, 0.25 HC std, OBD2
21	1994-1995	LDA-LDT	GAS	Adv.TWC	MPFI	1994-95, TLEV, AFC
22	1996	LDA-LDT	GAS	Adv.TWC	MPFI	1996+, TLEV, OBD2, AFC
23	1997-2003	LDA-LDT-MDV	GAS	Adv.TWC	MPFI	1996+,LEV, OBD2, GCL, CBC, AFC
24	1997-2003	LDA-LDT-MDV	GAS	Adv.TWC	MPFI	1996+,ULEV, OBD2, GCL, CBC, AFC
25	2000-2040	LDA-LDT1	ELE	na	na	ZEV-Pure Electric
26	1996-2000	LDT-MDV	GAS	TWC	MPFI	1996+, 0.7 NOx std., OBD2
27	1996-2000	LDT-MDV	GAS	TWC	TBI / Carb	1996+, OBD2
28	2004-2025	LDA-LDT-MDV	GAS	Adv.TWC	MPFI	2004+, LEV2, OBD2
29	2004-2020	LDA-LDT	GAS	Adv.TWC	MPFI	2004+, ULEV2, OBD2
30	2004-2014	LDA-LDT	GAS	Adv.TWC	MPFI	2004+, SULEV, OBD2
31	2003-2040	LDA-LDT1	GAS	Adv.TWC	MPFI	2004+, PZEV, OBD2
32	2009-2040	LDA-LDT1	GAS	Adv.TWC	MPFI	2004+, Tier2-3 120K //0.055/2.1/0.03, OBD2
33	2007-2040	LDA-LDT	GAS	Adv.TWC	MPFI	2004+, Tier2-4 120K //0.07/2.1/0.04, OBD2
34	2004-2006	MDV	GAS	Adv.TWC	MPFI	2004+, Tier2-8 120K //0.156/4.2/0.2, OBD2
35	2004-2006	LDT2	GAS	Adv.TWC	MPFI	2004+, Tier2-9 120K //0.09/4.2/0.3, OBD2
36	2004-2006	MDV	GAS	Adv.TWC	MPFI	2004+, Tier2-10 120K //0.23/6.4/0.6, OBD2
37	2003-2040	LDA-LDT1	GAS	Adv.TWC	MPFI	2003+, AT PZEV, OBD2
38	2020-2040	LDA-LDT	GAS	Adv.TWC	MPFI	2015+, SULEV 20, OBD2
39	2020-2040	LDA-LDT	GAS	Adv.TWC	MPFI	2015+, ULEV 50, OBD2
40	1965-1979	LDA	GAS	NonCat	Carb	Pre-1980, Mexican veh no secondary air
41	1975-1986	LDA	GAS	OxCat	Carb	1975-76, Mexican veh with secondary air
42	1980-1987	LDA	GAS	TWC	TBI/Carb	1980-87, Mexican veh, 0.7 NOx std.
43	1981-2040	LDA	GAS	TWC	MPFI	1981-2040, Mexican veh, 0.7 NOx std.

Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
44	2015-2025	LDA-LDT	GAS	Adv.TWC	MPFI	2015+, ULEV 70, OBD2
46	1965-1976	LHDT1	GAS	NonCat	Carb	Pre-1977
47	1977-1983	LHDT1	GAS	OxCat	Carb	1977-83
48	1984-1987	LHDT1	GAS	TWC	Carb	1984-87
49	1988-1990	LHDT1	GAS	TWC	FI	1988-90
50	1991-1995	LHDT1	GAS	TWC	FI	1991-94
51	1995-2001	LHDT1	GAS	TWC	MPFI	1995-01, MDV
52	2002-2003	LHDT1	GAS	TWC	MPFI	2002-03, LEV
53	2004-2008	LHDT1	GAS	Adv.TWC	MPFI	2004-08, ULEV
54	2008-2021	LHDT1	GAS	Adv.TWC	MPFI	2008+, USEPA 2008 stds.
58	2016-2040	LHDT1	GAS	Adv.TWC	MPFI	2016+ LEV 3 ULEV 250
59	2018-2040	LHDT1	GAS	Adv.TWC	MPFI	2018+ LEV 3 SULEV 170
60	1965-1974	LHDT1	DSL			Pre-1975
61	1975-1976	LHDT1	DSL			1975-76
62	1977-1979	LHDT1	DSL			1977-79
63	1980-1983	LHDT1	DSL			1980-83
64	1984-1986	LHDT1	DSL			1984-86
65	1987-1990	LHDT1	DSL			1987-90
66	1991-1993	LHDT1	DSL			1991-93
67	1994-1995	LHDT1	DSL			1994
68	1995-2001	LHDT1	DSL			1995-01, MDV?
69	2002-2003	LHDT1	DSL			2002-03, LEV
70	2004-2009	LHDT1	DSL			2004-09, ULEV
71	2007-2021	LHDT1	DSL			2007+, USEPA 2007 stds.
73	2016-2040	LHDT1	DSL			2016+ LEV 3 ULEV 250
74	2018-2040	LHDT1	DSL			2018+ LEV 3 SULEV 170
76	1965-1976	LHDT2	GAS	NonCat	Carb	Pre-1977,
77	1977-1983	LHDT2	GAS	OxCat	Carb	1977-83,

Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
78	1984-1987	LHDT2	GAS	TWC	Carb	1984-87,
79	1988-1990	LHDT2	GAS	TWC	FI	1988-90,
80	1991-1995	LHDT2	GAS	TWC	FI	1991-94,
81	1995-2001	LHDT2	GAS	TWC	MPFI	1995-01, MDV
82	2002-2003	LHDT2	GAS	TWC	MPFI	2002-03, LEV
83	2004-2008	LHDT2	GAS	Adv.TWC	MPFI	2004-08, ULEV
84	2008-2040	LHDT2	GAS	Adv.TWC	MPFI	2008+, USEPA 2008 stds.
86	2016-2040	LHDT2	GAS	Adv.TWC	MPFI	2016+ LEV 3 ULEV 400
87	2018-2040	LHDT2	GAS	Adv.TWC	MPFI	2018+ LEV 3 SULEV 230
90	1965-1974	LHDT2	DSL			Pre-1975,
91	1975-1976	LHDT2	DSL			1975-76,
92	1977-1979	LHDT2	DSL			1977-79,
93	1980-1983	LHDT2	DSL			1980-83,
94	1984-1986	LHDT2	DSL			1984-86,
95	1987-1990	LHDT2	DSL			1987-90,
96	1991-1993	LHDT2	DSL			1991-93,
97	1994-1995	LHDT2	DSL			1994
98	1995-2001	LHDT2	DSL			1995-01, MDV
99	2002-2003	LHDT2	DSL			2002-03, LEV
100	2004-2009	LHDT2	DSL			2004-09, ULEV
101	2007-2021	LHDT2	DSL			2007+, USEPA 2007 stds.
104	2016-2040	LHDT2	DSL			2016+ LEV 3 ULEV 400
105	2018-2040	LHDT2	DSL			2018+ LEV 3 SULEV 230
106	1965-1976	MHDV	GAS	NonCat	Carb	Pre-1977,
107	1977-1984	MHDV	GAS	OxCat	Carb	1977-83,
108	1984-1987	MHDV	GAS	TWC	Carb	1984-87,
109	1986-1990	MHDV	GAS	TWC	FI	1988-90,
110	1987-1997	MHDV	GAS	TWC	FI	1991-97,

Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
111	1994-2003	MHDV	GAS	TWC	MPFI	1998-03,
112	1998-2004	MHDV	GAS	TWC	MPFI	2004,
113	2004-2040	MHDV	GAS	TWC	MPFI	2005, 1g HC + NOx std.
114	2008-2040	MHDT	GAS	TWC	MPFI	2008+, USEPA 2008 stds.
120	1965-1974	MHDT-MH	DSL			Pre-1975,
121	1975-1976	MHDT-MH	DSL			1975-76,
122	1977-1979	MHDT-MH	DSL			1977-79,
123	1980-1983	MHDT-MH	DSL			1980-83,
124	1984-1986	MHDT-MH	DSL			1984-86,
125	1987-1990	MHDT-MH	DSL			1987-90,
126	1991-1993	MHDT-MH	DSL			1991-93,
127	1994-1997	MHDT-MH	DSL			1994-97,
128	1998-1998	MHDT-MH	DSL			1998,
129	1999-2002	MHDT-MH	DSL			1999-02,
130	2003-2006	MHDT-MH	DSL			2003-06, 2g NOx std.
131	2007-2009	MHDT-MH	DSL			2007-09, Transition 2010 stds.
132	2010-2040	MHDT-MH	DSL			2010+, US EPA 2010 stds.
133	2010-2040	MHDT-MH	DSL			2010+, US EPA 2010 stds/OBD
136	1965-1976	HHDV-LHV	GAS	NonCat	Carb	Pre-1977,
137	1977-1984	HHDV-LHV	GAS	OxCat	Carb	1977-84,
138	1985-1985	HHDV-LHV	GAS	TWC	Carb	1985
139	1986-1986	HHDV-LHV	GAS	TWC	FI	1986
140	1987-1993	HHDV-LHV	GAS	TWC	FI	1987-93,
141	1994-1997	HHDV-LHV	GAS	TWC	MPFI	1994-97,
142	1998-2003	HHDV-LHV	GAS	TWC	MPFI	1998-03,
143	2004-2040	HHDV-LHV	GAS	TWC	MPFI	2004-06,
150	1965-1974	HHDV-LHV	DSL			Pre-1975, CA stds.
151	1975-1976	HHDV-LHV	DSL			1975-76, CA Stds.

Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
152	1977-1979	HHDV-LHV	DSL			1977-79, CA Stds.
153	1980-1983	HHDV-LHV	DSL			1980-83, CA Stds.
154	1984-1986	HHDV-LHV	DSL			1984-86, CA Stds.
155	1987-1990	HHDV-LHV	DSL			1987-90, CA Stds.
156	1991-1993	HHDV-LHV	DSL			1991-93, CA Stds.
157	1994-1997	HHDV-LHV	DSL			1994-97, CA Stds.
158	1998-1998	HHDV-LHV	DSL			1998, CA Stds.
159	1999-2002	HHDV-LHV	DSL			1999-02, CA Stds.
160	2003-2006	HHDV-LHV	DSL			2003-06, CA 2g NOx Stds.
161	2007-2009	HHDV-LHV	DSL			2007-2009, USEPA 2007 stds.
162	2010+	HHDV-LHV	DSL			2010+, USEPA 2007 stds.
163	2010+	HHDV-LHV	DSL			2010+ , USEPA 2007 stds. W/OBD2
170	1965-1974	LDA-LDT-MDV	DSL			Pre-1975,
171	1975-1979	LDA-LDT-MDV	DSL			1975-79,
172	1980-1980	LDA-LDT-MDV	DSL			1980,
173	1981-1981	LDA-LDT-MDV	DSL			1981,
174	1982-1982	LDA-LDT-MDV	DSL			1982,
175	1983-1983	LDA-LDT-MDV	DSL			1983,
176	1984-1992	LDA-LDT-MDV	DSL			1984-92,
177	1993-2003	LDA-LDT-MDV	DSL			1993+,
178	2007-2025	LDA LT3	DSL	DPF SCR		2008+, LEV 160 DSL, OBD2
179	2007-2025	LDA LT3	DSL	DPF SCR		2008+, ULEV 125 DSL, OBD2
180	2020-2040	LDA LT3	DSL	DPF SCR		2020+, SULEV 30 DSL, OBD2
200	1965-1973	HHDV-LHV	DSL			Pre-1974, Federal Stds.
201	1974-1978	HHDV-LHV	DSL			1974-78, Federal Stds.
202	1979-1983	HHDV-LHV	DSL			1979-83, Federal Stds.
203	1984-1987	HHDV-LHV	DSL			1984-87, Federal Stds.
204	1988-1990	HHDV-LHV	DSL			1988-90, Federal Stds.

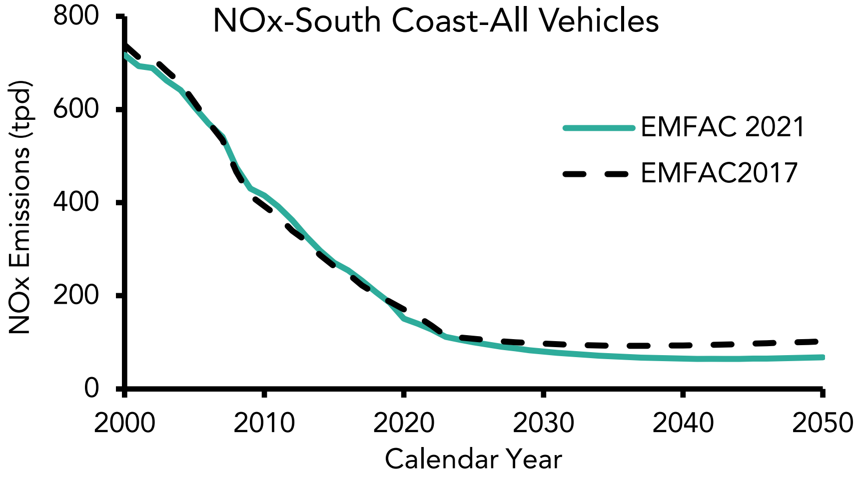
Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
205	1991-1993	HHDV-LHV	DSL			1991-93, Federal Stds.
206	1994-1997	HHDV-LHV	DSL			1994-97, Federal Stds.
207	1998-1998	HHDV-LHV	DSL			1998, Federal Stds.
208	1999-2003	HHDV-LHV	DSL			1999-02, Federal Stds.
209	2003-2009	HHDV-LHV	DSL			2003-06, Federal Stds.
210	2007-2009	HHDV-LHV	DSL			2007-2009, USEPA 2007 stds.
211	2010+	HHDV-LHV	DSL			2010+, USEPA 2007 stds.
216	1965-1986	UB	DSL			Pre-87,
217	1987-1990	UB	DSL			1987-90,
218	1991-1993	UB	DSL			1991-93,
219	1994-1995	UB	DSL			1994-95,
220	1996-1998	UB	DSL			1996-98,
221	1999-2002	UB	DSL			1999-02,
222	2003-2003	UB	DSL			2003,
223	2004-2006	UB	DSL			2004-06,
224	2007-2040	UB	DSL			2007,
225	2008-2040	UB	DSL			2008+, ZEV or ZEBS
228	1965-1976	SBUS	GAS	NonCat	Carb	Pre-77,
229	1977-1983	SBUS	GAS	OxCat	TBI / Carb	1977-83,
230	1984-1987	SBUS	GAS	TWC	FI	1984-87,
231	1988-1990	SBUS	GAS	TWC	FI	1988-90,
232	1991-1997	SBUS	GAS	TWC	FI	1991-97,
233	1998-2003	SBUS	GAS	TWC	MPFI	1998-03,
234	2004-2004	SBUS	GAS	TWC	MPFI	2004,
235	2005-2008	SBUS	GAS	TWC	MPFI	2005,1g HC+NOx Stds.
236	2008-2040	SBUS	GAS	TWC	MPFI	2008+, USEPAs Stds.
240	1965-1974	SBUS	DSL			Pre-75,
241	1975-1976	SBUS	DSL			1975-76,

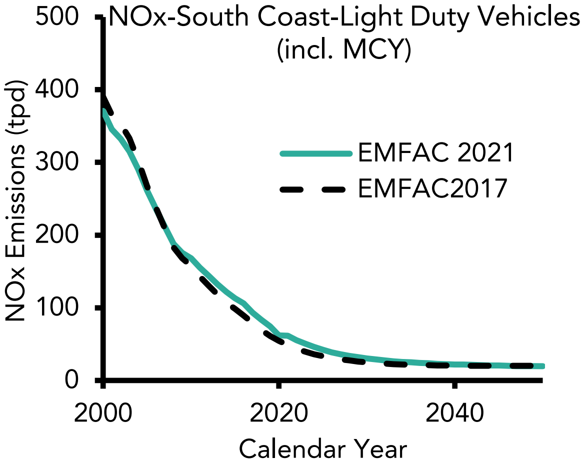
Tech. Group	Model Years Using TG in FRAC arrays	Vehicle Type Using TG in FRAC arrays	Fuel Type	Catalyst	Fuel Delivery	Description
242	1977-1979	SBUS	DSL			1977-79,
243	1980-1983	SBUS	DSL			1980-83,
244	1984-1986	SBUS	DSL			1984-86,
245	1987-1990	SBUS	DSL			1987-90,
246	1991-1993	SBUS	DSL			1991-93,
247	1994-1997	SBUS	DSL			1994-97,
248	1998-1998	SBUS	DSL			1998,
249	1999-2003	SBUS	DSL			1999-02,
250	2003-2009	SBUS	DSL			2003-06, 2g NOx Std
251	2007-2040	SBUS	DSL			2007+, USEPA Std.
260	1965-1977	MCY	GAS	NonCat	2-Stroke	All, 6g evap Std.
261	1965-1977	MCY	GAS	NonCat	Carb	Pre-1978, 6g evap Std.
262	1978-1979	MCY	GAS	NonCat	Carb	1978-79, 6g evap Std.
263	1980-1981	MCY	GAS	NonCat	Carb	1980-81, 6g evap Std.
264	1982-1984	MCY	GAS	NonCat	Carb	1982-84, 6g evap Std.
265	1985-1987	MCY	GAS	NonCat	Carb	1985-87, 2g evap Std.
266	1988-2003	MCY	GAS	NonCat	Carb	1988-03, 2g evap Std.
267	1994-2003	MCY	GAS	NonCat	FI	1988-03, 2g evap Std.
268	1995-2003	MCY	GAS	OxCat	Carb	1988-03, 2g evap Std.
269	1994-2003	MCY	GAS	TWC	FI	1988-03, 2g evap Std.
270	2004-2007	MCY	GAS	NonCat	Carb	2003-08, 2g evap Std.
271	2004-2007	MCY	GAS	NonCat	FI	2003-08, 2g evap Std.
272	2004-2007	MCY	GAS	OxCat	Carb	2003-08, 2g evap Std.
273	2004-2007	MCY	GAS	TWC	FI	03-08 MCY FI/cat/2g evap
274	2008-2040	MCY	GAS	NonCat	Carb	2008+, 2 evap Std.
275	2008-2040	MCY	GAS	NonCat	FI	2008+, 2 evap Std.
276	2008-2040	MCY	GAS	OxCat	Carb	2008+, 2 evap Std.
277	2008-2040	MCY	GAS	TWC	FI	2008+, 2 evap Std.

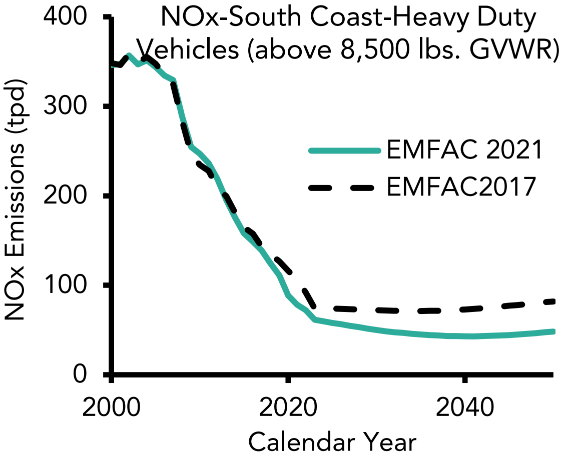
6.3 Emissions Impact in Air Basins

Comparison of Vehicle Emissions in the South Coast Air Basin between EMFAC2017 and EMFAC2021

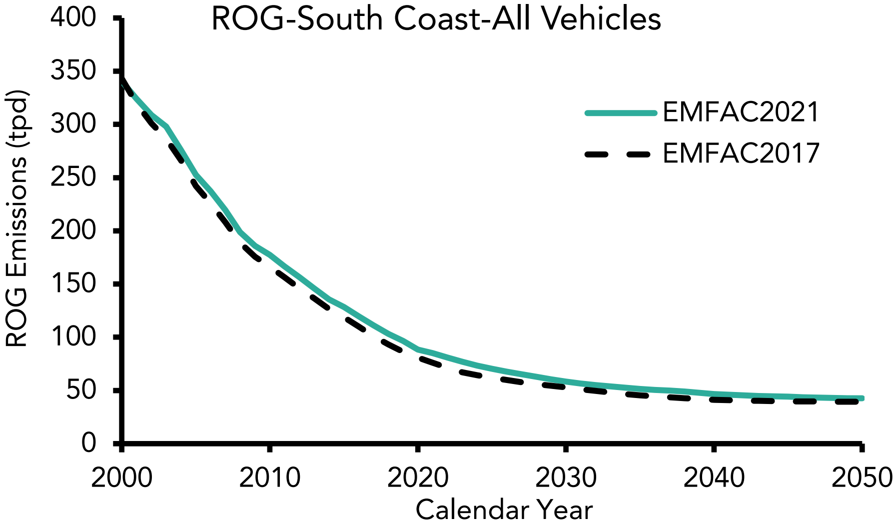
NOx

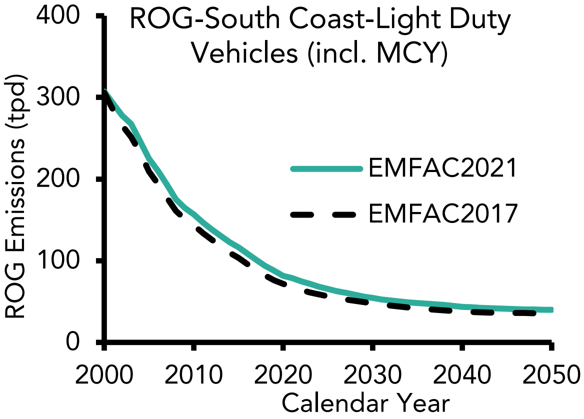


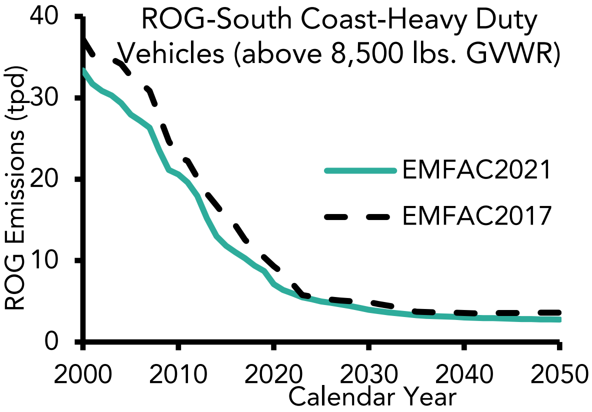




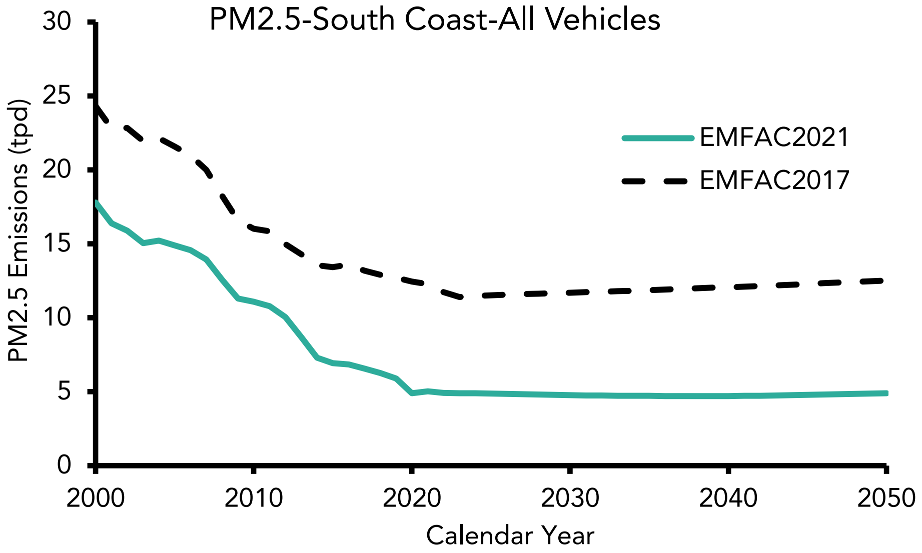
ROG

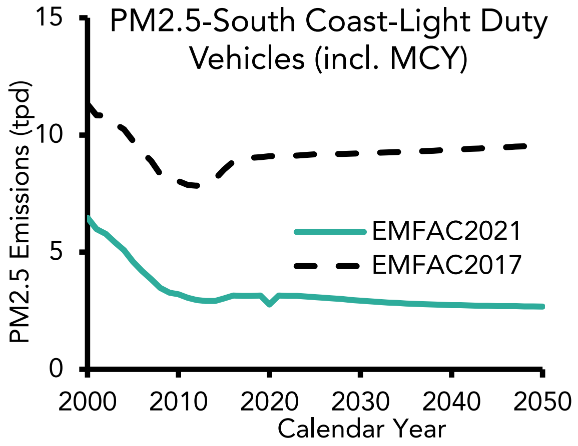

ROG-South Coast-All Vehicles
ROG Emissions (tpd)
400
350
300
250
200
150
100
50
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017

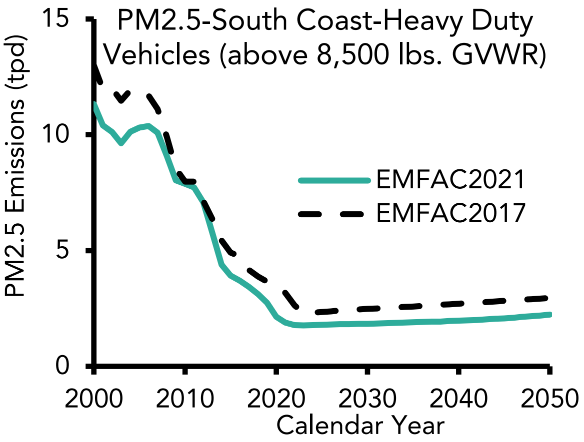

ROG-South Coast-Light Duty Vehicles (incl. MCY)
ROG Emissions (tpd)
400
300
200
100
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017


ROG-South Coast-Heavy Duty Vehicles (above 8,500 lbs. GVWR)
ROG Emissions (tpd)
40
30
20
10
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017

PM2.5

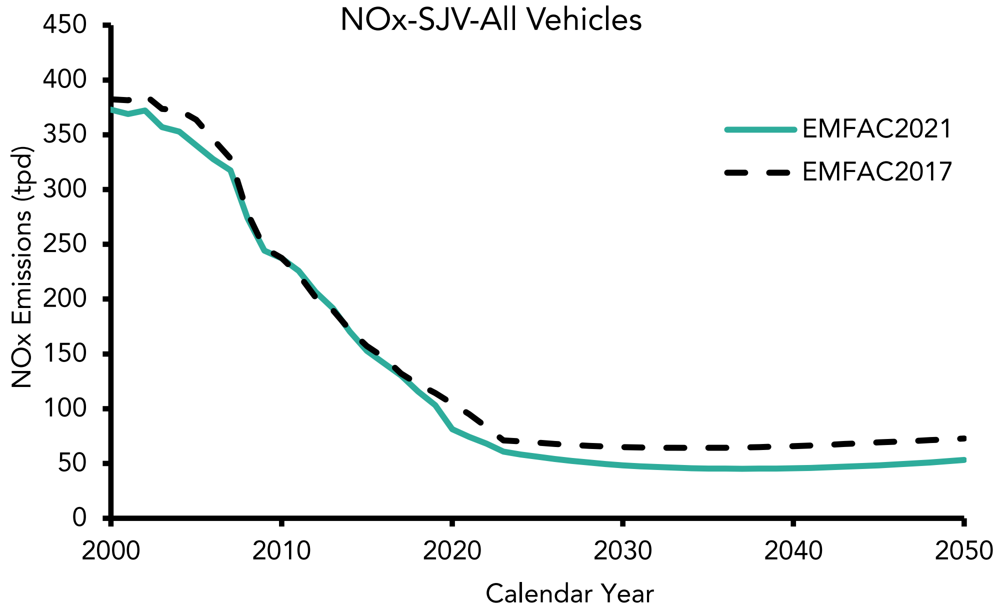

PM2.5-South Coast-All Vehicles
PM2.5 Emissions (tpd)
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017

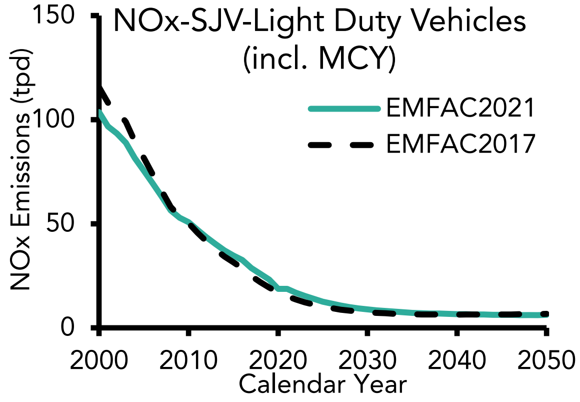

PM2.5-South Coast-Light Duty Vehicles (incl. MCY)
PM2.5 Emissions (tpd)
15
10
5
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017

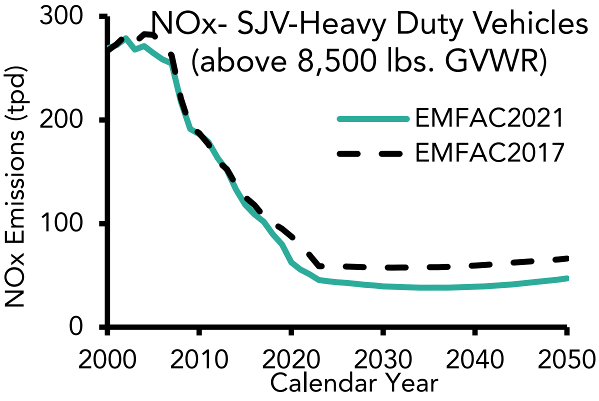

PM2.5-South Coast-Heavy Duty Vehicles (above 8,500 lbs. GVWR)
PM2.5 Emissions (tpd)
15
10
5
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017

Comparison of Vehicle Emissions in the San Joaquin Valley (SJV) between EMFAC2017 and EMFAC2021

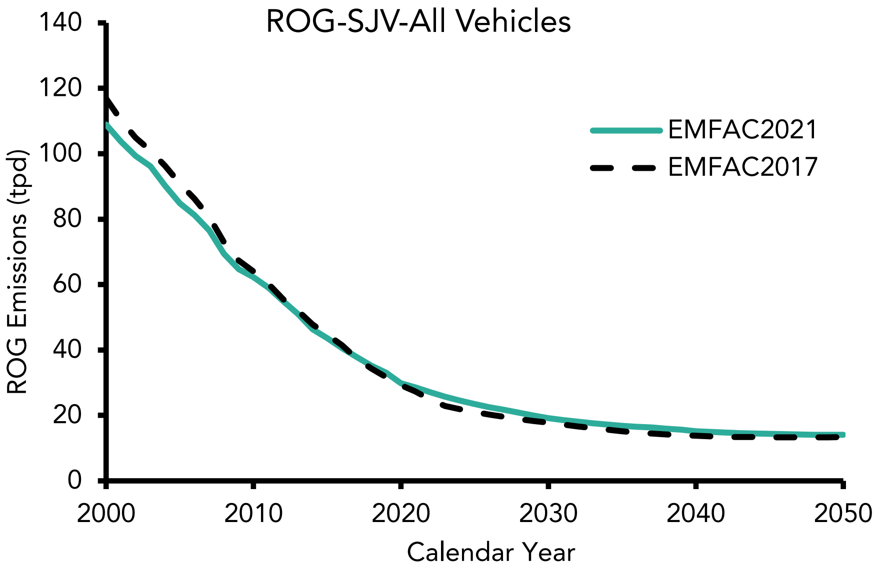
NOx

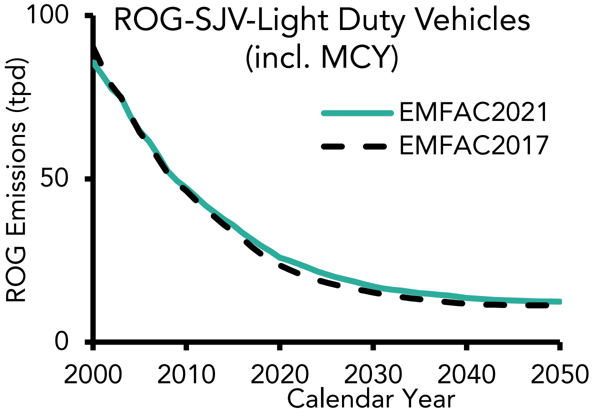


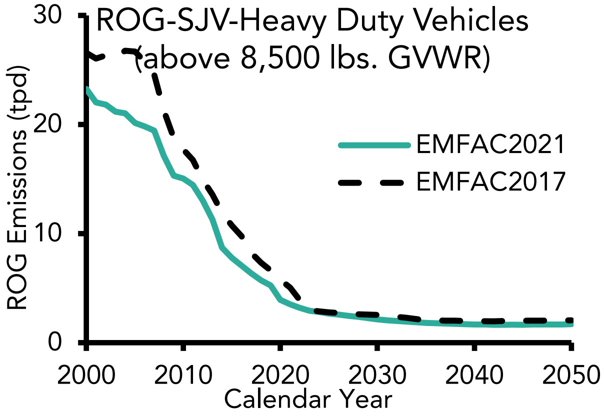




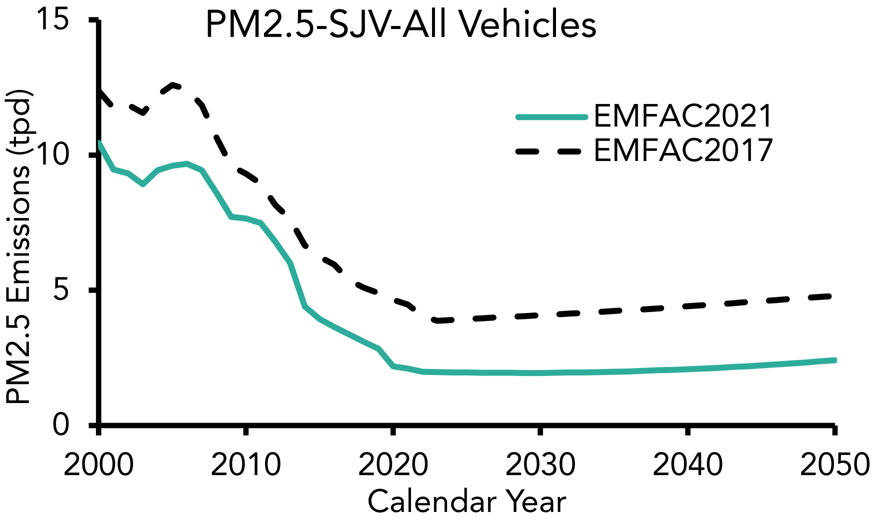
ROG

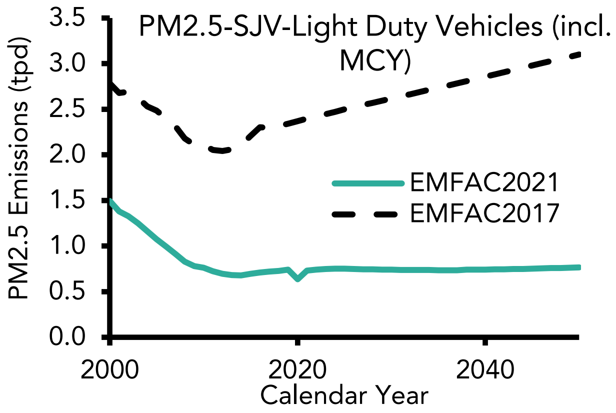

ROG-SJV-All Vehicles
EMFAC2021
EMFAC2017
ROG Emissions (tpd)
0
20
40
60
80
100
120
140
2000
2010
2020
2030
2040
2050
Calendar Year

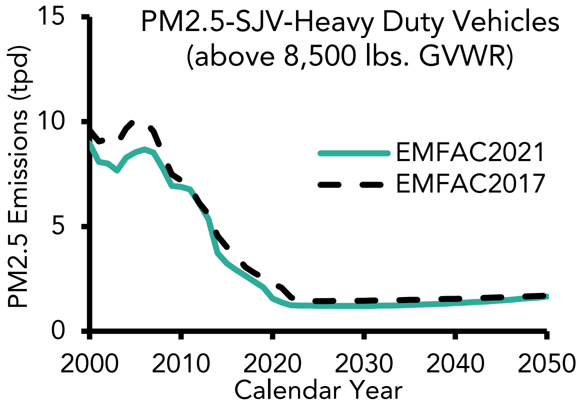

ROG-SJV-Light Duty Vehicles (incl. MCY)
EMFAC2021
EMFAC2017
ROG Emissions (tpd)
0
50
100
2000
2010
2020
2030
2040
2050
Calendar Year


ROG-SJV-Heavy Duty Vehicles (above 8,500 lbs. GVWR)
EMFAC2021
EMFAC2017
ROG Emissions (tpd)
0
10
20
30
2000
2010
2020
2030
2040
2050
Calendar Year

PM2.5


PM2.5-SJV-All Vehicles
PM2.5 Emissions (tpd)
15
10
5
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017


PM2.5-SJV-Light Duty Vehicles (incl. MCY)
PM2.5 Emissions (tpd)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2000
2020
2040
Calendar Year
EMFAC2021
EMFAC2017


PM2.5-SJV-Heavy Duty Vehicles (above 8,500 lbs. GVWR)
PM2.5 Emissions (tpd)
15
10
5
0
2000
2010
2020
2030
2040
2050
Calendar Year
EMFAC2021
EMFAC2017

6.4 Heavy Duty Natural Gas Penetration

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T6 Utility Class 5	Amador County APCD	0.083333	0	Flat12Yr
T6 Utility Class 6	Amador County APCD	0.083333	0	Flat12Yr
T6 Utility Class 7	Amador County APCD	0.083333	0	Flat12Yr
T6 Instate Tractor Class 7	Amador County APCD	0.013889	0	Flat12Yr
T6 Instate Delivery Class 7	Amador County APCD	0.013889	0	Flat12Yr
T6 Instate Other Class 7	Amador County APCD	0.013889	0	Flat12Yr
T6 Instate Tractor Class 7	Antelope Valley AQMD	0.027778	0	Flat12Yr
T6 Instate Delivery Class 7	Antelope Valley AQMD	0.027778	0	Flat12Yr
T6 Instate Other Class 7	Antelope Valley AQMD	0.027778	0	Flat12Yr
T7 POLA Class 8	Antelope Valley AQMD	0.099306	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Antelope Valley AQMD	0.006944	0	Flat12Yr
T7 Single Dump Class 8	Antelope Valley AQMD	0.006944	0	Flat12Yr
T7 Single Other Class 8	Antelope Valley AQMD	0.006944	0	Flat12Yr
SBUS	Antelope Valley AQMD	0.130057	0	Flat12Yr
T6 Public Class 4	Bay Area AQMD	0.066853	0	Flat12Yr
T6 Public Class 5	Bay Area AQMD	0.066853	0	Flat12Yr
T6 Public Class 6	Bay Area AQMD	0.066853	0	Flat12Yr
T6 Public Class 7	Bay Area AQMD	0.066853	0	Flat12Yr
T6 Utility Class 5	Bay Area AQMD	0.008433	0	Flat12Yr
T6 Utility Class 6	Bay Area AQMD	0.008433	0	Flat12Yr
T6 Utility Class 7	Bay Area AQMD	0.008433	0	Flat12Yr
T6 Instate Tractor Class 6	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Delivery Class 4	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Delivery Class 5	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Delivery Class 6	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Other Class 4	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Other Class 5	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Other Class 6	Bay Area AQMD	0.014131	0	Flat12Yr
T6 Instate Tractor Class 7	Bay Area AQMD	0.018565	0	Flat12Yr
T6 Instate Delivery Class 7	Bay Area AQMD	0.018565	0	Flat12Yr
T6 Instate Other Class 7	Bay Area AQMD	0.018565	0	Flat12Yr
T7 Public Class 8	Bay Area AQMD	0.008157	0	Flat12Yr
T7 CAIRP Class 8	Bay Area AQMD	0.001827	0	Flat12Yr
T7 POAK Class 8	Bay Area AQMD	0.002252	0	Flat12Yr
T7 POLA Class 8	Bay Area AQMD	0.076389	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Bay Area AQMD	0.057956	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T7 Single Dump Class 8	Bay Area AQMD	0.057956	0	Flat12Yr
T7 Single Other Class 8	Bay Area AQMD	0.057956	0	Flat12Yr
T7 Tractor Class 8	Bay Area AQMD	0.078304	0	Flat12Yr
SBUS	Bay Area AQMD	0.05757	0	Flat12Yr
All Other Buses	Bay Area AQMD	0.023012	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Butte County AQMD	0.006944	0	Flat12Yr
T7 Single Dump Class 8	Butte County AQMD	0.006944	0	Flat12Yr
T7 Single Other Class 8	Butte County AQMD	0.006944	0	Flat12Yr
T7 Tractor Class 8	Butte County AQMD	0.002976	0	Flat12Yr
T6 Instate Tractor Class 6	Calaveras County APCD	0.015152	0	Flat12Yr
T6 Instate Delivery Class 4	Calaveras County APCD	0.015152	0	Flat12Yr
T6 Instate Delivery Class 5	Calaveras County APCD	0.015152	0	Flat12Yr
T6 Instate Delivery Class 6	Calaveras County APCD	0.015152	0	Flat12Yr
T6 Instate Other Class 4	Calaveras County APCD	0.015152	0	Flat12Yr
T6 Instate Other Class 5	Calaveras County APCD	0.015152	0	Flat12Yr
T6 Instate Other Class 6	Calaveras County APCD	0.015152	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	El Dorado County APCD	0.010417	0	Flat12Yr
T7 Single Dump Class 8	El Dorado County APCD	0.010417	0	Flat12Yr
T7 Single Other Class 8	El Dorado County APCD	0.010417	0	Flat12Yr
All Other Buses	El Dorado County APCD	0.041667	0	Flat12Yr
T7 Tractor Class 8	Feather River AQMD	0.053407	0	Flat12Yr
T6 Instate Tractor Class 6	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Instate Delivery Class 4	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Instate Delivery Class 5	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Instate Delivery Class 6	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Instate Other Class 4	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Instate Other Class 5	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Instate Other Class 6	Great Basin Unified APCD	0.0625	0	Flat12Yr
T6 Public Class 4	Imperial County APCD	0.09035	0	Flat12Yr
T6 Public Class 5	Imperial County APCD	0.09035	0	Flat12Yr
T6 Public Class 6	Imperial County APCD	0.09035	0	Flat12Yr
T6 Public Class 7	Imperial County APCD	0.09035	0	Flat12Yr
T7 Public Class 8	Imperial County APCD	0.010417	0	Flat12Yr
T7 POLA Class 8	Imperial County APCD	0.171721	0	Flat12Yr
T7 Tractor Class 8	Imperial County APCD	0.014385	0	Flat12Yr
T7 POLA Class 8	Kern County APCD	0.041667	0	Flat12Yr
T7 Tractor Class 8	Kern County APCD	0.002604	0	Flat12Yr
T6 Instate Tractor Class 6	Lassen County APCD	0.027778	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T6 Instate Delivery Class 4	Lassen County APCD	0.027778	0	Flat12Yr
T6 Instate Delivery Class 5	Lassen County APCD	0.027778	0	Flat12Yr
T6 Instate Delivery Class 6	Lassen County APCD	0.027778	0	Flat12Yr
T6 Instate Other Class 4	Lassen County APCD	0.027778	0	Flat12Yr
T6 Instate Other Class 5	Lassen County APCD	0.027778	0	Flat12Yr
T6 Instate Other Class 6	Lassen County APCD	0.027778	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Mendocino County AQMD	0.024515	0	Flat12Yr
T7 Single Dump Class 8	Mendocino County AQMD	0.024515	0	Flat12Yr
T7 Single Other Class 8	Mendocino County AQMD	0.024515	0	Flat12Yr
T7 Tractor Class 8	Mendocino County AQMD	0.005556	0	Flat12Yr
T6 Public Class 4	Mojave Desert AQMD	0.070833	0	Flat12Yr
T6 Public Class 5	Mojave Desert AQMD	0.070833	0	Flat12Yr
T6 Public Class 6	Mojave Desert AQMD	0.070833	0	Flat12Yr
T6 Public Class 7	Mojave Desert AQMD	0.070833	0	Flat12Yr
T7 Public Class 8	Mojave Desert AQMD	0.055556	0	Flat12Yr
T7 CAIRP Class 8	Mojave Desert AQMD	0.000223	0	Flat12Yr
T7 POLA Class 8	Mojave Desert AQMD	0.046296	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Mojave Desert AQMD	0.022751	0	Flat12Yr
T7 Single Dump Class 8	Mojave Desert AQMD	0.022751	0	Flat12Yr
T7 Single Other Class 8	Mojave Desert AQMD	0.022751	0	Flat12Yr
T7 Tractor Class 8	Mojave Desert AQMD	0.00743	0	Flat12Yr
T6 Public Class 4	Monterey Bay Unified APCD	0.041667	0	Flat12Yr
T6 Public Class 5	Monterey Bay Unified APCD	0.041667	0	Flat12Yr
T6 Public Class 6	Monterey Bay Unified APCD	0.041667	0	Flat12Yr
T6 Public Class 7	Monterey Bay Unified APCD	0.041667	0	Flat12Yr
T6 Instate Tractor Class 7	Monterey Bay Unified APCD	0.017062	0	Flat12Yr
T6 Instate Delivery Class 7	Monterey Bay Unified APCD	0.017062	0	Flat12Yr
T6 Instate Other Class 7	Monterey Bay Unified APCD	0.017062	0	Flat12Yr
T7 Public Class 8	Monterey Bay Unified APCD	0.01513	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Monterey Bay Unified APCD	0.032989	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T7 Single Dump Class 8	Monterey Bay Unified APCD	0.032989	0	Flat12Yr
T7 Single Other Class 8	Monterey Bay Unified APCD	0.032989	0	Flat12Yr
T7 Tractor Class 8	Monterey Bay Unified APCD	0.002924	0	Flat12Yr
SBUS	Monterey Bay Unified APCD	0.002874	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	North Coast Unified AQMD	0.022488	0	Flat12Yr
T7 Single Dump Class 8	North Coast Unified AQMD	0.022488	0	Flat12Yr
T7 Single Other Class 8	North Coast Unified AQMD	0.022488	0	Flat12Yr
T6 Instate Tractor Class 7	Northern Sierra AQMD	0.070648	0	Flat12Yr
T6 Instate Delivery Class 7	Northern Sierra AQMD	0.070648	0	Flat12Yr
T6 Instate Other Class 7	Northern Sierra AQMD	0.070648	0	Flat12Yr
T7 Public Class 8	Placer County APCD	0.007564	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Placer County APCD	0.018315	0	Flat12Yr
T7 Single Dump Class 8	Placer County APCD	0.018315	0	Flat12Yr
T7 Single Other Class 8	Placer County APCD	0.018315	0	Flat12Yr
T7 Tractor Class 8	Placer County APCD	0.003333	0	Flat12Yr
T6 Public Class 4	Sacramento Metropolitan AQMD	0.110258	0	Flat12Yr
T6 Public Class 5	Sacramento Metropolitan AQMD	0.110258	0	Flat12Yr
T6 Public Class 6	Sacramento Metropolitan AQMD	0.110258	0	Flat12Yr
T6 Public Class 7	Sacramento Metropolitan AQMD	0.110258	0	Flat12Yr
T6 Utility Class 5	Sacramento Metropolitan AQMD	0.002604	0	Flat12Yr
T6 Utility Class 6	Sacramento Metropolitan AQMD	0.002604	0	Flat12Yr
T6 Utility Class 7	Sacramento Metropolitan AQMD	0.002604	0	Flat12Yr
T6 Instate Tractor Class 7	Sacramento Metropolitan AQMD	0.009707	0	Flat12Yr
T6 Instate Delivery Class 7	Sacramento Metropolitan AQMD	0.009707	0	Flat12Yr
T6 Instate Other Class 7	Sacramento Metropolitan AQMD	0.009707	0	Flat12Yr
T7 Public Class 8	Sacramento Metropolitan AQMD	0.027083	0	Flat12Yr
T7 CAIRP Class 8	Sacramento Metropolitan AQMD	0.010142	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T7 Single Concrete/Transit Mix Class 8	Sacramento Metropolitan AQMD	0.030047	0	Flat12Yr
T7 Single Dump Class 8	Sacramento Metropolitan AQMD	0.030047	0	Flat12Yr
T7 Single Other Class 8	Sacramento Metropolitan AQMD	0.030047	0	Flat12Yr
T7 Tractor Class 8	Sacramento Metropolitan AQMD	0.009123	0	Flat12Yr
SBUS	Sacramento Metropolitan AQMD	0.040438	0	Flat12Yr
All Other Buses	Sacramento Metropolitan AQMD	0.130316	0	Flat12Yr
T6 Public Class 4	San Diego County APCD	0.012872	0	Flat12Yr
T6 Public Class 5	San Diego County APCD	0.012872	0	Flat12Yr
T6 Public Class 6	San Diego County APCD	0.012872	0	Flat12Yr
T6 Public Class 7	San Diego County APCD	0.012872	0	Flat12Yr
T6 Instate Tractor Class 6	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Delivery Class 4	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Delivery Class 5	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Delivery Class 6	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Other Class 4	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Other Class 5	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Other Class 6	San Diego County APCD	0.017149	0	Flat12Yr
T6 Instate Tractor Class 7	San Diego County APCD	0.007641	0	Flat12Yr
T6 Instate Delivery Class 7	San Diego County APCD	0.007641	0	Flat12Yr
T6 Instate Other Class 7	San Diego County APCD	0.007641	0	Flat12Yr
T7 Public Class 8	San Diego County APCD	0.009151	0	Flat12Yr
T7 CAIRP Class 8	San Diego County APCD	0.000848	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	San Diego County APCD	0.070608	0	Flat12Yr
T7 Single Dump Class 8	San Diego County APCD	0.070608	0	Flat12Yr
T7 Single Other Class 8	San Diego County APCD	0.070608	0	Flat12Yr
T7 Tractor Class 8	San Diego County APCD	0.013263	0	Flat12Yr
SBUS	San Diego County APCD	0.020093	0	Flat12Yr
All Other Buses	San Diego County APCD	0.14921	0	Flat12Yr
T6 Public Class 4	San Joaquin Valley Unified APCD	0.123221	0	Flat12Yr
T6 Public Class 5	San Joaquin Valley Unified APCD	0.123221	0	Flat12Yr
T6 Public Class 6	San Joaquin Valley Unified APCD	0.123221	0	Flat12Yr
T6 Public Class 7	San Joaquin Valley Unified APCD	0.123221	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T6 Utility Class 5	San Joaquin Valley Unified APCD	0.002252	0	Flat12Yr
T6 Utility Class 6	San Joaquin Valley Unified APCD	0.002252	0	Flat12Yr
T6 Utility Class 7	San Joaquin Valley Unified APCD	0.002252	0	Flat12Yr
T6 Instate Tractor Class 7	San Joaquin Valley Unified APCD	0.02375	0	Flat12Yr
T6 Instate Delivery Class 7	San Joaquin Valley Unified APCD	0.02375	0	Flat12Yr
T6 Instate Other Class 7	San Joaquin Valley Unified APCD	0.02375	0	Flat12Yr
T7 Public Class 8	San Joaquin Valley Unified APCD	0.115163	0	Flat12Yr
T7 POLA Class 8	San Joaquin Valley Unified APCD	0.004902	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	San Joaquin Valley Unified APCD	0.035179	0	Flat12Yr
T7 Single Dump Class 8	San Joaquin Valley Unified APCD	0.035179	0	Flat12Yr
T7 Single Other Class 8	San Joaquin Valley Unified APCD	0.035179	0	Flat12Yr
T7 Tractor Class 8	San Joaquin Valley Unified APCD	0.015355	0	Flat12Yr
SBUS	San Joaquin Valley Unified APCD	0.229238	0	Flat12Yr
All Other Buses	San Joaquin Valley Unified APCD	0.096803	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	San Luis Obispo County APCD	0.021498	0	Flat12Yr
T7 Single Dump Class 8	San Luis Obispo County APCD	0.021498	0	Flat12Yr
T7 Single Other Class 8	San Luis Obispo County APCD	0.021498	0	Flat12Yr
T7 Tractor Class 8	San Luis Obispo County APCD	0.011624	0	Flat12Yr
All Other Buses	San Luis Obispo County APCD	0.060606	0	Flat12Yr
T6 Public Class 4	Santa Barbara County APCD	0.020833	0	Flat12Yr
T6 Public Class 5	Santa Barbara County APCD	0.020833	0	Flat12Yr
T6 Public Class 6	Santa Barbara County APCD	0.020833	0	Flat12Yr
T6 Public Class 7	Santa Barbara County APCD	0.020833	0	Flat12Yr
T6 Instate Tractor Class 6	Santa Barbara County APCD	0.001263	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T6 Instate Delivery Class 4	Santa Barbara County APCD	0.001263	0	Flat12Yr
T6 Instate Delivery Class 5	Santa Barbara County APCD	0.001263	0	Flat12Yr
T6 Instate Delivery Class 6	Santa Barbara County APCD	0.001263	0	Flat12Yr
T6 Instate Other Class 4	Santa Barbara County APCD	0.001263	0	Flat12Yr
T6 Instate Other Class 5	Santa Barbara County APCD	0.001263	0	Flat12Yr
T6 Instate Other Class 6	Santa Barbara County APCD	0.001263	0	Flat12Yr
T6 Instate Tractor Class 7	Santa Barbara County APCD	0.005853	0	Flat12Yr
T6 Instate Delivery Class 7	Santa Barbara County APCD	0.005853	0	Flat12Yr
T6 Instate Other Class 7	Santa Barbara County APCD	0.005853	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Santa Barbara County APCD	0.027401	0	Flat12Yr
T7 Single Dump Class 8	Santa Barbara County APCD	0.027401	0	Flat12Yr
T7 Single Other Class 8	Santa Barbara County APCD	0.027401	0	Flat12Yr
T7 Tractor Class 8	Santa Barbara County APCD	0.004167	0	Flat12Yr
SBUS	Santa Barbara County APCD	0.240605	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Shasta County AQMD	0.024683	0	Flat12Yr
T7 Single Dump Class 8	Shasta County AQMD	0.024683	0	Flat12Yr
T7 Single Other Class 8	Shasta County AQMD	0.024683	0	Flat12Yr
T7 Tractor Class 8	Shasta County AQMD	0.007517	0	Flat12Yr
SBUS	Shasta County AQMD	0.006944	0	Flat12Yr
T6 Public Class 4	Siskiyou County APCD	0.083333	0	Flat12Yr
T6 Public Class 5	Siskiyou County APCD	0.083333	0	Flat12Yr
T6 Public Class 6	Siskiyou County APCD	0.083333	0	Flat12Yr
T6 Public Class 7	Siskiyou County APCD	0.083333	0	Flat12Yr
T7 Tractor Class 8	Siskiyou County APCD	0.005952	0	Flat12Yr
T6 Public Class 4	South Coast AQMD	0.162558	0	Flat12Yr
T6 Public Class 5	South Coast AQMD	0.162558	0	Flat12Yr
T6 Public Class 6	South Coast AQMD	0.162558	0	Flat12Yr
T6 Public Class 7	South Coast AQMD	0.162558	0	Flat12Yr
T6 Utility Class 5	South Coast AQMD	0.005715	0	Flat12Yr
T6 Utility Class 6	South Coast AQMD	0.005715	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T6 Utility Class 7	South Coast AQMD	0.005715	0	Flat12Yr
T6 Instate Tractor Class 6	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Delivery Class 4	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Delivery Class 5	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Delivery Class 6	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Other Class 4	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Other Class 5	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Other Class 6	South Coast AQMD	0.007859	0	Flat12Yr
T6 Instate Tractor Class 7	South Coast AQMD	0.022221	0	Flat12Yr
T6 Instate Delivery Class 7	South Coast AQMD	0.022221	0	Flat12Yr
T6 Instate Other Class 7	South Coast AQMD	0.022221	0	Flat12Yr
T6 CAIRP Class 7	South Coast AQMD	0.000656	0	Flat12Yr
T7 Public Class 8	South Coast AQMD	-20.9769	0.010634	LinearGrowth
T7 CAIRP Class 8	South Coast AQMD	0.003645	0	Flat12Yr
T7 POAK Class 8	South Coast AQMD	0.002525	0	Flat12Yr
T7 POLA Class 8	South Coast AQMD	0.039228	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	South Coast AQMD	0.072393	0	Flat12Yr
T7 Single Dump Class 8	South Coast AQMD	0.072393	0	Flat12Yr
T7 Single Other Class 8	South Coast AQMD	0.072393	0	Flat12Yr
T7 Tractor Class 8	South Coast AQMD	0.026748	0	Flat12Yr
SBUS	South Coast AQMD	0.724926	0	Flat12Yr
All Other Buses	South Coast AQMD	0.249283	0	Flat12Yr
T7 Tractor Class 8	Tehama County APCD	0.005055	0	Flat12Yr
T7 Public Class 8	Ventura County APCD	0.041667	0	Flat12Yr
T7 CAIRP Class 8	Ventura County APCD	0.002506	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Ventura County APCD	0.032515	0	Flat12Yr
T7 Single Dump Class 8	Ventura County APCD	0.032515	0	Flat12Yr
T7 Single Other Class 8	Ventura County APCD	0.032515	0	Flat12Yr
T7 Tractor Class 8	Ventura County APCD	0.002381	0	Flat12Yr
SBUS	Ventura County APCD	0.037738	0	Flat12Yr
All Other Buses	Ventura County APCD	0.083333	0	Flat12Yr
T6 Instate Tractor Class 6	Yolo/Solano AQMD	0.012401	0	Flat12Yr
T6 Instate Delivery Class 4	Yolo/Solano AQMD	0.012401	0	Flat12Yr
T6 Instate Delivery Class 5	Yolo/Solano AQMD	0.012401	0	Flat12Yr
T6 Instate Delivery Class 6	Yolo/Solano AQMD	0.012401	0	Flat12Yr
T6 Instate Other Class 4	Yolo/Solano AQMD	0.012401	0	Flat12Yr
T6 Instate Other Class 5	Yolo/Solano AQMD	0.012401	0	Flat12Yr
T6 Instate Other Class 6	Yolo/Solano AQMD	0.012401	0	Flat12Yr

EMFAC 2021 Vehicle Category	Air District Name	Intercept	Slope	Prediction Class
T7 Public Class 8	Yolo/Solano AQMD	0.004386	0	Flat12Yr
T7 Single Concrete/Transit Mix Class 8	Yolo/Solano AQMD	0.045094	0	Flat12Yr
T7 Single Dump Class 8	Yolo/Solano AQMD	0.045094	0	Flat12Yr
T7 Single Other Class 8	Yolo/Solano AQMD	0.045094	0	Flat12Yr
T7 Tractor Class 8	Yolo/Solano AQMD	0.022099	0	Flat12Yr
All Other Buses	Yolo/Solano AQMD	0.144792	0	Flat12Yr

6.5 Dynamometer Test Data of Light Heavy-Duty Trucks from CARB Project 2R1702

Test Veh ID	Test Vehicle	Fuel	Odo (mi)	Test Cycle	HC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
1	2015 Dodge Ram 2500	Diesel	51,380	FTP-75	0.014	0.005	0.05	1.4	652
				MAC1	0.022	0.025	0.63	7.3	1,351
				MAC3	0.002	0.007	0.10	3.1	518
				MFC5	0.001	0.005	0.09	2.9	506
				MFC6	0.002	0.016	0.08	3.6	529
				MFC7	0.001	0.008	0.17	2.6	570
				HWFET	0.004	0.003	0.02	1.7	417
				UC	0.004	0.007	0.17	2.3	663
2	2017 Daimler Sprinter 2500	Diesel	22,860	FTP-75	0.007	0.015	0.03	2.1	604
				MAC1	0.011	0.015	0.06	3.5	1,026
				MAC3	0.008	0.010	0.02	3.5	504
				MFC5	0.003	0.013	0.06	1.8	547
				MFC6	0.000	0.015	0.08	2.1	592
				MFC7	0.000	0.021	0.11	1.6	667
				HWFET	0.005	0.007	0.06	2.2	482
				UC	0.039	0.047	0.14	54.4	703
3	2015 GM Silverado 2500	Diesel	64,600	FTP-75	0.044	0.140	0.56	17.3	912
				MAC1	0.149	1.606	0.57	6.5	1,532
				MAC3	0.012	0.097	0.13	3.0	525
				MFC5	0.008	0.069	0.11	1.7	479
				MFC6	0.004	0.016	0.09	3.2	502
				MFC7	0.004	0.007	0.10	1.7	552
				HWFET	0.005	0.004	0.27	1.3	411
				UC	0.038	0.237	0.28	8.7	744
4	2015 Ford F250	Diesel	30,460	FTP-75	0.081	0.029	0.27	2.5	723
				MAC1	0.044	0.131	0.77	1.8	1,176
				MAC3	0.006	0.213	0.08	1.9	470
				MFC5	0.041	0.071	0.34	1.4	486
				MFC6	0.005	0.053	0.18	1.7	505
				MFC7	0.004	0.026	0.18	1.5	553
				HWFET	0.008	0.032	0.01	1.7	396
				UC	0.031	0.051	0.28	1.7	612
5	2015 Ford F350	Diesel	70,630	FTP-75	0.019	0.016	0.16	3.6	661
				MAC1	0.029	0.387	2.34	2.6	1,289
				MAC3	0.006	0.020	0.24	1.9	528
				MFC5	0.002	0.023	0.63	1.4	553

Test Veh ID	Test Vehicle	Fuel	Odo (mi)	Test Cycle	HC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				MFC6	0.001	0.018	0.81	1.3	598
				MFC7	0.001	0.021	0.41	1.9	664
				HWFET	0.080	0.052	0.71	8.6	528
				UC	0.159	0.088	1.15	2.6	787
7	2017 Daimler Sprinter 3500	Diesel	8,630	FTP-75	0.004	0.012	0.02	0.9	565
				MAC1	0.010	0.061	0.14	2.2	955
				MAC3	0.002	0.017	0.08	1.3	480
				MFC7	0.000	0.023	0.32	1.1	645
				UC	0.002	0.011	0.06	1.7	623
8	2015 Dodge Ram 3500	Diesel	139,340	FTP-75	0.010	0.010	0.01	1.0	801
				MAC1	0.028	0.025	0.36	13.0	1,508
				MAC3	0.005	0.188	0.02	2.0	606
				MFC5	0.001	0.017	0.01	1.5	632
				MFC6	0.084	0.024	0.73	227	776
				MFC7	0.000	0.023	0.01	2.5	729
				HWFET	0.002	0.011	0.01	1.0	542
				UC	0.028	0.072	0.08	2.1	832
9	2015 GM Silverado 2500	Gasoline	42,400	FTP-75	0.007	0.014	0.01	0.3	766
				MAC1	0.050	1.683	0.01	3.3	1,412
				MAC3	0.006	0.159	0.01	0.4	535
				MFC5	0.006	0.179	0.01	0.7	526
				MFC6	0.009	0.910	0.03	0.7	544
				MFC7	0.007	0.619	0.02	0.9	604
				HWFET	0.003	0.271	0.01	0.4	456
				UC	0.008	0.404	0.02	1.0	700
10	2015 GM Sierra 2500	Gasoline	43,110	FTP-75	0.005	0.010	0.02	0.3	765
				MAC1	0.027	0.327	0.02	2.4	1,431
				MAC3	0.006	0.145	0.02	1.8	543
				MFC5	0.006	0.444	0.03	2.5	544
				MFC6	0.009	0.818	0.04	2.1	533
				MFC7	0.006	0.425	0.02	2.5	580
				HWFET	0.001	0.046	0.01	1.0	436
				UC	0.006	0.334	0.02	2.2	714
11	2015 GM Duramax	Diesel	24,570	FTP-75	0.04	0.24	0.01	3.5	862
				MAC1	0.04	0.26	0.50	15.3	1,492
				MAC3	0.00	0.15	0.09	0.4	551
				MFC5	0.01	0.08	0.06	1.4	556
				MFC6	0.00	0.02	0.33	2.1	587
				MFC7	0.00	0.02	0.27	0.8	606

Test Veh ID	Test Vehicle	Fuel	Odo (mi)	Test Cycle	HC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				HWFET	0.00	0.04	0.02	0.8	458
				UC	0.05	0.38	0.69	1.5	919
12	2006 Ford F250	Diesel	73,800	FTP-75	0.342	2.324	2.52	87.5	752
				MAC1	0.553	4.621	5.59	241	1,496
				MAC3	0.131	1.078	2.60	126	544
				MFC5	0.123	0.581	2.53	77.3	529
				MFC6	0.117	0.468	2.63	81.9	564
				MFC7	0.119	0.461	3.07	91.1	616
				HWFET	0.108	0.369	1.81	66.9	454
				UC	0.190	0.954	3.22	144	731
13	2006 GM Silverado 2500	Diesel	120,810	FTP-75	0.353	1.813	4.73	139	671
				MAC1	0.731	3.842	6.26	427	1,267
				MAC3	0.215	1.159	3.13	87.0	478
				MFC5	0.184	0.723	3.29	53.6	455
				MFC6	0.165	0.714	2.78	71.7	487
				MFC7	0.171	0.809	2.29	114	560
				HWFET	0.173	0.678	3.15	70.8	404
				UC	0.308	1.282	3.80	151	642

6.6 Dynamometer Test Data of Heavy Heavy-Duty Diesel Trucks from CARB Truck and Bus Surveillance Program

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
K-1	Paccar	2013	144,683	UDDS	0.008	0.509	0.96	0.5	1,978
				HHDT Creep	0.521	7.226	10.53	0.5	4,911
				Drayage Near Dock	0.078	1.244	4.12	2.0	2,127
				Drayage Local	0.018	0.398	1.38	0.9	2,074
				HHDT Cruise	0.005	0.025	0.17	1.3	1,261
				ARB HS Cruise	-	-	-	-	-
K-2	Paccar	2013	180,598	UDDS	0.008	0.082	2.65	8.6	2,005
				HHDT Creep	0.627	6.808	21.91	8.5	4,378
				Drayage Near Dock	0.225	0.859	13.88	2.8	2,148
				Drayage Local	0.102	0.320	7.87	2.0	2,028
				HHDT Cruise	0.005	0.012	0.47	12.3	1,365
				ARB HS Cruise	-	-	-	-	-
K-3	Paccar	2013	248,095	UDDS	0.007	0.394	0.55	3.7	2,096
				HHDT Creep	0.238	8.346	13.63	4.0	4,116
				Drayage Near Dock	0.050	1.036	2.87	2.4	2,379
				Drayage Local	0.022	0.321	1.61	2.5	2,122
				HHDT Cruise	0.004	0.037	0.22	6.7	1,367
				ARB HS Cruise	-	-	-	-	-
L-1	Cummins	2013	66,145	UDDS	0.017	0.003	4.92	1.7	2,048
				HHDT Creep	0.270	0.518	11.33	0.0	7,908
				Drayage Near Dock	0.079	0.013	4.11	2.1	2,949
				Drayage Local	0.059	0.003	5.22	3.1	2,303
				HHDT Cruise	0.010	0.003	1.25	2.4	1,226
				ARB HS Cruise	0.009	0.015	0.86	18.9	1,411
L-2	Cummins	2013	171,974	UDDS	0.022	0.014	9.65	4.9	2,098
				HHDT Creep	0.309	0.060	22.32	12.4	5,762
				Drayage Near Dock	0.137	0.033	10.70	3.5	2,511
				Drayage Local	0.082	0.077	9.42	4.0	2,383
				HHDT Cruise	0.013	0.024	1.95	5.4	1,367
				ARB HS Cruise	0.009	0.032	1.57	29.8	1,609
L-3	Cummins	2013	336,120	UDDS	0.021	0.043	6.01	7.1	2,217
				HHDT Creep	0.355	0.119	16.62	11.1	6,790
				Drayage Near Dock	0.110	0.063	7.91	4.0	2,853
				Drayage Local	0.038	0.043	5.70	3.2	2,461

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				HHDT Cruise	0.009	0.016	1.45	4.3	1,386
				ARB HS Cruise	0.007	0.018	1.43	16.9	1,641
M-1	Volvo	2014	187,291	UDDS	0.009	0.439	4.02	4.1	2,120
				HHDT Creep	0.193	8.693	38.65	2.8	4,319
				Drayage Near Dock	0.044	1.364	12.31	1.3	2,297
				Drayage Local	0.029	0.520	10.60	1.5	2,173
				HHDT Cruise	0.019	0.094	1.23	4.8	1,358
				ARB HS Cruise	0.011	0.087	1.32	9.5	1,519
M-2	Volvo	2014	370,454	UDDS	0.046	0.494	9.63	2.7	2,025
				HHDT Creep	0.332	11.541	43.82	2.7	3,792
				Drayage Near Dock	0.139	1.686	15.43	2.0	1,994
				Drayage Local	0.127	1.032	15.59	3.1	2,092
				HHDT Cruise	-	-	-	-	-
				ARB HS Cruise	0.020	0.099	6.04	-	1,443
M-3	Volvo	2014	72,055	UDDS	0.005	1.075	4.23	22.4	2,032
				HHDT Creep	0.125	5.550	34.90	4.2	3,701
				Drayage Near Dock	0.029	1.640	9.56	24.8	2,061
				Drayage Local	0.012	1.363	7.22	9.6	1,971
				HHDT Cruise	0.005	0.108	1.01	27.1	1,325
				ARB HS Cruise	0.003	0.105	0.84	16.5	1,470
N-1	DDC	2014	240,785	UDDS	0.009	0.032	1.58	1.2	2,019
				HHDT Creep	0.173	3.309	23.84	2.9	5,210
				Drayage Near Dock	0.042	0.296	6.51	1.8	2,029
				Drayage Local	0.023	0.053	3.42	0.7	1,928
				HHDT Cruise	0.008	0.031	0.48	0.6	1,202
				ARB HS Cruise	0.004	0.027	0.63	3.6	1,427
N-2	DD15	2014	177,394	UDDS	0.006	0.004	1.02	2.3	2,072
				HHDT Creep	0.124	0.451	17.77	0.0	4,550
				Drayage Near Dock	0.037	0.155	6.24	1.1	2,297
				Drayage Local	0.013	0.026	2.71	4.0	2,055
				HHDT Cruise	0.005	0.009	0.29	1.1	1,300
				ARB HS Cruise	0.002	0.004	0.16	4.9	1,482
N-3	DD15	2014	13,840	UDDS	0.004	0.006	0.46	3.4	2,003
				HHDT Creep	0.083	0.786	13.42	11.6	4,021
				Drayage Near Dock	0.021	0.016	3.33	2.3	2,012
				Drayage Local	0.010	0.009	1.75	1.6	1,874
				HHDT Cruise	0.002	0.009	0.17	2.1	1,289

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				ARB HS Cruise	0.001	0.019	0.27	0.0	1,441
O-1	Cummins	2014	144,194	UDDS	0.020	0.028	3.16	12.9	2,170
				HHDT Creep	0.413	0.488	8.19	4.5	9,864
				Drayage Near Dock	0.055	0.084	1.61	8.0	3,622
				Drayage Local	0.043	0.156	1.60	5.4	3,059
				HHDT Cruise	0.010	0.001	0.63	4.0	1,309
				ARB HS Cruise	0.008	0.013	0.23	67.8	1,469
O-2	Cummins	2014	185,078	UDDS	0.019	0.011	3.96	6.6	2,114
				HHDT Creep	0.303	0.000	14.17	4.9	8,969
				Drayage Near Dock	0.055	0.001	3.11	3.8	3,347
				Drayage Local	0.094	0.165	6.50	2.7	2,577
				HHDT Cruise	0.018	0.056	2.00	2.6	1,330
				ARB HS Cruise	0.014	0.033	1.59	27.6	1,464
O-3	Cummins	2014	112,134	UDDS	0.020	0.014	4.73	10.6	2,317
				HHDT Creep	0.263	0.001	11.48	6.6	8,796
				Drayage Near Dock	0.056	0.001	3.65	9.9	3,411
				Drayage Local	0.038	0.002	2.68	6.3	2,825
				HHDT Cruise	0.010	0.011	1.08	5.7	1,358
				ARB HS Cruise	0.007	0.023	0.83	41.0	1,564
P-1	Navistar	2014	132,796	UDDS	0.008	0.023	0.36	9.0	2,121
				HHDT Creep	0.387	5.343	9.32	7.9	5,094
				Drayage Near Dock	0.078	0.224	2.47	6.7	2,261
				Drayage Local	0.038	0.482	0.81	4.1	2,178
				HHDT Cruise	0.003	0.023	0.14	5.5	1,374
				ARB HS Cruise	-	-	-	-	-
P-2	Navistar	2014	179,350	UDDS	0.015	0.005	1.30	6.2	2,143
				HHDT Creep	1.151	1.759	14.73	9.4	5,530
				Drayage Near Dock	0.175	0.282	4.39	3.0	2,342
				Drayage Local	0.073	0.800	2.19	4.9	2,234
				HHDT Cruise	0.008	0.066	0.50	5.1	1,371
				ARB HS Cruise	0.007	0.011	0.28	38.0	1,648
Q-2	DDC	2015	219,059	UDDS	0.003	0.021	0.95	6.4	2,012
				HHDT Creep	0.116	5.256	19.07	3.9	3,669
				Drayage Near Dock	0.064	0.137	4.33	4.8	1,924
				Drayage Local	0.014	0.165	2.29	4.2	1,911
				HHDT Cruise	0.006	0.027	0.32	4.3	1,322
				ARB HS Cruise	0.001	0.011	0.26	14.7	1,623

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
R-1	Paccar	2014	290,981	UDDS	0.004	1.109	0.20	3.3	1,885
				HHDT Creep	0.208	2.575	9.28	10.3	4,359
				Drayage Near Dock	0.065	1.086	3.52	6.9	1,892
				Drayage Local	0.014	1.203	1.61	5.8	1,856
				HHDT Cruise	0.001	0.137	0.05	2.5	1,429
				ARB HS Cruise	0.001	0.017	0.01	2.6	1,691
R-2	Paccar	2014	275,565	UDDS	0.006	0.774	0.58	5.5	1,588
				HHDT Creep	0.672	13.891	8.04	12.3	3,766
				Drayage Near Dock	0.088	0.993	3.24	8.1	1,953
				Drayage Local	0.026	0.331	1.54	4.0	1,706
				HHDT Cruise	0.003	0.120	0.07	1.4	1,012
				ARB HS Cruise	0.003	0.000	0.15	7.3	1,154
R-3	Paccar	2014	234,326	UDDS	0.005	0.372	0.71	4.8	2,056
				HHDT Creep	0.140	1.041	9.87	12.9	5,158
				Drayage Near Dock	0.030	0.376	4.54	7.7	2,087
				Drayage Local	0.015	0.263	2.32	2.5	1,974
				HHDT Cruise	0.004	0.028	0.11	1.7	1,430
				ARB HS Cruise	0.002	0.001	0.06	1.3	1,578
V1-1	Volvo	2015	308,919	UDDS	0.004	0.183	2.66	7.4	1,916
				HHDT Creep	0.111	1.741	23.46	8.4	3,941
				Drayage Near Dock	0.017	0.640	6.58	5.6	2,024
				Drayage Local	0.014	0.359	6.13	1.0	1,968
				HHDT Cruise	0.011	0.021	0.94	19.6	1,198
				ARB HS Cruise	0.002	0.025	0.19	2.8	1,231
V1-2	Volvo	2015	511,406	UDDS	0.007	0.893	6.33	2.9	2,013
				HHDT Creep	0.098	3.439	25.32	2.6	3,655
				Drayage Near Dock	0.034	1.263	14.16	2.9	2,147
				Drayage Local	0.018	0.385	12.21	1.2	2,001
				HHDT Cruise	0.012	0.082	1.53	1.8	1,315
				Modified HS Cruise	0.007	0.263	1.75	n/a	1,484
V1-3	Volvo	2015	128,370	UDDS	0.004	0.338	3.76	1.5	1,647
				HHDT Creep	0.072	0.854	52.59	7.9	6,418
				Drayage Near Dock	0.017	0.525	17.75	3.5	2,350
				Drayage Local	0.008	0.180	10.57	3.0	1,954
				HHDT Cruise	0.002	0.069	0.74	0.7	927
				Modified HS Cruise	0.003	0.194	0.90	2.0	986

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
V2-1	Cummins	2015	241,304	UDDS	0.005	0.012	3.06	13.4	2,247
				HHDT Creep	0.240	0.041	14.04	14.6	6,849
				Drayage Near Dock	0.094	0.007	6.07	9.6	2,719
				Drayage Local	0.031	0.002	1.87	5.4	2,531
				HHDT Cruise	0.006	0.013	0.36	18.2	1,603
				ARB HS Cruise	0.004	0.016	0.33	26.7	1,959
V2-2	Cummins	2015	454,320	UDDS	0.017	0.130	2.78	8.0	2,091
				HHDT Creep	0.282	0.199	14.60	8.3	5,318
				Drayage Near Dock	0.150	0.234	7.66	5.0	2,547
				Drayage Local	0.076	0.120	4.96	3.4	2,253
				HHDT Cruise	0.014	0.046	0.44	27.7	1,357
				ARB HS Cruise	0.007	0.060	0.48	79.3	1,595
V3-1	DDC	2014	134,539	UDDS	0.004	0.024	0.43	3.3	2,154
				HHDT Creep	0.060	0.393	10.47	3.9	3,935
				Drayage Near Dock	0.026	0.096	3.64	2.2	2,079
				Drayage Local	0.020	0.038	2.16	2.3	2,044
				HHDT Cruise	0.007	0.024	0.52	3.8	1,544
				Modified HS Cruise	0.002	0.019	0.48	9.9	1,739
V3-2	DDC	2015	333,687	UDDS	0.004	0.040	0.94	0.8	2,003
				HHDT Creep	0.160	3.683	16.10	0.6	3,470
				Drayage NearDock	0.035	0.282	5.43	n/a	2,068
				Drayage Local	0.025	0.076	2.76	0.4	1,799
				HHDT Cruise	0.010	0.018	0.31	0.2	1,235
				Modified HS Cruise	0.005	0.013	0.40	2.9	1,379
V4-1-2	Paccar	2015	194,575	UDDS	0.004	0.098	0.12	3.1	1,981
				HHDT Creep	0.171	0.911	10.04	9.6	4,054
				Drayage NearDock	0.051	0.351	3.54	2.1	2,084
				Drayage Local	0.014	0.140	1.38	3.2	1,945
				HHDT Cruise	0.001	0.008	0.01	1.6	1,307
				Modified HS Cruise	0.001	0.004	0.05	1.9	1,480
V4-2	Paccar	2015	128,288	UDDS	0.004	0.052	0.31	2.0	1,840
				HHDT Creep	0.680	3.949	17.32	71.8	4,321
				Drayage NearDock	0.084	0.405	3.91	2.5	1,872
				Drayage Local	0.018	0.190	1.94	0.7	1,786
				HHDT Cruise	0.001	0.010	0.02	1.4	1,344

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				Modified HS Cruise	0.001	0.014	0.03	3.1	1,495
V6-1	Navistar	2016	13,769	UDDS	0.008	0.028	0.87	3.0	2,001
				HHDT Creep	0.824	1.402	16.98	8.9	4,875
				Drayage NearDock	0.121	0.198	4.63	33.4	2,484
				Drayage Local	0.036	0.080	2.96	1.1	2,054
				HHDT Cruise	0.002	0.003	0.34	0.9	1,314
				Modified HS Cruise	0.003	0.002	0.25	1.7	1,464
V7-1	Paccar	2016	149,709	UDDS	0.004	0.291	0.36	2.0	1,871
				HHDT Creep	0.189	2.137	15.13	0.0	4,442
				Drayage NearDock	0.052	0.280	3.74	2.6	1,971
				Drayage Local	0.016	0.296	2.00	1.4	1,899
				HHDT Cruise	0.003	0.009	0.03	1.7	1,368
				Modified HS Cruise	0.002	0.021	0.03	2.7	1,511
V7-3	Paccar	2016	212,460	UDDS	0.004	0.210	0.25	3.1	2,046
				HHDT Creep	0.740	7.491	17.58	4.4	4,630
				Drayage NearDock	0.085	0.793	4.67	5.8	2,036
				Drayage Local	0.016	0.302	1.77	2.3	1,930
				HHDT Cruise	0.001	0.035	0.04	1.5	1,577
				Modified HS Cruise	0.001	0.002	0.06	3.9	1,765
V8-1	Cummins	2016	98,594	UDDS	0.018	0.043	2.55	4.2	1,719
				HHDT Creep	0.247	0.010	6.60	24.8	9,171
				Drayage NearDock	0.080	0.043	4.91	3.5	2,644
				Drayage Local	0.029	0.087	3.14	1.9	2,294
				HHDT Cruise	0.009	0.012	0.70	1.2	1,085
				Modified HS Cruise	0.008	0.005	1.17	2.6	1,162
V8-2	Cummins	2016	62,107	UDDS	0.007	0.006	3.17	8.6	2,315
				HHDT Creep	0.314	0.011	10.95	28.1	9,275
				Drayage NearDock	0.075	0.018	4.11	5.0	3,345
				Drayage Local	0.035	0.018	2.74	5.9	2,766
				HHDT Cruise	0.003	0.010	0.36	6.9	1,624
				Modified HS Cruise	0.003	0.009	0.37	34.6	1,823
V9-1	Volvo	2018	54,343	UDDS	0.014	0.138	4.05	2.3	2,053
				HHDT Creep	0.550	0.673	24.02	7.2	4,373
				Drayage NearDock	0.140	0.223	9.67	2.7	2,230

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				Drayage Local	0.044	0.058	6.16	1.5	2,153
				HHDT Cruise	0.008	0.000	1.05	0.9	1,311
				Modified HS Cruise	0.008	0.011	2.98	3.6	1,542
V10-1	DDC	2016	284,928	UDDS	0.001	0.007	0.11	1.6	2,072
				HHDT Creep	0.118	1.098	22.67	4.2	4,026
				Drayage NearDock	0.068	0.393	4.87	8.2	2,076
				Drayage Local	0.023	0.338	1.83	12.0	2,020
				HHDT Cruise	0.005	0.012	0.20	2.5	1,523
				Modified HS Cruise	0.001	0.012	0.17	4.4	1,701
V10-2	DDC	2016	120,588	UDDS	0.005	0.027	0.33	n/a	2,123
				HHDT Creep	0.139	6.500	22.23	n/a	3,664
				Drayage NearDock	0.049	0.354	5.14	n/a	2,027
				Drayage Local	0.017	0.279	1.55	n/a	1,945
				HHDT Cruise	0.002	0.007	0.22	n/a	1,532
				Modified HS Cruise	0.002	0.010	0.20	n/a	1,696
V11-1	DDC	2017	170,529	UDDS	0.008	0.114	0.19	3.7	1,925
				HHDT Creep	0.087	1.023	14.96	0.8	3,177
				Drayage NearDock	0.067	0.205	5.18	1.6	1,870
				Drayage Local	0.032	0.102	2.33	1.2	1,814
				HHDT Cruise	0.004	0.013	0.30	1.4	1,199
				Modified HS Cruise	0.002	0.007	0.10	2.5	1,319
V12-1	Volvo	2016	101,767	UDDS	0.002	0.642	3.47	1.8	1,661
				HHDT Creep	0.051	0.604	39.98	2.3	5,950
				Drayage NearDock	0.007	0.417	16.24	6.1	2,437
				Drayage Local	0.004	0.116	7.34	2.2	1,958
				HHDT Cruise	0.001	0.026	0.70	1.7	959
				Modified HS Cruise	0.001	0.340	0.28	3.2	1,053
V13-1	HINO	2013	151,150	UDDS	0.005	0.000	1.05	1.8	1,100
				HHDT Creep	0.064	0.614	9.43	5.5	3,029
				Drayage NearDock	0.025	0.140	3.25	1.1	1,275
				Drayage Local	0.016	0.009	2.47	0.3	1,155
				HHDT Cruise	0.006	0.000	0.34	0.1	780
				Modified HS Cruise	0.005	0.000	0.24	1.3	855
V15-1		2019	24,228	UDDS	0.024	0.021	1.92	3.5	1,999

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
	Cummins			HHDT Creep	0.499	0.399	11.66	23.3	4,295
				Drayage NearDock	0.359	0.102	5.71	5.7	2,143
				Drayage Local	0.170	0.054	3.58	3.4	1,969
				HHDT Cruise	0.015	0.016	0.27	7.2	1,454
				Modified HS Cruise	0.011	0.018	0.43	13.4	1,638

6.7 Dynamometer Test Data of Medium Heavy-Duty Diesel Trucks from CARB Surveillance Program for On-Road Class 4-6 Heavy-Duty Vehicles

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
Veh 1	Cummins	2014	143,200	UDDS	0.005	0.115	0.46	0.7	1,153
				HHDDT Creep	0.810	0.390	8.57	5.0	3,289
				Parcel Delivery	0.003	0.130	0.89	2.4	1,538
				HHDDT Transient	0.000	0.111	0.95	0.9	1,100
				Local Cycle	0.000	0.055	0.56	2.5	989
				HHDDT Cruise	0.000	0.052	0.31	0.7	821
				Modified HS Cruise	0.001	0.043	0.52	2.1	948
Veh 2	Cummins	2015	58,475	UDDS	0.000	0.079	0.01	2.2	1,135
				HHDDT Creep	0.285	0.487	6.18	0.3	3,719
				Parcel Delivery	0.002	0.150	0.10	1.6	1,528
				HHDDT Transient	0.000	0.091	0.03	1.2	1,081
				Local Cycle	0.000	0.036	0.03	2.1	957
				HHDDT Cruise	0.000	0.052	0.02	0.6	820
				Modified HS Cruise	0.000	0.040	0.04	0.9	907
Veh 3	Cummins	2015	92,914	UDDS	0.000	0.084	0.05	1.1	1,142
				HHDDT Creep	0.506	0.478	6.41	1.0	3,357
				Parcel Delivery	0.000	0.160	0.11	1.1	1,517
				HHDDT Transient	0.000	0.101	0.01	-	1,048
				Local Cycle	0.001	0.054	0.05	1.5	978
				HHDDT Cruise	0.000	0.061	0.01	0.3	826
				Modified HS Cruise	0.000	0.046	0.03	0.8	954
Veh 4	Ford	2014	69,309	UDDS	0.000	0.114	1.01	1.5	862
				HHDDT Creep	0.000	1.420	9.36	5.1	2,499
				Parcel Delivery	0.007	0.176	1.61	0.7	1,135
				HHDDT Transient	0.022	0.114	1.37	0.1	790
				Local Cycle	0.002	0.062	0.24	5.3	774
				HHDDT Cruise	0.002	0.066	0.05	1.5	695
				Modified HS Cruise	0.000	0.047	0.18	9.1	778
Veh 5	Cummins	2017	155,537	UDDS	0.010	0.006	0.02	3.9	1,129
				Creep	0.699	0.051	7.11	6.6	3,185
				Drayage Near Dock	0.207	0.020	2.47	4.5	1,386
				Drayage Local	0.069	0.011	1.09	2.7	1,337
				Cruise	0.007	0.006	0.05	3.4	777
				Modified HS Cruise	0.007	0.008	0.07	6.7	857
VJ-1	Isuzu	2013	96,562	UDDS	0.002	0.642	3.47	1.8	1,661

Test Vehicle	Engine Make	Engine MY	Odometer (mi)	Test Cycle	THC (g/mi)	CO (g/mi)	NOx (g/mi)	PM (mg/mi)	CO2 (g/mi)
				Creep	0.051	0.604	39.98	2.3	5,950
				Drayage Near Dock	0.007	0.417	16.24	6.1	2,437
				Drayage Local	0.004	0.116	7.34	2.2	1,958
				Cruise	0.001	0.026	0.70	1.7	959
				Modified HS Cruise	0.001	0.340	0.28	3.2	1,053
V13-1	Hino	2013	151,150	UDDS	0.005	0.000	1.05	1.8	1,100
				Creep	0.064	0.614	9.43	5.5	3,029
				Drayage Near Dock	0.025	0.140	3.25	1.1	1,275
				Drayage Local	0.016	0.009	2.47	0.3	1,155
				Cruise	0.006	0.000	0.34	0.1	780
				Modified HS Cruise	0.005	0.000	0.24	1.3	855
V16-1	Cummins	2017	29,204	UDDS	0.011	0.012	0.49	3.3	1,960
				Creep	0.069	0.039	3.69	20.6	6,169
				Drayage Near Dock	0.027	0.019	0.98	7.3	2,459
				Drayage Local	0.012	0.017	0.68	5.2	2,121
				Cruise	0.003	0.008	0.37	2.1	1,585
				Modified HS Cruise	0.004	0.009	0.39	4.3	1,764

6.8 Mapping of CEC Vehicle Classes to EMFAC Vehicle Classes

As mentioned in Section 0, CEC's 18 vehicle classes (e.g., Car-Compact and Cross/Ut-midsize) are mapped to EMFAC vehicle classes (i.e., LDA, LDT1, LDT2, and MDV), utilizing 2019 DMV registration data as well as EMFAC and CEC's classification guides. Tables 1 shows the mapping for light-duty vehicles (sum of all fuel types) and table 2 shows the mapping of ZEVs in the base year 2019. The mapping for all fuel types and for ZEVs are found to be very different for three CEC vehicle classes (i.e., cross/ut-midsize, cross/ut-small-trk, and sport/ut-compact) in the base year. This is because there are few ZEV models for these classes in the market and how they are classified by EMFAC and CEC determines the result of the mapping. As the ZEV market is still growing and introducing more models, ZEV's vehicle class mapping is expected to be closer to the mapping of conventional vehicles. Therefore, staff assumes that the ZEV's and LDV (of all fuel types)'s mapping for these 3 categories reach the same in 2030. When mapping ZEV new sales from CEC vehicle classes to EMFAC vehicle classes, their percentages were interpolated between 2019 (following the mapping for ZEV) and 2030 (following the mapping for LDV, the sum of all fuel types).

Table 1. The percentage of CEC vehicle classes that are classified into different EMFAC light-duty vehicle classes for the sum of all fuel types in the base year 2019.

Type	LDA	LDT1	LDT2	MDV
Car-Subcompact	100%	0%	0%	0%
Car-Compact	100%	0%	0%	0%
Car-Midsize	100%	0%	0%	0%
Car-Large	100%	0%	0%	0%
Car-Sport	100%	0%	0%	0%
Cross/Ut-Small-Car	100%	0%	0%	0%
Cross/Ut-Small-Trk	22%	1%	63%	14%
Cross/Ut-Midsize	36%	0%	42%	22%
Sport/Ut-Compact	13%	19%	59%	9%
Sport/Ut-Midsize	0%	0%	64%	36%
Sport/Ut-Large	19%	0%	0%	81%
Van-Compact	0%	14%	79%	7%
Van-Std	0%	0%	0%	100%
Van-Heavy	0%	0%	0%	17%
Pickup-Compact	0%	0%	100%	0%
Pickup-Std	0%	0%	46%	54%
Pickup-Heavy	0%	0%	0%	0%

Table 2. The percentage of CEC vehicle classes that can be classified into EMFAC light-duty vehicle classes for zero-emission vehicles in the base year 2019.

Type	LDA	LDT1	LDT2	MDV
Car-Subcompact	100%	0%	0%	0%
Car-Compact	100%	0%	0%	0%
Car-Midsize	100%	0%	0%	0%
Car-Large	100%	0%	0%	0%
Car-Sport	100%	0%	0%	0%
Cross/Ut-Small-Car	100%	0%	0%	0%
Cross/Ut-Small-Trk	36%	0%	61%	2%
Cross/Ut-Midsize	100%	0%	0%	0%
Sport/Ut-Compact	100%	0%	0%	0%
Van-Compact	0%	0%	0%	100%

6.9 Heavy Duty VMT Distribution by Hour Figures

Figure (a). VMT distribution by hour of Out-of-state HD Vehicles (including T6 CAIRP, T6 OOS, T7 CAIRP, T7 NOOS, T7 NNOOS, Motor Coach) in EMFAC2021 and EMFAC2017

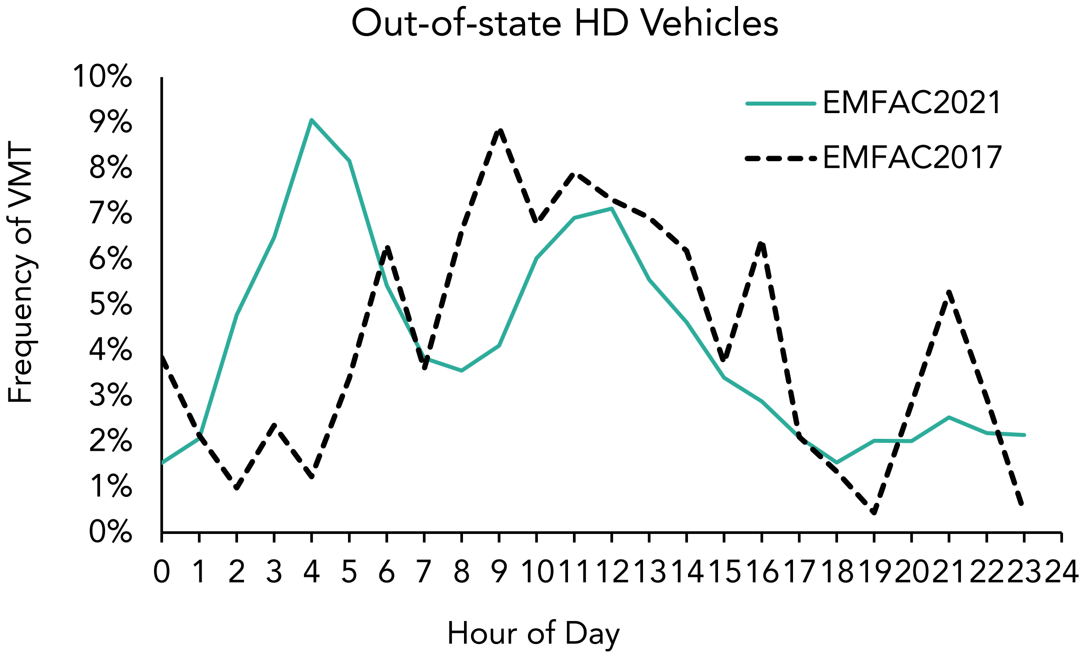


Figure (b). VMT distribution by hour of SBUS in EMFAC2021 and EMFAC2017

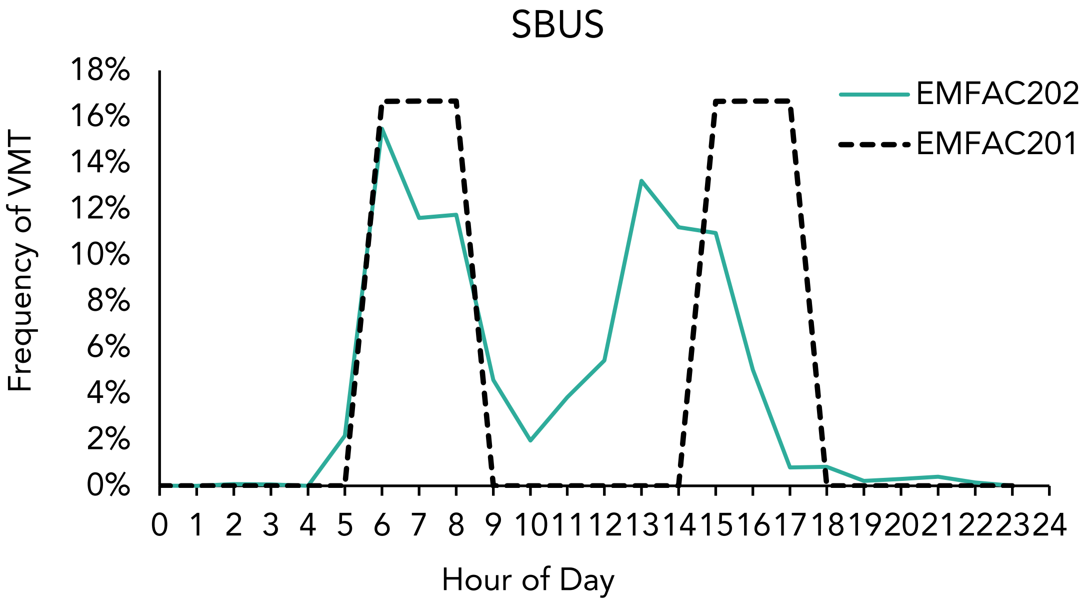


Figure (c). VMT distribution by hour of T6 Instate Delivery in EMFAC2021 and EMFAC2017

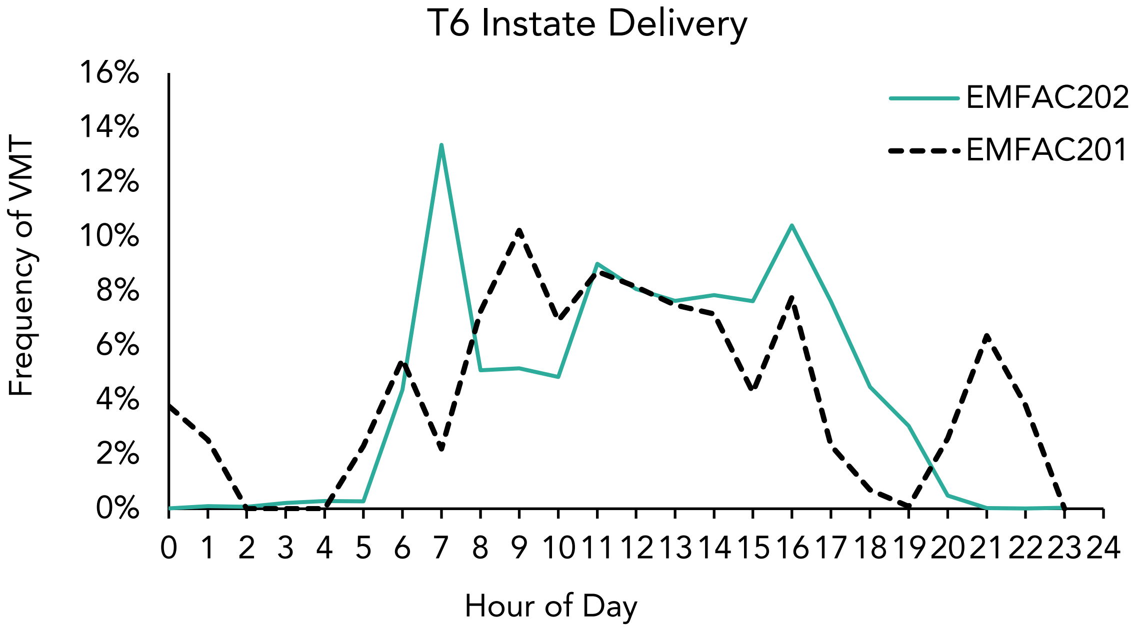


Figure (d). VMT distribution by hour of T6 Instate Tractor/Others in EMFAC2021 and EMFAC2017

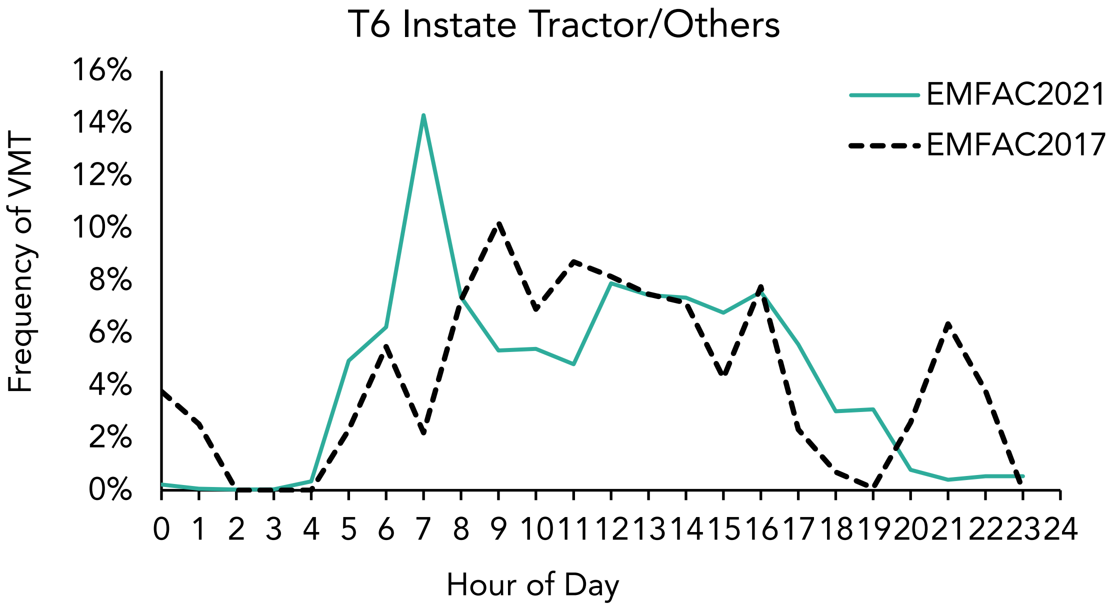


Figure (e). VMT distribution by hour of T7 POLA in EMFAC2021 and EMFAC2017

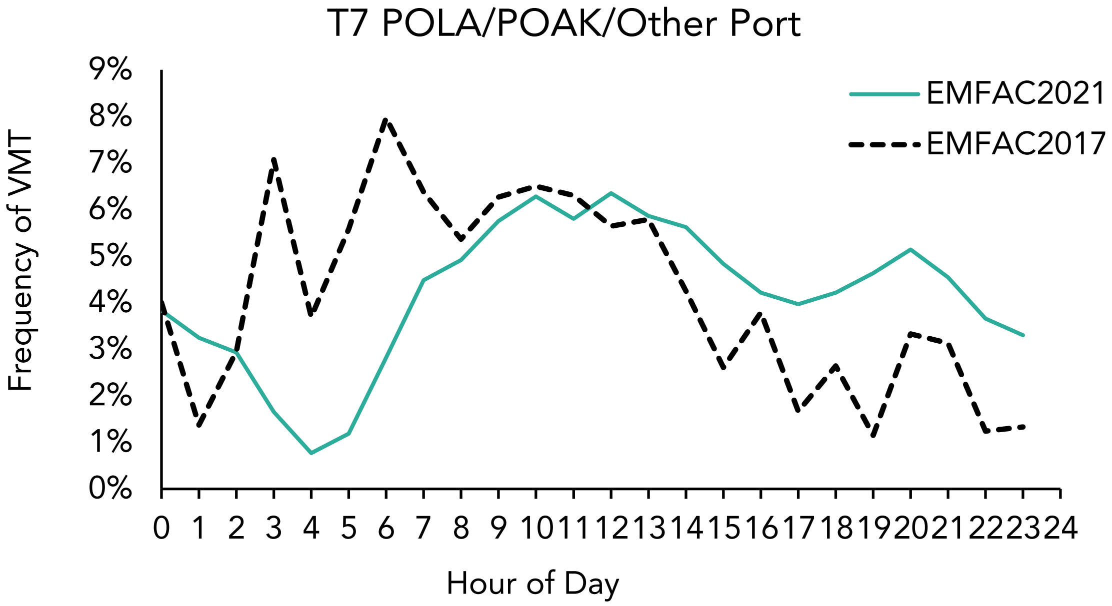


Figure (f). VMT distribution by hour of T7 Single in EMFAC2021 and EMFAC2017

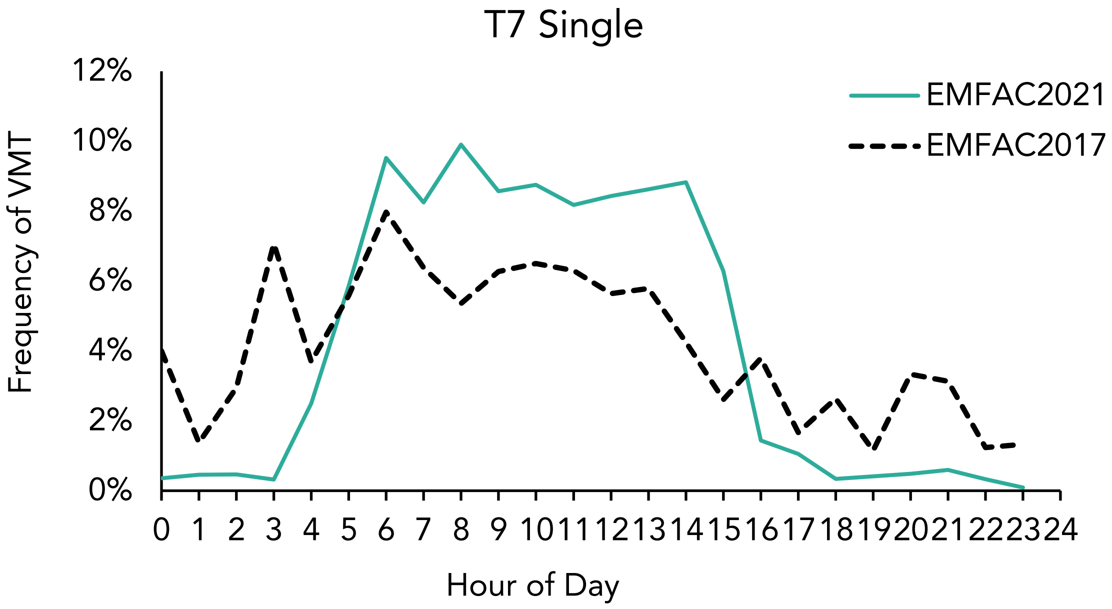


Figure (g). VMT distribution by hour of T7 SWCV in EMFAC2021 and EMFAC2017

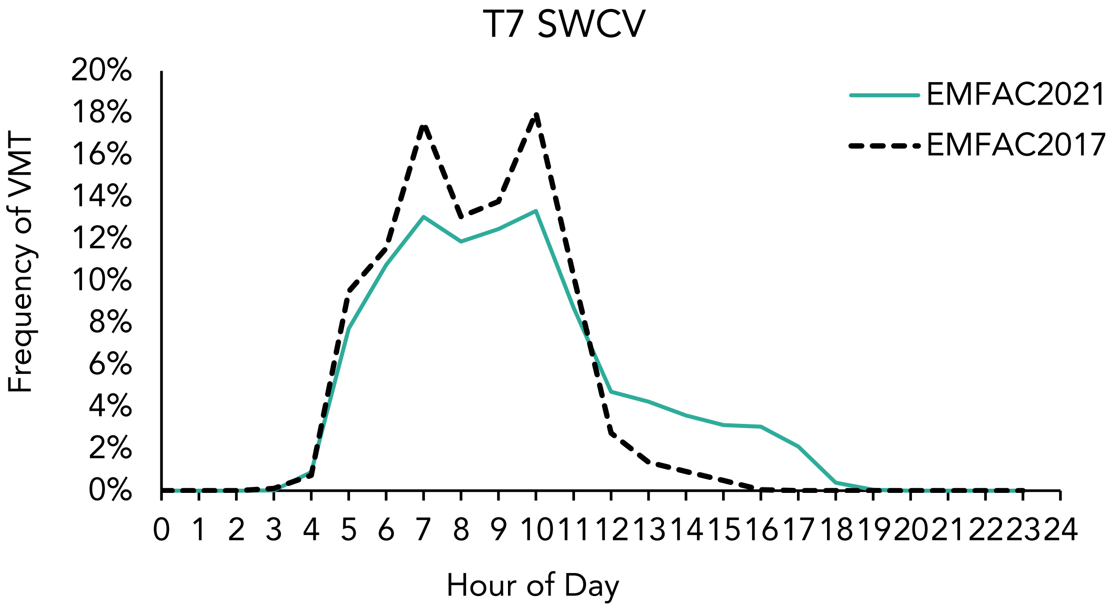


Figure (h). VMT distribution by hour of T7 Tractor in EMFAC2021 and EMFAC2017

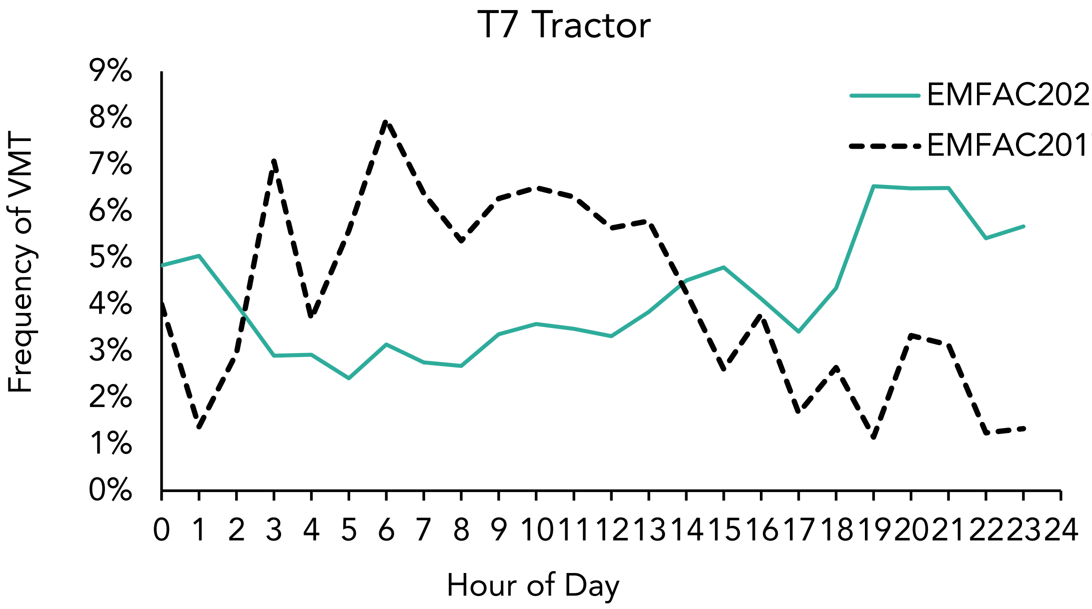
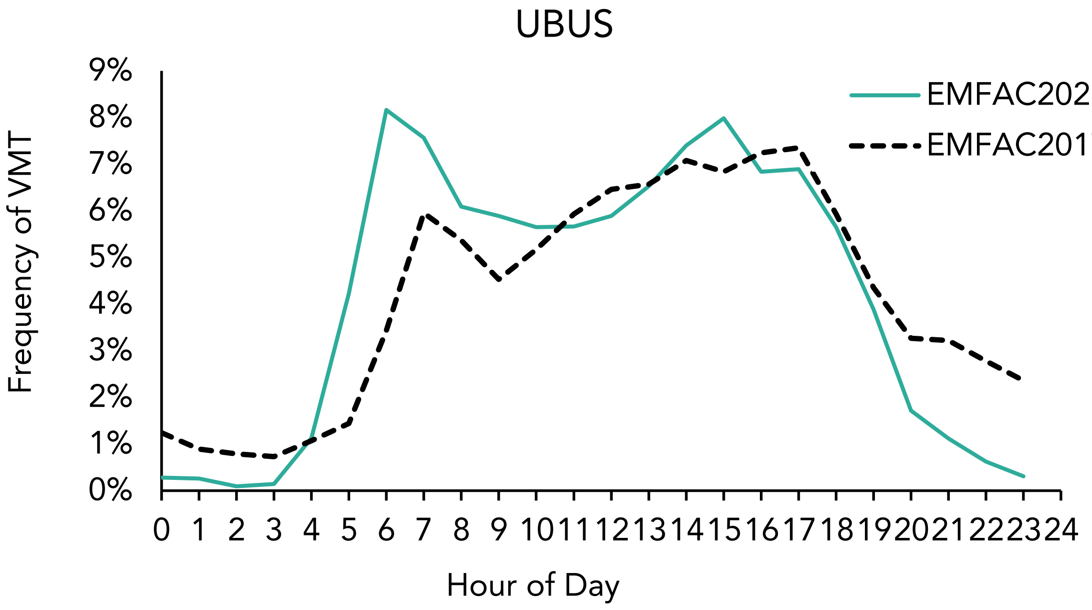


Figure (i). VMT distribution by hour of UBUS in EMFAC2021 and EMFAC2017



6.10 Heavy Duty VMT Distribution by Speed Figures

Figure (a). VMT distribution by speed of Out-of-state HD Vehicles (including T6 CAIRP, T6 OOS, T7 CAIRP, T7 NOOS, T7 NNOOS, Motor Coach) in EMFAC2021 and EMFAC2017

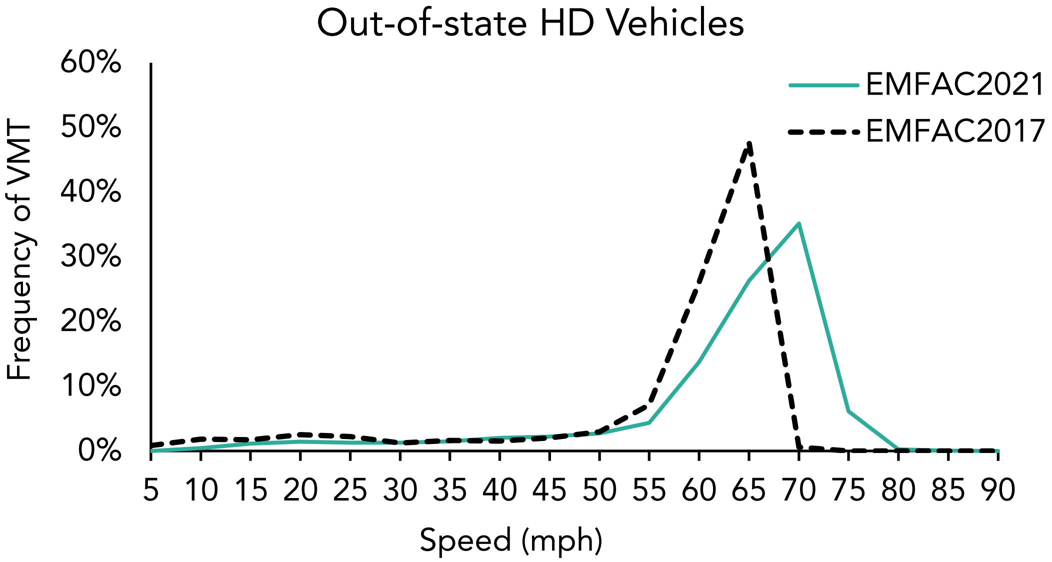


Figure (b). VMT distribution by speed of SBUS in EMFAC2021 and EMFAC2017

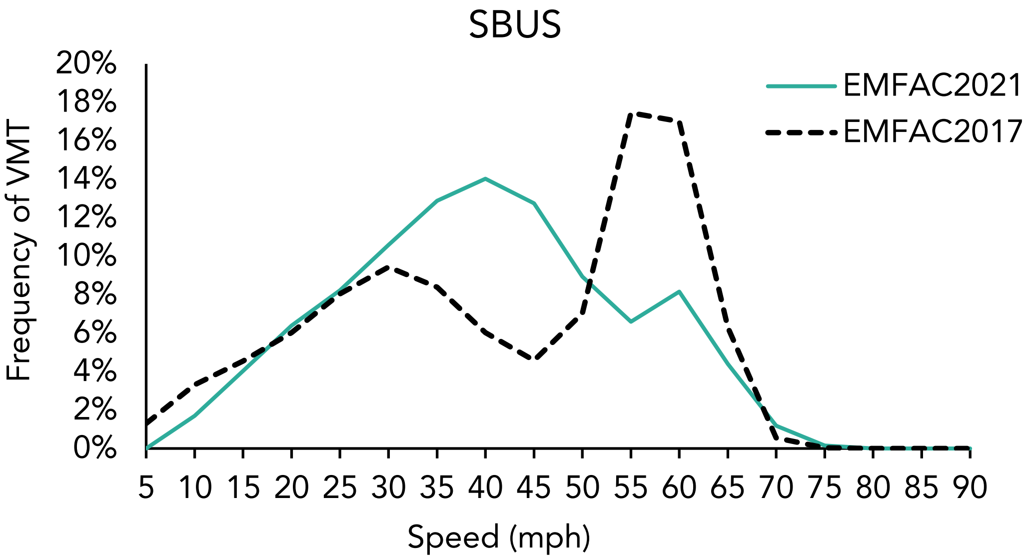


Figure (c). VMT distribution by speed of T6 Instate Delivery in EMFAC2021 and EMFAC2017

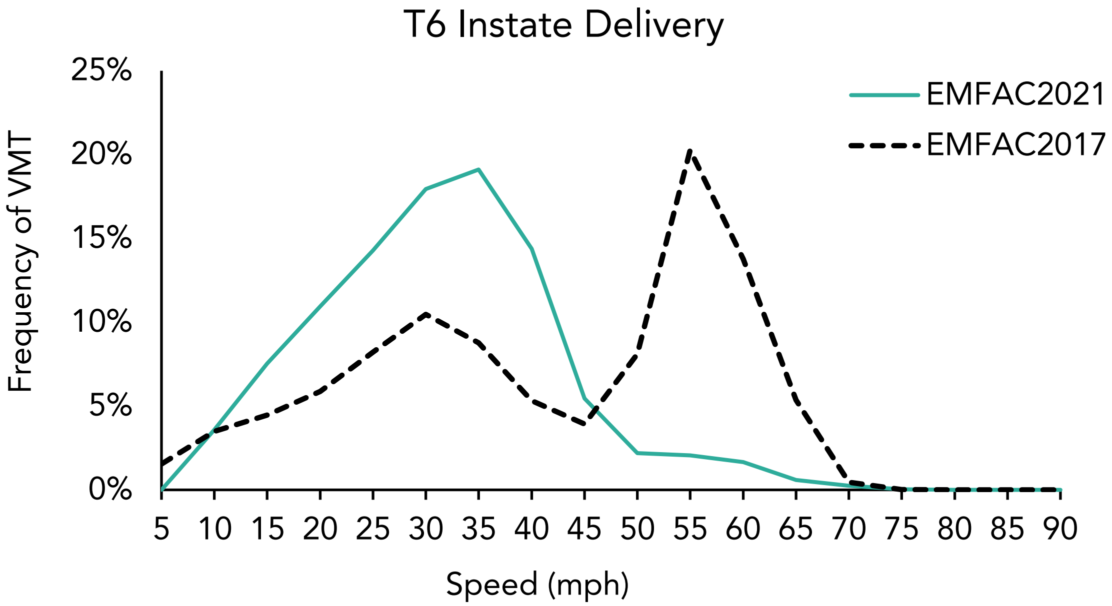


Figure (d). VMT distribution by speed of T6 Instate Tractor/Others in EMFAC2021 and EMFAC2017

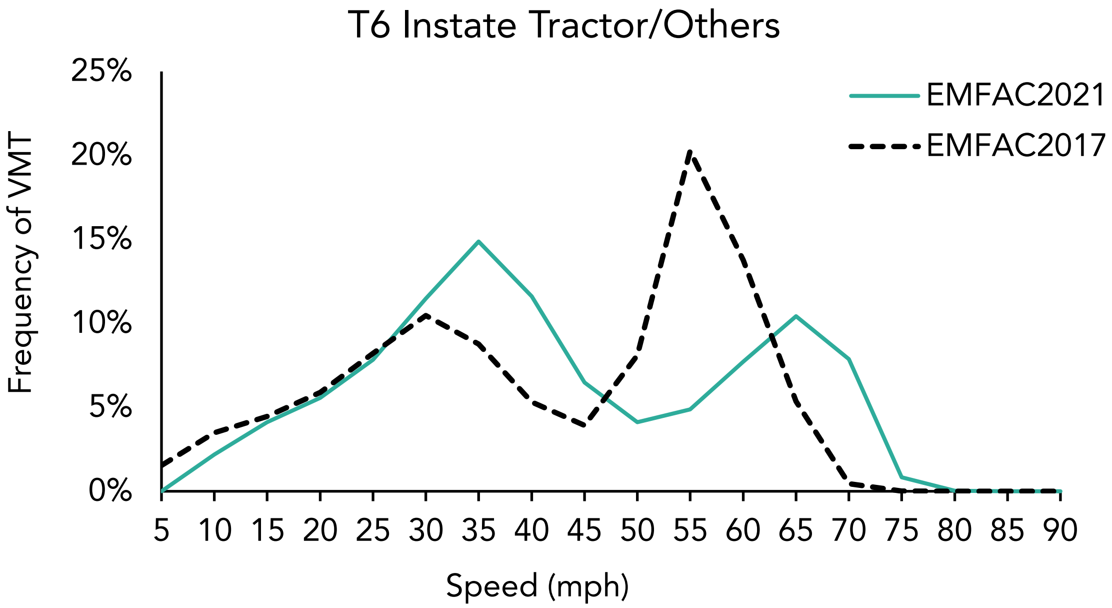


Figure (e). VMT distribution by speed of T7 POLA in EMFAC2021 and EMFAC2017

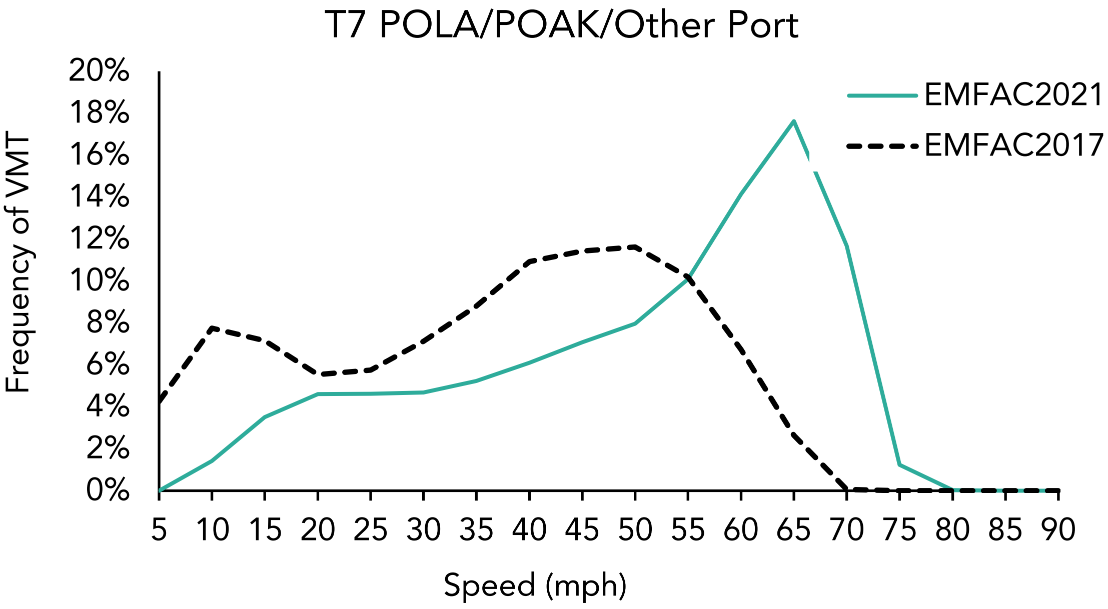


Figure (f). VMT distribution by speed of T7 Single in EMFAC2021 and EMFAC2017

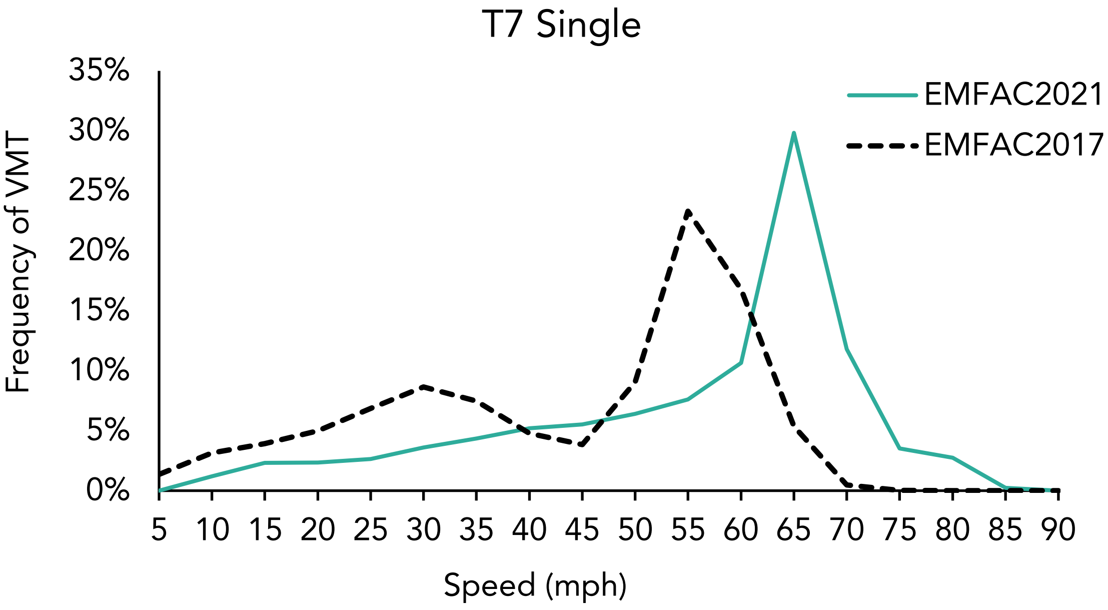


Figure (g). VMT distribution by speed of T7 SWCV in EMFAC2021 and EMFAC2017

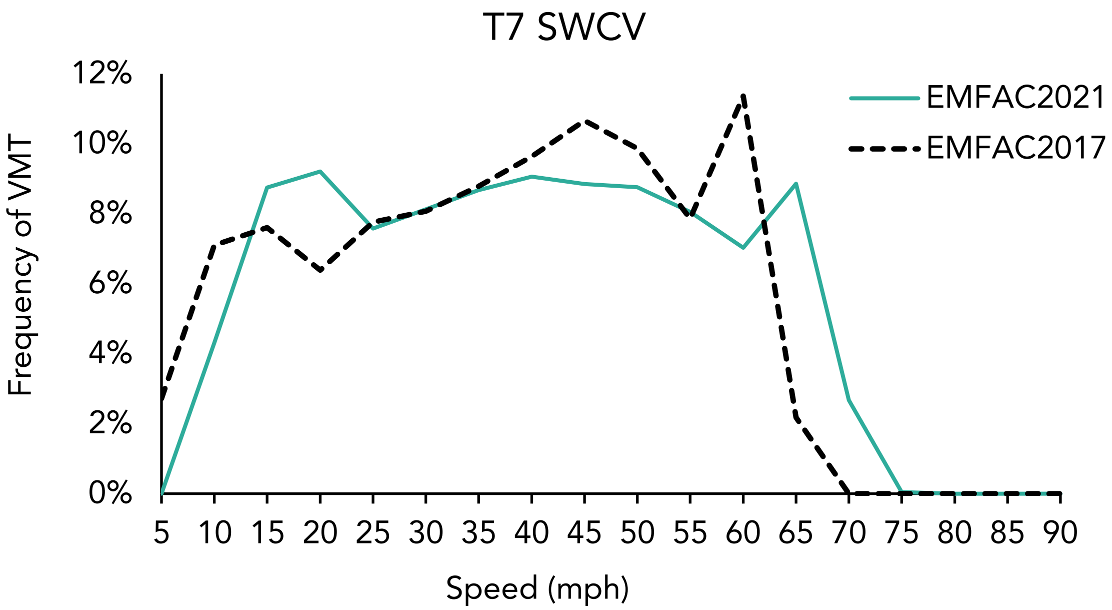


Figure (h). VMT distribution by speed of T7 Tractor in EMFAC2021 and EMFAC2017

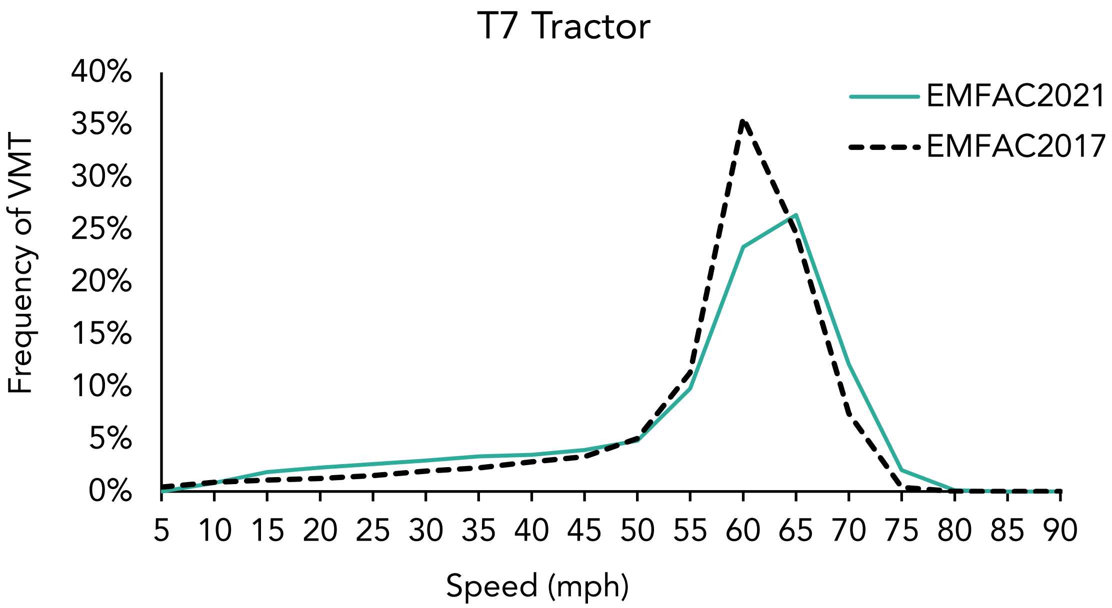
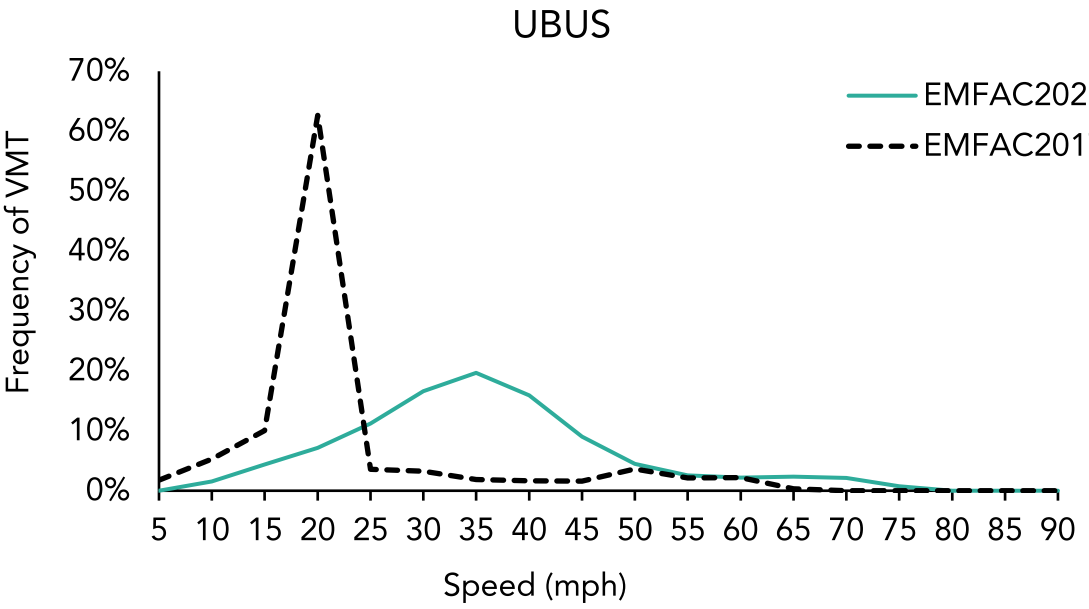


Figure (i). VMT distribution by hour of UBUS in EMFAC2021 and EMFAC2017



6.11 Engine Starts Distribution by Hour Figure

Figure (a). Engine starts distribution by hour of Out-of-states trucks in EMFAC2021

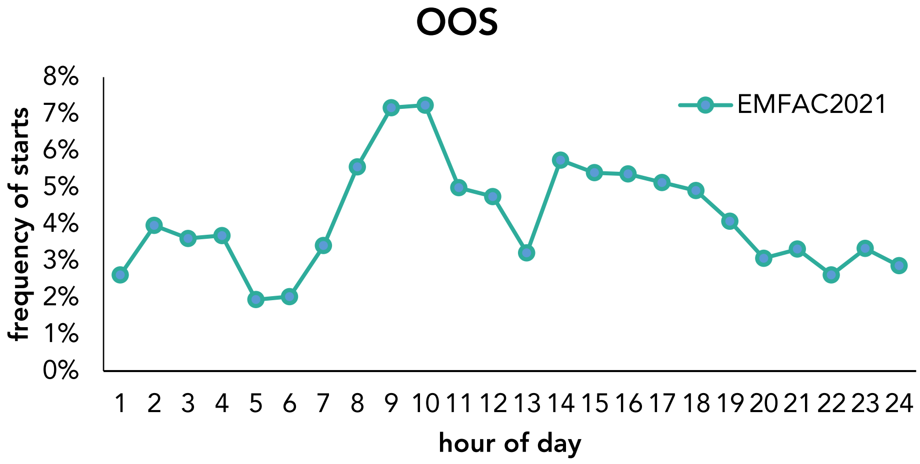


Figure (b). Engine starts distribution by hour of T6 Instate Delivery in EMFAC2021

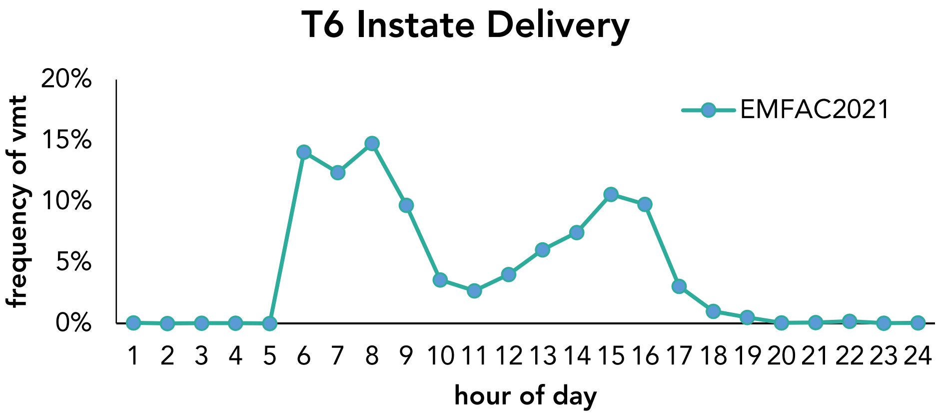


Figure (c). Engine starts distribution by hour of T6 Instate Tractor/Other in EMFAC2021

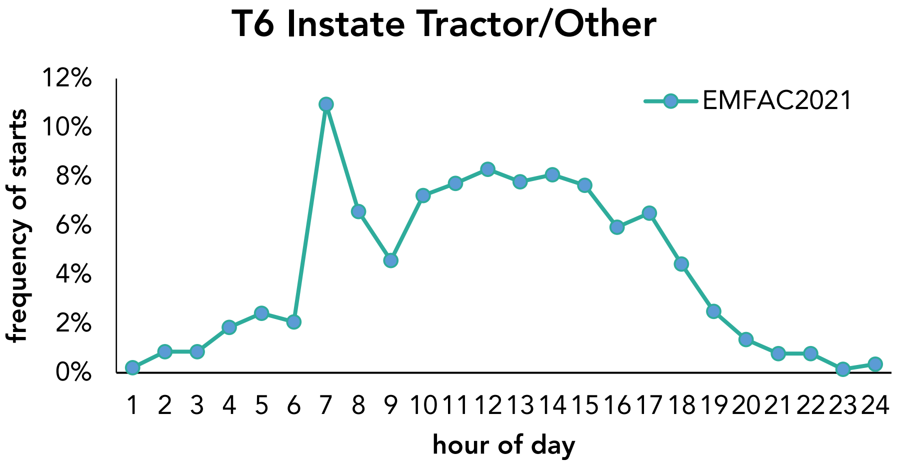


Figure (d). Engine starts distribution by hour of T7 Port trucks in EMFAC2021

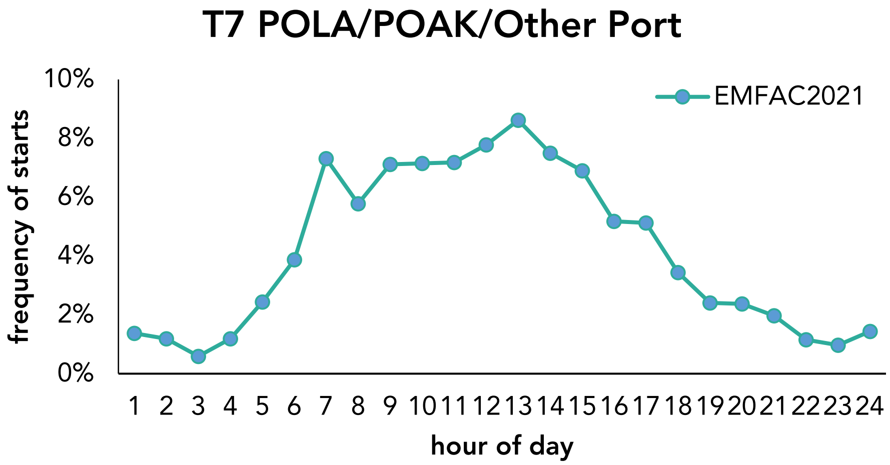


Figure (e). Engine starts distribution by hour of T7 Single trucks in EMFAC2021

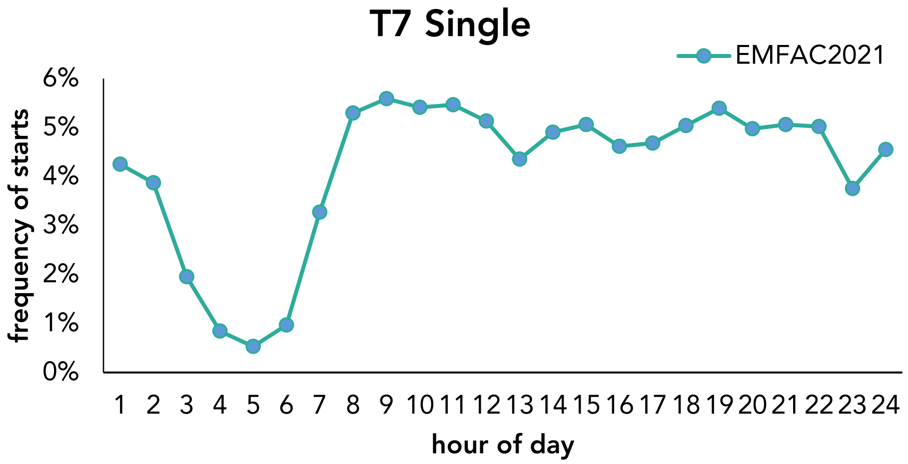


Figure (f). Engine starts distribution by hour of T7 SWCV in EMFAC2021

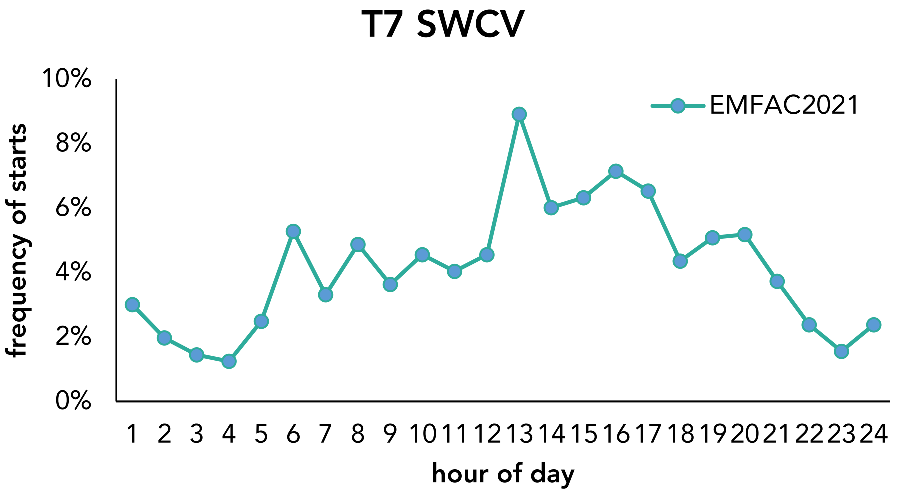


Figure (g). Engine starts distribution by hour of T7 Tractor in EMFAC2021

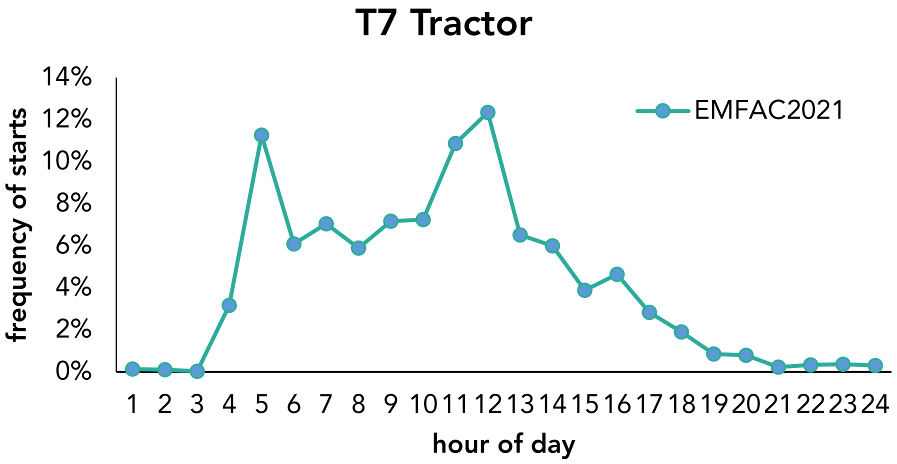
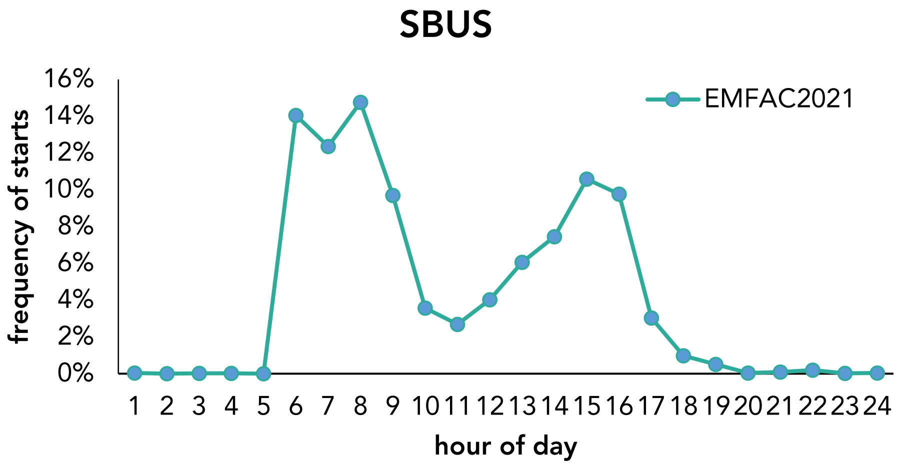


Figure (h). Engine starts distribution by hour of SBUS in EMFAC2021



6.12 Engine Starts Distribution by Soak Time Figure

Figure (a). Engine starts distribution by soak time of Out-of-states trucks in EMFAC2021

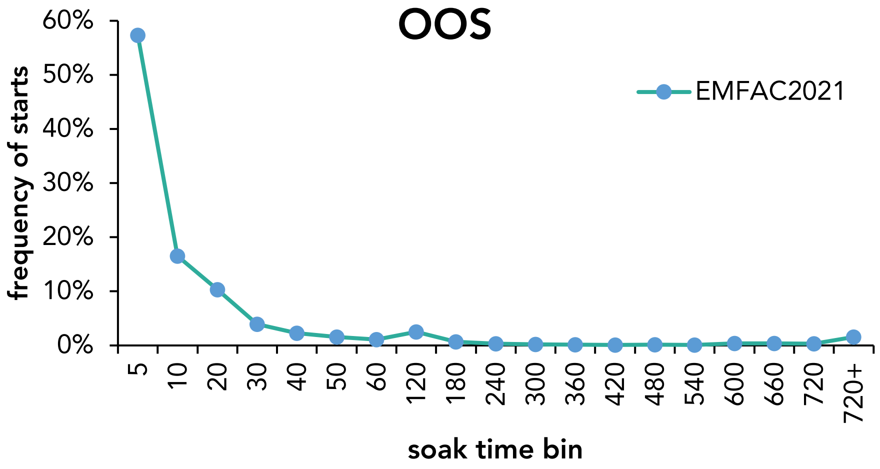


Figure (b). Engine starts distribution by soak time of T6 Instate Delivery in EMFAC2021

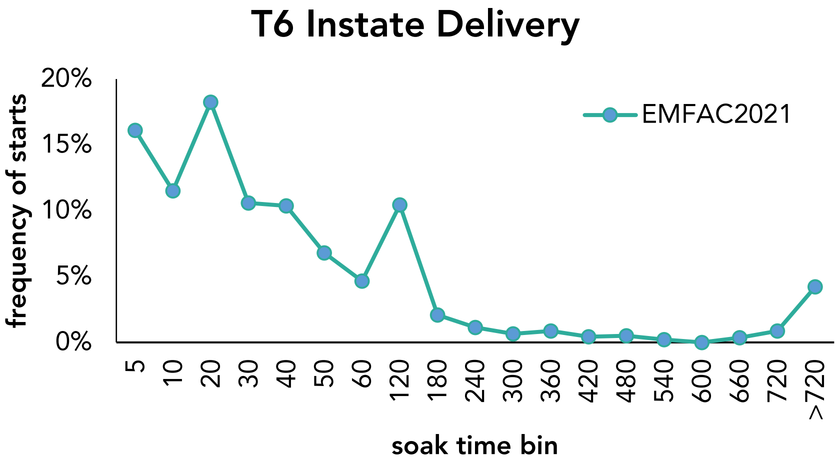


Figure (c). Engine starts distribution by soak time of T6 Instate Tractor/Other in EMFAC2021

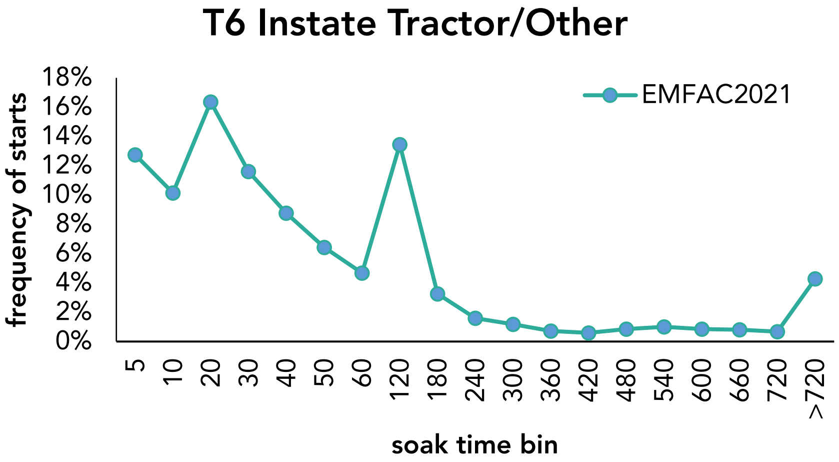


Figure (d). Engine starts distribution by soak time of T7 Port trucks in EMFAC2021

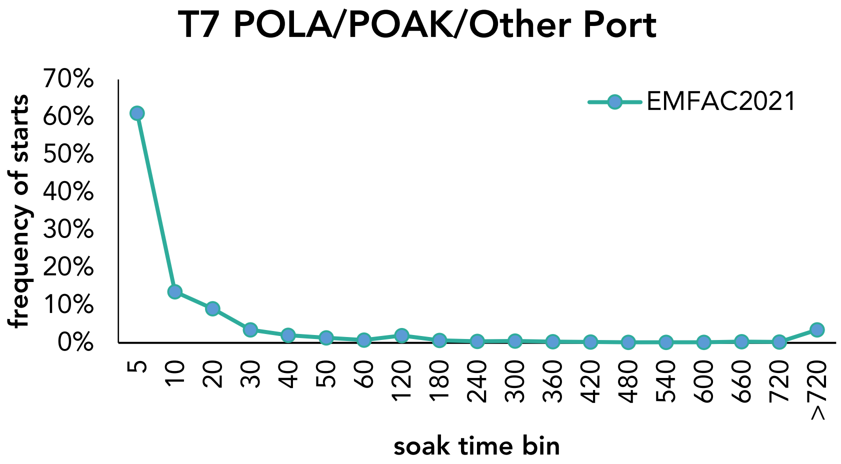


Figure (e). Engine starts distribution by soak time of T7 Single trucks in EMFAC2021

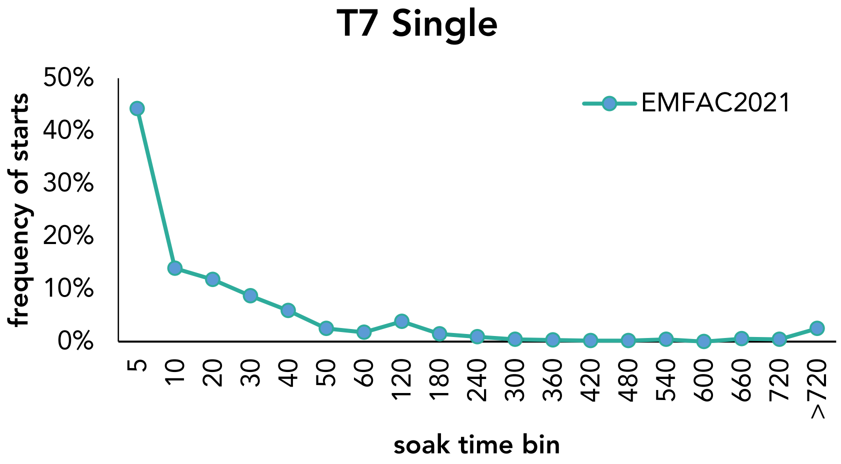


Figure (f). Engine starts distribution by soak time of T7 SWCV in EMFAC2021

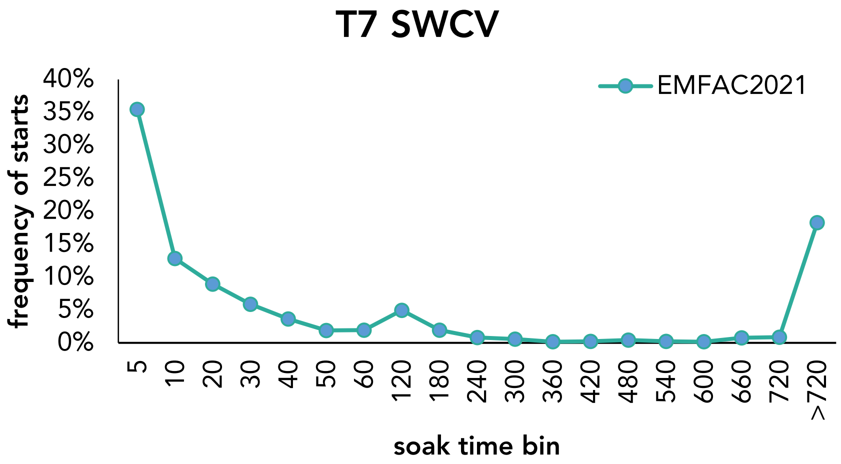


Figure (g). Engine starts distribution by soak time of T7 Tractor in EMFAC2021

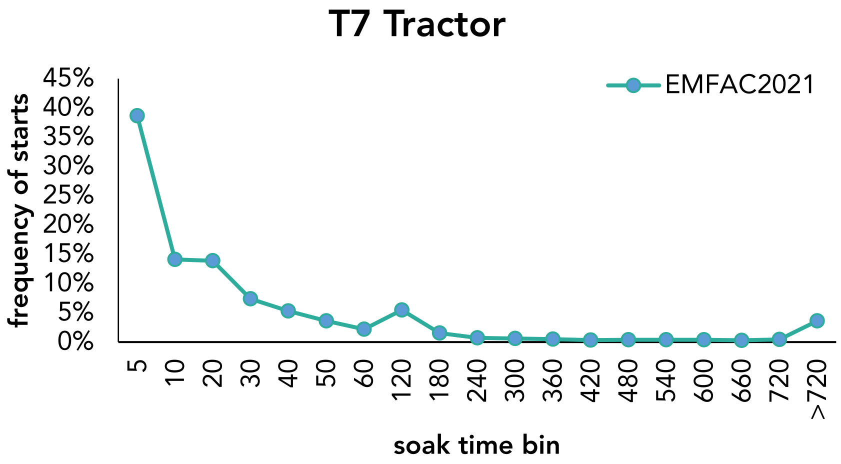


Figure (h). Engine starts distribution by soak time of SBUS in EMFAC2021