Appendix H: 2021 Update to Emissions Inventory for Transport Refrigeration Units

July 2021

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1. Summary and Background

This report covers the updates to the California Air Resources Board's (CARB) emissions inventory for transport refrigeration units (TRU). The previous inventory was released in 2011, and documentation is available online.[1] The recent updates include improvements to TRU populations, annual activity, emission factors, compliance choices under the Airborne Toxic Control Measure for In-Use Diesel-Fueled TRUs and TRU Generator Sets, and Facilities where TRUs Operate (TRU ATCM),[2] and growth factors. The updates were developed to provide data for CARB's 2019 Preliminary Health Analysis of TRUs.[3]

TRUs are diesel-powered refrigeration units installed on vehicles such as trucks, trailers, shipping containers, and railcars. The TRU emissions inventory also includes generator sets (gen set), systems designed to provide electricity to electrically-driven refrigeration units (including those on semi-trailer vans and shipping containers). TRUs are responsible for the safe transportation of most refrigerated goods, including meats, produce, dairy, and certain medicine and chemical products.

The diesel engines that power TRUs and TRU gen sets are a significant source of a number of pollutants, but are of particular concern due to the emissions of particulate matter under 2.5 microns in diameter (PM2.5) at locations and facilities where a large number of TRUs operate simultaneously, concentrating their emissions impact in the surrounding communities.

TRUs operating in California are subject to the TRU ATCM, which generally requires that TRUs meet in-use performance standards seven years after the engine model year. There are several ways to be in compliance with the in-use performance standards, meeting the U.S. EPA Tier 4 final emission standards for 25-50 horsepower engines, installing a Level 3 filter (with at least 85 percent PM control) on the TRU engine, or using a qualifying alternative technology. Compliance may also be maintained by replacing the existing unit (engine and refrigeration system) with a new TRU with a Tier 4 engine, which would then be in compliance until the seventh year after the replacement TRU's engine model year.

Although TRUs operate across the State, their impact is often concentrated in communities near facilities where dozens of TRUs may be operating simultaneously and continously.

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[1] *https://ww3.arb.ca.gov/msei/ordiesel.htm*

[2] *https://ww3.arb.ca.gov/diesel/tru/tru.htm*

[3] California Air Resources Board, Preliminary Health Analyses of Transport Refrigeration Units, October 18, 2019. (web link: *https://ww3.arb.ca.gov/cc/cold-storage/documents/hra_healthanalyses2019.pdf*)

California's anti-idling rule for trucks does not apply to TRU operations or reduce their emissions.

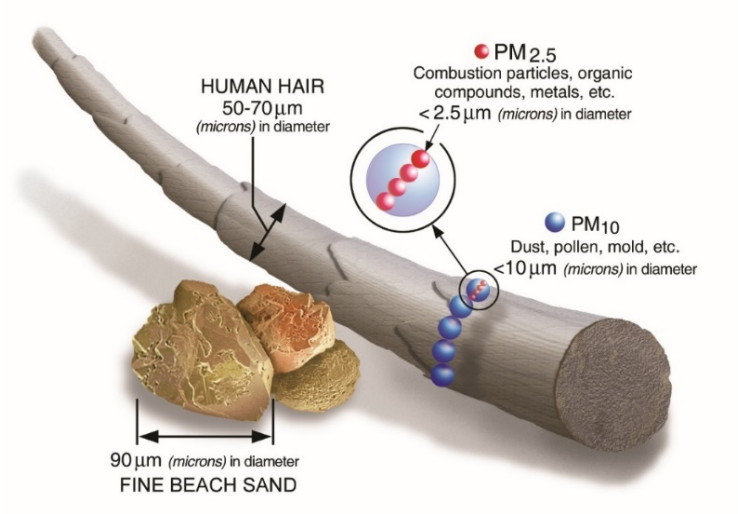
Figure 1 shows an example of a food distribution facility in Southern California.

Figure 1. Food Distribution Facility

TRUs are a relatively high source of particulate matter (PM) due to the lack of tight controls for particulate matter in the new engine standards for smaller diesel engines (see Section 2.1 below). These ultrafine particles are significantly smaller than most dust, pollen, and other sources of particulates, as shown in Figure 2. More information on the health risks associated with PM2.5 is available on CARB's website.[4]

[4] *https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health*

Figure 2. Particulate Matter Size Comparison



1.1. TRU Categories

TRU categories are determined based on the type of truck or container they are cooling (such as a single body truck, trailer, shipping container, or railcar) and the horsepower of the TRU. These groupings are important in identifying average horsepower, load factor, activity, percent of time spent in California, and turnover and purchasing habits.

Truck TRU: TRUs used to cool all types of single body trucks are referred to as truck TRUs. Generally, truck TRUs have between 7 and 19 horsepower, with an average of 13.9 horsepower. These trucks are generally used for local and regional delivery, and are assumed to be captive, meaning they do not leave California and all activity is within the State.

Trailer TRU: Trailer TRUs are the most common TRU type and are attached to trailers pulled by semi-trucks. Traditionally all trailer TRUs were rated between 25 and 35 horsepower. However, in the last few years, trailer TRUs were produced with engines between 23 and 25 horsepower. There are two subsets of trailer TRUs.

> **California Trailer TRU:** These TRUs are registered to a company or agency based in California and are required to register in the ARB Equipment Registration Program (ARBER) database.[5] California trailer TRUs are often used in long-haul transport and are not captive to California, since they often visit other states to deliver or bring in trailer loads. A majority of their activity is assigned to California.

[5] *https://ww2.arb.ca.gov/our-work/programs/transport-refrigeration-unit*

Out-of-State Trailer TRU: These TRUs are not registered to a company based in California and may voluntarily register in the ARBER database. A small fraction of their activity is assigned to California.

Railcar TRU: These TRUs supply refrigeration to railcar containers and are pulled by locomotives. A small fraction of their time is spent in California.

TRU Gen set: These TRUs are a gen set that provides power to a non-integrated refrigeration unit. Similar to trailer TRUs, most TRU gen sets were previously rated above 25 horsepower, but recent data from the ARBER database shows a majority of gen sets now sold are 23 to 25 horsepower engine units. Again, there are two subsets of TRU gen sets.

California TRU gen set: TRU gen sets are registered to a company based in California with reporting requirements in the ARBER database. Similar to trailer TRUs, a majority of their activity is assigned to California.

Out-of-State TRU gen set: These are TRU gen sets that are not registered to a company based in California and may voluntarily report tin the ARBER database. A small fraction of their activity occurs in California.

1.2. Emissions Inventory Methodology Overview and Sources

The following steps summarize the inventory process and identify each data source, with more detail included later in the report:

1. ARBER supplies TRU population data, including model year, horsepower, and any reported aftertreatment information
    a. Population data is scaled up based on CARB enforcement data that indicates not all TRUs report in ARBER (e.g., 96.3 percent of TRUs are assumed to be reported in ARBER database).
    b. Out-of-State TRUs are scaled up based on heavy duty truck populations from the EMFAC model as they have voluntary reporting requirements.
2. Activity is assigned based on survey data and TRU telematics reports. Activity is distributed for portion of time spent in-state vs out-of-state for trailer TRUs, railcars, and gen sets based on VMT patterns for in-state versus out-of-state trucks.
3. Load factors are assigned by TRU category, using analysis from the 2011 inventory, and supplemented by TRU telematics reports. TRU efficiency improvements in some categories are reflected in this step.
4. Future years are forecasted by applying a growth rate, along with a survival and purchasing curve based on reported age distributions.
5. Forecasted compliance with the TRU ATCM is based on observed compliance choices in the ARBER database and data from CARB's enforcement program.

6. Emissions are calculated for base and future years using Equation 1.

$$Emissions = Population * Activity * Hp * LF * EF * FCF \quad \text{(Equation 1)}$$

Where:

Population =	Count of equipment population
Activity =	Time the engine is running (hours)
Hp =	Horsepower (max brake horsepower) of the engine
LF =	Load factor (unit-less)
EF =	Emission factor (grams/kW-hr) specific to horsepower and model year and pollutant, and includes deterioration
FCF =	Fuel correction factor (unit-less) based on calendar year

2. TRU Data Base Year Inputs and Analysis

This section discusses data sources and analysis for the TRU emissions inventory model, including population, activity, load factor, and emission factors. These inputs are the foundation of the model and all forecasted years are built on this base year data.

2.1. Population and Age Distribution

The ARBER database provides a record of California-based TRUs and a partial record of TRUs that entered the State but are not based in California. Under the TRU ATCM, owners of TRUs based in California are required to report their TRUs to the ARBER database, with an initial reporting deadline of July 31, 2009. Owners of TRUs that are based outside California may report their TRUs but are not required to do so.

The ARBER database maintains reported information for each TRU, including the unit's model year, the engine model year, and any compliance actions taken, such as a diesel particulate filter (DPF) installation or engine replacement or rebuild. The database does not include information on annual activity, the amount of fuel used, or the load factor. As such, ARBER data can be used to analyze population and age distributions, but not activity.

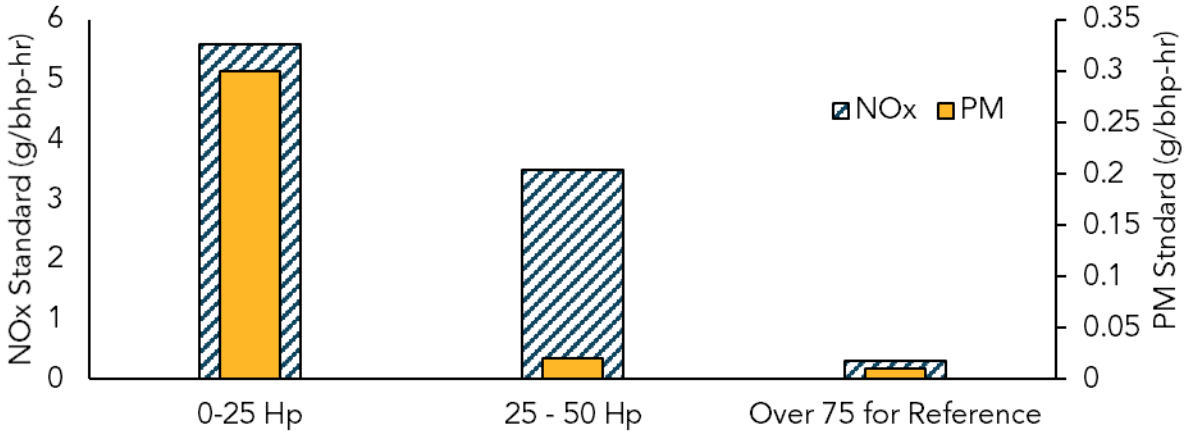
Data from the ARBER database was retrieved in November 2019 and is the primary input to estimate TRU population and age distribution in the 2021 TRU inventory.

The largest change in this new data set is the emergence of 23 to 25 horsepower trailer TRU engines. Figure 3 compares the difference in oxides of nitrogen (NOx) and PM emission factors (in grams per brake-horsepower-hour) according to horsepower groupings. Units with

engines under 25 horsepower have standards for PM 15 times higher than units with more than 25 horsepower, and emission standards NOx 1.5 times higher.

In the 2011 inventory, all trailer TRUs had engines ranging from 25 to 50 horsepower. Figure 3 includes diesel engines over 75 horsepower for comparison, although there are no TRUs in the inventory in this horsepower range. The diesel engines under 25 horsepower have significantly higher PM emissions standards because they lack DPFs and they have higher NOx emission standards as they also lack selective catalytic reduction systems (SCR). Diesel engines over 25 horsepower are expected to have DPFs or similar, and no SCRs. For comparison's sake only, most diesel engines above 75 horsepower are expected to have DPFs and SCRs, or equivalent emissions reduction. The increase of PM and NOx from engines between 23 and 25 horsepower is significant as the emergence of these smaller engines will become responsible for the majority of TRU emissions in the near future, if current trends continue.

Figure 3. Tier 4 Final Standards for Off-Road Diesel Engines by Horsepower Bin



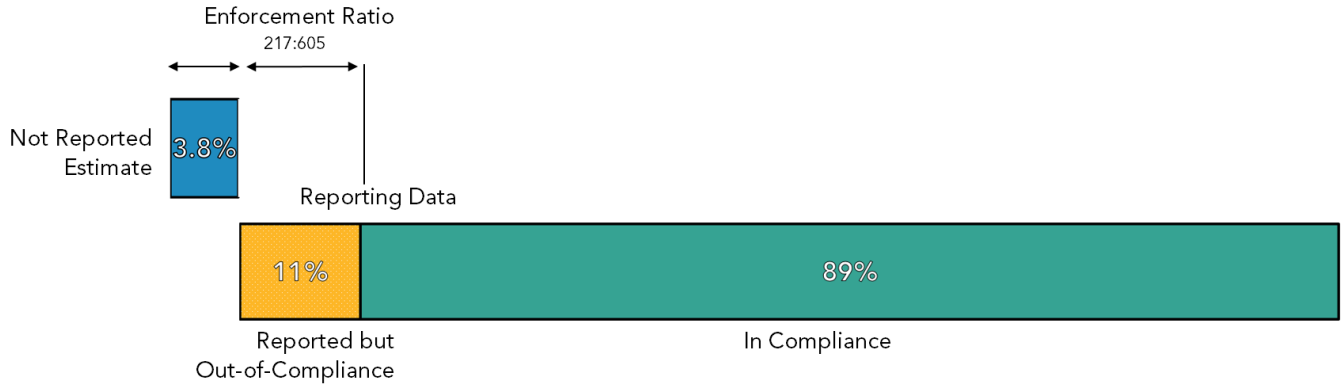
2.1.1. Population and Non-Reporting

Although TRUs based in California are required to report in ARBER, there is some level of non-compliance with this reporting requirement. Based on CARB enforcement data from 2009 and 2010, the previous 2011 model scaled up California units registered in ARBER by 3.12 percent to correct for those units that were not registered. New calendar year 2016 CARB enforcement data for TRUs was used to update the non-reporting factor in the 2021 inventory.

According to 2016 CARB enforcement data, non-compliance due to non-reporting was responsible for 217 violations, while non-compliance due to other issues was responsible for 605 violations. Essentially, for every three TRUs out of compliance for issues other than reporting, one was out of compliance for failure to report. The 2019 ARBER reporting data

indicates that compliant TRUs account for 89 percent of the population. Therefore, the remaining reported but non-compliant TRUs account for 11 percent. By applying the same ratio for non-reported units to reported but non-compliant units, the 3 to1 ratio can be multiplied by the 11 percent of non-compliant TRUs in the 2020 ARBER database. This results in a non-reporting rate of 3.75 percent, as shown in Figure 4 below.

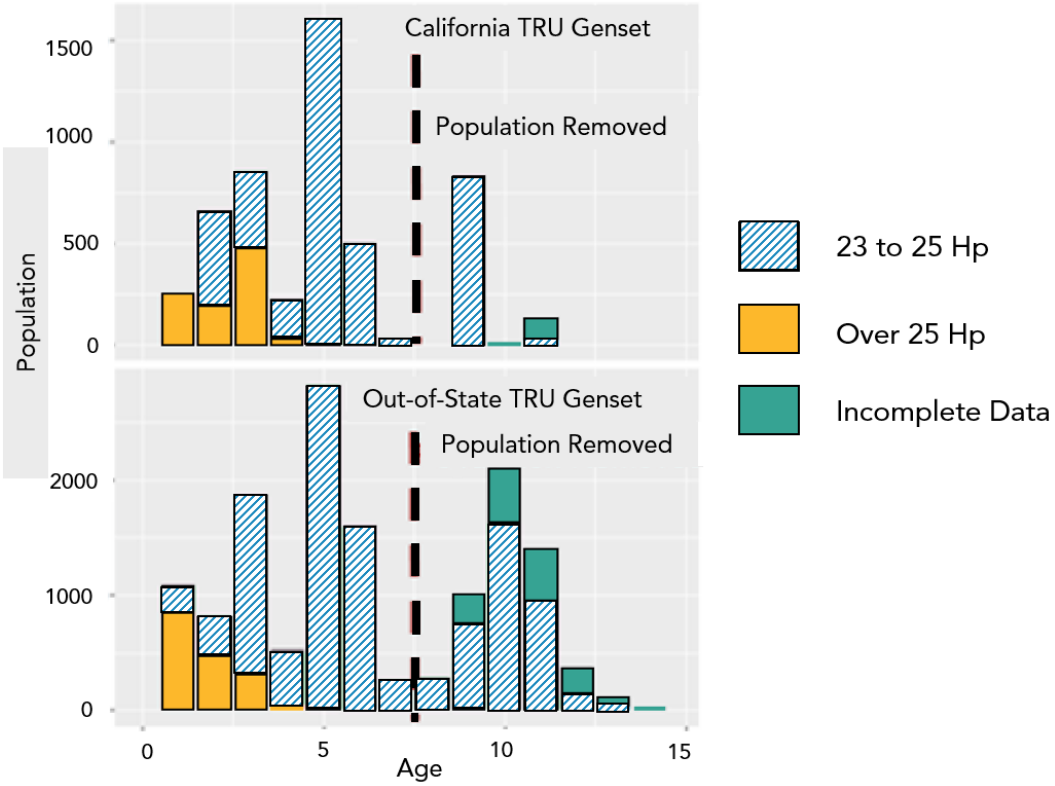
Figure 4. Determining TRU Non-Reporting Rates



2.1.2. TRU Gen Set Age Distribution Adjustments

According to information from TRU gen set owners and operators, as well as CARB staff, many TRU gen sets deemed non-compliant with the TRU ATCM remain registered in ARBER even though they are no longer brought into California. This was verified with data supplied by the TRU gen set companies as they have an electronic tracking program. The inventory reflects this practice by removing non-compliant TRU gen sets (those older than 7 years of age) from the base population from the ARBER dataset, for both in-state and out-of-state TRU gen sets. Figure 5 shows the age distributions before this adjustment, with all units older than 7 years of age removed following the compliance adjustment.

Figure 5. TRU Gen Set Age Distribution before Adjustment



2.1.3. Out-of-State TRU Population Scaling

Out-of-state TRUs are not required to report to ARBER, meaning the reporting data represents only a fraction of the total population of out-of-state units. To estimate the entire population of TRUs visiting California each year, the inventory uses the ratio for in-state versus out-of-state trucks from CARB's on-road mobile source emissions inventory, EMFAC2017.[6] Trucks used in the analysis were limited to T6 and T7, or medium-heavy and heavy-heavy duty truck types as those are most likely to pull a refrigerated trailer. Public trucks, port trucks, utility trucks, and other truck types unlikely to pull a refrigerated trailer were excluded.

Table 1 shows the in-state and out-of-state truck populations in a calendar year, and the ratio between the categories. Based on this analysis, the out-of-state trailer TRU population was scaled up to equal the number of California trailer TRUs multiplied by the ratio 3.64. This creates a target population of out-of-state TRUs of 131,160 (or 3.64 times the in-state population of registered TRUs).

[6] EMFAC2017, *https://www.arb.ca.gov/emfac/2017/*

Table 1. In-State and Out-of-State (T6 and T7) Truck Populations from EMFAC2017 from Applicable Categories

Truck Category	Population
Out-of-State[7]	601,690
In-state	165,300
Ratio of Out-of-State / In-state	3.64

Age distribution, after-treatment, and other characteristics were modeled using reporting data for out-of-state units. However, the total out-of-state TRU population was scaled up to 131,160, from approximately 58,540 seen in the reporting data. This equates to about 45 percent of the estimated out-of-state TRU fleet voluntarily reporting.

2.1.4. Railcar and DSC

There are currently 3,954 railcars registered in the ARBER database, with 67 percent of the railcars falling between 23 and 25 horsepower, and the remaining 33 percent over 25 horsepower. Railcar registration is currently voluntary, and this amount could increase with more complete registration in the future.

The 2019 ARBER population of domestic shipping containers (DSC) reports about 400 units with an average age of 4.3. These are included in the 2019 railcar population, based on discussion with industry indicating that DSCs and railcars have similar operational practice. They both are used almost exclusively by large companies, are not captive to California, are reported voluntarily, and spend only a small fraction of time in California. Based on the limited amount of data available for these categories, the out-of-state TRU age distribution was used for this category, similar to the 2011 inventory

2.1.5. 2019 Population and Age Distribution

Table 2 gives population and average age for each TRU category after scaling adjustments.

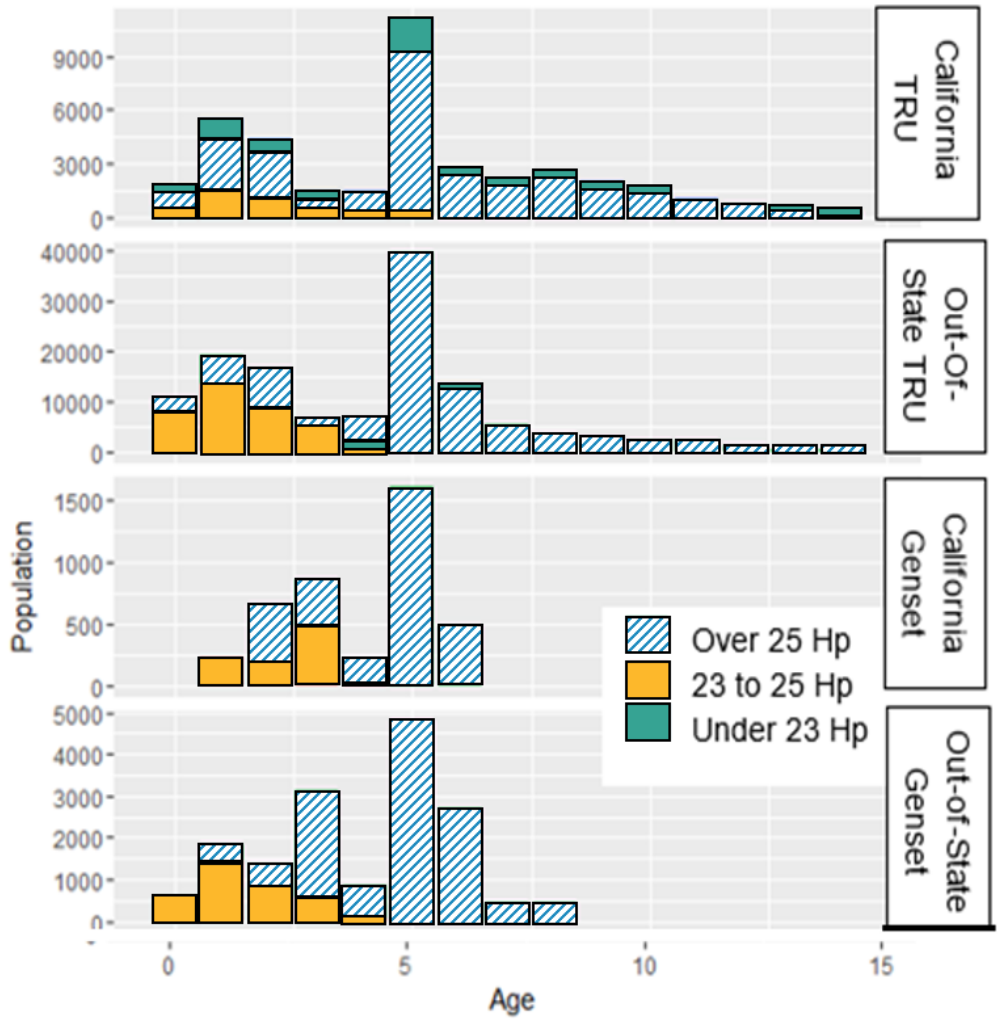
Table 2. 2019 Population and Average Age by Category

Category	Population	Average Age (years)
California-based TRU	39,938	5.1
Out-of-state TRUs	131,164	4.2
California-based TRU gen set	4,074	3.9
Out-of-state TRU gen set	16,200	4.0
Railcar and DSC	3,954	4.2

[7] Annual population of out of state trucks are being used for this analysis

Figure 6 displays the base year 2019 age distributions by category. The spike at age five, or model year 2012, corresponds to a regulatory deadline in the TRU ATCM as well as the last available year of Tier 4i engines in the 25 to 25 horsepower range. It should be noted the low age of units between 23 and 25 horsepower is not indicative of high turnover, but a result of their recent emergence in the market.[8]

Figure 6. Base Year TRU Age Distribution by Category



2.2. Engine Model and Average Horsepower

To determine the engine horsepower for each unit reported in ARBER, the inventory matches the engine model to the manufacturer's horsepower rating. ARBER's engine model input field is an open text field, so typed responses varied. As such, algorithms were used to verify

[8] Railcars are not shown as they follow the out of state TRU age distribution due to limited data.

the engine model. For example, the common model TK486V is often entered as "486 v", "486_v","tk-486 v", “486 tkv”, “tkv486”, “tk48v6”, and approximately 272 other variants.

Table 3 reports average horsepower for each TRU category and the engine horsepower bin. The average horsepower for each category is weighted by the population of each engine model in the reporting data. Only California-based TRUs have a group for units under 23 horsepower because all single body trucks are assumed to be California based units, and all trailer units are over 23 horsepower.

Table 3. Average Horsepower by Category

Category	Average Horsepower: Below 23 Hp Bin	Average Horsepower: 23 to 25 Hp Bin	Average Horsepower: 25 Hp and Over Bin
California-based TRU	17.2	24.8	33.8
Out-of-state TRU	-	24.7	33.7
California-based gen set	-	24.8	33.2
Out-of-state gen set	-	24.8	33.2
Railcar and DSC	-	24.7	33.7

2.3. Annual Activity

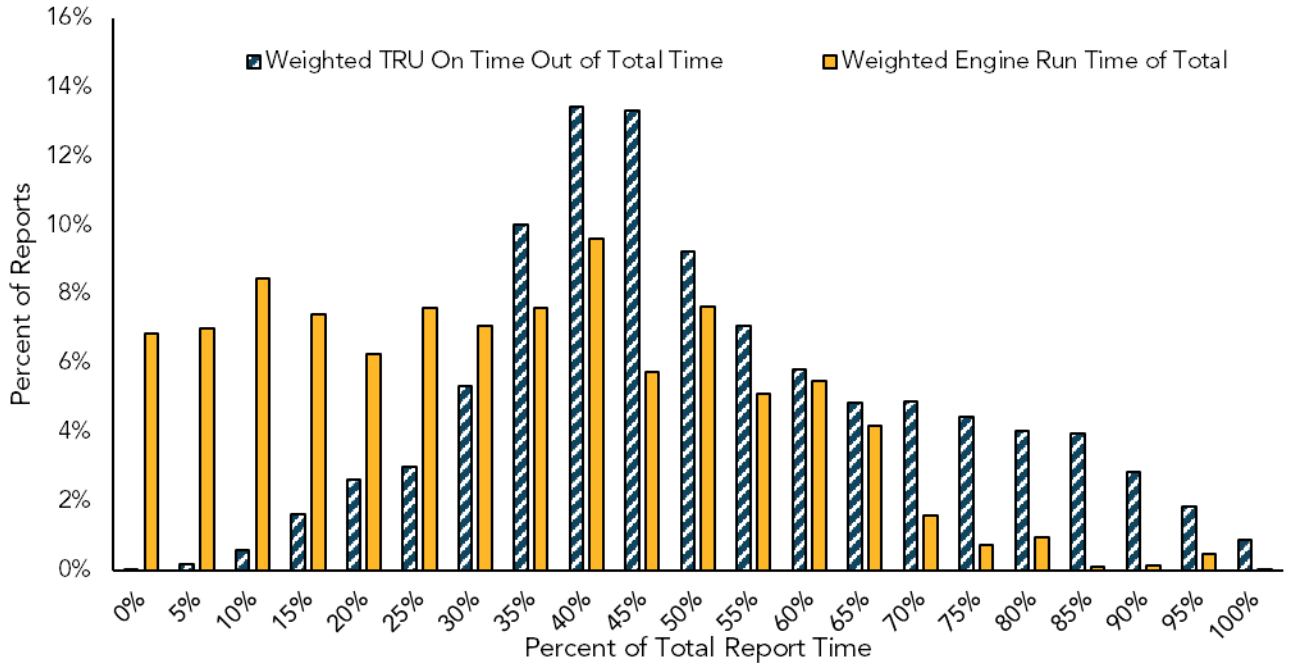
In the 2011 inventory, annual activity was based on a facility survey. The survey covered 54 different facilities that monitored TRU activity and provided the average total TRU activity, annually. For example, if a TRU visited a facility twice, one week apart, and had accumulated a total of 30 hours in that time, that TRU would be scaled up by 52 weeks to estimate 1,560 hours of annual use. The results from that survey are described in detail in the 2011 inventory analysis, which determined trailer TRUs had an average annual activity of 1,697 hours and 1,360 hours per year for truck TRUs.

For this 2021 TRU inventory update, CARB acquired telematics data from a number of trailer TRUs, detailing total time, time the unit (but not engine) was on, time the engine was on, whether the trailer was stationary or moving, and (in limited cases) the fuel use. The telematics data generally was recorded every 15 minutes, showing the changes in time, engine on time, and other metrics from the last recorded point. For example, one entry data point might show 900 seconds passing (15 minutes), with 900 seconds (15 minutes) of unit on time and 360 seconds (6 minutes) of engine on time during those 15 minutes.

After significant quality assurance, 811 telematics reports were used, representing 867,300 hours or 99.0 years of total time passing (engine on or not), and 285,000 hours of

engine run time. The TRU unit was on (engine running or not running) for an average of 51.8 percent of total recorded time, equivalent to 12.4 hours per day, or 4,500 hours per year. The engine was running for an average of 32.8 percent (weighted by total time of each report), equivalent to 7.9 hours per day, or 2,876 hours per year (the average percent of engine time-on **not** weighted by time was 32.5 percent, showing the data was not significantly influenced by outliers). Figure 7 compares the distribution of TRU on time (patterned in blue and white) and engine on time (colored in yellow). The blue-white bars represent the percent of time the unit was turned on, and yellow bars represent the percent of time the engine was running. The telematics data show that the TRU engines are generally running about 62.5 percent of the time that a TRU unit is turned on.

Figure 7. Telematics Data: TRU Unit On and Engine On



The telematics data, although detailed in temporal information, did not provide information on TRU models, ownership, or other variables to determine if the activity data represented all TRU operation in the State. To incorporate the telematics data while not overinflating the total activity statewide (from units potentially not represented by the telematics data), the 2011 facility survey data and the 2018 telematics data were combined to determine average TRU activity.

For each data source, CARB weighted the percent of engine time on by the duration of the report, to calculate a time-weighted average of engine run time. From the 2011 facility survey data, each facility was weighted by the number of trailer TRUs and multiplied by the average time period for a TRU report. Each telematics data point represents a single unit and was weighted according to the length of that telematics report. Table 4 shows how the

following two example facility reports and two telematics data points would be averaged to calculate TRU average on time rate.

Table 4. Example TRU Activity Average Calculation

Data Source	Number of TRUs	Average Time Period of Reports	TRU On Time Average for Facility	Total TRU Days	Average Rate: TRU on time
Facility 1 Report	50	10 day average	20%	50 x 10 = 500 days	500 days x 20 Percent
Facility 2 Report	10	5 day average	30%	10 x 5 = 50 days	50 days x 30 Percent
Telematics 1 Data	1	60 days	35%	1 x 60 = 60 days	60 days x 35 Percent
Telematics 2 Data	1	100 days	40%	1 x 100 = 100 days	100 days x 40 Percent
			Total	710 days	24.8 Percent Weighted Average

This can also be expressed in the calculation as follows:

$$\frac{[(500 \text{ days} \times 20 \text{ percent}) + (50 \text{ days} \times 30 \text{ percent}) + (60 \text{ days} \times 35 \text{ percent}) + (100 \text{ days} \times 40 \text{ percent})]}{710 \text{ total days}} = \text{Average of 24.8 percent of time on.}$$

Based on the average time-on of 24.8 percent, the annual activity would be 24.8 percent of 365 days per year, 24 hours per day, or 2,170 hours per year. This methodology gives higher weight to the facilities with larger number of units, reporting over a longer period, and to telematics data recorded over a longer period. Facility reports with few units, or a short period between reports, and telematics data recorded over a short period, have little impact on average activity. Table 5 and Table 6 show the results and overall information on the facility surveys, telematics data, and resulting activity average

Table 5. Trailer TRU Activity Data Sources and Average

Data Source	TRU Hours Represented	TRU Units Represented
Facility Survey	1,197,382	6,035
Telematics Data	867,368	811

Table 6. Trailer TRU Activity Average

Data source	Percent of Engine Time	Average Annual Hours
Facility Survey	19.5%	1,712
Telematics Data	32.8%	2,876
Overall Average (Time Weighted)	25.1%	2,201

The final result is an average trailer activity of about 42 percent weighted toward the new telematics data, and 58 percent weighted to the facility survey, based on total TRU hours represented by each. Telematics data for truck TRUs were not available in any statistically significant quantity, so facility survey results were used and unchanged from the 2011 inventory. The facility survey represented 459 trucks, with an average activity of 1,360 hours per year. Gen sets and railcars are also unchanged from the 2011 inventory, at 1,000 hours annually for both categories. This is based on discussions with gen set and railcar owners and TRU program staff in 2009 and 2010 and described in full in the 2011 inventory report.

2.4. Portion of Activity within California

The trailer, gen set, and railcar TRU populations have activity split between California and other states or countries. Truck TRUs, generally assigned to local or regional delivery duties, are assumed to be captive to California. Therefore, all truck TRU hours are assumed to be within California.

The division of activity for the trailer, gen set, and railcar TRUs, is based on the same methodology as the out-of-state trailer TRU population. The TRUs are modeled on the truck activity patterns from EMFAC2017, for the categories of freight trucks that are associated with refrigerated trailers or refrigerated transport

The International Registration Program (IRP) tracks vehicle miles traveled (VMT) for interstate trucks entering California, so it is possible to determine the percent of annual VMT both inside and outside of California in an average year. The California VMT for out-of-state trucks is estimated to be around 12.4 percent of their total VMT, meaning approximately 1 out of 8 for every mile driven is within California.

California-based trucks in EMFAC also include California IRP trucks (trucks based in California but registered in IRP that spend a significant portion of VMT outside of the State). Overall,

VMT for California based freight trucks (the combined average of both IRP and non-IRP trucks) is approximately 78 percent in California and 22 percent outside California. Table 7 lists total annual hours, hours within California, and compares this against the previous 2011 inventory estimate of hours spent within California.

Table 7. TRU Activity Totals and In-State Totals

Category	2021 Model Annual Hours	2021 Model Annual Hours Within California	2011 Model Annual Hours Within California
California Trailer TRU	2,201	1,719	1,325
Out-of-state Trailer TRU	2,201	272	210
Truck TRU	1,360	1,360	1,360
California Gen set	1,000	781	781
Out-of-state Gen set	1,000	124	124
Railcar and DSC	1,697	322	322

2.5. Moving and Non-Moving Time Periods

The telematics data also included stationary and moving time for TRUs. Data was limited to include whether the trailer was moving for the entire period of the report (generally 15 minutes), was stationary the entire time, or had some portion moving and some stationary. The telematics data also included information that determined the engine on-time during these periods.

The period where the trailer was moving only a portion of the time could represent anything from a trailer arriving a location in the middle of a recording interval, to traffic conditions that had significant start and stop movement, to several very short stops during the period. Unfortunately, this data can only definitively determine that total stationary time for trailer TRUs makes up between 33 and 65 percent of all engines on time where the 65 percent value is the 33 percent stationary lower limit plus the possible 32 percent that could also be stationary. In short, 33 percent represents a lower limit, and 65 percent an upper limit.

Table 8. Trailer TRU Stationary Activity Analysis

Movement Category	Hours	Percent
Stationary with Engine On	96,900	33%
Split Stationary/Moving with Engine On	94,598	32%
Moving with Engine On	105,103	35%

An equal split of the portion where the TRU movement could not be quantified would place 49 percent of the total TRU engine time as stationary and 51 percent of TRU engine time as taking place during truck movement. This compares reasonably well with the 2011 inventory

split of 50 percent time stationary and 50 percent time moving. This information informs both the spatial distribution of TRU emissions as well as the total hours at a facility per year but does not change the total emissions in the State.

2.6. TRU Load Factor (LF)

Table 9 provides the 2011 inventory load factors. The methodology behind these load factors is described in detail in the 2011 inventory documentation and is generally based on a combination of engine certification cycle data and engine torque and speed curves.

Table 9. 2011 TRU Inventory Load Factors

Model	Horsepower Bin	Load Factor
TRU (California-based and Out-of-State)	25-50	0.46
TRU	11-25	0.56
TRU	<11	0.56
Generator Set	All	0.33
Railcar	All	0.46

The telematics data described previously did include limited data on fuel use by TRUs. Fuel data from the telematics report were recorded 3.6 percent of the time, but still comprises slightly over 36,400 hours of fuel use consumption data. A load factor can be calculated from this fuel use, with several assumptions built in.

Fuel use in off-road diesel inventories is calculated using Equation 2.

Fuel Use = Horsepower*Hours*Load Factor*Fuel Consumption Rate (Equation 2)

Therefore, load factor can be determined if the other variables are known. In the telematics data, specific engine model data or horsepower information is not available. However, the vast majority of the telematics data is from trailer TRUs. The telematics data was based on 2016 to 2017 data, a time period when 23 to 25 horsepower TRUs were being sold but made up a small fraction of market share. For this analysis, CARB assumed the trailer TRUs had an average horsepower over 25 horsepower (i.e., 33.8 Hp). The fuel use rates were based on U.S. EPA[9] values for engines of 25 to 50 horsepower, or 0.408 pounds per horsepower-hour.

Using this data, it is possible to determine a time-weighted load factor of 0.467, which compares favorably with the 2011 TRU inventory load factor for trailers of 0.46. As there is no

[9] *https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100UXEN.TXT*

significant difference between this newly calculated load factor and the previous factors, the 2021 TRU inventory will continue to use the 2011 load factors, with one minor difference.

Based on discussions with manufacturers, TRU engines have improved efficiency between 2011 and 2019, with the largest improvements beginning around 2013. The primary evidence for this trend can be seen in the published data on fuel per hour consumption from manufacturers. Beginning in 2013, the inventory reflects a load factor reduction of 17 percent to simulate efficiency improvement for the 2013 and newer trailer TRUs. For units between 23 and 25 horsepower, the efficiency improvement is used to reduce the engine brake horsepower rating, and thus these units hold the same load factor as earlier trailer TRU units. A reduction in the load factor of 17 percent for the 25 to 50 horsepower units results in the same total effective power (maximum horsepower multiplied by the load factor) for all 2013 and newer trailer units, either above 25 horsepower or below 25 horsepower.

The telematics data, in theory, could show a lower load factor due to these efficiency improvements. However, during the time the telematics data was collected, only around 20 percent of TRU units were 2013 or newer. A 17 percent efficiency improvement in 20 percent of units would only show up as a 3.4 percent reduction overall in load. This minor reduction was not seen in the telematics data, possibly due to the majority of TRU units being pre-2013 model year, or simply due the magnitude of the reduction falling within the margin of error. The model assumes no efficiency improvement for engines below 23 horsepower, as no supporting information was available. Table 10 shows the previous and new load factors.

Table 10. 2021 TRU Load Factors

Category	Below 23 Hp	Between 23 and 25 Horsepower: (All Years)	Over 25 Horsepower: 2012 and Older	Over 25 Horsepower: 2013 and Newer
California TRU	0.56	0.46	0.46	0.38
Out-of-State TRU	-	0.46	0.46	0.38
California Gen sets	-	0.33	0.33	0.27
Out-of-State Gen set	-	0.33	0.33	0.27
Railcars	-	0.46	0.46	0.38

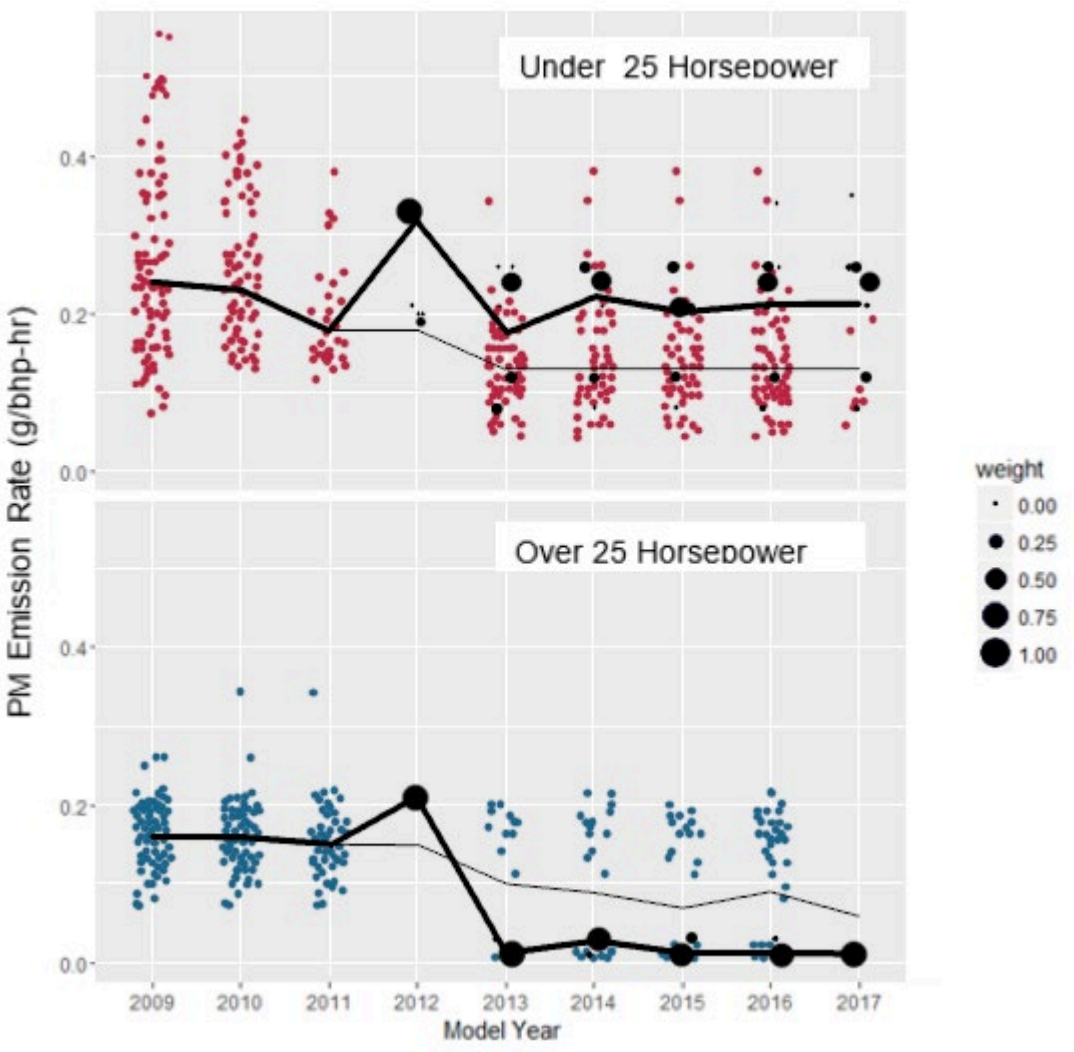
2.7. Emission Factors (EF)

The model utilizes a combination of the 2017 emission factors[10] for all diesel engines and a new analysis for engines certified to the TRU-specific certification cycle. The general off-road 2017 emission factors were developed based on certification test data covering all off-road diesel engines. The TRU-specific emissions factors were developed by including only tests based on TRU-specific certification cycles, and then weighting these tests using the engine families reported in ARBER. The TRU specific certification data are only available for PM and engine model years 2012 and newer. Therefore, the adjustment is made for PM only for engine model year 2012 and after and no adjustments are made for NOx. Each red data point in Figure 8 represents a general off-road diesel engine family. The fine black solid lines represent the overall off-road diesel emission factors (used in other categories).

Each blue data point represents a TRU specific engine family. The size of the black dot represents market share of the engine family. The solid black line is the TRU specific PM emission factor and is derived by taking a population weighted average of the black data points. The TRU specific PM emissions factors for engine model 2018 and after are estimated by averaging the 2014 to 2017 data points.

[10] 2017 Emission Factors, *https://ww3.arb.ca.gov/msei/ordiesel.htm*

Figure 8. PM Emission Factor Comparison



Notable is the fact that over 25 horsepower TRUs have PM emissions from certification below the average for off-road diesel engines, while engines under 25 horsepower have emissions significantly above the average for off-road diesel engines.

3. Forecasting and Growth

3.1. Population Forecast

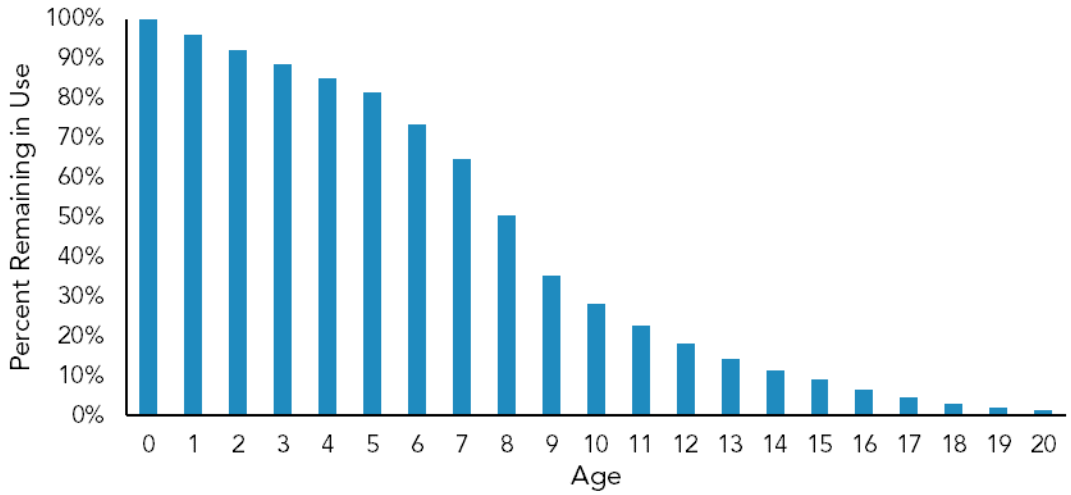
The 2021 TRU model forecasts future year population distributions in any given year by applying a series of actions to the previous year's population, in an iterative process (i.e., 2020 population is based on base year 2019, and 2021 is based off iterations on 2020, and so on). There are three distinct steps in this process: turnover, growth and purchasing, and compliance. In the first step, the model estimates the number of units that will likely retire in the year utilizing the survival curve, which characterizes the retirement behavior for

different ages. Then newly purchased units are calculated to reflect the population growth. Lastly, the population is adjusted by compliance actions such as forced retirement and/or replacement, based on enforcement and reporting data for real world compliance choices over the past 7 years. The following subsections cover model parameters used for these steps.

3.2. Population Turnover

Population turnover, or survival curves, describe what percent, on average, of purchased equipment are still in service after a set amount of time. Figure 9 shows a survival curve, which indicates the percent of the population still in service at each age, out to age 20. At age 3, 90 percent are still in service. By age 8, 50 percent are in service. By age 20, all are retired from service.

Figure 9. Example Survival Curve

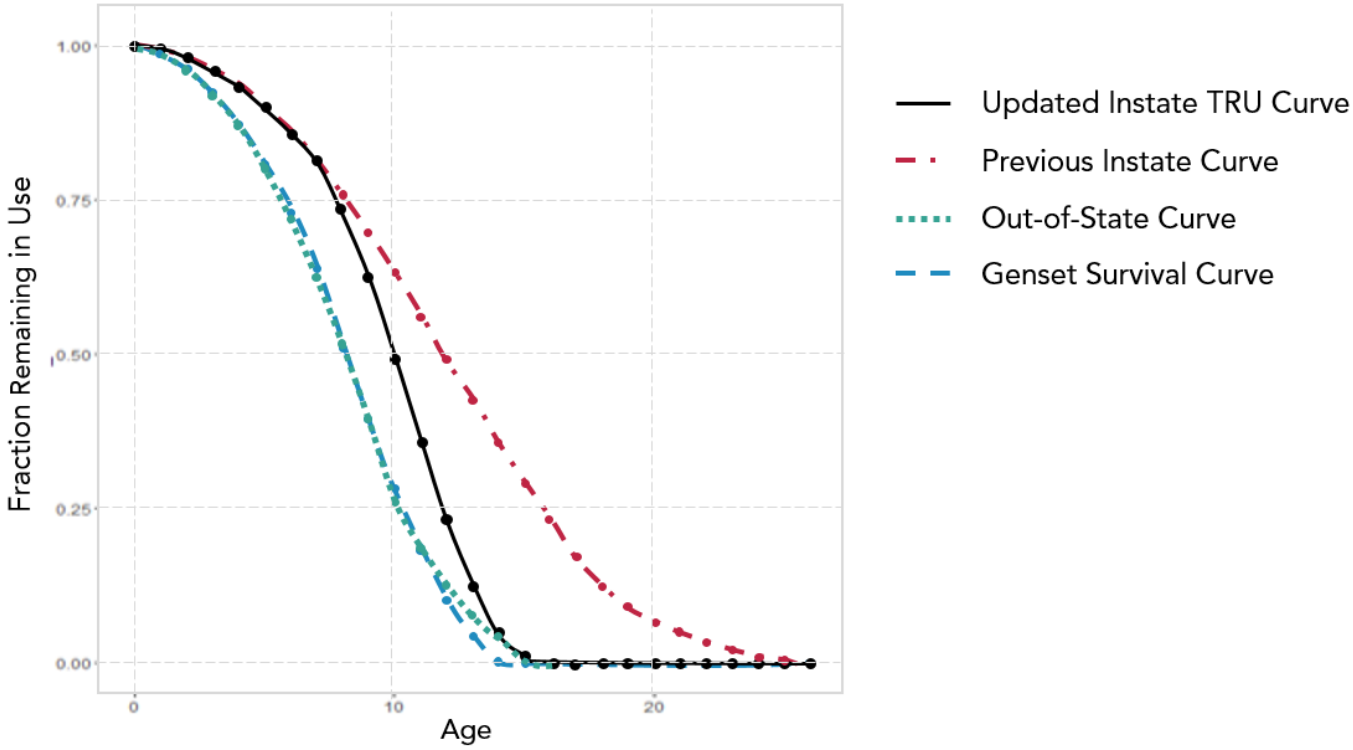


Survival curves are based the 2011 inventory model, with one significant adjustment. The general methodology for developing the survival curves is described in the 2011 inventory documentation, however it can generally be described as an iterative process where the previous decades of TRU sales data was compared to the 2011 inventory age distribution (as reported in ARBER). The goal of survival curve application was finding a curve that could be applied to sales data and resulted in the real world age distribution seen in the reporting data. The in-state and out-of-state populations have different survival curves, as out-of-state TRUs are significantly younger and are retired at a younger age, on average.

The adjustment to the 2011 survival rates came from comparing the in-state survival curve to the age distribution shown previously in Figure 9. While the survival curve extends to 25 years, the existing age distribution shows no units older than 15 years. Although the TRUs have been subject to the TRU ATCM, units older than 7 years with no aftertreatment are not in compliance, meaning there is no reason to suspect that age 10 and older units are retiring

primarily due to the TRU ATCM (as they are already out of compliance, or are already in compliance via aftertreatment and do not need to retire to meet regulatory requirements). To reflect this shift in retirement patterns, the new survival curve reaches zero at approximately 16 years, instead of the previous 25 years. The survival curves for different TRU populations are shown below in Figure 10.

Figure 10. TRU Survival Curve



3.3. Purchasing Trends

After applying the survival curve, the inventory models new purchases that replace or are added to the TRU fleet. New purchases for units with a 25 to 50 horsepower engine meeting the Tier 4 Final emission standards for MY 2013 and newer are classified as ULETRU (ultra-low emission TRU) and no further compliance action is required for these units. For engine horsepower below 25, the model assumes no Level 3 retrofit device installed at the time of purchase, again based on reporting data.

For the trailer, rail, and TRU gen sets, the percent of new units purchased with engines in the 23 to 25 horsepower bin was based on the reporting data from ARBER. In-state TRUs show that, on average, 60 percent of units have greater than 25 horsepower engines, and 40 percent have engines between 23 and 25 horsepower. All other units show that only 20 percent of TRU purchases have engines greater than 25 horsepower, and 80 percent have engines that are between 23 and 25 horsepower. At the time of this inventory, all new

gen sets registered were in the 23 to 25 horsepower range, however the data does not include enough years to be certain this is an ongoing trend. Future inventories will revisit this metric to determine the impact and longevity of trailer, rail, and gen set units in the 23 to 25 horsepower range.

Table 11. New Purchasing by Horsepower Bin

Category	Before 2015 25+ Hp / 23-25 Hp	2015 25+ Hp / 23-25 Hp	2016 and after 25+ Hp / 23-25 Hp
California Based TRU	100 / 0	70 / 30	60 / 40
Out-of-State TRU	100 / 0	20 / 80	20 / 80
California Based Gen set	100 / 0	20 / 80	20 / 80
Out-of-state Gen set	100 / 0	20 / 80	20 / 80
Rail	100 / 0	20 / 80	20 / 80

3.4. Compliance Choices

Following the application of survival curves and purchasing functions in the inventory, the inventory applies compliance choices for TRUs subject to the TRU ATCM. The TRU ATCM requires that fleet owners/operators take actions to reduce diesel particulate emissions once the engine becomes seven years old. Fleet owners have the choice of replacing the TRU unit, installing a retrofit device, or using alternative technology such as electric standby to allow the unit to run on supplied electric power while at a facility.

The compliance paths for TRUs includes;

- Install Level 3 retrofit
- Install alternative technology
- Replace unit with a new TRU with current MY engine.

In the 2019 reporting data, 86.2 percent of over 25 horsepower units complied (due either to age or actions taken), and 95.4 percent of units under 25 horsepower were in compliance, with an overall compliance rate of 89.0 percent.

For many owners of TRUs, both company and individuals, one of the primary compliance paths is the replacement of TRUs with newer units or shifting older TRUs out of the State and maintaining a fleet under 7 years of age. These actions are represented in the age distribution and are not identifiable specifically as compliance choices (i.e., there is no way to differentiate all these actions from the normal course of business). This compliance choice is implicit in the overall 89 percent compliance rate (e.g., these TRUs show up as newer units that are in compliance with the ATCM).

To model non-compliance in some units, the inventory uses the trend over the past two years for units that did not comply with turnover, retrofits, or alternative technology. For units facing their age 7 compliance date, the report shows that 31 percent take a specific action beyond natural turnover, over the past two years. It should be noted that this does not mean the compliance rate is 31 percent, as the overall compliance rate is (as described previously) 89 percent.

To determine the compliance parameters, TRUs with engine model years 2009 and 2010 were assessed directly from ARBER reporting data in 2016 and 2010 (the compliance year for those units). Of the 2,739 TRUs facing requirements, 885 (31 percent) either replaced the unit, or installed a Level 3 (ULETRU) retrofit, while 1,854 took no action. For TRUs under 23 horsepower, 270 faced compliance requirements, and 52 took some action, while 218 took no action (19 percent took action). Note that the number of TRUs facing compliance requirements does not include Tier 4 Final engines, those already retrofit or with alternative technology already installed, or those turned over in the normal course of business. These TRUs make up the bulk of all units, which is why the overall compliance rate is much higher, at 89 percent.

Table 12. Compliance Action Average in 2016 and 2017

	23 Horsepower and Above (Trailers, Rail, Gen sets)	**Below 23 Horsepower (Trucks)**
Replace TRU	313	35
Install ULETRU Retrofit	572	14
Install Alternative Technology	0	3
No Action Taken (out of compliance)	1,854	218

In each forecasted year, the units taking action to comply with the ATCM are modeled based on the TRU data between 2011 and 2018. The compliance paths are also split between under 23 horsepower units (all trucks) and over 23 horsepower units (trailers, rail, and gen sets). For over 23 horsepower units, almost 80 percent of the units taking action install a Level 3 retrofit, while 20 percent replace the unit. For under 23 horsepower units, only 50 percent install retrofits while 30 use alternative technology provisions, and 22 percent replace the unit. The numbers have been updated from the 2011 TRU inventory, and the results from both are shown below in Table 13

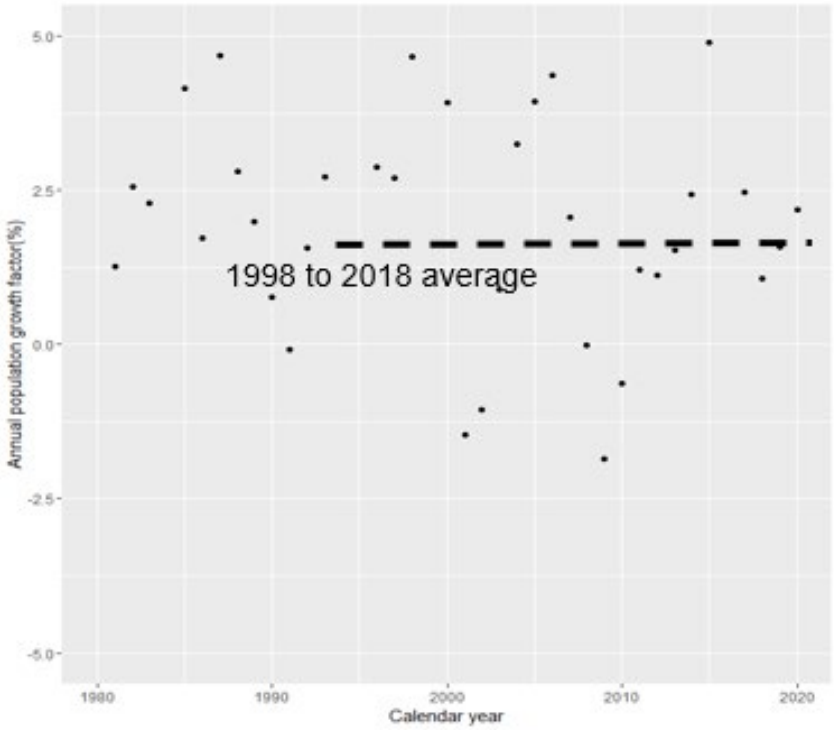
Table 13. Compliance Choices in 2011 and 2021 TRU Inventory

	Compliance Action	2011 TRU Inventory	2021 TRU Inventory
Compliance Rate for Age 7 TRUs	----	100%	31%
Over 23 Hp TRUs Compliance Choices (Trailers)	Install Level 3 retrofit	65%	78%
Over 23 Hp TRUs Compliance Choices (Trailers)	Alt tech	0%	3%
Over 23 Hp TRUs Compliance Choices (Trailers)	Replace unit	35%	19%
Under 23 Hp TRUs Compliance Choices (Trucks)	Install Level 3 retrofit	42%	48%
Under 23 Hp TRUs Compliance Choices (Trucks)	Alt tech	9%	30%
Under 23 Hp TRUs Compliance Choices (Trucks)	Replace unit	49%	22%

3.5. TRU Industry and Section Growth

The annual population growth rate is determined primarily by the ACT research's reefer population trend. As the model is focusing on mid to long-term projection (not just the next year's estimate), regression is conducted for the dataset of the past 20 years population trend from ACT research's reefer population data. Figure 11 below shows the annual population growth rate of nationwide reefers, from 1998 to 2018 averaging out to 1.6 percent annual growth.

Figure 11. ACT Research National Reefer Population Growth



IBIS World Reports for 2017, shown in Table 14 below, shows that industry trends for sectors using refrigerated units such as frozen food production and overall supermarket and grocery stores in the U.S. are growing at 1.6 percent annually as well, supporting this growth rate.

Table 14. IBIS World Reports Growth by NAICS

Sector	Category	Average Annual Growth 2011 to 2016
Manufacturing	Frozen food production in the US (NAICS 31141)	1.6%
Retail	Supermarkets & Grocery Stores in the US (44511)	1.6%

Note that this growth rate is applied only to the 2019 and future years. From 2011 to 2018, the growth rate is based on the average annual change in TRUs reported in ARBER.

3.6. Composite Population Forecast

The combination of turnover, purchasing, and growth results in the composite forecast (and backcast) are shown below in Figures 12 and 13. The 23 to 25 horsepower category, that is now a significant portion of new sales, grows as a proportion of the population until about 2025 where they reach an equilibrium (their percent of the population is equal to their

percent of new sales from Table 11). California-based TRUs and out-of-state TRUs are shown in the graphs below.

Figure 12. California TRU Population Forecast

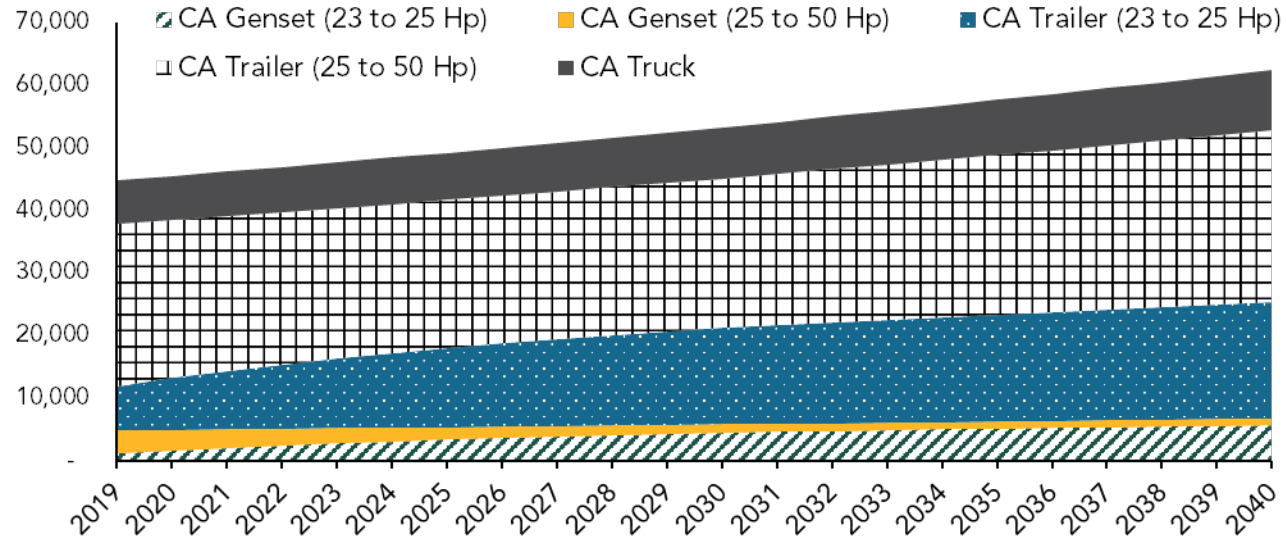
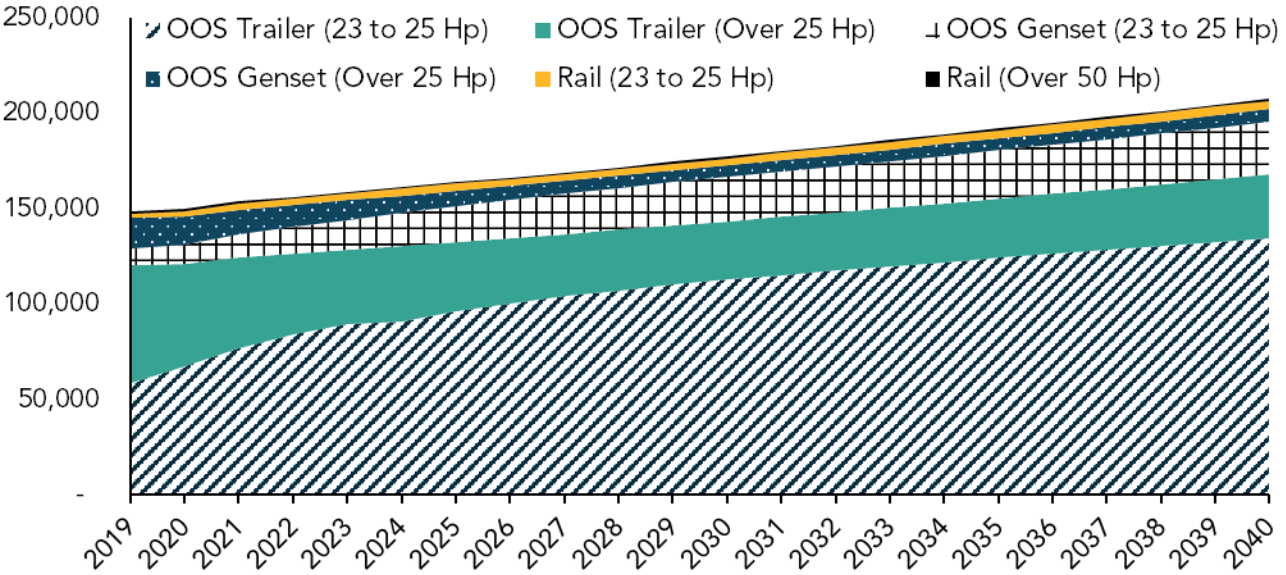


Figure 13. Out of State TRU Population Forecast



4. Summary of Proposed Amendments

CARB staff are proposing amendments to the TRU ATCM (Proposed Amendments) to transition diesel-powered truck TRUs to zero emission, as well as require a diesel PM emission standard for newly-manufactured TRUs in the remaining categories and the use of lower global warming potential refrigerant. The Proposed Amendments would require the following:

1. Beginning December 31, 2023, all truck TRU fleets shall turnover at least 15 percent each year to full zero-emission technology. All truck TRUs that operate in California shall be full zero-emission by December 31, 2029. This is modeled by a linear reduction in the activity, fuel, and emissions from diesel-powered truck TRUs beginning in 2024 and ending with a 100 percent reduction by 2030. This equates to an approximate annual reduction of 15 percent in truck TRU activity from 2024 to 2030.
2. Beginning December 31, 2022, all MY 2023 and newer trailer TRU, DSC TRU, railcar TRU, and TRU gen set engines shall meet a PM performance standard of 0.02 g/bhp-hr. This is modeled by reducing PM emissions for new sales of trailer TRUs, DSC TRUs, railcar TRUs, and TRU gen sets by 85 percent beginning in 2023, for those TRUs that do not already meet the 0.02 PM standard.

5. Emissions Results

The emissions results provided in this section reflect all previously described inputs, trends, and modeling. Figure 14 and Figure 15 show the statewide PM2.5 emissions in the baseline and under the Proposed Amendments, respectively. The population of 23 to 25 horsepower trailer TRUs (in-state trailer TRUs in brown and out-of-state trailer TRUs in grey) are forecast to dominate PM2.5 emissions under the baseline scenario.

Figure 14. Statewide PM2.5 Emissions by TRU Category in Baseline

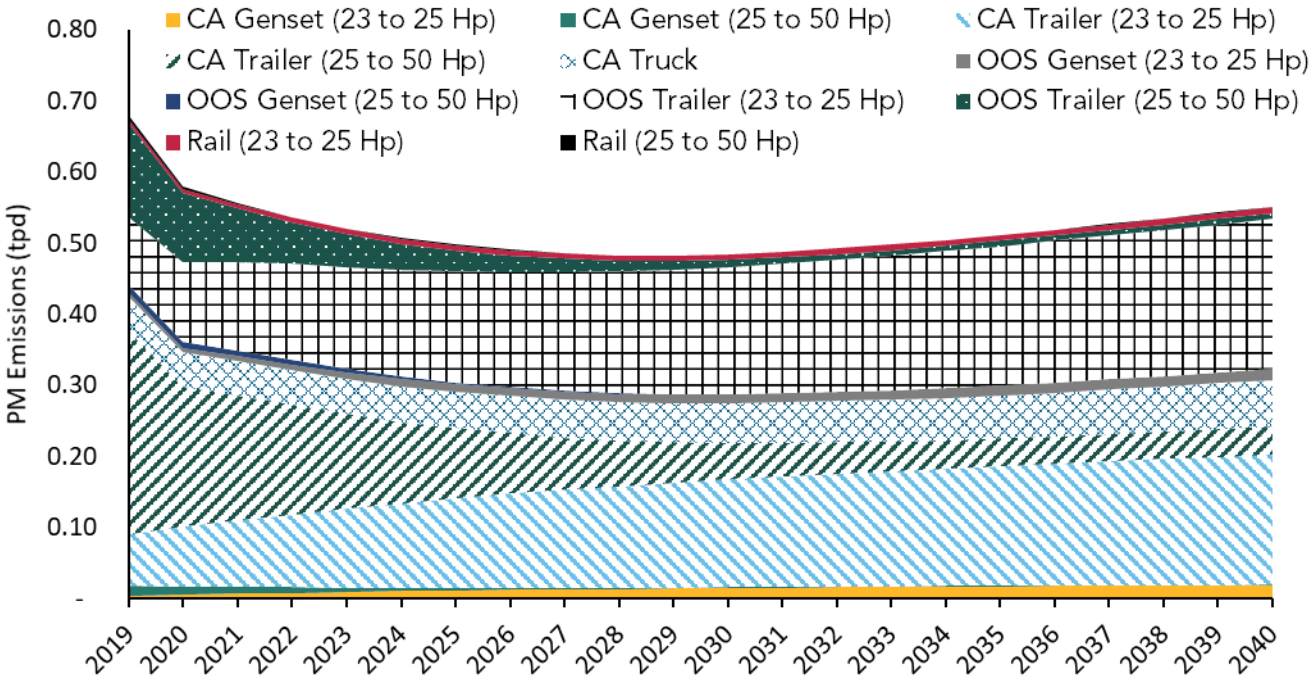
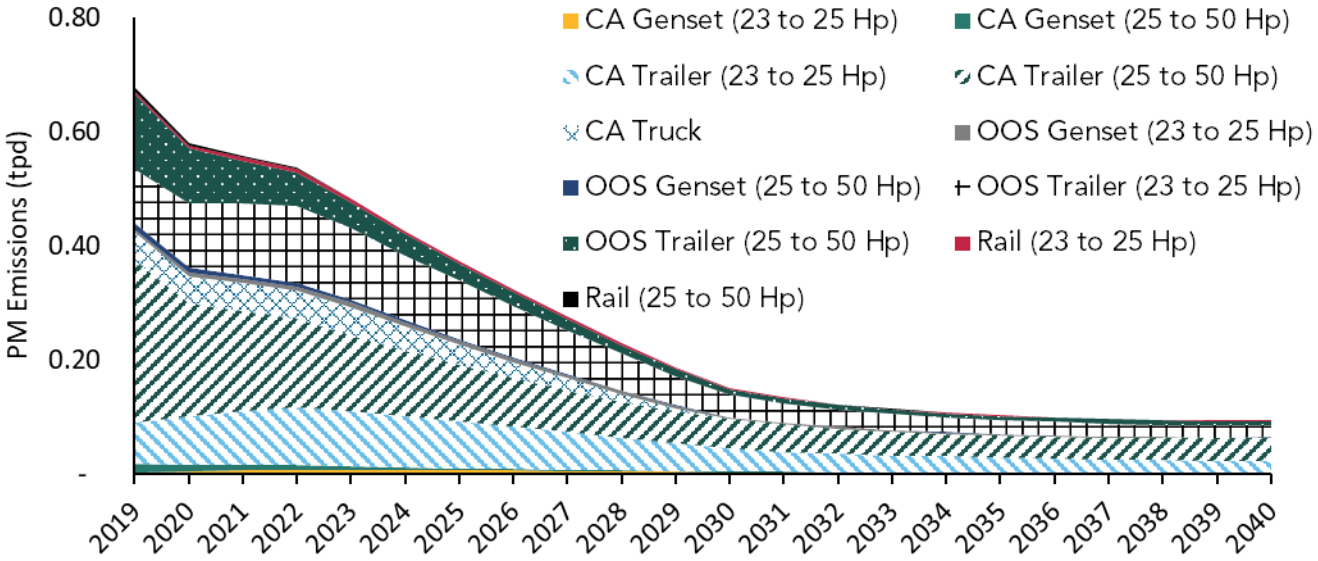


Figure 15. Statewide PM2.5 Emissions by TRU Category under Proposed Amendments



Under the Proposed Amendments, NOx emissions are only reduced by the requirement for California truck TRUs to transition to zero-emission, with no change in the trailer emissions. Figure 16 below shows the NOx emissions from TRUs, excluding truck TRUs, followed by the NOx emissions from truck TRUs in the baseline and under the Proposed Amendments in Figure 17.

Figure 16. Statewide NOx Emissions from TRUs Excluding Trucks.

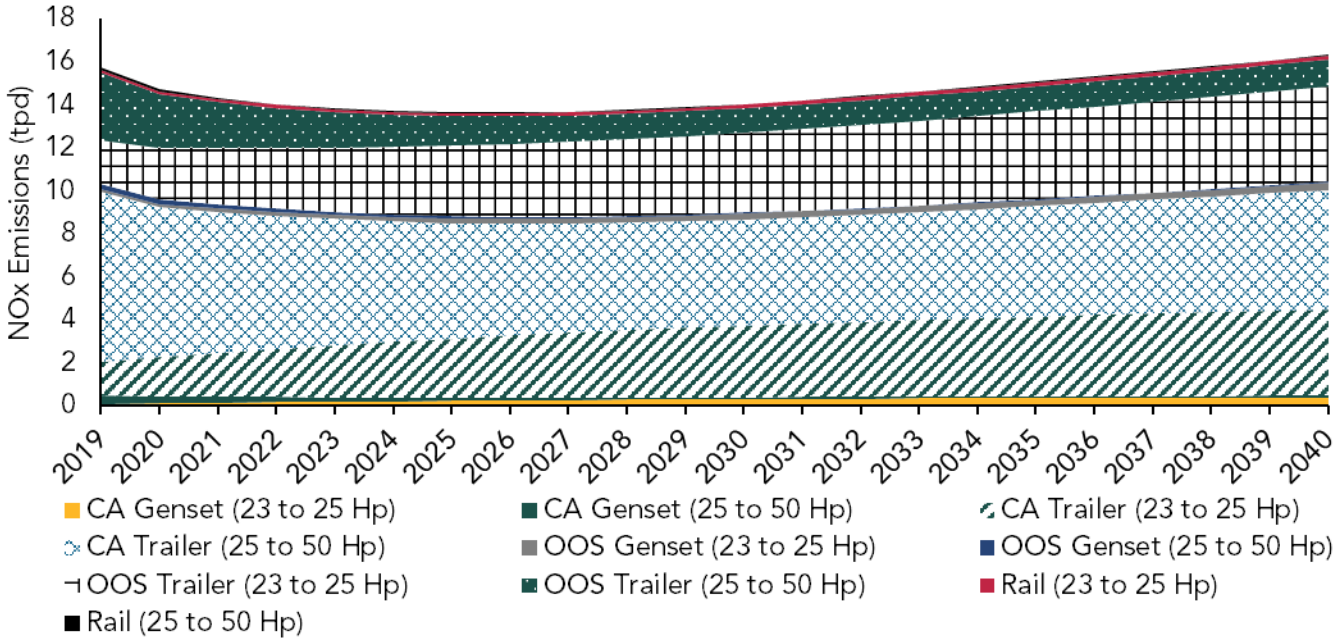
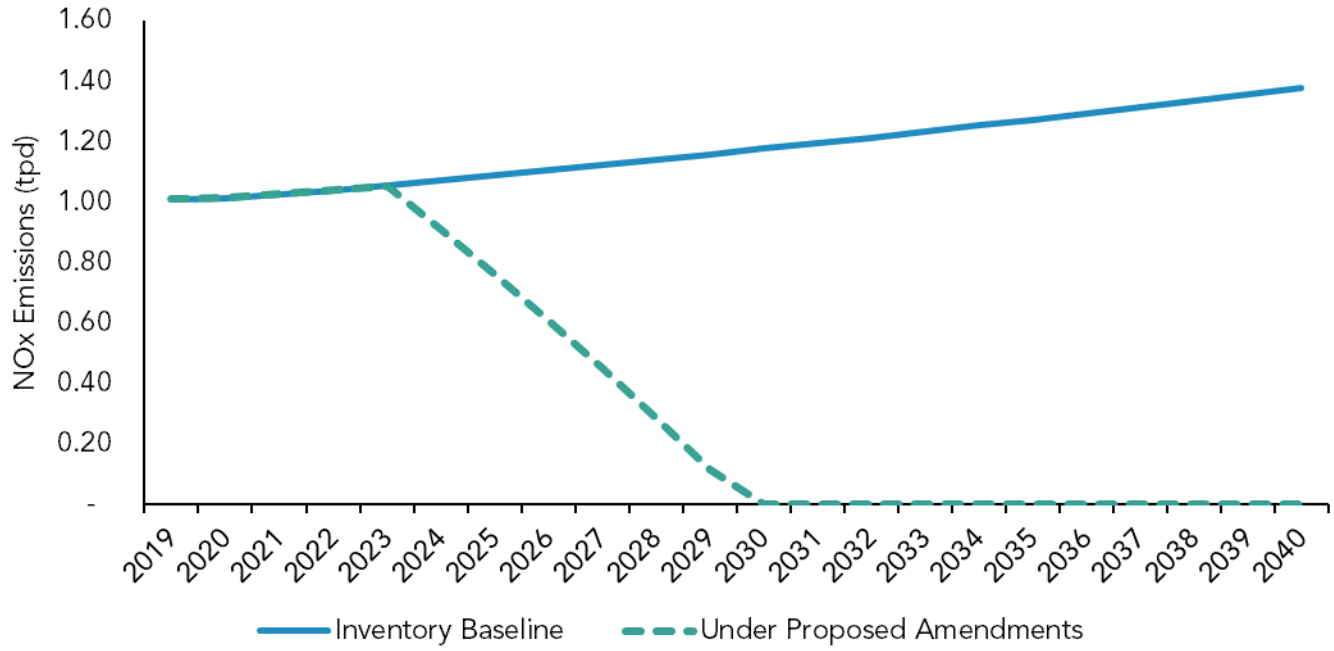


Figure 17. Statewide NOx Emissions from Truck TRUs



5.1. SRIA Emissions Results with 100 Percent Compliance

Per Department of Finance regulations (California Code of Regulations, title 1, sections 2000--2004),[11] the Proposed Amendments are a major regulation requiring a Standardized Regulatory Impact Assessment (SRIA) because the economic impact of the regulation is projected to exceed $50 million in a 12-month period. The following emissions results show the impacts of the Proposed Amendments relative to the SRIA baseline, in which full compliance with existing regulations is assumed.

Figure 18 shows the statewide PM2.5 emissions from TRUs in the SRIA baseline. The full compliance assumption causes significant turnover in 2020 to force compliance with the TRU ATCM, with an associated drop in PM emissions. The population of 23 to 25 horsepower trailers (in-state trailers in blue and out-of-state trailers in green) are forecast to dominate PM2.5 emissions.

[11] California Code of Regulations § 2000-2004, Division 3, Standardized Regulatory Impact Assessment for Major Regulation. (web link: https://govt.westlaw.com/calregs/Document/IAA1C7210595511E3BFC8D5B3615C797F?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)&bhcp=1#co_anchor_IA8F81D2F7A734A449389719B2F838650)

Figure 18. Statewide PM2.5 Emissions by TRU Category in Baseline with Full (i.e., 100 Percent) Compliance

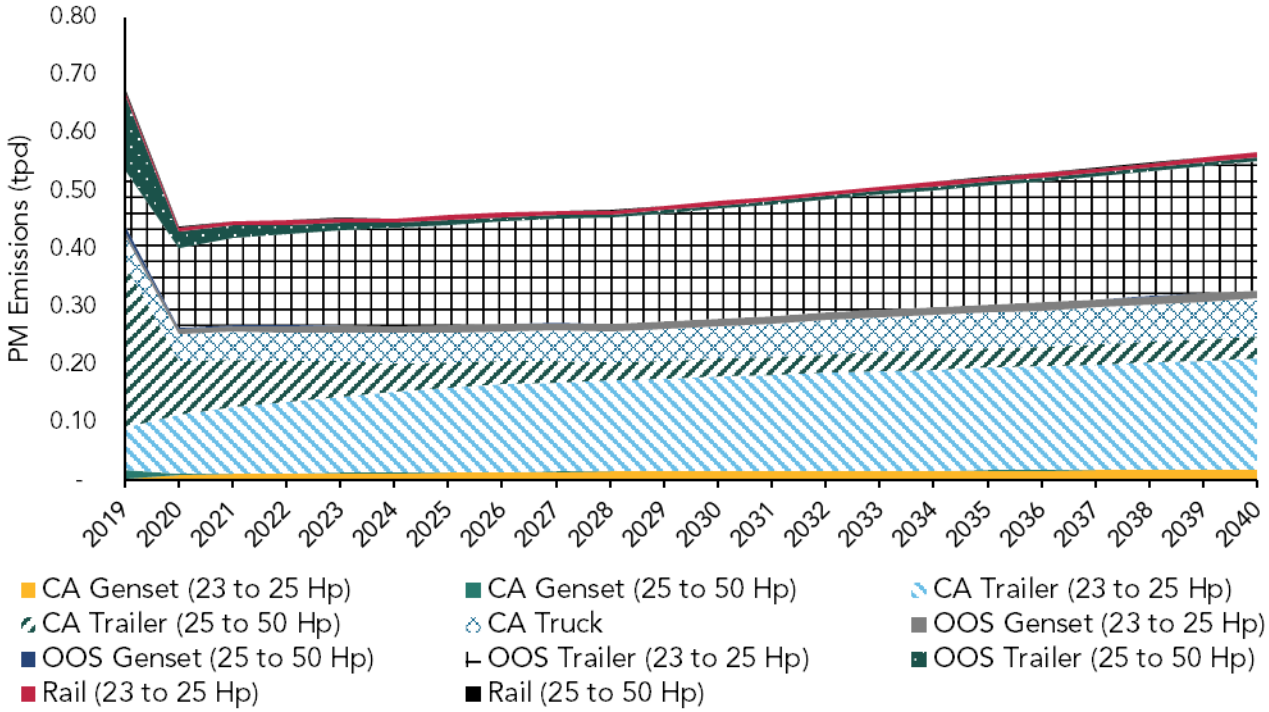


Figure 19 shows the statewide PM2.5 emissions that would result from the Proposed Amendments based on the SRIA baseline. Beginning in 2024, PM2.5 emissions are reduced as newly manufactured units are required to meet ULETRU.

Figure 19. Statewide PM2.5 Emissions by TRU Category under the Proposed Amendments with 100 Percent Compliance

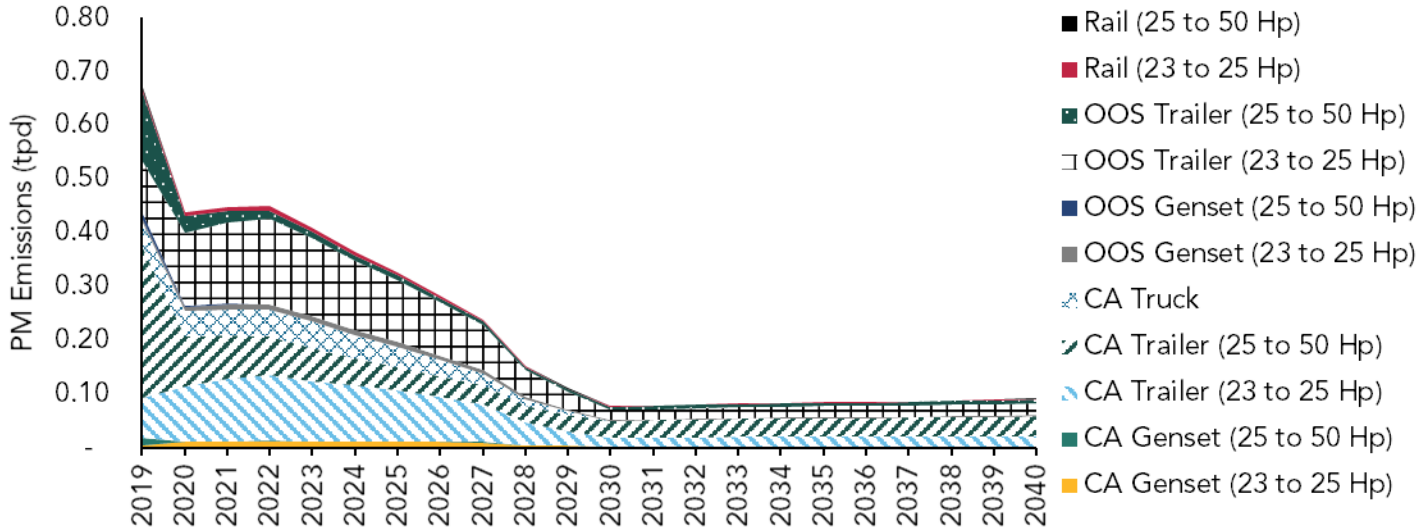


Figure 20 shows the Baseline statewide NOx emissions from TRUs. By 2035, NOx emissions will be slightly higher than 2019.

Figure 20. Baseline Statewide NOx Emissions by TRU Category with 100 Percent Compliance

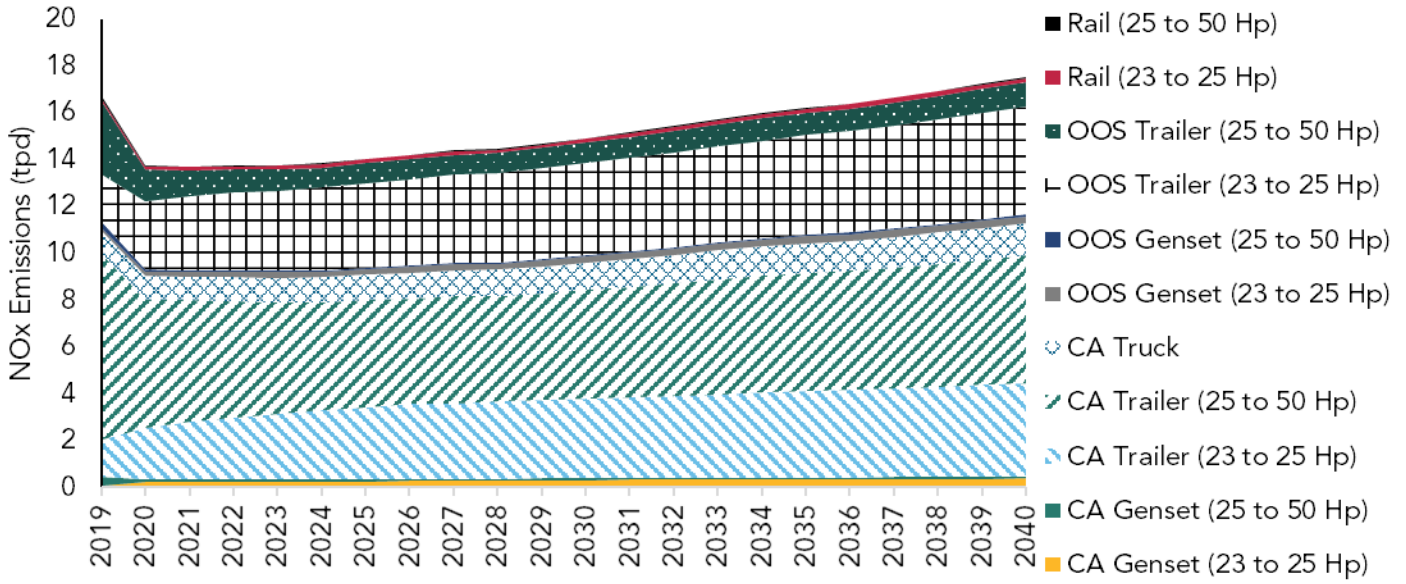


Figure 21 shows the statewide NOx emissions that would result from the Proposed Amendments based on the SRIA baseline. Beginning in 2024, NOx emissions are reduced slightly as truck TRUs begin to transition to zero-emission.

Figure 21. Statewide NOx Emissions by TRU Category under the Proposed Amendments with Full (i.e., 100 Percent) Compliance

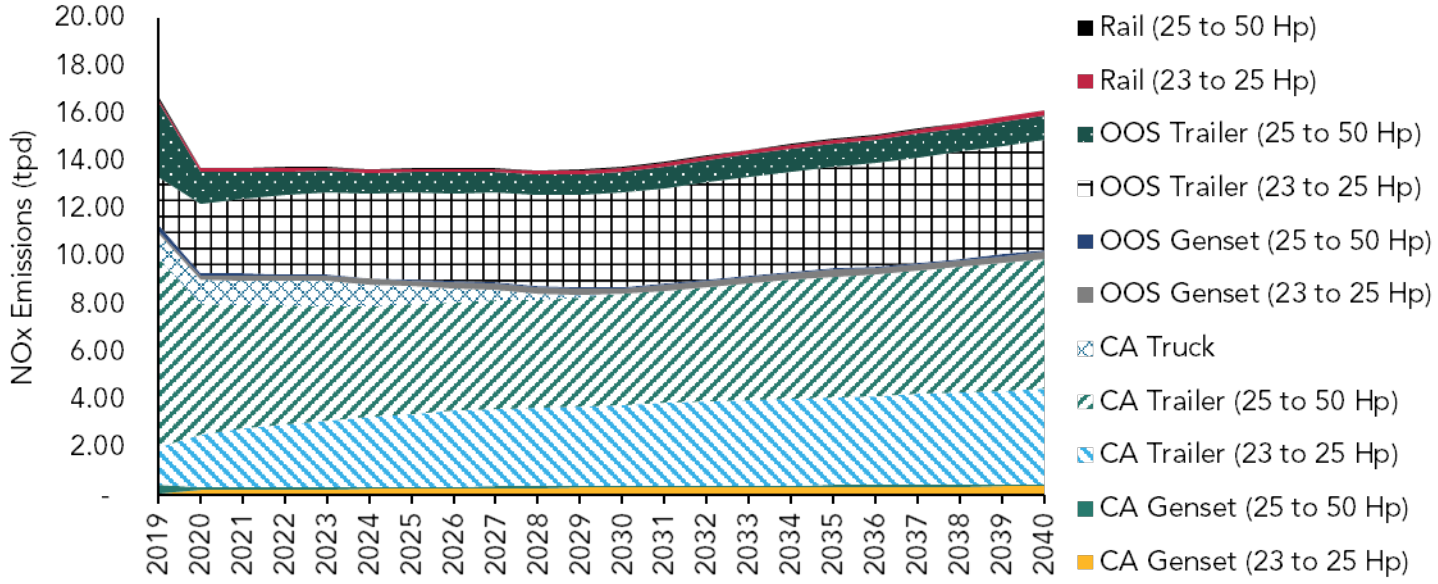


Figure 22 shows the impact of assuming full compliance for the SRIA in a comparison of PM2.5 under the baseline inventory, SRIA baselines, and the Proposed Amendments.

Figure 22. PM2.5 Emissions under Inventory and SRIA Compliance Scenarios