2025 Transport Refrigeration Unit Emissions Inventory

May 2025

CALIFORNIA AIR RESOURCES BOARD

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1 Executive Summary

This report provides information on the 2025 Transport Refrigeration Unit (TRU) Emissions Inventory for the California Air Resources Board (CARB).

An emission inventory accounts for the population, activity, horsepower (hp), and emission rate for a group of equipment, with an overall goal of describing the equipment use and resulting emissions. This 2025 TRU Emissions Inventory (or TRU Inventory) covers all diesel-powered TRUs operating in California. This report describes the data inputs, methodology, population, and resulting emissions in the TRU inventory. The main inventory updates include:

- Using TRU population data reported to CARB's Air Resources Board Equipment Registration Program (ARBER) Database as of January 2024,[1] including mandatory out-of-state TRU reporting for the first time,
- Updating growth rates and forecast of fleet retirement and purchase behavior,
- Updating emission factors based on CARB's TRU testing program and TRU engine certification data, and
- Reflecting the particulate matter (PM) emission standard for TRUs under 25 horsepower adopted in 2022.

The largest contributors to the difference in emissions are (1) more complete reporting including a number of older TRUs, which is the primary cause for the initial emissions being significantly higher, (2) updates to the emission factors showing higher oxides of nitrogen NOx than previous inventories, and (3) updates to the growth rate, changing the trajectory of emissions in 2030 and beyond.

Note that although pre-Tier 4 Final engines make up around 20% of the population, they contribute roughly 60% of the particulate matter under 2.5 microns (PM2.5). The new baseline emissions, including the benefits of a portion of the 2022 Amendments to the TRU Airborne Toxic Control Measure (ATCM), is shown below with PM2.5 and NOx in Figure 1 and Figure 2 respectively.

The 2022 Amendments included a more stringent PM emissions standard for TRUs on trailers, domestic shipping containers (DSC), railcars, and TRU generator sets rated under 25 horsepower and electrification of truck TRUs. A partial authorization was granted for the 2022 Amendments to the TRU ATCM from the federal Environmental Protection Agency (EPA), which included the tighter PM emissions standards for TRU on trailer, DSCs, railcars, and TRU generator sets rated under 25 horsepower. EPA did not act on the authorization for truck TRU electrification. Therefore, CARB is not reflecting truck TRU electrification in the TRU Inventory.

[1] Air Resources Board Equipment Registration System (ARBER) Reporting Database: https://arber.arb.ca.gov

Figure 1. Statewide PM2.5 Emissions by Diesel Tiers

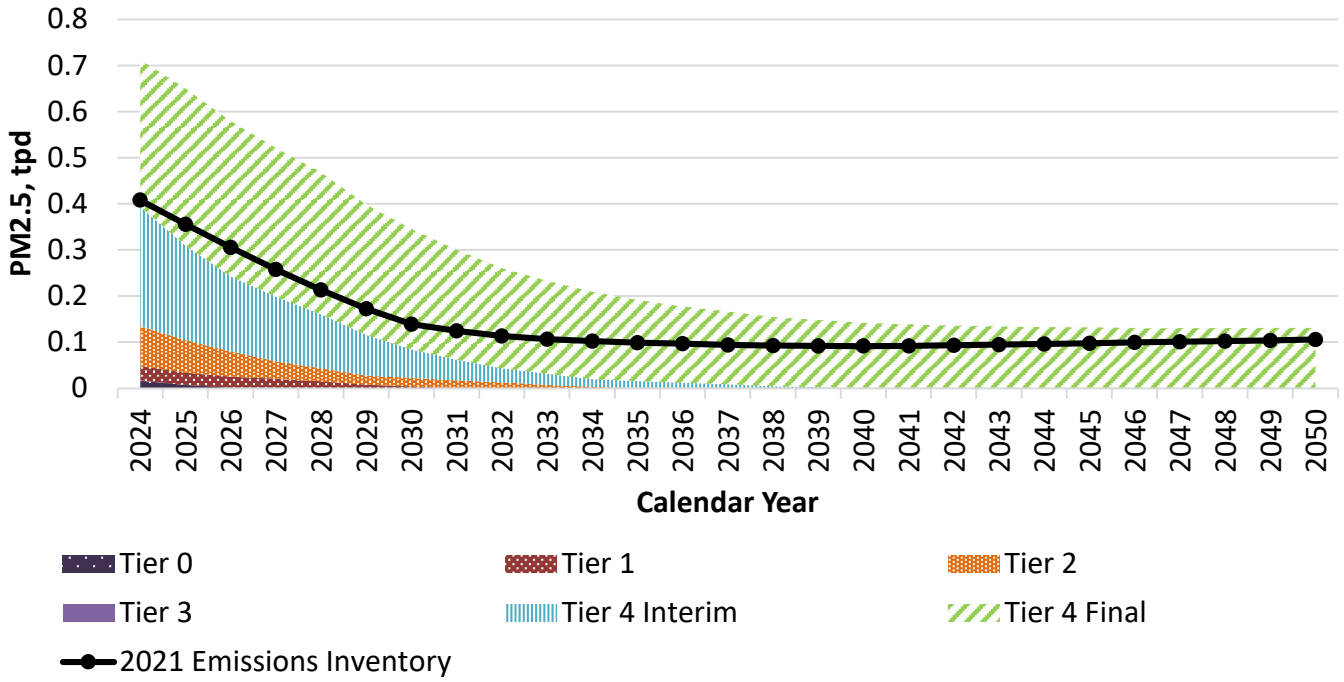
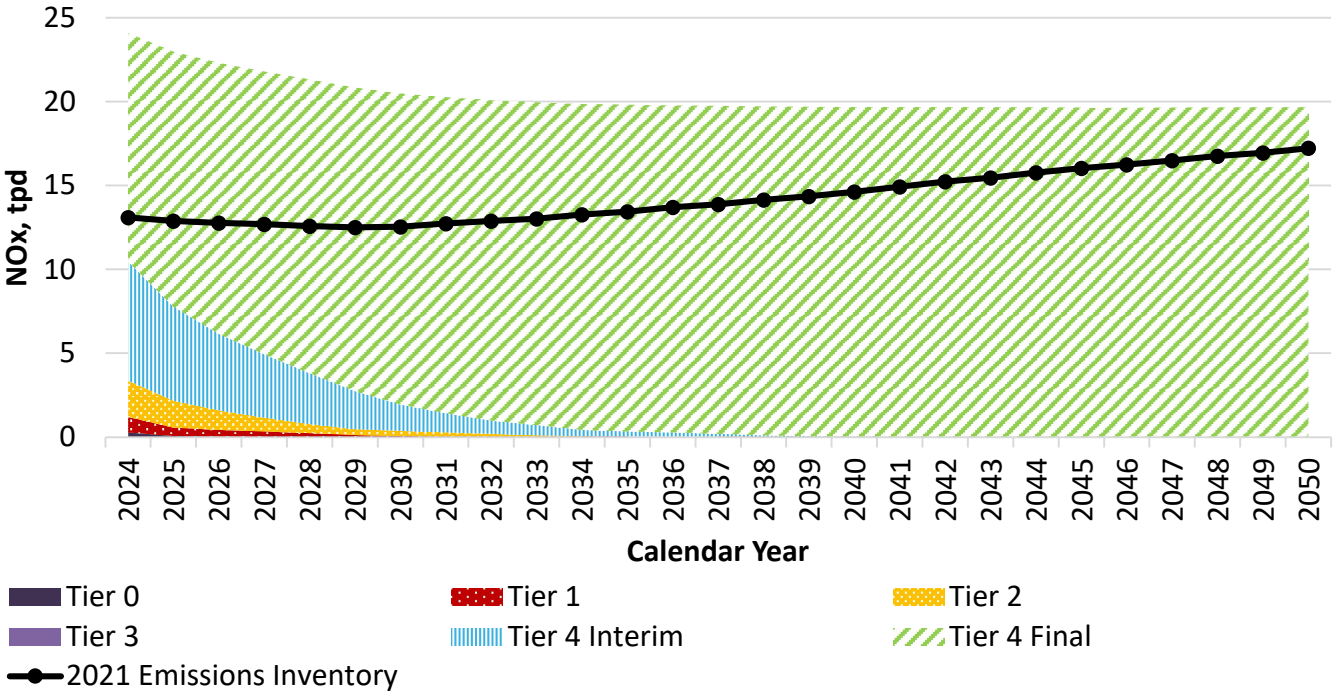


Figure 2. Statewide NOx Emissions by Diesel Tiers



2 Background on TRUs and Current Regulations

TRUs generally use diesel engines between 5 and 50 horsepower to power mobile refrigeration systems. TRUs are used in numerous applications to cool and supply air flow for products during transportation and storage, including frozen food, produce, meat and fish products, pharmaceuticals, and more. TRUs in California have a wide variety of activity patterns, from in-town local delivery routes to interstate and international commerce routes, or cold storage at a single location.

TRU activity and emissions occur on the road during transportation as seen in Figure 3 and at refrigerated warehouses, distribution centers, seaports, intermodal rail yards, and food and shopping centers. Many such centers have docks that can house dozens of trailers requiring cooling, which means dozens of active TRUs in a small area, such as the facility shown in Figure 4.

Figure 3. California Freight Corridors

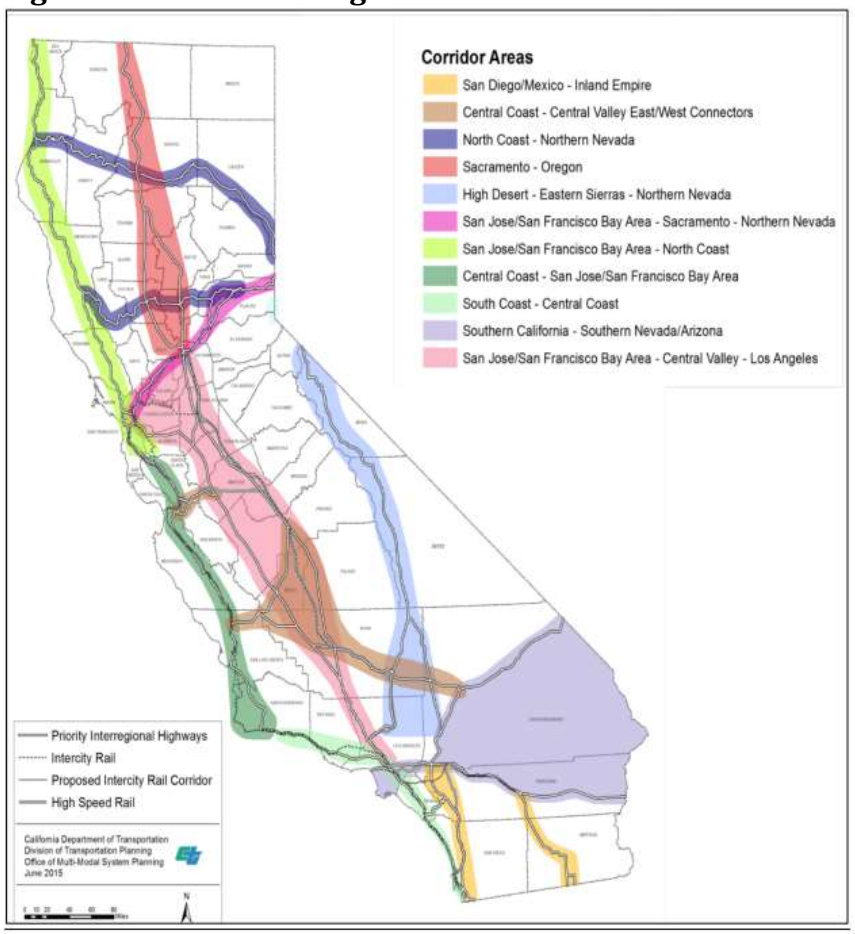


Figure 4. Food Distribution Facility in Southern California

This potential to concentrate emissions and consequent adverse health impacts makes controlling TRU emissions a vital component in improving air quality and protecting the health of 39 million Californians.

a. Previous Regulations

The first Airborne Toxic Control Measure (ATCM) for TRUs required mandatory TRU reporting for California-based TRUs. All TRUs are to meet the cleanest available emissions standard by the time the TRU is seven years old or older. This emissions standard could be met by installing the highest level of emissions aftertreatment or by purchasing an engine meeting the tightest level of emissions controls at the time.

The February 2022 Amendments to the TRU ATCM[2] modified the TRU ATCM to require the following:

- A more stringent PM emissions standard for TRUs on trailers, DSCs, railcars, and TRU generator sets rated under 25 horsepower;
- Zero-emission truck TRUs (CARB withdrew the EPA authorization request for this provision due to lack of EPA action, and is therefore not reflected in this inventory);

[2] *https://ww2.arb.ca.gov/resources/fact-sheets/2022-amendments-tru-atcm*

- Applicable facility registration and reporting; and
- Expanded TRU reporting and labeling.[3]

More specifically for the first bullet above, beginning with model year 2023, manufacturers of TRUs rated under 25 horsepower that are used on trailers, DSCs, railcars, and TRU generator sets must meet PM emissions standards in the 25 to 50 horsepower range.

This emission inventory does not reflect any truck TRU electrification requirements. For more information see the TRU regulation page at *https://ww2.arb.ca.gov/our-work/programs/transport-refrigeration-unit*.

3 Data Sources and Methodology

Mandatory reporting data, a facilities survey, and telematics data were used in developing the new 2025 TRU Emissions Inventory. Table 1 lists the data inputs and their corresponding sources, which include population, activity, emissions factors, and regional allocation profiles. The regional allocation profiles determine the portion of statewide population, activity, and emissions in the inventory allocated to each county and air basin in California.

Table 1. Data Sources Used in 2025 TRU Emission Inventory

Data Input	Source
Population	ARBER Database, January 2024
Activity Hours	TRU Facilities Survey, 2009, TRU Telematics Data, 2018
Emission Factors	CARB TRU Engine Testing from 2020 to 2024, TRU Engine Certification Data
Load Factors	TRU Engine Testing from 2020 to 2023, Telematics data, 2018
Growth	California Population Forecast[4], CA Dept of Finance, 2022
Regional Allocation	CARB Industrial Warehouse Space Geographic Information System (GIS) Layer, 2019 Truck and Freight Traffic Patterns

a. Population

The TRU Emission Inventory population comes directly from the ARBER database, an online database in which all TRU owners operating in California are required to report their fleet information. As of January 2024, the ARBER Database reflected 427,733 TRUs; however, only

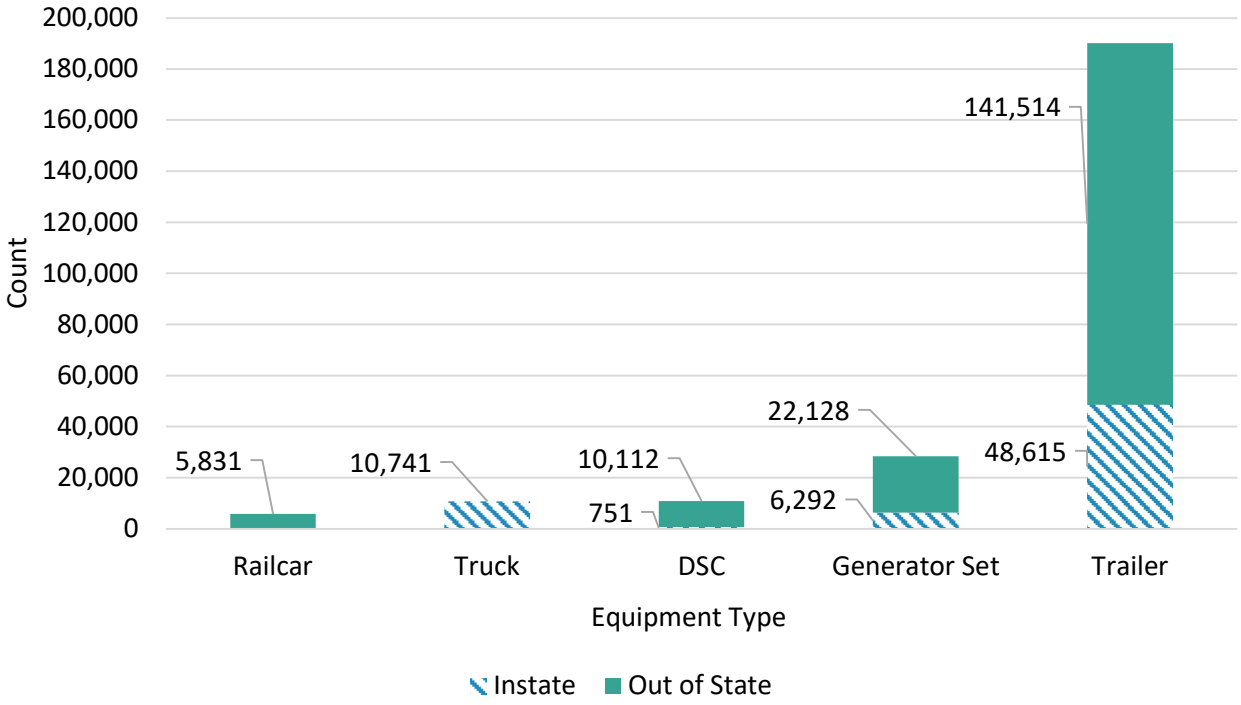
[3] Non-truck TRUs include TRUs for trailers, domestic shipping containers, railcars, and TRU generator sets.
[4] https://dof.ca.gov/forecasting/demographics/projections/

245,995 TRUs were listed as active, with the remainder being either sold, retired, or moved permanently out-of-State.

For the active TRUs, staff used the following ARBER reporting fields: TRU type (truck, trailer, etc.), horsepower bin, model year of the engine, and engine family. TRU owner information was used to forecast natural equipment retirement and replacement, as described later in the forecasting description.

As of December 31, 2023, all out-of-State TRUs are required to report in ARBER. Staff used company addresses entered for the ARBER account to determine whether the company was primarily in-state or out-of-state. If the address entered was out-of-state, all TRUs registered for that company are identified as out-of-state. This designation does not change the population but does impact activity within California. Figure 5 displays population by TRU type, and in-State or out-of-State status. Population numbers are also represented in

Figure 5. Equipment Type by In-State and Out-of-state Status



In some cases, TRUs also report the registration of the trailer they are attached to, including which state issued the registration. Staff evaluated using this information to designate In-State or Out-of-State status; however, trailer registrations were only available for some units, thus providing uncertainty if this is an accurate metric for TRUs operating primarily in California or out-of-State.

If trailer registrations were used to determine the state of primary operation, the emission inventory would shift by fewer than 2% of the TRUs between In-State and Out-of-State.

b. TRU Equipment Types

TRU categories are determined based on the type of truck or container they are cooling, such as a truck, trailer, DSC, or railcar. In this report, truck refers to single-body trucks only. These groupings are essential in identifying average horsepower, load factor, activity, percentage of time spent in California, and turnover and purchasing habits. Figure 6 shows the percentage of each TRU equipment type found in the 2024 base data (from the ARBER database). Most of the inventory comprises of out-of-state trailers at 58%, followed by in-State trailers at 20%. The remaining 22% of the inventory is comprised of TRU generator sets at 12%, DSC 4%, trucks 4%, and railcars at 2%. Table 2 shows the same information as Figure 6, with the additional population numbers per equipment type.

Figure 6. Base Data Population by TRU Equipment Type

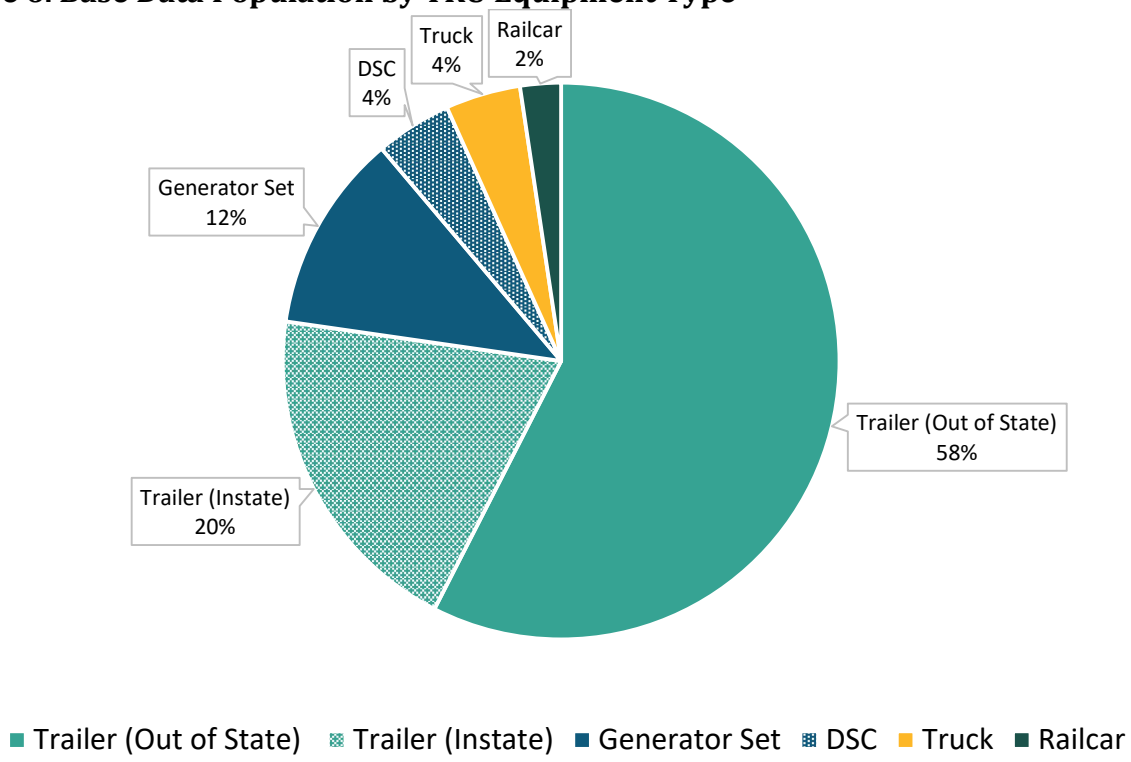


Table 2. Base Data Population by TRU Equipment Type

	In-State	Out-of-State	Percent of TRUs
Trailer TRUs	48,600	141,500	77%
Generator Set	6,300	22,100	12%
Domestic Shipping Container (DSC) TRUs	-	10,900	4%
Truck TRUs	10,700	-	4%
Railcar TRUs	-	5,800	2%

Truck TRU: TRUs used to cool all types of single-body trucks are called truck TRUs. Generally, truck TRUs have between 7 and 19 horsepower, with an average of 13.9 horsepower. These trucks are typically 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, almost all trailer TRUs were rated between 25 and 35 horsepower. However, in the last 10 years, trailer TRUs have been produced with engines between 23 and 25 horsepower. There are two subsets of trailer TRUs: (1) those primarily used in-State for regional routes and (2) out-of-state TRUs used in long-haul cross-country or international routes.

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

DSC TRU: These TRUs supply refrigeration to domestic shipping containers, which can be moved by locomotives, trucks and vessels. A small fraction of their time is spent in California.

TRU Generator Set (generator set): A TRU generator set provides power to a non-integrated refrigeration unit. Similar to trailer TRUs, most TRU generator sets were rated above 25 horsepower prior to 2016. However, recent ARBER data shows that most generator sets now sold are 23 to 25 horsepower engine units. Again, TRU generator sets have two subsets: (1) those primarily used in-State and (2) out-of-State generator sets used in long-haul applications.

4 Age Distribution and Compliance Status

a. Base Data Age Distribution

Figure 7 through 10 show the age distribution of the different TRU equipment types from the base year data. Figure 7 shows the age distribution of out-of-State trailers. The majority of out-of-State trailers fall between the ages of 2 and 8 years old. In-State trailers have a higher age range than

out-of-State trailers, with most equipment falling between 2 and 12 years old, as shown in Figure 8. Truck TRUs shown in Figure 9 fall between 1 and 9 years old. All three categories show a spike at the age of 12, corresponding to a regulatory deadline in the TRU ATCM. This was also the last year Tier 4 Interim engines in the 25 to 50 horsepower range would be available. DSCs, railcars, and generator sets, have a smaller age range than the other equipment types, with the majority of equipment falling between the ages of 2 and 5, as seen in Figure 10.

Figure 7. 2024 ARBER Out-of-State Trailer TRU Population Distribution by Age

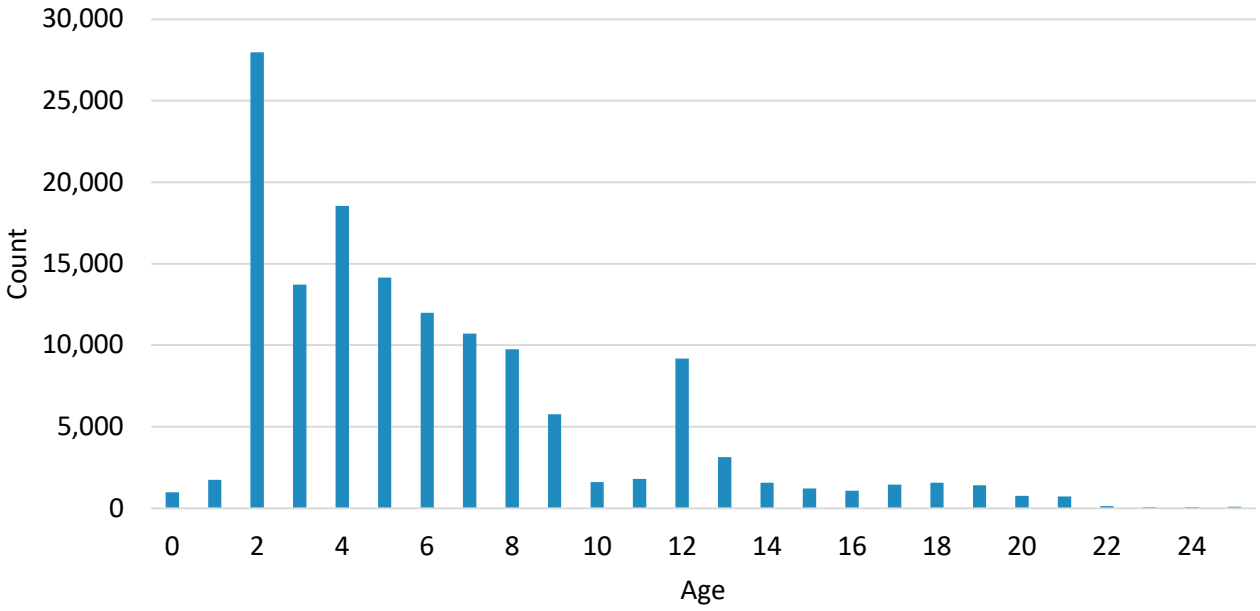


Figure 8. 2024 ARBER In-State Trailer TRU Population Distribution by Age

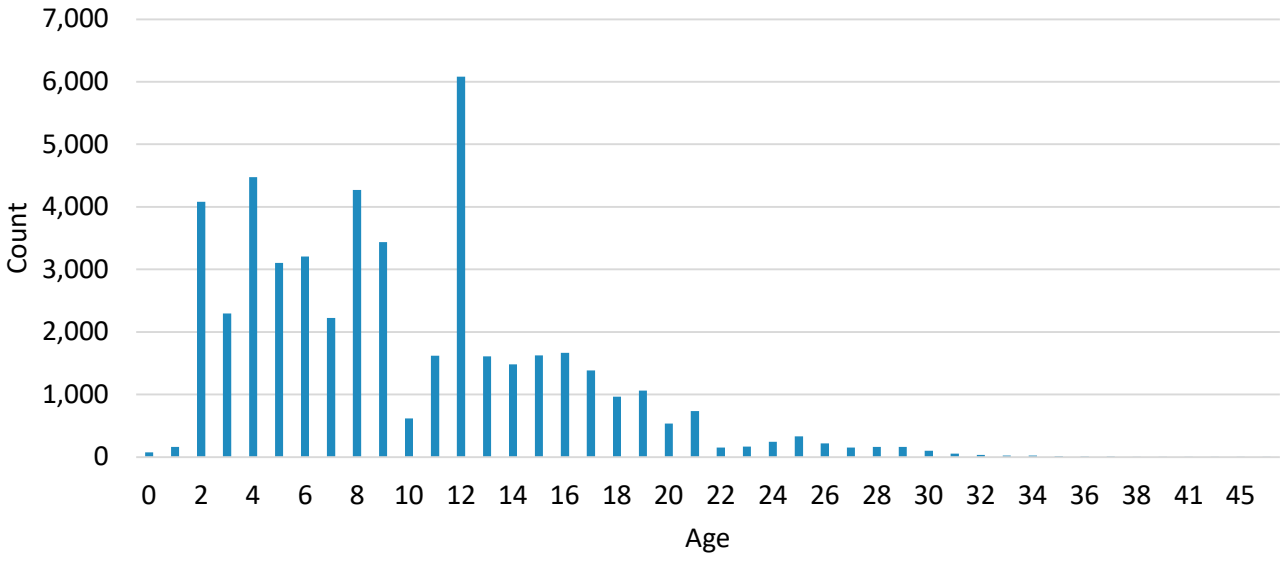


Figure 9. 2024 ARBER Truck TRU Population Distribution by Age

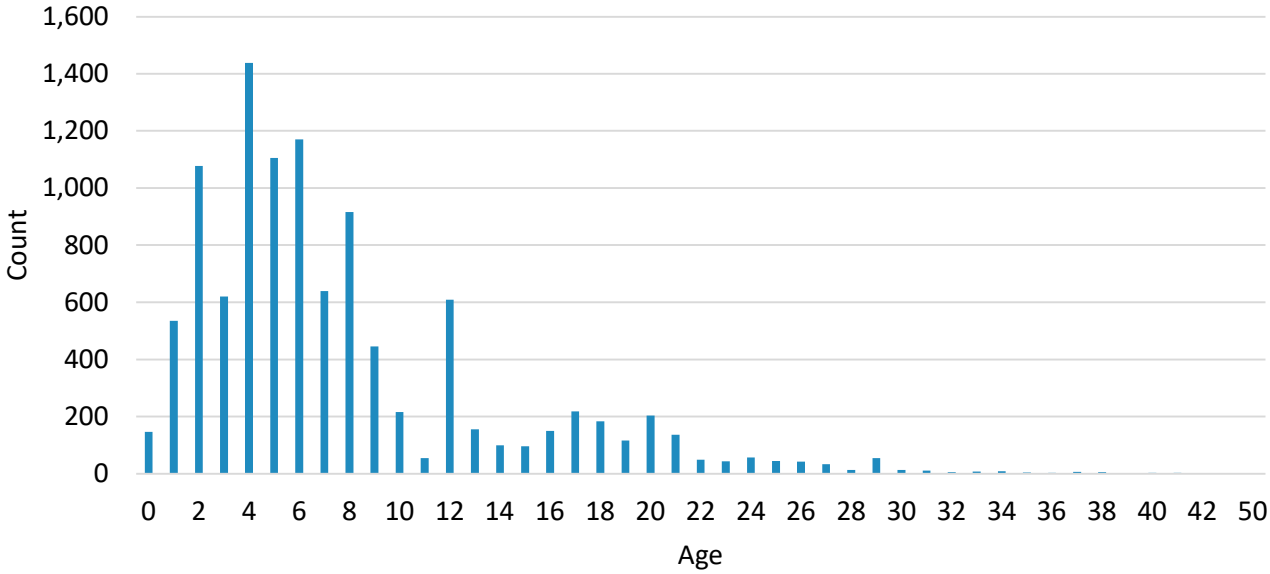


Figure 10. 2024 ARBER Railcar TRU, DSC TRU, and Generator Set Population Distribution by Age

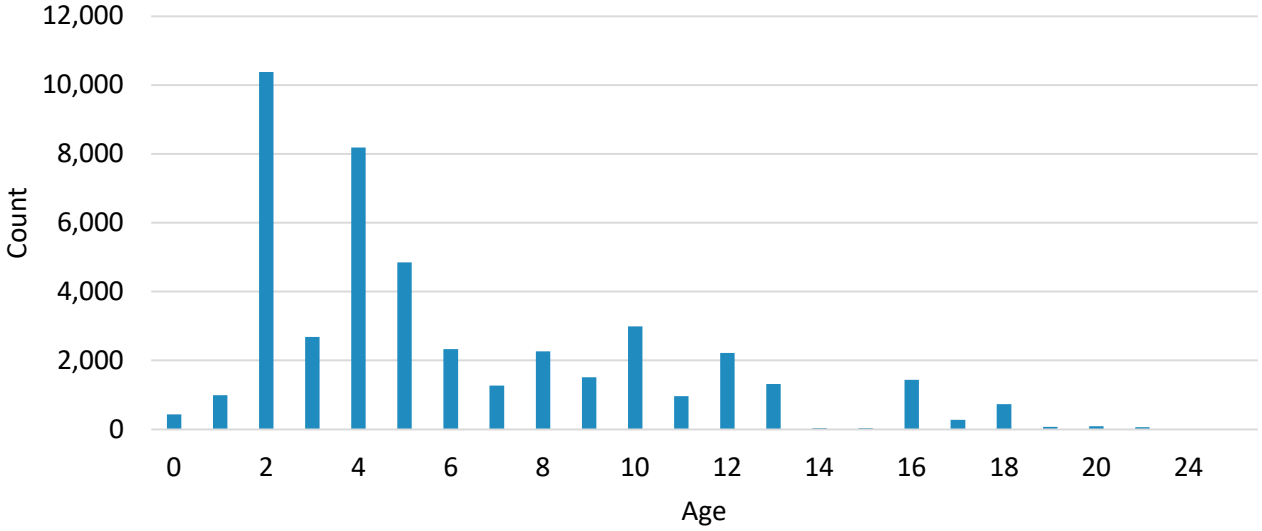


Figure 11 below shows the age distribution of trailer TRUs as a percent of the population.

Figure 11. Age Distribution of Trailer TRUs

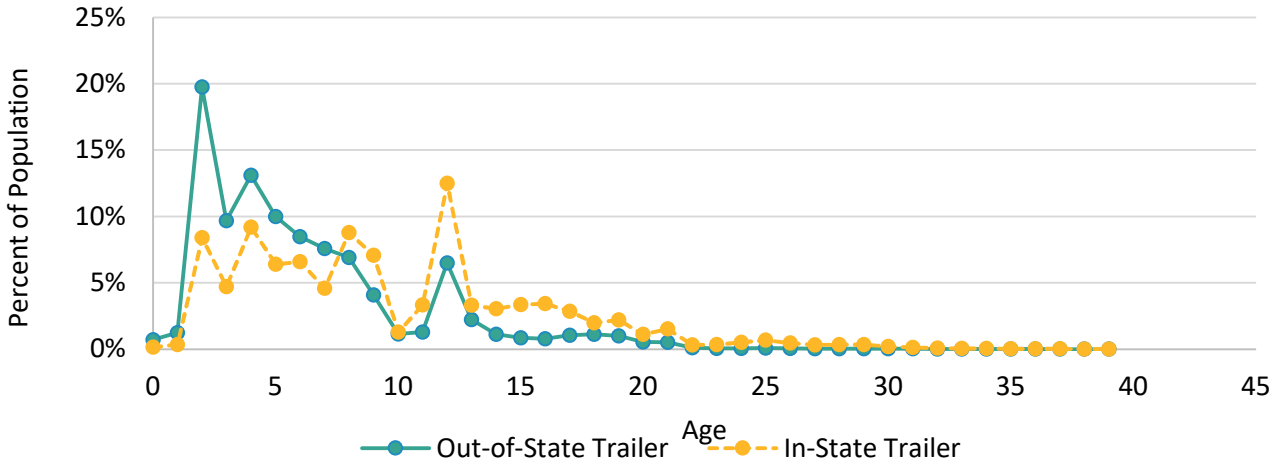


Table 3 below highlights how each equipment type has a different age distribution, with out-of-State fleets generally being younger on average.

Table 3. Average Age by Equipment Type and State Status

Equipment Type	In-State Average Age	Out-of-State Average Age
Trailer TRU	9.8	6.3
Generator Sets	9.4	6.4
Truck TRU	7.7	7.7
Railcar TRU	4.7	4.7
DSC TRU	2.4	2.4

b. Compliance Status

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

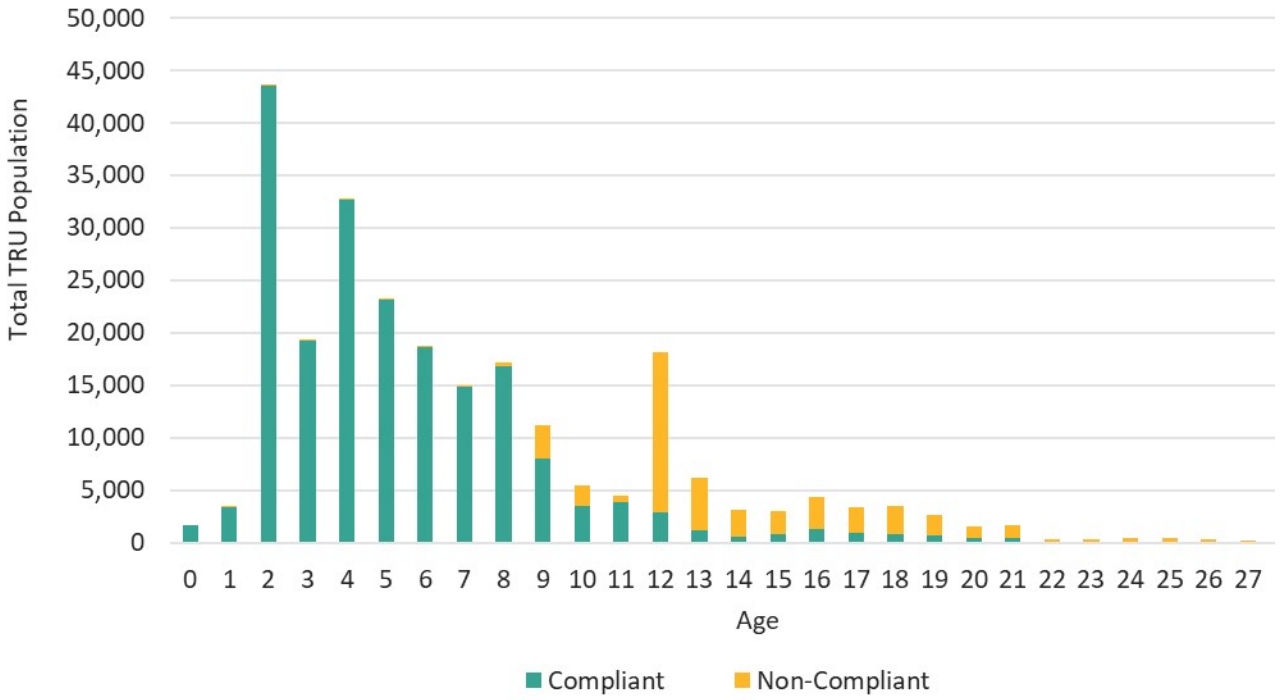
TRU unit, installing a retrofit device, or using alternative technology such as electric standby to allow the unit to run on supplied electric power while at the facility.

The compliance paths for TRUs are:

- Install Level 3 Verified Diesel Emission Control Strategy (VDECS, typically a retrofit diesel particulate filter (DPF))
- Install alternative technology
- Replace unit with a new TRU with current MY engine

In the 2024 ARBER data, 18% of registered TRUs are not compliant with the TRU ATCM. In Figure 12 below, the bars in green represent the compliant units, the majority of which are 11 years old or younger. Units 12 years of age and older are in yellow and are still registered in the ARBER database, but do not meet compliance. This is a change from 2021 TRU Emissions Inventory where 11% of TRUs were not compliant.

Figure 12. Population by Age and Compliance Status



To account for the reductions by retrofit engines, staff applied an 85% emission reduction to engines with a VDECS installed to meet compliance. Out of 245,994 total engines, 12,754 had VDECS installed, which is about 5% of the total population. Staff made the decision not to include vehicles 28 years or older in the inventory, and conversely will be retaining all reported TRUs that are age 27 and newer. This decision was made after reviewing enforcement data from roadside inspections of, which showed that only 3 TRUs inspected were older than 28 years out of approximately 1,200 total TRUs inspected.

a. 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. When reporting in ARBER, users enter the engine model in an open text field, so typed responses vary. 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. As such, algorithms were used to verify the engine model.

Table 4 reports the 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, and all trailer units are over 23 horsepower.

Table 4. Average Horsepower by Category

Category	Average Horsepower: Below 23 Horsepower Category	Average Horsepower: 23 to 25 Horsepower Category	Average Horsepower: 25 Horsepower and Over Category
Instate Truck and Trailer TRU	17.2	24.8	33.8
Out-of-state Truck and Trailer TRU	-	24.7	33.7
Instate generator set	-	24.8	33.2
Out-of-State generator set	-	24.8	33.2
Railcar and DSC TRUs	-	24.7	33.7

b. Annual Activity

Annual activity in this emission inventory refers to the total engine running time. TRUs can operate in several modes, divided in this report into:

(1) "TRU On Time" where the TRU will be on and monitoring temperature but will not always be running the diesel engine or producing emissions, and
(2) "Activity" or "Engine Run Time" where the engine is running and producing emissions. This is a subset of TRU On Time.

In 2007 to 2009, CARB surveyed a group of facilities that had loading docks for TRUs. The survey covered 54 facilities that monitored TRU activity and provided the average annual total TRU activity.

As a simplified example, if a TRU visited a facility twice, exactly one week apart, and accumulated 30 hours of engine run time in that week, that TRU weekly activity would be scaled up by 52

weeks to estimate 1,560 hours of annual use (equal to 30 hours/week times 52 weeks). The facility survey results determined that trailer TRUs had an average annual activity of 1,697 hours and truck TRUs had an average of 1,360 hours per year.

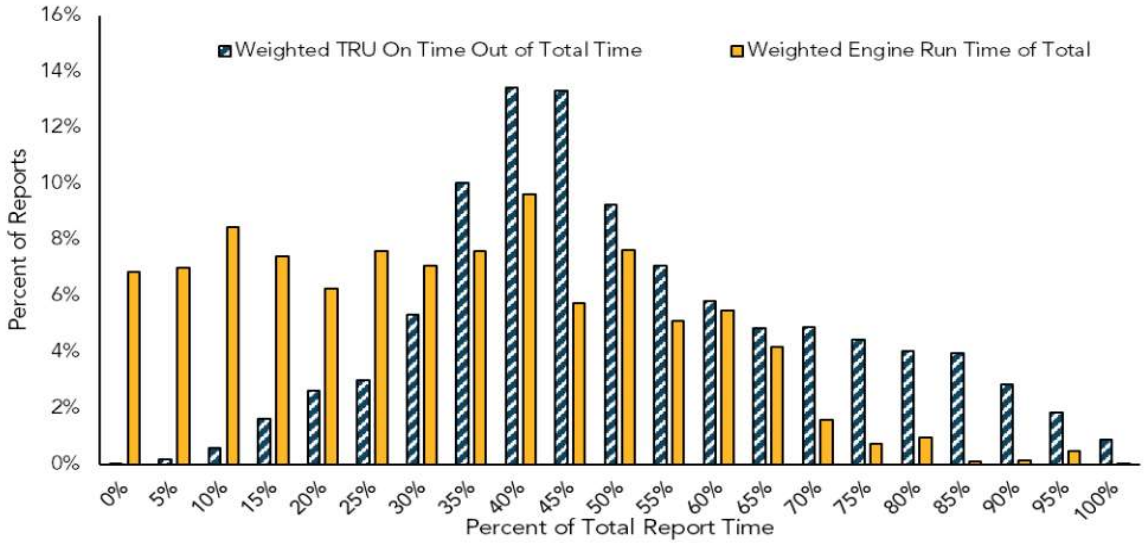
For the 2021 TRU emission inventory, CARB acquired telematics data from several trailer TRUs, detailing the total time the telematics covered, time the unit (but not necessarily the engine) was on, time the engine was on, whether the trailer was stationary or moving, and (in limited cases) the fuel use. The telematics data was primarily from 2018 activity and 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 (or 15 minutes), showing the unit was on for 900 seconds and the engine was on for 360 seconds (or 6 minutes) during those 15 minutes. After significant quality assurance, 811 telematics reports were used, representing 867,300 hours or 99 years of total time passing (with the engine either on or off) and 285,000 hours of engine run time.

The TRU On Time was 51.8% of the 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% of the total recorded time, 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%, showing outliers did not significantly influence the data).

Figure 13, from the 2021 TRU inventory report, 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 the yellow bars represent the percent of time the engine was running. The telematics data show that the TRU engines generally run about 62.5% of the time a TRU unit is turned on.

For example, in the 15% portion on the x-axis, the yellow bar is at 8%, meaning that 8% of the TRUs in the telematics data had engine run times that were between 10% and 15% of their total logged time. The blue bar is just under 2%, meaning slightly under 2% of the TRUs in the telematics data had TRU On Times that were between 10% and 15% of their total logged time.

Figure 13. Telematics Data: TRU Unit On and Engine On Times



The 2025 TRU emissions inventory uses both the annual activity facility survey results from the 2009 survey and the 2018 telematics data.

Although detailed in some ways, the telematics data did not provide information on TRU models, ownership, or other variables to determine if the activity data represented all TRU operations in the State. To incorporate the telematics data while not overinflating the total activity statewide (from units potentially not defined by the telematics data), the 2009 facility survey data and the 2018 telematics data were combined to determine average TRU activity. For each data source, staff weighted the percent of engine time on by the report's duration to calculate a time-weighted average of engine run time. From the 2009 facility survey data, each facility was weighted by the number of trailer TRUs and multiplied by the average time for a TRU report. Each telematics data point represented a single unit and was weighted according to the length of that telematics report.

Table 5 shows how the following two example facility reports and two telematics data points would be averaged to calculate the TRU average on-time rate.

Table 5. Example Truck and Trailer TRU Activity Average Calculation

Data Source	Number of TRUs	Time of Reports	TRU On Time Average	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%
Facility 2 Report	10	5 day (average)	30%	10 x 5 = 50 days	50 days x 30%

Data Source	Number of TRUs	Time of Reports	TRU On Time Average	Total TRU Days	Average Rate: TRU on time
Telematics 1 Data	1	60 days	35%	1 x 60 = 60 days	60 days x 35%
Telematics 2 Data	1	100 days	40%	1 x 100 =100 days	100 days x 40%
Total				710 days	24.8% Weighted Average

Based on the average time-on of 24.8%, the annual activity would be 24.8% of 365 days per year, and 24 hours per day, this totals 2,170 hours per year. This methodology gives higher weight to the facilities with a 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 brief period have little impact on average activity. Table 6 shows the results and overall information on the facility surveys, telematics data, and the resulting activity average.

Table 6. Trailer TRU and Truck TRU Activity Data Sources and Averages

Data Source	Cumulative TRU Time Represented	TRU Units Represented	Average Annual Hours	Time-weighted Average Hours
Facility Survey - Trailers	1,100,000 Hours (125 years)	5,535 Trailers	1,712	2,201
Telematics Data - Trailers	870,000 hours (99 years)	811 Trailers	2,876	
Facility Survey – Trucks	92,000 hours (11 years)	459 Trucks	1,360	1,360

This results in an average trailer activity of about 42% weighted toward the new telematics data and 58% 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 2009 facility survey. The facility survey represented 459 trucks, with an average activity of 1,360 hours per year. Because generator sets are used similarly to trailer TRUs, generator set activity was based on the above trailer activity, which resulted in 1,719 annual hours for in-State generator sets, and 272 annual hours for out-of-State generator sets.

c. Portion of Activity within California

Truck TRUs, generally assigned to local or regional delivery duties, are assumed captive to California. Therefore, the inventory assumes all truck TRU activity occurs within California.

The trailer, generator set, and railcar TRU populations split their activity between California and other states or countries. The division of activity for the trailer, generator set, and railcar TRUs is based on the same methodology as the out-of-state trailer TRU population. These TRUs are modeled using EMFAC2021[5] activity patterns for freight truck categories that are associated with refrigerated trailers or refrigerated transport.

[5] *https://ww2.arb.ca.gov/our-work/programs/msei/on-road-emfac*

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 13% of their total VMT. California-based trucks in EMFAC also include California IRP trucks (trucks registered in IRP but based in California). Overall, VMT for California-based freight trucks (the combined average of IRP and non-IRP trucks) is approximately 79% in California and 21% outside California. Table 7 lists total annual hours and hours within California by category.

Table 7. TRU Activity Totals and In-State Totals

Category	Annual Activity Inside and Outside California (hours)	IRP Data – Portion Inside California (%)	Average Annual Activity Inside California (hours)
In-State Trailer TRU and Generator Sets	2,201	78.0%	1,719
Out-of-State Trailer TRUs and Generator Sets*, Railcar* and DSC*	2,201	12.4%	272
Truck TRUs	1,360	100%	1,360

d. Load Factor

A load factor represents the average operating power of the equipment as compared to its maximum rated power. The load factor is an expression of how hard an engine works on average, ranging from 0 to 100%, and is used for calculating emissions from off-road equipment. Table 8 provides the 2025 Draft TRU Emissions Inventory load factors, which are the same as the 2021 inventory and described below.

Table 8. Load Factors

TRU Category	Below 23 Horsepower	Between 23 and 25 Horsepower: All Years	Over 25 Horsepower: Model Year 2012 and Older	Over 25 Horsepower: Model Year 2013 and Newer
California Truck and Trailer TRU	0.56	0.46	0.46	0.38
Out-of-State Truck and Trailer TRU	-	0.46	0.46	0.38
California Generator Sets	-	0.33	0.33	0.27
Out-of-State Generator Set	-	0.33	0.33	0.27
Railcars and DSC	-	0.46	0.46	0.38

In the 2021 TRU Emissions Inventory, telematics data included limited data on fuel use of TRUs. Fuel data from the telematics report were recorded 3.6% 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 by multiplying horsepower, hours, load factor, activity, and emission factors.

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. The telematics data was based on 2016 to 2017 data, a time when 23 to 25 horsepower TRUs were being sold but only made up a small fraction of the market share. For this analysis, CARB assumed the trailer TRUs had an average horsepower over 33.8 Horsepower. The fuel consumption rate of 0.408 pounds per horsepower-hour was based on U.S. EPA values for engines of 25 to 50 horsepower.[6]

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 significant difference between this newly calculated load factor and the previous factor, the 2025 TRU

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

inventory will continue to use the 2021 emission inventory load factors for engines below 23 horsepower, engines between 23 and 25 horsepower, and engines over 25 horsepower with a model year of 2012 or earlier.

For engines over 25 horsepower with model years 2013 and newer the load factor was updated in the 2021 TRU Emissions Inventory based on discussions with manufacturers. The manufacturers informed staff that 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% 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 17% reduction in the load factor 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% of TRU units were 2013 or newer. A 17% efficiency improvement in 20% of units would only show up as a 3.4% reduction overall in load. This minor reduction was not seen in the telematics data, possibly due to the majority of TRUs in the telematics data being pre-2013 model year, or simply due to the magnitude of the reduction falling within the margin of error. The model assumes no efficiency improvement for engines below 23 horsepower, because no supporting information was available from TRUs that use engines under 23 horsepower.

e. TRU Turnover

The emission inventory projects the TRU population and emissions in future years by predicting when, on average, fleets will replace their TRUs with newer units due to natural replacement and retirement of older equipment. Each fleet has its own turnover analysis based on the average age and specific equipment reported to ARBER. The core concept is that each fleet will maintain the average age in the base year. Broadly, a fleet with faster replacement cycle will consistently have newer TRUs and a lower average age, while a fleet with slower replacement cycles will have older TRUs.

The turnover analysis uses two important assumptions:

(1) TRU fleets will generally turn over their oldest equipment first, and
(2) fleets only purchase equipment as new as their youngest unit, as observed in the base year data, meaning many fleets purchase used equipment.

This maintains the assumption that young fleets will continue to purchase newer TRUs in future years while older fleets will continue to purchase used TRUs in future years.

Figure 14Figure 14 steps through this turnover example as follows. Assume in 2023, a fleet has five TRUs, and the average age is seven years (first row of Figure 14). As the emission inventory is forecast from calendar year 2023 to 2024, each TRU becomes one year older, and the average age

of TRUs is now eight (second row of Figure 14). To maintain the base year average age, the inventory forecasts that the fleet will retire the oldest TRU (12 in the example below) until the average age of all TRUs is once again seven years old or lower. In this example, the fleet replaces the oldest TRU to match the age of the youngest TRU in the base year, in this case, age two. The process of maintaining the average age may require turning over dozens of TRUs per year for very large fleets. On average, the example fleet below would need to turn over about one TRU every two years to maintain the average age of seven. Figure 14 illustrates this process for several more years.

Figure 14. Turnover Example for a Fleet Operating Five TRUs from 2023 through 2028

A fleet with 5 TRUs, with 12 years old average age, and 7 years old minimum age in base year

Calendar Year	TRU 1	TRU 2	TRU 3	TRU 4	TRU 5	Avg Age Before Turnover	Avg Age After Turnover
2023	Age 7	Age 9	Age 12	Age 16	Age 16	12	-
2024	Age 8	Age 10	Age 13	Age 17	Age ~~17~~ 7	13	11
2025	Age 9	Age 11	Age 14	Age 18	Age 8	12	-
2026	Age 10	Age 12	Age 15	Age ~~19~~ 7	Age 9	13	10.6
2027	Age 11	Age 13	Age 16	Age 8	Age 10	11.6	-
2028	Age 12	Age 14	Age ~~17~~ 7	Age 9	Age 11	12.6	10.6

f. Growth

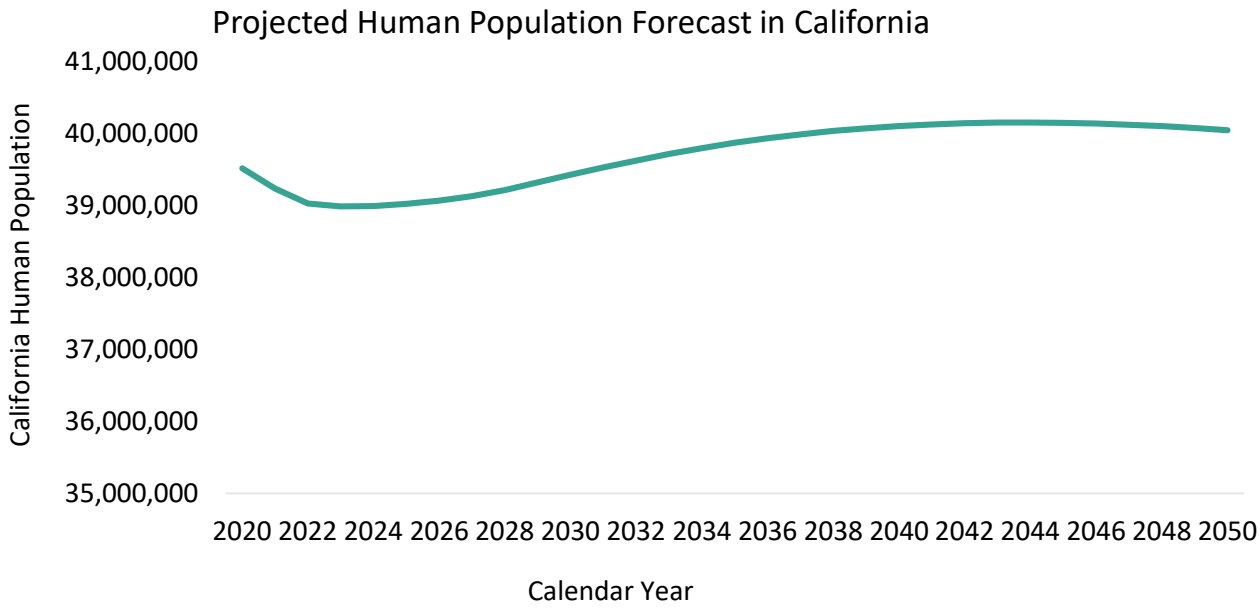
The primary purpose of TRUs is transporting temperature-controlled goods. To estimate overall growth of the TRU sector, staff focused on two main sources: (1) the population forecast of California and (2) the agricultural lands used to grow crops. The population forecast determines whether a higher population would create more food demand, including frozen or refrigerated food, thus growth in the TRU sector. Agricultural production forecasts determine whether California will produce additional produce or refrigerated goods for export, which could lead to a growth in TRU activity even if the California population remains constant.

Staff relied on the 2022 California Department of Finance[7] population projection for the population forecast.

[7] https://dof.ca.gov/forecasting/demographics/projections/

Figure 15 demonstrates the projection is essentially flat, increasing by less than 2% over 20 years and then falling. This results in less than a 0.1% annual growth rate to 2044 and then slightly under a 0.1% annual negative growth to 2060.

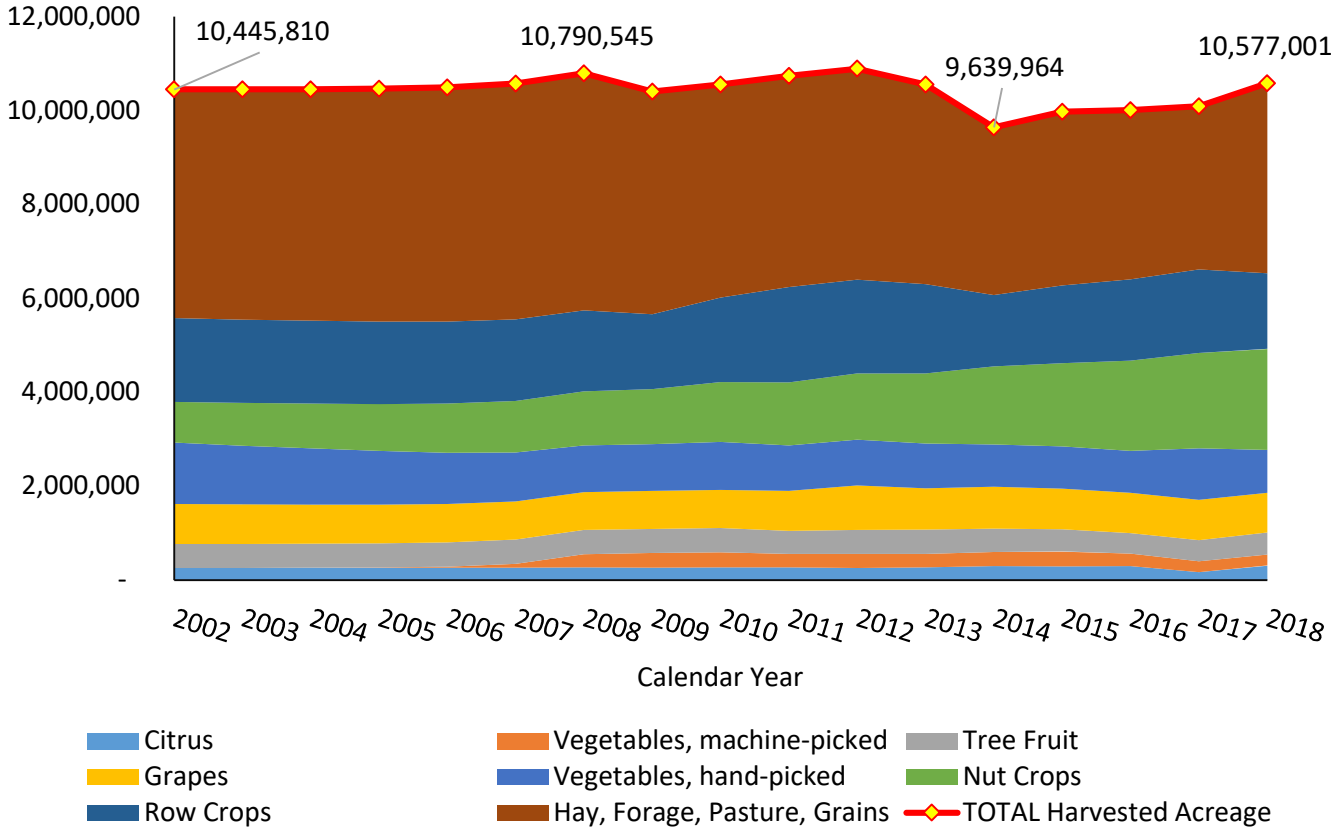
Figure 15. 2022 Department of Finance California Population Forecast



As described in CARB's 2021 Agricultural Emission Inventory[8], County Agricultural Commissioners' data reports that the total acreage of California's harvest farms has been relatively flat from 2002 to 2018, as shown below in Figure 16. Additionally, the 2021 Agricultural Emission Inventory has an overall negative growth forecast based on land use, economic modeling, and water availability, as further discussed in the report (linked above).

[8] CARB's 2021 Agricultural Equipment Emission Inventory Technical Document, https://ww2.arb.ca.gov/sites/default/files/2021-08/AG2021_Technical_Documentation_0.pdf

Figure 16. California Harvest Agricultural Lands (acres)

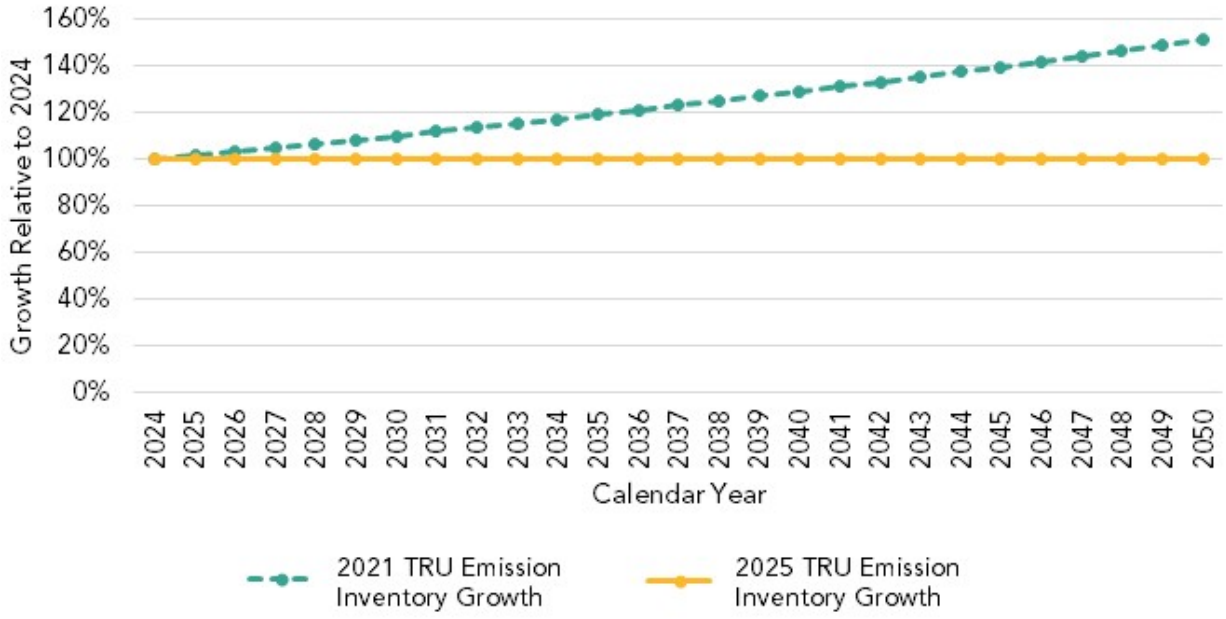


Based on the population forecast and agricultural trends showing no growth, Staff did not include a growth factor in this TRU emission inventory. Thus, total TRU population and activity are expected to remain constant.

The differences between growth factors in the 2021 Emissions Inventory and the 2025 Emissions Inventory are shown below in

Figure 17. The 2021 TRU Emissions incorporated a 1.6% annual growth rate which was based on the annual population growth rate of nationwide reefers. As discussed above, the updated 2025 Emissions Inventory is not implementing a growth rate.

Figure 17. Growth 2021 Emissions Inventory vs 2025 Emissions Inventory



g. Emission Factors

Emission factors represent the emissions per unit of work an engine produces. This emissions inventory measures emission factors using grams of pollutant per brake-horsepower-hour (g/b hp-hr). The model uses a combination of emissions testing results for NOx, EPA engine

certification data based on engine family for PM, and the more general off-road diesel emission factors for other pollutants or where TRU-specific data was not available[9].

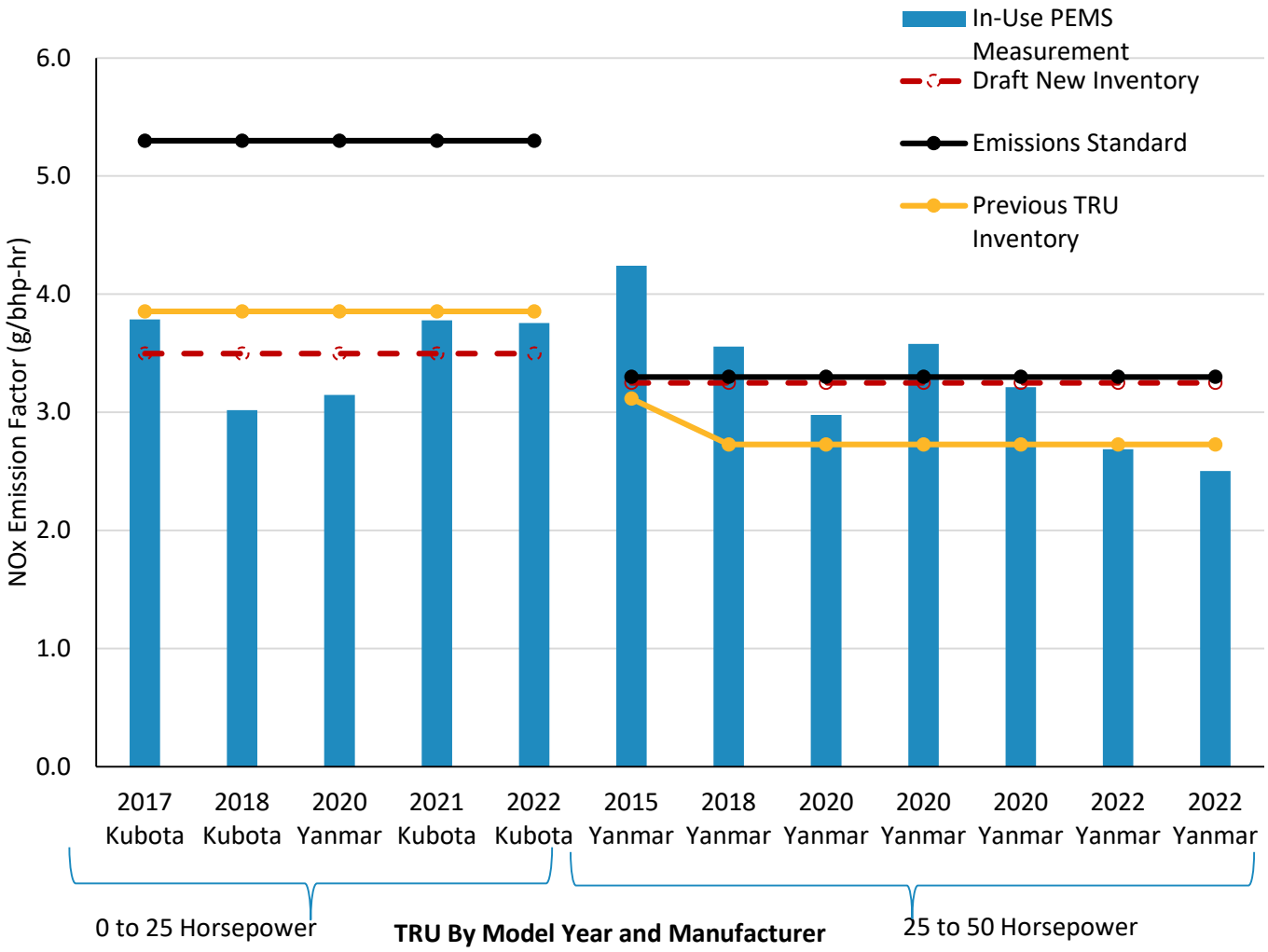
i. TRU Emission Testing

From 2020 to 2023, staff collected NOx emissions data from 13 trailer TRU units using Portable Emissions Measurement Systems (PEMS). The 13 trailer TRUs included five Kubota engines and eight Yanmar engines, in the 0 to 25 and the 25 to 50 horsepower bins. The engine testing method was based on running each of the 13 TRUs through 10 one-hour cycles. The cycles included activities designed to mimic real-world operation of TRUs, including trailer cooldown periods, maintaining low temperature with the trailer doors open, and maintaining low temperature with the trailer doors closed.

Figure 18 displays the average NOx emission rate resulting from each test, ranging from 2.5 to 4.2 g/bhp-hr. Additionally, the new emission factors for the inventory for each horsepower bin is shown in dotted red, first showing the 0 to 25 horsepower bin and continuing with the 25 to 50 horsepower bin. The emission standard is shown in solid black, showing a range from 2.5 to 4.2 g/bhp-hr, for each horsepower bin. The 2021 Emissions Inventory emission factors are shown in yellow below.

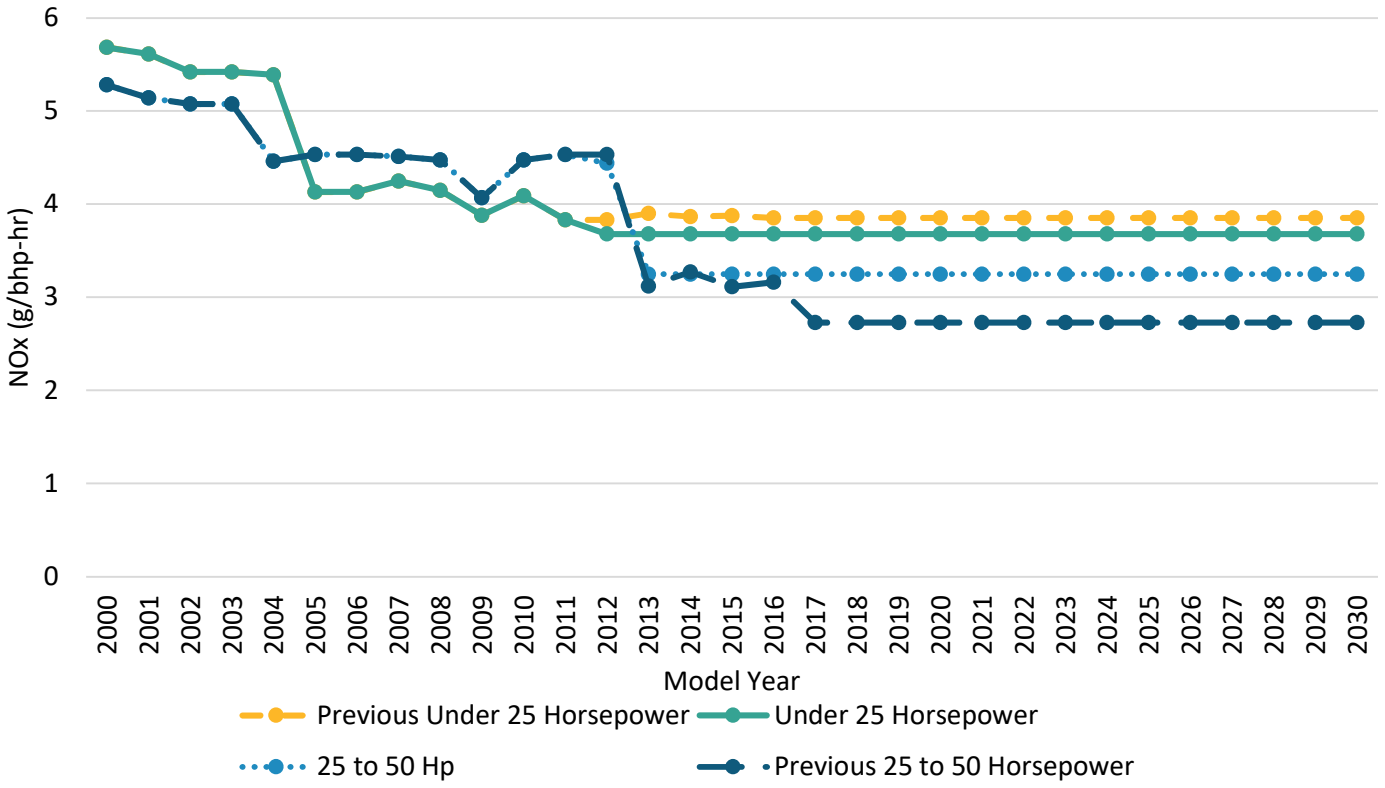
[9] *https://ww2.arb.ca.gov/our-work/programs/msei/road-categories/road-diesel-models-and-documentation*

Figure 18. TRU NOx Emission Testing Results



The average emission rate for each horsepower bin shown in the figure above is the basis for the NOx emission factors for Tier 4 Interim and Tier 4 Final TRUs. NOx emission factors for previous years are based on emission certification results as discussed in Section iii. Certification Data and shown in Figure 19 below.

Figure 19: NOx Emission Factors by Horsepower Bin



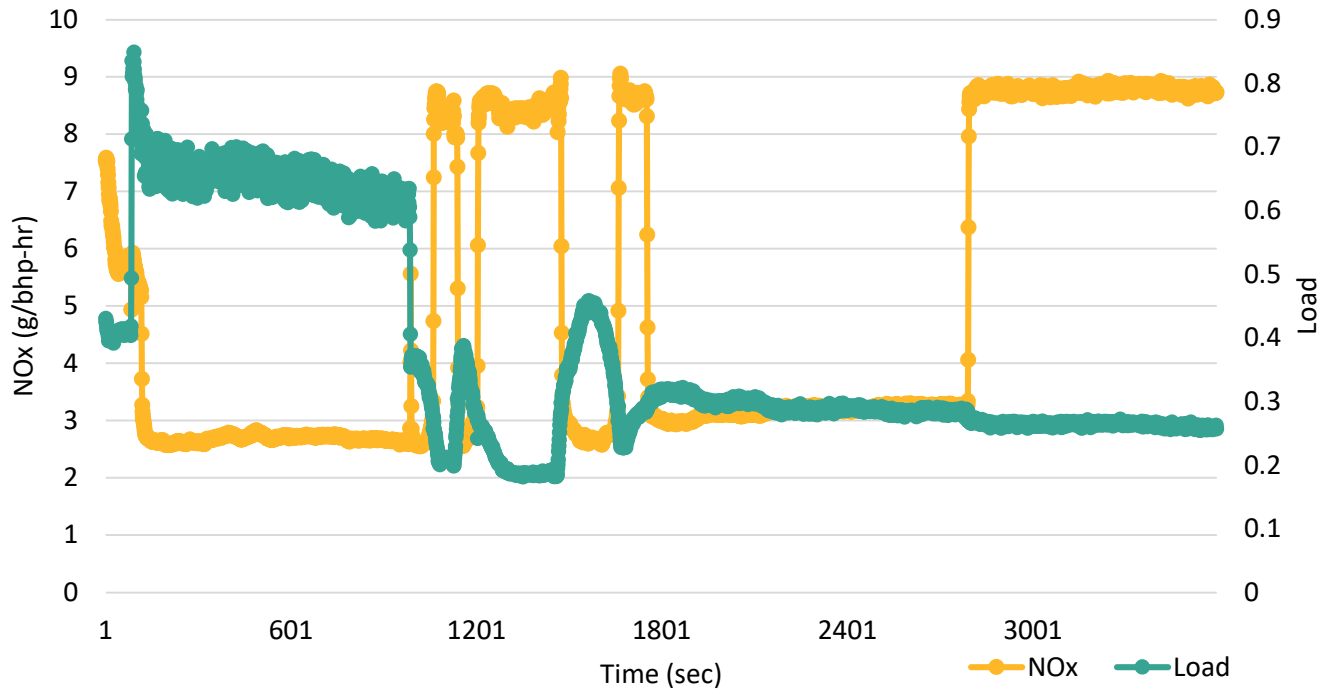
ii. Potential for Higher Emission Rates

In some tests, TRUs showed the potential to reach relatively high NOx emission rates for extended periods. These periods generally occurred near the end of the one-hour test and could reach roughly 9 g/bhp-hr of NOx, or over twice the average emission rate. While the overall average emission rate was below the emission standard, this period exceeded the NOx emission standard by a significant margin.

It is unclear from these tests why the emissions reached higher levels or if the period was temporary. As every test was completed in a one-hour period, it is possible that the emissions rate would not decline even if the test ran several more hours or multiple days, which could be possible in a cold storage application. The periods of higher emissions rates seem closely correlated with the TRU being at lower loads (between 20% and 30% load).

Figure 20 shows an example of this occurrence during a single one-hour test. This test is 1 of 10 performed on the unit. Engine load is colored green and uses the right-hand axis. NOx emission rate is colored yellow and uses the left-hand axis. Toward the end of the test, the load (green) stabilizes, and the emission rate (yellow) reaches and stays at roughly 9 g/bhp-hr of NOx until the test ends.

Figure 20. One-Hour TRU Test Showing High NOx Period



These periods of relatively high NOx are included in the emission factor average but are not given additional weight or assumed to continue after the testing period.

However, it is possible real-world TRU engines maintain these higher emission rates for long periods during cold storage, overnight transportation, or other periods where the doors stay closed and maintaining temperature does not require high loads. In that case, this analysis may underestimate average emissions.

For example, if this issue impacted half of the TRU engines and occurred during approximately 50% of the activity from that half, the average NOx emission from all Tier 4 Final TRU engines would increase by 30%. It would increase the average emission rate from 3.37 g/bhp -hr to 4.5 g/bhp-hr. From 2032 and beyond, when virtually all TRUs are projected to be Tier 4 Final, this emission increase would add 4.5 tpd of NOx statewide.

iii. Certification Data

The engine testing described in the previous section focused on NOx emissions for Tier 4 Final engines. No testing data is available for earlier engine tiers nor pollutants such as PM, hydrocarbons (HC), and reactive organic gases (ROG). For these pollutants, staff used engine certification data. Each engine manufacturer must test engines following a specific engine cycle

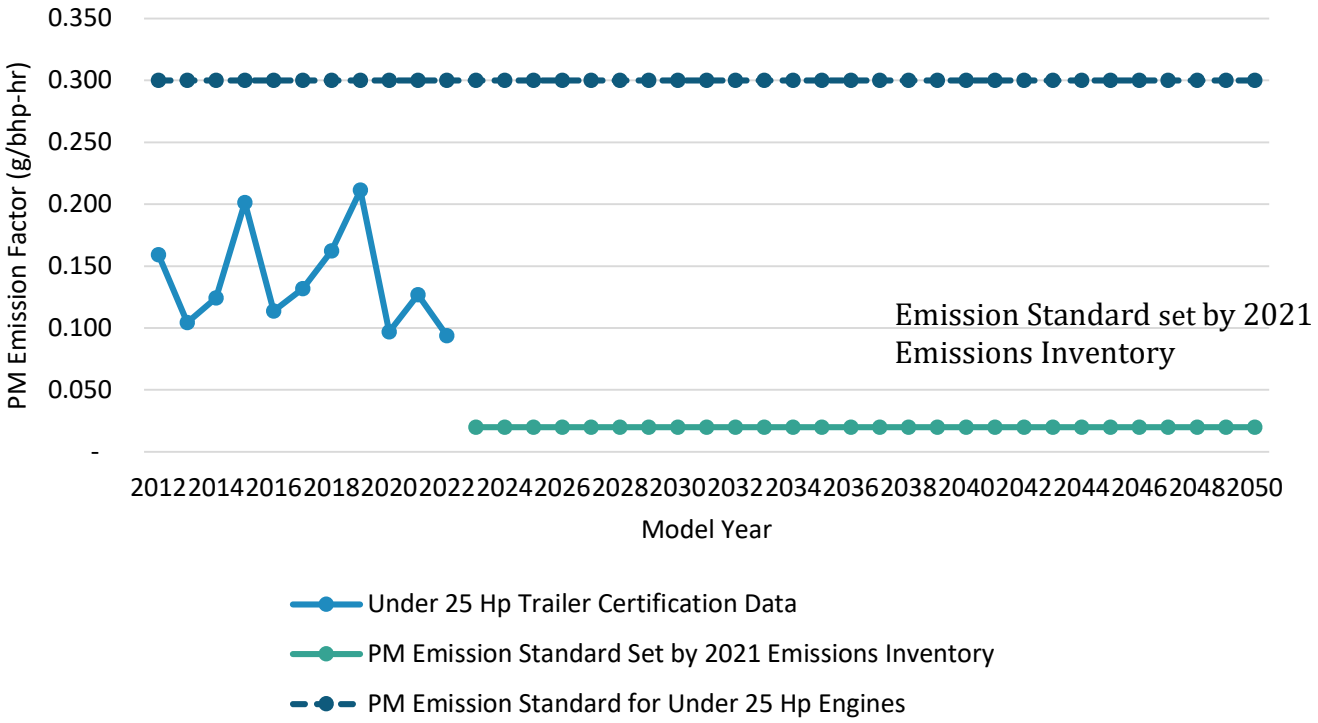
and report the results to both U.S. EPA and CARB. The procedures and results for all off-road diesel engines sold in the U.S. are available online[10].

To determine which engine test results to use, staff reviewed the ARBER reporting data to determine which engine families are most commonly used in TRUs. The population of TRUs by engine family was also used to weight the emission factor.

Staff also forecast the emission rates from the certification data by taking a population-weighted average of the last five years of certification data.

Figure 21 shows PM emissions for the under 25 horsepower engines. Notably, in the under 25 horsepower range, the new certification-based PM emission factor dropped significantly from that used in the previous 2021 TRU emission inventory. This is due to the certification data from 2020 to 2022 showing an average of 0.1 g/bhp-hr, compared to the standard of 0.3 g/bhp-hr. The 2021 Emissions Inventory set a standard of 0.02 g/bhp-hr which aligned with the 25-50 horsepower emission standard.

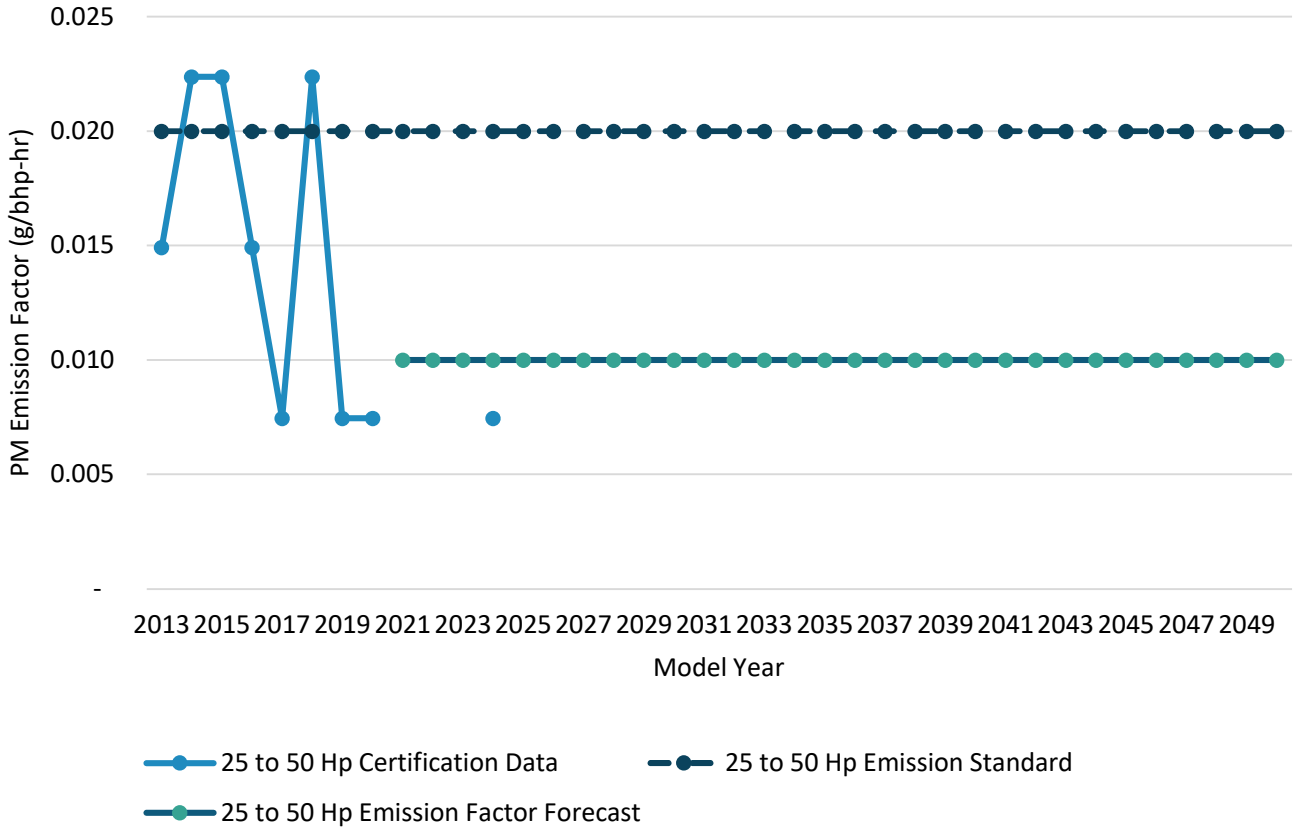
Figure 21. PM Emission Factors Under 25 Horsepower



10 U.S. EPA Engine Certification Data *https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment*

For engines between 25 and 50 horsepower, the results are shown below in Figure 22. The resulting values for certification and emission factor forecast are also below the previous PM emission factor by a smaller margin. The certification data from 2020-2024 showed an average 0.01 g/bhp-hr compared to the standard of 0.02 g/bhp-hr.

Figure 22. PM Emission Factors for 25 to 50 Horsepower



5 Modeling TRU Regulations

In 2022, CARB proposed amendments to transition diesel-powered truck TRUs to zero emissions, as well as requiring a diesel PM emission standard for newly manufactured TRUs in the remaining categories. However, U.S. EPA did not act on the zero-emission truck TRU fleet requirement, so, the transition of diesel-powered truck TRUs to zero emissions was withdrawn and is not reflected in this inventory.

a. PM2.5 Emission Standards for Under 25 Horsepower TRUs

The 2021 Emissions Inventory stated that beginning December 31, 2022, all model year 2023 and newer TRUs in trailers, DSCs, railcars, and generator set engines must 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 generator sets in the under-25 horsepower category to meet the 0.02 g/bhp-hr standard.

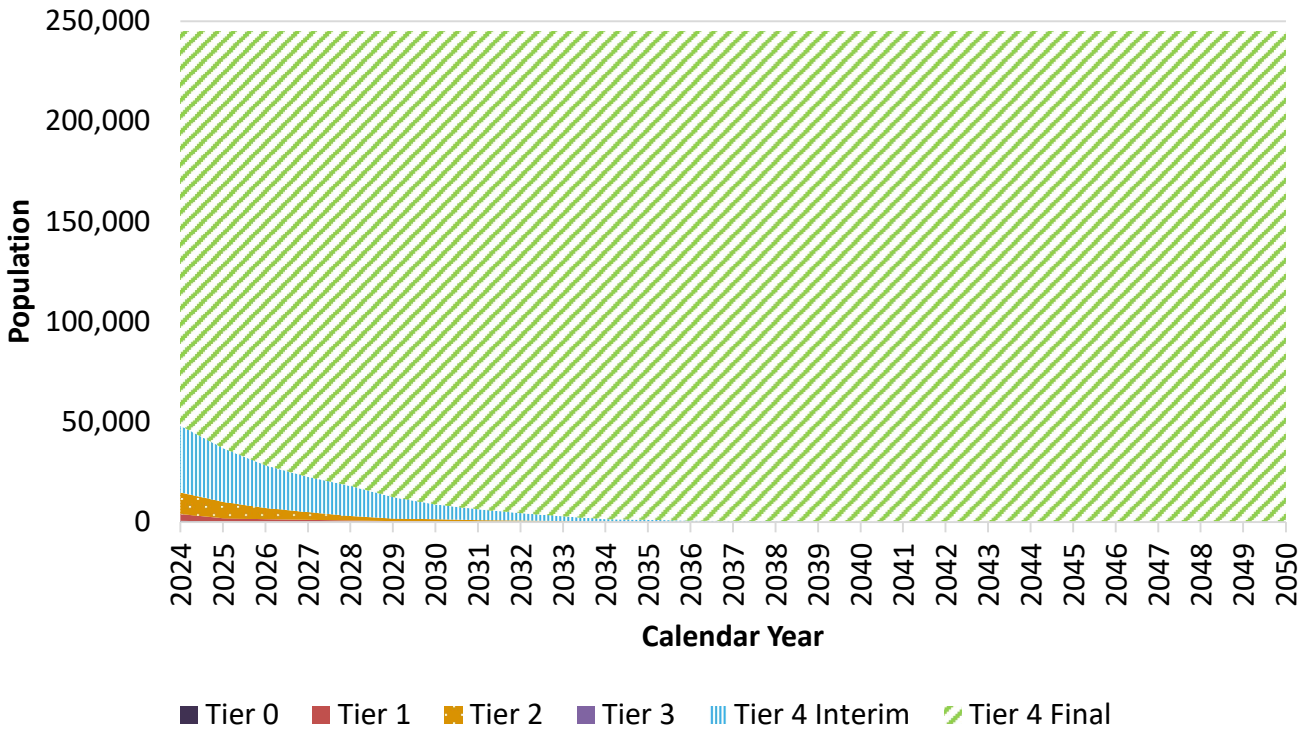
6 Results

The results provided in this section reflect all previously described inputs, trends, and modeling.

a. Population Results

Figure 23 shows the changes in the TRU population projection by diesel engine tier. The population forecast is from 2024 to 2050 and reflects the 2021 Emissions Inventory. The figure below shows that all TRUs will be Tier 4 Final by 2034.

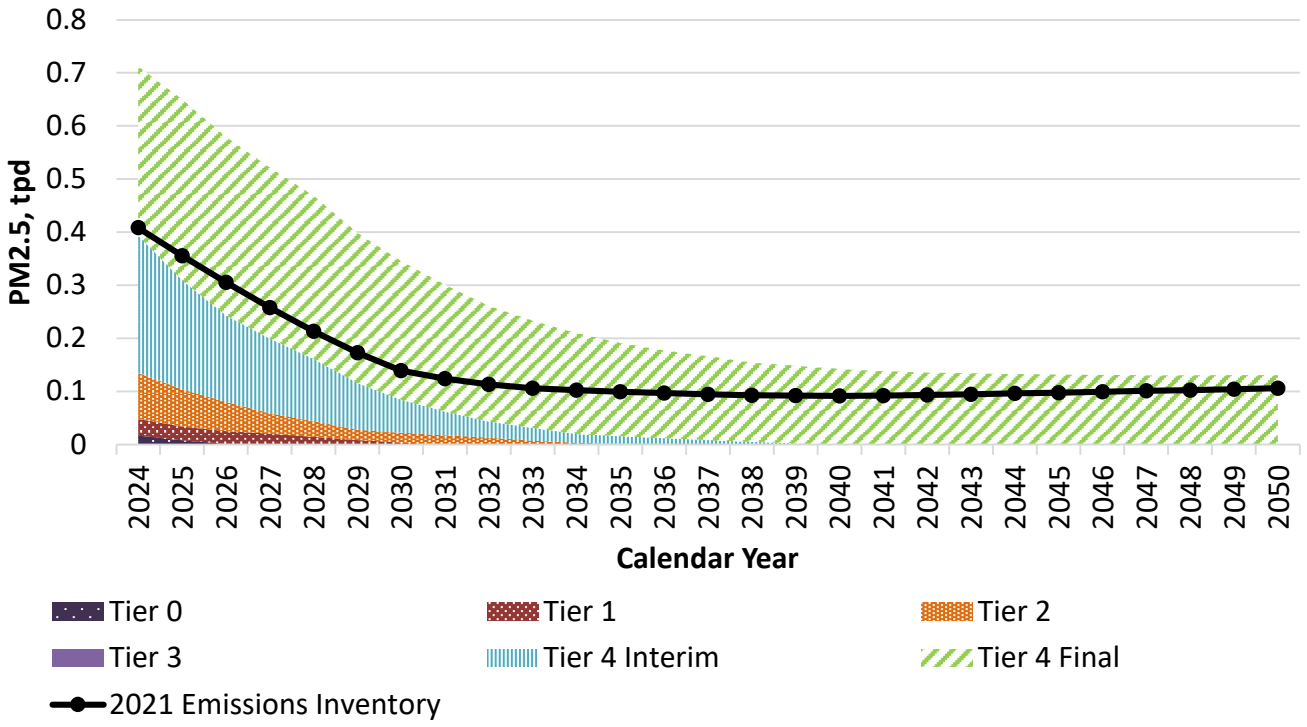
Figure 23. Statewide TRU Population Projected to 2050



b. Emissions Results

PM2.5 emissions shown in Figure 24 below are projected to be higher than in the 2021 Emissions Inventory, which is represented by the black line in Figure 24. This is due to the increased TRU population compared to the 2021 Emissions Inventory and including non-compliant units due to additional enforcement data. PM2.5 is still projected to be significantly reduced by 2035 due to the requirement for all model years 2023 and newer TRU engines to meet the stricter PM standard for trailer TRU, DSC TRU, railcar TRU, and TRU generator set engines.

Figure 24. Statewide TRU PM2.5 Emissions Projected to 2050



NOx emissions are projected as higher than the 2021 Emissions Inventory, which is represented by the black line in Figure 25 below. This is due to the increase in population and updated methodology for NOx emission factors, as well as Truck TRUs not transitioning to zero emissions. NOx emissions are still projected to decline slightly as more engines transition to Tier 4. NOx emissions are represented in Figure 25 below.

Figure 25. Statewide TRU NOx Emissions Projected to 2050