2022 CARB Construction, Industrial, Mining and Oil Drilling Emissions Inventory

August 2022

CALIFORNIA
AIR RESOURCES BOARD

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1 Executive Summary

This inventory provides an update to the emissions from off-road diesel equipment subject to the California Air Resources Board's (CARB) In-Use Off-Road Diesel-Fueled Fleets Regulation (Off-Road Regulation). The previous inventory was last updated in 2011. The Off-Road Regulation applies to all off-road, diesel, self-propelled equipment over 25 horsepower used in California that is not exempted under agricultural or cargo handling equipment provisions, and does not include transport refrigeration units (TRUs), marine, or locomotive categories. Broadly, this equipment is used in construction, mining, industrial, oil drilling and airport ground support operations. A few examples of equipment types include excavators, loaders, backhoes, cranes, forklifts, oil-drilling rigs, and aircraft towing tugs.

CARB first adopted the Off-Road Regulation in 2007, which required owners of equipment to report to CARB, label the equipment with an equipment identification number (EIN), and either accelerate turnover to newer, cleaner equipment, or install exhaust retrofits to reduce diesel particulate matter (PM) tailpipe emissions. The inventory was updated in 2008 based on the Diesel Off-road On-line Reporting System (DOORS) population data, and then again in 2011 to improve engine load factors and reflect updated activity patterns following the 2008 global economic recession and U.S. housing crisis.

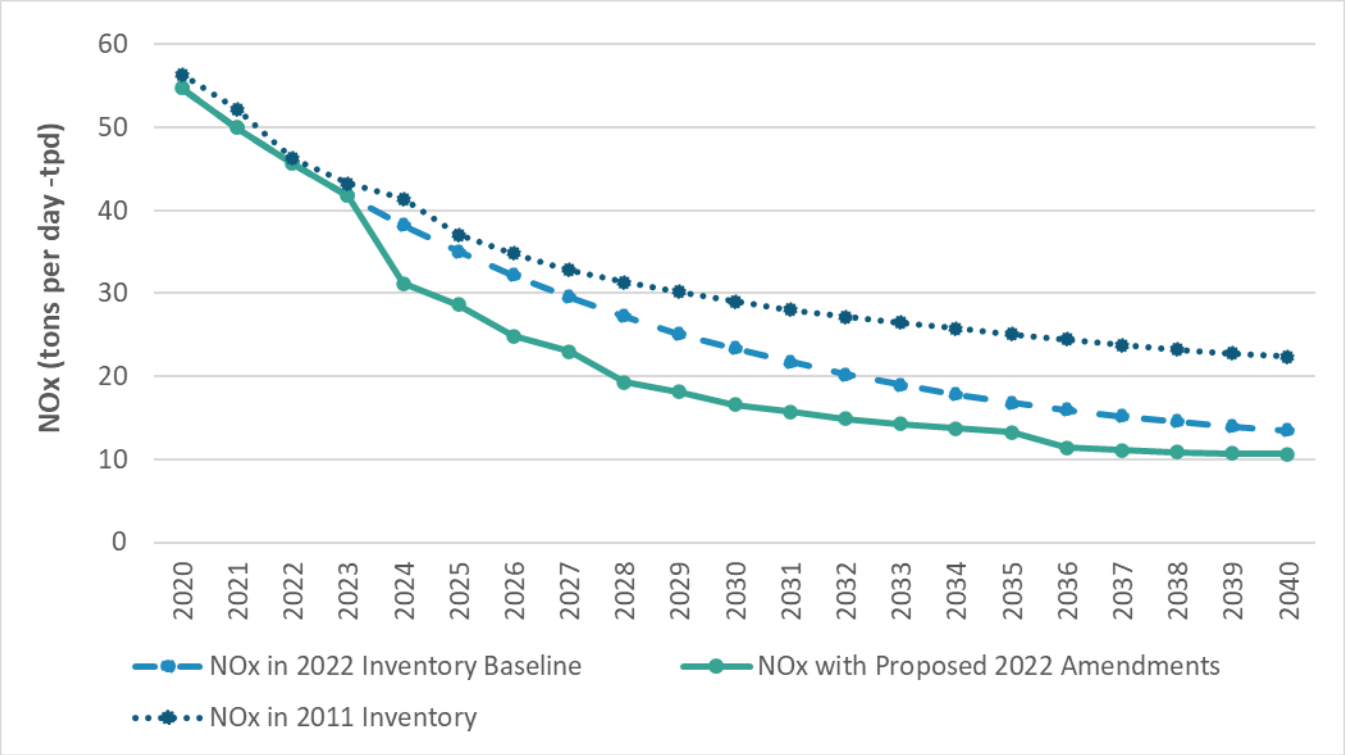
This update was completed to support the 2022 Proposed Amendments to the Off-Road Regulation, discussed further in the Section 4: Regulatory Scenario. Generally, the Proposed Amendments require the retirement of Tier 0 to Tier 2 off-road equipment following the final requirements of the Off-Road Regulation, require the use of renewable diesel, and set a retirement date for low use equipment.

This inventory update includes the following components:

- Updated **population** of equipment based on DOORS data for reported equipment as of calendar year 2020
- Updated **annual activity** of equipment and updated **load factors** based on 2020 survey of DOORS fleets
- Updated **emission factors** to reflect off-road diesel emission factor updates that were published in 2017
- Updated **natural turnover** and existing **regulation compliance choices** based on DOORS data and fleet behavior from 2011 to 2020
- Updated **growth** projections based on 2010 to 2019 fuel use trends
- Reflect the **2022 proposed amendments** to the Off-Road Regulation

Figure 1 shows NOx in the 2011 inventory, the new 2022 baseline, and the emissions under the Proposed Amendments. The main drivers of lower emissions in the new baseline inventory are the changes to growth forecasts and the updated emission factors. The Proposed Amendments would provide additional reductions beyond the new 2022 baseline due to accelerated turnover of the oldest equipment and requirements for renewable diesel.

Figure 1. Statewide NOx Emissions in Baseline Inventory, Proposed Rulemaking and 2011 Inventory



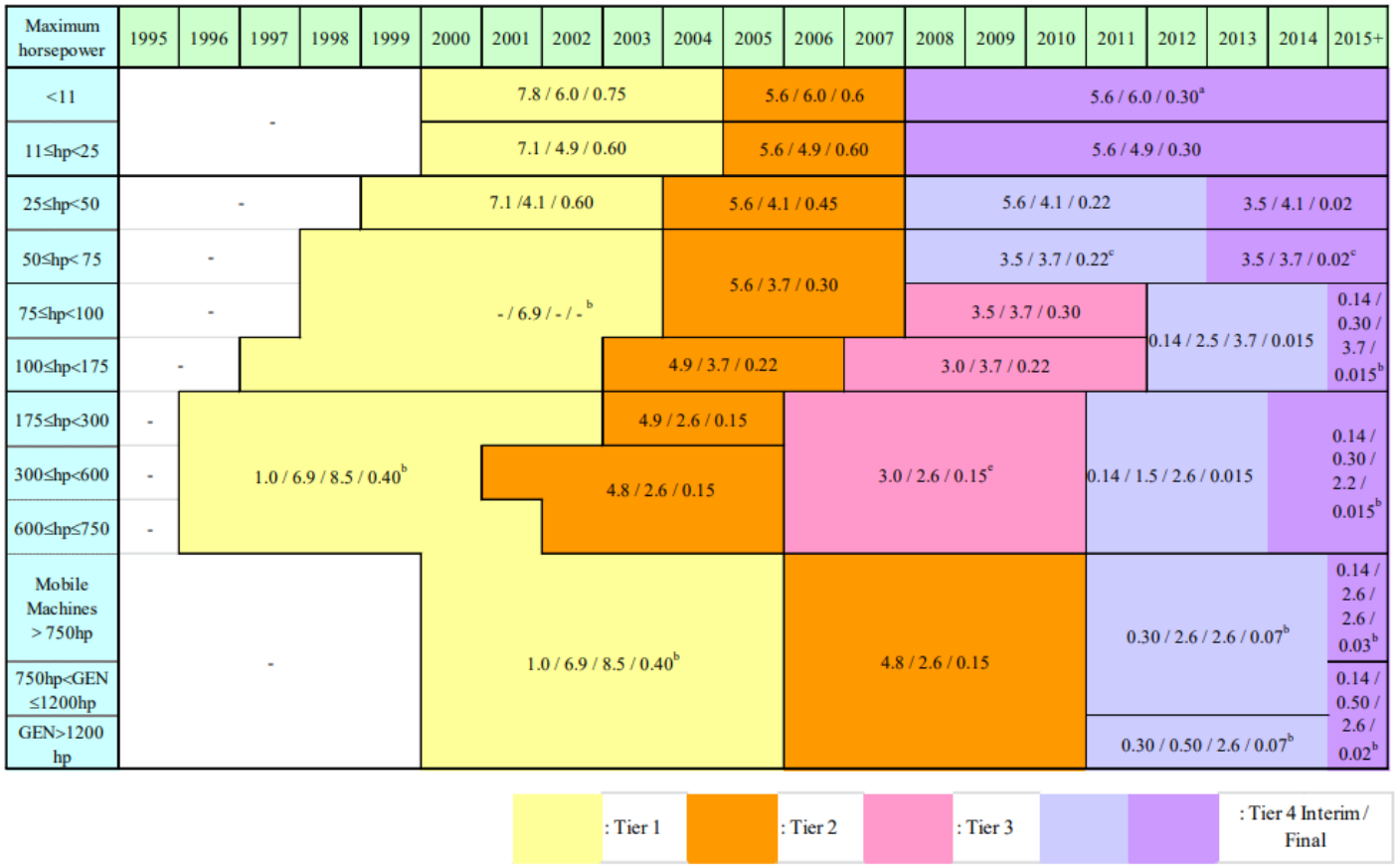
2 Background on Existing Rule

2.1 Off-Road Diesel Tiers

CARB and U.S. Environmental Protection Agency (U.S. EPA) require off-road engine manufacturers to meet emission standards for each engine they produce and sell. These standards are different for different horsepower bins, but generally become stricter over time in a series of step functions. These step functions create model-year groups of engines subject to the same standards, which are defined as engine tiers. The first engine standards began in 1996 for select horsepower groups, and are defined as Tier 1. The most recent standards are Tier 4 Final, which took effect in 2014 or 2015 for most horsepower groups. Engines produced before standards took effect are referred to as Tier 0, or sometimes "pre-Tier".

These standards apply to newly sold engines, and do not impact engines already in use. The purpose of CARB's Off-Road Regulation is to accelerate retirement of older, higher-emitting engines, and increase purchases of newer, cleaner engines. Figure 2 shows the off-road engine tiers by horsepower bin and model year. The cleanest engine standard as of the release of this package is Tier 4 Final (or Tier 4F).

Figure 2: Off-Road Diesel Engine Tier Standards



Standards given are NMHC/NO_x/CO/PM in g/bhp-hr.

2.2 Off-Road Regulation Structure and Requirements

The following points summarize key points of the existing Off-Road Regulation:

I. Equipment owners are divided into fleet sizes based on the total horsepower of applicable equipment in their fleet
   a. Small fleets: under 2,500 total horsepower.
   b. Medium fleets: 2,500 to 5,000 horsepower.
   c. Large fleets: over 5,000 horsepower, or a state or government fleet of any size.

II. Fleets must report all equipment to CARB and label it with an EIN. New equipment purchases must also be reported to CARB and labeled as well.

III. Fleets were not allowed to purchase or register a Tier 0 or Tier 1 piece of equipment beginning in 2014. Purchases and registrations of Tier 2 equipment were prohibited in 2016.

IV. Fleets must meet either a fleet average requirement, or a Best Available Control Technology (BACT) requirement.
   a. The fleet average requires fleets to meet a specific emissions-based target for their equipment, averaging the emissions from each piece of equipment based

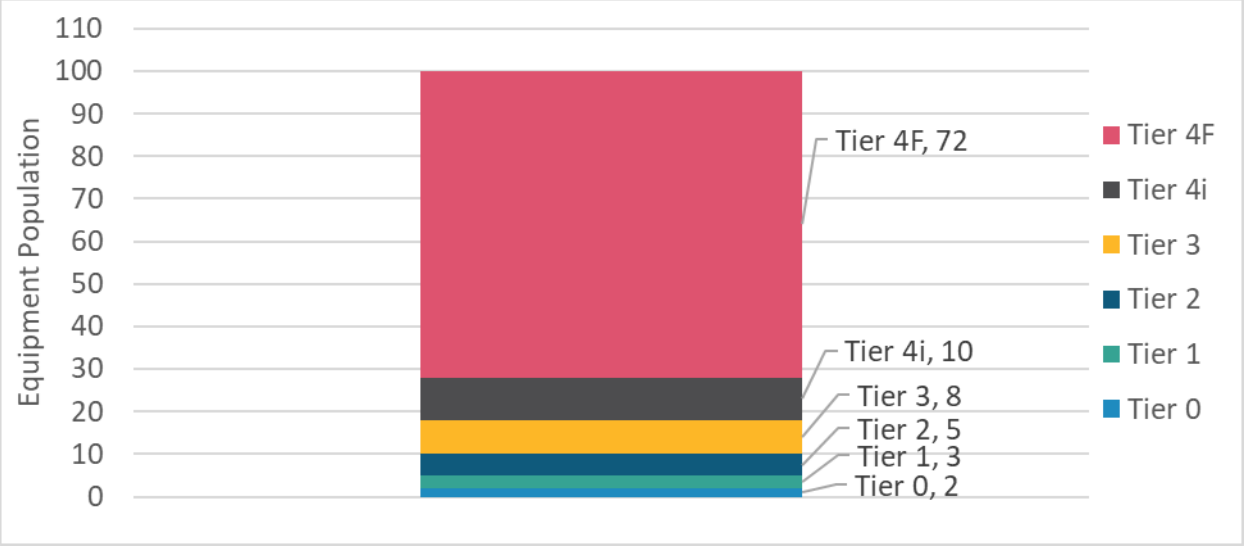
on its horsepower and age. Fleets that generally maintain very new equipment may meet this fleet average without taking any additional actions beyond natural retirement and replacement cycles (natural turnover). The fleet average becomes more stringent over time, requiring a cleaner fleet as the regulation progresses.

i. Large and medium fleets have fleet average requirements beginning in 2013 and phasing in through 2023
ii. Small fleets have fleet average requirements beginning in 2018 and phasing in through 2028

V. For some fleets, meeting the fleet average has required turning over a significant portion of the total fleet in a single year (up to 90 percent in some cases). For these fleets, a BACT provision allows turn over or retrofit of 10 percent of the total fleet horsepower per year to meet requirements, in lieu of meeting the fleet average. At full implementation of the Off-Road Regulation, the regulatory provisions and the final fleet average will result in different mixes of equipment, and does not explicitly ban the oldest, dirtiest equipment.

Figure 3 shows an example of a hypothetical large or medium fleet that would meet the requirements of the existing Off-Road Regulation at full implementation in or after 2023. Notably, the fleet only has a few pieces of older equipment (Tier 0 and Tier 1) but assuming equal activity across all equipment, these pieces make up half of the fleet NOx emissions.

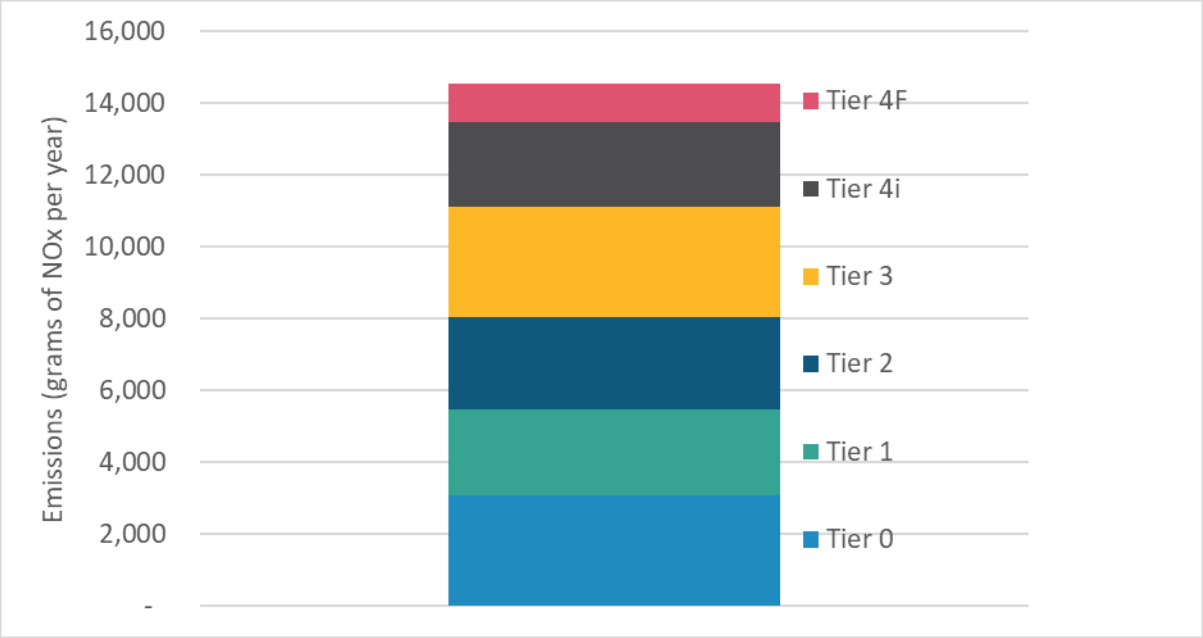
Figure 3: Population by Tier of an Example Fleet Compliant with Final Fleet Average Requirements



Note that in the fleet above, 72 of the 100 pieces of equipment are Tier 4 Final, and only 10 pieces are Tier 2, Tier 1, or Tier 0. However, because the NOx emission rate of the older equipment is up to 80 times higher than a Tier 4 Final engine, these 10 pieces of equipment could make up half of the fleets total emissions, as shown in Figure 4. Note, that in this

example CARB staff assumes equal activity across all equipment, while the inventory reflects changing activity by age derived from a survey of equipment owners, which is covered later in this report.

Figure 4: Emissions by Tier from an Example Fleet Compliant with Final Fleet Average



3 Data Sources and Methodology

3.1 Methodology for Estimating Emissions

The basis of the emissions inventory is calculated using the generic equation shown below. This calculation is completed separately for each group of equipment in the inventory, which is divided into fleet size, horsepower bin, equipment type, and engine model year.

Emissions = Population * Activity * Hp * LF * EF

Where:

Population = Count of equipment

Activity = Time the engine is running in hours per year

HP = Average maximum brake horsepower of the engine

LF = Load factor (Average fraction of maximum power rating of engine during operation)

EF = Emission Factor (grams per brake horsepower-hour) specific to horsepower, engine build year, and the specific pollutant. The emission factor includes a deterioration factor based on the age of the equipment, and a fuel correction factor.

The following sections detail the source of the each of these inputs, how they are used, and how they are forecast.

3.2 Population Data

The information fleet owners are required to report to DOORS includes total number of equipment, equipment type, engine model year, engine horsepower, and other detailed characteristics about each piece of equipment in the fleet. These annual reports do not include activity or fuel except in certain cases for specialty equipment. For this inventory, a snapshot of the DOORS database as of July 2020 was used as the base year for equipment population. CARB staff performed no scaling for potentially unreported equipment. If owners and operators did not report equipment to CARB, and is not reflected in the population totals, emissions from unreported equipment are still accounted within the model as a result of the fuel balancing adjustment discussed below in Section 3.5.

Table 1 shows the population of active equipment (i.e. not including sold or retired equipment) by fleet size and horsepower bin. The majority of all equipment is in large fleets, with small fleets having a slightly smaller share. The appendix (Table 9 in Section 7) at the end of this report presents the populations for each equipment type.

Table 1: DOORS Population as of July 2020 by Fleet Size and Engine Size

Engine HP Bin	Small Fleet	Medium Fleet	Large Fleet	Total
25-50	15,101	2,348	15,560	**33,009**
51-75	15,832	3,541	26,538	**45,911**
76-100	14,272	3,221	14,274	**31,767**
101-175	13,387	4,618	23,342	**41,347**
176-300	5,543	2,967	12,148	**20,658**
301-600	2,969	1,940	12,489	**17,398**
601-750	125	108	1,229	**1,462**
751+	100	109	796	**1,005**
Total	**67,329**	**18,852**	**106,376**	**192,557**

3.2.1 Special Equipment Types

Equipment submitted to DOORS can be designated as one of a few special operational categories that are exempt from Off-Road Regulation requirements for fleet averages or BACT. These categories are emergency, snow removal equipment, low use equipment, and agricultural-use equipment (over 50 percent but less than 100 percent of activity as agricultural use). This equipment is still reported and is in the emission inventory, but is not

included in a fleet's compliance calculations (i.e. it is not required to be turned over). Table 2 shows the reported population by each special equipment designation.

Table 2: Special Equipment Type Populations

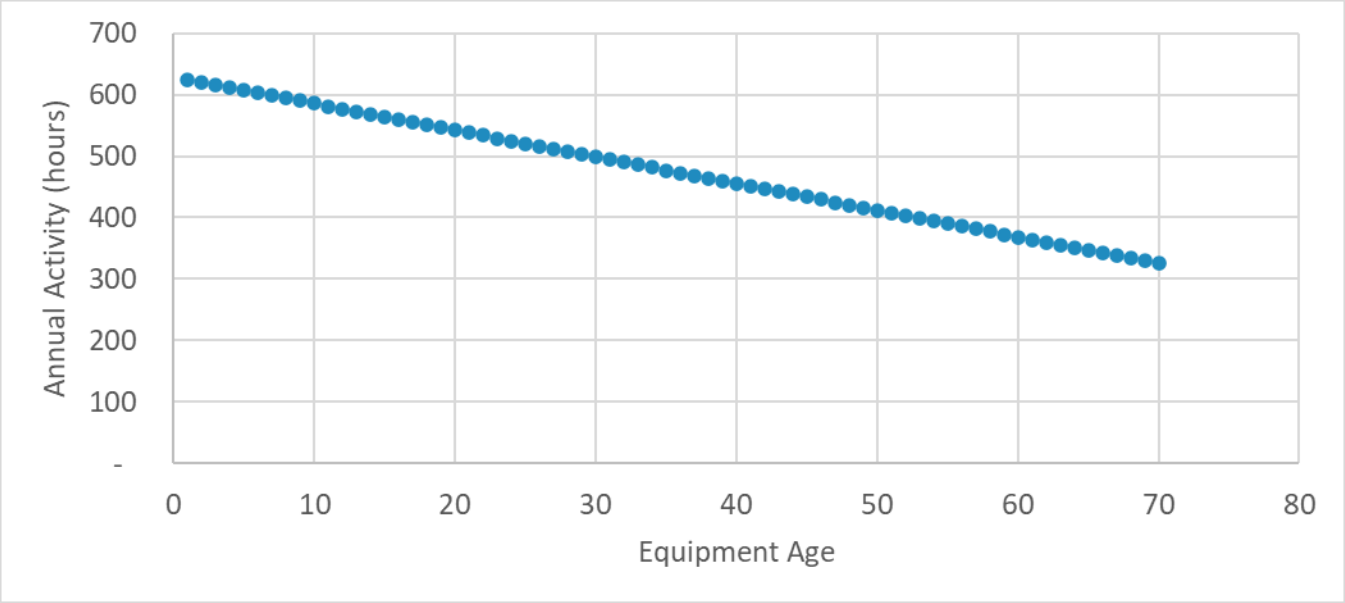
Fleet Size	Low Use Designation	Emergency/Snow Removal	50 to 100 Percent Agricultural Use
Small Fleets	10,157	1,041	1,142
Medium Fleets	1,459	243	493
Large Fleets	3,276	413	402
Total	**14,892**	**1,697**	**2,037**

3.3 Activity

The Off-Road Regulation requires owners to report equipment population, equipment and engine model year, and horsepower, but not activity or fuel use. In support of updating the emissions inventory, CARB released a survey in 2020 that was sent to all DOORS users to collect activity (in units of hours per year) and fuel use (in gallons per year). The survey requested equipment owners to report activity and fuel for equipment during the 12 month period beginning on January 1, 2019 and ending on December 31, 2019. The survey also requested fuel used by each piece of equipment during the same period. Fleet owners were also provided the opportunity to submit activity data in response to the survey in any other format by email to CARB staff.

Ultimately, data was gathered from 5,589 pieces of equipment for activity, and 2,361 of those pieces of equipment also included fuel data. This survey data is the basis for activity in the inventory, but is also adjusted for a sector-wide comparison based on fuel sales, as discussed later in the report. Using data collected from the survey administered to fleets for operation in 2019, CARB developed a base activity profile over age, based on all responses. As shown in Figure 5, this base activity reflected the trend for newer equipment to be used at higher activity level than older equipment..

Figure 5: Base Activity Profile from All Survey Data



This base activity profile was modified to reflect differences of fleet size, horsepower bin, and equipment type.

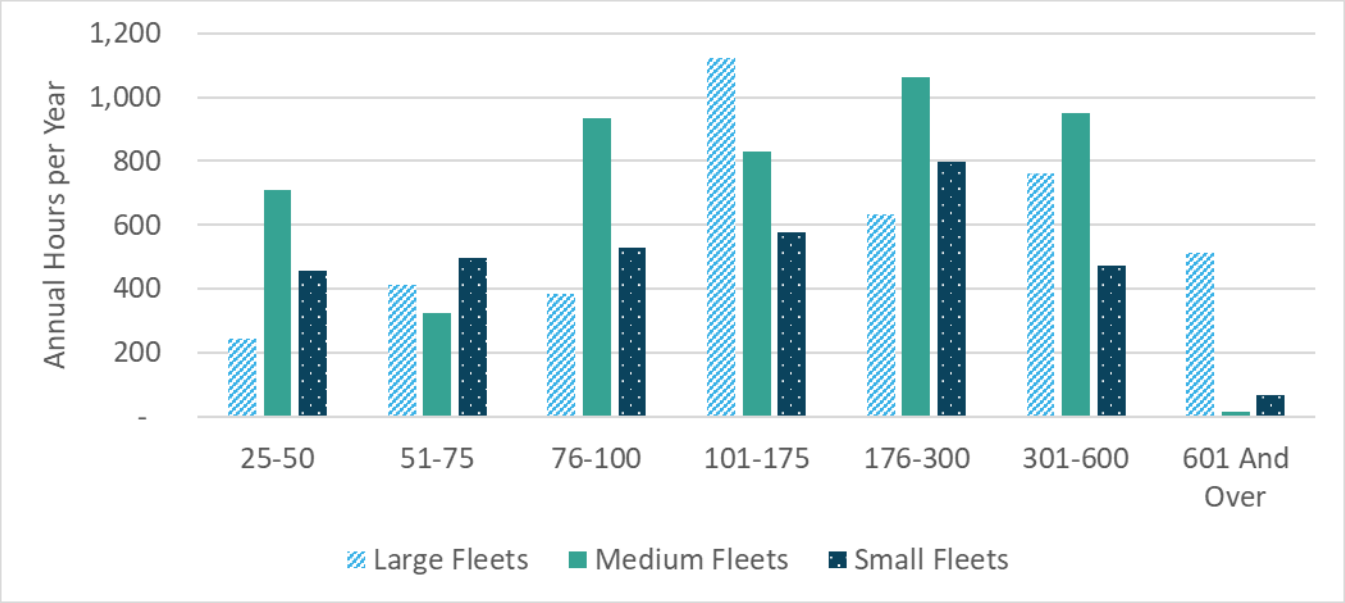
Figure 6 shows the average activity by fleet size and horsepower bin. The base activity profile (in Figure 5) was further adjusted based on the average hours in the horsepower bin and fleet size, using the equation:

Activity Profile = Base Activity Profile * (Average Activity in Horsepower and Fleet Size Bin) / (Average Activity of All Equipment)

This process creates a unique activity profile for each fleet size and horsepower bin. For example, the highest activity of any bin was equipment between 100 and 175 horsepower in large fleets. The activity in this bin was 65 percent above the average for all equipment. The activity profile for equipment between 100 and 175 horsepower in large fleets is the base activity profile from Figure 5 multiplied by 1.65 at all ages.

Note that for equipment over 600 horsepower, small and medium fleets had limited responses (11 pieces of equipment combined), and so their activity horsepower bin was based on the average of other horsepower bins, 25 to 600 horsepower, for their fleet size.

Figure 6: Average Activity by Fleet Size and Horsepower Bin



Additionally, the following equipment types had sufficient responses to further adjust activity based on the equipment type. Each equipment type listed had more than 35 responses, while all other equipment types had 14 or fewer responses. These activity multipliers are applied in addition to fleet and horsepower bin adjustments to activity profile, using the equation:

Activity Profile = Base Activity Profile * (Average Activity in Horsepower and Fleet Size Bin) / (Average Activity of All Equipment) * (Average Activity by Equipment Type)/(Average Activity of Equipment Type)

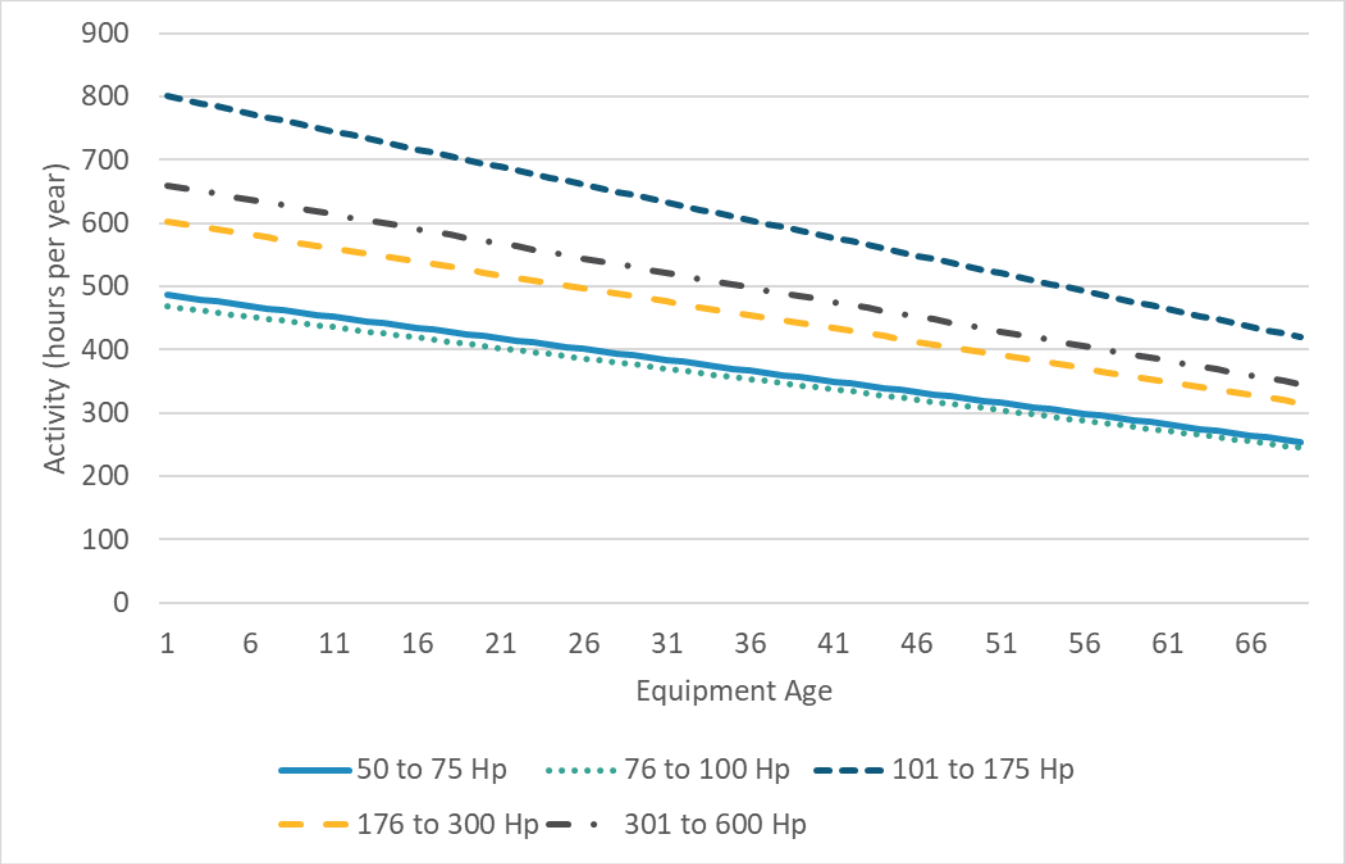
The activity multiplier for each equipment type with sufficient survey responses is shown in Table 3. Any equipment types not shown in this table do not have a unique activity multiplier by equipment type, but would be impacted by fleet size and horsepower bin activity multipliers.

Table 3: Activity Multiplier by Equipment Types

Equipment Types	Activity Multiplier
Cranes	0.42
Aerial Lifts	0.57
Scrapers	0.57
Graders	0.63
Sweepers/Scrubbers	0.63
Rough Terrain Forklifts	0.63
Other Construction Equipment	0.67
Trenchers	0.70
Bore/Drill Rigs	0.72
Crawler Tractors	0.74
Other Material Handling Equipment	0.79
Rollers	0.80
Forklifts	0.83
Paving Equipment	0.86
Pavers	0.86
Skid Steer Loaders	0.88
Other General Industrial Equipment	0.90
Tractors/Loaders/Backhoes	0.94
Surfacing Equipment	1.00
Mower	1.00
Excavators	1.01
Rubber Tired Loaders	1.11
Off-Highway Trucks	1.29
Workover Rig (Mobile)	1.40
Off-Highway Tractors	1.40
Yard Goat	1.69

The result of the activity analysis is a unique activity profile by age, fleet size and horsepower bin, and equipment type (for the equipment types listed above). Figure 7 shows an example for activity of excavators in large fleets as a function of age and horsepower bin.

Figure 7: Example Activity for Excavators in Large Fleets by Horsepower Bin Upper Bound



For specialty equipment, including low-use, emergency, and snow-removal designation, activity was reduced from the method described above to reflect the hourly low-use activity limit in the Off-Road Regulation. Emergency and snow-removal equipment do not have the same hourly limit as low-use equipment, but generally have more limited use than average equipment based on discussions with equipment owners during the regulation development process in 2007, and inventory workshops in 2020. Without further information on the activity for emergency and snow-removal equipment, CARB staff included emergency and snow-removal equipment with low-use equipment at the low-use threshold of 200 hours per year.

3.4 Load Factor

Load factors represent the average fraction or percent of the engine maximum rated horsepower used during operation. This reflects the fact that equipment does not constantly run at maximum horsepower, but on average uses a fraction of the maximum horsepower. CARB staff continually collects data on both activity, fuel use, and load factor to best reflect emissions from each of the off-road equipment types.

Load factors for this inventory are based on equipment type, and vary from 0.20 to 0.54, with an average of 0.38. This means, given one of each equipment type, off-road equipment would use about 38 percent of maximum horsepower on average (over a year long period, only considering the time the engine is turned on).

In the 2011 inventory, load factors were based on OFFROAD2007, but were adjusted based on sector-wide fuel consumption analysis that suggested the load factors were too high on average.

In the 2020 activity survey, fleets were also given the option to report fuel. Using both fuel and activity, an average load factor can be derived using the following relationship:

Fuel Used = Activity * Horsepower * Fuel Consumption Factor[1] (gallon/horsepower-hour) * Load

Table 4 below shows the count of responses in the 2020 survey, the resulting load factor derived from the survey using the above equation, and the load factor from the 2011 inventory update for the top 4 equipment types by count of responses. Only 6 equipment types had more than 100 responses. Of those that had responses, results compared reasonably with the previous inventory. Based on this comparison, and the lack of addition data for most equipment types, the 2011 inventory load factors were retained and not adjusted in this update.

Table 4: Load Factor Comparison Between 2020 Survey and 2011 Inventory for Select Types

Equipment Type	Count of Responses	2011 Inventory Load Factor	2020 Survey Load Factor Result
Tractors/Loaders/Backhoes	463	37%	36%
Skid Steer Loaders	241	40%	37%
Forklifts	239	27%	20%
Excavators	170	39%	49%
Rubber Tired Loaders	121	35%	36%
Rough Terrain Forklifts	102	40%	31%

CARB staff is currently involved in a study to data log over 100 pieces of construction equipment for one year to better understand the distribution of engine loads on a subset of equipment. If this study or follow-up studies suggest that load factors used in the inventory need further refining, CARB staff will reflect those changes in future releases of the inventory The additional data may allow CARB to reflect the percent of time the equipment stays at low load conditions, high load conditions, and idle, instead of using a simple average. The

[1]U.S. EPA Fuel Consumption Factors for off-road diesel equipment https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=541849&Lab=OTAQ

percentage of time equipment is operated in a particular load bin could be used with load-dependent emission factors, if they are derived in the future based on in-use testing data.

The current load factors for this this inventory are shown in Table 5 by equipment type.

Table 5: Load Factor by Equipment Type

Equipment Category	Equipment Type	Load Factor
Air Ground Support Equipment (GSE)	Aircraft Tug Narrow Body	0.54
Air Ground Support Equipment (GSE)	Aircraft Tug Wide Body	0.54
Air Ground Support Equipment (GSE)	Air Conditioner	0.38
Air Ground Support Equipment (GSE)	Air Start	0.38
Air Ground Support Equipment (GSE)	Aircraft Tractor	0.38
Air Ground Support Equipment (GSE)	Baggage Tractor	0.38
Air Ground Support Equipment (GSE)	Baggage Tug	0.37
Air Ground Support Equipment (GSE)	Bdt Loader	0.34
Air Ground Support Equipment (GSE)	Belt Loader	0.34
Air Ground Support Equipment (GSE)	Bobtail	0.37
Air Ground Support Equipment (GSE)	Cargo Loader	0.34
Air Ground Support Equipment (GSE)	Cargo Tractor	0.36
Air Ground Support Equipment (GSE)	Cart	0.38
Air Ground Support Equipment (GSE)	Catering Truck	0.38
Air Ground Support Equipment (GSE)	De-icer	0.38
Air Ground Support Equipment (GSE)	Forklift	0.20
Air Ground Support Equipment (GSE)	Forklift (GSE)	0.20
Air Ground Support Equipment (GSE)	Fuel Truck	0.38
Air Ground Support Equipment (GSE)	Generator	0.38
Air Ground Support Equipment (GSE)	Ground Power Unit	0.38
Air Ground Support Equipment (GSE)	Hydrant Truck	0.38
Air Ground Support Equipment (GSE)	Lavatory Cart	0.38
Air Ground Support Equipment (GSE)	Lavatory Truck	0.38
Air Ground Support Equipment (GSE)	Lift	0.34
Air Ground Support Equipment (GSE)	Nurse Rig Aircraft Supply	0.38
Air Ground Support Equipment (GSE)	On-Road Equivalent GSE	0.38
Air Ground Support Equipment (GSE)	Other	0.34
Air Ground Support Equipment (GSE)	Other GSE	0.34
Air Ground Support Equipment (GSE)	Passenger Stand	0.40
Air Ground Support Equipment (GSE)	Service Truck	0.38
Air Ground Support Equipment (GSE)	Water Truck	0.38
Construction and Mining	Bore/Drill Rigs	0.50
Construction and Mining	Bucket	0.38
Construction and Mining	Compactor	0.36
Construction and Mining	Concrete Mixer	0.36
Construction and Mining	Concrete Pump	0.36

Construction and Mining	Crane 35ton or more	0.29
Construction and Mining	Crane less than 35ton	0.29
Construction and Mining	Cranes	0.29
Construction and Mining	Crawler Tractors	0.43
Construction and Mining	Crushing/Processing Equipment	0.36
Construction and Mining	Excavators	0.38
Construction and Mining	Graders	0.41
Construction and Mining	Hopper Tractor Trailer	0.36
Construction and Mining	Nurse Rig Other	0.36
Construction and Mining	Off Highway Tractors	0.37
Construction and Mining	Off Highway Trucks	0.38
Construction and Mining	Off-Highway Tractors	0.44
Construction and Mining	Off-Highway Trucks	0.38
Construction and Mining	Other Construction Equipment	0.42
Construction and Mining	Other Material Handling Equipment	0.40
Construction and Mining	Pavers	0.42
Construction and Mining	Paving Equipment	0.36
Construction and Mining	Rollers	0.38
Construction and Mining	Rough Terrain Forklifts	0.40
Construction and Mining	Rubber Tired Dozers	0.40
Construction and Mining	Rubber Tired Loaders	0.36
Construction and Mining	Scrapers	0.48
Construction and Mining	Skid Steer Loaders	0.37
Construction and Mining	Spray Truck	0.38
Construction and Mining	Spreader Tractor Trailer	0.30
Construction and Mining	Spreader Truck	0.38
Construction and Mining	Surfacing Equipment	0.30
Construction and Mining	Tank Truck	0.38
Construction and Mining	Tanker Truck Trailer	0.38
Construction and Mining	Telescopic Handler	0.34
Construction and Mining	Tractors/Loaders/Backhoes	0.37
Construction and Mining	Trenchers	0.50
Construction and Mining	Vacuum Truck	0.38
Construction and Mining	Water Truck	0.38
Industrial	Aerial Lifts	0.31
industrial	Boom	0.34
Industrial	Forklifts	0.20
Industrial	Garbage Refuse	0.38
Industrial	Garbage Transfer	0.38
Industrial	Mower	0.38

Industrial	Other General Industrial Equipment	0.34
Industrial	Other Truck	0.38
Industrial	Railcars or Track Cars	0.38
Industrial	Sweepers/Scrubbers	0.46
Industrial	Tow Tractor	0.37
Industrial	Yard Goat	0.38
Oil Drilling	Bore/Drill Rigs	0.50
Oil Drilling	Drill Rig	0.50
Oil Drilling	Drill Rig (Mobile)	0.50
Oil Drilling	Workover Rig (Mobile)	0.50

3.5 Fuel Balancing

To evaluate potential uncertainty in total activity or fuel from the model inputs based on operator-reported data, CARB staff compared the total fuel use from off-road equipment against statewide fuel sales. The Energy Information Administration (EIA) is a federal agency that tracks fuel sales by state[2]. However, the categories that EIA uses to define fuel use do not directly correlate to the equipment categories used by CARB.

Off-road fuel use at CARB can be grouped into this inventory (construction, mining, industrial, oil drilling, ground support equipment), Cargo Handling Equipment (CHE), Portable equipment (generators and pumps), Transport Refrigeration Units (TRUs), Logging or Forestry, and a small group of non-categorized off-road equipment[3]. The combined fuel totals from these categories should be equivalent to the combined categories from EIA of general off-road (includes construction, logging, transport refrigeration units), industrial (includes mining and equipment used in processing or manufacturing like forklifts), and commercial (includes all equipment of nonmanufacturing businesses and agencies).

The additional categories EIA uses are Residential, Oil Company, Farm, Electric Power, Railroad, Vessel Bunkering, On-Highway, Military, and All Other. These categories either match up to separate emission inventories that CARB develops, or do not overlap the off-road categories in this inventory.

In addition to the EIA categories, a portion of on-road fuel sold in California (which is not included in the EIA categories above), is used in off-road sectors. When this occurs, the business or agency that purchased the fuel may apply for a refund on taxes paid for on-road

[2] EIA Website of fuel consumption by end use category: https://www.eia.gov/dnav/pet/pet_cons_821use_dcu_SCA_a.htm

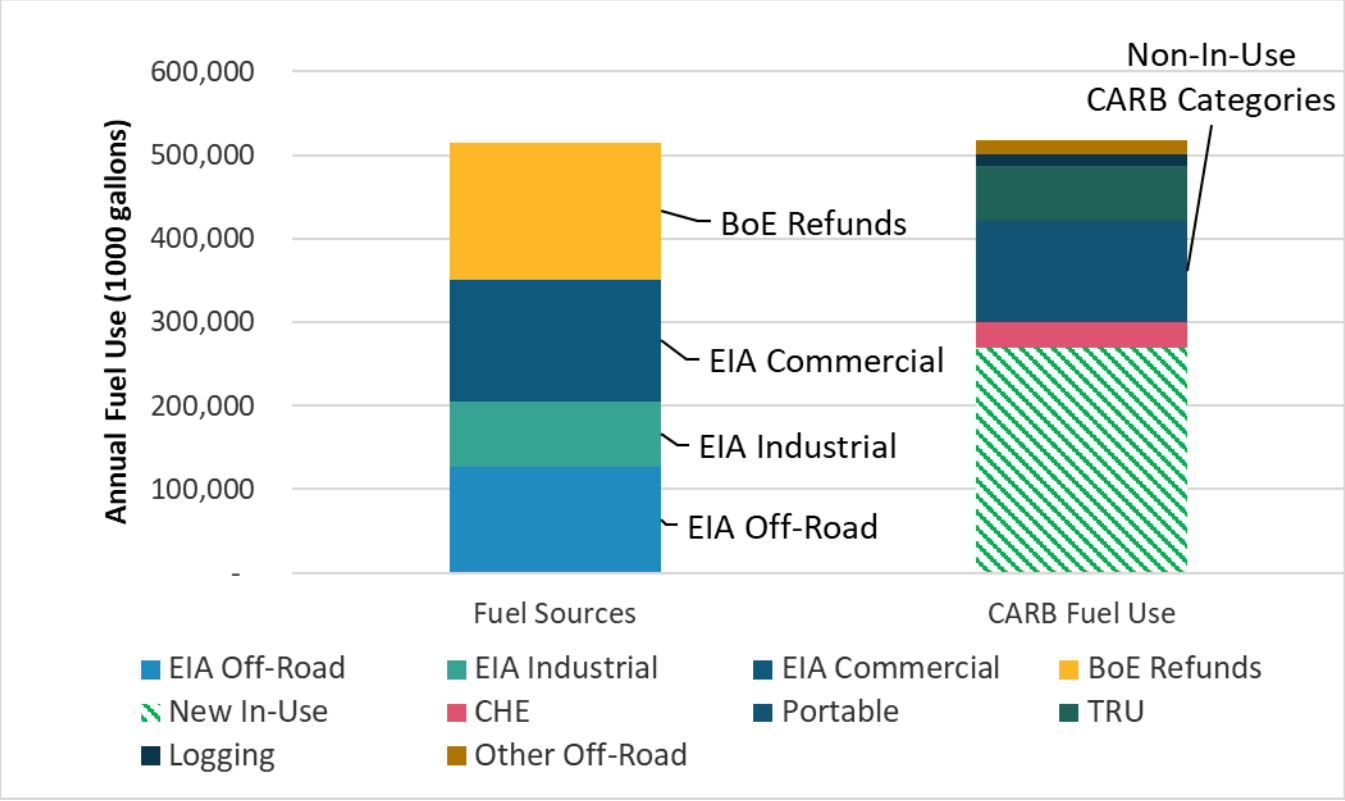
[3] For more information on categories of off-road diesel equipment, please see the off-road diesel inventory page: https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road

fuel. This refund is processed by the Board of Equalization (BoE) and the data are used in this analysis as well, supplementing the fuel totals provided by EIA. This analysis does not include any assumption of fuel entering California from out of state for off-road use, or fuel sold in California leaving the state in any significant quantity.

When the population, activity, horsepower and load were used to calculate fuel, the initial fuel total for this inventory was 305 million gallons per year. When combined with the other off-road sectors, this exceeds the EIA and BoE combined fuel by 36 million gallons, showing that the total unadjusted fuel was likely an overestimate.

A correction in either population, horsepower, load, or activity would be required to match the fuel totals. Population and horsepower are reported fields directly from industry, and the least likely to be in error. CARB staff could adjust either load or activity, or both, to reduce the fuel total and match EIA data. The uncertainty in both analyses is similar; however, load reasonably matches with the results of the recent survey for most equipment types, and there is no secondary source to compare with the activity. Based on this, **CARB staff decreased activity by 14 percent across all equipment in the inventory**. Following the adjustment, the fuel totals between the CARB off-road inventory sectors and EIA and BoE match, as shown in Figure 8. The fuel used by equipment covered by the Off-Road Regulation is on the right bar at the bottom in diagonal lines, and represents the adjusted total of 269 million gallons per year.

Figure 8: Fuel Comparison between CARB Inventory and EIA and BoE Totals



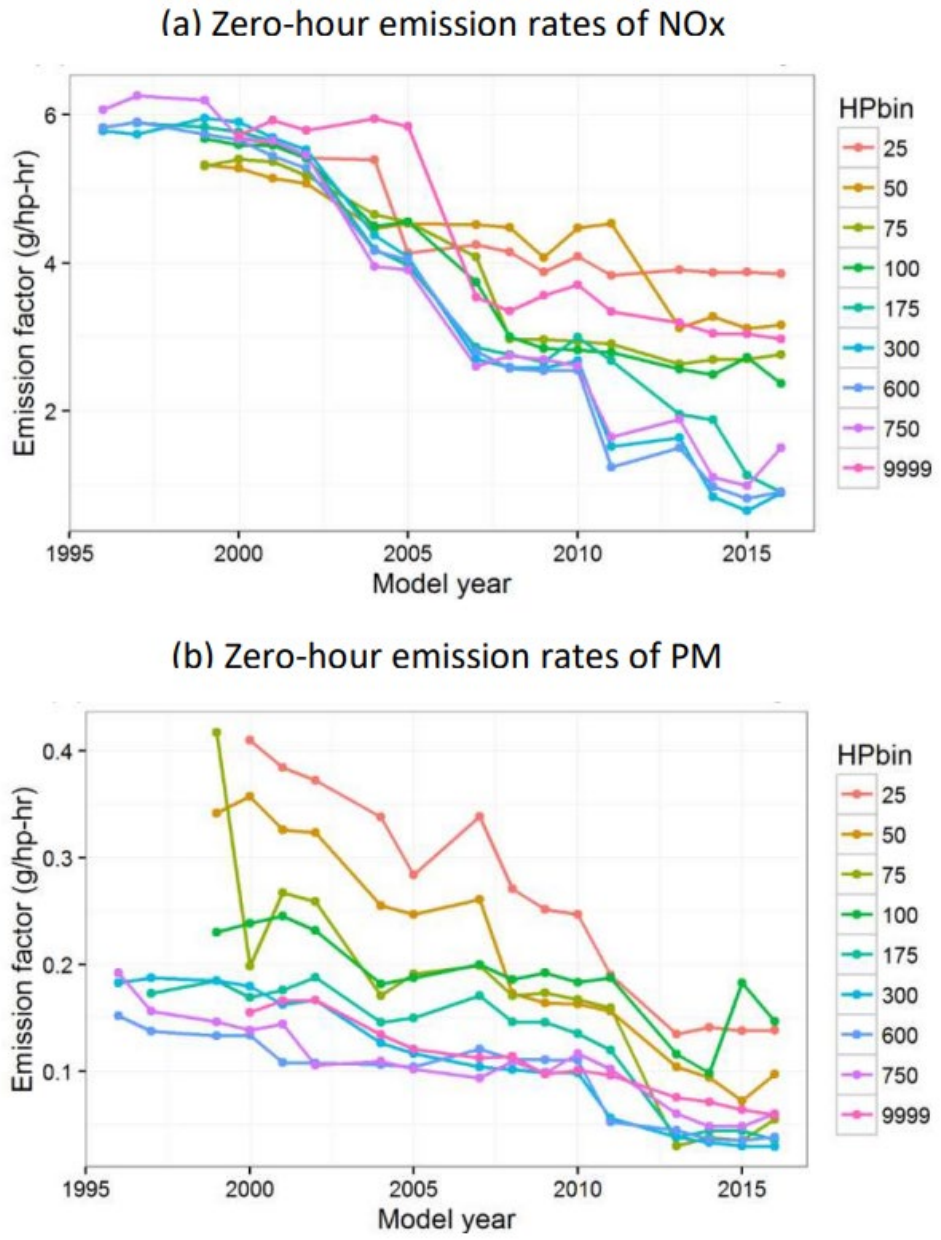
3.6 Emission Factors

Emission factors represent the amount of pollutant an engine produces per unit of useful work or fuel used. CARB staff[4] developed new emission factors in 2017, primarily using engine certification data. The zero-hour certification represents engine testing with zero or near-zero total running hours on the engine.

Figure 9 shows the emissions factors for NOx and PM for model year (MY) 1995 to 2016 engines. Note that the emission factors loosely follow the emission standards, but vary each year. This is due to flexibility in the emission standards. In some years manufacturers may use credit or averaging to certify at a higher emission level than the standards, in other years they are significantly below the standards.

[4] Documentation on the emission factor updates is available here: https://ww3.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017.pdf

Figure 9: Emission Factors for NOx and PM by Model Year



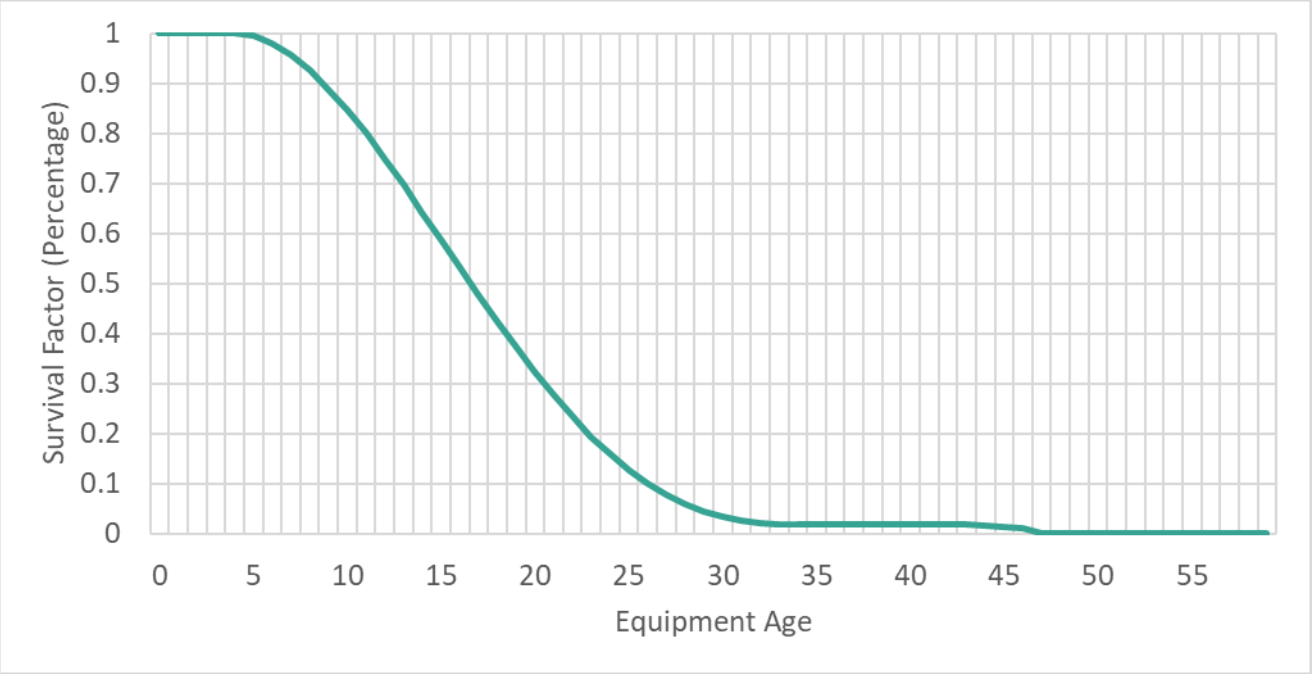
4 Forecasting and Growth

4.1 Age Distribution Forecasting

The starting age distribution for all equipment is based on the reported fleet characteristics in DOORS as of July 2020. Forecasting future years requires predicting the pattern of natural retirement and purchasing habits of all fleets in the inventory. Each forecasted year handles this process by applying a survival curve to the previous year's population. The survival curves

describe, on average, what percent of a population would be retired at every age. Figure 10 presents an example of a survival curve where the line starts at 1.00 at age zero, reflecting that 100 percent of the population has not been retired. The line begins to drop around age 6, slowly at first, showing that initial population decrease begins at that point (this might reflect selling the equipment out of State rather than retiring). By age 18, the line reaches 0.50, reflecting that half of the population would generally be retired by this point. By age 26, only 10 percent of equipment remains in service. Finally, the line extends to reflect a small portion of equipment kept out to age 47.

Figure 10: Example Survival Curve



In the inventory, survival curves were developed for small, medium, and large fleets separately, based on the age distribution in reporting data. Survival curves for equipment were based on the 2020 DOORS inventory populations age distribution. . The lack of equipment from 2008 to 2010 does not reflect retirements, but instead an extremely low purchasing rate.

Figure 11, presents the age distribution of small, medium, and large fleets.. The age distribution of large fleets shows a relatively quick drop in population, reaching half of maximum population by age 7 or 8, which is also reflected in the survival curve for large fleets as shown in Figure 12. The age distribution of medium fleets does not show the same drop in populations until age 18, indicating the average medium fleet maintains equipment longer than the average large fleet. Small fleets take longer than even medium fleets to show an initial decline in age distribution, but then decline at roughly the same rate as medium fleets and show a similar retirement rate from age 20 to 35.

Figure 11. Age Distribution by Fleet Size

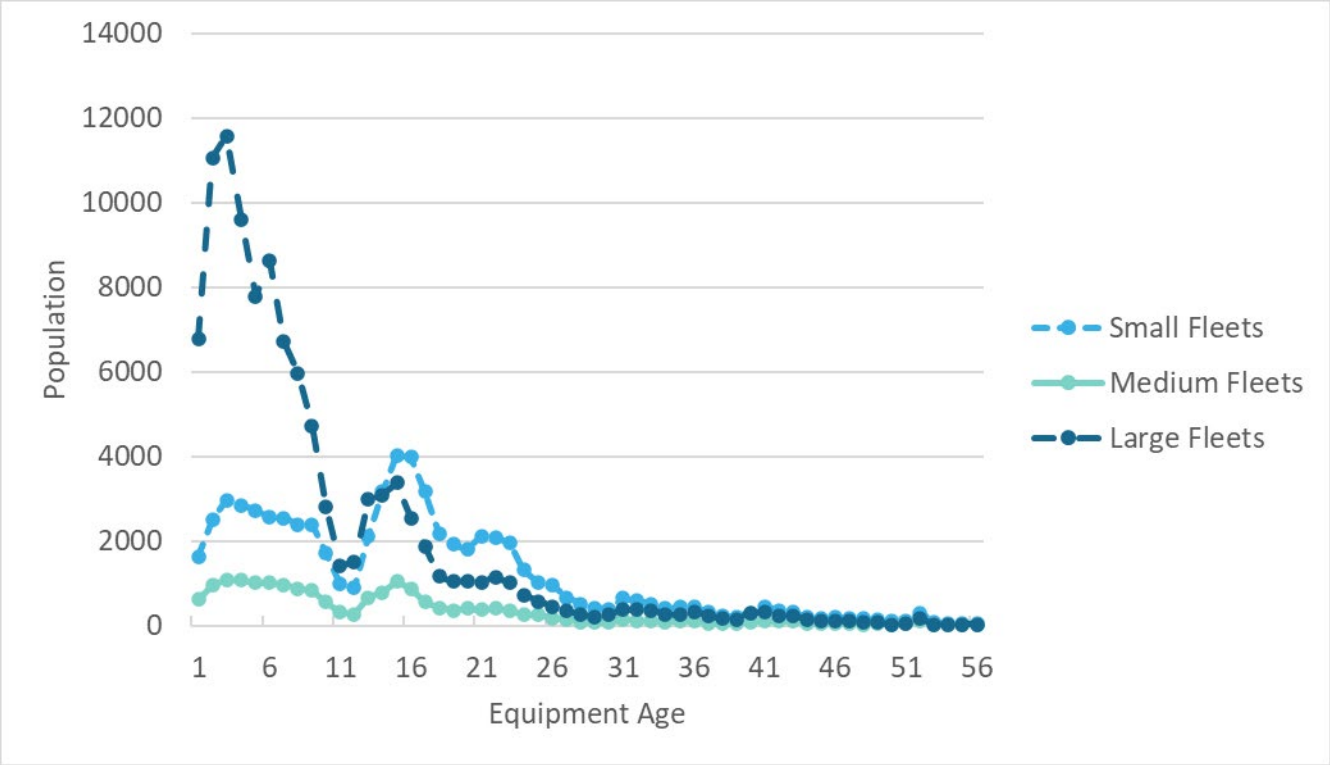
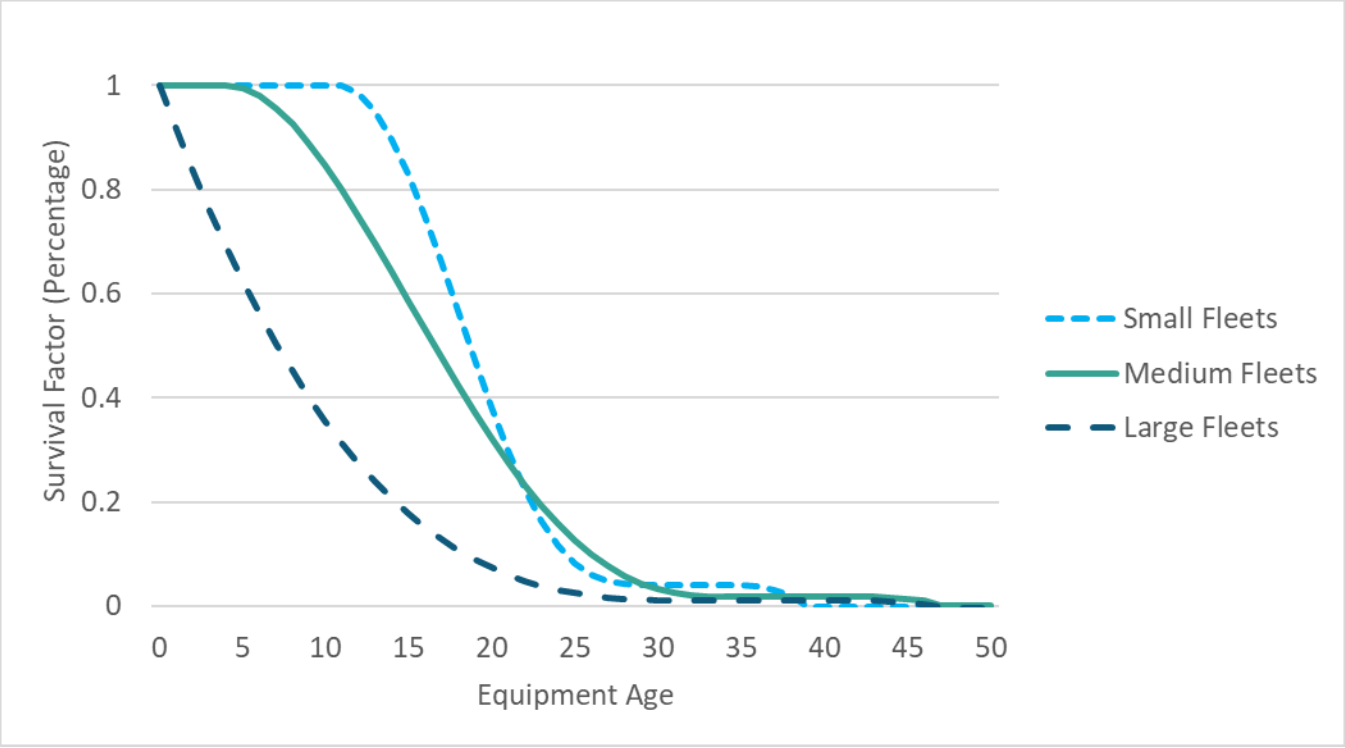


Figure 12. Survival Curves by Fleet Size



4.2 Regulation Effects on Forecasting

The average age of fleets can change over time, especially when influenced by regulation. These shifts in average age are visible by comparing fleet reporting data from 2013 to subsequent snapshots of fleet reporting data, such as in 2020. In 2013 and prior, there were no turnover requirements in the Off-Road Regulation that would have changed the fleet age distribution. The reporting data from this period could include any preparations that fleets owners made to comply with upcoming regulatory requirements, and may introduce some bias to the age distribution. However, there is no comprehensive dataset for this equipment prior to the reporting requirements of the Off-Road Regulation.

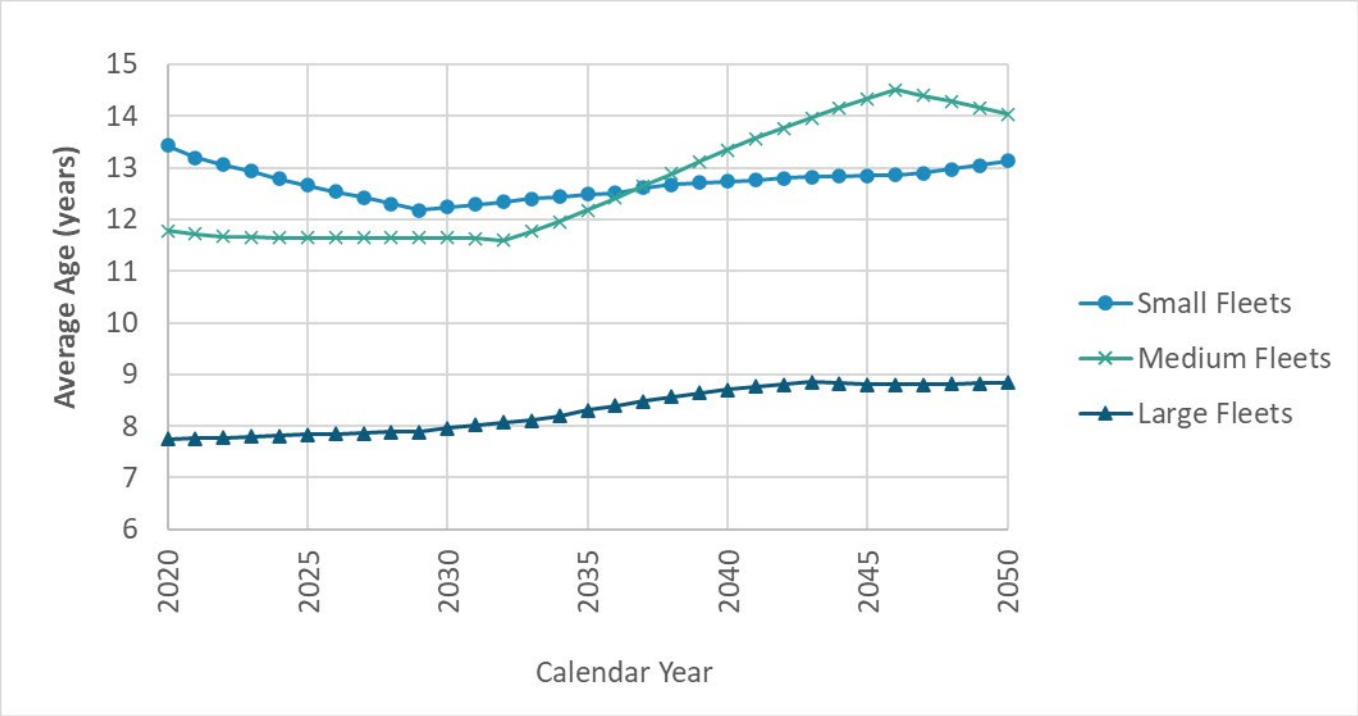
The average age of fleets dropped noticeably during the regulatory period after 2013. For example, large fleets had an average age of 9.2 years in 2013, and by 2020 that average age dropped to 7.8. The fleet average and BACT requirements for large fleets started in 2014 and end in 2023, meaning the current Off-Road Regulation reduced the average age by 1.4 years. Taking another example, medium fleets had an average age of 14.0 in 2013, and by 2020 that average age changed to 11.8. The start of the compliance for medium fleets was 2017 and the requirements end in 2023. So, the effects of regulation had reduced the average age by 2.2 years in four years. The assumption made in the inventory is that the average age of equipment in small fleets would be reduced by a similar amount over the course of the regulation implementation as seen in medium and large fleets. The fleet average or BACT requirements for small fleets begin in 2019 and end in 2028.

After full implementation of the existing Off-Road Regulation, CARB staff assumed the average age of the fleet would return to the pre-regulation average age. This means the forecast in the inventory will require fleets meet the final requirements of the regulation, then allow slower than normal turnover until a fleet returns to the pre-regulation average age. This is visible in Figure 13 below, where medium and large fleets start increasing in age slowly, over a decade or more, after meeting the regulatory requirements. Small fleets continue to lower average age until their final requirements in 2028, and then by 2040 to 2044, gradually return to their average age as assessed in the 2013.

The inventory model returns fleets to their previous average age by applying the survival curve, but then increasing or limiting the total turnover, based on average age of the fleet. For example, in some cases the survival curve could retire 12 percent of the fleet per year, reducing the overall fleet average age. If this occurred during a period where the average age is predicted to increase after compliance with the existing Off-Road Regulation, then turnover would be reduced from 12 percent to a lower amount. Thepercent of the fleet allowed to turn over each year is determined in an iterative process that determines the percent of turnover that would allow the fleet to return to the average age prior to the regulation. The exact percent varies by year and fleet, and is tailored so that the fleet groups gradually return to the pre-regulatory age following the fleet average or BACT requirements of the regulation. There is uncertainty in the exact time it will take fleets to return to the pre-regulatory average age. It may occur within two years if fleets halt all new purchases. However, CARB staff assumed a lengthier period of approximately 12 years to reflect normal equipment failure and replacement, the continued natural turnover of naturally younger

fleets, and the creation and development of new fleets of equipments. The average age of each fleet size is shown in Figure 13.

Figure 13: Average Age by Fleet Size



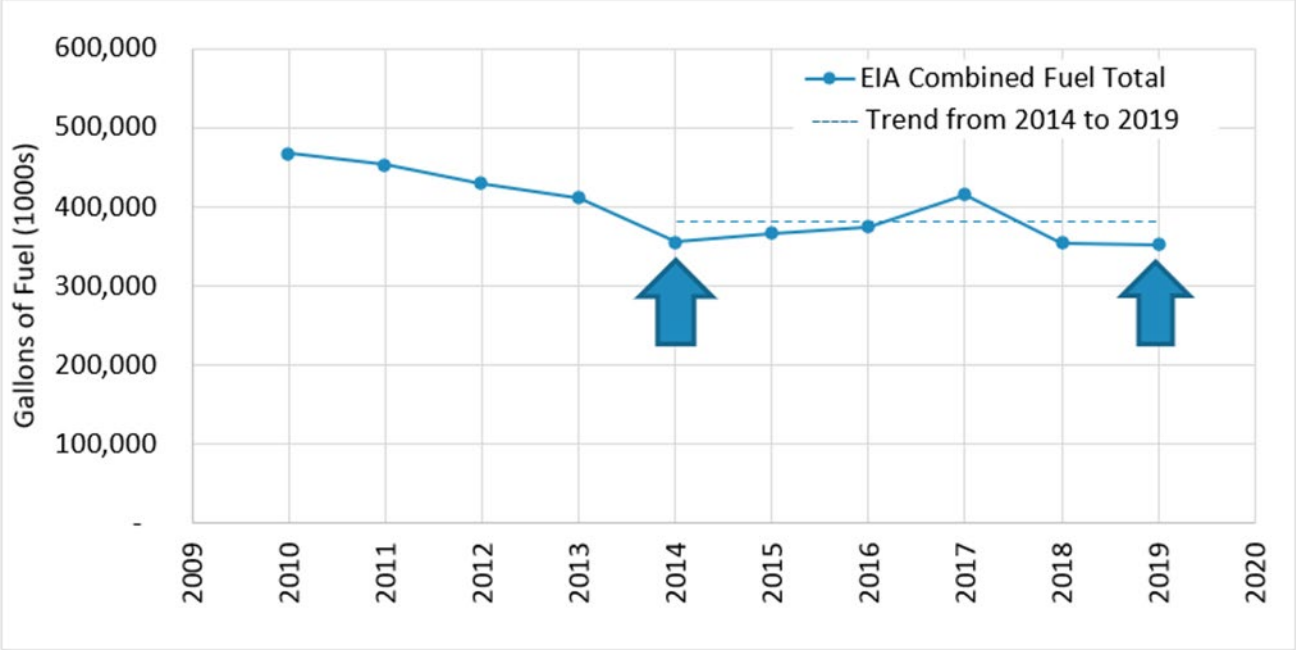
4.3 Growth Rates

In many inventories, an overall growth rate is used to project the increase in population or activity all equipment in future years. In previous versions of the in-use inventory, construction spending forecasts and overall population growth were used to project positive future growth rates.

For this inventory analysis, CARB staff reviewed the historical fuel pattern from the EIA for the past decade, using the categories covered in the fuel-balancing analysis. This trend is shown in Figure 14, with a decreasing trend from 2009 to 2014, and a relatively flat trend from 2014 to 2019 (the dotted line shows averaged trends). Based on this trend, CARB staff applied no growth or decline to population for future calendar years.

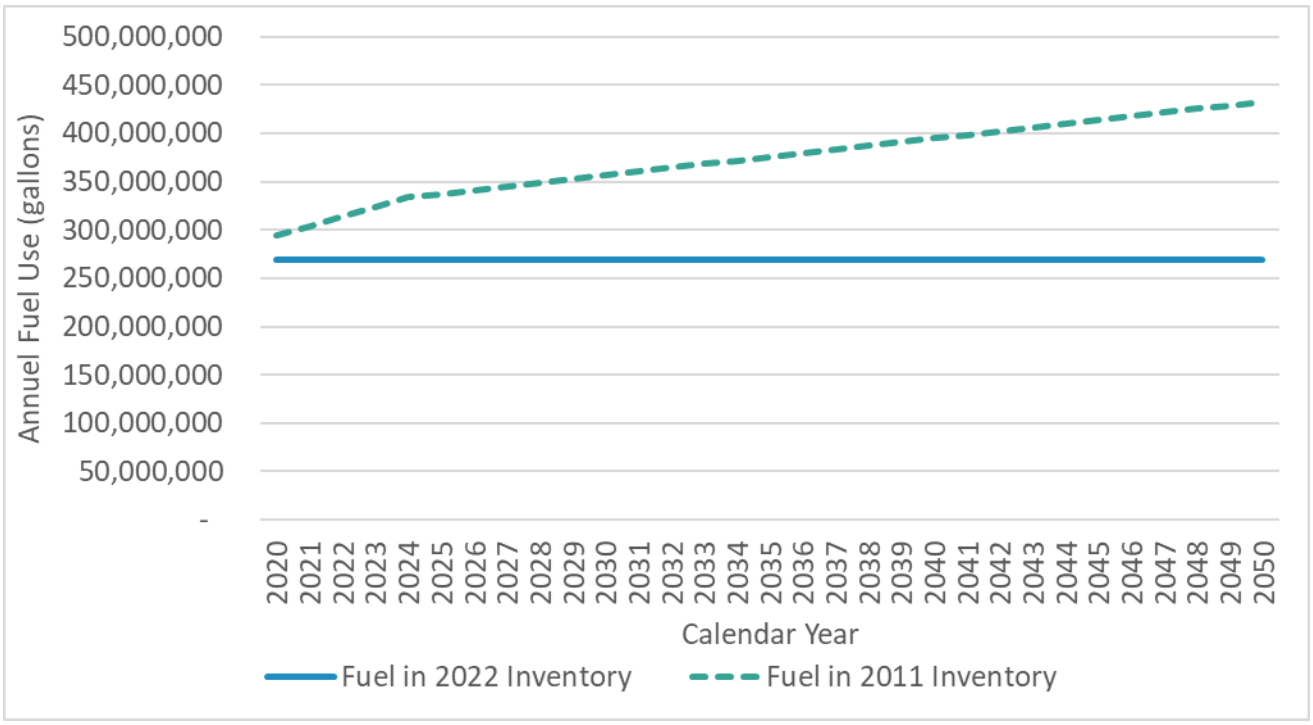
The EIA releases data approximately one to two years after the calendar year. For example, EIA released calendar year 2020 fuel data in Summer 2022, but CARB staff were only able to incorporate data from. the 2009 to 2019 period because it was the most recent and the best-available data during the development of the inventory that was finalized by late Spring 2022.

Figure 14: Off-Road Fuel Trends from 2010 to 2019



from the 2011 inventory for the 2020 calendar year, over time, the updated growth factor has a larger impact. By 2040, the fuel use in the updated inventory is 32 percent below the 2011 inventory projection, as shown in the Figure 15. The fuel total from the 2022 inventory includes the adjustment to fuel balance.

Figure 15: Fuel Use Comparison in 2011 and 2022 Inventories



5 Regulatory Scenario

CARB staff used the baseline inventory with the existing Off-Road Regulation as a starting point to estimate the emissions expected under the Proposed Amendments. The difference between the emissions in the baseline inventory and the Proposed Amendments scenario is the expected emissions reductions.

To calculate the emissions reductions under the Proposed Amendments scenario, CARB staff adjusted the age distribution of the populations (but not overall population) in the baseline 2022 inventory to account for the additional requirements of the Proposed Amendments, which are the Tier Phase-out, renewable diesel requirements, and the 2036 Tier 0 low-use phase-out provisions. The following sections provide details on CARB staff's methodology to calculate the emission benefits of the Proposed Amendments. The calculations for the two alternatives also follow the same methodology.

A new "ultra-small" fleet size is also part of the Proposed Amendments and the two alternatives, and would have a delayed deadline for the Tier 2 engine phase-out. As the inventory itself does not subdivide ultra-small fleets, which have a total horsepower of up to 500, from small fleets, CARB staff analyzed DOORS data to determine the proportion of Tier 2 engines in small fleets that are also ultra-small fleets, excluding equipment with special designations. CARB staff determined from this analysis that 35 percent of Tier 2 engines in small fleets meet the proposed definition of ultra-small fleets.

5.1 Tier Phase-Out

The Tier Phase-out provision requires fleets to phase out of the older equipment, based on a schedule based on fleet size and engine tier, as shown in Table 6. To meet the requirement to phase out a equipment, the fleet may choose to either sell or retire the equipment, or to designate it as low use, which allows the fleet to continue to use the equipment for a limited number of hours per year.

Table 6. Phase-Out Dates by Fleet Size and Tier

Fleet Size	Tier 0 Phase-Out	Tier 1 Phase-Out	Tier 2 Phase-Out
Large	2024	2026	2028
Medium	2026	2028	2030
Small	2028	2030	2032
Ultra-Small	2028	2030	2036

The emission benefits for the Tier Phase-out depend on the action that was taken in the phase-out of the equipment, such as whether the phased-out equipment was retired or designated as low use, and whether a new equipment, a used equipment, or no equipment was purchased as a replacement. To determine the replacement emissions, CARB staff referred to the results of the survey conducted after the October 2021 workshop; specifically, the "Purchasing Behavior Questions" section of the survey. The relevant questions are shown in Table 7.

Table 7. Questions in Survey on Fleet Purchasing Options

Purchasing Behavior Questions	Responses:
How often do you purchase **brand new** vehicles?	Choose Percentage: [select menu]
How often do you purchase **used** vehicles?	Choose Percentage: [select menu]
If you purchase used vehicles, what is the typical age of the vehicle you look for?	[typed number response]
Staff is considering including in the Proposed Amendments to the Off-Road Diesel Regulation a ban on the operation of Tier 0-2 equipment in California. CARB would like to understand what compliance pathway your fleet would potentially utilize to become compliant with this requirement. Please assign a percentage to how likely you are to use each compliance pathway listed to the right, with the intent that the total would not exceed 100%.	[See options below]
Remove the old vehicles from your fleet and purchase a new or used Tier 4 final or cleaner vehicle	Choose Percentage: [select menu]
Remove the old vehicles from your fleet and rent a Tier 4 final or cleaner vehicle	Choose Percentage: [select menu]
Remove the old vehicles from your fleet without replacing it	Choose Percentage: [select menu]

Place the old vehicles under the low-use provision and purchase a new or used Tier 4 final or cleaner vehicle	Choose Percentage: [select menu]
Place the old vehicles under the low-use provision without replacing it	Choose Percentage: [select menu]

Table 7 shows the questions in the survey pertaining to purchasing preferences and actions that fleets would potentially take to meet the Proposed Amendments. Not shown in Table 7 are additional background questions about the fleet, including the fleet size classification under the current Off-Road Regulation. The responses to the questions were grouped by the fleet size, and further divided into six categories based on a combination of whether fleets, when phasing out a equipment, would retire or designate as low use, whether the fleet would replace this phased-out equipment, and if yes, whether the replacement equipment would be a new or used equipment. Responses from medium fleets were combined with those from small fleets. The results shown in Table 8 were normalized to give the relative frequencies of each of the options for the two fleet size categories so that the sum of the answers for each fleet size category adds up to one. Note, the values in the table may not add up exactly to one due to rounding.

Table 8. Survey Responses on Compliance Choices for the Proposed Amendments

	Large	Medium/Small
Retire - Replace with New	0.779	0.537
Retire - Replace with Used	0.051	0.102
Retire - No Replacement	0.047	0.120
Low use - Replace with New	0.058	0.101
Low use - Replace with Used	0.004	0.019
Low use - No Replacement	0.062	0.120

In addition to determining the relative frequency of each of the six possible actions, the survey also helped determine an average age of used equipment at the time of purchase. CARB staff assumed the average age of replacement equipment was 5 years based on the survey responses. This preference was used in the emissions analysis for the two options in which the fleet replaces the phased-out equipment with a used equipment.

For example, for a large fleet that must replace or retire 100 pieces of equipment, with 12 percent of those being low use, 83.7 would be replaced with a new equipment, 5.4 would be replaced with a five-year-old equipment, and 10.9 would be retired and not replaced.

The next step was to determine the emissions impacts associated with taking each of these six possible actions any given calendar year. For this analysis, CARB staff performed the calculations on a per equipment basis, which consists of two parts: the emissions from the phased-out equipment and the emissions from the replacement equipment. For options in which the phased-out equipment is placed into low use, the emissions for the phased-out equipment are determined by using the average emissions from a low use piece of equipment.

As mentioned earlier, an adjustment to the methodology is needed for small fleets, specifically for Tier 2 engines operated by ultra-small fleets. The 35 percent of Tier 2 engines in ultra-small fleets are removed from the calculation of the benefits from the small fleet Tier 2 phase-out date until the ultra-small fleet Tier 2 phase-out date.

5.2 Renewable Diesel

The Proposed Amendments would require the use of renewable diesel in all equipment that are not powered with a Tier 4 Final engine, and are expected to reduce emission of NOx by 10 percent and PM by 30 percent[5]. The emissions reductions expected from the renewable diesel provision of the Proposed Amendments would then be 10 percent of the total NOx emissions and 30 percent of the total PM emissions of equipment in all tiers except Tier 4 Final, including both low-use and regular use equipment.

5.3 2036 Permanent Low-Use Phase-Out

The Proposed Amendments would require the phase-out of any remaining Tier 0 engines, specifically, those designated as Permanent Low-Use, by 2036. The emissions reductions would be equal to the total emissions of all remaining Tier 0 engines in 2036 minus the emissions of the replacement Tier 4 Final engines.

[5] Durbin, Thomas D. et al. (2021). Final Report: Low Emission Diesel (LED) Study: Biodiesel and Renewable Diesel Emissions in Legacy and New Technology Diesel Engines. California Air Resources Board. Retrieved July 6, 2022 https://ww2.arb.ca.gov/sites/default/files/2021-11/Low_Emission_Diesel_Study_Final_Report.pdf

6 Emissions Results

Summary

The following charts show the baseline emissions split by engine tier and fleet size. In addition, charts provide a comparison with the 2011 inventory, and the benefits of the Proposed Amendments by calendar year.

Figure 16: Statewide NOx Emissions Comparisons shows the statewide NOx emissions under the previous 2011 inventory, 2022 update, and the Proposed Amendments. Figure 17Figure 16: Statewide NOx Emissions Comparisons shows the statewide PM emissions under the previous 2011 inventory, 2022 update, and the Proposed Amendments.

Figure 16: Statewide NOx Emissions Comparisons

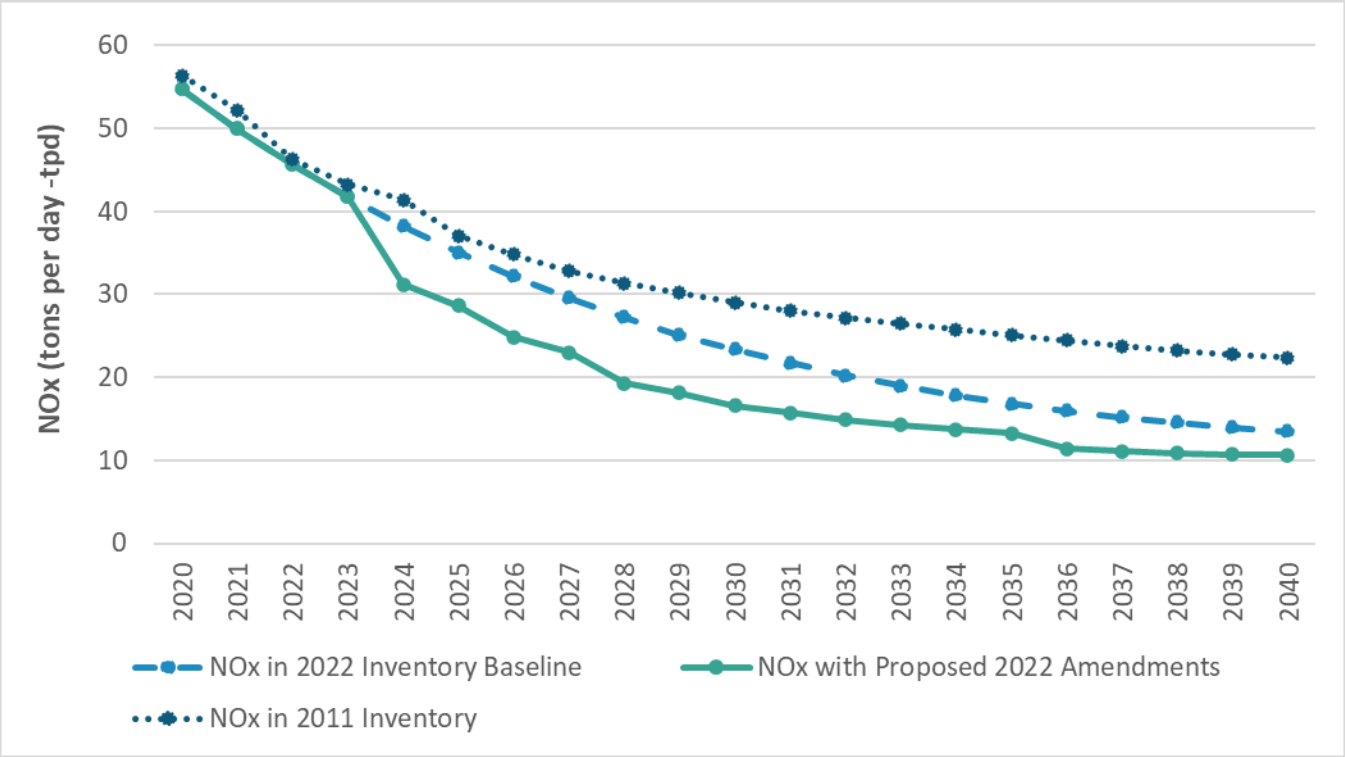


Figure 17: Statewide PM Emissions Comparisons

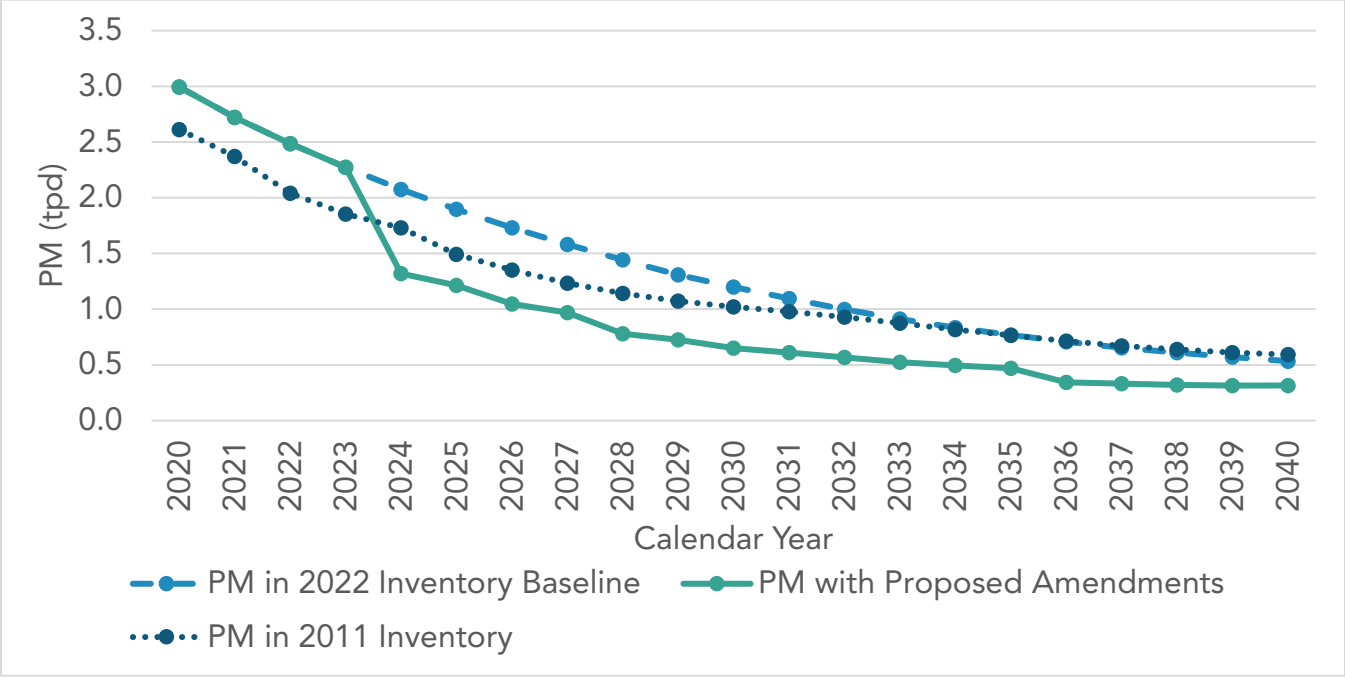


Figure 18 shows the state NOx and PM emission reductions from the Proposed Amendments by calendar year.

Figure 18: Statewide NOx and PM Emission Reductions from Proposed Amendments

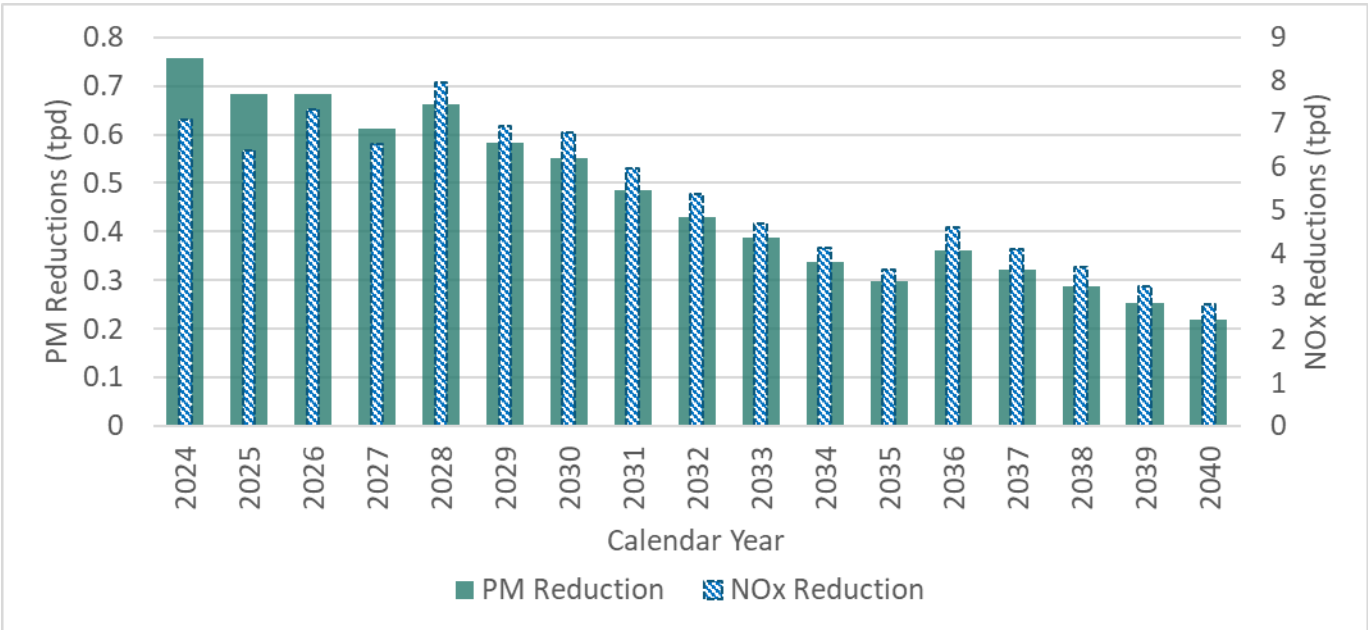


Figure 19 and 20 show the state NOx and PM for the 2022 emission inventory update by engine Tier without the Proposed Amendments. Each Tier is shown in the same order in the graph as shown in the legend (from top to bottom).

Figure 19. Baseline Statewide NOx emissions by Engine Tier

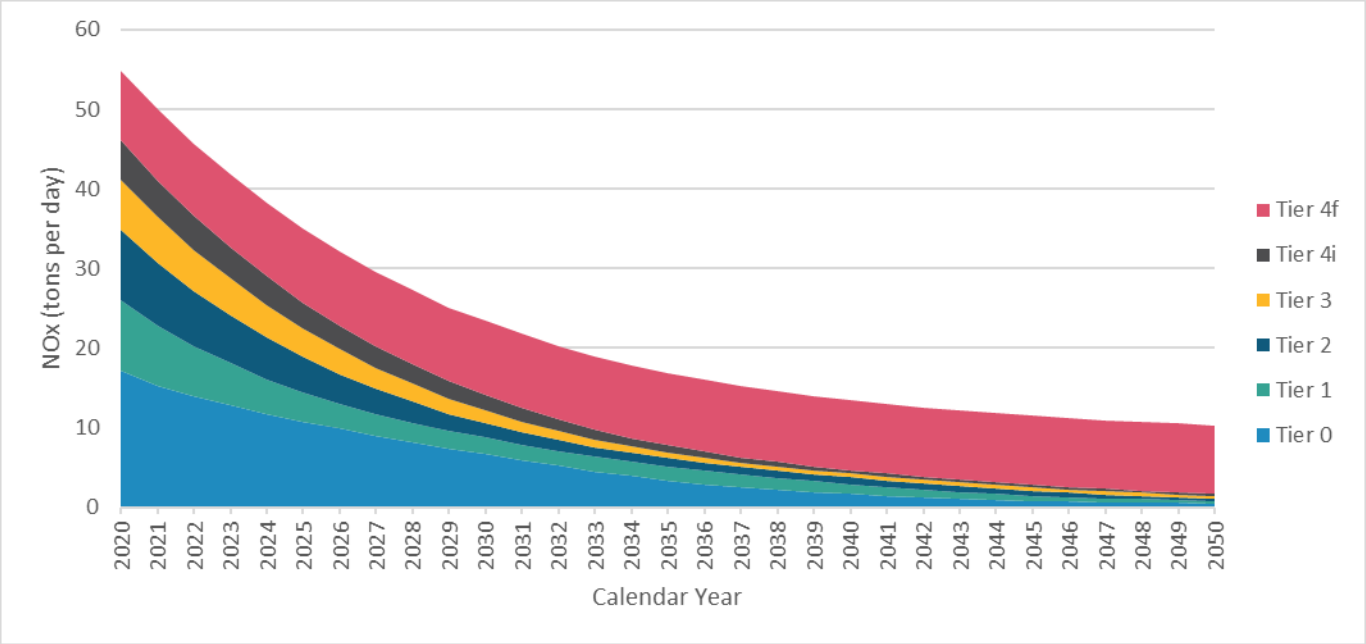


Figure 20. Baseline Statewide PM emissions by Engine Tier

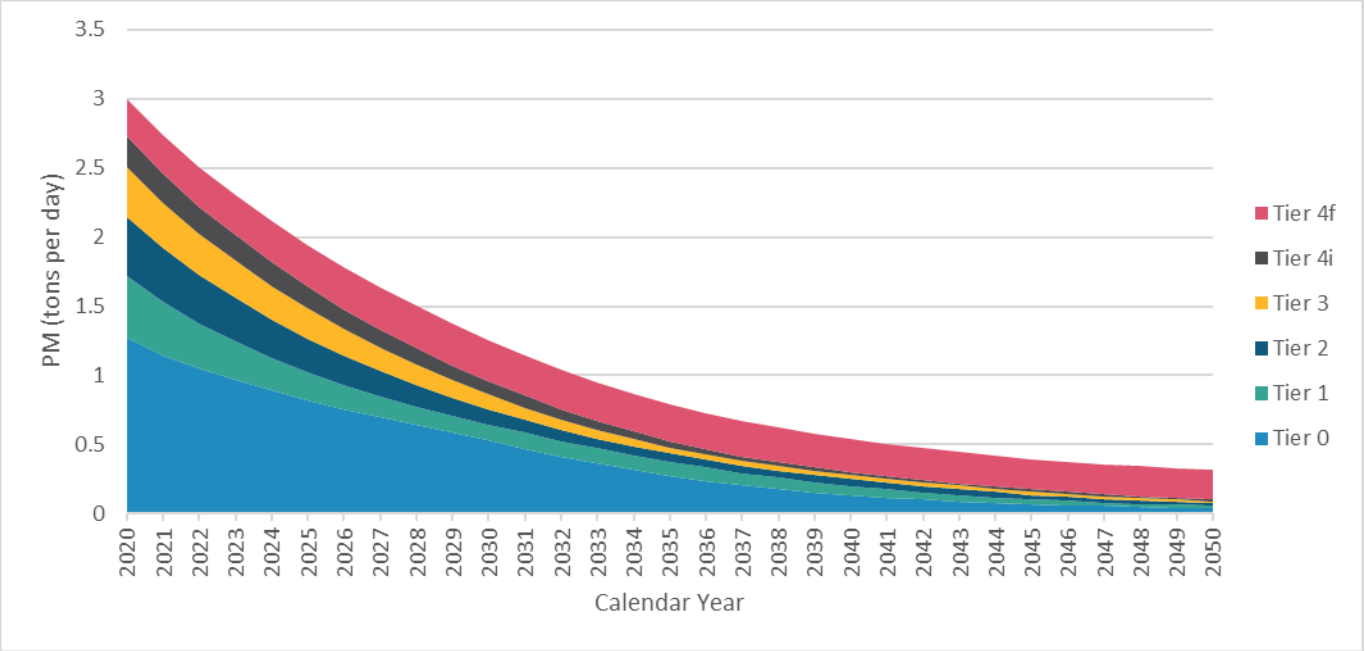


Figure 21 and 22 show the statewide NOx and PM emissions by fleet size before the Proposed Amendments. Each fleet size is shown in the same order in the graph, as shown in the legend (from top to bottom).

Figure 21. Baseline Statewide NOx Emissions by Fleet Size

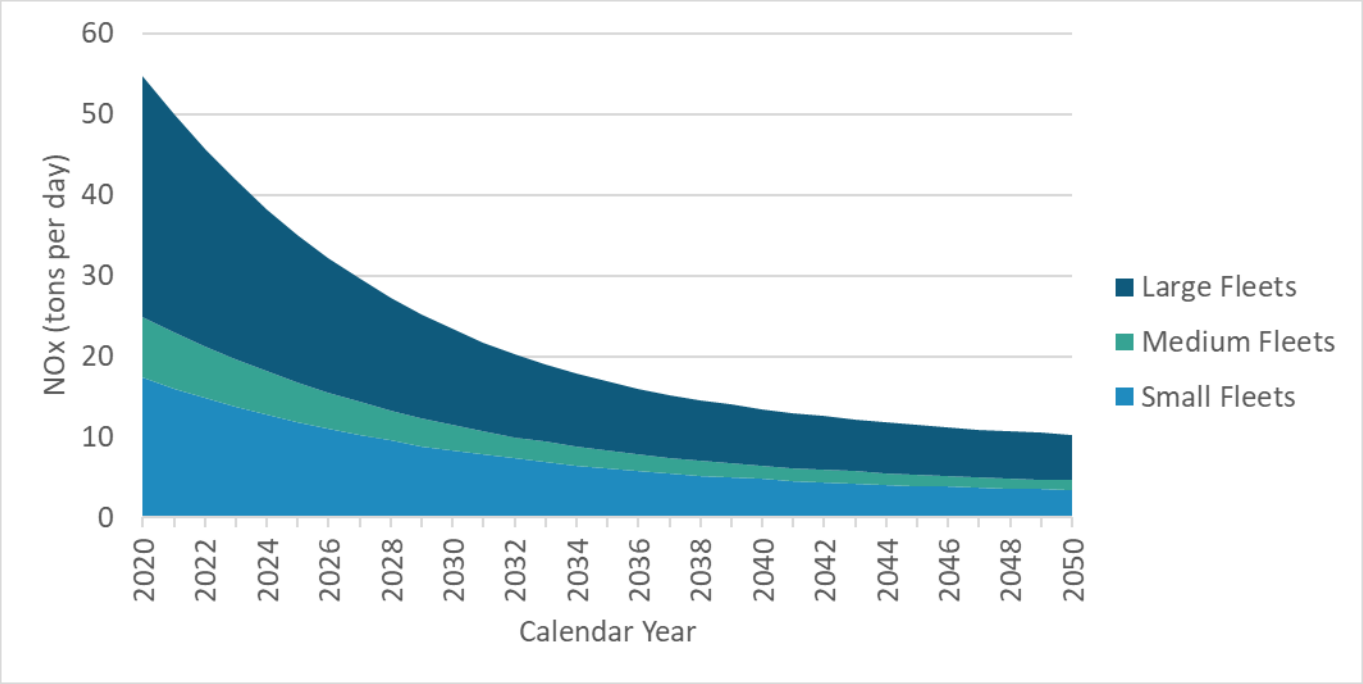
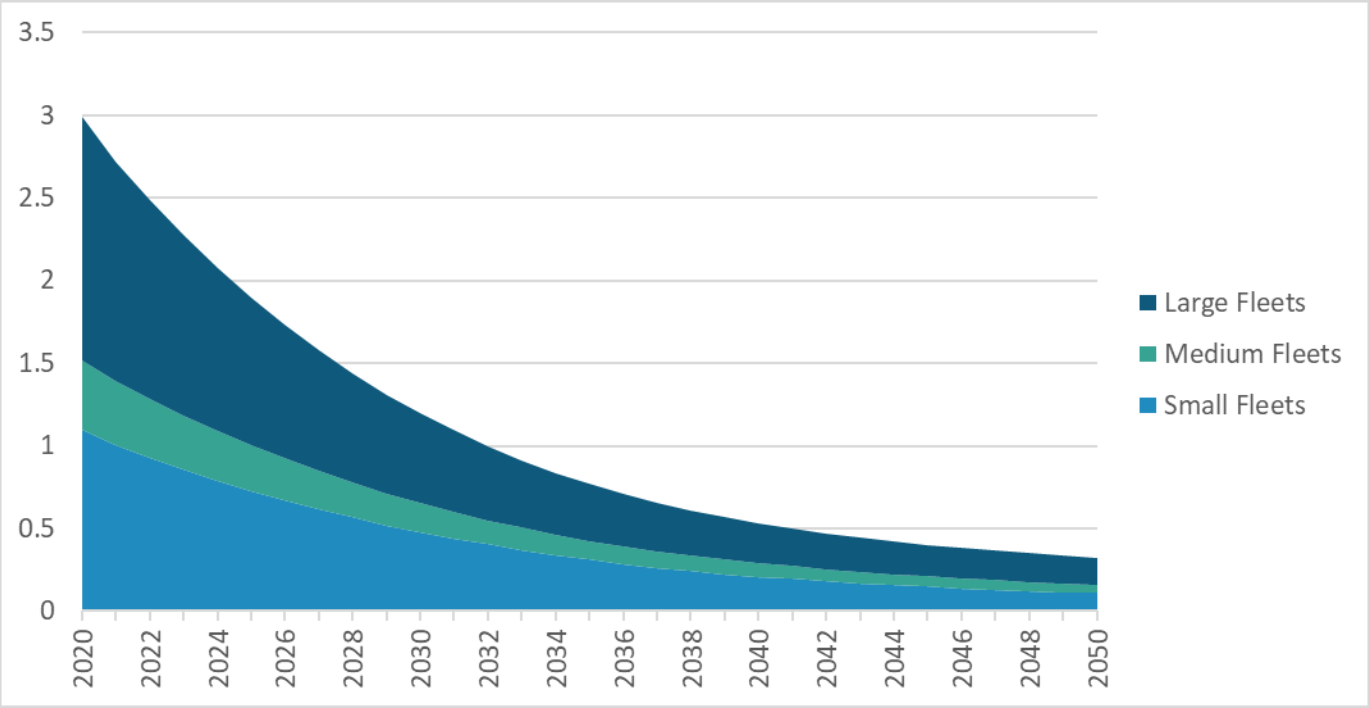


Figure 22. Baseline Statewide PM Emissions by Fleet Size



7 Appendices

Table 9. Baseline Emissions by Air District

	2020	2020	2037	2037
Air District	NOx (tpd)	PM (tpd)	NOx (tpd)	PM (tpd)
AMA	0.08	0.0042	0.02	0.0009
AV	0.25	0.0137	0.08	0.0031
BA	6.43	0.3495	1.93	0.0788
BUT	0.51	0.0278	0.13	0.0060
CAL	0.08	0.0044	0.02	0.0010
COL	0.17	0.0097	0.03	0.0016
ED	0.32	0.0173	0.09	0.0038
FR	0.70	0.0382	0.18	0.0081
GBU	0.06	0.0031	0.02	0.0007
GLE	0.10	0.0055	0.02	0.0011
IMP	0.48	0.0260	0.13	0.0058
KER	0.36	0.0198	0.10	0.0044

	2020	2020	2037	2037
Air District	NOx (tpd)	PM (tpd)	NOx (tpd)	PM (tpd)
LAK	0.11	0.0058	0.03	0.0013
LAS	0.05	0.0028	0.01	0.0006
MBU	0.81	0.0439	0.23	0.0098
MEN	0.10	0.0054	0.03	0.0012
MOD	0.03	0.0015	0.01	0.0003
MOJ	0.98	0.0537	0.27	0.0119
MPA	0.03	0.0014	0.01	0.0003
NCU	0.17	0.0091	0.05	0.0020
NS	0.07	0.0039	0.02	0.0009
NSI	0.14	0.0077	0.04	0.0017
PLA	0.72	0.0395	0.20	0.0088
SAC	1.73	0.0949	0.47	0.0205
SB	0.33	0.0182	0.09	0.0039
SC	21.57	1.1767	6.17	0.2617
SD	3.47	0.1893	0.99	0.0423
SHA	0.33	0.0182	0.09	0.0040
SIS	0.04	0.0024	0.01	0.0005
SJU	12.26	0.6741	3.15	0.1410
SLO	0.24	0.0131	0.06	0.0028
TEH	0.14	0.0075	0.04	0.0017
TUO	0.06	0.0032	0.02	0.0007
VEN	1.25	0.0683	0.33	0.0145
YS	0.63	0.0346	0.17	0.0073

Table 10: Equipment Population by Type

Equipment Type	2020 Population
Tractors/Loaders/Backhoes	34,051
Excavators	22,803
Forklifts	21,573
Skid Steer Loaders	19,729
Rubber Tired Loaders	10,604
Rough Terrain Forklifts	9,232
Rollers	8,092
Aerial Lifts	7,643
Crawler Tractors	6,041
Scrapers	5,301
Other Construction Equipment	4,964

Boom	4,354
Graders	3,538
Cranes	3,075
Other General Industrial Equipment	3,061
Mower	2,403
Off-Highway Tractors	2,176
Off-Highway Trucks	1,711
Paving Equipment	1,670
Pavers	1,603
Trenchers	1,513
Bore/Drill Rigs	1,443
Sweepers/Scrubbers	1,336
Other Material Handling Equipment	1,294
Yard Goat	1,244
Drill Rig (Mobile)	886
Drill Rig	848
Crane 35ton or more	783
Off Highway Trucks	746
Telescopic Handler	714
Workover Rig (Mobile)	636
Baggage Tug (Airport GSE)	593
Off Highway Tractors	582
Other Truck	532
Rubber Tired Dozers	502
Cargo Tractor (Airport GSE)	488
Surfacing Equipment	472
A/C Tug Narrow Body (Airport GSE)	467
Cargo Loader (Airport GSE)	464
Belt Loader (Airport GSE)	458
Forklift (Airport GSE)	438
Other Airport GSE	364
Water Truck	339
Lift (Airport GSE)	278
Crushing/Processing Equipment	246
A/C Tug Wide Body (Airport GSE)	207
Vacuum Truck	200
Crane less than 35ton	176
Spray Truck	104
Compactor	100
Tank Truck	87
Concrete Pump	74

Railcars or Track Cars	67
Bucket	61
Spreader Truck	45
Passenger Stand (Airport GSE)	38
Bobtail (Airport GSE)	23
Garbage Refuse	20
Concrete Mixer	17
Tanker Truck Trailer	13
Spreader Tractor Trailer	10
Other (Airport GSE)	8
Aircraft Tractor (Airport GSE)	7
Fuel Truck (Airport GSE)	4
Garbage Transfer	4
Hopper Tractor Trailer	4
Generator (Airport GSE)	2
Nurse Rig Other	1
Tow Tractor	1