2021 Forestry Diesel Equipment Emissions Inventory

Air Quality Planning and Science Division
Mobile Source Analysis Branch
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CALIFORNIA
AIR RESOURCES BOARD

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1. Executive Summary

The California Air Resources Board (CARB) has developed a new 2021 Forestry Diesel Equipment Emissions Inventory to replace the previous emissions inventory for diesel forestry equipment based on OFFROAD2007. This inventory includes all new data collected from a forestry-specific statewide survey, on-site operations and mill activity, timber harvest statistics, as well as the geographical information on logging related activities. This report describes the California logging data inputs, methodology, geographical allocations, and resulting emissions.

In close collaboration with the forestry industry, CARB received anonymized survey data collected from the Associated California Loggers[1] and CalForests[2] for calendar year 2017. The survey data provided a sample size of current California-specific logging activity including detailed equipment information and timber harvest data, as well as information for almost 600 pieces of forestry equipment that represent 23 percent of harvesting activity for on-site logging in California and 34 percent of milling activity in California. Staff also updated load factors for forestry specific equipment using the raw survey data.

Equipment data were analyzed, and subsequently divided into three main groupings, based on the equipment's function such as: Extraction, Manufacturing, and Road Maintenance & Construction. Staff estimated that in 2017, there are over 2,300 pieces of diesel logging equipment in California with a maximum equipment age of about 60 years. The inventory also forecasts future year age distributions based on the survey data, projecting over time that much of the older dirtier equipment will be replaced with newer engines, thereby reducing emissions.

Figure 1 compares the statewide Nitrogen Oxides (NOx) from diesel logging equipment in OFFROAD2007 versus the new 2021 Forestry Inventory. The base year 2017 emissions are 2.7 tons per day higher in the new 2021 inventory, which can be attributed to new California forestry-specific data. Even though the timber harvest statistics projects a growth rate of 1.36 percent annually, emissions are projected to decline over time due to equipment turnover to cleaner engines. Emissions from OFFROAD2007 were based on national averages for equipment population and usage and was not California specific. The updated 2021 inventory shows logging is a larger industry with greater usage than previously represented by the scaled national data.

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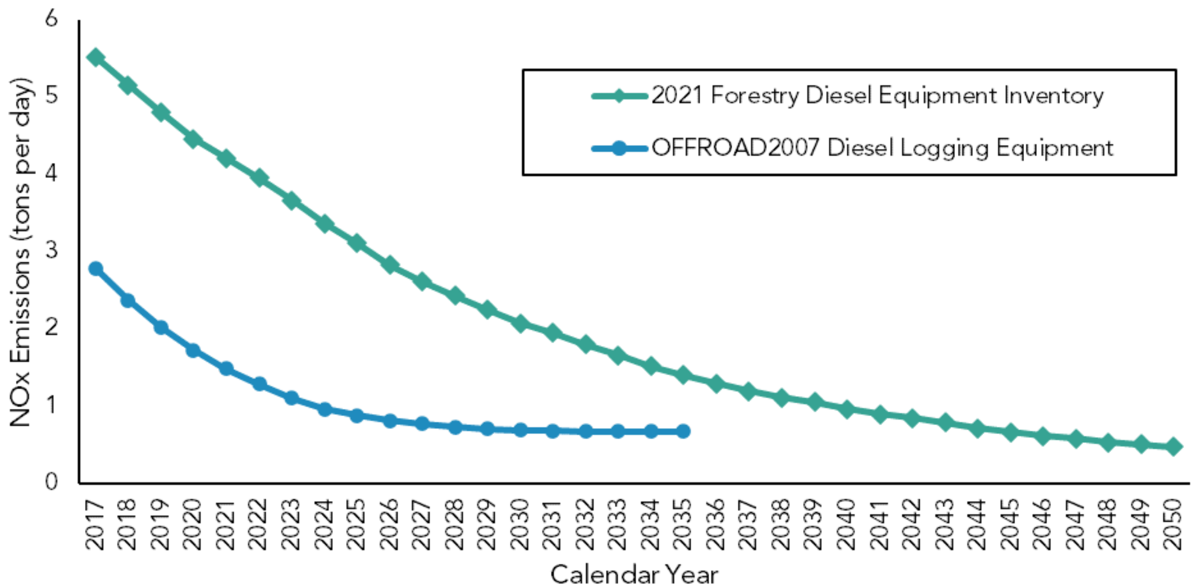
[1] Associated California Loggers *http://californialoggers.com/*

[2] CalForests *https://calforests.org/*

Figure 1: Statewide NOx Emissions Comparison



This 2021 forestry inventory is a major improvement from the previous OFFROAD2007 inventory due to the participation of the forestry and lumber industries, the availability of California-specific data, and the establishment of forestry-specific load factors and activity. These findings will improve CARB's future planning and policy development. The inventory will be used to understand which parts of the state are most affected by forestry activity, and what strategies can be employed to reduce criteria emissions in those regions.

2. Forestry Diesel Equipment Emission Inventory Development

An emissions inventory for a specific industry sector accounts for the equipment population, how often it is used (activity), the age of the equipment, as well as the region where the equipment is used. The inventory also projects the total resulting emissions in future years. The 2021 Forestry Diesel Equipment Inventory was developed to update the previous 2007 statewide forestry inventory, OFFROAD2007. The forestry sector is responsible for logging on private and public lands and complies with wildlife patterns in those areas. As such, forestry equipment is generally used six to seven months out of the year.

3. Inventory Data Inputs and Methodology

CARB's forestry inventory was developed using two main data sources: Survey data provided by the industry and statewide timber harvest statistics provided by the California Department of Tax and Fee Administration (CDTFA)[3]. For the survey data, the Associated California Loggers, who represent logging operations, and CalForests, who represent the mills, collected and supplied anonymized data to CARB. These two logging associations provided calendar year 2017 data, which included equipment characteristics such as equipment make and model name, model year, annual hours of use (activity), and annual fuel use. The survey data also collected the amount of harvested or processed lumber occurring at logging and mill operations.

Depending on the typical job performed, the anonymized equipment data was grouped into three categories: extraction equipment, manufacturing equipment, and road maintenance and construction equipment. Table 1 lists all equipment collected in the raw survey data and assigns them to the appropriate equipment grouping.

Table 1: Equipment Survey Data sorted into Equipment Groups

Extraction Equipment	Manufacturing Equipment	Road Maintenance & Construction Equipment
Boom Truck	Forklift	Backhoe
Carrier	Lift	Crane
Chipper	Straddle Buggy	Dozer
De-limber	Telehandler	Dump Truck
Dozer/Skidder	Tink Bucket Loader	Excavator
Dozer/Track Skidder		Grader
Feller Buncher		Loader/Backhoe
Forwarder		P&H Crane
Front End Loader		Roller
Grinder		Sweeper

[3] https://www.cdtfa.ca.gov/taxes-and-fees/timber-tax.htm

Harvester		Sweeper Truck
Heel Boom		Water Tender
Heel Boom Loader		Water Truck
Loader		
Log Loader		
Log Processor		
Masticator		
Rubber Tired Skidder		
Skid Steer		
Skidder		
Stroke De-limber		
Truck Mount Loader		
Wheel Loader		
Yarder		

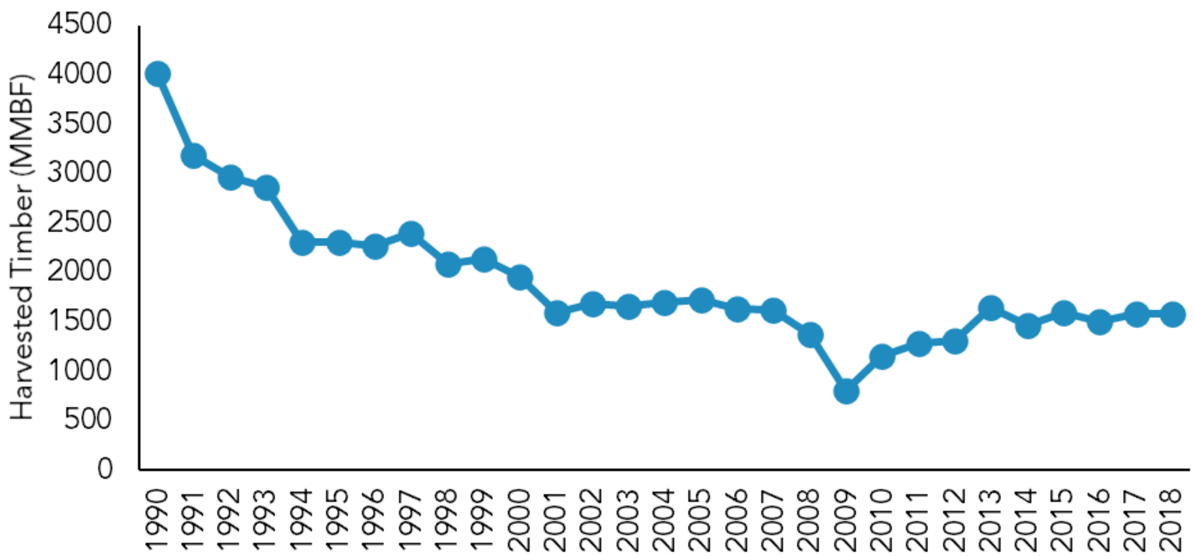
Table 2 shows the equipment groups and corresponding population reported in the raw survey data.

Table 2: Equipment Population Survey Responses

Equipment Group	Mill Survey Responses	Operations Survey Responses	Total Responses
Extraction Equipment	48	306	354
Manufacturing Equipment	76	-	76
Road Maintenance & Construction Equipment	15	142	157
Total	**139**	**448**	**587**

In addition to the survey data, CDTFA provides the statewide timber harvest statistics shown in Figure 2. This annual report collects harvest data on both public and private lands. Data shows that the timber harvest has steadily declined, with a drop during the recession to its lowest point in 2009, and then a steady increase thereafter. In 2017, the statewide timber harvest was 1,578 million board feet (MMBF). Board feet is a unit of measurement to describe the volume of a piece of lumber that is 1 foot long by 1 foot wide by 1 inch thick.

Figure 2: Historical Timber Harvest



3.1 Equipment Group Profiles

As previously mentioned, the reported survey equipment is grouped into three categories (Extraction Equipment, Manufacturing Equipment, and Road Maintenance & Construction Equipment) based on similar job functions. Each group has an individualized profile bin used for scaling and projecting statewide equipment population and activity. For example, Figure 3 displays the age distribution, with blue diamond-shaped markers, for the reported survey equipment in the Extraction Equipment Group. The green dashed curve shows the best fit curve used to estimate the population age distribution for equipment in the extraction group. As depicted, the number of equipment declines with age. The average equipment age is about 17 years with most equipment retiring after 49 years, and a few outliers staying for a longer period. This same process is used to estimate equipment population profiles in the remaining two equipment groups.

Figure 3: Extraction Equipment Group Age Distribution

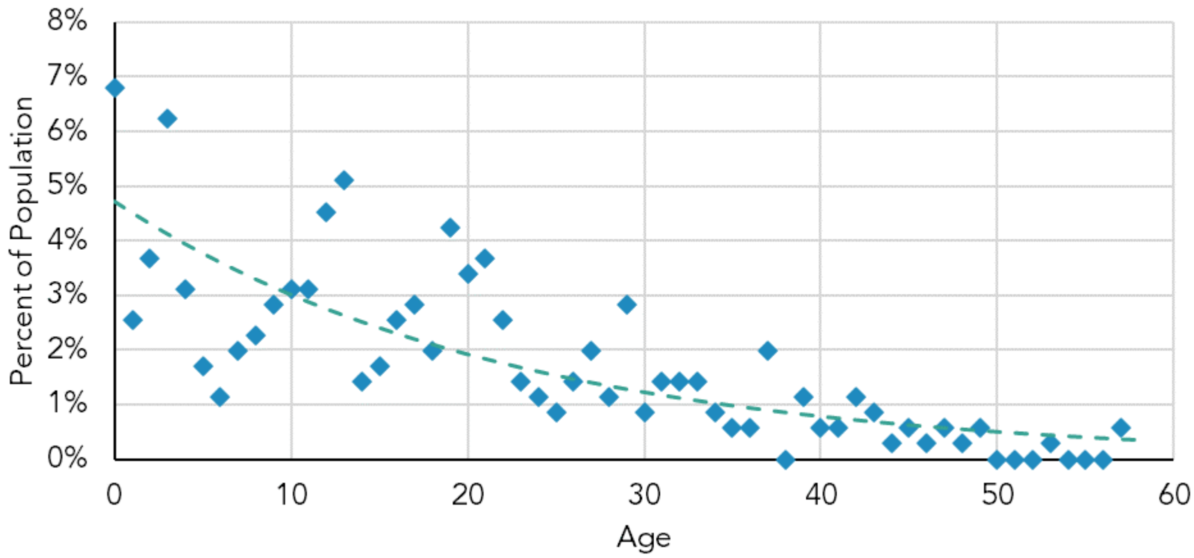
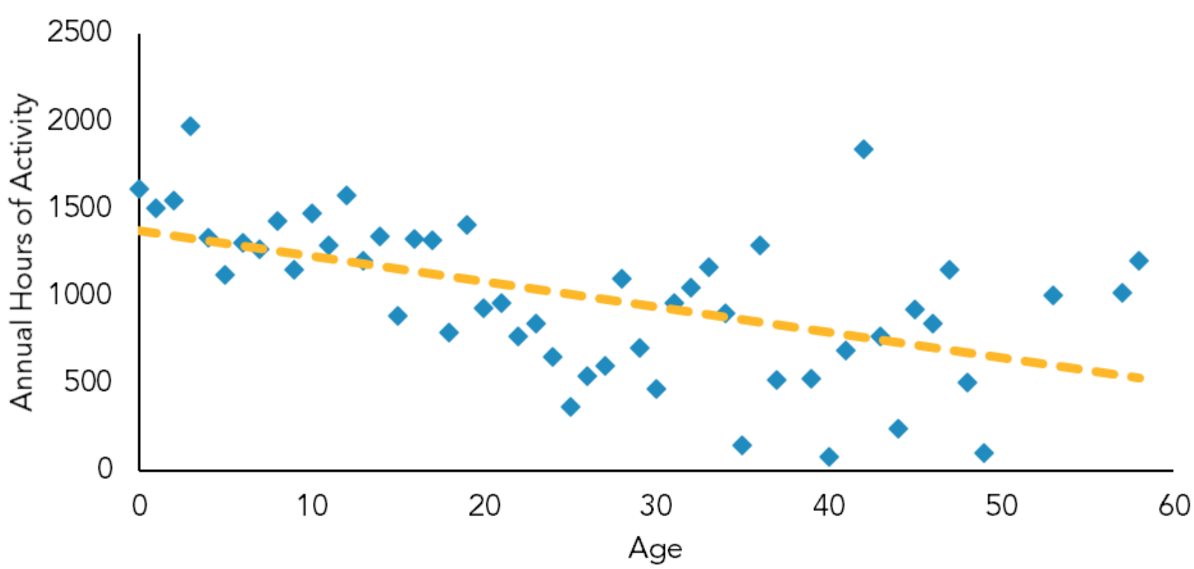


Figure 4 shows the activity distribution for the same extraction equipment group, in blue diamond-shaped markers and the yellow trend line as a best-fit representation of the average activity of equipment in this group. The overall trend indicates reduced use as equipment ages, with a few outliers showing some older equipment with high activity. The best-fit line informs that on average, new equipment operates almost 1,400 hours annually, and the operation hours decline to almost 500 hours per year as they reach almost 60 years of age.

Figure 4: Extraction Equipment Group Activity Distribution



The same analysis was completed to generate age and activity profiles for the remaining two equipment groups (i.e., Manufacturing Equipment and Road Construction & Maintenance Equipment) which are then used to predict future population and activity.

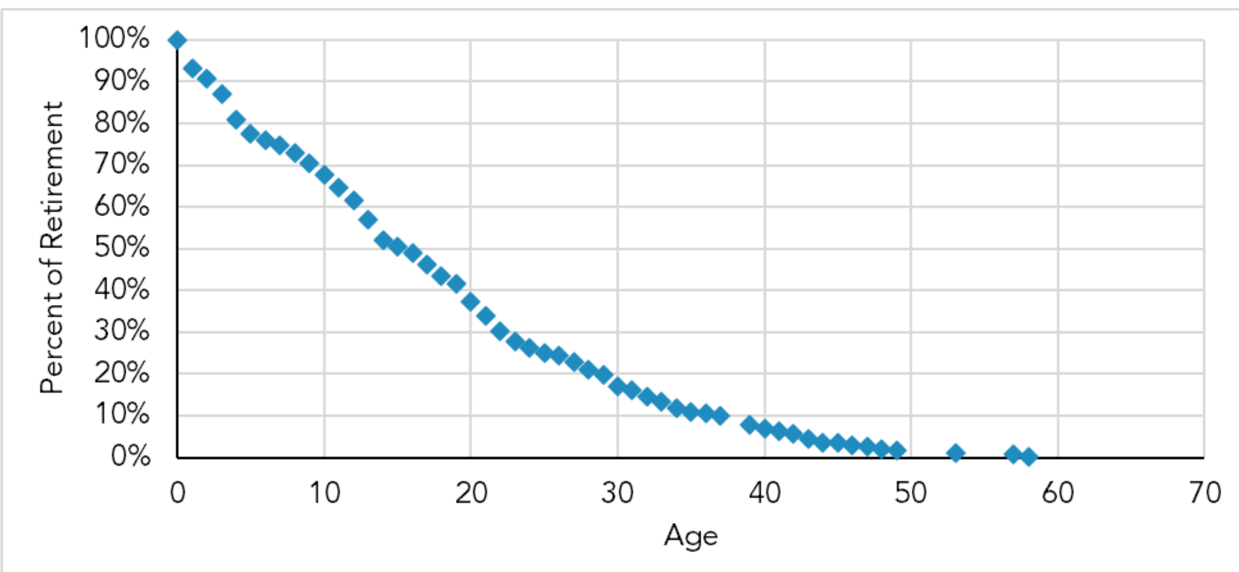
3.2 Equipment Turnover and Attrition

The model projects forestry equipment population and emissions in future years by predicting the retirement and purchasing habits of forestry equipment. The model attempts to predict a business as usual (BAU) behavior based on the 2017 survey data.

To estimate the fraction of the fleet that remains from one year to the next, equipment age distributions were created from the survey data. As shown in Figure 5, the age distribution of extraction equipment shows that only 50 percent of the new equipment remain in the fleet after 15 years of age, and that almost all equipment will retire once they reach 50 years of age, with few remaining. The rate at which the dotted blue line decreases indicates average retirement trends, which can be used to determine the percent of the population remaining at a certain age, also known as a survival curve.

Because the population distribution curve never increases, it indicates there is no continuous large scale purchasing that introduces used equipment into California operations, either from other states or equipment sectors, late in the equipment life. This does not mean equipment may not be sold between operations in California, only that the forestry industry does not appear to import used equipment. Therefore, all equipment is modeled as new purchases only.

Figure 5: Retirement Curve: Extraction Equipment Group



This same process developed purchasing and retirement curves to forecast population for equipment in the Manufacturing Equipment and Road Maintenance & Construction Equipment groups.

3.3 Population Scaling

To represent statewide forestry operations, the survey data is scaled up using the timber harvest to represent statewide totals. Because the survey data was grouped into two main logging types that are responsible for different aspects of the timber harvest (i.e., on-site logging operations and mill activity), each sector has a unique scaling method. As shown in Table 2, on-site logging includes equipment used in extraction and road maintenance while mill activity includes equipment used in extraction, manufacturing, and road maintenance.

Activity data for the two logging types were scaled up to statewide levels using the 2017 timber harvest, reported at 1,578 MMBF in Figure 2. The survey data captured 23 percent of in-field operations activity, producing a scaling factor of 4.32 (1,578 MMBF statewide divided by the 365.32 MMBF from operations that participated in the survey) specifically for in-field operations. Additionally, the survey data captured 34 percent of milling activity, and a scaling factor of 2.95 to be applied to mill activities (1,578 MMBF divided by the 534.78 MMBF from mills that responded to the survey). Table 3 displays the scaling factors according to log type.

Table 3: Scaling Factors

Log Type	Reported 2017 MMBF	Survey 2017 MMBF	Scaling Factor
Operations	1,578	365.32	4.32
Mill	1,578	534.78	2.95

After applying the scaling factors to the survey data, the equipment is scaled up to represent statewide totals. Table 4 categorizes the equipment populations according to equipment type and their assigned mill or operation location. Equipment located at mills were scaled up from 139 to 410 pieces, and equipment used in logging operations grew from 488 to 1,933 pieces, representing more than 2,300 pieces of logging equipment statewide.

Table 4: Scaled up Equipment Population

Equipment Group	Mill Equipment Scaled up to Statewide	Operations Equipment Scaled up to Statewide	Total Statewide Equipment Population
Extraction	142	1,322	1,464
Manufacturing	224	-	224
Road Maintenance & Construction	44	611	657
Total	**410**	**1,933**	**2,345**

3.4 Load Factor

A load factor represents the average utilized power of an equipment as compared to its rated power. The load factor is a surrogate of how hard an equipment's engine works, ranging from 0 to 100 percent, and is used extensively for calculating emissions from off-road equipment. New load factors were developed for this inventory to accurately represent forestry equipment.

The following steps calculated new load factors. First, Equation 1 calculates the maximum annual fuel use (gallons per year) by multiplying the equipment's horsepower (hp), activity (hours per year), and brake specific fuel consumption (BSFC) (pounds per horsepower-hour), and divides to convert to gallons. BSFC is 0.408 for engines less than 100 horsepower, and 0.367 for engines with more than 100 horsepower.

Equation 1: Load Factor Equation - Step 1

$$Max\ Annual\ Fuel\ (gal/yr) = \frac{Horsepower\ (hp)\ *\ Activity\ \left(\frac{hr}{yr}\right) * BSFC\left(\frac{lbs}{hphr}\right)}{7.1\ \left(\frac{lbs}{gal}\right)}$$

Next, Equation 2 divides the survey-reported equipment annual fuel use (gallons per year) by the maximum annual fuel use (from Equation 1) to calculate the load factor.

Equation 2: Load Factor Equation - Step 2

$$Load\ Factor = \frac{Reported\ Annual\ Fuel\ (\frac{gal}{yr})}{Max\ Annual\ Fuel\ (\frac{gal}{yr})}$$

Table 5 shows the forestry-specific load factors for each of the three equipment groupings calculated using this two-step process, using the survey-reported data, to include annual fuel use, activity, and horsepower for the 587 pieces of equipment in Table 2. These load factors compare reasonably to those used in the agricultural and construction sectors, which range from 0.3 to 0.65, depending on equipment type.

Table 5: Forestry Load Factors

Equipment Group	Load Factor
Extraction Equipment	0.52
Manufacturing Equipment	0.26
Road Maintenance & Construction Equipment	0.54

3.5 Statewide Fuel and Activity

This inventory projects statewide fuel use using the statewide historical timber harvest statistics as a surrogate. Equation 3 calculates annual fuel use (measured in gallons per year) as the product of annual activity, population, load (unitless), horsepower, BSFC, and the pounds to gallon conversion factor.

Equation 3: Annual Fuel Consumption Equation

$$Fuel\ \left(\frac{gal}{yr}\right) = \frac{Activity\ \left(\frac{hr}{yr}\right) \times Population\ \times Load\ \times horsepower\ (hp)\ \times BSFC\ (\frac{lbs}{hphr})}{7.1\ (\frac{lbs}{gal})}$$

Using average timber harvest data from the post-recession years of 2014 to 2018, provided in Figure 2, a projected growth rate of 1.36 percent annually is assumed to forecast forestry equipment fuel use in future years. The fuel growth rate represents the activity relationship between equipment fuel consumption and the California historical timber statistics.

3.6 Geographical Allocation

Equipment population, activity, and their associated emissions occurring from on-site logging operations are allocated across the state based on the 2017 county timber harvest distribution shown in Figure 6. Humboldt County has the largest portion of on-site operations, representing 18 percent of California’s logging.

Figure 6: Pie Chart of the 2017 Timber Harvest by County[4]

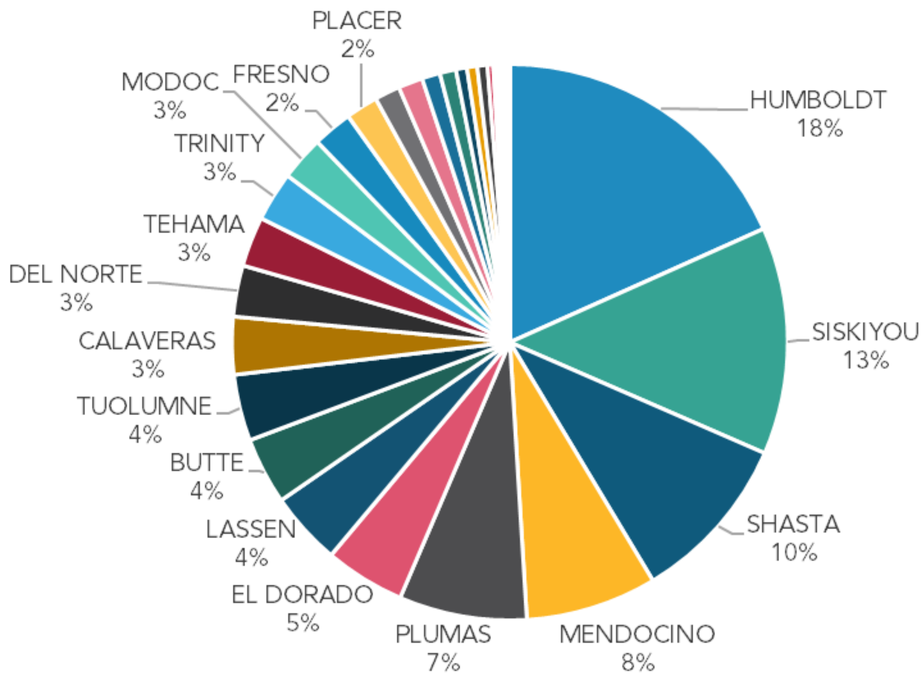


Table 6 shares the 2017 county timber harvest numbers, allocated according to county with the volume of harvested timber and corresponding relative statewide distribution. The table lists the counties from greatest percent of the statewide distribution to lowest.

Table 6: 2017 Timber Harvest by County

County	MMBF 2017	Percent Timber Harvest by County
Humboldt	288.982	18.3%
Siskiyou	208.745	13.2%
Shasta	155.656	9.9%
Mendocino	120.46	7.6%
Plumas	117.392	7.4%
El Dorado	73.606	4.7%
Lassen	67.128	4.3%
Butte	61.485	3.9%
Tuolumne	60.836	3.9%
Calaveras	52.933	3.4%
Del Norte	46.909	3.0%

[4] California Timber Harvest *https://www.cdtfa.ca.gov/taxes-and-fees/timber-tax.htm*

County	MMBF 2017	Percent Timber Harvest by County
Tehama	45.786	2.9%
Trinity	45.445	2.9%
Modoc	40.734	2.6%
Fresno	36.233	2.3%
Placer	29.641	1.9%
Nevada	23.158	1.5%
Yuba	22.586	1.4%
Sierra	16.668	1.1%
Sonoma	14.875	0.9%
Santa Cruz	10.096	0.6%
Mariposa	9.519	0.6%
Amador	9.222	0.6%
San Mateo	5.176	0.3%
Madera	3.137	0.2%
Tulare	3.008	0.2%
Stanislaus	2.411	0.2%
Kern	2.257	0.1%
Lake	2.029	0.1%
Santa Clara	2.022	0.1%

Associated emissions from equipment operating at mills are allocated according to the mill's geographic location and the amount of lumber processed, which were provided by CalForests. Table 7 lists the counties and air districts containing mills.

Table 7: Mill Allocation by Air District

County	Air District	Percent Mills by District
Shasta	Shasta County AQMD	23.7%
Humboldt	North Coast Unified AQMD	19.3%
Plumas	Northern Sierra AQMD	19.1%
Placer	Placer County APCD	10.8%
Tuolumne	Tuolumne County APCD	6.8%
Mendocino	Mendocino County AQMD	5.3%
Sonoma	Northern Sonoma County APCD	4.5%
Trinity	North Coast Unified AQMD	3.9%
Butte	Butte County AQMD	2.6%
Tulare	San Joaquin Valley Unified APCD	2.6%
Santa Cruz	Monterey Bay Unified APCD	1.5%

3.7 Emission Factors, Fuel Correction Factors, and Tier Introduction

Emissions from off-road equipment are impacted by several factors including the engine tier, rated horsepower, equipment's usage, sulfur content of the fuel, engine's deterioration due to age, and engine load. An equipment engine's tier is based on the engine manufacturer's date, with Tier 4 being the cleanest engine and Tier 0 being the oldest and dirtiest. Emission factors differ based on an engine's tier. This off-road diesel inventory follows U.S. EPA's established introduction rates for new engine tiers[5].

First, to calculate emissions for off-road diesel engines, the forestry inventory uses CARB's 2017 emission factors[6]. Equation 4 is used to calculate the emission factor accounting for zero hours emissions (i.e., emission when equipment is new) along with the excessive emissions due engine's deterioration.

Equation 4: Emission Factor Equation

$$Emission\ Factor\ \left(\frac{g}{hphr}\right) = Zero\ Hour + (Deterioration\ Rate\ \times Accumulated\ Hours)$$

Next, Equation 5 calculates the total emissions from an equipment by multiplying the emission factor with the engine's rated horsepower, load factor, activity, and the fuel correction factor. The fuel correction factor is unit-less and adjusts for the fuel's sulfur content. The emissions are then summed to represent the entire equipment population.

Equation 5: Emissions Equation

$$Emissions\ \left(\frac{tons}{yr}\right) =$$
$$Horsepower\ (hp) \times Activity\ (hr) \times Load\ Factor\ \times Emission\ Factor\ (\frac{g}{hphr}) \times Fuel\ Correction\ Factor$$

4. Results

Figure 7 and Figure 8 illustrate the forestry inventory's projected statewide NOx emissions, distinguished by engine tier distribution and logging activity type, respectively. As both figures show, NOx emissions are projected to decline over time due to natural equipment turnover from older, dirtier engines to cleaner engines.

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[5] https://www.epa.gov/sites/production/files/2018-02/documents/02-update-tier-4-nonroad-diesel-engines-2017-12-06.pdf

[6] CARB's 2017 Emission Factors. https://ww3.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017_v7.xlsx

Figure 7: Statewide NOx Emissions by Tier Distribution

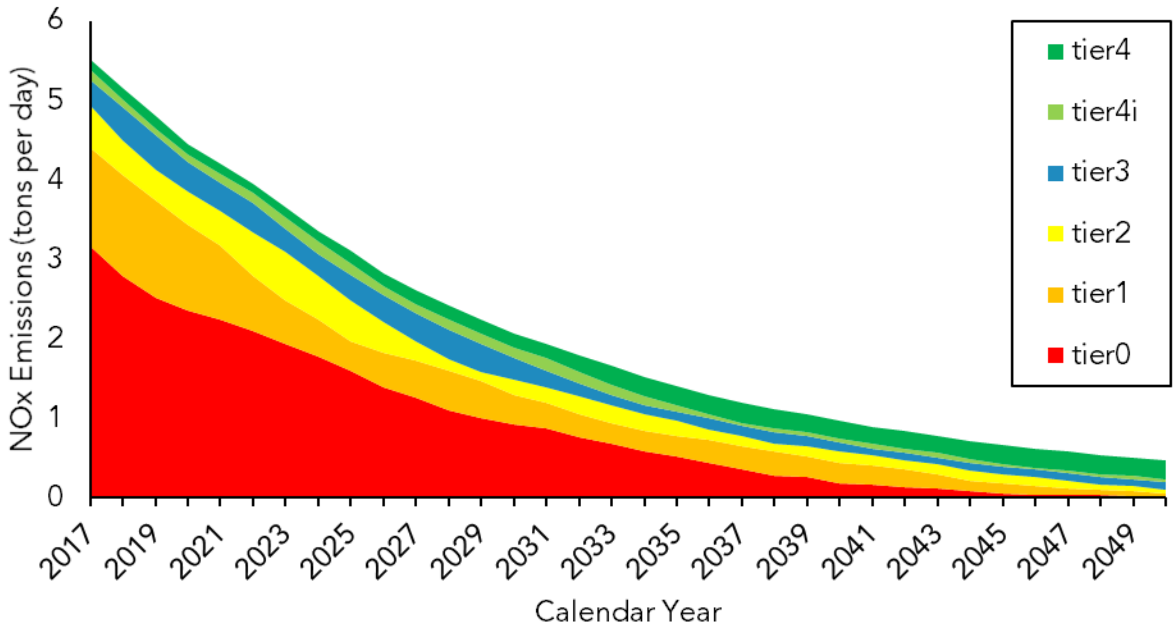


Figure 8 attributes NOx emissions according to milling and operations, exemplifying that equipment activity and thereby emissions are higher on the operations side.

Figure 8: Statewide NOx Emissions by Mill and Operations

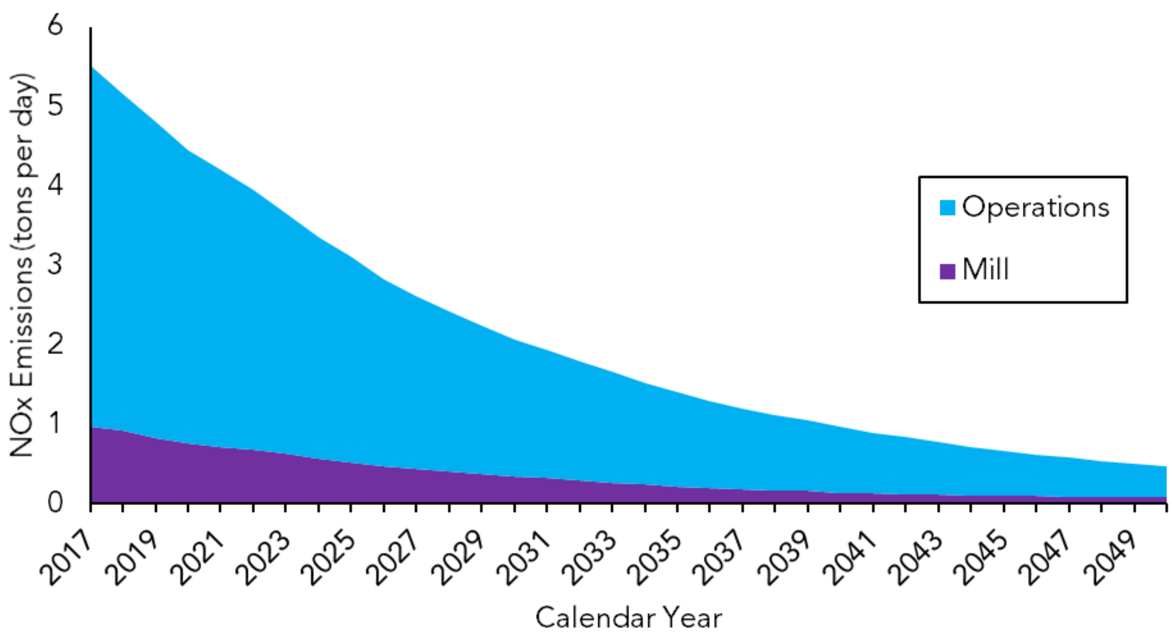


Figure 9 shows the forestry inventory's projected statewide PM emissions, by engine tier. As shown, PM emissions from this sector are expected to decline in future years due to natural turnover of equipment which replaces the older Tier 0 equipment with newer Tier 4 equipment.

Figure 9: Statewide PM Emissions (tons per day)

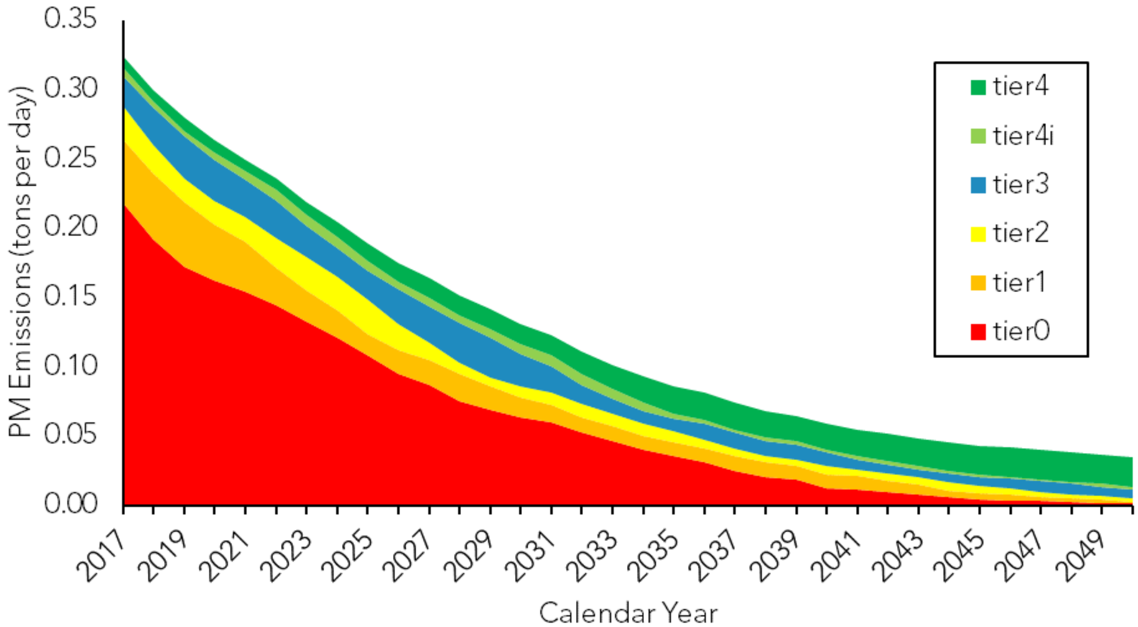
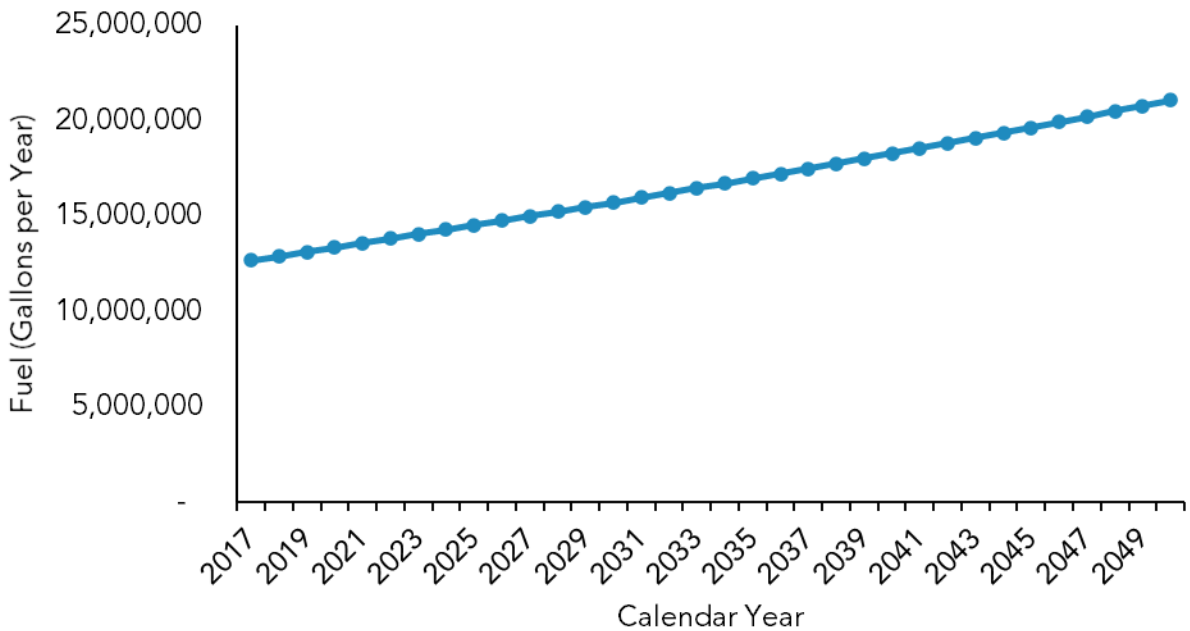


Figure 10 displays statewide fuel projections, with 2017 fuel estimated to be nearly 12.7 million gallons. Fuel increases over time resulting from the 1.36 percent annual growth rate based on the California timber harvest activity projections, as there is a direct relationship between equipment fuel consumption and the quantity of timber harvested.

Figure 10: Statewide Fuel Projection



4.1 Statewide Emissions Distribution

Of all the counties with on-site logging emissions, there are four counties that fall within the boundaries of multiple air basins and air districts: El Dorado, Kern, Placer, and Sonoma. Using deciduous, evergreen, and mixed forest geographical crop data in ArcGIS from USDA's NASS 2017 Cropland Data[7], these four counties were geographically proportioned to their appropriate air districts. This is necessary when considering the geographical impacts of emissions at an air district level. These on-site logging emissions were then combined with the mill emissions to formulate the 2020 statewide NOx emissions distribution shown in Table 8. The table contains air districts listed in order of greatest statewide NOx contributions to least. Districts that are not listed are assumed to have no forestry equipment related activity or emissions.

[7] USDA 2017 NASS Cropland Data. *https://nassgeodata.gmu.edu/CropScape/*

Table 8: 2020 NOx Emissions Distribution by Air District

District	2020 NOX Distribution
NORTH COAST UNIFIED AQMD	23.99%
SHASTA COUNTY AQMD	12.21%
NORTHERN SIERRA AQMD	11.51%
SISKIYOU COUNTY APCD	10.98%
MENDOCINO COUNTY AQMD	7.23%
TUOLUMNE COUNTY APCD	4.36%
EL DORADO COUNTY APCD	3.87%
BUTTE COUNTY AQMD	3.67%
LASSEN COUNTY APCD	3.53%
PLACER COUNTY APCD	3.40%
SAN JOAQUIN VALLEY UNIFIED APCD	2.84%
CALAVERAS COUNTY APCD	2.78%
TEHAMA COUNTY APCD	2.41%
MODOC COUNTY APCD	2.14%
NORTHERN SONOMA COUNTY APCD	1.41%
FEATHER RIVER AQMD	1.19%
MONTEREY BAY UNIFIED APCD	0.79%
BAY AREA AQMD	0.52%
MARIPOSA COUNTY APCD	0.50%
AMADOR COUNTY APCD	0.48%
LAKE COUNTY AQMD	0.11%
KERN COUNTY APCD	0.07%
GLENN COUNTY APCD	0.01%