2021 Agricultural Equipment Emission Inventory

July 2021

CALIFORNIA AIR RESOURCES BOARD

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1 Executive Summary

California is the nation's leader in agricultural production, producing over 400 different commodities that generate over $40 billion in annual sales and over 400,000 jobs statewide. The corresponding self-propelled off-road equipment used in agricultural goods production and supply processes make up the statewide agricultural emissions inventory. Diesel particulate matter (PM) and Nitrogen Oxide (NOx) emissions from diesel agricultural equipment significantly contribute to California's air quality issues, especially in the Central Valley. This is especially important because the San Joaquin Valley (SJV) has 56 percent of the state's harvested acres and its associated farming equipment.

In order to reflect recent agricultural trends, the California Air Resources Board (CARB) updated its 2011 agricultural diesel equipment emissions inventory with the latest available data on farm acreage, equipment population, activity, and overall sector fuel consumption. CARB conducted a statewide anonymized survey to reflect 2018 farm sizes, crops, and corresponding equipment usage. In conjunction with the survey, the inventory uses USDA's 2017 Agricultural Census[1], the 2018 County Agricultural Commissioners' Data[2], and Energy Information Association's[3] (EIA) agricultural diesel fuel consumption as additional data sources.

The 2018 survey data, which was reported anonymously, groups respondents according to their roles (e.g., producer, custom operator, first processor, and rental equipment company). In consultation with agricultural stakeholders, crop data were assigned to twelve main commodity types and equipment were divided into fifteen main categories. Further divisions include farm size and commodity by acreage bins and equipment by horsepower bins.

Several significant findings influence the results in the new 2021 agricultural equipment emission inventory. First, USDA's Agricultural Census data suggest that 22,000 small farms have consolidated since 2007, while harvested acres increased 3 percent over the same time period. Additionally, there are less pieces of equipment per acre, so the estimated 2018 equipment population in the SJV decreased from 83,600 (2011 inventory) to 68,500 (2021 inventory). Further, incentives have been successful in bringing more Tier 4f equipment to SJV than what was projected in the 2011 inventory, with over 7,000 additional Tier 4f tractors beyond the previous inventory's predictions by 2024. Even though the state is transitioning to cleaner agricultural equipment, fuel use is 19 percent higher than estimated by the 2011 model.

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[1] USDA Agricultural Census. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/California/

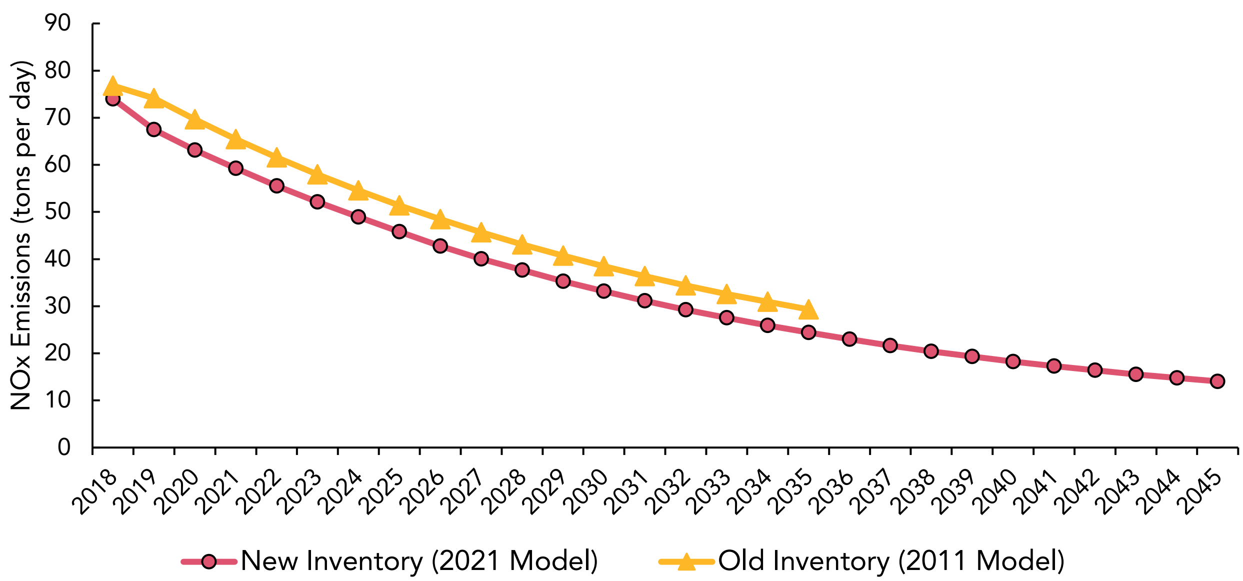
[2] County Ag Commissioners' Reports. https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/index.php

[3] https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=K2DVFMSCA1&f=A

Based on the last decade of trends in acreage and equipment, statewide harvested acres are forecasted to decline slightly, along with equipment per acre, with a reduced population of 0.9 percent per year. Despite a lower tractor population with more Tier 4 equipment, increased fuel use has offset many emission reductions, but the new inventory does report slightly lower NOx emissions. The new inventory also projects that in the absence of future incentive funding, there still remain about 18,000 Tier 0 through Tier 2 tractors in the SJV in 2024. Therefore, the potential exists to replace these equipment and continue reducing emissions.

Figure 1 summarizes these discoveries which demonstrate that the updated emissions inventory projects lower NOx emissions at the statewide level. This trend is also apparent in the SJV, which is a particularly important region for agriculture.

Figure 1: Previous and Updated Statewide Agricultural NOx Emissions

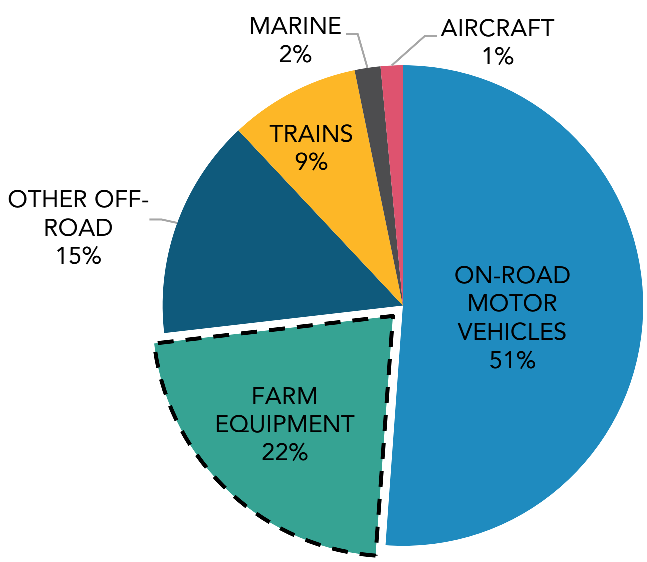


2 Agricultural Equipment Emission Inventory

An emission inventory for an industry sector is an accounting of its equipment population, how much the equipment is used (activity), engine characteristics such as model year and horsepower (newer equipment is generally cleaner), and geographically where the equipment is used (generally by county). This data is used to calculate the total equipment population's resulting emissions. Emission inventories are an important tool that help CARB understand where air pollution comes from and provide data necessary to create strategies for emission reductions.

According to CARB's emissions inventory[4], in 2020 farm equipment were responsible for 22 percent, or 36 tons per day, of the mobile source NOx emissions in the San Joaquin Valley, a region of the state where a majority of agricultural equipment are located. As emissions from on- and off-road vehicles are declining due to CARB's emissions standards and in-use regulations, the relative contribution from farm equipment has increased since 2012, when farm equipment emissions made up only 14 percent of mobile NOx emissions in the San Joaquin Valley. Figure 2 shows the relative contribution of farm equipment to NOx emissions in the San Joaquin Valley region as compared to other mobile source sectors.

Figure 2: 2020 San Joaquin Valley Mobile Sources NOx Emission Contribution



[4] CEPAM https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php

In 2011, CARB developed the Diesel Agricultural Equipment Emission Inventory[5] to replace and improve CARB's prior inventory, the OFFROAD2007 Model[6]. The 2011 inventory used data collected from a 2008 statewide survey on diesel agricultural equipment over 25 horsepower, USDA's 2007 Agricultural Census, and 2007 County Ag Commissioners' data.

The survey collected California-specific data on equipment use per acre of crop for a sample of representative growers across the state. Using regional weighting factors, the survey successfully gathered information from almost 1,800 respondents and over 10,000 pieces of equipment in different agricultural regions of California. Survey responses addressed such questions as equipment population, activity data, retirement and purchasing rates, load factor, and more. To develop a comprehensive statewide inventory, the survey responses were scaled up using acreage data from the County Ag Commissioners' report and the USDA 2007 Census of Agriculture. The final inventory estimated that in 2008, there were 158,000 diesel agricultural vehicles greater than 25 horsepower operating in California, of which 80,000 were in the San Joaquin Valley.

Updating the agricultural equipment inventory is necessary, as the emissions projections are important in understanding emission sources and making decisions on reduction strategies. It also provides important updates on emissions in the San Joaquin Valley, an area with some of the highest emissions in the state. CARB's 2021 Agricultural Equipment Emission Inventory catalogs pollutants created by self-propelled, or mobile, agricultural equipment of any horsepower and any fuel type, operating in California. Most of the equipment in this inventory is a form of tractor, with the remaining a mix of harvesters, combines, agricultural forklifts, or similar equipment. This report details all inputs and methodology used to build the inventory, and pollutant calculations for these engines, all discussed in detail in Section 5.

2.1 Need for an Updated Inventory

Updating the inventory focused on working with farmers and others within the agricultural sector while using substantive, specific information on California commodities, equipment, and farming practices. The collected data were used to build this 2021 agricultural inventory based directly on reports from farms and first processors, and not on data aggregated from other states. Incorporating California specific data on both farm size and commodities grown provides the 2021 inventory with an increased level of detail and specificity, which is needed to understand where emissions from the agricultural sector occur, thereby informing potential approaches to reduce emissions.

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[5] Emission Inventory for Agricultural Diesel Vehicles (2018). https://ww3.arb.ca.gov/msei/ordiesel/ag2011invreport.pdf

[6] OFFROAD2017. https://ww3.arb.ca.gov/msei/offroad/downloads/models/offroad2007_1215_exe.zip

CARB's 2011 Diesel Agricultural Equipment Emission Inventory[7] was developed with widespread support using the most comprehensive data sources at the time. After ten years, it is important to update the inventory using the latest available information to understand any potential shifts in the agricultural industry such as changes in equipment population and usage, changes in farms or crops, and to monitor changes in equipment age due to incentives. Compared to the previous 2011 inventory, the updated 2021 agricultural equipment inventory described in this report:

- Updates the input data vintage by almost 10 years;
- Reflects the latest USDA Census of Agriculture and County Ag Commissioner's data on California acreage for allocation across the state;
- Utilizes the latest available data on in-use emissions of various equipment;
- Reflects the large number of agricultural equipment incentive projects accomplished with the assistance of the San Joaquin Valley Air Pollution Control District (SJVAPCD) funds, NRCS funds, and Moyer funding sources from 2009 to 2017 in the baseline equipment population reported in the survey data; and
- Reflects the latest farm fuel usage data reported by EIA.

Just like the previous 2011 inventory, the updated 2021 inventory described in this report is based on data specific to California farms and farming practices, and maintains specificity to include commodities grown, farm size, and equipment type. The inventory continues to reflect the decline in activity as equipment ages rather than having one average activity regardless of equipment age, and uses the agricultural-specific load factors to reflect agricultural practices and not general diesel engine operations.

2.2 Incentive Programs

Since 2009, over $524 million dollars in private and public funding has been invested in the San Joaquin Valley to replace older agricultural tractors with newer, cleaner models. The following incentive programs play a major role in funding the replacement of agricultural equipment: CARB's Funding Agricultural Replacement Measures for Emission Reductions (FARMER) Program[8], the San Joaquin Valley APCD's Tractor Replacement Program, and NRCS's Environmental Quality Incentive Program (EQUIP)[9]. Prior to FARMER, CARB's Carl Moyer Program included funds for agricultural equipment.

CARB's agricultural incentive program, FARMER, facilitates distribution of state funds allocated by the California Legislature to incentivize turnover of agricultural equipment. The FARMER program guidelines, adopted in March 2018, detail the types of projects eligible for

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[7] https://ww3.arb.ca.gov/msei/ordiesel/ag2011invreport.pdf

[8] CARB FARMER Program. https://ww2.arb.ca.gov/our-work/programs/farmer-program

[9] USDA NRCS EQIP. https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

funding from the applicable allocations and specify the amount of funding distributed to various districts throughout the state. Over three fiscal years (fiscal years 2017-18 through 2019-20), the FARMER Program has been appropriated $323 million for agricultural vehicle and equipment projects statewide, of which $256 million has been allocated to the San Joaquin Valley. In addition, the SJVAPCD receives local funds to improve air quality from sources that can also be used to incentivize the accelerated turnover of agricultural equipment through their Tractor Replacement Program.

EQIP funding originates from the 2008 Farm Bill, which amended Section 1240H of the Food Security Act of 1985, by authorizing payments for producers to implement practices and innovative technologies that addresses the air quality concerns from agricultural operations and meets Federal, State, and local regulatory requirements. From 2009-2021, NRCS obligated $253.7 million for the turnover of in-use off-road farm equipment operating within nonattainment counties of California, of which $194.2 million funded San Joaquin Valley projects. Reauthorized in the 2018 Farm Bill, EQIP funding to address California's air quality concerns will continue through 2023.

Due to the success of these incentive programs, the agricultural industry continues to advocate for additional funding to incentivize the replacement of farm equipment. Through 2020, CARB's FARMER Program, the San Joaquin Valley APCD's Tractor Replacement Program, and NRCS's EQIP have provided approximately $340 million for the replacement of over 7,000 Tier 0 and Tier 1 tractors, plus other agricultural equipment, in the San Joaquin Valley. The incentives targeted replacement of the largest and most used tractors, in addition to other types of farm equipment. Significant continued investments are on-going.

To provide cleaner tractors to small farms, CARB staff, the SJVAPCD, and the agricultural industry are working to implement a new tractor trade-up pilot project with funding provided by two previous CARB Air Quality Improvement Program[10] (AQIP) grants and the FARMER Program. The tractor trade-up pilot project will assist small farmers in overcoming potential financial barriers in procuring cleaner mobile agricultural technologies, and will accelerate emission reductions by replacing the oldest tractors with cleaner used models. Maximizing reductions, in light of these economic considerations, will require careful design of the program and the optimum use of incentives.

The updated 2021 agricultural inventory will further inform the development and implementation of these incentive programs to ensure that they can achieve maximum technologically feasible and cost-effective emission reductions.

[10] CARB AQIP. https://www.arb.ca.gov/msprog/aqip/aqip.htm

3 Statewide Agricultural Equipment Survey

The main data used in this inventory was collected from a 2018 statewide survey of California farms, custom operations, first processors, and equipment rental facilities. A very similar survey was used to collect 2008 data for the 2011 inventory. CARB staff, SJVAPCD staff, and agricultural stakeholders collaboratively updated the 2008 survey in 2018. The survey was administered by a third-party contractor, Cal Poly San Luis Obispo (CalPoly SLO). The survey was available via paper or online through survey monkey, and all responses were anonymized by CalPoly SLO prior to delivery to CARB.

The survey gathered a representative sample of California farm operations and used acreage data from USDA's 2017 Census of Agriculture and crop data from County Ag Commissioners' reports to scale up the survey responses to represent statewide farms. The 2018 survey had roughly 900 participants, reporting nearly 2,000 pieces of equipment. Figure 3 shows a comparison of respondents in the 2008 survey, with more than 1,700 participants, and the 2018 survey, grouped by farm size acres. There was a decline in survey respondents, but this is very consistent with the quantity of farms that disappeared. The USDA 2018 Agricultural Census (Section 4.1) reports the loss of more than 22,000 farms under 50 acres, with additional losses evident in nearly every farm size grouping.

Figure 3: Comparison of 2008 and 2018 Agricultural Equipment Survey Responses

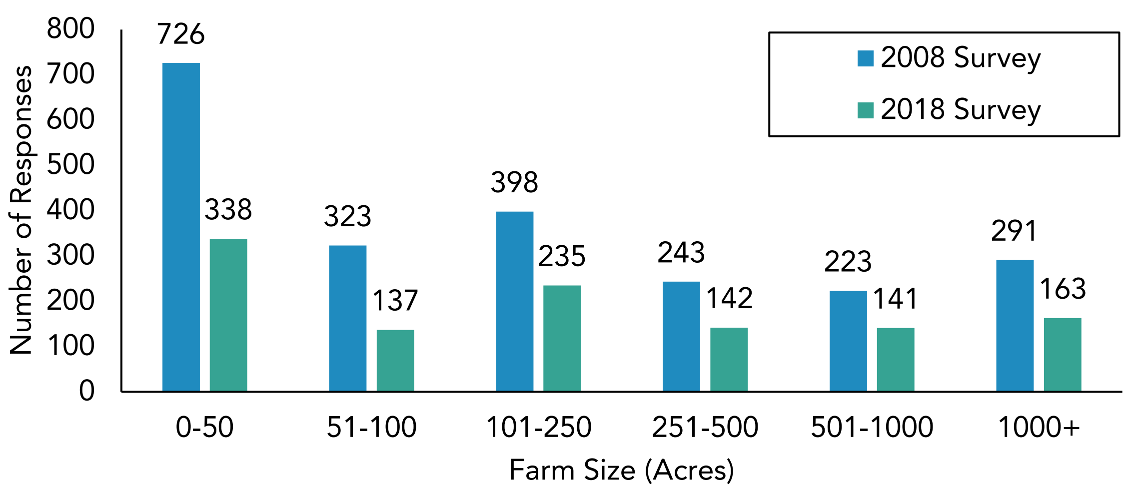

Table 1 compares the 2008 and 2018 survey results, grouping data by Air Basin. It also shares the percentage of acres reported in the 2007 and 2017 USDA Agricultural Census data. As shown, the overall distribution of survey respondents is similar. In the 2008 survey, more than 70 percent of respondents were from the San Joaquin Valley and Sacramento Valley air basins. In the 2018 survey, about 68 percent represented those same air basins. It is important to note that these distributions do not necessarily translate to emissions.

Table 1: Comparison of 2008 and 2018 Survey Respondents and USDA Acres by Air Basin

Air Basin	Percentage of 2008 Survey Respondents	Percentage of USDA 2007 Acres	Percentage of 2018 Survey Respondents	Percentage of USDA 2017 Acres
San Joaquin Valley	48.6%	53.3%	44.1%	54.2%
Sacramento Valley	22.7%	21.0%	23.7%	19.4%
South Central Coast	5.1%	3.9%	3.6%	3.9%
North Coast	3.7%	0.8%	3.0%	0.8%
North Central Coast	3.7%	3.7%	1.5%	4.3%
Northeast Plateau	3.4%	3.3%	0.6%	3.1%
San Francisco Bay Area	3.1%	2.6%	11.3%	2.7%
San Diego	2.7%	0.9%	2.1%	0.6%
Mountain Counties	2.2%	0.4%	1.8%	0.5%
South Coast	1.4%	2.4%	2.9%	1.9%
Salton Sea	1.2%	5.3%	2.4%	6.3%
Lake County	0.9%	0.2%	2.0%	0.2%
Mojave Desert	0.8%	2.0%	0.7%	1.9%
Great Basin Valleys	0.5%	0.1%	0.3%	0.1%
Lake Tahoe	0.2%	0.0%	0.0%	0.0%

3.1 Statewide Survey, Outreach and Participation

CARB and industry representatives conducted a robust statewide outreach to promote participation in the survey beginning in August 2018, with the survey launch in March 2019, culminating in December 2019, as outlined in Table 2.

Table 2: 2018 Agricultural Survey Outreach Timeline

Survey Discussion Timeline	
August 22, 2018	• CARB briefed the California Air Pollution Control Officers Association (CAPCOA), who represent all 35 local air quality agencies throughout California, on the upcoming agricultural survey. CAPCOA provided CARB with a list of the interested parties to form an Agricultural Inventory District Workgroup.
September 4, 2018	• Staff held a meeting with major agricultural stakeholders in Fresno to discuss and improve the new survey.
September 17, 2018	• An agricultural survey plan summary was shared with the CAPCOA interested parties, along with a discussion which resulted in modifications to the survey and improved language.

Survey Discussion Timeline	
November 27, 2018	• Shared a letter announcing the upcoming survey with agricultural stakeholders and CAPCOA interested parties.
January 7, 2019	• CARB requested outreach assistance on the upcoming agricultural survey at the CAPCOA Winter Retreat.
January 15, 2019	• Survey launched by Cal Poly San Luis Obispo. Survey link located on their website, with paper surveys also available.
January 18, 2019	• CARB staff informed the Central Valley Air Quality Coalition (CVAQ) on the new survey along with details on its release
February 8, 2019	• **CARB listserv announcing launch of survey, with March 30, 2019 deadline to participate**
February 12, 2019	• NRCS forwarded the announcement to state field offices, state leadership, and National Air Quality Team. • Informed SJV District Staff of survey launch. • Informed agricultural stakeholders such as California Farm Bureaus, County Agricultural Commissioners', and agricultural groups like the Fruit Producers Association, Cotton Ginners, Nisei Farmers league, among others
February 13, 2019	• Informed air district representatives (which include CAPCOA representatives) to inform them the survey was live • Farm Bureau advertised in their Ag Alert announcement • California Citrus Mutual also advertised via Market Memo
March 20, 2019	• CARB listserv reminder to complete the survey
April 2, 2019	• CARB listserv reminder to complete the survey, and announce extension until May 15, 2019 • Informed various ag groups on the extension
April 29, 2019	• CARB listserv reminder to complete the survey, and announce extension until May 15, 2019
May 13, 2019	• Meeting in Fresno with agricultural stakeholders to update them on survey and inventory plans
June 24, 2019	• CalPoly SLO anonymized survey data and delivered to CARB
July 29, 2019	• CARB briefed CAPCOA subcommittee with raw survey data summary
December 31, 2019	• Survey link was live until December 31, 2019, but did not receive any further responses

Table 3 lists a majority of the groups assisting in the outreach efforts, sharing survey participation information with producers, custom operations, and first processors. This is not a comprehensive list, as other groups were also involved in survey outreach.

Table 3: Outreach Partners for the 2018 Agricultural Survey

Participating Groups
Ag Council of California
Almond Board of California
American Pistachio Association
CAAA
California Apple Commission
California Association of Nurseries and Garden Centers
California Association of Wheat Growers AND California Grain and Feed Association
California Association of Winegrape Growers
California Cattlemen's Association
California Citrus Mutual
California Cotton Ginners and Growers Association
California Dairy Campaign
California Farm Bureau Federation
California Federation of Certified Farmers Markets
California Fresh Fruit Association
California Grain and Feed Association
California League of Food Processors
California Poultry Federation
California Poultry Industry Federation
California Rice Commission
California Strawberry Association
Far West Equipment Dealers Association
Fresno County Farm Bureau
Grower-Shipper Association of San Luis Obispo and Santa Barbara Counties
Harris Ranch
Imperial Valley Vegetable Growers
Milk Producers Council
Nisei Farmers League
Pacific Egg and Poultry Association;

Participating Groups
Raisin Bargaining Association
San Joaquin County Farm Bureau
San Joaquin Valley Air District
Stanislaus County Farm Bureau
Sun Maid Growers
The California Association of Wheat Growers; and,
The California Bean Shipper Association;
The California Grain and Feed Association;
The California Seed Association;
The California Warehouse Association;
The Pacific Coast Renderers Association.
The Wine Group
USDA NRCS
Ventura County Agricultural Association
Western Agricultural Processors Association
Western Farm Service
Western Growers Association
Western Plant Health Association
Western United Dairymen
Wine Institute

4 California Crop and Farm Data

The inventory used data from the most recent 2017 USDA Agricultural Census[11] for farm size and harvest acreage information across the state. The 2018 County Ag Commissioners' reports[12], as well as historical reports from 2002 and 2008 through 2017, informed crop trends in the state.

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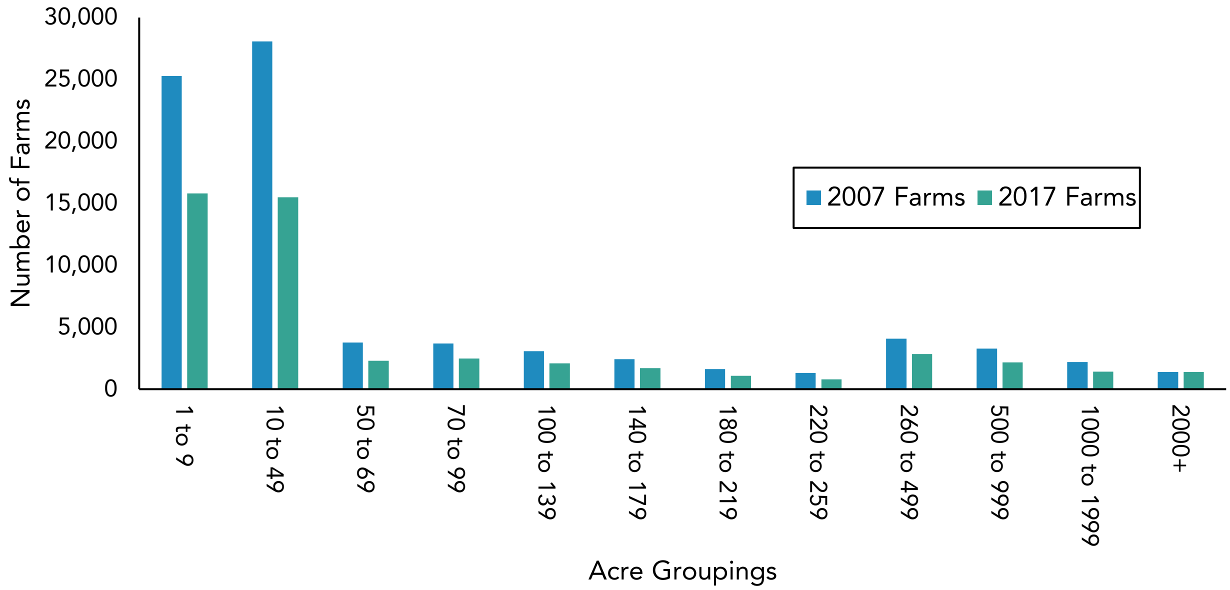
[11] USDA Agricultural Census. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/California/

[12] County Ag Commissioners' Reports. https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/index.php

4.1 2017 USDA Agricultural Census

Figure 4 uses USDA's 2017 Census of Agricultural to compare the shift in the number of farms by acre groupings from 2007 to 2017. While all farm size groupings show a reduction in number of farms, there is a significant loss of over 22,000 farms for farms under 50 acres.

Figure 4: USDA 2017 Agricultural Census, Count of Farms by Acre



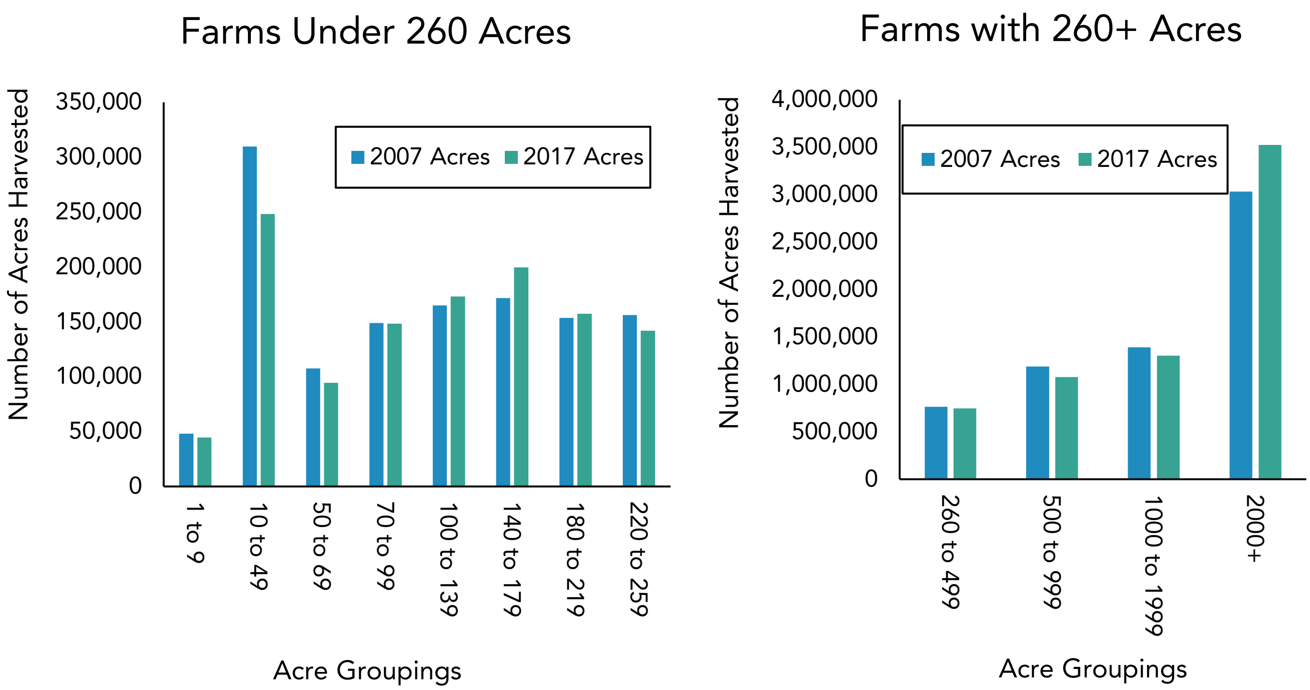
Overall, the 2017 USDA Agricultural Census reports that while total acres harvested had declined by 10 percent from 2002 to 2007, from 8.5 million acres to 7.6 million acres, the number of harvested acres has grown by 3 percent from 2007 to 2017, increasing to 7.9 million acres, as seen in Table 4.

Table 4: Change in USDA Acres Harvested

Census Year	Acres Harvested	Percent Change from Previous Census Year
2002	8.5 M	
2007	7.6 M	- 10%
2017	7.9 M	+ 3%

When looking closer at harvested acres according to farm size grouping, Figure 5 shows the differences in farms under 260 acres and those with harvested acres greater than 260 acres. The 2017 USDA Agricultural Census reports a decline in the number of harvested acres from 2007 to 2017, specifically in smaller farms with less than 100 acres. The census reports an increase in harvested acres in larger farms measuring over 2,000 acres. It is assumed that farms over 2,000 acres are acquiring land from smaller farms that have disappeared (see Figure 4).

Figure 5: USDA 2017 Ag Census, Number of Acres Harvested

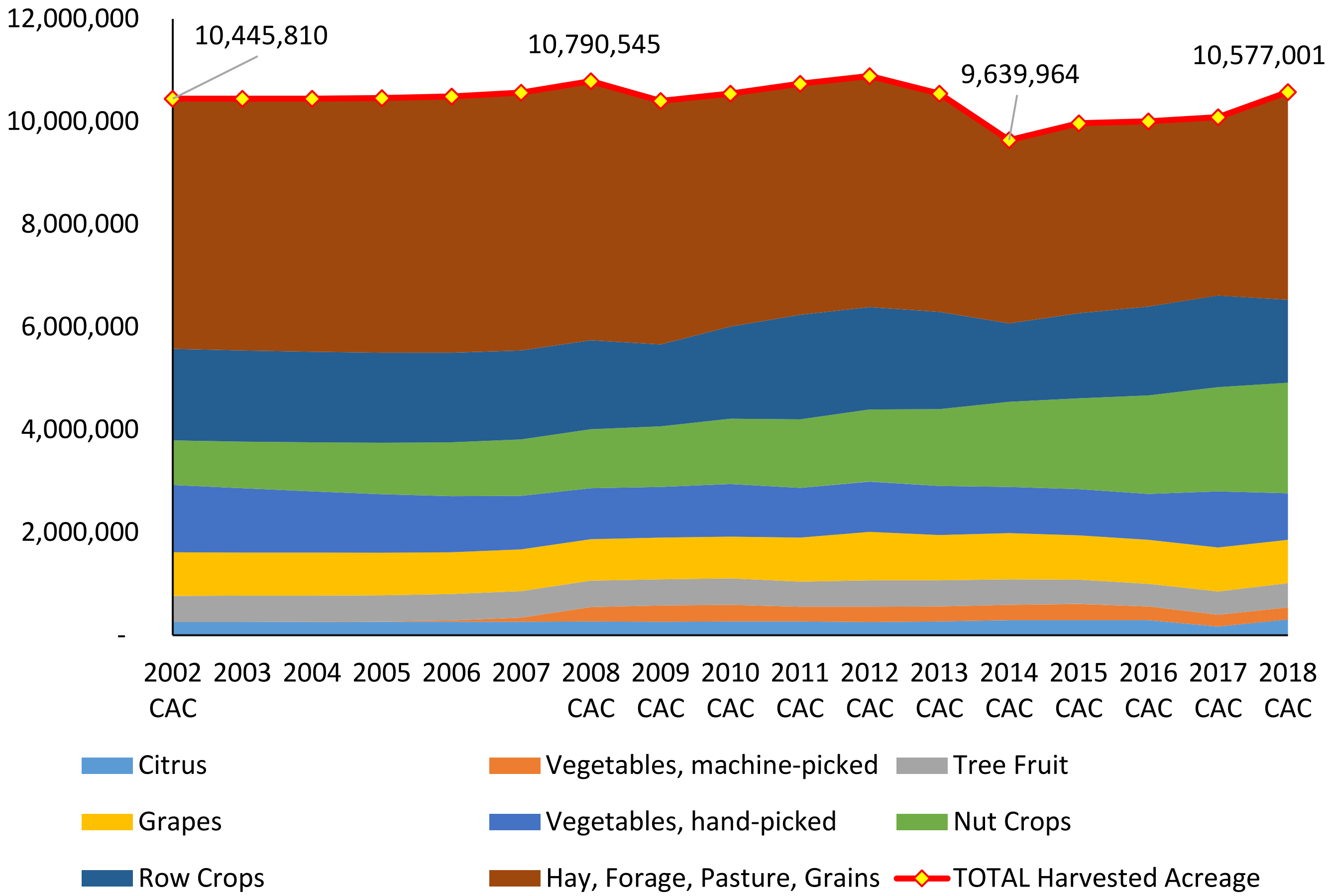


Results from the 2012 agricultural census were ignored in this analysis since the statewide survey data was not updated during that time period.

4.2 County Agricultural Commissioners' Reports

The County Agricultural Commissioners' reports collect county level crop data. Historical crop trends from 2002, and 2008 through 2018 are shown in Figure 6. Years 2003 through 2007 were extrapolated using the 2002 and 2008 reported crop data due to various formatting challenges. Total harvested acreage has remained fairly constant, aside from a small dip in 2014, which then increased back to similarly previous levels. There is a shift in the quantity of crops harvested. Nut crops have grown significantly, with an average annual growth of 6.5 percent over the last 10 years, while hay, forage, pasture, and grains have declined at a rate of 2.2 percent over the last 10 years. Some harvested acreage account for double cropping, and thus appear to be greater than the USDA harvested acreage totals which represent harvested land acres whereas this represents harvested crop acres.

Figure 6: County Ag Commissioners' Data: Harvested Acres by Crop



5 Emission Inventory Development

Data inputs for the emissions inventory can be sorted into four groups:

1. Statewide Survey Data – 2018 statewide survey of all fuel types and horsepower type equipment, and crop and farm size according to Producer, Custom Operator, First Processor, and Rental Equipment Company
2. Crop and Farm Data – 2017 USDA Agricultural Census and 2018 County Agricultural Commissioners' Reports
3. Data from the 2011 Agricultural Inventory Report – CARB's 2008 Agricultural Load Factors and supplemental data from the 2008 agricultural survey
4. Other Inputs – CARB's 2017 Emission Factors, Tier 4 introduction timeline, and fuel projection based on Energy Information Association (EIA) historical farm diesel

A series of steps were used to process the statewide survey's raw data, which include grouping of crops and equipment and profiling the age and activity data of the equipment reported. Individual crops were grouped into crop type bins, just as individual pieces of equipment were grouped into equipment group bins. This is a necessary step to properly scale the raw survey data to represent statewide operations.

For example, if only three pluot producers responded to the survey, that would not provide a representative sample size for scaling to statewide levels. Therefore, pluots are combined into a larger tree fruit grouping, thereby providing a larger number of survey responses that can be more accurately scaled to statewide levels.

The same actions apply for equipment. Assume there is only one 1950 model year tractor in the 75 to 100 horsepower bin, and it reports 1,000 hours of annual use. If this one piece of equipment is scaled to statewide levels, the inventory would report a significantly higher number of old tractors with the same characteristics, which is unlikely. Thus, grouping this tractor with others that have similar characteristics, and creating profile bins, will better represent the average agricultural equipment activity operating in California. As such, these steps were necessary to fill in survey gaps and transform the raw data into a model that represents California's agricultural sector.

5.1 Commodity, Farm Size, and Equipment Bins

5.1.1 Commodity or Crop Type

California grows hundreds of commodities and the USDA Agricultural Census identifies 55 common groups. With the expertise of stakeholders who represent much of California's agriculture community, these 55 commodities were further sorted into 12 general groups. For example, the commodity 'Romaine' is part of the 'Lettuce' group, which is then grouped into 'Hand-picked Vegetables'.

The purpose of grouping commodities is to create statistically robust datasets that represent an average farm instead of many small datasets that may not represent average operations. Table 5 lists the commodities within their larger commodity groups that are used to categorize agricultural production for the purposes of the emissions inventory.

Table 5: Commodity Groups

Commodity Group	Commodities
Citrus	• Citrus • Grapefruit • Lemons • Oranges (all)
Grapes	• Grapes • Raisins
Hay, Forage, Pasture, Grains	• Hay, Alfalfa • Oats, Rye

Commodity Group	Commodities
	• Pasture, Rangeland, Grass • Rice • Sorghum • Wheat, Silage Wheat, Grains, Seed crops, Barley
Nursery, Greenhouse, Floriculture	• Nursery, Flowers, Foliage • Sod, Seeds
Nut Crops	• Almonds • Other Nuts • Pecans • Pistachios • Walnuts
Other	• Forest, Lumber, Timber • Other (Beehives, Horses, Sheep, Swine, etc.)
Row Crops	• Beans • Corn, Silage Corn • Cotton (all) • Sunflower, Safflower
Tree Fruit	• Apples • Apricots • Avocados • Berries (all) • Cherries • Figs • Kiwis • Nectarines • Olives • Orchards, Tree Fruit, Stone Fruit • Peaches • Pears • Persimmons • Plums • Pluots • Pomegranates • Prunes
Vegetables, hand-picked	• Broccoli • Cabbage • Lettuce (all) • Melons (all) • Peppers • Tomatoes (fresh)

Commodity Group	Commodities
	• Vegetables
Vegetables, machine-picked	• Carrots • Onions • Potatoes, Sweet Potatoes • Tomatoes (processing)
Beef Cows	• Beef Cows
Milk Cows	• Milk Cows
Poultry	• Poultry

5.1.2 Farm Size

The USDA Census of Agriculture uses a variety of farm size characteristics, which vary between descriptions of farm size by acres, farm employment, and farm income. USDA reports will show different farm size categories for different types of data. To scale the raw survey results to statewide levels using the USDA Agricultural Census data, the inventory uses the farm size characteristics that best match the USDA data, which is the county specific listing of acres of production by farm size by county. Table 6 lists farm size groupings by acreage, and minor modifications were necessary. These groupings match those from the 2011 inventory which is necessary when supplementing the adjusted survey data (discussed in Section 5.4) as well as identifying changes and making comparisons to the 2011 inventory. These grouping adjustments do not change the overall acreage. For livestock categories, the USDA Ag Census typically groups farms by head.

Table 6: Farm Size Groupings

Farm Size Groups
0 to 15 Acres
16 to 50 Acres
51 to 100 Acres
101 to 250 Acres
251 to 500 Acres
501 to 1,000 Acres
Over 1,000 Acres

5.1.3 Equipment Horsepower Bins

Table 7 lists the horsepower bins used to group equipment, which are the same horsepower bins used by both the U.S. EPA and CARB for emission standards for off-road diesel engines.

Table 7: U.S. EPA and CARB Inventory Horsepower Groupings

Horsepower Group
Under 25 HP
26 to 50 HP
51 to 75 HP
76 to 100 HP
101 to 175 HP
176 to 300 HP
301 to 600 HP
601 to 750 HP
Over 750 HP

5.2 Equipment Profiles

As discussed in previous sections, equipment were sorted into smaller groups based on similar characteristics, whether by horsepower bin, farm size bin, or operator type. Profile bins were assigned to calculate population age distributions and average activity. The goal of this step is to group similar equipment together to create reasonable averages that can be applied to the statewide population following the scaling process. Table 8 describes the 10 different equipment profile bins, reporting average age, population count, fuel type, and engine horsepower. Just like analyses from the 2011 Agricultural Diesel Equipment Inventory, this analysis also determined that operator type, equipment type, farm size, and horsepower bin were the strongest factors influencing age and activity of equipment. While commodity played a role, it was not as influential as other factors.

Table 8: Equipment Profile Bins

Bin ID	Survey Group	Average Age	Count	Fuel	Crop Units	Description
1	Producer	26	263	Diesel	Acres	Tractors: hp bin 25, 50, 75 (all farm sizes)
2	Producer	16	333	Diesel	Acres	Tractors: hp bin 100 (all farm sizes) & hp bin 175 (farms < 1000 acres)
3	Producer	11	151	Diesel	Acres	Tractors: hp bin 175 (farms 1000+ acres) & hp bin 300, 600 (all farm sizes)
4	Producer	49	22	Gasoline	Acres	Gasoline Tractors
5	Producer	15	285	Diesel	Acres	Others: Non-Tractor Diesel

Bin ID	Survey Group	Average Age	Count	Fuel	Crop Units	Description
6	Producer	17	177	Diesel	Head	Equipment for livestock (measured in head)
7	Producer	10	192	Diesel, Gasoline, Electric	All	ATVs
21	Custom Operator	19	156	Diesel	Acres	All equipment
31	Rental	7	345	Diesel	Acres	All equipment
41	First Processor	18	176	Diesel, Gasoline	Acres	All equipment

Table 9 provides a visualization illustrating how the producer diesel tractors in Bins 1-3 are grouped according to Farm Size bins (in acres) and Equipment Horsepower bins.

Table 9: Producer Tractors Profile Bin Visualization

Farm Size/Equipment HP	25 hp	50 hp	75 hp	100 hp	175 hp	300 hp	600 hp
up to 15 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 2	Bin 3	Bin 3
up to 50 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 2	Bin 3	Bin 3
up to 100 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 2	Bin 3	Bin 3
up to 250 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 2	Bin 3	Bin 3
up to 500 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 2	Bin 3	Bin 3
up to 1000 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 3	Bin 3	Bin 3
more than 1000 acres	Bin 1	Bin 1	Bin 1	Bin 2	Bin 3	Bin 3	Bin 3

The following figures focus on Bin 2, as represented in Table 8, the profile bin with the largest population. Bin 2 represents producer diesel tractors in the 100-horsepower bin for all farm sizes plus diesel tractors in the 175-horsepower bin operating on farms smaller than 1,000 acres. Figure 7 shows the population distribution by age for diesel tractors owned by producers in the horsepower bins operating on farms with the characteristics as described for Bin 2. Figure 8 displays the activity distribution by age for the same profile bin. Both figures show a decline in population and activity with age. In this profile bin, there are still some tractors in use over 40 years of age, but with slightly lower activity. Any dots located on the x-axis indicate that 0 percent of the equipment population is reported at that age. The best-fit polynomial for population and the best-fit line for activity for this profile bin were used to project population and activity in this inventory. Notable in the charts, as these tractors approach the end-of-life, their estimated annual use is minimal.

Figure 7: Bin 2 Population Distribution by Age

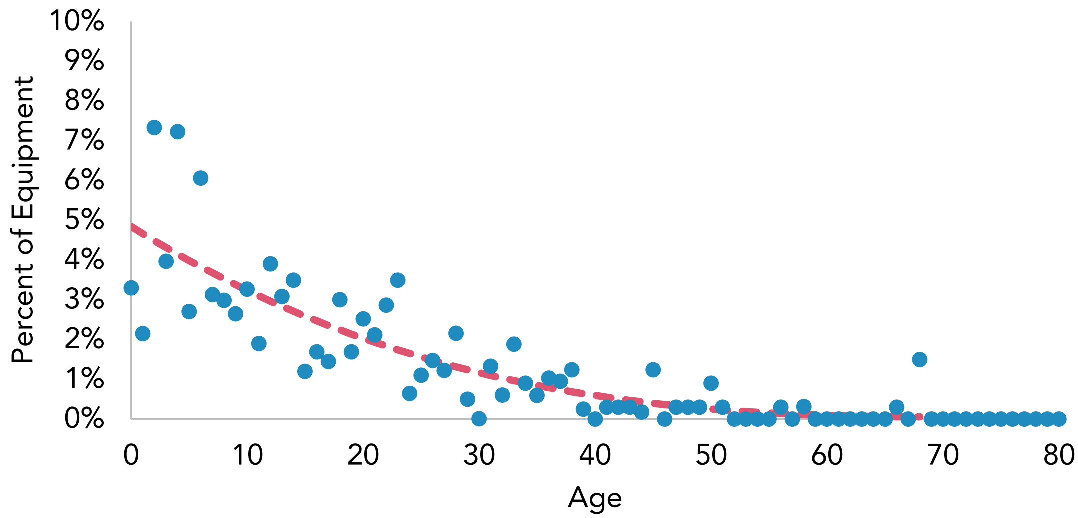
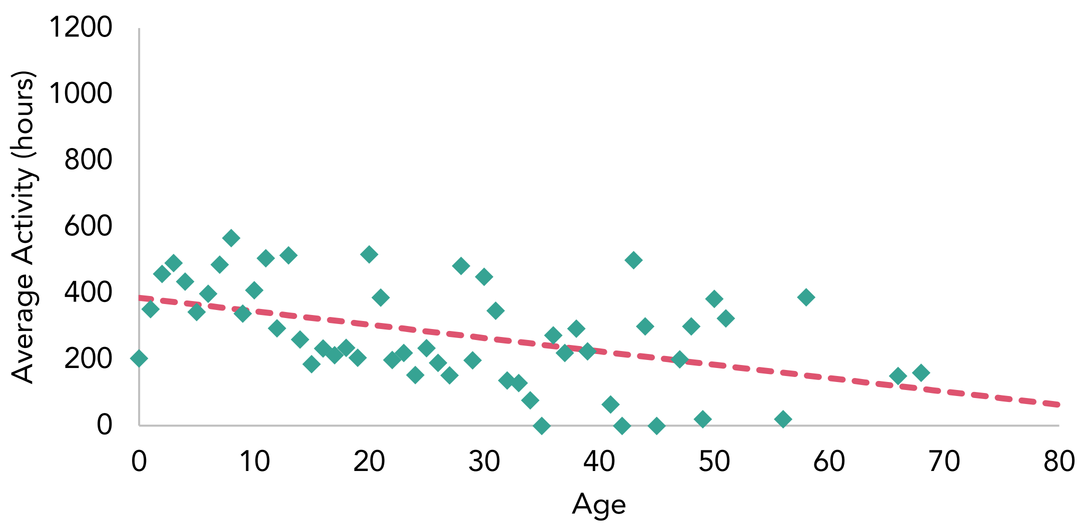


Figure 8: Bin 2 Activity Distribution by Age



This same analysis was completed for the remaining nine profile bins. They all display similar age and activity trends, indicating that population declines with age as does average activity.

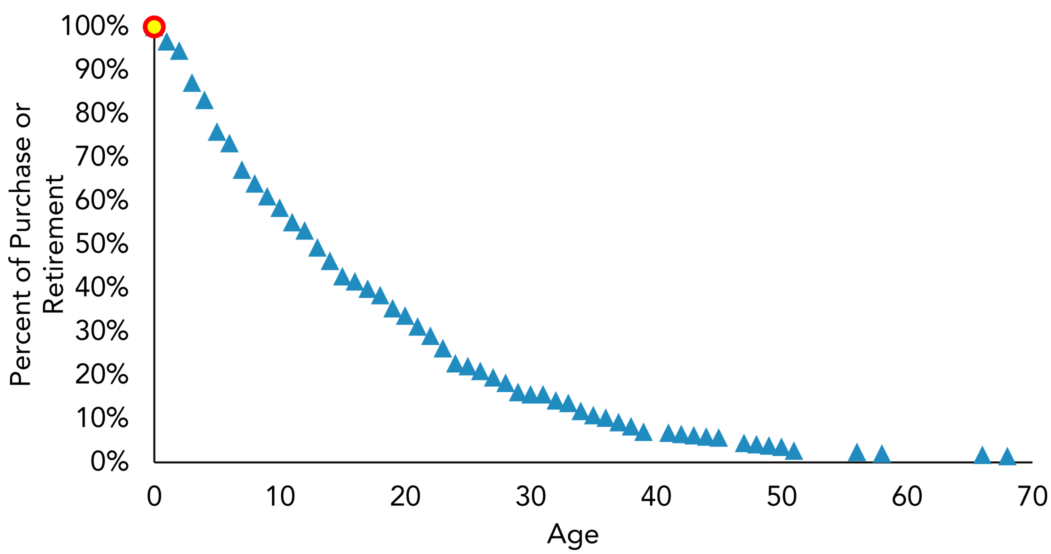
The detailed data for each bin is available in the emission inventory release accompanying this report.

5.3 Equipment Turnover and Attrition

To forecast equipment in future years, the model must attempt to predict average, or business as usual (BAU), farm practices of retiring and purchasing equipment. Retirement and purchase behavior is modeled using the same profile bins described earlier, which provides a snapshot of farm equipment operating in California in 2018. This also assumes the survey data collected is a reasonable depiction of the average California equipment in most years, and that it is representative enough of the average year to derive purchasing and retirement practices.

According to the characteristics for equipment in Profile Bin 2, Figure 9 shows the purchase or retirement pattern necessary to produce the age characteristics described in the previous section. For this bin, all tractors will be purchased new, as indicated by the yellow circle. There will be a gradual retirement of approximately 50 percent of new tractors by age 13, and about 75 percent of new tractors by age 23. Nearly all tractors will be retired by age 51, with a very few still lingering for about another 15 years.

Figure 9: Bin 2 Purchasing and Retirement Curve



This same process was completed for the remaining nine profile bins. They all have individualized purchase and retirement distributions, depending on the characteristics of the equipment in those bins. This data is also available in the accompanying 2021 agricultural emission inventory model.

5.4 Supplementing with the 2008 Survey Data

A smaller than expected sample size was collected in the 2018 survey, suggesting supplemental data is necessary to ensure the derived equipment population, and activity profiles are representative. Additional analyses of the 2008 raw survey data determined how the 2018 survey data could be supplemented. Table 10 shows the response rates from the 2018 and 2008 surveys, counting individual respondents according to Producer, Custom Operator, First Processor, and Rental Facility. Specifically, the 2018 survey bins lack enough samples for some horsepower and farm size groups, but 2018 Producer data have sufficient survey responses for many categories. To generalize agricultural emissions characteristics, more survey samples are necessary for a successful 2018 agricultural vehicle emission inventory update. Therefore, CARB staff supplemented the 2018 survey data with adjusted 2008 raw survey data.

Table 10: Raw Survey Responses

Agricultural Sector	Survey Responses 2018	Survey Responses 2008
Producer	283	1552
Custom Operator	41	151
First Processor	6	52
Rental Facility	4	11

Various approaches were considered and investigated, such as determining the number of survey bins and cluster analysis for survey groupings. Ultimately, the most comprehensive and defensible method assessed was to adjust the 2008 survey data's age distribution, activity distribution, and fuel consumption to reflect generally newer populations of equipment. Then, this supplemental data was added to the 2018 survey data, thus creating a more robust 2018 synthetic dataset. Table 11 shows different data groupings, whether the 2018 data is sufficient, and which 2008 datasets are used in the adjustment process.

Table 11: Equipment Groupings for Supplemental Data

Agricultural Sector	2018 Responses	2008 Responses	2008 Groupings to be Supplemented	2018 Sufficient Data (no adjustments)
Producer	283	1,552	• All Others (non-tractor/non-ATV)	• Tractors • ATVs
Custom Operator	41	151	• Tractors • ATVs • All Others	
First Processor	6	52	• All Equipment	
Rental Equipment	4	11	• All Equipment	

The Producer Tractors and ATV subsets have a sufficient sample size, and therefore do not need any supplemental data. However, the remaining Producer equipment were supplemented with an adjusted 2008 dataset comprised of All Other equipment. The 2008 Custom Operator dataset is divided into Tractors, ATV, and All Other (general harvesting, construction, and other types) equipment groups, and is adjusted by age, activity, and fuel type. The 2008 datasets for First Processor and Rental Equipment were significantly smaller, so they will be adjusted as a whole, and not by equipment subset. The adjustments assume the Producer Tractors dataset is representative of variations in age and activity, and can be used to adjust other agricultural equipment groups.

5.4.1 Comparing the 2008 and 2018 Survey Data

Figure 10 and Figure 11 each compare the overall age distributions between the 2008 and 2018 raw survey data for all Producer Equipment or Custom Operator Equipment, respectively. The 2008 age distribution is 10 years older, and will be adjusted using a multiplier matrix to shift the dataset to the left, making it not only 10 years younger but also matching the *average age* of the 2018 dataset, according to the different equipment grouping schemes required. Figure 10 illustrates that the 2008 Producer Equipment age distribution can be easily horizontally shifted without changing the shape.

Figure 10: Producer Equipment Age Distribution

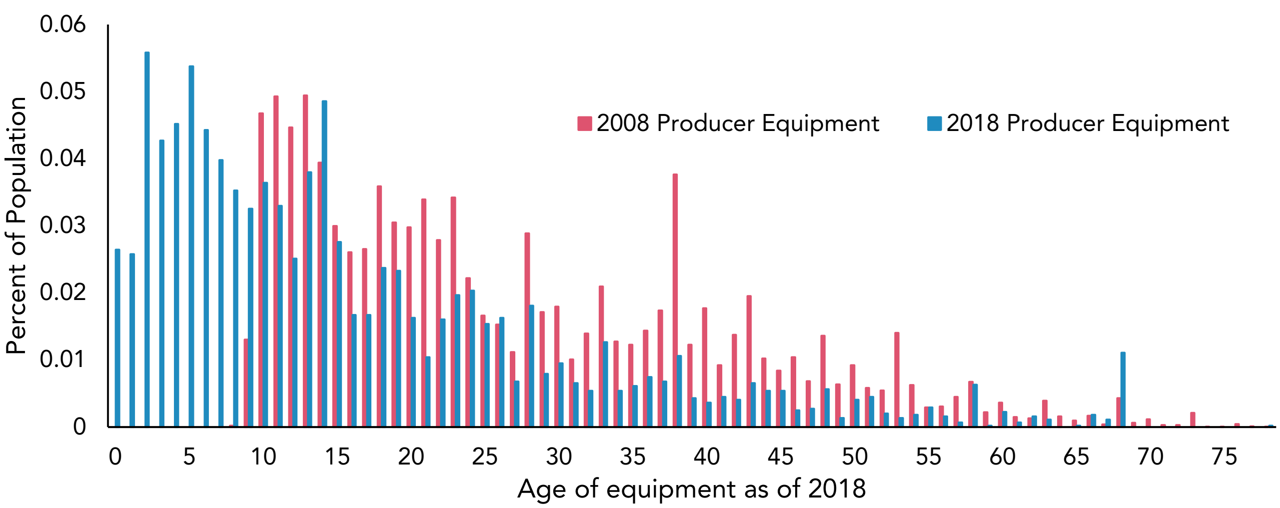
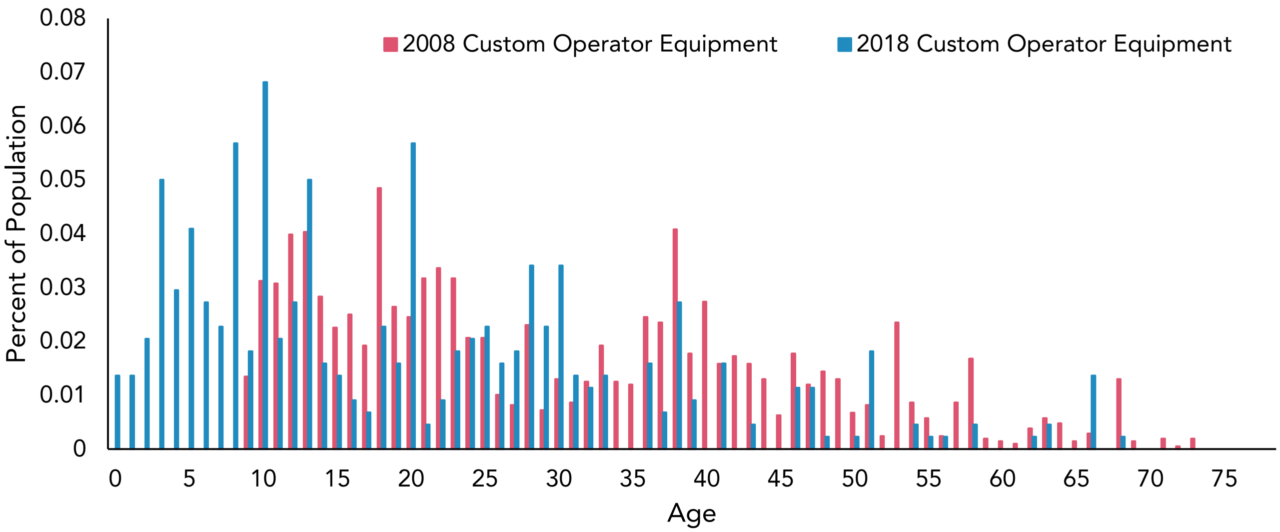


Figure 11 shows that Custom Operator equipment may behave slightly different than Producer equipment. It is important to note that the 2018 Custom Operator dataset is significantly smaller than the 2008 dataset. There are some apparent spikes due to Custom Operator equipment having groups of specific model years.

Figure 11: Custom Operator Age Distribution



5.4.2 Analyzing the 2008 Survey Data

The 2008 data are adjusted based on differences of age, activity, and fuel consumption between the 2008 and 2018 datasets. Data for all groupings are analyzed according to equipment type, horsepower bin, fuel type, commodity group, and farm size. The 2008 subsets were converted using a multiplier matrix, which was applied to the various 2008 equipment groupings and adjusted the data to become 10 years newer. The method adjusts the aging behavior of a larger, older dataset, into a synthetic dataset. This is added to the smaller 2018 dataset, ultimately creating a larger dataset. For example, when the age distribution of the 2008 datasets were shifted to reflect equipment that is 10 years newer, they also shift activity and fuel consumption based on typical usage of newer equipment.

5.4.2.1 Determining Data Groupings for Adjustments

To understand and adjust survey data, equipment needs to be grouped according to similarities. Sturge's[13,14,15] Rule, shown in Equation 1, is widely used for these type of analyses and determines the number of bins to ensure the analysis is statistically significant. In this case, the equation accounts for the number pieces of equipment in the dataset (N) and outputs the number of recommended bins (K).

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[13] Sturges, Herbert A. "The choice of a class interval." Journal of the American statistical association 21.153 (1926): 65-66.

[14] https://www.statisticshowto.datasciencecentral.com/choose-bin-sizes-statistics/

[15] http://www.geocities.ws/duna/material/frequency%20table.pdf

Equation 1: Sturge's Equation

$$K = 1+3.322\log(N)$$

where: K = Number of class intervals (bins)
N = Number of observations in the data

Table 12 lists a portion of the datasets, the corresponding sample size (N), and the number of bins (K) calculated using Sturge's equation. The average and median K values are close to 21. Therefore, this analysis divides each dataset into 21 bins. Equipment are already organized into seven horsepower bins. Since horsepower is directly correlated with emissions level, that division remains, and the data is further divided into three farm size classes, creating 21 total bins for adjustment analysis.

Table 12: Number of Bins using Sturge's Rule

Dataset	Number of Samples (N)	Number of Bins (K)
2008 Producer Tractor data	13,019	32.4
2018 Producer Tractor data	2,872	27.4
2008 Producer ATV data	6	7.0
2018 Producer ATV data	31	12.4
2008 Producer Non-tractor data	802	23.2
2018 Producer Non-tractor data	224	19.0
2008 Custom Operator Tractor data	1,276	24.8
2018 Custom Operator Tractor data	185	18.34
Average	-	20.6
Median	-	21.1

Table 13 shows how the seven horsepower bins and three farm size bins are divided into 21 groups. Note that the farm size bins are grouped into further subsets: small farms less than 100 acres, mid-size farms between 100 and 500 acres, and large farms more than 500 acres.

Table 13: Groupings for 21 Adjustment Bins

<table>
<tr><th rowspan="2">Farm Size (acres)</th><th colspan="7">Engine Horsepower</th></tr>
<tr><th>25-50</th><th>50-75</th><th>75-100</th><th>100-175</th><th>175-300</th><th>300-600</th><th>600+</th></tr>
<tr><td>0-15</td><td rowspan="3">Group 1</td><td rowspan="3">Group 4</td><td rowspan="3">Group 7</td><td rowspan="3">Group 10</td><td rowspan="3">Group 13</td><td rowspan="3">Group 16</td><td rowspan="3">Group 19</td></tr>
<tr><td>15-50</td></tr>
<tr><td>50-100</td></tr>
<tr><td>100-250</td><td rowspan="2">Group 2</td><td rowspan="2">Group 5</td><td rowspan="2">Group 8</td><td rowspan="2">Group 11</td><td rowspan="2">Group 14</td><td rowspan="2">Group 17</td><td rowspan="2">Group 20</td></tr>
<tr><td>250-500</td></tr>
<tr><td>500-1000</td><td>Group 3</td><td>Group 6</td><td>Group 9</td><td>Group 12</td><td>Group 15</td><td>Group 18</td><td>Group 21</td></tr>
</table>

5.4.3 Adjusting the 2008 Survey Data

The following example addresses adjustments to the 2008 Custom Operator Tractor data so it can be appended to the 2018 Custom Operator Tractor dataset. Producer Tractor data is used since tractors represent the inventory's largest equipment group and has a sufficient response rate from the 2018 survey. It is important to note that all 2018 survey data remains unchanged. The adjusted 2008 data is appended to the 2018 datasets to supplement the data, not replace the data.

The next two sections show these adjustments in detail, and describe how the 2008 survey data's activity and age characteristics were shifted to match characteristics of the new 2018 data set to aid in population scaling to statewide levels.

5.4.3.1 Age Distribution Adjustments

Using the assumption that Custom Operator and Producer equipment age distributions are similar, the analysis calculates a Multiplier Matrix for adjusting the 2008 data. Once the age multipliers are applied, the equipment ages will be shifted to match the 2018 bin averages. Once activity and fuel adjustments are complete, the dataset will be appended to the 2018, creating an adjusted baseline dataset.

Equation 2 provides the calculation used to determine each multiplier in the multiplier matrix. The multiplier calculates the relative change from the Producer 2008 tractor dataset to the Producer 2018 tractor dataset, for each of the 21 groups. For example, the multiplier for Group 1 is calculated by subtracting the 2018 average age of 32.50 from the 2008 average age of 35.17, and then divides that difference by the 2008 average age (e.g., (35.17 – 32.50) / 35.17 = 0.077).

Equation 2: Multiplier Matrix Equation

$$\boldsymbol{Multiplier_i} = \frac{\mathbf{2008}\ \boldsymbol{Average\ Age_i} - \mathbf{2018}\ \boldsymbol{Average\ Age_i}}{\mathbf{2008}\ \boldsymbol{Average\ Age_i}}$$

where i = *Group number*

The age multiplier matrix in Table 14 consists of percentage differences between each equipment group of the 2008 and 2018 Producer tractor datasets. This matrix is multiplied to the age distribution of the 2008 Custom Operator tractor dataset, shifting the age distribution of Custom Operator tractors and making them 10 years newer. This adjusted 2008 survey dataset, with recalculated age, may be appended to the 2018 Custom Operator dataset after activity and fuel are adjusted.

Table 14: Producer Tractors Age Multiplier Matrix

Group 1	Group 4	Group 7	Group 10	Group 13	Group 16	Group 19
0.077	0.217	0.257	0.470	0.469	0.447	0.447
Group 2	Group 5	Group 8	Group 11	Group 14	Group 17	Group 20
0.156	0.238	0.235	0.547	0.470	0.442	0.442
Group 3	**Group 6**	**Group 9**	**Group 12**	**Group 15**	**Group 18**	**Group 21**
0.473	0.510	0.305	0.518	0.467	0.380	0.380

Equation 3 provides the calculation to adjust age for each of the 21 groups (K). The product of the 2008 age and the corresponding multiplier matrix is subtracted from the 2008 age, which is then added to the 2008 age updating the adjusted age of the 2008 dataset.

Equation 3: Adjustment Equation from 2008 to 2018

$$Adj.Age_{CO,\ OLD}^{group\ k} = Age_{CO,\ OLD}^{group\ k} - (Age_{CO,\ OLD}^{group\ k} \times Multiplier\ Matrix_{Age,prod}^{group\ k})$$

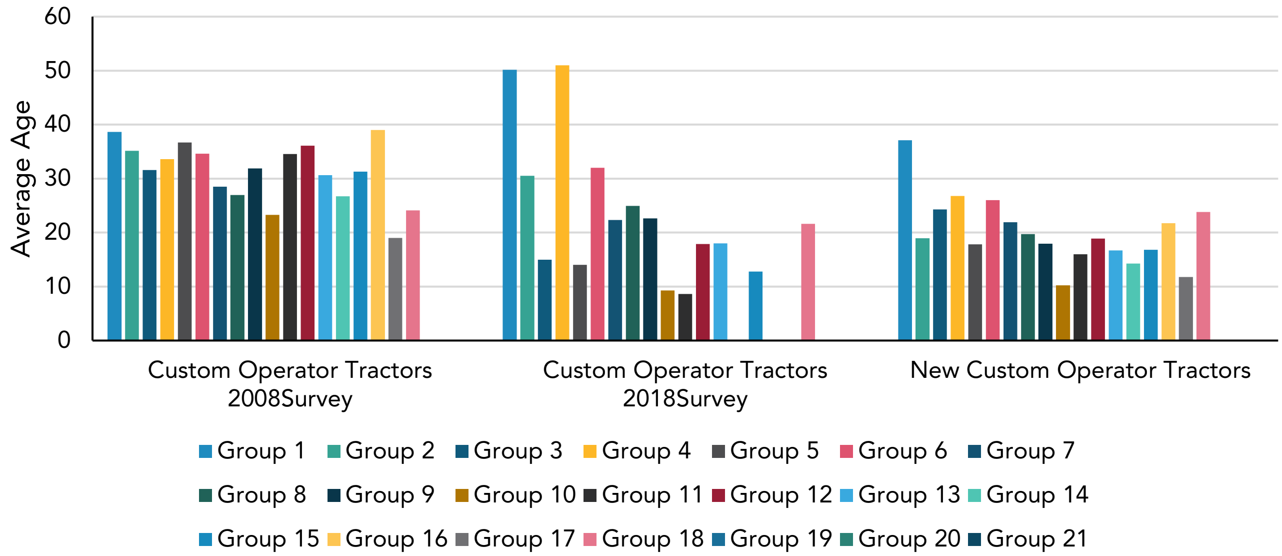
where:

- $Age_{CO,\ OLD}^{group\ k} = Age\ of\ group\ K\ in\ the\ 2008\ Custom\ Operator\ tractor\ data$
- $Multiplier\ Matrix\ (MM)_{Age,prod}^{group\ k} =$

  $Age\ multiplier\ matrix\ of\ group\ K\ obtained\ from\ Producer\ tractor\ data$
- $Adj.Age_{CO,\ OLD}^{group\ k} = Adjusted\ age\ of\ group\ K\ in\ 2008\ Custom\ Operator\ tractor\ data$

The average age is calculated for each of the 21 groups in each of the 2008 and 2018 datasets. Once the 2008 dataset is adjusted using the multipliers and Equation 3, the adjusted data is simply combined with the 2018 dataset, thus creating the new dataset. Figure 12 shows the following datasets, according to the 21-group scheme, from left to right: 2008 survey data for Custom Operator Tractors, 2018 survey data for Custom Operator Tractors, and the resulting age adjusted 2008 data added to the 2018 Custom Operator Tractors.

Figure 12: Age Distribution Process for Custom Operator Tractors



5.4.3.2 Activity Distribution Adjustments

Similar to the age multiplier matrix in Table 14, Table 15 provides the activity multiplier matrix which are percentage differences for the 21 groups to adjust activity from the 2008 data to reflect activity for equipment that are 10 years newer. This matrix is multiplied to the activity distribution of the 2008 Custom Operator Tractor dataset, to better represent activity.

Table 15: Producer Tractors Activity Multiplier Matrix

Group 1	Group 4	Group 7	Group 10	Group 13	Group 16	Group 19
0.175	-0.114	-0.245	-0.454	-0.721	-0.199	-0.199
Group 2	Group 5	Group 8	Group 11	Group 14	Group 17	Group 20
0.187	-0.115	0.059	0.502	0.496	0.790	0.790
Group 3	Group 6	Group 9	Group 12	Group 15	Group 18	Group 21
0.518	0.282	0.650	0.688	0.725	0.866	0.866

Using the Multiplier Matrix in Table 15 and Equation 2 (calculating activity instead of age), the Custom Operator Tractor activity is calculated. Once fuel is adjusted in this same manner, the adjusted 2008 dataset, with recalculated age, activity, and fuel, may be appended to the 2018 Custom Operator dataset.

5.4.3.3 Fuel Consumption Adjustments

Fuel adjustments use the same multipliers as activity since fuel consumption is directly related to usage. If equipment usage increases, the fuel required would also increase at the same rate. Likewise, when usage decreases, less fuel is required. Now that fuel is adjusted, this updated 2008 dataset, with recalculated age, activity, and fuel consumption, may now be appended to the 2018 Custom Operator dataset.

This same methods for adjusting age, activity, and fuel consumption are used for all remaining datasets that need 2008 supplemental data, listed in Table 11, to include Producer All Other (non-tractor/non-ATV) equipment, Custom Operator ATV and All Others, First Processor, and Rental Equipment.

5.5 Statewide Scaling

The responses collected from the statewide survey represent a fraction of the total equipment and need to be scaled up to represent agricultural operations in California. Scaling factors were applied to the equipment population based on the ratio of the acreage represented in the survey to the state acreage reported by the County Agricultural Commissioners' data and the USDA Agricultural Census.

The following two examples walk through the steps of the scaling process and illustrate the basic calculations. This same scaling methodology was used in the 2011 Agricultural Emission Inventory report[16], and more details are available there.

5.5.1 Simplified Example

Consider an example survey response coming from a 200-acre nut farm with two 80 horsepower tractors (both tractors are categorized into the 100 horsepower bin and the farm is categorized as a nut farm in the 250 acre bin). This data averages to a population of one tractor in the 100 horsepower bin per 100 acres of nut farm.

Assume statewide, there are 45,000 acres in nut farms between 100 to 250 acres (250 acre bin). The inventory calculates (1 tractor / 100 acres) * (45,000 acres) = 450 tractors between 75 to 100 horsepower (100 horsepower bin) on nut farms of 100 to 250 acres (250 acre bin).

5.5.2 Actual Data Example

Table 16 shares an actual response from the survey, with the original survey response in black and CARB-added sorting or analysis in blue. This anonymous respondent has three commodities, grouped into the Nut, Grapes, and Tree Fruit commodity groups. Each commodity is also sorted into a farm size bin. All commodity acres from this respondent are

[16] https://ww3.arb.ca.gov/msei/ordiesel/ag2011invreport.pdf

summed. Next, the fraction of commodity acres out of total acres is calculated, with the fractional sums totaling 1. Each commodity has a fraction that will be used in later steps for equipment scaling.

Table 16: Commodity Reported by Respondent, with Scaling Example

Commodity	Units	Amount	CARB Fraction (Acres/Total Acres from respondent)	CARB Commodity Group	CARB Farm Size Bin
Walnuts	Acres	100	100/181 = 0.5525	Nut	50 to 100 Acres
Grapes, Wine Type	Acres	80	0.4420	Grapes	50 to 100 Acres
Apples	Acres	1	0.0055	Tree Fruit	1 to 15 Acres
	SUM	**181**	**1.0000**		

In addition to the above commodities, Table 17 shows this respondent also reported eight pieces of equipment. The equipment is grouped into CARB-defined horsepower bins, shown in blue. The survey responses did not identify which equipment works on which commodity (which is likely different from farm to farm).

Table 17: Equipment Reported by Respondent

Type	Manufacturer	Model	Year	Horsepower	CARB Hp Bin	Fuel	Hours	Gallons
Agricultural tractors	John Deere	650	1995	30	50	Diesel	150	100
Agricultural tractors	John Deere	2550	1985	60	75	Diesel	150	400
Agricultural tractors	John Deere	5510	2000	60	75	Diesel	200	400
Agricultural tractors	John Deere	6410	2000	100	100	Diesel	150	600
Agricultural tractors		464	1976	45	50	Diesel	200	400
Agricultural tractors		595	1991	60	75	Diesel	350	600
Agricultural tractors		595	1993	60	75	Diesel	320	600
Sprayers/spray rigs (self-propelled)		Sprayer	1995	120	175	Diesel	120	250

First, equipment is grouped by type and horsepower bin, as in Table 18.

Table 18: Equipment Count

Type	CARB Hp Bin	Count
Agricultural tractors	50	2
Agricultural tractors	75	4
Agricultural tractors	100	1
Sprayers/spray rigs (self-propelled)	175	1

To scale up the equipment to statewide levels, the inventory splits the equipment in Table 18 based on the commodity fractions calculated in Table 16. Staff assumed that equipment usage on each commodity is proportional to acreage distribution among different commodities.

Table 19: Example Scaling Equipment by Commodity Group

For every 100 Acres of Nuts (Bin: 50 to 100 Acres of Nut Farms)

2 tractors * 0.552 fraction =	**1.100**	50 Hp	Agricultural tractors
4 tractors * 0.552 fraction =	**2.200**	75 Hp	Agricultural tractors
1 tractor * 0.552 fraction =	**0.552**	100 Hp	Agricultural tractors
1 sprayer * 0.552 fraction =	**0.552**	175 Hp	Sprayers/spray rigs

For every 80 Acres of Grapes (Bin: 50 to 100 Acres of Grape Farms)

2 tractors * 0.4420 fraction =	0.88	50 Hp	Agricultural tractors
4 tractors * 0.4420 fraction =	1.77	75 Hp	Agricultural tractors
1 tractor * 0.4420 fraction =	0.44	100 Hp	Agricultural tractors
1 sprayer * 0.4420 fraction =	0.44	175 Hp	Sprayers/spray rigs

For every 1 Acre of Tree Fruit (Bin: 1 to 15 Acres Tree Fruit Farms)

2 tractors * 0.0055 fraction =	0.011	50 Hp	Agricultural tractors
4 tractors * 0.0055 fraction =	0.022	75 Hp	Agricultural tractors
1 tractor * 0.0055 fraction =	0.006	100 Hp	Agricultural tractors
1 sprayer * 0.0055 fraction =	0.006	175 Hp	Sprayers/spray rigs

Next the inventory sums both the survey acres in each bin and all equipment fractions in that bin. Looking at nut crop farms in the bin 50 to 100 Acres, the inventory sums all acres and equipment fractions. For this example, assume the survey has 6,540 acres in nut commodities on farms of 50 to 100 acres. Statewide total acres in nut commodities in the 50 and 100 Acres farm bin is 40,219 acres. So, total acres of 40,219 divided by survey acres of 6,540 creates a scalar of 6.15. This means for every acre represented in the survey, there are 6.15 acres in the state of that particular commodity and farm size.

Table 20: Example Equipment Scaling for Nut Farms of 50 to 200 Acres

Survey Data: Summed Equipment Fractions from 6,542 Acres	Equipment Group	HP Bin	Scalar	Scaled Up Population
63.2	Tractors	50 hp	6.15	388.54
97.4	Tractors	75 hp	6.15	598.80
102.3	Tractors	100 hp	6.15	628.92
23.5	Tractors	175 hp	6.15	144.47
3.2	Tractors	300 hp	6.15	19.67
8.54	Harvesters	50 hp	6.15	52.50
14.3	Harvesters	75 hp	6.15	87.91
23.5	Harvesters	100 hp	6.15	144.47
11.3	Harvesters	175 hp	6.15	69.47
11.4	Sprayers	100 hp	6.15	70.09
23.9	Sprayers	175 hp	6.15	146.93

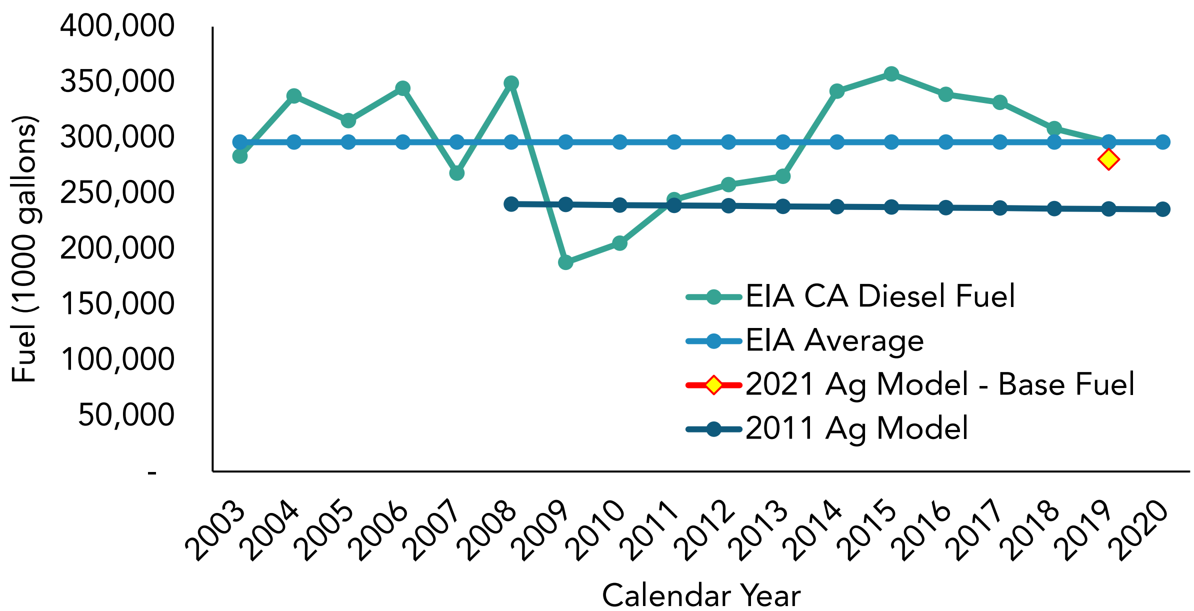
5.6 Statewide Fuel

Fuel use is a product of an equipment's fuel consumption rate, load factor, horsepower, population, and activity. The inventory projects statewide fuel use based on historical diesel fuel provided by EIA[17] (California No 2 Diesel Sales per Deliveries to Farm Consumers). EIA is the only source at this time reporting farm diesel consumption for California. Figure 13 shows

[17] https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=K2DVFMSCA1&f=A

EIA's historical fuel use, and its farm fuel average of 296 million gallons per year from 2003 to 2018. It is important to note that EIA may retroactively adjust their fuel reports, as methodologies are updated and improved. Also, the figure shows the 2011 agricultural inventory's diesel fuel began at 240 million gallons and slightly declined over time. The starting point for the 2021 agricultural emission inventory is nearly 281 million gallons, which is 20 million gallons less than EIA average due to considerations for stationary agricultural pumps and anti-frost wind machines, similar to the 2011 inventory[18].

Figure 13: Historical Diesel Fuel



Unlike the 2011 inventory, USDA fuel costs were not used to estimate fuel for the 2021 inventory. USDA reports total fuel expense by region[19], so there are many assumptions used when estimating fuel consumption in gallons such as the percent of diesel used[20] and the average fuel cost at that time, before converting to gallons of fuel. Thus, EIA is the most reliable source for farm fuel at this time.

5.7 Growth

Growth rates are calculated using historical data from the County Agricultural Commissioners' reports, as seen in Figure 6. Table 21 reflects the new 2021 commodity

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[18] https://ww3.arb.ca.gov/msei/ordiesel/ag2011invreport.pdf

[19] USDA Fuel in California. *https://quickstats.nass.usda.gov/#447D6B8A-2865-3BC6-B786-16615D4DF733*

[20] *https://quickstats.nass.usda.gov/#6CC19FF0-1FFC-356F-9398-D273157C1A0A*

group growth rates and show how they compare to the growth rates used in the 2011 Agricultural Equipment Emission Inventory. The new growth rates capture both the reduction of harvested acres and improved efficiency in equipment per acre. These growth rates are applied to both the equipment population and equipment activity, and result in a reduced population of 0.9 percent per year.

Table 21: Commodity Group Growth Rates

Commodity Group	2011 model Growth Rate	2021 model Growth Rate
Beef Cows	0.0%	-1.6%
Citrus	-0.1%	-1.6%
Grapes	0.0%	-1.6%
Hay, Forage, Pasture, Grains	-0.4%	-1.6%
Milk Cows	0.0%	-1.0%
Nursery, Greenhouse, Floriculture	0.0%	-0.7%
Nut Crops	0.0%	0.2%
Poultry	0.0%	0.2%
Row Crops	-0.5%	-1.2%
Tree Fruit	0.0%	-1.3%
Vegetables, hand-picked	0.2%	-1.3%
Vegetables, machine-picked	0.1%	-1.6%
Equipment Rental	-0.2%	-1.6%

5.8 Load Factors

A load factor represents how hard an equipment's engine works, on average, and ranges from 0 to 100 percent. It is a unit-less number and part of the emissions calculations. The load factor equation has two steps. In the first step, Equation 4 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 then divides by the pounds to gallon conversion factor. The equation relies on the U.S. EPA[21] BSFC rate of 0.408 pounds per horsepower-hour for engines with 100 horsepower or less, and 0.367 for engines greater than 100 horsepower.

[21] Exhaust Emission Factors for Nonroad Engine Modeling--Compression-Ignition, Report No. NR-009A, February 13, 1998.

Equation 4: Load Factor Equation: Step 1

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

In the second step, Equation 5 uses the survey-reported equipment annual fuel use (gallons per year) divided by the maximum annual fuel use (from Equation 3.1) to calculate the load factor.

Equation 5: Load Factor Equation: Step 2

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

Agricultural-specific load factors were developed for the 2011 Diesel Agricultural Equipment Inventory using the 2008 survey data. The following information was necessary in calculating these load factors and was provided by the 2008 survey respondents: fuel consumption, annual activity, and horsepower for 1,549 vehicles (70 percent were tractors). Data on equipment types were combined in the following groups: agricultural tractors, balers and bale wagons, construction, forklifts, ATVs and others, harvesters of all types, hay squeeze, and spray rigs. Since hay squeezes lacked sufficient data, they were combined with tractors, the largest category, and share the same load factor. Table 22 expresses load factor by equipment type. Based on all the responses, tractors have an average load factor of 0.48, with the other equipment types coming in between 0.4 to 0.5.

Table 22: Agricultural Equipment Load Factors

Equipment Type	Load Factor
Agricultural Tractors	0.48
ATVs	0.40
Bale Wagons (Self-Propelled)	0.50
Balers (Self-Propelled)	0.50
Combine Harvesters	0.44
Cotton Pickers	0.44
Crawler/Backhoe/Loader/Dozer/Grader	0.40
Forage & Silage Harvesters	0.44
Forklifts	0.40
Hay Squeeze/Stack Retriever	0.42
Nut Harvester	0.44
Other Harvesters	0.44
Others	0.40
Sprayers/Spray Rigs	0.42
Swathers/Windrowers/Hay Conditioners	0.48

These same equations were used to calculate load factors using the 2018 survey data to see if an update was necessary. Load factors from the 2018 survey are very close to the 2008 load factors and therefore staff continued to use 2008 agricultural-specific load factors for the updated emissions inventory.

5.9 Emission Rates and Fuel Correction Factors

This inventory utilizes CARB's 2017 off-road diesel emission factors[22], developed for off-road equipment, and used in inventories such as construction equipment, cargo handling equipment, and other off-road diesel sectors. CARB's emission factors documentation[23] is summarized in this report.

An emission factor reflects emissions from an engine that is new, known as its zero-hour emission factor, added to the product of the engine's deterioration rate over time and its accumulated lifetime hours. Equation 6 shows the emission factor equation.

Equation 6: Emission Factor

$$EF\ (\frac{grams}{hp-hr}) = EF_0 + (EF_{DR} \times Accumulated\ Hours)$$

where EF = Emission Factor $(\frac{grams}{hp-hr})$

EF_0 = Zero-hour Emission Factor $(\frac{grams}{hp-hr})$

EF_{DR} = Deterioration Rate $(\frac{grams}{hp-hr^2})$

Emissions from a group of equipment is based on the equipment population, horsepower, activity, age, engine deterioration due to age, load factor, and in some cases the sulfur content of fuel. Equation 7 represents a simplified emission calculation for one piece of equipment for a specific pollutant. When this equation is summed for all pieces of equipment in a sector, it creates a statewide emissions inventory for that pollutant.

Equation 7: Emission Equation

$$Emission\ (\frac{grams}{year}) = Hp \times Activity \times LF \times (EF_0 + EF_{DR}) \times FCF$$

where Hp = Horsepower of the engine (hp)

Activity = usage of engine $(\frac{hours}{yr})$

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

[23] https://ww3.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017.pdf

LF = Load Factor of the engine (unit-less)

EF_0 = Zero-hour Emission Factor $(\frac{grams}{hp-hr})$

EF_{DR} = Deterioration Rate $(\frac{grams}{hp-hr^2})$

FCF = Fuel Correction Factor (unit-less)

Agricultural-specific load factors are used, as described in Table 22. The fuel correction factor is unit-less and accounts for adjustments in the sulfur content of diesel fuel. Information pertaining to adjustments resulting from lower sulfur content in diesel fuel (ultra-low sulfur diesel) is available in CARB's report for off-road diesel emission factors[24]. Diesel's sulfur content had dramatic reductions in 2007 and was further reduced through 2015, with the national average sulfur content of diesel fuel being 11 parts per million. Alterations to the sulfur content significantly impact sulfur oxides (SOx) and PM emissions.

5.10 Tier Introduction Timeline

This 2021 inventory uses an updated engine tier introduction timeline, following CARB's Off-Road Diesel New Engine Emission Standards[25]. The previous 2011 inventory was designed using estimated Tier 4i and Tier 4f introduction timelines since the timeline was not yet finalized. As a result, it is possible there may be some shifts in equipment population by engine tier when comparing the 2011 inventory to the 2021 inventory. Specifically, the 2011 inventory assumed Tier 4 would not be available until 2018 to 2020, based on discussions with agricultural equipment dealerships. Table 23 shows the Tier standards of off-road diesel engines by model year and horsepower of the engine.

[24] https://ww3.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017.pdf

[25] https://ww3.arb.ca.gov/msei/ordiesel/ordieselstandards.xlsx

Table 23: Off-Road Compression-Ignition Diesel Engine Standards

HP (kW)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015+
< 11 (8)	See Table 2 footnote (a)					7.8 / 6.0 / 0.75 (10.5 / 8.0 / 1.0)					5.6 / 6.0 / 0.60 (7.5 / 8.0 / 0.80)			5.6 / 6.0 / 0.30[a] (7.5 / 8.0 / 0.40)							
≥ 11 (8) < 25 (19)						7.1 / 4.9 / 0.6 (9.5 / 6.6 / 0.80)					5.6 / 4.9 / 0.60 (7.5 / 6.6 / 0.80)			5.6 / 4.9 / 0.30 (7.5 / 6.6 / 0.40)							
≥ 25 (19) < 50 (37)	-					7.1 / 4.1 / 0.60 (9.5 / 5.5 / 0.80)				5.6 / 4.1 / 0.45 (7.5 / 5.5 / 0.60)				5.6 / 4.1 / 0.22 (7.5 / 5.5 / 0.30)					3.5 / 4.1 / 0.02 (4.7 / 5.5 / 0.03)		
≥ 50 (37) < 75 (56)						- / 6.9 / - / -[b] (- / 9.2 / - / -)				5.6 / 3.7 / 0.30 (7.5 / 5.0 / 0.40)				3.5 / 3.7 / 0.22[c] (4.7 / 5.0 / 0.30)					3.5 / 3.7 / 0.02[c] (4.7 / 5.0 / 0.03)		
≥ 75 (56) < 100 (75)														3.5 / 3.7 / 0.30 (4.7 / 5.0 / 0.40)				0.14/ 2.5/ 3.7/ 0.01[b,d] (0.19/ 3.4 / 5.0 /0.02)			0.14 (0.19) 0.30 (0.40) 3.7 (5.0) 0.01[b] (0.02)
≥ 100 (75) < 175 (130)									4.9 / 3.7 / 0.22 (6.6 / 5.0 / 0.30)				3.0 / 3.7 / 0.22 (4.0 / 5.0 / 0.30)								
≥ 175 (130) < 300 (225)	-	1.0 / 6.9 / 8.5 / 0.40[b] (1.3 / 9.2 / 11.4 / 0.54)							4.9 / 2.6 / 0.15 (6.6 / 3.5 / 0.20)			3.0 / 2.6 / 0.15[e] (4.0 / 3.5 / 0.20)					0.14 / 1.5 / 2.6 / 0.01[b,d] (0.19/ 2.0 / 3.5 /0.02)			0.14 (0.19) 0.30 (0.40) 2.6 (3.5) 0.01[b] (0.02)	
≥ 300 (225) < 600 (450)							4.8 / 2.6 / 0.15 (6.4 / 3.5 / 0.20)														
≥ 600 (450) ≤ 750 (560)																					
Mobile Machines > 750 (560)	-					1.0 / 6.9 / 8.5 / 0.40[b] (1.3 / 9.2 / 11.4 / 0.54)						4.8 / 2.6 / 0.15 (6.4 / 3.5 / 0.20)					0.30 / 2.6 / 2.6 / 0.07[b] (0.40 / 3.5 / 3.5 / 0.10)				0.14 (0.19) 2.6 (3.5) 2.6 (3.5) 0.03[b] (0.04)
GEN >750 (560) ≤1207 (900)																					0.14 (0.19) 0.50 (0.67) 2.6 (3.5) 0.02[b] (0.03)
GEN>1207 (900)																	0.30 / 0.50 / 2.6 / 0.07[b] (0.40 / 0.67 / 3.5 / 0.10)				

a) The PM standard for hand-start, air cooled, direct injection engines below 11 hp (8 kW) may be delayed until 2010 and be set at 0.45 g/bhp-hr (0.60 g/kW-hr).
b) Standards given are NMHC/NOx/CO/PM in g/bhp-hr (or g/kW-hr).
c) Engine families in this power category may alternately meet Tier 3 PM standards [0.30 g/bhp-hr (0.40 g/kW-hr)] in 2008-2011 in exchange for introducing final PM standards in 2012.
d) The implementation schedule shown is the three-year alternate NOx approach. Other schedules are available.
e) Certain manufacturers have agreed to comply with these standards by 2005.

: Tier 1 : Tier 2 : Tier 3 : Tier 4 Interim / Final

5.11 County Spatial Allocation

There are eight counties with boundaries falling across multiple air basins and districts: El Dorado, Kern, Los Angeles, Placer, Riverside, San Bernardino, Solano, and Sonoma. To ensure inventory emissions are allocated to the appropriate district, each of these counties were assessed using USDA's NASS 2017 CropLand Data Layer[26] (CDL) satellite data to calculate the percent of crop acres in each air district. CDL's 2017 calendar year data was used since it best matches with the 2017 USDA Agricultural Census data. CDL data is based on daily satellite imagery during the growing season and NASS validates the data with several sources (i.e. field surveys, USDA Common Land Unit data, USGS Land Cover Dataset,

[26] https://nassgeodata.gmu.edu/CropScape/

etc.). The data was processed in ArcGIS Pro, and overlayed with CARB's CoAbDis (County-Air Basin-District) shapefile, splitting the crop data over county, air basin, and air district boundaries.

Figure 14 shows the geographical image for Kern County as well as the crops harvested in that county. Kern County is split between San Joaquin Valley Unified APCD and Kern County APCD. The red boundary represents the larger portion of harvested acres, which increased to 99.8 percent. The yellow boundary reflects the smaller potion, which decreased to 0.2 percent, as compared to the 2008 allocation data used in the 2011 inventory.

Figure 14: Kern County Acres Allocation

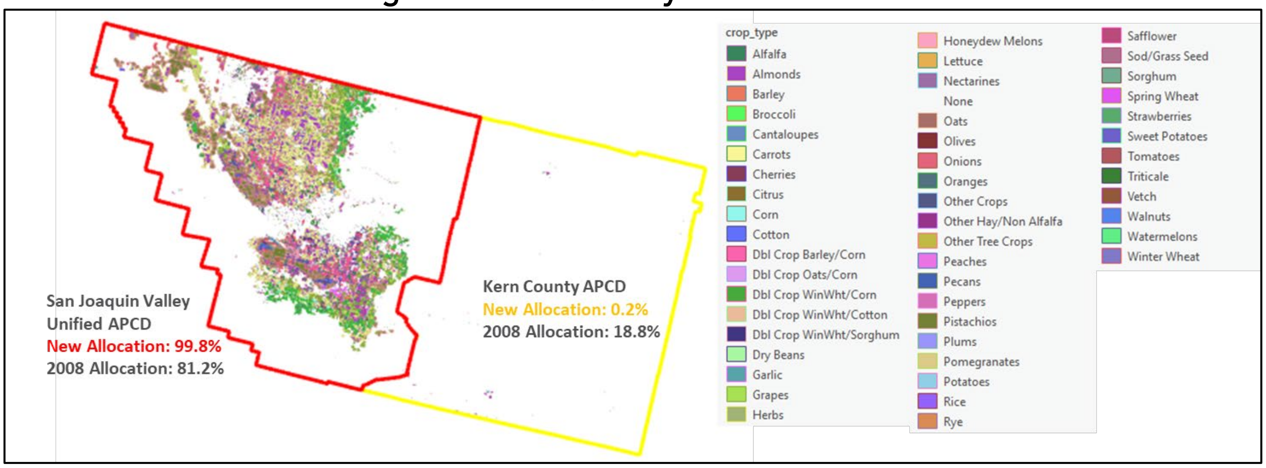
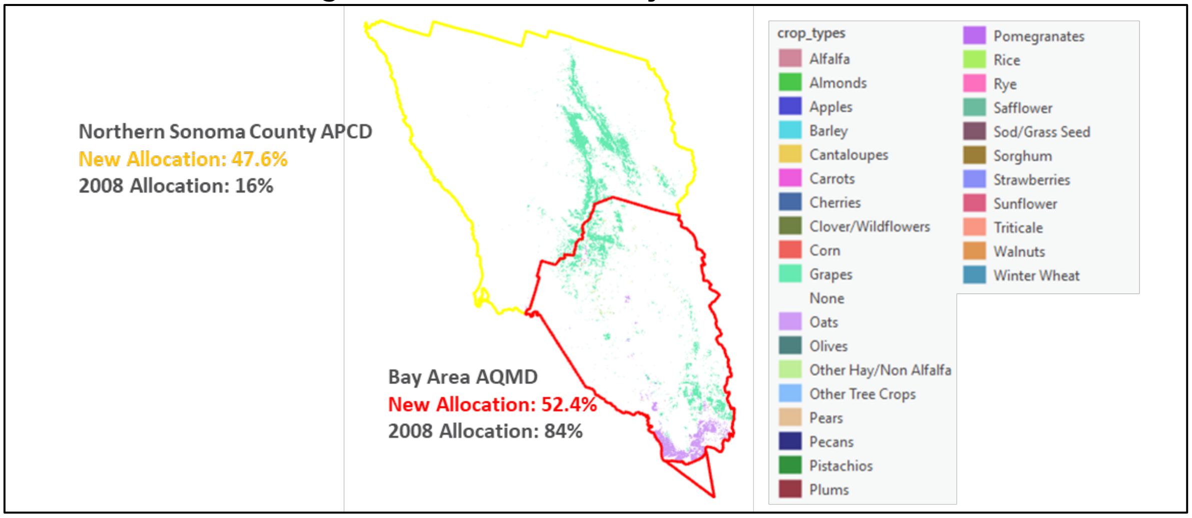


Figure 15 shows another geographical example of a split county. Sonoma County is shared between Northern Sonoma County APCD as well as Bay Area AQMD. The new data shows 47.6 percent of actual harvested crop acres belong to Sonoma County APCD while 52.4 percent is associated with the Bay Area AQMD. The allocations used in 2011 inventory (shown as 2008 allocations) are also provided in the chart.

Figure 15: Sonoma County Acres Allocation



This new methodology is a significant improvement over the 2008 method used in the 2011 inventory. The 2008 allocation was based on population data at the county levels whereas the new 2017 allocation reflects actual harvested crop acres. Thus, it results in some shifts, and the complete updated allocation for all eight counties can be seen in Table 24, organized by county, air basin, air district, and percent of county acres for 2008 and 2017.

Table 24: Comparison of 2008 and 2017 County Acres

County	Basin	Air District	2008 Percent of County Acres	2017 Percent of County Acres
El Dorado	Lake Tahoe	El Dorado APCD	0.00%	0.45%
El Dorado	Mountain Counties	El Dorado APCD	100.00%	99.55%
Kern	Mojave Desert	Kern APCD	18.80%	0.19%
Kern	San Joaquin Valley	San Joaquin Valley AQMD	81.20%	99.81%
Los Angeles	Mojave Desert	Antelope Valley APCD	2.00%	97.75%
Los Angeles	South Coast	South Coast AQMD	98.00%	2.25%
Placer	Lake Tahoe	Placer County APCD	0.00%	0.00%
Placer	Mountain Counties	Placer County APCD	12.00%	0.31%
Placer	Sacramento Valley	Placer County APCD	88.00%	99.69%
Riverside	Mojave Desert	Mojave Desert AQMD	1.58%	42.47%
Riverside	Mojave Desert	South Coast AQMD	0.22%	0.01%
Riverside	Salton Sea	South Coast AQMD	19.50%	24.82%
Riverside	South Coast	South Coast AQMD	78.70%	32.71%
San Bernardino	Mojave Desert	Mojave Desert AQMD	19.00%	95.56%
San Bernardino	South Coast	South Coast AQMD	81.00%	4.44%
Solano	San Francisco Bay Area	Bay Area AQMD	0.00%	10.53%
Solano	Sacramento Valley	Yolo-Solano AQMD	100.00%	89.47%
Sonoma	San Francisco Bay Area	Bay Area AQMD	84.01%	52.42%
Sonoma	North Coast	Sonoma Northern AQMD	15.99%	47.58%

The updated crop acres allocation alters the air district emissions allocations, shown in Table 25. The table highlights the affected air district changes from the 2011 inventory to the new 2021 inventory.

Table 25: Updated Agricultural Emissions Allocation

Air District	2011 Inventory	2021 Inventory
Bay Area AQMD	4.01%	5.1%
Mojave Desert AQMD	0.14%	1.74%
Northern Sonoma County APCD	0.30%	1.50%
South Coast AQMD	2.84%	1.37%
El Dorado County APCD	0.30%	0.48%
Placer County APCD	0.35%	0.74%
Antelope Valley AQMD	0.01%	0.33%
Kern County APCD	1.10%	0.01%

5.12 Potential Impact from the Oroville Dam

The California Hydra Map[27] in ArcGIS was used to geographically trace the water flow from the Feather River in Butte County, as it meets the Sacramento River, in Figure 16, to investigate potential changes in harvested acres due to impacts from the Oroville Dam. Five counties are affected by this water flow: Butte, Sacramento, Sutter, Yolo, and Yuba.

Figure 16: Counties with Sacramento and Feather River Flow

[27] California Hydra Map. https://hub.arcgis.com/datasets/de8d118c32da4a22a091848458e761fd_0?where=NAME%20%3D%20%27Feather%20River%27

Using County Agricultural Commissioners' data, Figure 17 displays harvested crop acres for Sutter County. Variations were reported in non-bypass years (2014 and 2015), but averages from 2014 to 2018 show no obvious changes in harvested acres, indicating no apparent changes due to the Oroville Dam or other land leases.

Figure 17: County Agricultural Commissioner's Harvested Acres in Sutter County

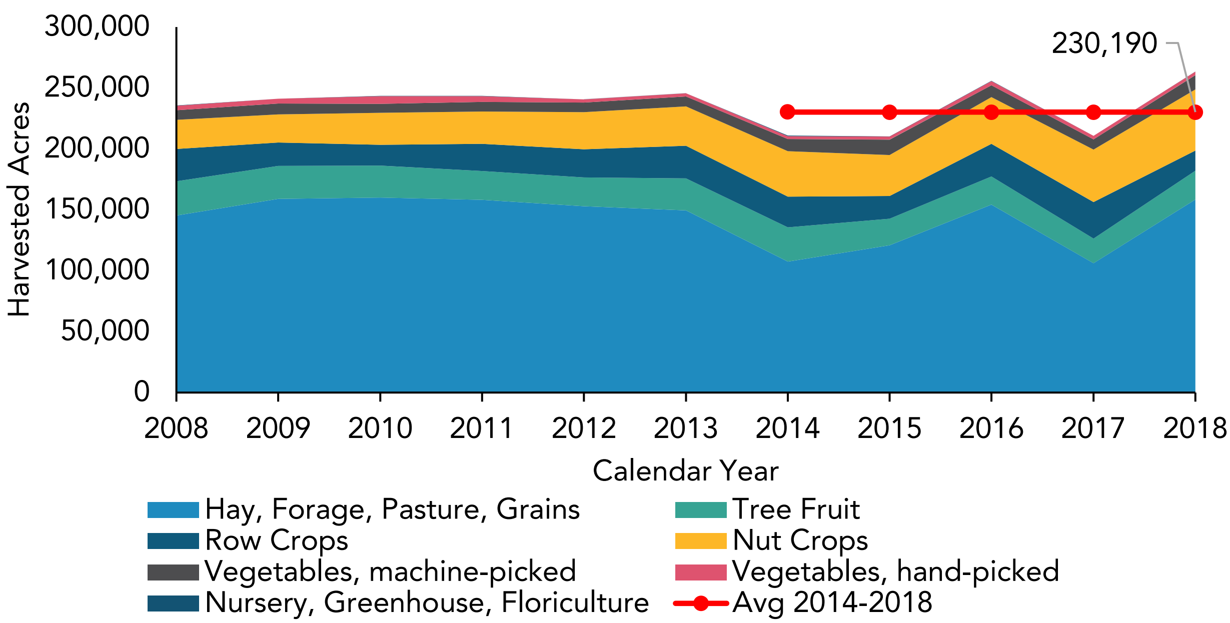
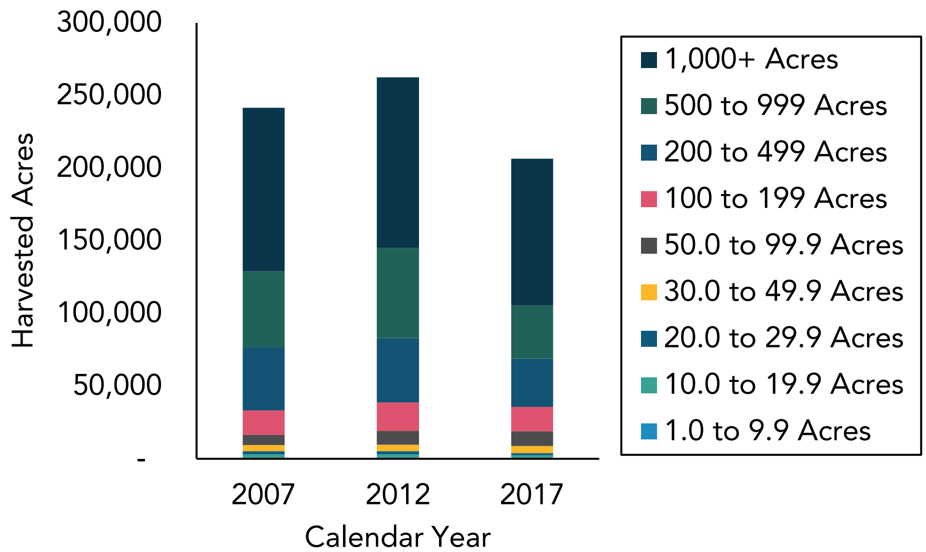


Figure 18 displays USDA Agricultural Census data for Sutter County, which indicates a growth in harvested acres from 2007 to 2012, and a drop from 2012 to 2017.The fluctuations reported in the County Agricultural Commissioners' data match the USDA Agricultural Census report data and are therefore not anomalous.

Figure 18: USDA Agricultural Census Harvested Acres in Sutter County

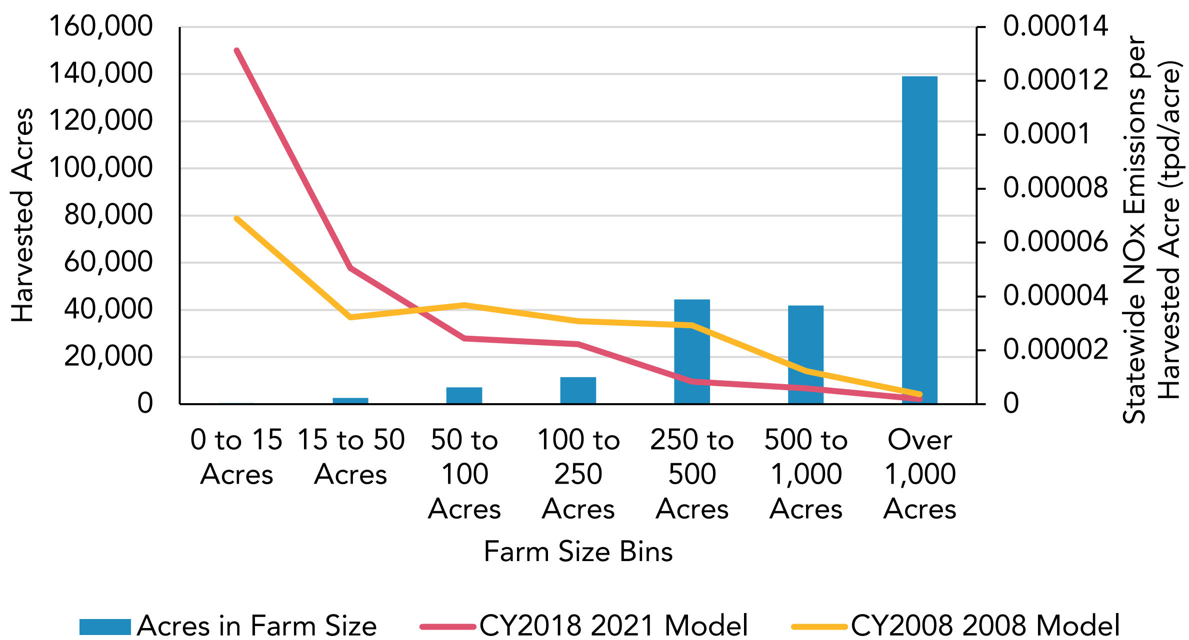


6 Emission Inventory Results

The results from the 2021 Agricultural Equipment Emission Inventory account for all equipment horsepower and fuel types related to mobile agricultural production in California. Emissions results reflect the age and activity of these equipment as they work on California's farms to grow and harvest crops, which are categorized into previously described commodity groups and farm acre groupings. Equipment are grouped into horsepower bins and categorized into equipment groupings as well. All emission projections are based on the previously described equipment profile bins, age distributions, and purchasing and retirement curves, which inform that equipment activity declines with age. This 2021 inventory does not explicitly account for the incentive projects since it is assumed incentives are captured in the equipment population and model years reflected in the 2018 survey data. Of course, this inventory does not reflect the impact of future incentive funds in accelerating the turnover of older agricultural equipment.

Emissions results account for the decrease in number of farms and slight increase in statewide harvested acres, all while farming practices have been refined and equipment has become more efficient. Figure 19 shows the relationship between county-specific harvested acres (blue bars using the left y-axis) as compared to total statewide NOx emissions per statewide harvested acres (tpd/acre) (lines using the right y-axis). The NOX emissions rates compare changes seen in the base year 2011 inventory (Calendar Year 2008) to base year 2021 inventory (Calendar Year 2018). Data for county harvested acres grouped into farm size acre bins. As an example, this figure uses the farm acreage distribution for Colusa County. The emission rates indicate that large farms show a reduced emission contribution in the 2021 inventory as compared to the 2011 inventory, while smaller farms have increased emissions in the 2021 inventory. Thus, counties with primarily large farms show decreased emissions in the new 2021 inventory, and counties with farms under 250 acres tend to show increased emissions. As shown, Colusa county has an overall reduction in emissions, as the county agricultural acres are primarily composed of large farms, with very few small farms.

Figure 19: Colusa County Harvested Acres and Statewide NOx Emissions per Harvested Acres



Additional county data and supporting materials are available in the appendix.

6.1 San Joaquin Valley Results

The San Joaquin Valley is home to about 50 percent of the state's agricultural equipment, 56 percent of the state's harvested acres, and contributes 53 percent of the state's NOx. The new inventory does not show a significant change in San Joaquin Valley's allocation of statewide acreage or equipment (56 percent with the new 2021 inventory as compared to 55 percent from the 2011 inventory).

Figure 20 displays the tractor population in the San Joaquin Valley, projected out to 2045 and demonstrates a decline in population over time. The figure accounts for natural turnover and assumes any incentive projects are reflected in the base year 2018. Future incentives are not projected.

Figure 20: SJV Tractor Population by Tier

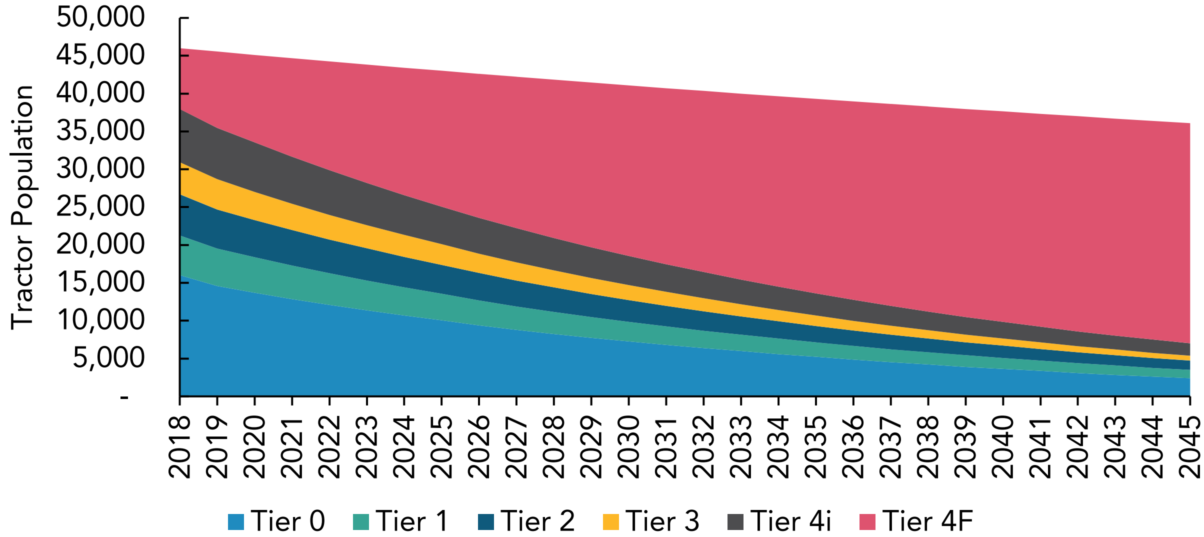


Figure 21 shows the San Joaquin Valley tractor population in calendar years 2018 and 2024, comparing results from the 2011 inventory and the new 2021 inventory. With less equipment per acre, the 2021 inventory shows a smaller tractor fleet, totaling 46,000 in 2018, and 43,400 tractors in 2024. Population decreased from the 2011 inventory projections, which estimated nearly 60,800 tractors in 2018 and 60,500 in 2024.

The 2011 inventory results did not include any Tier 4f tractors in 2018 due to the tier introduction timeline. As mentioned previously, the tier introduction timeline has been updated to reflect actual tier introduction years and the 2018 results for the new 2011 inventory do show 8,000 Tier 4f tractors.

In 2024, the proportion of Tier 4f tractors has increased from 15 percent (2011 inventory) to 39 percent (2021 inventory), demonstrating the effectiveness of incentives. Over 7,000 additional Tier 4f tractors beyond previous predictions by 2024 clearly illustrate effectiveness of incentives (e.g., FARMER Program). In 2024, 18,000 Tier 0 through Tier 2 tractors are projected to still remains in SJV, showing clear potential for additional emissions reductions with further incentive funding.

Figure 21: Comparison of the 2011 Inventory and 2021 Inventory: SJV Tractor Population

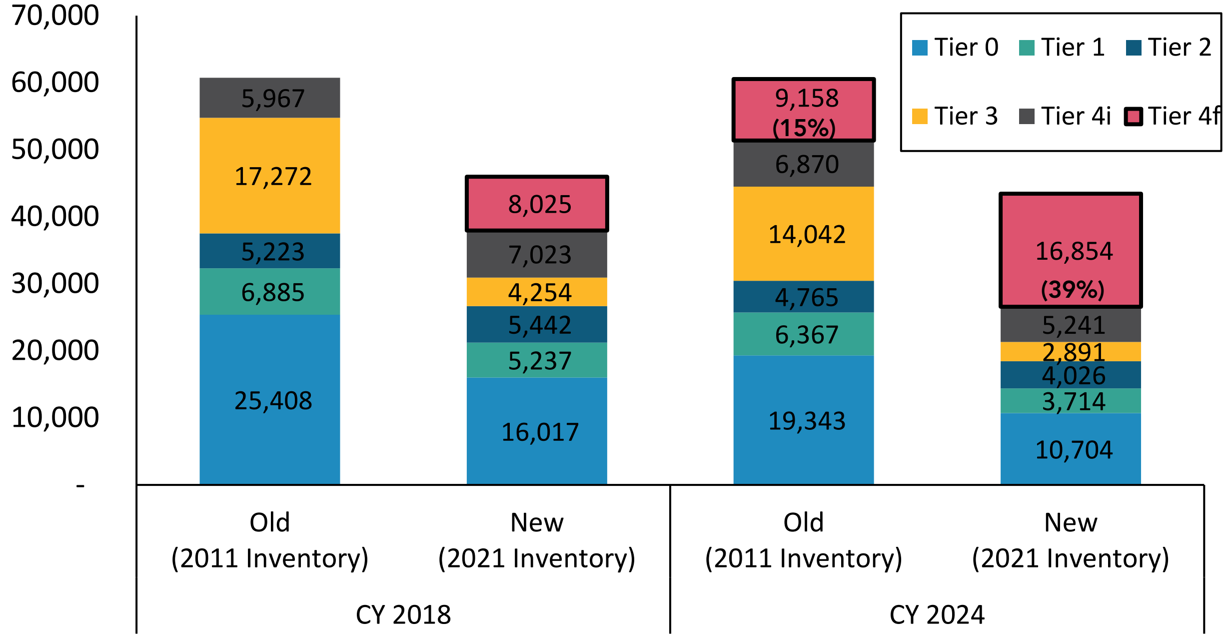
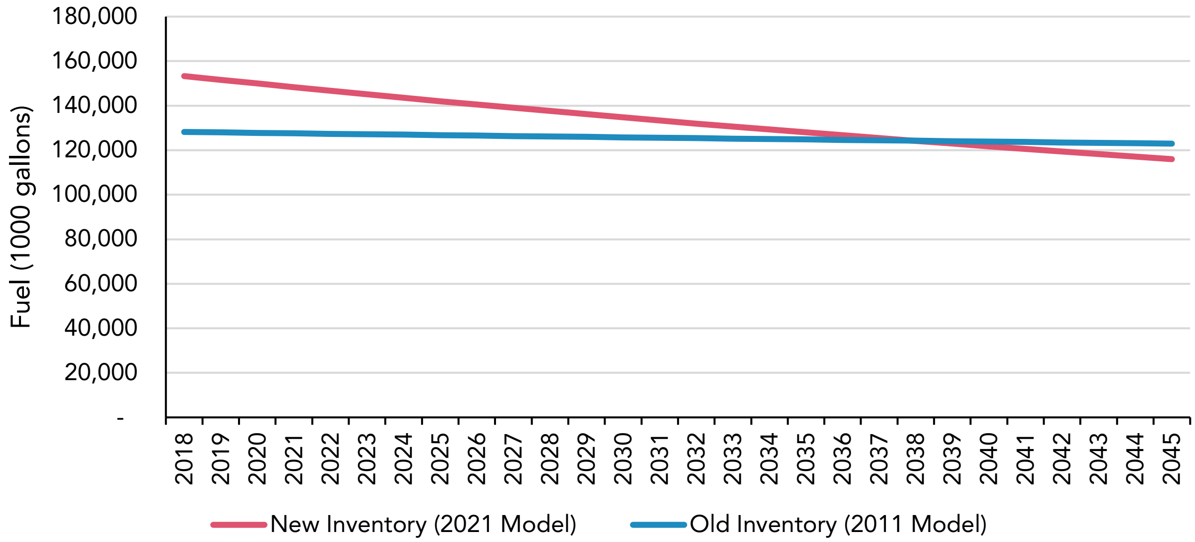


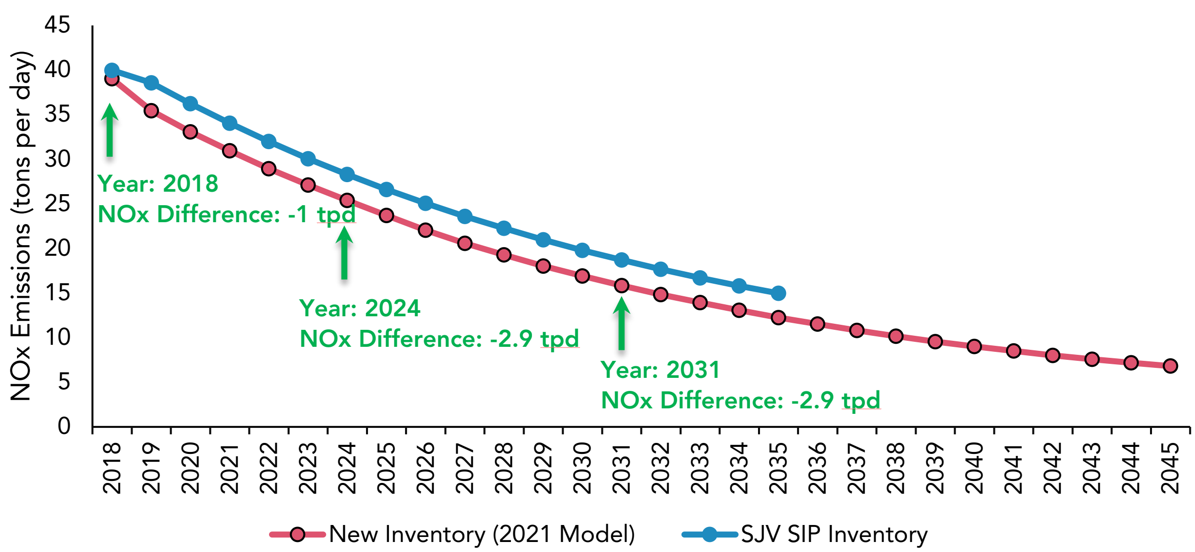
Figure 22 compares fuel use in the 2011 and 2021 inventories in the San Joaquin Valley. As discussed previously, the new 2021 inventory shows higher fuel consumption than the 2011 inventory, with about 153 million gallons of gasoline and diesel fuel being consumed in 2018. Fuel decreases over time due to declining commodity growth rates and improvements in equipment efficiencies.

Figure 22: Agricultural Equipment Fuel in the San Joaquin Valley



While the 2021 inventory reports less equipment and more fuel than the 2011 inventory, the NOx emissions are forecasted to be slightly lower than 2011 inventory. Figure 23 shows the projected NOx emissions in the San Joaquin Valley and compares them to the SJV SIP emission inventory. In 2018, NOx emissions are 1 ton per day (tpd) lower in the new inventory, 2.9 tpd lower in 2024, and 2.9 tpd lower in 2031, with continued reductions over time. Any reductions due to incentives would be reflected in the base year 2018 survey responses and the SJV SIP emissions do not reflect any incentives after 2008.

Figure 23: Agricultural Equipment NOx Emissions in the San Joaquin Valley



6.2 Statewide Results

Statewide inventory results show a decline in equipment population of -0.9 percent annually. Figure 24 depicts the statewide tractor population and Figure 25 compares the new 2021 inventory population projections to the 2011 inventory. Statewide, there is an estimated 95,000 tractors in 2018 with 17 percent Tier 4f, dropping to 90,000 in 2024 with 38 percent Tier 4f. Incentives have been successful in introducing Tier 4f equipment much faster than projected in the 2011 inventory, where it was projected that 15 percent would be Tier 4f in 2024.

Figure 24: Statewide Tractor Population

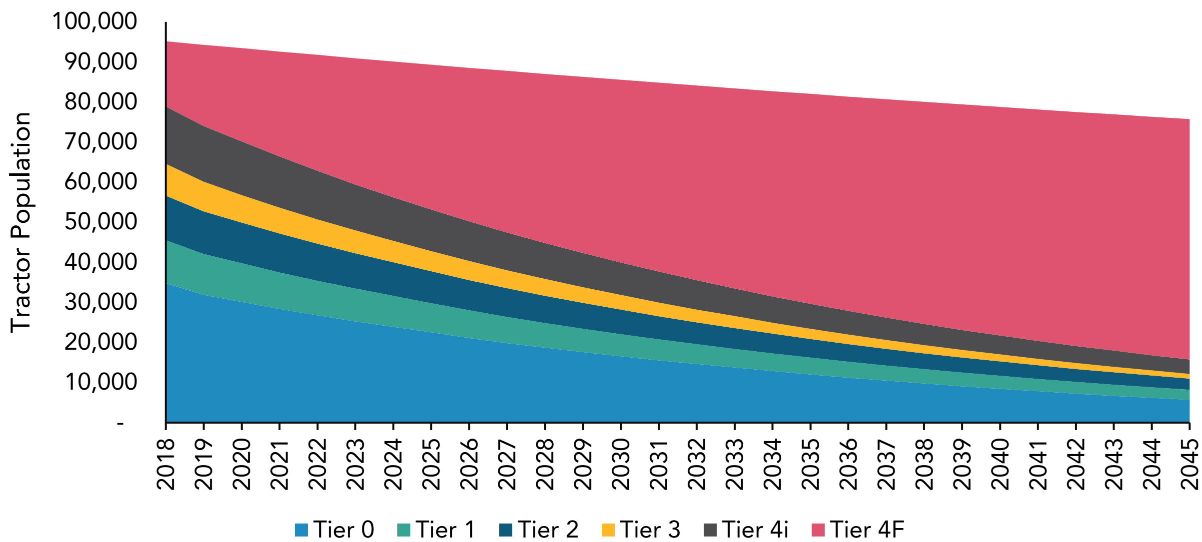


Figure 25: Statewide Tractor Population Comparison

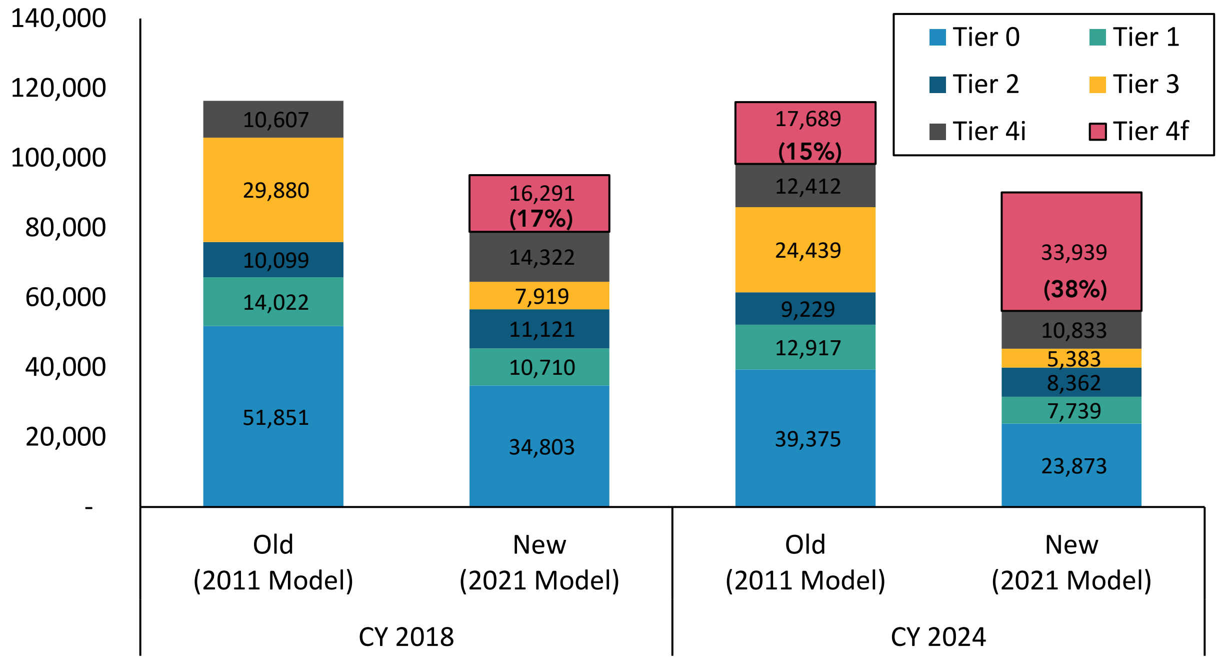
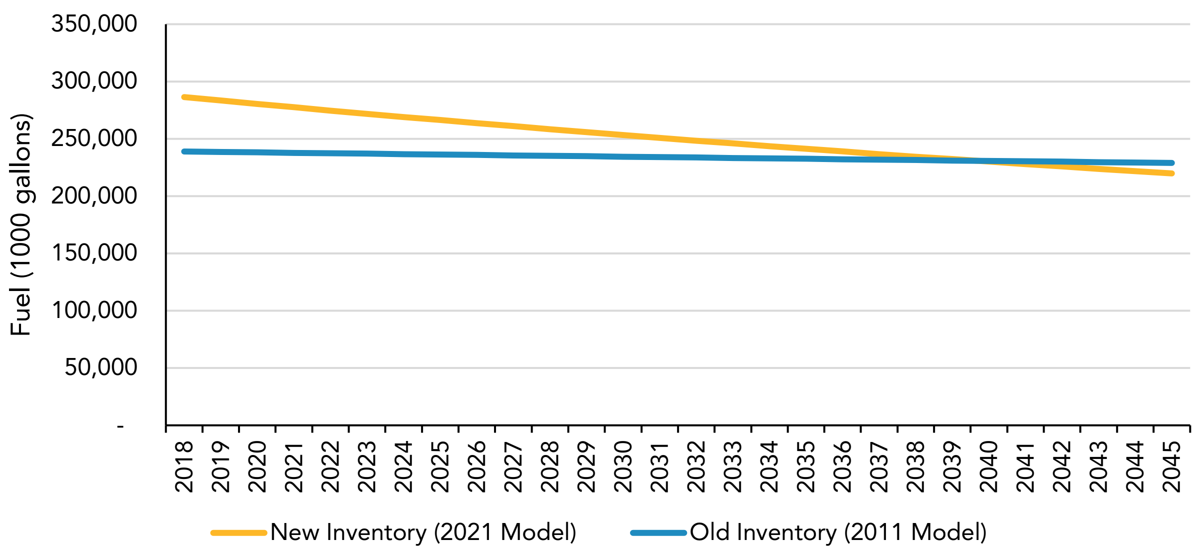


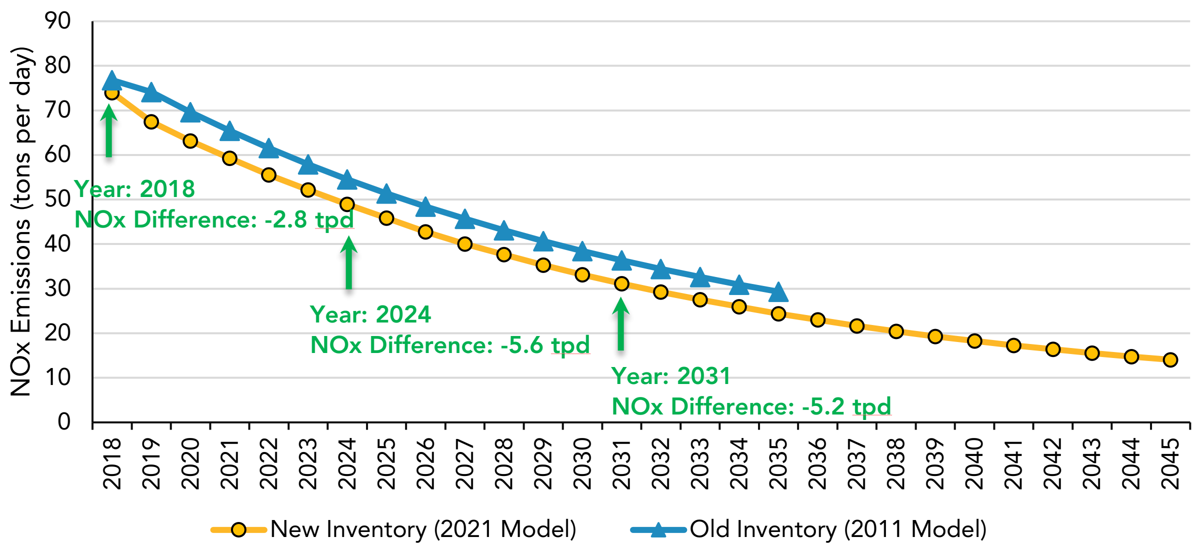
Figure 26 also shows the statewide fuel consumption by agricultural equipment as estimated by the 2021 emissions inventory.

Figure 26: Statewide Agricultural Equipment Fuel



Reduced equipment population with a greater proportion of Tier 4f equipment presents a decrease in emissions, even when statewide fuel use has increased. Figure 27 shows the 2021 inventory's NOx emission projections, which are 2.8 tpd lower in 2018, 5.6 tpd less in 2024, and 5.2 tpd less in 2031, than the 2011 inventory.

Figure 27: Statewide Agricultural Equipment NOx Emissions



6.3 Statewide Allocation Results

Based on the inventory results and new county allocation methodology (discussed in Section 5.11), Table 26 reports the relative statewide NOx emissions distribution by air district. The table compares the results from the 2011 inventory to the new 2021 results. In the 2021 inventory, districts with more than one percent of statewide NOx emission contribution are located on the left side of the table, and districts with less than one percent are located on the right side.

Table 26: 2020 NOx Emissions Distribution by Air District

Air District	2011 model	2021 model	Air District	2011 model	2021 model
San Joaquin Valley Unified APCD	52.7%	53.0%	North Coast Unified AQMD	0.43%	0.92%
Bay Area AQMD	4.0%	5.1%	Modoc County APCD	0.86%	0.91%
Feather River AQMD	4.5%	3.1%	Siskiyou County APCD	0.88%	0.86%
Monterey Bay Unified APCD	2.8%	3.1%	Placer County APCD	0.35%	0.74%
San Diego County APCD	2.2%	2.9%	Shasta County AQMD	0.34%	0.55%
Yolo/Solano AQMD	3.4%	2.8%	Lake County AQMD	0.53%	0.52%
Butte County AQMD	3.7%	2.6%	Lassen County APCD	0.41%	0.49%
Ventura County APCD	2.2%	2.3%	El Dorado County APCD	0.30%	0.48%
Glenn County APCD	3.3%	2.3%	Northern Sierra AQMD	0.25%	0.34%
San Luis Obispo County APCD	1.8%	2.1%	Antelope Valley AQMD	0.01%	0.33%
Imperial County APCD	2.2%	1.9%	Amador County APCD	0.17%	0.30%
Colusa County APCD	3.2%	1.9%	Calaveras County APCD	0.10%	0.20%
Santa Barbara County APCD	1.3%	1.8%	Great Basin Unified APCD	0.14%	0.16%
Mojave Desert AQMD	0.1%	1.7%	Tuolumne County APCD	0.05%	0.14%
Northern Sonoma County APCD	0.3%	1.5%	Mariposa County APCD	0.04%	0.12%
South Coast AQMD	2.8%	1.4%	Kern County APCD	1.10%	0.01%
Tehama County APCD	1.2%	1.3%			
Sacramento Metropolitan AQMD	1.48%	1.15%			
Mendocino County AQMD	0.64%	1.01%			

7 Future Inventory Planning

Every inventory update is an improvement over the previous version, and there is always room for enhancements and further refinement in an agricultural equipment emission inventory. At this time, the next statewide survey is not yet scheduled, but CARB will look towards the guidance and support of the agricultural community and California's air districts to update the emissions inventory in the future. As usual, any future survey would collect both agricultural equipment and commodity data, similar to the 2008 and 2018 surveys, and all data would be anonymized through a third-party contractor. Any future inventory would also depend on the latest USDA Census of Agriculture and County Agricultural Commissioners' reports. The main areas for improvement would always be updated data, inclusion of additional equipment, additional fuel data, and appropriate representation of farming practices in the entire state.