2020 Emissions Model for Small Off-Road Engines – SORE2020

CALIFORNIA AIR RESOURCES BOARD

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Table of Contents

1. Executive Summary

Small off-road engines (SORE) are spark-ignition engines rated at or below 19 kilowatts (i.e., 25 horsepower). Engines in this category are used in lawn and garden equipment as well as other outdoor power equipment and specialty vehicles, and cover a broad range of equipment such as lawn mowers, leaf blowers, chainsaws, and generators. The majority of this equipment belongs to the Lawn & Garden (e.g., lawn mower, leaf blower) and Light Commercial (e.g., compressor, generator) categories of the California Air Resources Board's (CARB) SORE emissions inventory model. This document details the updated baseline emissions inventory as utilized in CARB's SORE emissions inventory model, SORE2020, which will be used to inform future regulatory development as well as air quality and climate change planning efforts (e.g. State Implementation Plan or SIP and Climate Change Scoping Plan).

The newly developed, stand-alone SORE2020 Model reflects the recovering California economy from the 2008 economic recession and incorporates emission results from CARB's recent in-house testing as well as CARB's most recent Certification Database. CARB also has conducted an extensive survey of SORE operating within California through the Social Science Research Center (SSRC) at the California State University, Fullerton (CSUF). Data collected through this survey provides the most up-to-date information regarding the population and activity of SORE equipment in California. The new SORE2020 Model incorporates the latest information for the base year population, population growth, equipment usage (hours/year), spatial allocation, and emission factors, along with an intuitive, graphical user interface. As compared to the previous emissions inventory model, OFFROAD2007, which only contained equipment used in the residential and business[1] sectors, the SORE2020 Model also includes a third sector referred to here as vendors[2]. In addition, electric-powered SORE equipment is included to estimate the impact of the increasing trend toward electrification in the Lawn & Garden and Light Commercial categories. The SORE2020 Model is designed to be user-friendly and allows flexibility in selecting categories with specified inputs, such as population, activity, or emission factors, to accommodate custom outputs or to run different scenarios.

Figure 1 below compares the summer statewide baseline emissions for all SORE categories from OFFROAD2007 and SORE2020 for calendar years 2020 through 2050.

[1] Businesses are defined as all businesses within the State of California, excluding those involved in landscaping or lawn/garden care

[2] Vendors are defined as any businesses involved in lawn and garden care, landscaping, or landscaping-related activities (such as landscape architecture or design) within the State of California.

The Reactive Organic Gases (ROG) emission estimates from SORE2020 are higher than those from OFFROAD2007, and range from 23 percent higher in calendar year 2020, to a 4 percent difference in 2050. Similarly, the Oxides of Nitrogen (NO_x) emission estimates from SORE2020 are also higher than OFFROAD2007, and range from 15 percent higher in calendar year 2020, to 10 percent higher in 2050. The population of equipment in the vendor sector is relatively low, however the activity is significantly higher than it is for those designated for residential use. In addition, the total equipment population in the Light Commercial category was updated in the SORE2020 Model, which resulted in a three-fold increase in emissions despite the fact that equipment usage in the final SORE2020 Model for light commercial equipment ended up being lower than in OFFROAD2007. The increase in the population of the Light Commercial category was one of the main reasons for the increase in total emissions in the SORE2020 Model versus OFFROAD2007, as shown in Figure 1 below.

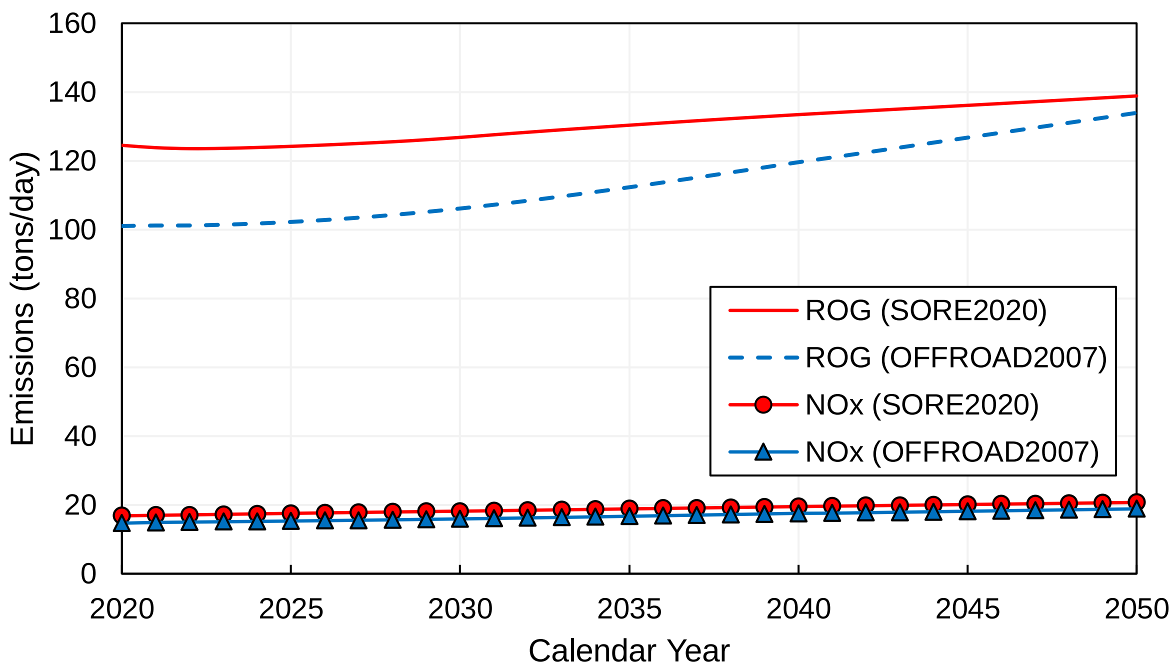


Figure 1. Baseline Statewide Summer Emissions for All SORE Categories (SORE2020 vs. OFFROAD2007)

Figure 2 shows the baseline emissions of just the Lawn & Garden equipment category from OFFROAD2007 and SORE2020. The Lawn & Garden emissions from SORE2020 are lower than they are in OFFROAD2007 mainly due to a lower equipment population. The 2018 CSUF SORE survey indicated that the population of gasoline Lawn & Garden equipment in 2018 is approximately 11 million, as compared to the 16 million units of equipment that were previously estimated by the OFFROAD2007 model. The growing popularity of electric-powered Lawn & Garden equipment has significantly shifted the sales from gasoline to electric equipment. In 2018, almost 47 percent of Lawn &

Garden equipment in California was estimated to be electric. Similarly, Figure 3 compares the baseline emissions of the Light Commercial category from OFFROAD2007 and SORE2020. The total emissions from the Light Commercial category are higher than in OFFROAD2007, due to a nearly seven-fold increase in the population observed from the 2018 CSUF SORE survey. For example, the OFFROAD2007 Model was estimating a total of 439,000 units of Light Commercial equipment in 2018 as compared to approximately 3.2 million units of equipment estimated by the 2018 CSUF SORE survey. The CSUF SORE survey also indicated that in 2018, there were approximately 7.8 million units of electric Light Commercial equipment operating in California, the majority of which were air compressors, pressure washers, and pumps.

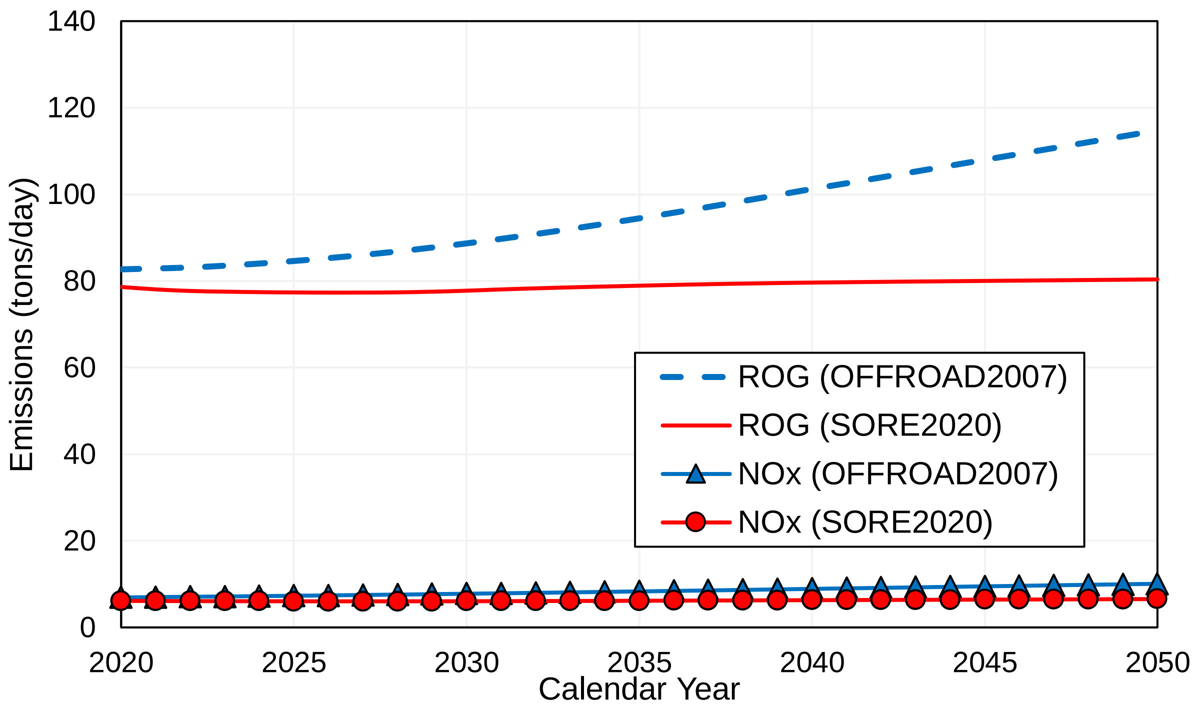


Figure 2. Baseline Statewide Summer Emissions for Lawn & Garden Equipment (SORE2020 vs. OFFROAD2007)

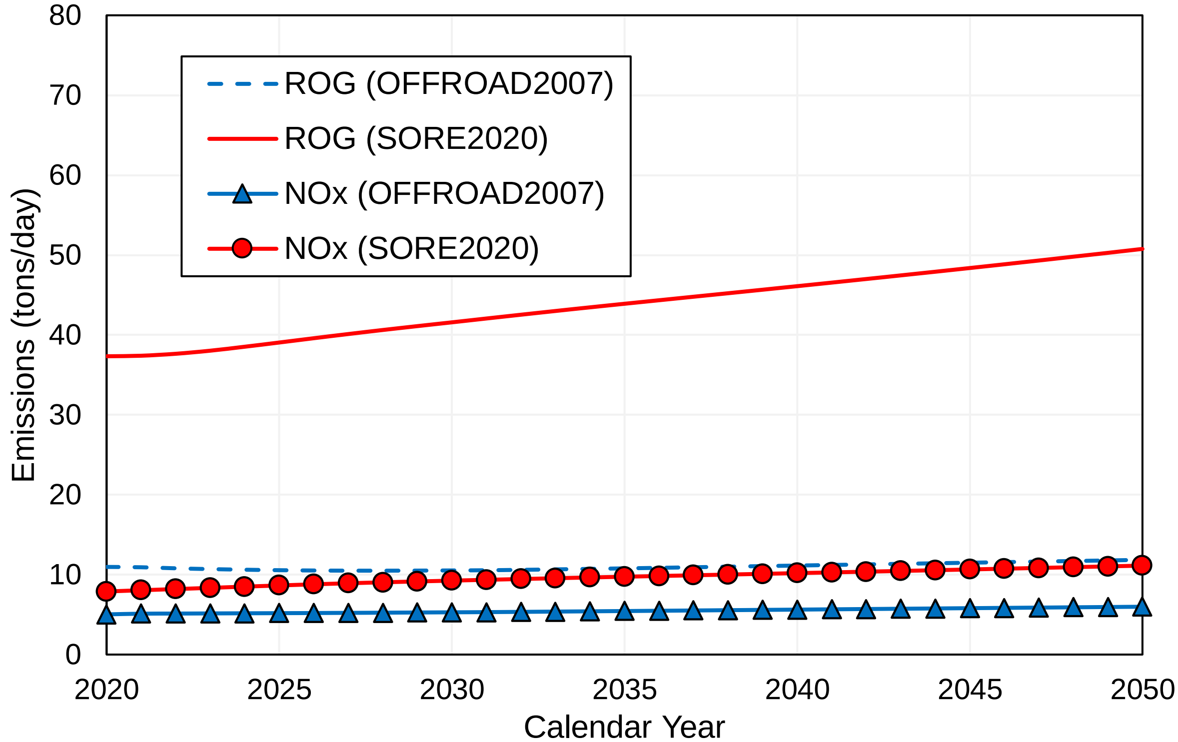


Figure 3. Baseline Statewide Summer Emissions for Light Commercial Equipment (SORE2020 vs. OFFROAD2007)

2. Background

Despite significant improvement in California's air quality in the last four decades, several areas in California are still classified as nonattainment with national ambient air quality standards (NAAQS). The South Coast and the San Joaquin Valley are the only two areas in the nation with an "Extreme" classification for the federal ozone standard. The health and economic impacts of exposure to elevated levels of air pollution in California are considerable; improving air quality will pay substantial dividends in terms of reducing costs associated with emergency room visits and hospitalization, lost work and school days, and most critically, premature mortality.

Historically, mobile sources have been the largest contributor of air pollutants in California. As on-road mobile sources have become progressively cleaner, the emissions from off-road sources, as well as mobile sources under federal and international jurisdiction (e.g., ships, locomotives, and aircraft), have become relatively more significant. This requires CARB to develop innovative policies and enforcement strategies to achieve further emissions reductions from these equipment and vehicles. To effectively develop these policies and strategies, it is necessary to develop an updated and more detailed understanding of emissions and characteristics of off-road equipment in California.

Small off-road engines include spark-ignition, gasoline-powered two-stroke (G2) engines, gasoline-powered four-stroke (G4), and compressed natural gas (CNG) engines, rated at or below 19 kilowatts (25 horsepower [hp]) which are utilized within a broad range of equipment in a variety of different categories such as:

- Lawn & Garden
- Light Commercial
- Industrial
- Construction
- Logging
- Transport Refrigeration Units (TRU)
- Airport Ground Support (GSE)
- Agriculture

In the SORE2020 Model, about two-thirds of the equipment are within the Lawn & Garden category and about one-third of SORE equipment are in the Light Commercial category. Tables 1 and 2 below describe the most common Lawn & Garden and Light Commercial SORE equipment used in California.

Table 1. Common SORE Equipment (Lawn & Garden)

Equipment Type	Equipment Photo	Description
Lawn Mower		A machine utilizing one or more revolving blades to cut a grass surface to an even height
Chainsaw		A portable, mechanical saw which cuts with a set of teeth attached to a rotating chain

Equipment Type	Equipment Photo	Description
Trimmer		A garden tool used for cutting grass and groundcover using a flexible monofilament line instead of a blade
Leaf Blower		A gardening tool that propels air out of a nozzle to move debris, such as leaves and grass cuttings
Riding Mower		A type of lawn mower on which the operator is seated, unlike mowers which are pushed or towed

Table 2. Common SORE Equipment (Light Commercial)

Equipment Type	Equipment Photo	Description
Generator		A portable device which provides temporary electrical power
Pump		A device that moves fluid or water for irrigation, well-water, or firefighting applications

Equipment Type	Equipment Photo	Description
Compressor		A device that converts power into potential energy stored in pressurized air
Welder		A machine used to fabricate and assemble metal structures and equipment
Pressure Washer		A high-pressure sprayer used to remove loose paint, mold, grime, dust, mud, and dirt from surfaces

Most of the SORE are gasoline powered and therefore they are a significant source of ROG and NO_x emissions, which are precursors to smog. Though major progress has been made in reducing ROG and NO_x through exhaust emission standards implemented between 1995 and 2008 and evaporative emission standards implemented between 2006 and 2013, emissions from SORE are still higher than the emissions emitted from the 14.4 million passenger cars operating on California roadways.

The SORE2020 Model estimates the statewide emissions from SORE equipment in eight different categories, as listed in Table 3.

Table 3. All SORE Equipment Types by Category (SORE2020 Model)

Category	Equipment Type	Preempt (P) or Non preempt (N)
Lawn and Garden	Chainsaws	N
	Chainsaws Preempt	P
	Chippers/Stump Grinders/Shredders	P
	Lawn Mowers	N
	Leaf Blowers/Vacuums	N
	Other Lawn & Garden Equipment	N
	Riding Mowers	N
	Snow Blowers	N
	Tillers	N
	Trimmers/Edgers/Brush Cutters	N
	Wood Splitters	N
Light Commercial	Air Compressors	P
	Generator Sets	N
	Pressure Washers	N
	Pumps	N (<40cc), P (≥40cc)
	Welders	P
Industrial	Aerial Lifts	P
	Forklifts	N
	Other General Industrial Equipment	N
	Sweepers/Scrubbers	N
Construction	Asphalt Pavers	P
	Bore/Drill Rigs	P
	Cement and Mortar Mixers	P
	Concrete/Industrial Saws	P
	Crushing/Processing Equipment	P
	Dumpers/Tenders	P
	Paving Equipment	P
	Rollers	P
	Signal Boards	P
	Skid Steer Loaders	P
	Surfacing Equipment	P
	Tampers/Rammers	P
	Trenchers	P
Logging	Chainsaws	P
Transport Refrigeration Units (TRU)	Transport Refrigeration Units	N
Airport Ground Support	Cart	N
	Lavatory Cart	N
Agriculture	2-Wheel Tractor	P
	Agricultural Mower	P
	Hydro Power Units	P
	Other Agricultural Equipment	P
	Sprayers	P
	Tillers	N

The 1990 amendments to the federal Clean Air Act preempt California control of emissions from new farm and construction equipment under 175 horsepower. Emissions from these new engines are beyond CARB's authority to regulate. U.S. EPA has sole authority to establish emission standards for these preempt engines. Table 3 provides a list of the preempt equipment under the SORE category. Of the eight major categories covered by the SORE2020 Model, the Lawn & Garden and Light Commercial categories, representing over 97 percent of SORE, are the two that have undergone major updates and revisions. The population and activity for these two categories were updated using the latest data collected in 2018. The SORE equipment residing in other categories, including Construction, Industrial, Agriculture, and Airport Ground Support, have not been updated and were carried over into the SORE2020 Model from OFFROAD2007. The SORE2020 Model provides two additional features:

- The addition of a third sector in the Lawn & Garden and Light Commercial categories to include equipment from vendors/landscapers
- The addition of electric-powered equipment populations in the Lawn & Garden and Light Commercial categories

The vendor sector represents any business involved in lawn and garden care, landscaping, or landscaping-related activities (such as landscape architecture or design) within the State of California and include both licensed and unlicensed landscapers. Though the population of lawn and garden equipment utilized by this sector is small, the annual activity is significant from daily use for landscaping services provided. The inclusion of electric-powered Lawn & Garden and Light Commercial equipment in the SORE2020 Model, is essential due to recent advancements in battery technology and lawn and garden equipment exchange programs sponsored by local air districts. The popularity of electric SORE equipment has steadily increased among the general public, and the SORE2020 Model tracks the growth trends of the electric SORE population in relation to their gasoline-powered counterparts.

3. Data Sources

Inventory estimates rely on multiple data sources to best characterize the amount of emissions from SORE equipment. Table 4 lists the data sources used to update the inventory inputs including population, activity, and emission rates.

Table 4. Summary of Data Sources in SORE2020

Source	Engine	Equipment	Frequency	Estimate Method	Model Input
Survey: 2001, 2012, 2018		+	One Time	Survey	Population, Activity
SORE Certification Database	+		Annual	Manufacturer Submission	Emission Factor, Avg. HP
SORE Production Line Testing (PLT)	+		Quarterly	Manufacturer Submission	Population
SORE Evaporative Reporting		+	Annual	Manufacturer Submission	Population, Avg. HP
CARB Emission Testing	+	+	One Time	Actual Testing	Emission Factor

3.1 2018 SORE Survey

CARB determined that it was necessary to obtain updated information, including an estimate of the population of existing SORE equipment operating in California, electric-powered equipment versus gasoline-powered equipment, annual usage in hours per year, and equipment life cycle. Because SORE equipment are not individually registered, unlike passenger vehicles, it was necessary to develop population estimates for SORE based on a survey which was then extrapolated to estimate the total SORE population. CARB contracted with SSRC at CSUF in 2018 to conduct a statewide telephone survey to obtain this information. To obtain full coverage of the equipment population, three sectors were separately surveyed, including (1) residential households, (2) businesses, and (3) vendors/licensed and unlicensed landscapers. The residential survey included single family residences, apartments, condominiums, town houses, and mobile homes or recreational vehicles, with 70 percent of the respondents in single family homes. The business survey included all businesses within California, excluding home-based businesses and those involved in the landscaping or lawn/garden care industry. The vendor survey included any licensed or unlicensed business involved in lawn/garden care, landscaping, or landscaping-related activities (e.g., landscape architecture or design) throughout the state.

To estimate the population of equipment owned by California households, CSUF completed 1,152 telephone surveys of residences, inquiring about the pieces of SORE equipment they owned, specifically lawn and garden and other outdoor power equipment. CSUF used statistical method to analyze the survey data and estimate the statewide population. In addition to collecting information on the population of equipment owned by households, where possible, data were collected on the power type, usage pattern, age, and retention time of each equipment. Approximately 75 percent of the respondents lived in a residence with a landscaped area, in which 50 percent performed their own landscape maintenance, 30 percent contracted a landscape service or vendor, and 20 percent utilized a combination of both. In addition, nearly 40 percent of residences owned equipment in the Light Commercial category, including compressors, generators, and pressure washers.

While the CSUF's methodology to scale up the survey results to estimate the statewide population is statistically sound, it does not take into account the geographical characteristics of the samples. For instance, snow blowers are likely to be found in high elevation areas rather than in coastal areas. As a result, staff processed the CSUF household survey data and weighted it, with respect to geographical area and housing type, to arrive at the final fleet population estimate for residential equipment (commercial and vendor equipment populations are not re-weighted from the CSUF survey's original reported numbers). The revised method took into account geographical areas separated by northern, central/upper, and southern portions of the state and geographical weights are used to proportionally reflect the higher concentration of households primarily in the southern and northern bay areas of the state, as compared to the rural regions of central and far northern California. To do that, the data obtained from the residential survey were further aggregated by respondent dwelling: single family residence (SFR) or non-SFR (apartment/condo/town house/mobile home). In addition, single family homes are distinguished from apartment/condo dwellings as a weighting factor, due to a greater likelihood of possessing SORE equipment. Appendix A contains further details on the geographical weights and methodology.

For the business sector, CSUF interviewers completed 1,350 telephone surveys statewide to obtain population estimates for SORE equipment utilized/stored at businesses. Approximately 50 percent of the businesses surveyed possessed a landscaped area that required maintenance, of which 75 percent utilized a landscaping service or vendor. The survey revealed that approximately 15 percent of the businesses owned Lawn & Garden equipment, and 25 percent owned Light Commercial SORE equipment. Survey data were collected on population, power type, usage, and average age for equipment owned/stored at businesses.

For the vendor/independent gardener sector, CSUF surveyed 471 licensed vendors and 158 unlicensed vendors in California. Nearly 100 percent of licensed and unlicensed vendors possessed several types of SORE equipment under the Lawn & Garden category and at least 30 percent owned equipment in the Light Commercial category. The majority of equipment owned by vendors is gasoline powered, primarily driven by the vendors to specific performance needs. Survey data were collected on population, power type, activity, and age of equipment from the vendor sector. Figure 4 illustrates the survey participation by sector.

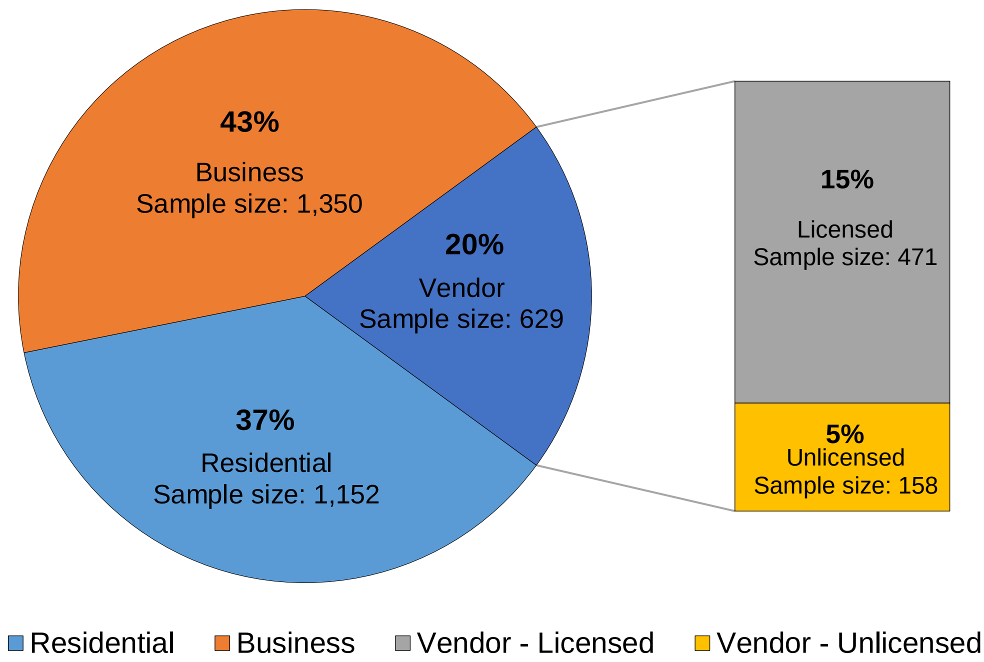


Figure 4. 2018 CSUF Survey Participants

The results from the residential, business, and vendor surveys were combined to obtain an overall estimate of the SORE population statewide, in addition to information on gasoline versus electric power types, annual usage, and average life span of SORE equipment operating within California.

3.2 SORE Certification Database

Certification applies to all SORE manufacturers subject to California's exhaust and evaporative emission standards and test procedures, as required for engine sales in California. As part of the SORE certification, engine manufacturers must provide emission test data for each test engine during the application process. CARB's current SORE Certification Database contains data collected from year 2002 through 2018. Certification data were utilized in the update process for the zero-hour emission factors in the SORE2020 Model, as well as to determine the average horsepower, horsepower splits, and weighted average durability hours of residential and commercial equipment.

3.3 Production Line Testing (PLT) Data

CARB's exhaust emission regulations for SORE require that manufacturers submit PLT results for small off-road engines on a quarterly basis and Title 13, of the California Code of Regulations, requires that manufacturers submit quarterly reports on engine production volume. For model years 2000 and later, engine manufacturers are also required to provide either (1) actual California sales data or (2) other information acceptable to the Executive Officer, including estimates based on market analyses and federal production or sales.

Table 5 lists a sample of equipment types from PLT data. Small gasoline engine equipment often utilize general-purpose engines used in different categories such as Lawn & Garden, Light Commercial, Agricultural, and Construction Equipment; the majority of engines produced are utilized within the Lawn & Garden and Light Commercial categories.

Table 5. Equipment Types from PLT Data

Category	Equipment
Lawn & Garden	Chainsaws
	Chipper/Stump Grinders
	Commercial Turf
	Lawn & Garden Tractors
	Lawn Mowers
	Leaf Blowers
	Riding Mowers
	Shredders
	Snow Blowers
	Tillers
	Trimmers
	Wood Splitters
Light Commercial	Air Compressors
	Generator Set
	Pressure Washers
	Pumps
	Welders
Other	Augers
	Bullwheel Tensioners
	Cement & Mortar Mixers
	Compactors
	Dusters
	Paving Equipment
	Sprayers

Staff used the reported PLT production data for years 2002 to 2018 to determine the past shipment growth rates for small engines. These production numbers incorporate both U.S. and California engine production data. In some cases, California production numbers may be an estimate based on market analysis and U.S. production or sales. Since the California production numbers may be an estimate, staff used the U.S.

production growth trends as a proxy for California's historical small engine growth rates. Table 6 below provides the historic shipment growth rates for years 2002 through 2018. A portion of the actual production may be absent from what is shown below due to missing or un-readable reports.

Table 6. Historic Shipment Growth Rates (PLT)

Year	U.S. Production	Historical Shipment Growth Rate (%)
2002	11,925,535	4.0
2003	14,733,427	23.5
2004	17,503,333	18.8
2005	20,619,063	17.8
2006	25,580,666	24.1
2007	8,846,597	-65.4
2008	6,372,493	-28.0
2009	3,597,041	-43.6
2010	14,793,145	311.3
2011	18,639,703	26.0
2012	21,135,820	13.4
2013	22,165,925	4.9
2014	23,260,578	4.9
2015	23,178,997	-0.4
2016	23,482,173	1.3
2017	23,670,803	0.8
2018	25,149,589	6.2

3.4 Manufacturer Evaporative Production Volume Reports (PVR)

Since 2018, equipment manufacturers are required to submit evaporative family PVR annually to CARB. Specifically, manufacturers must report the production volume for each of their certified small spark-ignition evaporative families on an annual basis. In addition, production volume must be provided for each equipment type, by engine family and fuel tank volume, within each evaporative family. Production volume represents the number of engines or equipment units produced for sale under the evaporative engine family Executive Order (EO) that the manufacturer has a reasonable basis to conclude were or may be available for purchase within California. The manufacturer may estimate production volume through market analysis but must provide supporting documentation.

Manufacturers' end-of-year production volume reports for each small spark-ignition evaporative family must be submitted within 90 days of the end of the model year, and final production volume reports must be submitted within 270 days of the end of the model year for all 2018 and later models. For each evaporative family, the regulation requires manufacturers to break down production numbers by equipment type. In situations where the exact breakdown is not available, manufacturers may provide "an educated and consistent estimate with the best available documentation."

Due to the limitations of the PLT database, staff used evaporative PVR data to better ascertain how small engines are utilized with regards to the specific equipment types. Since the PLT data lists only the engine family, a particular engine may be placed in multiple types of equipment, such as in lawn mowers, pressure washers, or compressors. Staff utilized the 2018 manufacturer evaporative PVR to determine *specific* engine production numbers for individual equipment types. Where available, CARB staff used evaporative PVR data to refine the modeling of population estimates to match first year sales in 2018. Note that since 2018 was the first year for evaporative reporting, some PLT engine families may have not been represented.

4. Emissions Inventory Inputs

4.1.1 Population

Population estimates for small gasoline engines are based on past and recent surveys and studies, including CARB's 2001 Lawn & Garden Study, 2012 Lawn & Garden Survey (ARB), and the "Survey of Small Off-Road Engines (SORE) Operating within California: Results from Surveys with Four Statewide Populations" (CSUF, 2018). Note that the 2001 and 2012 surveys primarily focused on the residential sector, whereas the 2018 survey included all SORE equipment including those owned by residents, businesses, and vendors. The 2018 survey is the first comprehensive survey that attempted to cover all SORE in California. In addition to the 2018 SORE survey, staff also utilized production volume data from both PLT data for years 2002 through 2018 and the 2018 SORE evaporative PVR data. For thoroughness, the population estimates developed by CARB staff were compared against shipment data and market research results to assess reasonableness.

To forecast the population of small off-road engines, staff utilized the methodology described below:

1. Fleet data for small engine equipment were extracted from surveys conducted in calendar years 2001, 2012, and 2018. Fleet data include both gasoline and electric-powered (cord and battery) engines.
2. Age distributions for each equipment type were obtained from 2001, 2012, and 2018 surveys.

3. Age distributions for each equipment type were then used to estimate the survival curves (i.e. the number of years a piece of SORE equipment is used before being scrapped).
4. The first year sales/shipment data were extracted from PLT and 2018 SORE evaporative PVR data.
5. Staff then developed a population model that estimated the population of SORE equipment from 2000 to 2018, for each equipment type, by fuel type (gas/electric) and user type (residential/commercial [business]/vendor), utilizing the first year sales and survival rates. The model results were aligned with the fleet survey values from 2001, 2012, and 2018 surveys, and the sales growth rates from year 2002 to 2018 were based on the PLT data. Using this method, staff adjusted the survival curves such that the model accurately reflected equipment population for the years where actual fleet data are available.
6. For future years, calendar year 2019 and onward, CARB staff utilized household growth as a surrogate to forecast the population of SORE in the future.
7. The fleet population estimates and first year sales were further evaluated using additional sources such as Outdoor Power Equipment Institute (OPEI) shipment data and 2018 SORE Evaporative reporting data.

Additional details and examples of the population modeling methodology used by CARB staff are included in Appendices A through D. Table 7 provides the base year populations for the 2018 calendar year from the SORE2020 Model. Note that front mowers, lawn & garden tractors and rear engine riding mowers have been combined and labeled as “Riding Mowers.” Likewise, shredders have been combined with chippers/stump grinders under the label of “Chippers/Stump Grinders/Shredders.”

Table 7. 2018 Base Year Population (SORE2020)

Category	Equipment	SORE2020 Base Year Population (CY2018)		
		Gasoline	Electric	Total
Lawn & Garden	Chainsaws	1,417,055	836,104	2,253,159
	Chainsaws Preempt	763,029	450,210	1,213,239
	Chippers/Stump Grinders/Shredders	10,401	3,772	14,172
	Lawn Mowers	3,665,918	1,095,836	4,761,754
	Leaf Blowers/Vacuums	1,446,774	3,325,559	4,772,333
	Other Lawn & Garden Equipment	46,805	0	46,805
	Riding Mowers	378,523	17,393	395,916
	Snow Blowers	55,892	4,000	59,892
	Tillers	87,232	11,383	98,615
	Trimmers/Edgers/Brush Cutters	2,751,448	3,726,353	6,477,800
	Wood Splitters	107,033	0	107,033
	Air Compressors	264,855	3,215,602	3,480,457

Category	Equipment	SORE2020 Base Year Population (CY2018)		
		Gasoline	Electric	Total
Light Commercial	Generator Sets	1,639,897	307,291	1,947,188
	Pressure Washers	919,103	1,705,284	2,624,387
	Pumps	146,244	1,737,520	1,883,764
	Welders	193,359	810,520	1,003,879

4.1.2 Survival Rate

The survival rate estimates the attrition or scrappage of engines with respect to age. The methodology to extract the survival rate is complex and results in obtaining the best fit regarding the equipment population modeling. The first step requires the determination of the year-over-year (YOY) age distribution for base year 2000. The age distribution was derived from the 2001 survey. Next, the general shape of the YOY age distribution was used to calculate survival rates. The methodology assumes a survival rate using the base population in CY2000 and forecast to CY2012 and then CY2018 for a given survival rate. After several trials of different survival rates, pre-recession years (2000 to 2007) and post-recession years (2008 and after) survival rates were selected based on their closest match to 2012 and 2018 fleet population values from the CARB surveys. Other factors, such as first year sales data from the SORE evaporative PVR requirement, assisted in determining the best fit survival rate. A list of the calculated survival rates for major SORE equipment can be found in Appendix C.

Below is an example to further illustrate how survival rates are utilized in the SORE2020 Model to forecast the population of gasoline and electric equipment. For this example, assume the population of residential chainsaws of model year 2018 in calendar 2018 is 100. Note most SORE equipment are not sold in the same calendar year they are produced, and some may be in various stages of distribution for a few years before they are sold. This lag time results in an increase of the survival rate for the first couple years, as shown in the following example. Using the survival rate, one can estimate the model year population of chainsaws in future years:

- Population of MY2018 residential chainsaws in CY2018 is 100
  (this is a hypothetical assumption)
- Population of MY2018 residential chainsaws in CY2019 becomes
  *100 * 1.35 = 135 where 1.35 is the survival rate of residential chainsaws at age 1*
- Population of MY2018 residential chainsaws in CY2020 becomes
  *135 * 1.10 = 148.5 where 1.10 is the survival rate of residential chainsaws at age 2*
- Population of MY2018 residential chainsaws in CY2021 becomes
  *148.5 * 1.03 = 153 where 1.03 is the survival rate of residential chainsaws at age 3*
- Population of MY2018 residential chainsaws in CY2022 becomes
  *153 * 1.002 = 153.3 where 1.002 is the survival rate of residential chainsaws at age 4*
- Population of MY2018 residential chainsaws in CY2023 becomes
  *153.3 * 0.97 = 149 where 0.97 is the survival rate of residential chainsaws at age 5*

- This process is repeated to estimate the population of MY2018 residential chainsaws in all future years.

4.1.3 Annual Sales Growth Forecast

To forecast the annual sales growth of small off-road engines, CARB staff considered a number of different growth surrogates whose behavior mirrors the sales of SORE, including household formation, changes in automobile vehicle registration, and growth of capital goods. Annual sales growth is representative of the growth in the "first year" sales as opposed to the overall fleet growth. California's household formation is a good proxy for small engine growth, since the number of small engines per household is similar to the per capita of durable goods. In addition, the number of small engines a household possesses would remain relatively consistent over the years, and is not likely to fluctuate wildly, thus rendering it a stable, long-term forecast indicator. The actual annual growth rate for small off-road engines may fluctuate with positive or negative values; however, the overall average annual growth would remain relatively constant in the long term.

Figure 5 shows the historic growth in of the number of California households based on data compiled by the California Department of Finance (DOF). The data were analyzed assuming two discrete time periods (2000 - 2008, 2009 - 2018) to account for the effects of the 2008 recession on sales. A third order polynomial was fitted for the California household data, from 2000 to 2008, and the average year over year growth was determined to be about 1 percent. A separate second order polynomial was fitted for the California household data from 2009 to 2018.

Due to the economic downturn as a result of the recession, the post-recession second slope from 2009 to 2018 averaged 0.4 percent. The second order polynomial was extrapolated regressed from 2019 to 2030 to obtain the future year forecast, which is projected to have an average growth of 0.6 percent, as seen in Table 8 below. For inventory modeling purposes, it was assumed that for 2019 and beyond, the annual growth would maintain this 0.6 percent rate.

Staff also analyzed the California household data from 2000 to 2018 and found the overall average California household growth to be about 0.68 percent, despite experiencing a major economic recession from about 2008 to 2010. Overall, the annual growth estimated for the SORE is reasonable and consistent with the changes in the California household data.

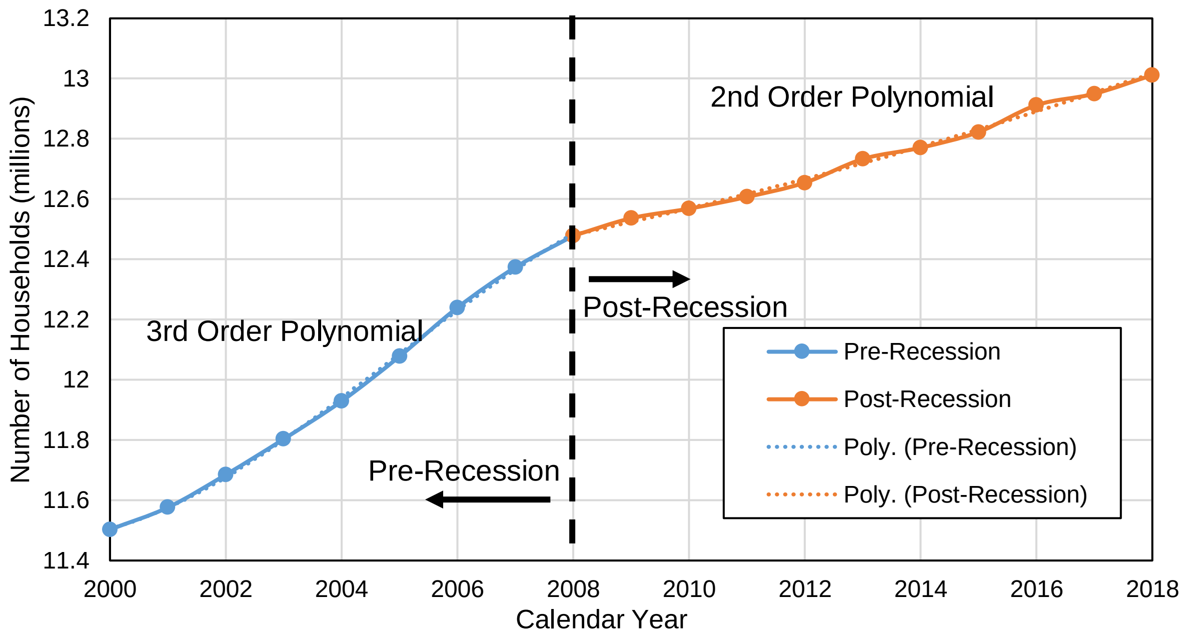


Figure 5. 2000-2018 California Household Growth (CA Department of Finance)

Table 8. Average Annual Growth Rates (Historical and Projected Data)

Calendar Year	California Household*	Polynomial Regression of CA Household	Annual Growth Rate (%)	Comment
2000	11,502,871	11,498,197		Pre-recession average growth rate of 1%
2001	11,576,277	11,568,091	0.61%	
2002	11,685,031	11,669,164	0.87%	
2003	11,803,283	11,793,305	1.06%	
2004	11,928,994	11,932,404	1.18%	
2005	12,077,568	12,078,350	1.22%	
2006	12,239,726	12,223,032	1.20%	
2007	12,373,402	12,358,339	1.11%	
2008	12,478,123	12,476,159	0.95%	
2009	12,536,360	12,524,069	0.38%	Post-recession average growth rate of 0.4%
2010	12,568,167	12,569,130	0.36%	
2011	12,607,090	12,616,642	0.38%	
2012	12,654,509	12,666,604	0.40%	
2013	12,732,969	12,719,016	0.41%	
2014	12,770,525	12,773,879	0.43%	
2015	12,822,751	12,831,191	0.45%	
2016	12,911,897	12,890,954	0.47%	
2017	12,949,741	12,953,167	0.48%	
2018	13,011,609	13,017,830	0.50%	

Calendar Year	California Household*	Polynomial Regression of CA Household	Annual Growth Rate (%)	Comment
2019	Projected by CARB Staff	13,084,943	0.52%	Future average growth rate of 0.6%
2020		13,154,506	0.53%	
2021		13,226,520	0.55%	
2022		13,300,984	0.56%	
2023		13,377,898	0.58%	
2024		13,457,262	0.59%	
2025		13,539,076	0.61%	
2026		13,623,341	0.62%	
2027		13,710,055	0.64%	
2028		13,799,220	0.65%	
2029		13,890,835	0.66%	
2030		13,984,901	0.68%	

* Source: California Department of Finance

After the base year population of 2018, CARB staff set the targeted future growth rate in the model to be 0.6%, for small off-road engines, including both gasoline and electric types. To account for fleet growth, the sales-weighted growth rates for each type of equipment were derived to achieve the composite 0.6 percent fleet population growth target for all small off-road engines. Although some SORE equipment may grow at a rate greater than 0.6 percent, the composite of all small engine growth hits this target rate. As shown in Table 9 below, these growth rates are conservative and lower than the 1.3 to 1.9 percent growth, as reported by market research documented by the Freedonia Group.[3] For gasoline handheld equipment (e.g., chainsaws, leaf blowers, and trimmers), the growth rate was assumed to be zero. This zero percent growth assumption for gasoline handheld equipment was derived from industry feedback[4] and the analysis of PLT data trends for handheld equipment.

For ground-supported equipment, such as lawn mowers, generators, and riding mowers, shipment data suggests an overall growth of 0.5 percent. While the PLT shipment data does not identify which equipment grows at a faster rate than others, industry data[4] indicated that sales of gasoline walk-behind lawn mower has flattened due to the increase in sales for both electric and gasoline riding mowers. From this information, the future growth of ground-support equipment is most likely to occur in the Light Commercial category, which includes gasoline generators, pressure washers and pumps. As shown in Table 9, for all Lawn & Garden equipment except for riding mowers, staff assumed there would be no growth in sales of gasoline-powered equipment into the future. While industry data[4] suggested a much higher growth rate

[3] Freedonia Group. Power Lawn & Garden Equipment. September 2018.
[4] http://www.opeesa.com/wp-content/uploads/2019/03/2019-B-Melka-State-of-the-Industry.pdf

than one percent for consumer and commercial riding mowers, staff used the one percent growth rate as a long term forecast.

Also note that the purpose of this forecasting exercise was to illustrate how the model determines the long term baseline growth of gasoline and electric equipment, for both the Lawn & Garden and Light Commercial categories. For example, the PLT data shows that starting in 2010 there has been a steady growth in the national market of SORE, with California closely following that trend. While 2013 to 2014 marked a drop in shipment of SORE equipment to California, there was an increase in SORE equipment sales to California in 2015[5]. Therefore, significant increases or decreases in sales from one year to the next cannot be used as a surrogate for growth and an analysis, consisting of multiple years of data, is essential to derive a representative baseline growth rate for each equipment category in the SORE2020 Model.

Table 9. Average Growth Rates (SORE2020)

Equipment	2018 New Sales*		Compound Annual Growth Rates (CAGR) assumed in SORE2020		Targeted Weighted Composite Growth	Freedonia Group Market Research Composite Unit Growth
	Gas	Electric	Gas	Electric		
Lawn Mower	364,000	110,000	**0.00%**	1.80%	0.42%	1.80%
Chainsaw	201,000	144,000	**0.00%**	1.43%	0.60%	1.90%
Leaf Blower	249,000	556,000	**0.00%**	0.87%	0.60%	1.70%
Trimmer	432,000	728,000	**0.00%**	0.95%	0.60%	1.30%
Generator	224,000	40,000	1.20%	0.00%	1.02%	N/A
Pressure Washer	131,000	285,000	0.60%	0.60%	0.60%	N/A
Compressor	37,000	431,000	0.60%	0.60%	0.60%	N/A
Riding Mower	29,000	2,000	1.00%	0.00%	0.94%	N/A
Welder	23,000	91,000	0.30%	0.50%	0.46%	N/A
Pump	18,000	241,000	0.60%	0.60%	0.60%	N/A
Tiller	10,200	820	**0.00%**	0.00%	0.00%	N/A
Wood Splitter	5,480	2,000	**0.00%**	0.00%	0.00%	N/A
Snow Blower	5,100	630	**0.00%**	0.00%	0.00%	N/A
Chipper	1,150	430	**0.00%**	0.00%	0.00%	N/A
			Composite Growth		**0.60%**	

* These are approximate estimates

Appendix B contains a discussion on the other surrogates considered for growth, but not utilized.

[5] For more information see response to questions 21 on CARB's document titled "Webinar Questions and Answers" at: https://ww3.arb.ca.gov/msei/sore2020_march2020_public_workshop_q_and_a_ada.pdf

4.1.4 Inclusion of Electric Equipment

Historically, off-road emissions inventory modeling included only equipment powered by internal combustion engines fueled by gasoline, natural gas/liquid propane, or diesel. The updated SORE2020 Model includes populations from non-fuel based equipment, such as corded or battery-powered electric equipment. The use of electric motors for lawn and garden, and light commercial applications has increased over the last 20 years. As shown in Table 10, the Freedonia Group's market research report highlights the increasing popularity of electric-powered equipment, compared to gasoline-powered equipment, over the past 15 years.

Table 10. Market Research Historic Demand (Freedonia Group)

Year	U.S. Unit Demand (million)	
	Gas	Electric
2007	15.54	5.98 (27%)
2012	14.8	6.31 (30%)
2017	15.49	7.49 (33%)
2022	15.98	8.70 (35%)

Nationwide, approximately 35 percent of the small-engine market is now electric. In comparison to the larger, non-handheld equipment such as walk-behind lawn mowers, the sales of smaller engine types, such as leaf blowers and trimmers, has gravitated toward electric, as shown in Figure 6.

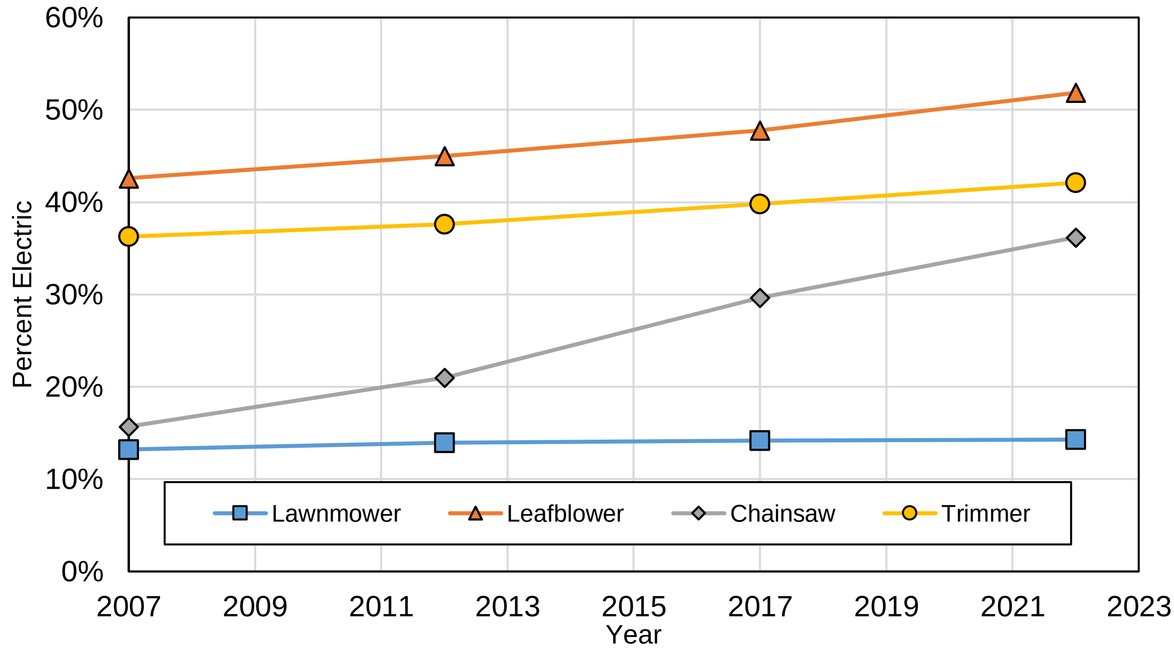


Figure 6. Trend of Nationwide Electrification by Equipment Type (2018 Freedonia Group)

In comparison to the nationwide trends shown in Figure 6, California's population of lawn and garden equipment that is electric is significantly higher in 2018, including leaf blowers (69.7 percent), trimmers (57.5 percent), chainsaws (36.5 percent), and lawn mowers (22.7 percent).

4.1.5 Population Comparison (SORE2020 vs OFFROAD2007)

Tables 11 and 12 below compare the 2018 population inputs in the SORE2020 Model to those from OFFROAD2007 and the range of population estimates from the 2018 CSUF survey, respectively.

Table 11. 2018 Population Comparison (SORE2020 vs OFFROAD2007)

Category	Equipment	2018 Population (OFFROAD2007)	2018 Population (SORE2020)		
		Gasoline	Gasoline	Electric	Total
Lawn & Garden	Chainsaws	1,869,499	1,417,055	836,104	2,253,159
	Chainsaws Preempt	961,701	763,029	450,210	1,213,239
	Chippers/Stump Grinders/Shredders*	2,612	10,401	3,772	14,172
	Commercial Turf	27,252	0	0	0
	Front Mowers	441,670	0	0	0
	Lawn & Garden Tractors	311,437	0	0	0
	Lawn Mowers	5,414,884	3,665,918	1,095,836	4,761,754
	Leaf Blowers/Vacuums	1,585,665	1,446,774	3,325,559	4,772,333
	Other Lawn & Garden Equipment	447,525	46,805	0	46,805
	Riding Mowers*	305,651	378,523	17,393	395,916
	Shredders	303,503	0	0	0
	Snow Blowers	90,018	55,892	4,000	59,892
	Tillers	150,065	87,232	11,383	98,615
	Trimmers/Edgers/Brush Cutters	3,852,156	2,751,448	3,726,353	6,477,800
	Wood Splitters	259,483	107,033	0	107,033
Light Commercial	Air Compressors	13,246	264,855	3,215,602	3,480,457
	Generator Sets	375,407	1,639,897	307,291	1,947,188
	Pressure Washers	30,795	919,103	1,705,284	2,624,387
	Pumps	70,577	146,244	1,737,520	1,883,764
	Welders	40,951	193,359	810,520	1,003,879

*Note: Front mowers, lawn & garden tractors, and rear engine riding mowers have been combined and labeled as "Riding Mowers." Likewise, shredders have been combined with chippers/stump grinders under the label of "Chippers/Stump Grinders/Shredders."

Table 12. 2018 Population Comparison (SORE2020 versus CSUF 2018 Survey)

Category	Equipment	Calendar Year 2018 Statewide	
		SORE2020 Model[6]	2018 CSUF Survey
		Total Population	Total Lower and Upper Bound Population Estimate
Lawn & Garden	Chainsaws (preempt & non preempt)	3,518,982	2,618,442–4,872,593
	Lawn Mowers	4,824,378	3,556,489–5,666,539
	Leaf Blowers/Vacuums	4,772,333	3,586,109–5,838,265
	Riding Mowers	395,916	6,130–31,638
	Snow Blowers	59,892	5,171–127,981
	Trimmers/Edgers/Brush Cutters	6,477,800	3,986,351–6,416,511
Light Commercial	Air Compressors	3,480,457	2,700,989–4,548,007
	Generator Sets	1,947,188	1,341,226–2,712,064
	Pressure Washers	2,624,387	1,993,077–3,268,933
	Pumps	1,883,764	1,309,294–2,685,668
	Welders	1,003,879	858,923–1,974,620

Staff also modeled the population estimates for Lawn & Garden and Light Commercial equipment using multiple updated inputs, including calculated survival rates, historical growth rates derived from PLT data, age distribution, and fleet population estimates based on 2001, 2012, and 2018 surveys and 2018 SORE evaporative reporting data. To verify the assumptions in the modeling process, an evaluation for reasonableness is included in Appendix D.

4.2 Activity

The activity or annual operation of off-road equipment is quantified in annual average hours of use and may vary by equipment type, horsepower and occupational sector. The activity values for SORE equipment were derived based on the average activity as obtained from the raw data provided by the 2018 SORE Survey for residential, business, and vendor applications. Table 13 contains a comparison of the updated activity in SORE2020 as compared to the previous values from OFFROAD2007, as well as EPA's NONROAD Model[7].

In processing the raw survey data, some responses were excluded from the activity analysis if insufficient or unreasonable information was provided in the responses (see Appendix J for more details). Criteria for the removal of responses include:

1. Those responses where either the frequency of use or duration of use was entered as "Don't know" or "Refused"
2. Fuel type other than gasoline (e.g., diesel, electric, propane)

[6] Refer to appendix A for the derivation of equipment population in SORE2020 model
[7] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf

3. Horsepower >25 (Business, Vendor)
4. Blank or missing data for either the frequency of use or duration of use
5. High frequency and/or duration
    a. Residential – Responses with ≥ 7 times per week for Lawn & Garden equipment, except blowers
    b. Business – Responses with ≥ 7 times per week and 8 hours per use for Lawn & Garden equipment
    c. Vendor – Responses with ≥ 7 times per week and 8 hours per use for Lawn & Garden equipment
6. Analysis of Comments – After reviewing comments[8] from OPEI received on June 30, 2020 regarding some of the survey responses with relatively high usage values (referred to by OPEI as outliers), staff conducted further evaluations of the equipment usage responses reported in all three 2018 surveys (i.e., residential, business, and vendor) and removed a number of the responses from the activity analysis that were deemed unreasonable or infeasible. This evaluation is further described in Appendix J

For the analysis presented in this document, all valid survey responses (except for those listed above) for frequency, duration and age were used 'as-is'. Some responses were binned in a range, in which the average value of the range of values reported was used. For example, if a response was in the range of "Four to eleven times per year", it would be assigned a value of "8 times per year" for data analysis purposes. One variation is for the response "At least once a day", which was assigned a value of "365" in the Business Survey; the Vendor Survey assigned a value of "312", based on the assumption of a 6-day work week for a typical vendor or independent gardener.

In addition, the Business and Vendor Surveys included responses for ownership of 'greater than 5 equipment' per each type of equipment, in which those responses were assigned a binned range, similar to the above; the average of the range was typically used. For the duration response range of "More than 1 hour", a value of "75 minutes or 1.25 hours" was assigned, which is a conservative assumption. The 'greater than 5 equipment' responses were processed along with the individual survey responses and used in the data analysis to derive the updated average activity for each equipment type. Using a similar analysis, staff also updated the number of starts per year for both the Lawn & Garden and Light Commercial equipment categories. The number of engine starts are used by the SORE2020 Model to help estimate the total hot soak evaporative emissions.

[8] OPEI's letter to CARB dated June 30, 2020 RE: OPEI Comments to CARB 6/9 Potential SORE Regulations Workshop

Table 13. Comparison of Average Activity (hrs/yr) – SORE2020, OFFROAD2007, and EPA NONROAD2008 Models

Category	Equipment	CARB's OFFROAD2007		EPA's NONROAD		CARB's SORE2020 - Gas		
		R	B	R	B	R	B	V
Lawn & Garden	Lawn Mower	16	229	25	406	19	84	240
	Chainsaw	5	289	13	303	18	53	140
	Trimmer	22	136	9	137	15	63	162
	Leaf Blower	5	196	10	282	15	149	207
	Other L&G	4	69	61		10	60	126
	Riding Mower	29	271	41*	645*	83	-	246
Light Commercial	Generator	91	134	115		50	146	62
	Pump	174	258	221		10	168	153
	Compressor	380	566	484		166	182	176
	Welder	208	208	408		44	115	25
	Pressure Washer	90	134	115		29	76	30

R: Residential **B**: Business/Commercial **V**: Vendor

* Average of Rear Engine Rider and Lawn & Garden Tractor

Regarding the utilization of the average activity versus activity by age of equipment in the SORE2020 Model, staff analysis showed that the emissions will become slightly higher if activity by age is used instead of an average activity across all ages. However, due to the lack of a sufficiently large sample size for each of the age bins, staff decided to use the average activity across all the age bins to model emissions, as further described in Appendix E.

4.3 Average Horsepower

Staff utilized the 2018 CARB Certification Database to compile the updated average horsepower for small off-road equipment. The average horsepower is calculated from both the certification reports, which provide horsepower data and the SORE evaporative PVR data, which provides production volume data. For example, for each engine family, staff searched the Executive Orders for the appropriate horsepower rating for the engine family, and used the production volume for that specific engine family and equipment to calculate the population-weighted average horsepower. For engine families with multiple horsepower ratings, an average horsepower was selected. Table 14 below shows the comparison between the updated average horsepower in SORE2020 as compared to the average horsepower in OFFROAD2007. Overall, the average horsepower values are lower in SORE2020 as compared to OFFROAD2007.

Table 14. Average Horsepower by Equipment Type (SORE2020)

Equipment	2018 Certification Data (Population Weighted)						OFFROAD2007			
	G2 0-2hp	G2 2-5hp	G4 0-5hp ≤80cc	G4 0-5hp	G4 5-15hp	G4 15-25hp	G2 0-2hp	G4 0-5hp	G4 5-15hp	G4 15-25hp
Chainsaw	1.65	2.15	-	-	-	-	1.03	-	-	-
Chipper/Stump Grinder/Shredder	-	-	1.47	4.35	6.80	-	-	4	11	18
Lawn Mower	-	-	2.10	3.84	5.42	16.77	-	4	-	-
Leaf Blower	1.07	3.14	3.23	3.52	8.95	23.97	1	2	-	-
Others	-	-	-	3.53	7.03	19.34	-	4	8	17
Riding Mower/Garden Tractor	-	-	-	3.58	9.16	22.65	-	-	11	18
Snow Blower	-	-	-	4.56	9.03	18.77	-	4	9	16
Tiller	1.39	-	1.16	3.48	5.74	-	-	4	-	-
Trimmer	1.11	2.12	1.51	3.70	6.22	17.22	0.9	1	-	-
Wood Splitter	-	-	2.55	4.08	7.31	21.79	-	5	-	-
Compressor	-	-	-	3.58	9.18	22.98	-	5	7	17
Generator	1.59	-	2.93	3.13	9.45	19.16	1	4	9	19
Pressure Washer	-	-	2.01	4.29	8.09	21.39	-	5	7	18
Pump	1.34	-	1.55	3.57	7.59	18.77	1	3	8	17
Welder	-	-	-	-	9.02	-	-	-	11	17

4.4 Load Factor

The load factor is the average operational level of an engine as a fraction or percentage of the engine manufacturer's maximum rated horsepower. For example, at a 0.3 (or 30 percent) load factor, an engine rated at 10 hp would be producing an average of 3 hp over the course of normal operation. Since emissions are directly proportional to engine horsepower, load factors are used in the emissions inventory calculations to adjust the maximum rated horsepower to normal operating levels. Load factors are difficult to characterize since they are highly dependent on equipment use and operation. Most equipment load factors are carried over from the OFFROAD2007 Model, with the exception of handheld equipment, such as chainsaws, blowers and trimmers. The steady-state duty cycle for laboratory testing for handheld equipment, submitted by manufacturers, has a load factor of 0.85. Additionally, US EPA's NONROAD Model[9] utilizes load factors that are higher than in OFFROAD2007. As stated in the US EPA's technical document (Report No. NR-005d published on July 2010), "for the three most populous handheld applications (i.e., chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums), the previous version of NONROAD assumed a load factor of 0.50.

[9] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf

The estimate of 0.50 was supplied by manufacturers to the California Air Resources Board in 1990 and is based on manufacturers' belief that it accurately reflects the typical usage pattern of most portable two-stroke power equipment. In support of a more recent effort to analyze the test cycle currently used for certification of Phase 1 handheld engines, manufacturers monitored the in-use operation of a number of chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums to determine the appropriate weighting of wide open throttle (WOT) and idle operation for certification testing purposes. Based on this information, the load factors for chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums are now 0.70, 0.91, and 0.94, respectively". Considering that US EPA is using more recent data on load factors as compared to CARB, staff has updated the load factors of chainsaws, trimmers and blowers to reflect the latest information from U.S. EPA. Table 15 lists the load factors utilized in the SORE2020 Model.

Table 15. Load Factors by Equipment Type (SORE2020)

Category	Equipment	SORE2020 Load Factor	OFFROAD2007 Load Factor
Lawn & Garden	Chainsaws	0.7*	0.5
	Lawn Mowers	0.36	0.36
	Leaf Blowers/Vacuums ≤ 5hp	0.94*	0.5
	Leaf Blowers/Vacuums > 5hp	0.36	0.36
	Trimmers/Edgers/Brush Cutters ≤ 5hp	0.91*	0.5
	Trimmers/Edgers/Brush Cutters > 5hp	0.36	0.36
Light Commercial	Air Compressors	0.56	0.56
	Generator Sets	0.68	0.68
	Pressure Washers	0.85	0.85
	Pumps	0.69	0.69
	Welders	0.51	0.51

*Updated using data from U.S. EPA

4.5 Median Life

Median life is a calculated value based on the equipment category's age distribution of all the equipment in that category. Generally, the median life is defined as the age of the equipment corresponding to the fiftieth percentile of the population and can be used as a surrogate to understand how new and old the equipment are for each category. While the median life is not directly used in the model, it provides an overview of the age distribution of each equipment category. Table 16 shows the median life for the Lawn & Garden and Light Commercial equipment categories based on data collected in the 2018 SORE Survey.

Table 16. Median Life for Lawn & Garden and Light Commercial Categories

Category	Gasoline Equipment	2018 Survey Median Life (years)		
		Residential	Business	Vendor
Lawn & Garden	Chainsaws	5	3	2
	Lawn Mowers	6	5	3
	Leaf Blowers	5	3	2
	Other Lawn & Garden	-	3	2
	Riding Mowers	8	-	5
	Trimmers	5	3	2
Light Commercial	Compressors	3	3	3
	Generator	7	5	4
	Pressure Washers	5	3	3
	Pumps	6	8	3
	Welders	10	5	4

4.6 Spatial Allocation

Based on 2018 estimates of household units reported at the county level by the California Department of Finance (DOF),[10] the statewide SORE equipment population was spatially allocated across California as shown in Figure 7 below. Ideally, equipment allocation would be based on data collected from the 2018 CSUF survey, with the raw data apportioned to the survey respondent's county. Due to limitations in sample size where some counties contained no data, CARB staff used household units by county as reported by the DOF as a surrogate for allocating the SORE population. Both the DOF household units by county and 2018 CSUF survey data had similar allocation percentages for the larger counties, suggesting that the DOF household unit data was a reasonable surrogate for SORE ownership rates.

[10] E-5 Population and Housing Estimates for Cities, Counties, and the State, 2011-2019 with 2010 Census Benchmark. http://dof.ca.gov/Forecasting/Demographics/Estimates/E-5/

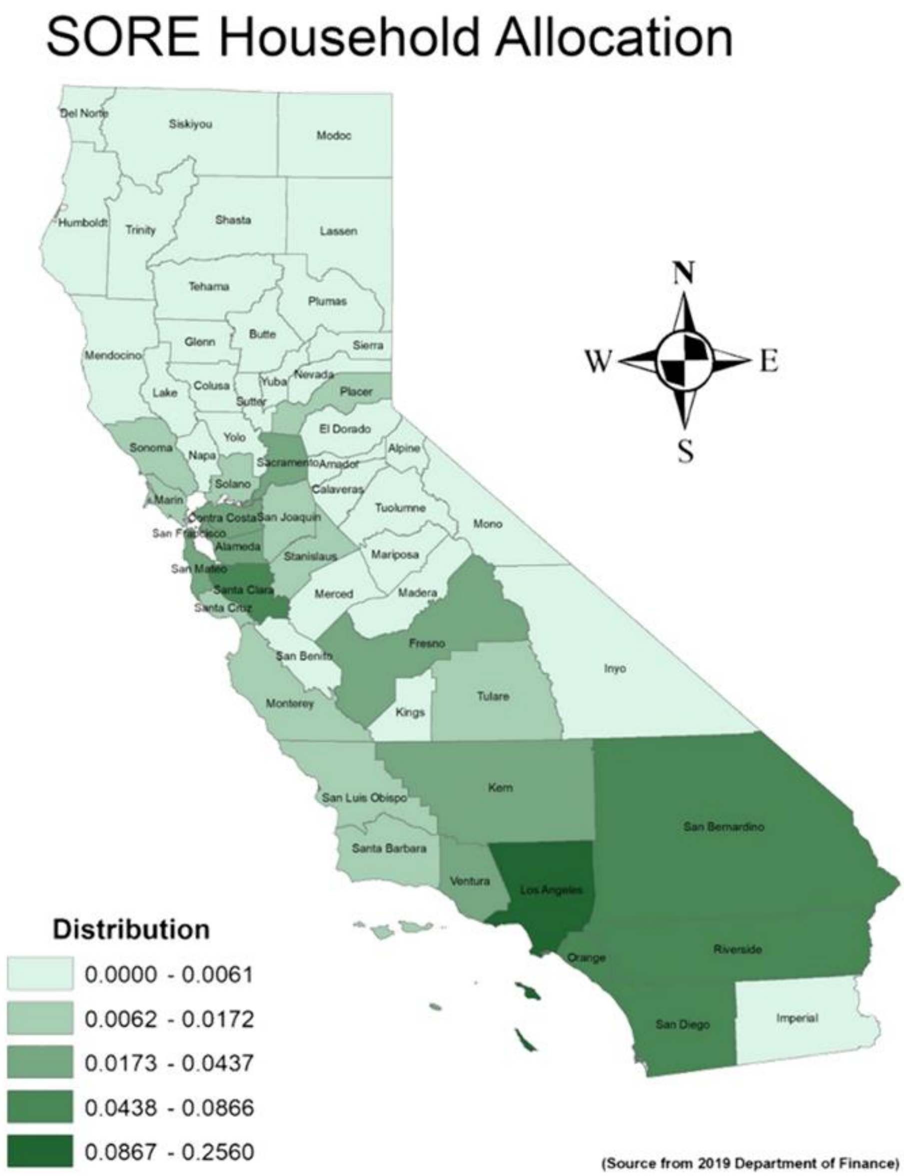


Figure 7: Allocation of SORE Equipment

4.7 Seasonality

SORE equipment usage varies by the season of the year. Although peak usage for most lawn and garden and light commercial equipment is during the summer months, snow blowers are the only category with peak use in the winter, as shown in Table 17. To be consistent with when reformulated fuels are used in California, summer is defined as May through October while winter is defined as November through April. Note that the seasonality factors used in SORE2020 are the same as the ones used in OFFROAD2007.

Table 17. Seasonality Factors (SORE2020)

Category	Equipment	Seasonality Factor		
		Annual	Summer	Winter
Lawn & Garden	Chainsaws	1.000	1.114	0.886
	Lawn Mowers	1.000	1.114	0.886
	Leaf Blowers/Vacuums	1.000	1.114	0.886
	Trimmers/Edgers/Brush Cutters	1.000	1.114	0.886
	Snow Blowers	1.000	0.039	1.961
Light Commercial	Air Compressors	1.000	1.114	0.886
	Generator Sets	1.000	1.114	0.886
	Pressure Washers	1.000	1.114	0.886
	Pumps	1.000	1.114	0.886
	Welders	1.000	1.114	0.886

4.8 Fuel Consumption

The brake specific fuel consumption (BSFC) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational or shaft power, and is derived by the rate of fuel consumption divided by the power produced. BSFC allows the fuel efficiency of different engines to be directly compared. In the SORE2020 Model, the fuel consumption (gallon per day) is derived from mass balance using carbon monoxide (CO), carbon dioxide (CO_2), and total organic gas (TOG) or ROG. The formulas are shown below, and the fuel consumption coefficients are shown in Table 18.

<u>For hydrocarbons reported as ROG:</u>

$$\text{Fuel consumption} = [(12.011/(12.011+\text{Alpha}*1.008))*\text{TOG}/\text{ROG}_{adj}+0.429*\text{CO}+0.273*\text{CO}_2] /(0.854*453.592*\text{Fuel Density}) \quad \textbf{(1)}$$

<u>For hydrocarbons reported as TOG:</u>

$$\text{Fuel consumption} = [(12.011/(12.011+\text{Alpha}*1.008))*\text{TOG}+0.429*\text{CO}+0.273*\text{CO}_2] /(0.854*453.592*\text{Fuel Density}) \quad \textbf{(2)}$$

Table 18. Coefficients Used for Fuel Consumption Calculations

Fuel Type	Calendar Year	Alpha	TOG Adj.	ROG Adj.	Fuel Density (lb./gal)
G2	Pre-1996	1.85	1.02	0.91	6.17
	1996-2003	1.85	1.09	0.92	
	2004+	1.85	1.10	0.92	
G4	Pre-1996	1.85	1.04	0.86	
	1996-2003	1.85	1.09	0.92	
	2004+	1.85	1.10	0.92	

4.9 Emission Factors

4.9.1 Sources for Emission Factors

Updating emission factors for SORE equipment involved obtaining new emissions test data for both exhaust and evaporative emissions, as well as compiling and reviewing certification data submitted by manufacturers when certifying engines for sale in California. The general methodology utilized by SORE2020, to calculate the off-road mobile exhaust emissions in tons per day (tpd) for gasoline two-stroke (G2) and four-stroke (G4) engines, uses emission factors by model year for hydrocarbons HC, CO, NO_X, PM, and CO_2. The emission factors are expressed in grams per brake horsepower hour (g/bhp-hr), and deterioration rates which represent the rate of emission increase per hour, are in units of g/bhp-hr^2. The exhaust emission factors are calculated by the following equation:

$$EF_{exhaust} = ZH + dr * CHrs \qquad \textbf{(3)}$$

Where,

EF = emission factor, in grams per brake horsepower-hour (g/bhp-hr)
ZH = zero-hour emission rate or when the equipment is new (g/bhp-hr)
dr = deterioration rate or the increase in ZH emissions as the equipment is used (g/bhp-hr^2)
CHrs = cumulative hours or total number of hours accumulated on the equipment

The evaporative emission factors are expressed in grams/start for hot soak, grams/day for 24-hour diurnal and grams/hour for running loss emissions. The evaporative emission factors for 24-hour diurnal are calculated by the following equation:

$$EF_{evap} = ZH + dr * years \qquad \textbf{(4)}$$

Where,

EF = emission factor in grams/day for 24-hour diurnal
ZH = zero-hour emission rate or when the equipment is new
dr = deterioration rate or the increase in ZH emissions as the equipment ages
years = age of the equipment

The OFFROAD2007 emission factors were based on emission testing done in the early 2000s time frame and primarily focused on uncontrolled engines. To update these emission factors in SORE2020, CARB staff relied on the results from baseline as well as validation and compliance testing of a large number of small gasoline engines, ranging from lawn mowers to generators, performed from year 2016 to present. Tables 19 and 20 below summarize the exhaust and evaporative emission test results, respectively.

Table 19. Average Exhaust Emissions (g/bhp-hr) from Baseline Testing

Fuel/Technology Type	Equipment	HP Bin	Number of Tests	HC (g/hp-hr)	NO_x (g/hp-hr)
Gasoline 4-stroke	Lawn Mower	5	9	3.51	3.18
	Riding Mower	15	3	1.99	2.96
		25	3	2.63	1.59
	Trimmer	2	9	8.38	6.15
	Tiller	15	3	2.88	2.26

Table 20. Average Evaporative Emission Results (grams and g/day)

Technology	Equipment (Model Year > 2010)	HP Bin	Number of Tests	Evaporative Emissions Test Data*	
				Hot Soak (g)	24-hour Diurnal (g/day)
Gasoline 4-stroke	Blower	2	9	0.126	0.529
	Generator		3	0.847	12.366
	Trimmer		18	0.078	0.593
	Generator	5	15	1.387	2.747
	Lawn Mower		65	0.157	0.823
	Pressure Washer		10	0.136	0.608
	Trimmer		6	0.082	0.545
	Generator (49-state)		1	0.537	1.881
	Chipper/Stump Grinder		3	0.160	1.488
	Compressor	15	10	0.411	8.178
	Generator		36	0.831	2.922
	Lawn Mower		10	0.195	0.796
	Pressure Washer		10	0.164	1.171
	Riding Mower		6	0.135	0.965
	Tiller		14	0.107	0.839
	Chipper (49-state)		1	0.319	2.476
	Chipper/Stump Grinder		5	0.177	0.896
	Riding Mower	25	21	0.379	2.122
	Tractor		9	0.582	1.769
Gasoline 2-stroke	Blower	All	3	0.138	0.460
	Chainsaw		3	0.129	0.390
	Generator		1	1.031	1.931
	Tiller		1	0.724	2.624
	Trimmer		4	0.086	0.431

* Emissions test data for tests with E10 fuel are converted to E0 for use in the model

The 2018 CARB Certification Database, which contains emission factors reported by manufacturers for years 2001 to 2018, was also utilized to update the exhaust emission factors. Exhaust emission factors have not changed since the exhaust regulation that began with the 2007-2008 model year engines. Table 21 below contains the certification data that were utilized to update the emission factors in the SORE2020 Model.

Table 21. Comparison of Zero Hour (ZH) Emission Rates (2018 CARB Certification Database vs. OFFROAD2007)

Category	Equipment	Tech Type	HP	OFFROAD2007 (g/bhp-hr)		2018 Certification Data (g/bhp-hr)	
				HC-ZH	NO_X-ZH	HC-ZH	NO_X-ZH
Lawn & Garden	Chainsaws	G2-Carb	2	13.88	1.31	45.53	1.39
			5	-	-	29.41	1.00
	Chainsaws Preempt	G2-Carb	2	-	-	59.75	1.82
			5	13.88	1.31	55.18	1.88
	Chippers/Stump Grinders/Shredders	G4-Carb	2	-	-	19.31	2.08
			5	3.66	0.86	4.52	1.63
			15	3.9	2.9	3.83	1.81
	Lawn Mowers	G4-Carb	2	-	-	8.09	3.91
			5	3.66	0.86	4.30	1.70
			15	3.66	0.86	3.99	1.83
			25	2.64	1.71	3.45	1.18
	Leaf Blowers/Vacuums	G2-Carb	2	13.88	1.31	30.44	0.48
			5	-	-	32.95	0.75
		G4-Carb	2	-	-	8.74	2.02
			5	3.66	0.86	5.54	1.71
			15	2.51	1.86	3.01	2.25
			25	2.64	1.71	2.60	1.89
		G4-FI	25	2.64	1.71	1.22	4.57
	Other Lawn & Garden Equipment	G4-Carb	5	3.66	0.86	3.89	1.52
			15	2.51	1.86	3.90	1.40
			25	2.64	1.71	2.81	1.92
	Riding Mowers/Tractors	G4-Carb	5	3.66	0.86	4.09	1.63
			15	2.51	1.86	3.49	1.58
			25	2.64	1.71	3.05	1.24
		G4-FI	25	2.64	1.71	2.28	3.03
	Snow Blowers	G4-Carb	5	3.66	0.86	4.46	1.89
			15	2.51	1.86	4.08	1.96
			25	2.64	1.71	2.85	2.04
	Tillers	G2-Carb	2	-	-	23.90	0.16
		G4-Carb	2	-	-	9.80	3.11
			5	3.66	0.86	4.45	1.45
			15	2.51	1.86	4.11	2.01
	Trimmers/Edgers/Brush Cutters	G2-Carb	2	13.88	1.31	31.18	0.77
			5	-	-	28.29	0.75
		G4-Carb	2	-	-	14.09	2.06
			5	6	2.7	4.45	1.36
			15	3.66	0.86	4.13	1.59
			25	2.51	1.86	3.41	1.42
	Wood Splitters	G4-Carb	2	-	-	7.64	4.31
			5	3.66	0.86	4.56	1.61
			15	3.66	0.86	3.76	1.88
			25	2.51	1.86	3.39	1.42

Category	Equipment	Tech Type	HP	OFFROAD2007 (g/bhp-hr)		2018 Certification Data (g/bhp-hr)	
				HC-ZH	NO_X-ZH	HC-ZH	NO_X-ZH
Light Commercial	Air Compressors Preempt	G4-Carb	5	6	2.7	5.30	1.57
			15	3.9	2.9	3.21	1.96
			25	4.12	2.68	2.75	2.57
		G4-FI	25	4.12	2.68	1.33	3.39
	Generator Sets	G2-Carb	2	3.66	0.86	30.39	0.79
		G4-Carb	2	-	-	8.21	2.74
			5	3.66	0.86	5.66	1.27
			15	2.51	1.86	3.26	1.63
			25	2.64	1.71	3.00	1.67
		G4-FI	15	2.51	1.86	1.15	2.09
			25	2.64	1.71	1.33	3.39
	Pressure Washers	G4-Carb	2	-	-	8.43	2.86
			5	3.66	0.86	4.54	1.84
			15	2.51	1.86	3.58	1.82
			25	2.64	1.71	3.23	1.58
	Pumps Preempt	G2-Carb	2	3.66	0.86	23.40	0.14
		G4-Carb	2	-	-	10.85	1.96
			5	6	2.7	5.20	1.72
			15	3.9	2.9	3.42	1.91
			25	4.12	2.68	2.85	2.04
	Welders Preempt	G4-Carb	15	3.9	2.9	3.39	1.47

Note: G4-Carb, 2 hp is G4-Carb 0–5 hp ≤ 80cc

Using data from baseline emissions testing in combination with data from the 2018 Certification Database, CARB staff updated the emission factors for the SORE2020 Model. For equipment where emissions test data was available (Table 19), staff combined them with certification emission factor data and used an averaged emission rate as the final input into the model. Table 22 shows the updated exhaust emission factors (g/bhp-hr) utilized by the SORE2020 Model for HC and NO_x.

Table 22. Exhaust Emission Factors in SORE2020 (g/bhp-hr)

Category	Equipment	Tech Type	HP	SORE2020 Emission Factors (g/bhp-hr)	
				HC-ZH	NO_X-ZH
Lawn & Garden	Chainsaws	G2-Carb	2	45.53	1.39
			5	29.41	1.00
	Chainsaws Preempt	G2-Carb	2	59.75	1.82
			5	55.18	1.88
	Chippers/Stump Grinders/Shredders	G4-Carb	2	19.31	2.08
			5	4.52	1.63
			15	3.83	1.81
	Lawn Mowers	G4-Carb	2	8.09	3.91
			5	3.91	2.44
			15	3.99	1.83
			25	3.45	1.18
	Leaf Blowers/Vacuums	G2-Carb	2	30.44	0.48
			5	32.95	0.75
		G4-Carb	2	8.74	2.02
			5	5.54	1.71
			15	3.01	2.25
			25	2.60	1.89
		G4-FI	25	1.22	4.57
	Other Lawn & Garden Equipment	G4-Carb	5	3.89	1.52
			15	3.90	1.40
			25	2.81	1.92
	Riding Mowers/Tractors	G4-Carb	5	4.09	1.63
			15	2.74	2.27
			25	2.84	1.42
		G4-FI	25	2.28	3.03
	Snow Blowers	G4-Carb	5	4.46	1.89
			15	4.08	1.96
			25	2.85	2.04
	Tillers	G2-Carb	2	23.90	0.16
		G4-Carb	2	9.80	3.11
			5	4.45	1.45
			15	3.50	2.14
	Trimmers/Edgers/Brush Cutters	G2-Carb	2	31.18	0.77
			5	28.29	0.75
		G4-Carb	2	11.23	4.10
			5	4.45	1.36
			15	4.13	1.59
			25	3.41	1.42
	Wood Splitters	G4-Carb	2	7.64	4.31
			5	4.56	1.61
			15	3.76	1.88
			25	3.39	1.42

Category	Equipment	Tech Type	HP	SORE2020 Emission Factors (g/bhp-hr)	
				HC-ZH	NO_X-ZH
Light Commercial	Air Compressors Preempt	G4-Carb	5	5.30	1.57
			15	3.21	1.96
			25	2.75	2.57
		G4-FI	25	1.33	3.39
	Generator Sets	G2-Carb	2	30.39	0.79
		G4-Carb	2	8.21	2.74
			5	5.66	1.27
			15	3.26	1.63
			25	3.00	1.67
		G4-FI	15	1.15	2.09
			25	1.33	3.39
	Pressure Washers	G4-Carb	2	8.43	2.86
			5	4.54	1.84
			15	3.58	1.82
			25	3.23	1.58
	Pumps Preempt	G2-Carb	2	23.40	0.14
		G4-Carb	2	10.85	1.96
			5	5.20	1.72
			15	3.42	1.91
			25	2.85	2.04
	Welders Preempt	G4-Carb	15	3.39	1.47

Note: G4-CARB, 2hp is G4-CARB 0-5hp ≤80cc

Emission factors for CO, CO_2, and PM were updated similarly to HC and NO_X, with the majority of equipment updated using the CO, CO_2 and PM certification data, as reported by manufacturers. If test data exist (Table 19), the emission factors were based on the average of the test data and certification data. Manufacturers are only required to submit PM certification data for two-stroke engines with displacement less than or equal to 80 cubic centimeters. CO_2 emission data from the certification database were also used to update CO_2 emission rates for all model years.

4.9.2 Exhaust Deterioration Factors

Deterioration rates are defined as the change in emissions as a function of usage. Pertaining to mobile source emissions inventory, deterioration is reflective of both the natural degradation of an engine (i.e., wear and tear), as well as the increase in emissions resulting from mal-maintenance (i.e., improper or lack of maintenance) and emission control system malfunctions.

Previously in the OFFROAD2007 Model, exhaust emission factors were derived by initially setting the zero-hour emission factor for HC+NO_X at a level that was below the emission standards. Then over time, it would deteriorate and the emissions would become equal to the standard at the end of the durability period. The durability period is the time (in hours of use) during which a manufacturer certifies the engine will not exceed the emission standard. As shown in Table 24, manufacturers certify to a range of durability hours, with some engines certifying at lower durability hours and others at the maximum. Staff assigned the highest durability hours, within the durability range, to commercial/vendor equipment and the remainder was designated to residential equipment. In the SORE2020 Model, the durability hour for residential equipment is population weighted by horsepower and it is assumed that residential equipment would meet the emissions standard at the end of the residential durability hours. Similarly, commercial/vendor equipment would meet the standard at the commercial durability hours, as shown in Table 23 below.

Table 23. Residential and Commercial Durability Hours

Category	Equipment	Tech Type	HP	Durability Hours	
				Residential (Population Weighted)	**Commercial**
Lawn & Garden	Chainsaws	G2-Carb	2	69.0	300
			5	53.7	300
	Chainsaws Preempt	G2-Carb	2	69.0	300
			5	53.7	300
	Chippers/Stump Grinders/Shredders	G4-Carb	2	123.8	300
			5	125.0	500
			15	250.0	1,000
	Lawn Mowers	G4-Carb	2	300.0	300
			5	162.8	500
			15	250.0	1,000
			25	310.5	1,000
	Leaf Blowers/Vacuums	G2-Carb	2	77.7	300
			5	54.3	300
		G4-Carb	2	300.0	300
			5	250.0	500
			15	250.0	1,000
			25	1,000.0	1,000
		G4-FI	25	1,000.0	1,000
	Other Lawn & Garden Equipment	G4-Carb	5	125.0	500
			15	250.0	1,000
			25	1,000.0	1,000
	Riding Mowers/Tractors	G4-Carb	5	125.0	500
			15	280.5	1,000
			25	370.7	1,000
		G4-FI	25	500.0	1,000
	Snow Blowers	G4-Carb	5	250.0	500
			15	250.0	1,000
			25	1,000.0	1,000
	Tillers	G2-Carb	2	50.0	300
		G4-Carb	2	125.0	300
			5	145.0	500
			15	250.0	1,000
		G2-Carb	2	64.2	300

Category	Equipment	Tech Type	HP	Durability Hours	
				Residential (Population Weighted)	Commercial
	Trimmers/Edgers/Brush Cutters		5	300.0	300
		G4-Carb	2	98.4	300
			5	126.3	500
			15	309.5	1,000
			25	500.0	1,000
	Wood Splitters	G4-Carb	2	300.0	300
			5	250.0	1,000
			15	250.0	1,000
			25	1,000.0	1,000
Light Commercial	Air Compressors Preempt	G4-Carb	5	185.5	500
			15	250.0	1,000
			25	1,000.0	1,000
		G4-FI	25	1,000.0	1,000
	Generator Sets	G2-Carb	2	50.0	300
		G4-Carb	2	97.6	300
			5	238.0	500
			15	283.3	1,000
			25	470.4	1,000
		G4-FI	15	500.0	1,000
			25	1,000.0	1,000
	Pressure Washers	G4-Carb	2	125.0	300
			5	222.6	500
			15	250.0	1,000
			25	1,000.0	1,000
	Pumps Preempt	G2-Carb	2	50.0	300
		G4-Carb	2	125.0	300
			5	197.2	500
			15	250.0	1,000
			25	1,000.0	1,000
	Welders Preempt	G4-Carb	15	500.0	500

*Carb = carburetor FI = fuel injected G2 = 2 stroke G4 = 4 stroke

In OFFROAD2007, there was a limit on engine deterioration beyond a set hour. The capped hours have been revised in SORE2020, due to the low hours assumed back in 1998. CARB staff have revised the capped deterioration rates to 1.5 times the highest durability hours for each respective horsepower group for residential and commercial/vendor equipment type as shown in Table 24. For equipment with 5 horsepower or greater, the previous deterioration hour cap in OFFROAD2007 was too low, since manufacturers presently certify engines with durability hours greater than the capped hours. Similarly, the deterioration hour cap for residential equipment with 2 horsepower and less, was lower than the OFFROAD2007 deterioration cap of 300 hours. This methodology is different from US EPA NONROAD Model, which does not set a cap on deterioration and is based upon a sloped, linear regression line of the test data[11]. US EPA used in-use emissions data from approximately 40 lawn mowers (up to

[11] “Updates to Phase 2 Technology Mix, Emission Factors, and Deterioration Rates for Spark- Ignition Nonroad Non-handheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model,”

18 years of age) tested by the Center for Emission Research & Analysis (CERA) and concluded that HC and CO emissions do not stop deteriorating at the median life (estimated to be just under 6 years by the NONROAD Model), but continues to deteriorate throughout the equipment's entire life. Despite this conclusion, CARB staff still considered the use of deterioration cap hours for the SORE2020 Model, since the test data only encompassed ages 0 to 18 years. Therefore, setting a residential deterioration cap at 375 hours (the equivalent of 18 - 19 years of lawn mower usage) is considered to be reasonable for SORE2020 Model.

Table 24. Exhaust Deterioration Hour Cap

Tech Type	HP	HP Bin	Deterioration Hour Cap			Range of Durability Period (hr)
			OFFROAD2007	SORE2020 Residential	SORE2020 Commercial	
G2-Carb	0-5	2,5	300	187.5	450	50/125/300
G4-Carb	0-5,≤ 80cc	2	300	187.5	450	50/125/300
	0-5	5	300	375	750	125/250/500
	5-15	15	500	750	1500	250/500/1000
	15-25	25	500	750	1500	250/500/1000

An example of how the deterioration rate and deterioration cap is applied for residential and commercial lawn mowers is shown in Figure 8 below.

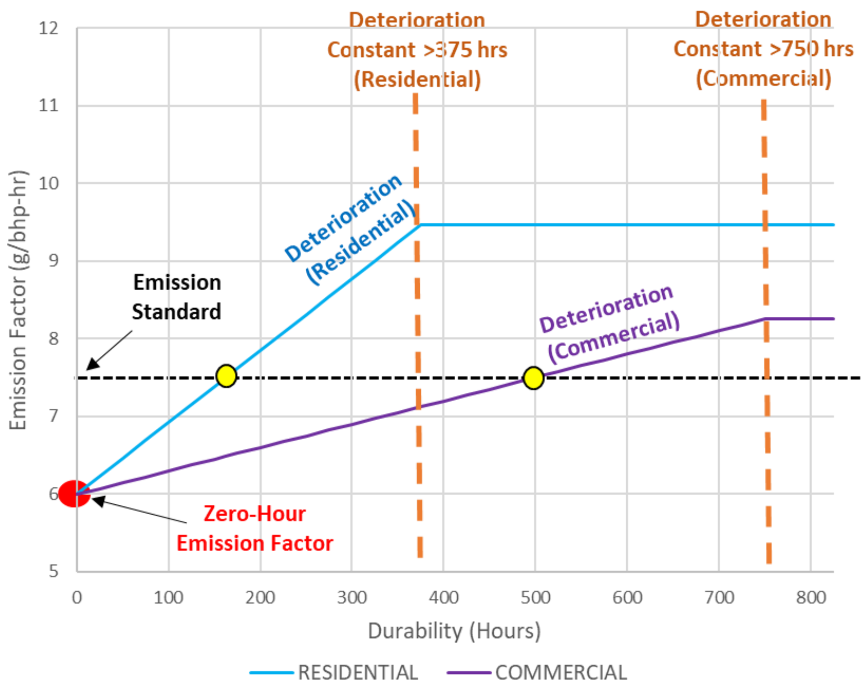


Figure 8. Lawn Mower Exhaust Deterioration Example

Memo from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, March 6, 2007. Docket Document EPA-HQ-OAR-2004-0008-0543.

Industry has suggested using manufacturer's certification deterioration rate as the basis for the inventory modeling of deterioration. Staff believes that the emission deterioration, in the current mobile source emissions inventory, is reflective of both the natural degradation of an engine (i.e., wear and tear) as well as the increase in emissions due to engine mal-maintenance and malfunctions of the emission control systems. Therefore, the emission deterioration, assumed for emissions inventories, will typically be higher than the deterioration rates provided by manufacturers during certification, which do not account for mal-maintenance. According to the 2018 CSUF Survey data, only 50% of business/vendors and 40% residential owners properly maintain their equipment in accordance with the manufacturer recommended maintenance schedule. In the absence of available in-use data on emission deterioration, the methodology outlined above is the most reasonable assumption of emission deterioration. Appendix H provides further details regarding exhaust deterioration assumptions in the SORE2020 Model. In addition to above mentioned updates, due to lack of information on CO exhaust deterioration, the CO deterioration factors in the SORE2020 model are now set to zero for model year 2007 and newer equipment. Previously, the model assumed a negative deterioration rate for CO for certain model years of SORE equipment. This could eventually cause the CO composite emission factor to become less than zero if the activity increases significantly and therefore could have resulted in incorrect estimate of CO emissions.

4.9.3 Evaporative Emission Factors

Table 25 shows the updated evaporative emission factors (hot soak and diurnal) utilized by the SORE2020 Model.

Table 25. Hot Soak and Diurnal Emission Factors (SORE2020)

Category	Equipment	Tech Type	HP	Evap Emission Factors Hot Soak (g/start)	Evap Emission Factors 24-hr Diurnal (g/day)
Lawn & Garden	Chainsaws	G2-Carb	2	0.129	0.390
			5	0.129	0.390
	Chainsaws Preempt	G2-Carb	2	0.129	0.390
			5	0.129	0.390
	Chippers/Stump Grinders/Shredders	G4-Carb	2	0.160	1.488
			5	0.160	1.488
			15	0.177	0.896
	Lawn Mowers	G4-Carb	2	0.157	0.823
			5	0.157	0.823
			15	0.195	0.796
			25	0.195	0.796
	Leaf Blowers/Vacuums	G2-Carb	2	0.138	0.460
			5	0.138	0.460
		G4-Carb	2	0.126	0.529
			5	0.126	0.529
			15	0.378	3.278
			25	0.378	3.278
		G4-FI	25	0.378	3.278
	Other Lawn & Garden Equipment	G4-Carb	5	0.157	0.823
			15	0.195	0.796
			25	0.195	0.796
	Riding Mowers/Tractors	G4-Carb	5	0.135	0.965
			15	0.135	0.965
			25	0.480	1.945
		G4-FI	25	0.480	1.945
	Snow Blowers	G4-Carb	5	0.126	0.529
			15	0.378	3.278
			25	0.378	3.278
	Tillers	G2-Carb	2	0.724	2.624
		G4-Carb	2	0.157	0.823
			5	0.157	0.823
			15	0.195	0.796
	Trimmers/Edgers/Brush Cutters	G2-Carb	2	0.086	0.431
			5	0.086	0.431
		G4-Carb	2	0.078	0.593
			5	0.082	0.545
			15	0.378	3.278
	Wood Splitters	G4-Carb	2	0.160	1.488
			5	0.160	1.488
			15	0.177	0.896
			25	0.177	0.896

Category	Equipment	Tech Type	HP	Evap Emission Factors	
				Hot Soak (g/start)	24-hr Diurnal (g/day)
Light Commercial	Air Compressors Preempt	G4-Carb	5	0.537	1.881
			15	0.411	8.178
			25	0.411	8.178
		G4-FI	25	0.411	8.178
	Generator Sets	G2-Carb	2	1.031	1.931
		G4-Carb	2	1.297	4.350
			5	1.387	2.747
			15	0.831	2.922
			25	0.831	2.922
		G4-FI	15	0.320	2.460
			25	0.320	2.460
	Pressure Washers	G4-Carb	2	0.136	0.608
			5	0.136	0.608
			15	0.164	1.171
			25	0.164	1.171
	Pumps	G2-Carb	2	0.724	2.624
	Pumps Preempt	G4-Carb	2	0.537	1.881
			5	0.537	1.881
			15	0.397	1.629
			25	0.397	1.629
	Welders Preempt	G4-Carb	15	0.397	1.629

*Note: 24-hr Diurnal is diurnal + resting loss; Carb = Carburetor FI = Fuel Injection G2 = 2 stroke G4 = 4 stroke
Preempt refers to 49 states

The basis for the update was derived from the CARB compliance and validation evaporative emission test found in Table 20. The test program did not test all equipment types included in the SORE2020 Model, therefore some equipment utilized a surrogate or the average of several equipment types to derive an updated evaporative emission factor. In addition, since running loss data were not collected, the emission factors were carried over from OFFROAD2007. Table 26 contains the assumptions utilized.

Table 26. Surrogates for Evaporative Emission Factors (SORE2020)

Category	Equipment	Type	HP	Surrogates
Lawn & Garden	Chainsaw Preempt	G2-Carb	All	Chainsaw test data
	Chippers/Stump Grinders/Shredders	G4-Carb	2	5hp Chippers/Stump Grinders test data
	Lawn Mowers	G4-Carb	2,25	Lawn Mower test data
	Leaf Blowers	G4-Carb G4-FI	15,25	Average of Compressor, Generator, Tiller, and Pressure Washer
	Other Lawn & Garden	G4-Carb	All	Lawn Mower test data
	Riding Mowers	G4-Carb	15	Riding Mower test data
	Riding Mowers	G4-Carb	25	Average of Riding Mower and Tractor test data
	Snow Blowers	G4-Carb	All	Same as Leaf Blower
	Tillers	G4-Carb	2,5	Lawn Mower test data
	Trimmers	G4-Carb	15	Same as Leaf Blower

Category	Equipment	Type	HP	Surrogates
	Wood Splitters	G4-Carb	All	Same as Chippers/Stump Grinders/Shredders
Light Commercial	Air Compressor Preempt	G4-Carb	5	Generator (49-State) test data
	Air Compressor Preempt	G4-Carb	15,25	Air Compressor test data
	Air Compressors Preempt	G4-FI	25	Air Compressor test data
	Generator Set	G4-FI	All	Estimates from OFFROAD2007
	Generator Set*	G4-Carb	2	Weighted average of 2 and 5 hp bin Generator test data
	Generator Set	G4-Carb	25	15 hp Generator test data
	Pressure Washer	G4-Carb	2,25	Pressure Washer test data
	Pumps Preempt	G2-Carb	2	Tiller test surrogate
	Pumps Preempt	G4-Carb	2,5	Generator (49-State) test data
	Pumps Preempt	G4-Carb	15,25	Average of Pressure Washer, Lawn Mower, and Generator tests
	Welders Preempt	G4-Carb	15	Average of Pressure Washer, Lawn Mower, and Generator tests

* Considering that only one engine family is tested for G4-Carb 2 hp bin Generator, staff decided to use a weighted average (using number of test data) of 2hp and 5hp bin generator test data to represent evaporative emissions for 2hp bin generators.

4.9.4 Evaporative Deterioration Factors

Evaporative deterioration rates are typically derived from emissions test data collected for in-use equipment. Since certification test data does not include a deterioration factor for evaporative emissions and there is a lack of evaporative emissions test data for small off-road gasoline engines, no major update has been made to the evaporative deterioration factors included in the SORE2020 Model. However, a few modifications were incorporated, including proportioning the deterioration rate to reflect the new, zero-hour evaporative emission rates and the inclusion of two deterioration rates (a slower rate from the zero hour to its useful life and a sharper slope from the useful life and beyond) for lawn mowers[12] exclusively. Please note that useful lives of 5 years, 4 years, and 9 years are assumed for commercial, vendor, and residential lawn mower categories, respectively. The useful life is the age at which only 50% of the number of equipment sold has remained in the fleet and differs from the median life.

According to the CARB Technical Memo (2003) titled, “Addition of Evaporative Emissions for Small Off-Road Engines”, test data from 23 in-use lawn mowers were used to estimate the zero hour emission rate of lawn mowers. The used lawn mowers were randomly obtained from dealer customer service departments and were assumed to be representative of the in-use lawn mower fleet. The test results of these mowers were averaged to establish a deterioration factor. Finally, the emission rates of the old lawn mowers were averaged to estimate the evaporative emissions from lawn mowers at the end of their lives. The evaporative emissions estimate at 14 years was the average of the emissions from two lawn mowers (mowers 20 and 23), of which one was

[12] In accordance to CARB’s 2003 technical memo titled “Addition of Evaporative Emissions for Small Off-Road Engines” at: https://www.arb.ca.gov/msei/offroad/techmemo/SORE_Evaporative1.doc

found to have a liquid fuel leak (mower 23). Because the deterioration rates, beyond year seven, are highly influenced by the emissions of this liquid leaker, staff surveyed a number of lawn mower repair shops and requested manufacturers' input to determine how often these types of problems occur. Although it was confirmed that lawn mowers with fuel leaks are not uncommon, it was not possible to determine the frequency of these leaks with accuracy. Staff found no compelling reason to exclude mower 23 from the analysis. Using this test data, staff suggested two different deterioration rates, known as DR1 and DR2, for lawn mowers in both OFFROAD2007 and in SORE2020 Model. However as described earlier, DR2 in the SORE2020 Model, is exclusively applicable to lawn mowers and not any other equipment types.

Additionally, it is worth mentioning that in September 2015, the U.S. Consumer Product Safety Commission (CPSC) published a study titled, "Study of Fuel Leaks Associated with Outdoor Ground-Supported Gasoline-Powered Equipment" which described gasoline fuel leakages from outdoor ground-supported equipment, including lawn mowers and generators, and the fire hazards they posed. This report is publically available and can be found on the CPSC website. The sources of leakage were found to include the fuel tank, hoses, fuel filters, fuel caps, and grommets. The study also found that despite the requirements detailed in ANSI/OPEI B71.10, leaks were a recurring hazard over a 14 year time period, which resulted in 1.7 million pieces of equipment being recalled between 2000 to 2013. Therefore, staff believed that there was clear evidence from consumer reports, as well as some emission test data from CARB, indicating that some of the SORE equipment leak in real-world applications. However, due to a paucity of available evaporative emission data across different ages of equipment, staff decided to rely on the deterioration rates assumed in OFFROAD2007.

Currently the SORE2020 Model assumes no evaporative emission deterioration (except for running loss) for Light Commercial equipment, though CARB has identified leaking compressors during in-house evaporative emission testing. Of the 10 brand-new compressor units tested at CARB, two of them were discovered to be leaking. Since the average of all of the data is used in the model, staff believes that the impact of fuel leakage is implicitly accounted for in the Model. However, with additional in-use test data, staff may re-evaluate the impact of evaporative emissions deterioration on emissions from Light Commercial equipment.

4.10 Correction Factors

4.10.1 Exhaust Fuel Correction Factors

Fuel correction factors[13] (FCFs) are dimensionless multipliers applied to the basic exhaust emissions rates that account for differences in the properties of certification fuels compared to those of commercially dispensed fuels. California has transitioned through three phases of reformulated gasoline in the past two decades: California Reformulated Phase 1 Fuel (1992 to 1995), California Reformulated Phase 2 Fuel (1996 to 2003), and California Reformulated Phase 3 Fuel (2004+) including 6 percent ethanol gasoline (E6) and 10 percent ethanol gasoline (E10). In those instances where engines or vehicles are not required to be certified, the FCFs reflect the impact of changes in dispensed fuel over time as refiners respond to changes in fuel specific regulations compared to the fuel used to obtain the test data.

Current emission factors are derived based on gasoline without ethanol blended (E0), since the majority of manufacturers' submitted test data that is reported in the CARB Certification Database was performed on E0. Beginning in 2020, certification data will be based on gasoline blended with 10 percent ethanol (E10), and correction factors will be applied accordingly in the future.

4.10.2 Temperature Correction

For hydrocarbons and oxides of nitrogen (NO_x), the temperature correction is:

$$CF_{Temp} = e^{(T-75)a} \tag{5}$$

Where,

T = ambient temperature (°F)
a = coefficient which depends on engine type and whether the ambient temperature is above or below 75°F as shown in Table 27.

Table 27. Coefficients for Temperature Correction

Pollutant	Low Temp (< 75°F)		High Temp (> 75°F)	
	G2	G4	G2	G4
CO	0.0000	-0.0146	0.0000	0.01494
HC	0.0000	-0.0113	0.0000	0.00484
NOx	0.0000	-0.0059	0.0000	0.0000

To simplify the calculation methods used in developing the SORE emissions inventory, staff applied the temperature correction on a daily basis to the average daily

[13] The document on FCFs can be found at: http://www.arb.ca.gov/msei/offroad/techmemo/arb_offroad_fuels.pdf

temperature. This approach captures the general trend of the correction factor without requiring calculations on an hourly basis.

4.10.3 Humidity Correction

For humidity correction for NO_x, the correction factor is:

$$CFHumd = 1 - 0.0038*(A - 75) \quad \textbf{(6)}$$

where A is the absolute humidity. The absolute humidity is derived from the relative humidity and ambient temperature based on the following equation:

$$ABH = RH *(- 0.09132 + 0.01594 * T - 0.00029*T^2 + 0.00000437*T^3) \quad \textbf{(7)}$$

Where,

ABH = scenario humidity (grains/pound)
RH = relative humidity (%)
T = scenario temperature (°F)

This equation is valid for ambient temperatures between 40°F and 120°F, and to predict absolute humidity values less than or equal to 200 grains/pound. If the ambient temperature is less than 40°F, then 40°F is used for the calculation. Similarly, if the ambient temperature is higher than 120°F, then 120°F is used for the calculation. Finally, if the calculated absolute humidity is greater than 200 grains/pound, then only 200 grains/pound is used.

4.10.4 Evaporative Correction Factors

Correction factors are necessary to adjust baseline emissions to the range of meteorological conditions that occur in California over the course of a year. The methodology to correction evaporative emission remains the same as in OFFROAD2007 as detailed in CARB's OFFROAD Modeling Change Technical Memo[14].

In order to account for spatial, temporal and seasonal variations in ambient temperature and dispensed fuel properties, correction factors for RVP and temperature were developed. To determine the magnitude of the effects of these parameters, two lawn mowers were tested using different temperature profiles and fuels. Finally, a general linear model was used to find the variables that best fit the data. The resulting statistical analysis indicated that a multi-variable polynomial equation was best for both the diurnal and resting loss correction factor.

The RVP correction is applied to the hot soak and running loss of the evaporative emissions that are measured with fuel with RVP of 7 psi. When the winter fuel with RVP of 9 psi is used, the following formula is used:

[14] https://www.arb.ca.gov/msei/offroad/techmemo/SORE_Evaporative1.doc

$$CF_{RVP} = 0.3*RVP-1.1 \quad \textbf{(8)}$$

Applying an RVP of 9 psi, the above equation becomes 0.3*9-1.1 = 1.6 which is used for all Geographical Area Index (GAI) regions, when winter fuel is used. For summer fuel (RVP is at 7 psi), there is no correction for RVP, indicating that CFRVP is 1.0.

4.10.5 Pollutant Conversion

Conversion for total hydrocarbons (THC), TOG, and ROG

During exhaust or evaporative emissions testing, the hydrocarbon emissions are measured using a flame ionization detector (FID). The FID measures total hydrocarbons or compounds with hydrogen and carbon atoms only; carbonyls produce a less intense signal. This is reflected in the exhaust and evaporative emission rates, which are measured as THC. TOG includes all organic gases emitted to the atmosphere. ROG is the fraction of TOG that is reactive and does not include compounds that are exempt from regulations. The fraction of TOG, that is either THC or ROG, is determined by examination of the speciation profiles. Since the gasoline content affects the composition of HC in evaporative and exhaust emissions, the conversion factors are different for the three phases of California reformulated gasoline regulations.

The conversion factors to estimate TOG and ROG from THC vary by calendar year (mainly due to phase-in schedule of reformulated gasoline regulations), engine type, and emissions process (i.e., evaporative or exhaust). These conversion factors are listed in Table 28.

Table 28. Coefficients Used for TOG/ROG Conversion from THC

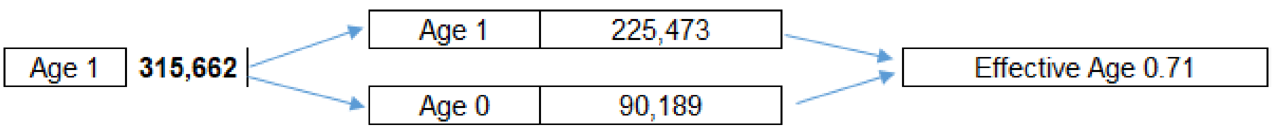
Year	Engine	Process	TOG	ROG
All	Diesel	Exhaust	THC*1.44	THC*1.21
	CNG/LPG	Exhaust	THC*0.99	THC*0.09
Pre-1996	Gasoline	Exhaust (G2)	THC*1.01	THC*0.92
		Exhaust (G4)	THC*1.04	THC*0.89
		Evaporative	THC*1.04	THC*1.04
1996-2003	Gasoline	Exhaust	THC*1.09	THC*1.00
		Evaporative	THC*1.12	THC*1.12
2004+	Gasoline	Exhaust	THC*1.10	THC*1.01
		Evaporative	THC*1.14	THC*1.14

4.10.6 Effective Age Correction

In the process of modeling population, it was apparent that nearly all new equipment sales do not occur in the first year. The majority of equipment required two or three years to reach maximum sales for that particular model year. Therefore, in calculating the emissions, a correction was applied to account for the fact that not all of the population, for a given model year, are the same age or deteriorated at the same rate. As shown in the example of residential lawn mowers, Table 29 illustrates how a percentage of the equipment is at Age 1 and another percentage is at Age 0 or brand-new.

Table 29. Population of Residential Lawn Mowers by Model Year

Gasoline Residential Lawnmower Population				
Age	CY2017	CY2018	CY2019	CY2020
0	212,215	225,473	225,473	225,473
1	294,734	297,102	315,662	**315,662**
2	299,657	303,576	306,015	325,132
3	299,208	298,158	302,058	304,485
4	283,701	297,712	296,668	300,548



To ensure that the correct age is utilized when the model calculates the emissions deterioration, the effective age correction, which is based on the population-weighted age, is applied. Table 30 below shows an example of the effective age correction for residential lawn mowers.

Table 30. Effective Age for Residential Lawn Mowers (Gas)

Equipment	Type	Age	Effective Age	Age	Effective Age	Age	Effective Age	Age	Effective Age
Lawn Mower	Residential	**0**	0	**16**	15.66	**32**	31.66	**48**	47.66
		1	0.71	**17**	16.66	**33**	32.66	**49**	48.66
		2	1.66	**18**	17.66	**34**	33.66	**50**	49.66
		3	2.66	**19**	18.66	**35**	34.66	**51**	50.66
		4	3.66	**20**	19.66	**36**	35.66	**52**	51.66
		5	4.66	**21**	20.66	**37**	36.66	**53**	52.66
		6	5.66	**22**	21.66	**38**	37.66	**54**	53.66
		7	6.66	**23**	22.66	**39**	38.66	**55**	54.66
		8	7.66	**24**	23.66	**40**	39.66	**56**	55.66
		9	8.66	**25**	24.66	**41**	40.66	**57**	56.66
		10	9.66	**26**	25.66	**42**	41.66	**58**	57.66
		11	10.66	**27**	26.66	**43**	42.66	**59**	58.66
		12	11.66	**28**	27.66	**44**	43.66	**60**	59.66
		13	12.66	**29**	28.66	**45**	44.66		
		14	13.66	**30**	29.66	**46**	45.66		
		15	14.66	**31**	30.66	**47**	46.66		

5. Updated Emissions Baseline

5.1 SORE2020 versus OFFROAD2007

The population and emissions estimates for CY2018 from OFFROAD2007 are shown in Tables 31 and 32. Similarly, Tables 33 and 34 show population and emissions estimates for CY2018 for the SORE2020 Model, for comparison.

Table 31. OFFROAD2007 Population and Statewide Summer Emissions (tpd) (Lawn & Garden Equipment)

Equipment	2018 Pop	2018 Summer Emissions (tpd)			
	Gasoline	ROG Exhaust	ROG Evap	ROG Total	NO_x
Chainsaws	1,869,500	11.41	2.99	14.40	0.20
Chainsaws Preempt	961,701	9.04	1.53	10.57	0.16
Chippers/Stump Grinders	2,613	0.38	0.01	0.39	0.25
Commercial Turf	17,448	1.46	0.12	1.58	1.08
Front Mowers	441,670	1.17	1.53	2.71	0.83
Lawn & Garden Tractors	310,643	0.77	0.91	1.68	0.55
Lawn Mowers	5,414,886	5.84	15.78	21.62	1.50
Leaf Blowers/Vacuums	1,585,665	9.94	2.52	12.46	0.22
Other Lawn & Garden Equipment	447,484	0.16	1.90	2.06	0.06
Rear Engine Riding Mowers	305,651	2.16	0.91	3.07	1.55
Shredders	303,503	0.13	0.64	0.77	0.06
Snow Blowers	90,018	0.00	0.12	0.12	0.00
Tillers	150,065	0.14	0.33	0.48	0.04
Trimmers/Edgers/Brush Cutters	3,852,156	6.79	3.81	10.60	0.29
Wood Splitters	259,483	0.13	0.99	1.12	0.03
Total	16,012,487	49.54	34.10	83.63	6.80

Table 32. OFFROAD2007 Population and Statewide Summer Emissions (tpd) (Light Commercial Equipment)

Equipment	2018 Pop Gasoline	2018 Summer Emissions (tpd)			
		ROG Exhaust	ROG Evap	ROG Total	NO_x
Air Compressors Preempt	11,182	0.56	0.05	0.61	0.31
Generator Sets	293,696	4.54	2.41	6.95	2.78
Pressure Washers	30,660	0.47	0.23	0.70	0.22
Pumps Preempt	67,770	1.42	0.47	1.88	0.87
Welders Preempt	35,890	1.37	0.22	1.59	0.90
Total	439,198	8.36	3.37	11.73	5.07

Table 33. SORE2020 Population and Statewide Summer Emissions (tpd) (Lawn & Garden Equipment)

Equipment	2018 Population			2018 Summer Emissions (tpd)			
	Gasoline	Electric	Total	ROG Exhaust	ROG Evap	ROG Total	NO_x
Chainsaws	1,417,055	836,104	2,253,159	9.16	1.00	10.16	0.28
Chainsaws Preempt	763,029	450,210	1,213,239	7.83	0.54	8.37	0.26
Chippers/Stump Grinders/Shredders	10,401	3,772	14,172	0.01	0.03	0.04	0.004
Lawn Mowers	3,665,918	1,095,836	4,761,754	2.92	17.26	20.18	1.49
Leaf Blowers/Vacuums	1,446,774	3,325,559	4,772,333	14.87	1.14	16.01	0.51
Other Lawn & Garden Equipment	46,805	N/A	46,805	0.05	0.13	0.18	0.02
Riding Mower/Tractor	378,523	17,393	395,916	6.04	5.43	11.47	2.81
Snow Blowers	55,892	4,000	59,892	0.001	0.13	0.14	0.0004
Tillers	87,232	11,383	98,615	0.11	0.33	0.44	0.02
Trimmers/Edgers/Brush Cutters	2,751,448	3,726,353	6,477,800	9.68	1.78	11.45	0.57
Wood Splitters	107,033	N/A	107,033	0.62	1.21	1.84	0.25
Total	**10,730,110**	**9,470,609**	**20,200,719**	**51.30**	**28.99**	**80.29**	**6.22**

Note: Front mower, Lawn & Garden tractors, and rear engine riding mowers have been combined and labeled as “Riding Mowers.” Likewise, shredders have been combined with chippers/stump grinders under the label of “Chippers/Stump Grinders/Shredders.”

Table 34. SORE2020 Population and Statewide Summer Emissions (tpd) (Light Commercial Equipment)

Equipment	2018 Population			2018 Summer Emissions (tpd)			
	Gasoline	Electric	Total	ROG Exhaust	ROG Evap	ROG Total	NO_x
Air Compressors Preempt	264,855	3,215,602	3,480,457	3.60	3.21	6.80	1.95
Generator Sets	1,639,897	307,291	1,947,188	10.06	11.61	21.66	3.51
Pressure Washers	919,103	1,705,284	2,624,387	2.59	2.07	4.65	1.14
Pumps Preempt	146,244	1,737,520	1,883,764	0.84	0.90	1.74	0.31
Welders Preempt	193,359	810,520	1,003,879	1.76	1.33	3.09	0.65
Total	**3,163,457**	**7,776,218**	**10,939,675**	**18.85**	**19.10**	**37.95**	**7.57**

While the 2018 population of Lawn & Garden equipment in the SORE2020 Model is lower than OFFROAD2007, the exhaust ROG emissions are slightly higher in the SORE2020 Model than they are in OFFROAD2007. Similar to population, evaporative ROG as well as exhaust NO_x emissions from Lawn & Garden equipment in the SORE2020 Model are lower than OFFROAD2007. For Light Commercial equipment, SORE2020 Model estimates are significantly higher for population and total emissions. Considering that Light Commercial equipment has relatively higher activity and operation horsepower (i.e., the product of the rated horsepower and the load factor), the increase in population of Light Commercial equipment will result in significantly higher emissions. Although the total Lawn & Garden and Light Commercial gasoline population in SORE2020 is lower from OFFROAD2007 by almost 2.6 million pieces of equipment, the emissions estimates are higher than OFFROAD2007.

Table 35 contains the percent change for lawn mowers and generators, the two main contributors to the SORE equipment category, to illustrate the contribution of various factors, including population, emission factors, activity, and average horsepower, toward the overall difference in emissions.

Table 35. Percent Change from OFFROAD2007 to SORE2020 (CY2018)

Equipment	Sector	Percent Change from OFFROAD2007 to SORE2020						
		2018 Pop	Activity	Avg Hp	ROG EXHAUST EF**	NOx EF**	ROG Exhaust	NOx
Lawn Mowers	Residential	-32	19	-4	-22	98	-20	48
	Commercial*	-40	-28	-4	-25	98	-73	-38
Generators	Residential	1030	-45	-57	160	33	324	161
	Commercial*	10	-6	-57	160	33	-7	-47

* Includes weighted Commercial and Vendor
** Emission factors at durability hours

Compared to OFFROAD2007, the contribution of ROG and NO_x vary depending on the input factors. For lawn mowers, emissions generally decreased in SORE2020 Model as compared to OFFROAD2007 due to the decrease in both the population and average horsepower. For residential generators, the increase in emissions is attributed to significant updates to the population estimate. Appendix G contains detailed population and emissions information for SORE equipment by commercial/residential/vendor sector.

6. SORE2020 Emissions Model Development

The development of the SORE2020 Model includes three key components: (1) modeling processes, (2) a schematic flowchart, and (3) the model's installation and user manual.

6.1 SORE2020 Computer Modeling Process

SORE2020 was developed based on an ACCESS platform, using Visual Basic for Application (VBA). It consists of eight individual emission estimation modules: Airport Ground Support Equipment, Agricultural Equipment, Construction Equipment, Industrial Equipment, Lawn & Garden Equipment, Light Commercial Equipment, Logging Equipment, and Transport Refrigeration Equipment.

The model approach, used for emission estimation, is shown in the following equation:

$$\text{Emissions} = \text{Population} * \text{Activity} * \text{Emission Factor} * \text{Correction Factor} \quad \textbf{(8)}$$

For each type of equipment, the total emissions is the product of the population, activity, and emission factor. Correction factors may be applied to account for differences related to geographic areas, environment conditions (temperature and humidity), and fuel properties, and to reflect regulations.

In the SORE2020 Model, data for the factors used for emission estimation was stored in comma-separated value (CSV) files. Each module has its own file folder and corresponding files. The general filing structure of the SORE2020 Model is shown in Figure 9.

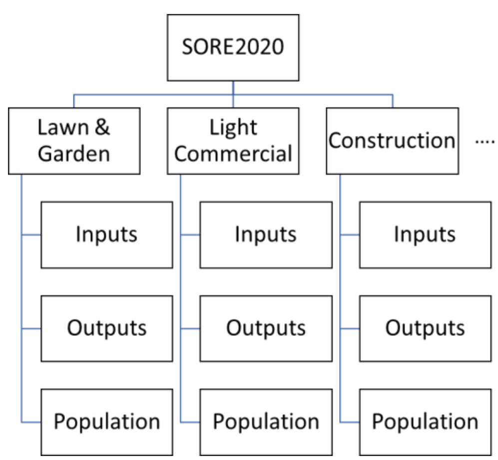


Figure 9. SORE2020 Model Filing Structure

The SORE2020 Model consists of eight secondary folders for all SORE categories, with each category having a corresponding folder. Furthermore, each secondary folder has its own inputs, outputs, and population folders. Namely, all input files are stored in the inputs folder, and all output files are stored in the outputs folder. The population folder is used to store information required for population estimation if needed, including population growth rate, survival ratio, and base year population.

There are multiple key advantages to the new file structure used in the SORE2020 Model including:

1. Each module is independent of the other modules, so module maintenance is not complicated.
2. The data required to estimate emissions are stored in separate files that facilitate updates to input files. For example, if the population requires an update, only the population file must be changed. The SORE2020 Model will run as long as all the required files are available in the corresponding folders.
3. The separation of input and output files make data organization easier, which simplifies model maintenance.

6.2 SORE2020 Model Flowchart

As shown in Figure 10, the SORE2020 Model reads in population, activity, emission factors, and other correction information from its individual files and outputs the emissions estimate. The Model outputs two types of results simultaneously: (1) the aggregated emissions based on each calendar year, and (2) detailed emissions by model year for each calendar year. Both input and output files are CSV-based.

The computation of emissions is achieved by looping over multiple factors, including CRVU (**C**ommercial/**R**esidential/**V**endor/**U**nknown), horsepower (hp) range, fuel technology, age, equipment type, and calendar year. The innermost looping is the application type (if applicable) and the outermost looping is the calendar year.

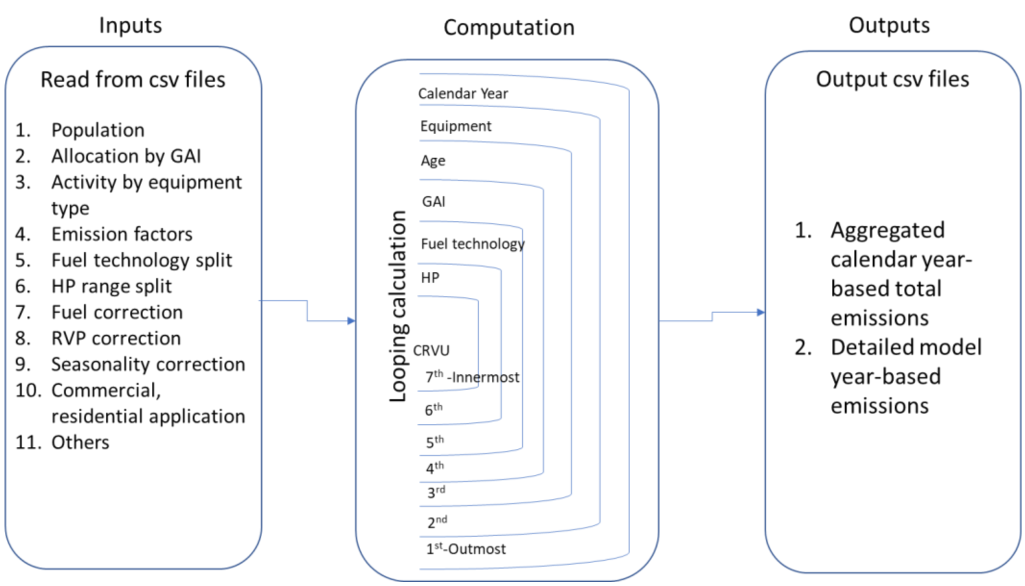


Figure 10. Schematic Diagram of the SORE2020 Model

6.3 SORE2020 Model Installation & User's Guide

Since SORE2020 is a stand-alone ACCESS file, it does not require any particular installation. To set up the SORE2020 Model, create a folder to store the Model files and its associated subfolders for all the included categories. For example, as shown in Figure 11, the SORE2020 Model (SORE2020-v3401.accdb) was stored in the folder called "SORE-2020-Development," along with all the associated subfolders for all the SORE categories, such as the folder "Lawn2017."

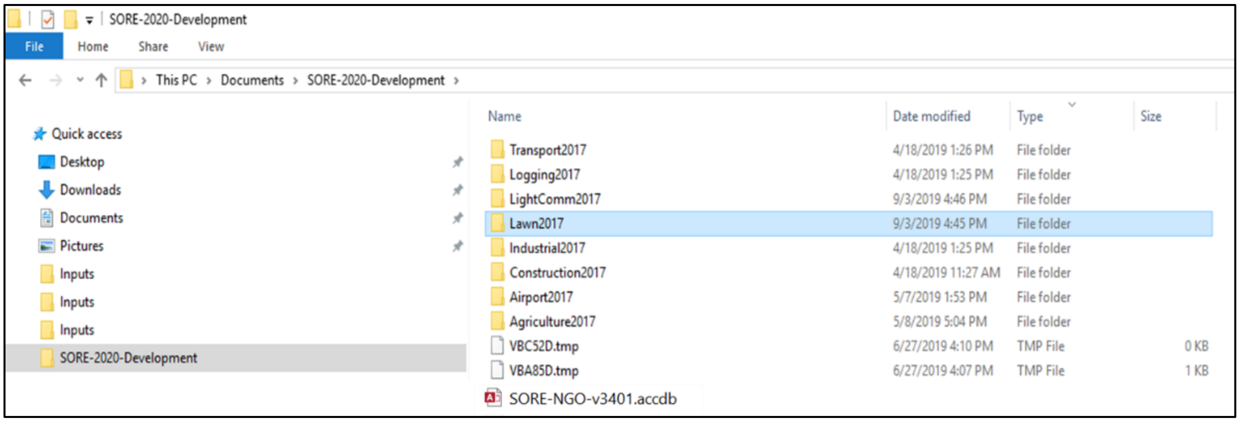


Figure 11. SORE2020 Model Setup Folder Structure

Furthermore, for each of the category folders (e.g., Lawn2017), there are three subfolders to store input, output, and population files, as shown in Figure 12. The "Population" folder is created to store files needed to estimate population, such as base year population, growth rate, and survival rates. A population forecasting module was also developed and embedded in the SORE2020 Model and used to update population data if needed, based on new information.

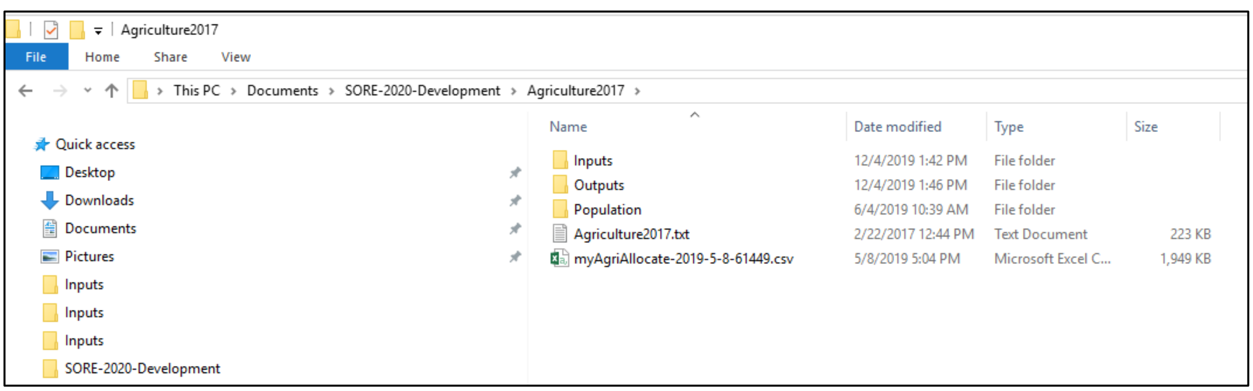


Figure 12. SORE2020 Model Individual Module Setup Folder Structure

Below, Figure 13 illustrates the graphical user interface (GUI) of the Model. To run a specific category, the user clicks on that specific category.

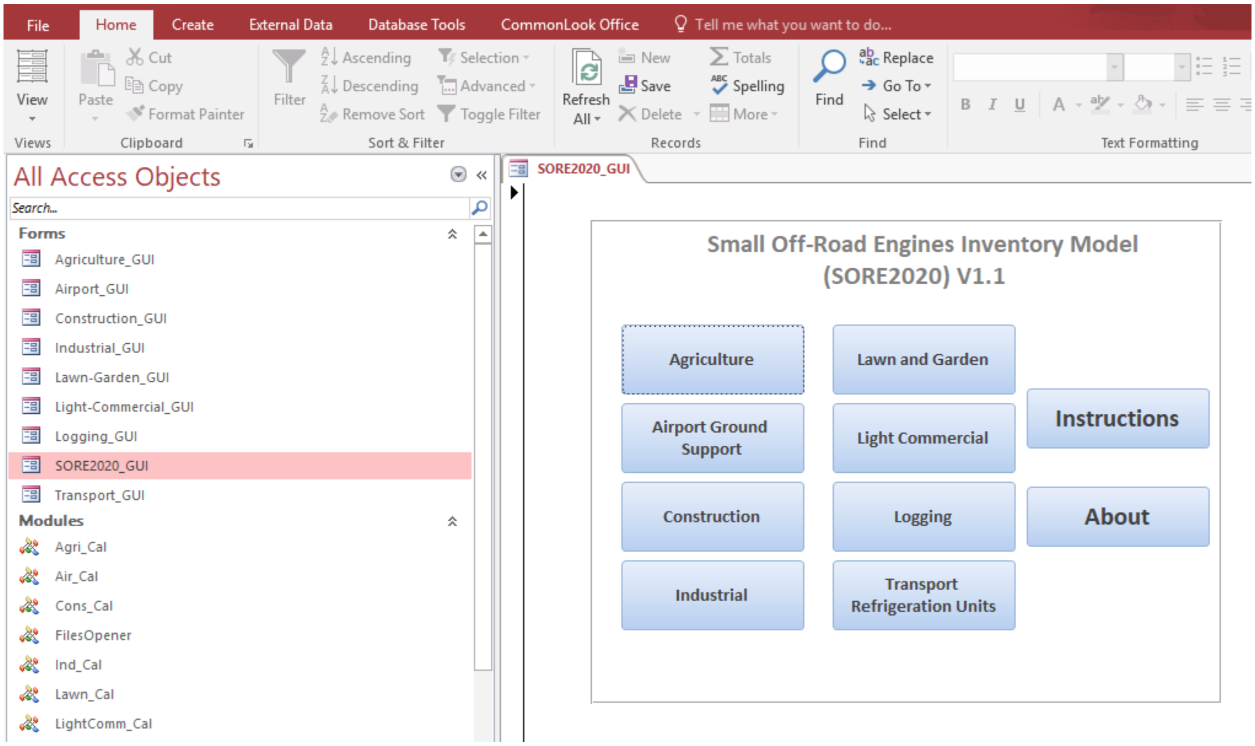


Figure 13. SORE2020 Model's Graphical User Interface

When a secondary GUI appears, as shown in Figure 14, by default, the user should only specify the seasonality and beginning calendar year to run the model. If any other specific input files are needed, then the option for "Customized Files" may be checked and each of the input files are selected by clicking each individual file button and/or using the Windows File Explorer to specify the corresponding files. Once all of the information and customizations are provided, the user selects "OK, Continue." By choosing "Cancel, Go back", the user will arrive back to the initial input screen of the SORE2020 Model.

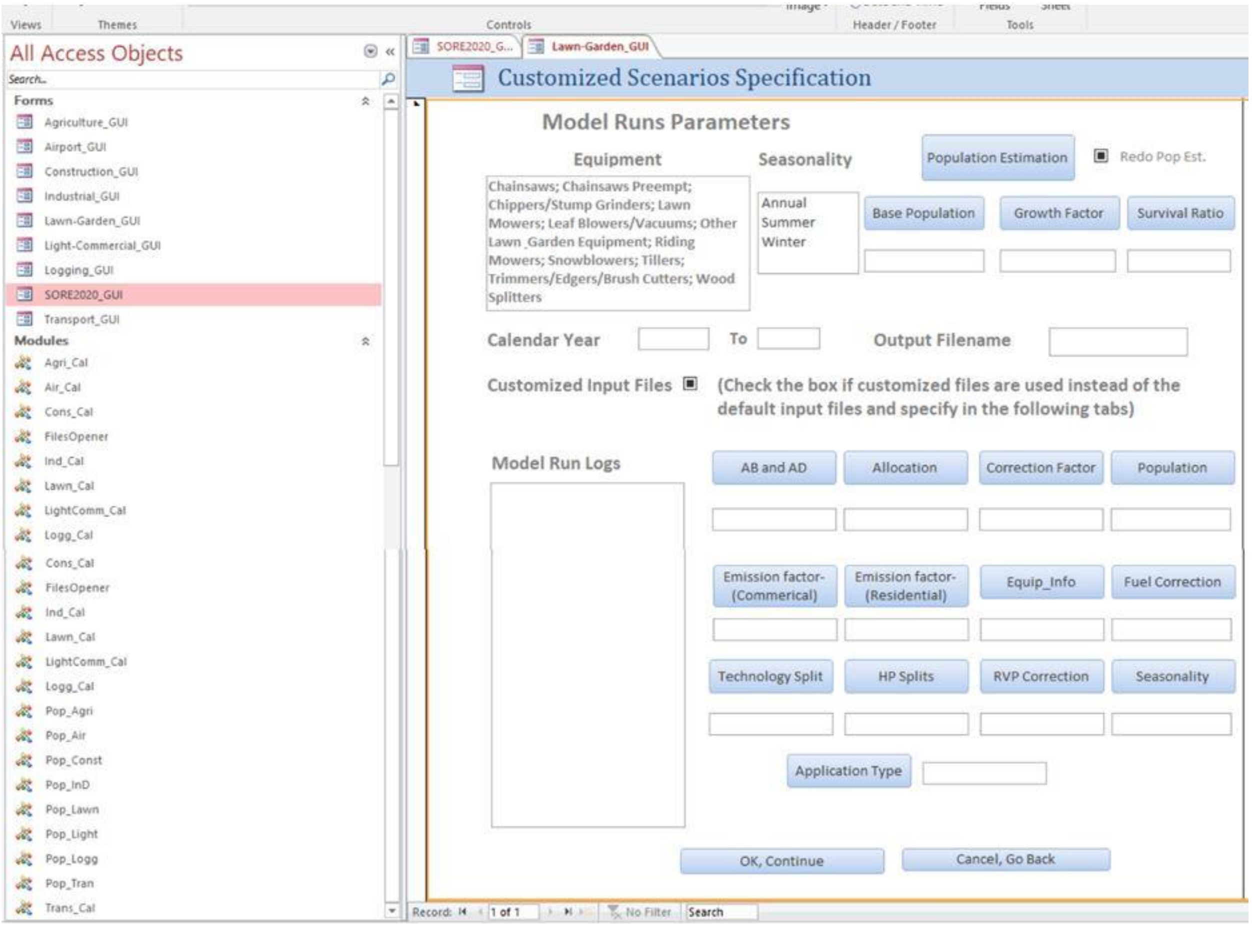


Figure 14. An Example of the SORE2020 Model's Secondary Graphical User Interface

Appendix A – Population Methodology

In 2001, the U.S. Environmental Protection Agency (U.S. EPA) funded a study with CARB to determine the residential Lawn & Garden population and usage estimates[15]. CARB staff reviewed the methodology used in the 2001 U.S. EPA study and determined that re-weighting the data by geographical area was appropriate. In the 2001 survey analysis, the calculation consisted of taking the survey sample results for each piece of equipment by type and fuel and dividing it by the total number of survey respondents; the percentage was extrapolated statewide by multiplying by the number of California households in 2001 (11,502,870) to derive the population estimate. Staff assessed that a revised weighting method should be utilized to take into account geographical areas separated by northern, central/upper, and southern portions of the state. As a result, in the SORE2020 Model, geographical weights are used to proportionally reflect the higher concentration of households primarily in the southern and northern bay areas of the state, as compared to the rural regions of central and far northern California. Figure A1 shows the geographical area map used for weighting in the SORE2020 Model.

[15] "OFFROAD Modeling Change Technical Memo: Change in Population and Activity Factors for Lawn & Garden Equipment", can be found under the "2001 Residential Lawn & Garden Survey" link at: https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road-0.

Figure A1: Geographical Areas for Weighting

The data obtained from the surveys are further aggregated by respondent dwelling: single family residence (SFR) or non-SFR (apartment/condo/town house/mobile home). In addition, single family homes are distinguished from apartment/condo dwellings as a weighting factor, due to the greater likelihood of possessing small engine equipment. For consistency, this new geographical weighting method was applied to the raw data obtained from the 2001, 2012, and 2018 surveys.

The results are divided by the number of total completed surveys. This percentage is weighted against the appropriate statewide household population that has been divided into geographical or dwelling type factor. An example for the 2001 and 2018 population estimate methodology is shown below in Tables A1 and A2.

Table A1. Population Estimate Methodology Example (2001)

Equipment	**Northern**				**Southern**				**Central/Upper**				**Total**
	SFR		**Non-SFR**		**SFR**		**Non-SFR**		**SFR**		**Non-SFR**		
	Gas	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	**Gas**	**Electric**	
Chainsaws	114	70	5	2	63	47	4	3	205	60	8	4	
Chippers/Stump Grinders	1	1	1	0	0	0	0	0	0	0	0	0	
Lawn Edgers	20	44	1	3	57	29	4	5	97	61	5	2	
Lawn Mowers (Riding)	26	0	2	0	4	1	0	0	49	1	5	0	
Lawn Mowers (Walk Behind)	216	55	5	4	177	26	12	3	339	39	20	5	
Leaf Blowers	39	133	3	9	34	75	4	7	87	138	5	11	
Shredders	19	5	1	1	5	3	0	0	18	5	1	0	
Snow Blowers	2	0	0	0	3	0	0	0	6	0	1	0	
String Trimmers	91	168	2	11	79	110	4	11	167	155	8	8	
Brushcutters	12	31	1	0	4	30	0	1	16	41	2	3	
Tractors	10	1	1	0	4	0	1	0	25	0	1	0	
Wood Splitters	11	0	1	0	3	0	0	0	18	0	3	0	
Other(s)	24	15	2	2	9	8	1	1	28	9	4	3	
Completed Surveys	**562**		**207**		**456**		**198**		**575**		**167**		**2165**
Number of Households	**1,862,500**		**917,351**		**4,301,741**		**2,216,049**		**1,764,184**		**441,046**		**11,502,870**

SFR – Single Family Residence
Non-SFR – Condominium/Apartment/Town House/Mobile Home

Table A2. Population Estimate Methodology Example (2018)

Equipment	Northern				Southern				Central/Upper				Total
	SFR		Non-SFR		SFR		Non-SFR		SFR		Non-SFR		
	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	
Chainsaws	57	26	9	2	52	62	5	3	60	25	4	2	
Other-Chippers/Stump Grinders	0	1	0	0	0	1	0	0	0	0	0	0	
Pressure Washers	19	42	2	3	19	59	3	9	26	35	0	4	
Pumps	2	37	1	3	2	64	0	7	4	41	0	3	
Lawn Mowers (Walk Behind)	75	23	0	2	136	49	3	6	99	21	3	1	
Leaf Blowers	24	78	0	2	43	129	1	11	32	74	1	4	
Shredders													
Snow Blowers	0	0	0	0	2	1	0	0	2	0	0	0	
Trimmers	37	73	3	2	79	114	6	11	50	58	2	3	
Compressors	5	52	0	10	5	129	1	12	7	79	0	4	
Generators	30	1	3	2	57	15	3	2	37	6	6	1	
Welders	0	12	0	1	8	30	2	2	3	25	0	2	
Other-Wood Splitters	0	0	0	0	0	0	0	0	1	1	0	0	
Other-Tillers	3	3	0	0	0	0	0	0	3	1	0	0	
Other-Trimmers	8	21	0	1	18	23	0	3	6	21	1	1	
Other-Riding Mowers	2	1	1	0	4	0	1	0	5	1	3	0	
Others	4	0	0	0	0	0	0	0	0	0	0	0	
Completed Surveys	**191**		**79**		**429**		**235**		**181**		**36**		**1,151**
Number of Households	2,106,789		1,037,672		4,865,966		2,506,710		1,995,578		498,894		13,011,609

SFR – Single Family Residence
Non-SFR – Condominium/Apartment/Town House/Mobile Home

Tables A3 through A5 show the fleet data results from 2001, 2012, and 2018 surveys for residential gas and electric engines. Note that “Non-SFR” are non-single-family houses and include condominiums, town houses, apartments, and mobile homes. Table A6 shows the 2018 CSUF survey results for fleet populations from commercial (business) and vendor type users. Commercial and vendor equipment populations are not re-weighted from the study’s original reported numbers.

Table A3. 2001 Residential CARB Lawn & Garden Survey Results

Equipment	Gas			Electric			Gas + Electric Total
	SFR	Non-SFR	Total Residential	SFR	Non-SFR	Total Residential	
Chainsaws	1,601,092	88,055	1,689,147	859,454	53,004	912,458	2,601,604
Chippers/Stump Grinders/Shredders	168,676	11,504	180,180	63,526	4,432	67,958	248,138
Riding Mowers/Tractors	421,818	40,333	462,151	15,816	0	15,816	477,967
Lawn Mowers (Walk Behind)	3,425,693	209,284	3,634,977	547,206	64,508	611,714	4,246,690
Leaf Blowers	716,921	71,269	788,189	1,571,697	147,281	1,718,978	2,507,167
Snow Blowers	53,338	2,641	55,979	0	0	0	55,979
Trimmers/Edgers/Brushcutters	2,587,420	146,879	2,734,299	3,188,115	286,643	3,474,758	6,209,056
Wood Splitters	119,982	12,355	132,337	0	0	0	132,337
Other(s)	250,348	30,619	280,968	152,793	27,978	180,772	461,739
Total			**9,958,227**			**6,982,454**	**16,940,677**

SFR – Single Family Residence
Non-SFR – Condominium/Apartment/Town House/Mobile Home

Table A4. 2012 Residential Lawn & Garden Survey Results

Equipment	Gas			Electric			Gas + Electric Total
	SFR	Non-SFR	Total Residential	SFR	Non-SFR	Total Residential	
Chainsaws	319,859	38,264	358,123	170,080	23,283	193,363	551,486
Chippers/Stump Grinders/Shredders	157,552	12,644	170,195	53,382	4,806	58,188	228,383
Lawn Mowers (Walk Behind)	3,310,275	177,780	3,488,054	419,213	18,477	437,690	3,925,744
Leaf Blowers	521,346	43,301	564,647	594,321	57,023	651,345	1,215,992
Riding Mowers/Tractors	418,786	37,186	455,972	11,947	0	11,947	467,919
Snow Blowers	42,348	3,033	45,380	0	0	0	45,380
Trimmers/Edgers/Brushcutters	1,151,849	86,139	1,237,988	992,609	82,926	1,075,534	2,313,522
Wood Splitters	115,190	13,903	129,093	0	0	0	129,093
Other(s)	225,555	26,315	251,871	124,150	23,283	147,433	399,304
Total			**6,701,323**			**2,575,500**	**9,276,823**

SFR – Single Family Residence
Non-SFR – Condominium/Apartment/Town House/Mobile Home

Table A5. 2018 Residential CSUF Survey Results (Weighted)

Equipment	Gas			Electric			Gas + Electric Total
	SFR	Non-SFR	Total Residential	SFR	Non-SFR	Total Residential	
Chainsaws	1,880,059	226,983	2,107,042	1,265,660	85,987	1,351,647	3,458,689
Chippers/Stump Grinders/Shredders	0	0	0	22,373	0	22,373	22,373
Lawn Mowers (Walk Behind)	3,461,368	73,575	3,534,943	1,041,015	104,129	1,145,144	4,680,087
Leaf Blowers	1,105,268	24,525	1,129,793	3,139,428	199,038	3,338,466	4,468,259
Riding Mowers/Tractors	122,557	65,376	187,934	22,056	0	22,056	209,989
Snow Blowers	44,736	0	44,736	11,343	0	11,343	56,078
Trimmers/Edgers/Brushcutters	2,214,010	144,981	2,358,991	3,461,780	244,174	3,705,954	6,064,945
Wood Splitters	11,025	0	11,025	11,025	0	11,025	22,051
Others	44,121	0	44,121	0	0	0	44,121
Other-Tillers	66,167	0	66,167	44,116	0	44,116	110,283
Compressors	189,041	10,667	199,708	2,907,767	314,786	3,222,552	3,422,261
Generators	1,385,372	154,555	1,539,927	247,321	61,462	308,783	1,848,710
Pressure Washers	711,742	58,271	770,013	1,518,370	190,840	1,709,210	2,479,223
Pumps	88,847	13,135	101,982	1,586,083	155,648	1,741,731	1,843,713
Welders	123,817	21,334	145,150	748,273	62,185	810,458	955,609
Total			**12,241,532**			**17,444,858**	**29,686,391**

SFR – Single Family Residence
Non-SFR – Condominium/Apartment/Town House/Mobile Home

Table A6. 2018 CSUF Commercial & Vendor Survey Results (Avg. Population)

Equipment	Gas		Electric	
	Commercial	Vendor	Commercial	Vendor
Chainsaws	160,765	203,584	9,177	5,264
Lawn Mower (Walk Behind)	106,224	107,904	3,739	2,450
Leaf Blower	188,936	131,279	90,969	11,392
Riding Mower/Tractor	-	10,761	-	-
Snow Blowers	6,109	4,602	-	-
Trimmers/Edgers/Brushcutters	166,699	235,688	41,675	12,799
Compressor	53,448	2,942	245,859	14,333
Generator	183,185	8,657	24,182	692
Pressure Washer	134,175	15,518	111,025	3,261
Pump	45,964	1,848	90,675	3,031
Welder	46,910	1,144	154,314	6,778
Total	**1,092,415**	**723,927**	**771,615**	**60,000**

Population estimates for small gasoline engines are based on past and recent surveys and studies, including CARB's 2001 Lawn & Garden Study, 2012 Lawn & Garden Survey, and the "Survey of Small Off-Road Engines (SORE) Operating within California: Results from Surveys with Four Statewide Populations" (CSUF, 2018). Note that the 2001 and 2012 surveys primarily focused on the residential sector, whereas the 2018 survey included all SORE equipment owned by residents, businesses, and vendors. The 2018 survey is the first comprehensive survey that attempted to cover all SORE in California. In addition to the 2018 SORE survey, staff also utilized production volume data from both PLT data for years 2002 through 2018 and data from the 2018 SORE evaporative reporting requirement. For thoroughness, the population estimates were examined against shipment data, and market research results for reasonableness.

To forecast the population of small off-road engines, staff utilized the methodology described below:

1. Fleet data for small engine equipment were extracted from surveys conducted in calendar years 2001, 2012, and 2018. Fleet data included both gasoline and electric-powered (cord and battery) engines.
2. Age distributions for each equipment type were obtained from 2001, 2012, and 2018 surveys.
3. Age distributions for each equipment type was then used to estimate the survival curves.
4. The first year sales/shipment data were extracted from PLT and 2018 SORE evaporative PVR data.
5. CARB staff then developed a population model that estimated the population of SORE equipment from 2000 to 2018 for each equipment type by fuel type (gas/electric) and user type (residential/commercial [business]/vendor), using the first year sales and survival rates. The model results were aligned with the fleet survey values from 2001, 2012, and 2018 surveys, and the sales growth rates for CY2020 to 2018 were derived from the PLT data. Using this method, staff adjusted the survival curves such that the model accurately reflected equipment population for the years where actual fleet data was available.
6. For future years, CY2019 and onward, CARB staff utilized household growth as a surrogate to forecast the population of SORE in the future.
7. The fleet population estimates and first year sales were further evaluated using additional sources such as Outdoor Power Equipment Institute (OPEI) shipment data and 2018 SORE evaporative PVR data.

Table A7 shows an example of the population modeling calculation. Population modeling begins with the 2000 fleet population, and the age distribution from the 2001 survey is applied. The result is the base year 2000 population by equipment age. For

2001, the Age 0 population from the 2000 fleet population is multiplied by the annual growth rate for 2001, resulting in the new-year sales for Age 0 in the 2001 fleet population. Next, the survival rates are applied to the remaining 2000 population by age to determine the rest of the 2001 population by age. Note that at Age 2, the population increases because most equipment is shelved for a few years before being sold. The same methodology can be applied to calculate the population of CY2002 to 2018. Beginning in CY2019 and after, a forecasted growth rate must be applied.

Table A7. Population Modeling Example

Age	Survival Curve	Calendar Year 2000 Age Distribution	Calendar Year 2000	Calendar Year 2001	Comment
0		0.028	102,760	102,760	Growth rate is 1.00 for CY2001
1	2.1	0.075731	277,935	215,796	Multiply 102,760 x 2.1 = 215,796
2	1.07	0.122203	448,485	297,390	Multiply 277,935 x 1.07 = 297,390
3	0.995	0.100402	368,474	446,243	
4	0.995	0.100975	370,579	366,632	
5	0.98	0.089501	328,468	363,168	
6	0.98	0.083764	307,413	321,899	
7	0.96	0.060815	223,190	295,116	
8	0.96	0.043029	157,917	214,262	
9	0.85	0.06	220,200	134,230	
10	0.85	0.051635	189,501	187,170	
11	0.8	0.056799	208,451	151,601	
12	0.8	0.013769	50,534	166,761	
13	0.8	0.012048	44,217	40,427	
14	0.8	0.018359	67,378	35,373	
15	0.8	0.017212	63,167	53,902	
16	0.8	0.016638	61,061	50,534	
17	0.8	0.008	29,360	48,849	
18	0.8	0.007458	27,372	23,488	
19	0.8	0.007458	27,372	21,898	
20	0.8	0.008032	29,478	21,898	
21	0.8	0.004016	14,739	23,582	
22	0.8	0.004016	14,739	11,791	
23	0.7	0.003442	12,633	10,317	
24	0.7	0.001721	6,317	8,843	
25	0.7	0.001	3,670	4,422	
26	0.7	0.001	3,670	2,569	
27	0.7	0.001	3,670	2,569	
28	0.6	0.001	3,670	2,202	

Age	Survival Curve	Calendar Year 2000 Age Distribution	Calendar Year 2000	Calendar Year 2001	Comment
29	0.6	0.001	3,670	2,202	
30	0.5	0.001	3,670	1,835	
31	0.4	0	0	1,468	
32	0.3	0	0	0	
Total Fleet Population			**3,673,761**	**3,631,197**	

When estimating the population, staff checked the 2018 sales estimated by the SORE2020 Model against the production volume report provided by manufacturers for each equipment type, to ensure that the SORE2020 Model closely estimated similar numbers of equipment as reported. One noted exception were the gasoline generators, where the number reported by manufacturers was much higher than what was estimated by the model and in the 2018 Survey. The 2018 production volume report estimated a total of ~330,000 generators produced for sale in California, whereas the model estimated a lower number than that. Staff is currently assessing the discrepancy between the survey results and the high sales reported in the 2018 production volume report. As staff finalize the SORE2020 inventory model, the 2018 survey and 2018 PVR data will be corroborated with the 2019 PVR data to ensure that the SORE2020 Model is accurately estimating the number of gasoline generators.

Appendix B – Growth Methodology

CARB staff considered different surrogates to forecast the growth of small off-road engines, but they were not utilized due to several factors. In the past, many economic data surrogates, including the annual change in automobile registration and per capita ownership of capital goods, have closely followed small engine shipment data from the PLT database, as shown below in Figure B1.

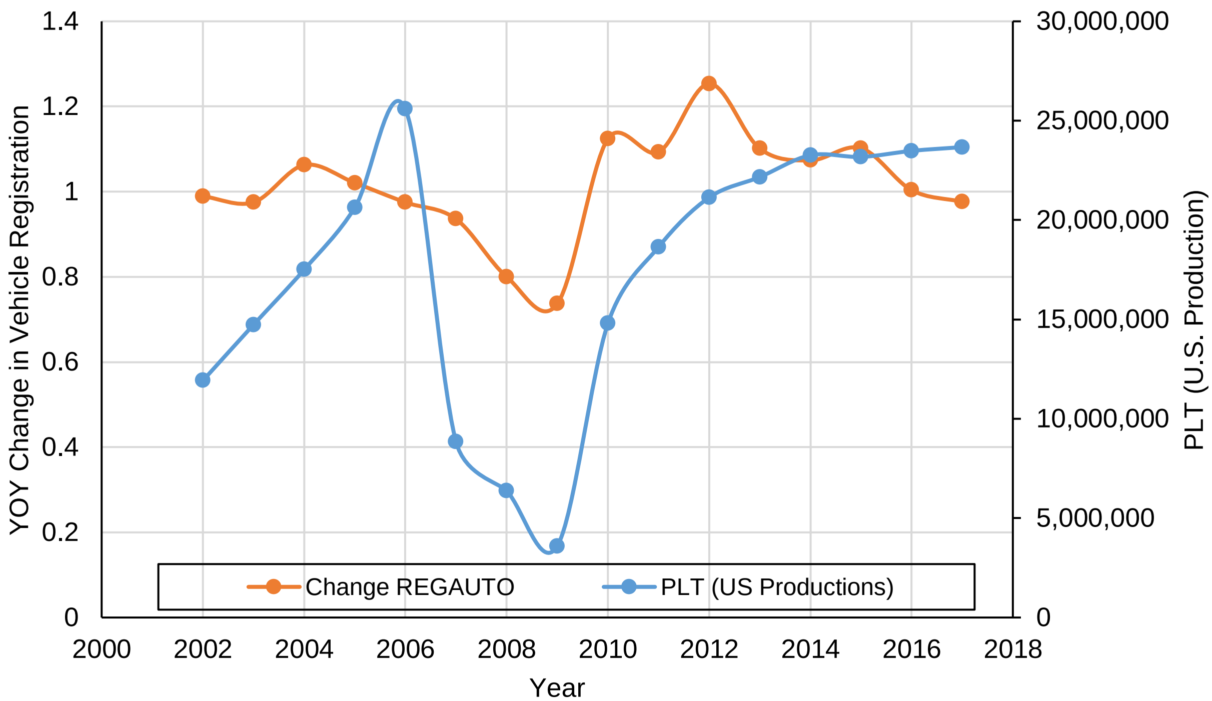


Figure B1. Economic Surrogate (DMV Registration vs. PLT)

The use of vehicle registration as a surrogate showed some correlation, but has some drawbacks. Although, registration fluctuated less than PLT shipments during the recession, it has constantly declined since CY2012. This trend can be attributed to high recent auto sales or changes in consumer preferences toward other travel model choices as opposed to personal car ownership. For forecasting small engine growth, the vehicle registration surrogate has decreased in reliability due to the decline of vehicle purchases. Although, the yearly changes in per capita ownership of capital goods would be a more representative surrogate for historical small engine growth, as shown below in Figure B2, the lack of data available to forecast the trend of capital goods (5 to 10 years) makes its surrogacy difficult to justify.

Figure B2. Change in Per Capita Goods vs. US Production from PLT

Appendix C – Survival Rate Charts

The year-over-year (YOY) survival rates for major SORE equipment, as utilized in the SORE2020 Model, are contained in the tables C1 to C8 below. Pre-recession refers to calendar year 2000 to 2011. Post-recession refers to calendar year 2012 and later. The year-over-year survival rate can be used as:

Population (Age=x) = Population (Age=x-1)*Survival Rate (Age = x)

Table C1. Lawn Mower Survival Rates

Age	Lawn Mower							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	2.100	3.900	5.000	1.700	1.400	3.900	5.000	2.040
2	1.070	1.300	1.200	1.030	1.030	1.300	1.200	1.236
3	0.995	1.000	0.919	0.980	0.995	1.000	0.919	1.176
4	0.995	0.962	0.823	0.950	0.995	0.962	0.823	1.140
5	0.980	0.898	0.748	0.900	0.980	0.898	0.748	1.080
6	0.980	0.860	0.687	0.900	0.980	0.860	0.687	1.080
7	0.960	0.839	0.636	0.850	0.960	0.839	0.636	1.020
8	0.960	0.832	0.591	0.750	0.960	0.832	0.591	0.900
9	0.850	0.835	0.552	0.700	0.850	0.835	0.552	0.840
10	0.850	0.845	0.517	0.700	0.850	0.845	0.517	0.840
11	0.850	0.852	0.485	0.700	0.850	0.852	0.485	0.840
12	0.850	0.845	0.456	0.700	0.850	0.845	0.456	0.840
13	0.850	0.811	0.429	0.700	0.850	0.811	0.429	0.840
14	0.800	0.738	0.404	0.650	0.800	0.738	0.404	0.780
15	0.800	0.604	0.381	0.650	0.800	0.604	0.381	0.780
16	0.800	0.500	0.360	0.650	0.800	0.500	0.360	0.780
17	0.800	0.500	0.340	0.650	0.800	0.500	0.340	0.780
18	0.800	0.500	0.321	0.650	0.750	0.500	0.321	0.780
19	0.800	0.500	0.302	0.650	0.750	0.500	0.302	0.780
20	0.800	0.500	0.285	0.650	0.700	0.500	0.285	0.780
21	0.800	0.500	0.269	0.650	0.700	0.500	0.269	0.780
22	0.800	0.500	0.250	0.650	0.700	0.500	0.250	0.780
23	0.700	0.500	0.250	0.650	0.700	0.500	0.250	0.780
24	0.700	0.500	0.250	0.650	0.700	0.500	0.250	0.780
25	0.700	0.500	0.250	0.650	0.650	0.500	0.250	0.780
26	0.700	0.500	0.250	0.650	0.650	0.500	0.250	0.780
27	0.700	0.500	0.250	0.650	0.650	0.500	0.250	0.780
28	0.600	0.500	0.250	0.624	0.500	0.500	0.250	0.749
29	0.600	0.500	0.250	0.624	0.500	0.500	0.250	0.749

Age	Lawn Mower							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
30	0.500	0.500	0.250	0.520	0.500	0.500	0.250	0.624
31	0.400	0.500	0.250	0.416	0.400	0.500	0.250	0.499
32	0.300	0.500	0.250	0.312	0.250	0.500	0.250	0.375
33	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
34	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
35	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
36	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
37	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
38	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
39	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300
40	0.300	0.500	0.250	0.250	0.250	0.500	0.250	0.300

Table C2. Chainsaw Survival Rates

Age	Chainsaw							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	1.350	2.741	3.500	2.600	1.350	3.045	3.500	2.600
2	1.100	1.412	0.997	1.070	1.100	1.412	0.997	1.070
3	1.030	1.013	0.900	0.990	1.030	1.013	0.900	0.990
4	1.002	0.869	0.750	0.970	1.002	0.869	0.750	0.970
5	0.972	0.786	0.700	0.940	0.972	0.786	0.700	0.940
6	0.950	0.729	0.700	0.850	0.950	0.729	0.700	0.850
7	0.933	0.691	0.600	0.800	0.933	0.691	0.600	0.800
8	0.917	0.679	0.600	0.800	0.917	0.679	0.600	0.800
9	0.902	0.706	0.600	0.750	0.902	0.706	0.600	0.750
10	0.885	0.783	0.600	0.750	0.885	0.783	0.600	0.750
11	0.800	0.881	0.600	0.750	0.800	0.881	0.600	0.750
12	0.853	0.935	0.500	0.750	0.853	0.935	0.500	0.750
13	0.841	0.909	0.400	0.700	0.841	0.909	0.400	0.700
14	0.837	0.813	0.400	0.700	0.837	0.813	0.400	0.700
15	0.850	0.647	0.350	0.700	0.850	0.647	0.350	0.700
16	0.885	0.337	0.350	0.600	0.885	0.337	0.350	0.600
17	0.943	0.300	0.350	0.600	0.943	0.300	0.350	0.600
18	1.000	0.300	0.300	0.600	1.000	0.300	0.300	0.600
19	1.000	0.300	0.300	0.500	1.000	0.300	0.300	0.500
20	0.999	0.300	0.250	0.500	0.999	0.300	0.250	0.500
21	0.862	0.300	0.250	0.500	0.862	0.300	0.250	0.500

Age	Chainsaw							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
22	0.506	0.300	0.250	0.500	0.506	0.300	0.250	0.500
23	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
24	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
25	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
26	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
27	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
28	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
29	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
30	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
31	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
32	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
33	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
34	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
35	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
36	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
37	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
38	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
39	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500
40	0.500	0.300	0.250	0.500	0.500	0.300	0.250	0.500

Table C3. Trimmer Survival Rates

Age	Trimmer							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	2.400	4.077	2.169	3.000	1.600	4.077	2.169	2.700
2	1.250	1.244	1.105	1.200	1.100	1.244	1.105	1.080
3	0.974	0.910	0.875	0.900	0.974	0.910	0.875	0.900
4	0.874	0.766	0.748	0.900	0.874	0.766	0.748	0.900
5	0.828	0.667	0.640	0.750	0.828	0.667	0.640	0.750
6	0.813	0.580	0.519	0.750	0.813	0.580	0.519	0.750
7	0.821	0.499	0.336	0.700	0.821	0.499	0.336	0.700
8	0.845	0.449	0.665	0.700	0.845	0.449	0.665	0.700
9	0.868	0.500	0.500	0.700	0.868	0.500	0.500	0.700
10	0.875	0.500	0.500	0.700	0.875	0.500	0.500	0.700
11	0.855	0.500	0.500	0.700	0.855	0.500	0.500	0.700
12	0.805	0.500	0.500	0.700	0.805	0.500	0.500	0.700
13	0.723	0.500	0.500	0.700	0.723	0.500	0.500	0.700

Age	Trimmer							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
14	0.601	0.500	0.500	0.700	0.601	0.500	0.500	0.700
15	0.874	0.500	0.500	0.700	0.874	0.500	0.500	0.700
16	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
17	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
18	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
19	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
20	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
21	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
22	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
23	0.300	0.500	0.500	0.700	0.300	0.500	0.500	0.700
24	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
25	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
26	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
27	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
28	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
29	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
30	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
31	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
32	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
33	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
34	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
35	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
36	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
37	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
38	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
39	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500
40	0.300	0.500	0.500	0.500	0.300	0.500	0.500	0.500

Table C4. Leaf Blower Survival Rates

Age	Leaf Blower							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	3.200	4.933	1.678	3.000	2.650	4.933	1.678	3.000
2	0.970	1.246	1.091	1.150	0.970	1.246	1.091	1.150
3	0.940	0.929	0.908	0.940	0.940	0.929	0.908	0.940
4	0.920	0.790	0.798	0.920	0.920	0.790	0.798	0.920
5	0.900	0.700	0.705	0.900	0.900	0.700	0.705	0.900

Age	Leaf Blower							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
6	0.850	0.700	0.602	0.850	0.850	0.700	0.602	0.850
7	0.780	0.700	0.451	0.750	0.780	0.700	0.451	0.750
8	0.750	0.700	0.374	0.750	0.750	0.700	0.374	0.750
9	0.750	0.700	0.300	0.750	0.750	0.700	0.300	0.750
10	0.750	0.700	0.300	0.750	0.750	0.700	0.300	0.750
11	0.700	0.700	0.300	0.750	0.700	0.700	0.300	0.750
12	0.700	0.700	0.300	0.750	0.700	0.700	0.300	0.750
13	0.700	0.700	0.300	0.750	0.700	0.700	0.300	0.750
14	0.500	0.700	0.300	0.700	0.500	0.700	0.300	0.700
15	0.500	0.745	0.300	0.700	0.500	0.745	0.300	0.700
16	0.500	0.585	0.300	0.700	0.500	0.585	0.300	0.700
17	0.500	0.514	0.300	0.600	0.500	0.514	0.300	0.600
18	0.500	0.300	0.300	0.600	0.500	0.300	0.300	0.600
19	0.500	0.300	0.300	0.600	0.500	0.300	0.300	0.600
20	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
21	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
22	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
23	0.500	0.300	0.300	0.300	0.500	0.300	0.300	0.300
24	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
25	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
26	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
27	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
28	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
29	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
30	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
31	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
32	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
33	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
34	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
35	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
36	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
37	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
38	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
39	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250
40	0.500	0.300	0.300	0.250	0.500	0.300	0.300	0.250

Table C5. Generator Survival Rates

Age	Generator							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	4.000	3.306	4.032	1.800	4.000	3.306	4.032	1.800
2	1.250	1.146	1.235	1.400	1.250	1.146	1.235	1.400
3	0.990	0.878	0.957	1.000	0.990	0.878	0.957	1.000
4	0.980	0.880	0.843	0.990	0.980	0.880	0.843	0.990
5	0.960	0.880	0.782	0.990	0.960	0.880	0.782	0.990
6	0.940	0.880	0.751	0.990	0.940	0.880	0.751	0.990
7	0.900	0.880	0.749	0.980	0.900	0.880	0.749	0.980
8	0.850	0.880	0.777	0.900	0.850	0.880	0.777	0.900
9	0.850	0.880	0.828	0.800	0.850	0.880	0.828	0.800
10	0.850	0.880	0.877	0.700	0.850	0.880	0.877	0.700
11	0.800	0.880	0.895	0.650	0.800	0.880	0.895	0.650
12	0.750	0.880	0.872	0.650	0.750	0.880	0.872	0.650
13	0.750	0.880	0.817	0.600	0.750	0.880	0.817	0.600
14	0.750	0.890	0.749	0.600	0.750	0.890	0.749	0.600
15	0.700	0.787	0.706	0.600	0.700	0.787	0.706	0.600
16	0.700	0.665	0.796	0.600	0.700	0.665	0.796	0.600
17	0.700	0.474	0.700	0.600	0.700	0.474	0.700	0.600
18	0.700	0.700	0.700	0.600	0.700	0.700	0.700	0.600
19	0.700	0.700	0.700	0.600	0.700	0.700	0.700	0.600
20	0.700	0.700	0.700	0.600	0.700	0.700	0.700	0.600
21	0.600	0.600	0.600	0.500	0.600	0.600	0.600	0.500
22	0.600	0.600	0.600	0.500	0.600	0.600	0.600	0.500
23	0.600	0.600	0.600	0.300	0.600	0.600	0.600	0.300
24	0.600	0.600	0.600	0.300	0.600	0.600	0.600	0.300
25	0.600	0.600	0.600	0.300	0.600	0.600	0.600	0.300
26	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
27	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
28	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
29	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
30	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
31	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
32	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
33	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
34	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
35	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
36	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
37	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300

Age	Generator							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
38	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
39	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300
40	0.500	0.500	0.500	0.300	0.500	0.500	0.500	0.300

Table C6. Pressure Washer Survival Rates

Age	Pressure Washer							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	1.300	2.682	6.470	4.400	1.300	2.682	6.470	4.400
2	1.100	1.160	1.313	1.182	1.100	1.160	1.313	1.182
3	1.000	0.907	0.991	0.846	1.000	0.907	0.991	0.846
4	0.990	0.800	0.857	0.930	0.990	0.800	0.857	0.930
5	0.950	0.800	0.773	0.823	0.950	0.800	0.773	0.823
6	0.920	0.800	0.706	0.874	0.920	0.800	0.706	0.874
7	0.870	0.800	0.650	0.936	0.870	0.800	0.650	0.936
8	0.850	0.800	0.606	0.966	0.850	0.800	0.606	0.966
9	0.770	0.800	0.593	0.944	0.770	0.800	0.593	0.944
10	0.750	0.800	0.663	0.881	0.750	0.800	0.663	0.881
11	0.750	0.800	0.866	0.790	0.750	0.800	0.866	0.790
12	0.600	0.800	1.081	0.680	0.600	0.800	1.081	0.680
13	0.600	0.800	1.127	0.564	0.600	0.800	1.127	0.564
14	0.600	0.757	1.046	0.512	0.600	0.757	1.046	0.512
15	0.500	0.586	0.920	0.500	0.500	0.586	0.920	0.500
16	0.500	0.500	0.770	0.500	0.500	0.500	0.770	0.500
17	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
18	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
19	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
20	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
21	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
22	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
23	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
24	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
25	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
26	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
27	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
28	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
29	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

Age	Pressure Washer							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
30	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
31	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
32	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
33	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
34	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
35	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
36	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
37	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
38	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
39	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
40	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

Table C7. Pumps Survival Rates

Age	Pumps							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	2.480	1.088	2.000	2.480	2.480	1.088	2.000	2.480
2	1.279	1.047	0.950	1.279	1.279	1.047	0.950	1.279
3	1.050	1.000	0.910	1.050	1.050	1.000	0.910	1.050
4	0.948	0.995	0.900	0.948	0.948	0.995	0.900	0.948
5	0.887	0.990	0.800	0.887	0.887	0.990	0.800	0.887
6	0.846	0.979	0.500	0.846	0.846	0.979	0.500	0.846
7	0.818	0.968	0.500	0.818	0.818	0.968	0.500	0.818
8	0.800	0.958	0.500	0.800	0.800	0.958	0.500	0.800
9	0.794	0.946	0.500	0.794	0.794	0.946	0.500	0.794
10	0.800	0.932	0.500	0.800	0.800	0.932	0.500	0.800
11	0.819	0.916	0.500	0.819	0.819	0.916	0.500	0.819
12	0.846	0.898	0.500	0.846	0.846	0.898	0.500	0.846
13	0.868	0.875	0.500	0.868	0.868	0.875	0.500	0.868
14	0.873	0.848	0.300	0.873	0.873	0.848	0.300	0.873
15	0.844	0.813	0.300	0.844	0.844	0.813	0.300	0.844
16	0.763	0.767	0.300	0.763	0.763	0.767	0.300	0.763
17	0.900	0.701	0.300	0.900	0.900	0.701	0.300	0.900
18	0.800	0.595	0.300	0.800	0.800	0.595	0.300	0.800
19	0.800	0.378	0.300	0.800	0.800	0.378	0.300	0.800
20	0.800	0.300	0.300	0.800	0.800	0.300	0.300	0.800
21	0.700	0.300	0.300	0.700	0.700	0.300	0.300	0.700

Age	Pumps							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
22	0.700	0.300	0.300	0.700	0.700	0.300	0.300	0.700
23	0.700	0.300	0.300	0.700	0.700	0.300	0.300	0.700
24	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
25	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
26	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
27	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
28	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
29	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
30	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
31	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
32	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
33	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
34	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
35	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
36	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
37	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
38	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
39	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500
40	0.500	0.300	0.300	0.500	0.500	0.300	0.300	0.500

Table C8. Air Compressor Survival Rates

Age	Air Compressor							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
1	1.800	4.000	2.800	4.000	1.800	4.000	2.800	4.000
2	1.100	1.299	1.214	1.250	1.100	1.299	1.214	1.250
3	0.980	0.964	0.900	0.980	0.980	0.964	0.900	0.980
4	0.960	0.830	0.902	0.963	0.960	0.830	0.902	0.963
5	0.940	0.750	0.900	0.936	0.940	0.750	0.900	0.936
6	0.920	0.695	0.900	0.863	0.920	0.695	0.900	0.863
7	0.900	0.666	0.800	0.889	0.900	0.666	0.800	0.889
8	0.900	0.677	0.800	0.880	0.900	0.677	0.800	0.880
9	0.900	0.753	0.700	0.880	0.900	0.753	0.700	0.880
10	0.850	0.887	0.667	0.880	0.850	0.887	0.667	0.880
11	0.800	0.996	0.500	0.880	0.800	0.996	0.500	0.880
12	0.800	1.015	0.500	0.880	0.800	1.015	0.500	0.880
13	0.800	0.965	0.500	0.833	0.800	0.965	0.500	0.833

Age	Air Compressor							
	Pre-recession				Post-recession			
	Residential	Commercial	Vendor	Electric	Residential	Commercial	Vendor	Electric
14	0.800	0.886	0.500	0.750	0.800	0.886	0.500	0.750
15	0.800	0.810	0.500	0.700	0.800	0.810	0.500	0.700
16	0.700	0.779	0.500	0.686	0.700	0.779	0.500	0.686
17	0.700	0.889	0.340	0.625	0.700	0.889	0.340	0.625
18	0.700	0.526	0.321	0.600	0.700	0.526	0.321	0.600
19	0.500	0.500	0.302	0.600	0.500	0.500	0.302	0.600
20	0.500	0.500	0.285	0.600	0.500	0.500	0.285	0.600
21	0.500	0.500	0.269	0.615	0.500	0.500	0.269	0.615
22	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
23	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
24	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
25	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
26	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
27	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
28	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
29	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
30	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
31	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
32	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
33	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
34	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
35	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
36	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
37	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
38	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
39	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500
40	0.500	0.500	0.250	0.500	0.500	0.500	0.250	0.500

Appendix D – Evaluation of Population Inputs

CARB staff modeled the population estimates for Lawn & Garden and Light Commercial equipment using multiple inputs, including calculated survival rates; historical growth rates from the PLT database; age distribution; fleet population estimates from three different years of 2001, 2012, and 2018; and the SORE evaporative reporting. Therefore, it is essential to check the assumptions used in the modeling for reasonableness. Figure D1 shows the age distribution comparison between the newly calculated age distribution and the 2018 survey age distribution. The 2018 calculated age distribution is determined by applying the growth rates and survival ratio from CY2000 to 2018 to the 2000 age distribution.

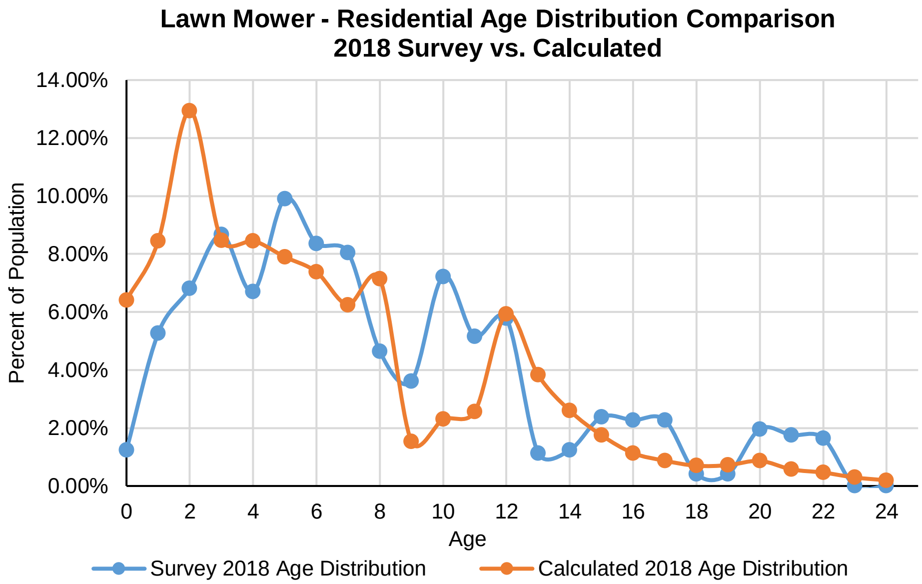


Figure D1. Age Distribution Comparison

The population model was evaluated to ensure that it reflects the fleet population from the 2001, 2012, and 2018 survey results. Figure D2 shows an example of the residential lawn mower population modeling as it correlates to the various survey results.

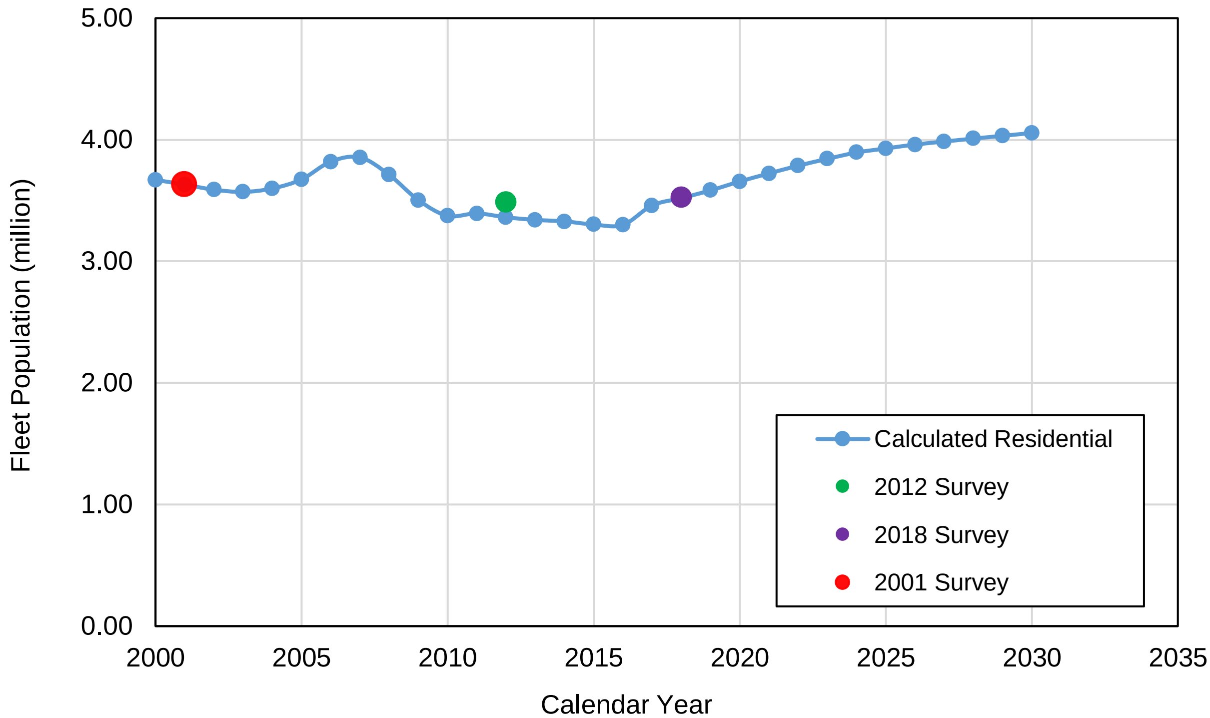


Figure D2. Example of Lawn Mower Fleet Population

The Outdoor Power Equipment Institute (OPEI) represents the interests of power equipment, small engine, utility vehicle (UTV), golf cart, and personal transport vehicle manufacturers and suppliers. OPEI shipment data included only Lawn & Garden equipment (no Light Commercial equipment data) from their members. CARB staff also evaluated confidential OPEI member shipment data to evaluate growth trends for different equipment categories. As discussed in section 4.1.3, this dataset, along with other data sources, were used to assume a zero percent growth rate for sales of handheld equipment, and lawn mowers in the SORE2020 Model.

Appendix E – Evaluation of Activity by Age

CARB staff evaluated the effect of applying different activity usage by the age of the equipment for residential equipment. Staff assumes that residential household usage is greatest when the equipment is new and declines as the equipment ages, similar to other off-road equipment modeling, including pleasure craft (boats) and recreational equipment (off-road motorcycles and all-terrain vehicles), where the activity by age is applied.

The activity data from the 2018 CSUF survey were analyzed by age for the different SORE equipment. Some equipment types contained more data points/responses than others; hence, either a linear or logarithmic fit was applied to derive the equipment's activity by age. Table E1 below compares the average activity versus activity by age for residential SORE equipment.

As shown in Table E1, for certain Light Commercial equipment, including generators, pumps, and welders, the difference between using the average activity and the activity by age will not impact the emissions estimates. For residential Lawn & Garden equipment, the pattern indicates that newer equipment is used more than older equipment, as compared to the average activity. Staff estimates that emissions will become slightly higher if activity by age are used instead of an average activity across all ages. Staff decided to use the average activity which is based on the survey sample size to model emissions.

Table E1. Comparison of Activity by Age vs. Average Activity (hrs/yr)

Average Activity (hr/yr)	18	19	15	16	166	50	29	10	44
Age	**Chainsaw**	**Lawn Mower**	**Leaf Blower**	**Trimmers**	**Compressor**	**Generators**	**Pressure Washer**	**Pumps**	**Welders**
0	34	26	26	21	241	60	45	10	49
1	34	26	26	21	241	60	45	10	49
2	27	23	21	19	230	59	42	10	49
3	23	22	18	17	218	58	39	10	49
4	21	20	16	16	207	56	37	10	48
5	19	20	14	15	195	55	34	10	48
6	17	19	13	14	183	54	31	10	48
7	15	18	12	14	172	53	28	10	47
8	14	18	11	13	160	52	25	10	47
9	13	17	10	13	149	50	23	10	47
10	12	17	10	12	137	49	20	10	46
11	11	17	9	12	126	48	17	10	46
12	10	16	8	12	114	47	14	10	46
13	10	16	8	11	103	46	11	10	45
14	9	16	7	11	91	45	9	10	45
15	8	15	7	11	79	43	6	10	45
16	8	15	6	11	68	42		10	44
17	7	15	6	10	56	41		10	44
18	6	15	6	10	45	40			44
19	6	14	5	10	33	39			44
20	5	14	5	10	22	37			43
21	5	14	5	9		36			43
22	5	14	4	9		35			43
23	4	14	4	9		34			42
24	4	14	4	9		33			42
25	3	13	3	9		32			42

Average Activity (hr/yr)	**18**	**19**	**15**	**16**	**166**	**50**	**29**	**10**	**44**
Age	**Chainsaw**	**Lawn Mower**	**Leaf Blower**	**Trimmers**	**Compressor**	**Generators**	**Pressure Washer**	**Pumps**	**Welders**
26	3	13	3	9		30			41
27	3	13	3	8		29			41
28	2	13	3	8		28			41
29	2	13	2	8		27			40
30	2	13	2	8		26			40
31	1	13	2	8		24			40
32	1	12		8		23			39
33	1	12		8		22			39
34	0	12		8		21			39
35	0	12		7		20			38

Appendix F – Emissions Estimation Methodology

The general methodology, utilized by SORE2020, to calculate the off-road mobile exhaust emissions in tons per day (tpd) for gasoline two-stroke (G2) and four-stroke (G4) engines uses emission factors by model year for HC, CO, NO_x, PM, and CO_2. The emission factors are expressed in gram per brake horsepower hour (g/bhp-hr), and deterioration rates representing the rate of emission increase per hour (g/bhp-hr^2). The emission factors are calculated by the following equation:

$$EF = ZH + dr * CHrs \qquad \textbf{(9)}$$

Where,

EF = emission factor, in grams per horsepower-hour (g/bhp-hr)
ZH = zero-hour emission rate, or when the equipment is new (g/bhp-hr)
dr = deterioration rate or the increase in ZH emissions as the equipment is used (g/bhp-hr^2)
CHrs = cumulative hours or total number of hours accumulated on the equipment

Utilizing the emission factor above, the exhaust emissions in tons per day are calculated by the following equation:

$$\text{Emissions (exhaust)} = Pop * HP_{ave} * LF * Activity * EF \qquad \textbf{(10)}$$

Where,

Pop = Population
HP_{ave} = Maximum rated average horsepower (hp)
LF = Load factor
Activity = Activity or annual operation (hr/yr)
EF = Emission factor (g/hp-hr)

<u>Evaporative Emissions</u>

Evaporative emissions are only necessary for gasoline-powered equipment, since diesel fuel has low volatility and liquefied petroleum gas (LPG) or compressed natural gas (CNG) systems are pressure sealed. Evaporative emissions generally occur through gasoline vapor venting from the fuel tank and the permeation of gasoline fuel through plastic and rubber components of the engine and fuel delivery system of a vehicle. Sometimes, diurnal is listed as the 24-hour diurnal where it includes both the rising and falling temperature profile. For inventory calculation purposes, the term diurnal refers to the emissions during the rising temperature portion. The evaporative emissions inventory is separated into four distinct processes:

1. Diurnal – Emissions from vapor expansion and venting during the heating part of the diurnal temperature cycle. Fuel also permeates as a function of rising

temperature from fuel lines and gas tanks and evaporates on the outside surfaces of these components. Diurnal emissions occur in equipment that is not in operation.
2. Resting loss – Emissions that occur as a result of fuel permeation through rubber or plastic fuel system components such as fuel hoses and fuel tanks. They occur during the cooling part of the diurnal temperature cycle. Resting loss emissions occur in equipment that is not in operation.
3. Hot soak – Emissions that occur after an engine is shut off as the temperature of equipment and fuel delivery system rises and then gradually returns to ambient temperature.
4. Running loss – Emissions that occur while the equipment is operating and the temperature of the equipment and fuel delivery systems are above ambient temperature.

Equations 11, 12, and 13 provide the general equations for estimating evaporative emissions:

$$\text{Diurnal/Resting} = \text{Population} * \text{EF Diurnal/Resting} * \text{Temp/RVP Correction} \quad \textbf{(11)}$$

$$\text{Hot Soak} = \text{Population} * \text{EF Hot Soak} * \text{RVP Correction} \quad \textbf{(12)}$$

$$\text{Running Loss} = \text{Population} * \text{EF Running Loss} * \text{Activity} * \text{RVP Correction} \quad \textbf{(13)}$$

Where,

EF Diurnal/Resting = Emission factor in gram per day for diurnal and resting losses
EF Hot Soak = Emission factor in gram per event of hot soak
EF Running Loss = Emission factor in grams per hour of running loss
Activity = Usage (hr/yr)
RVP Correction = Reid vapor pressure correction factor (region specific)
Temp/RVP Correction = Temperature and RVP correction factor (region specific)

Appendix G – 2018 Population and Emissions – OFFROAD2007 vs. SORE2020

This appendix contains the 2018 statewide summer baseline population and tons per day emissions for the Lawn & Garden and Light Commercial categories by sector: residential, business, and vendor. Tables G1 and G2 include the 2018 baseline from OFFROAD2007 and the SORE2020 Model.

Table G1. 2018 Baseline (OFFROAD2007)

Statewide Summer (tons per day)									
Category	**Equipment**	**Comm/Res**	**Gas Pop**	**Electric Pop**	**Total Pop**	**ROG EXH**	**ROG Evap**	**ROG Total**	**NO_x**
Lawn & Garden	Chainsaws	Commercial	152,619	N/A	152,619	10.65	0.14	10.79	0.17
		Residential	1,716,881	N/A	1,716,881	0.76	2.84	3.60	0.03
	Chainsaws Preempt	Commercial	78,509	N/A	78,509	8.35	0.06	8.42	0.13
		Residential	883,192	N/A	883,192	0.69	1.46	2.15	0.02
	Chippers/Stump Grinders	Commercial	940	N/A	940	0.37	0.01	0.38	0.24
		Residential	1,673	N/A	1,673	0.01	0.01	0.02	0.00
	Commercial Turf	Commercial	17,448	N/A	17,448	1.46	0.12	1.58	1.08
		Residential	0	N/A	0	0.00	0.00	0.00	0.00
	Front Mowers	Commercial	13,250	N/A	13,250	0.29	0.04	0.33	0.21
		Residential	428,420	N/A	428,420	0.88	1.50	2.38	0.62
	Lawn & Garden Tractors	Commercial	41,442	N/A	41,442	0.45	0.09	0.54	0.32
		Residential	269,200	N/A	269,200	0.32	0.82	1.14	0.22
	Lawn Mowers	Commercial	346,056	N/A	346,056	3.23	0.69	3.92	0.83
		Residential	5,068,831	N/A	5,068,831	2.61	15.09	17.70	0.67
	Leaf Blowers/Vacuums	Commercial	449,775	N/A	449,775	9.63	0.74	10.37	0.20
		Residential	1,135,890	N/A	1,135,890	0.31	1.78	2.09	0.01
	Other Lawn & Garden Equipment	Commercial	14,137	N/A	14,137	0.06	0.03	0.09	0.02
		Residential	433,347	N/A	433,347	0.10	1.87	1.98	0.04
	Rear Engine Riding Mowers	Commercial	162,844	N/A	162,844	2.00	0.42	2.42	1.43
		Residential	142,807	N/A	142,807	0.16	0.48	0.65	0.12
	Shredders	Commercial	8,039	N/A	8,039	0.10	0.01	0.12	0.05
		Residential	295,463	N/A	295,463	0.03	0.63	0.66	0.01

Statewide Summer (tons per day)									
Category	**Equipment**	**Comm/Res**	**Gas Pop**	**Electric Pop**	**Total Pop**	**ROG EXH**	**ROG Evap**	**ROG Total**	**NO_x**
	Snowblowers	Commercial	9,002	N/A	9,002	0.00	0.01	0.01	0.00
		Residential	81,016	N/A	81,016	0.00	0.11	0.11	0.00
	Tillers	Commercial	30,724	N/A	30,724	0.06	0.06	0.12	0.02
		Residential	119,341	N/A	119,341	0.08	0.28	0.36	0.02
	Trimmers/Edgers/Brush Cutters	Commercial	345,998	N/A	345,998	2.67	0.41	3.08	0.11
		Residential	3,506,158	N/A	3,506,158	4.11	3.40	7.52	0.17
	Wood Splitters	Commercial	9,981	N/A	9,981	0.12	0.02	0.14	0.03
		Residential	249,503	N/A	249,503	0.02	0.97	0.99	0.00
	Grand Total		**16,012,487**		**16,012,487**	**49.54**	**34.10**	**83.63**	**6.80**
Light Commercial	Air Compressor Preempt	Commercial	6,261	N/A	6,261	0.37	0.03	0.40	0.20
		Residential	4,920	N/A	4,920	0.19	0.02	0.21	0.11
	Generator Sets	Commercial	164,470	N/A	164,470	2.77	1.10	3.87	1.80
		Residential	129,226	N/A	129,226	1.76	1.31	3.08	0.98
	Pressure Washers	Commercial	17,169	N/A	17,169	0.29	0.10	0.39	0.14
		Residential	13,490	N/A	13,490	0.18	0.13	0.31	0.08
	Pump Preempt	Commercial	37,951	N/A	37,951	0.92	0.23	1.15	0.57
		Residential	29,819	N/A	29,819	0.50	0.24	0.73	0.30
	Welder Preempt	Commercial	35,890	N/A	35,890	1.37	0.22	1.59	0.90
		Residential	0	N/A	0	0.00	0.00	0.00	0.00
	Grand Total		**439,198**		**439,198**	**8.36**	**3.37**	**11.73**	**5.07**

* Front mower, Lawn & Garden tractors, and rear engine riding mowers have been combined together and labeled “Riding Mowers.”
**Likewise, shredders have been combined with chippers/stump grinders under the label of “Chippers/Stump Grinders/Shredders.”

Table G2. 2018 Baseline (SORE2020)

Statewide Summer (tons per day)									
Category	**Equipment**	**Comm/Res**	**Gas Pop**	**Electric Pop**	**Total Pop**	**ROG EXH**	**ROG Evap**	**ROG Total**	**NO_x**
Lawn & Garden	Chainsaws	Commercial	104,292	5,617	109,909	1.01	0.07	1.09	0.03
		Residential	1,180,653	827,266	2,007,918	4.76	0.82	5.58	0.14
		Vendor	132,110	3,222	135,331	3.39	0.10	3.49	0.11
	Chainsaws Preempt	Commercial	56,157	3,024	59,182	0.84	0.04	0.88	0.03
		Residential	635,736	445,451	1,081,187	3.97	0.44	4.41	0.13
		Vendor	71,136	1,735	72,871	3.02	0.06	3.07	0.11
	Chippers/Stump Grinders/Shredders*	Commercial	0	0	0	0	0	0	0
		Residential	10,401	3,772	14,172	0.01	0.03	0.04	0.00
		Vendor	0	0	0	0	0	0	0
	Lawn Mowers	Commercial	100,483	3,559	104,042	0.24	0.49	0.72	0.13
		Residential	3,457,147	1,089,945	4,547,092	2.07	16.28	18.36	0.98
		Vendor	108,288	2,332	110,620	0.62	0.49	1.10	0.38
	Leaf Blowers/Vacuums	Commercial	185,741	87,922	273,662	5.80	0.17	5.98	0.20
		Residential	1,129,817	3,226,627	4,356,444	3.37	0.83	4.20	0.11
		Vendor	131,217	11,010	142,227	5.70	0.14	5.84	0.20
	Other Lawn & Garden Equipment	Commercial	0	0	0	0	0	0	0
		Residential	44,005	0	44,005	0.03	0.12	0.15	0.01
		Vendor	2,800	0	2,800	0.02	0.01	0.03	0.01
	Riding Mowers-*	Commercial	5,272	505	5,776	< 0.01	0.03	0.03	< 0.01
		Residential	361,402	16,888	378,291	5.62	5.28	10.90	2.60
		Vendor	11,849	0	11,849	0.42	0.12	0.54	0.22
	Snow Blowers	Commercial	6,090	0	6,090	< 0.01	0.01	0.02	< 0.01
		Residential	45,175	4,000	49,175	< 0.01	0.11	0.11	< 0.01
		Vendor	4,627	0	4,627	< 0.01	0.01	0.01	< 0.01
	Tillers	Commercial	720	0	720	< 0.01	< 0.01	< 0.01	< 0.01
		Residential	85,797	11,383	97,181	0.11	0.32	0.43	0.02

Statewide Summer (tons per day)									
Category	**Equipment**	**Comm/Res**	**Gas Pop**	**Electric Pop**	**Total Pop**	**ROG EXH**	**ROG Evap**	**ROG Total**	**NO_x**
		Vendor	715	0	715	< 0.01	< 0.01	< 0.01	< 0.01
	Trimmers/Edgers/Brush Cutters	Commercial	166,600	52,158	218,758	1.13	0.11	1.24	0.07
		Residential	2,349,580	3,658,176	6,007,755	4.10	1.48	5.58	0.23
		Vendor	235,268	16,019	251,287	4.45	0.19	4.64	0.26
	Wood Splitters	Commercial	0	0	0	0	0	0	0
		Residential	106,825	0	106,825	0.62	1.21	1.83	0.24
		Vendor	209	0	209	< 0.01	< 0.01	< 0.01	< 0.01
	Total		**10,730,110**	**9,470,609**	**20,200,719**	**51.30**	**28.99**	**80.29**	**6.22**
Light Commercial	Air Compressor Preempt	Commercial	53,564	10,443	64,007	0.74	0.60	1.35	0.39
		Residential	194,069	3,198,317	3,392,386	2.67	2.44	5.11	1.46
		Vendor	17,222	6,843	24,065	0.19	0.16	0.35	0.11
	Generator Sets	Commercial	172,074	22,271	194,345	2.54	1.64	4.18	0.94
		Residential	1,459,676	284,383	1,744,058	7.47	9.92	17.39	2.56
		Vendor	8,147	637	8,785	0.04	0.05	0.09	0.02
	Pressure Washers	Commercial	134,101	5,538	139,639	0.83	0.40	1.23	0.37
		Residential	769,485	1,696,117	2,465,602	1.72	1.63	3.35	0.76
		Vendor	15,517	3,629	19,146	0.04	0.03	0.07	0.02
	Pump Preempt	Commercial	45,004	5,643	50,647	0.75	0.48	1.23	0.28
		Residential	99,399	1,728,180	1,827,579	0.07	0.41	0.48	0.02
		Vendor	1,841	3,697	5,538	0.02	0.01	0.02	0.01
	Welder Preempt	Commercial	46,841	128,737	175,579	0.95	0.36	1.30	0.33
		Residential	145,376	676,128	821,504	0.81	0.97	1.78	0.33
		Vendor	1,142	5,655	6,797	< 0.01	< 0.01	0.01	< 0.01
	Total		**3,163,457**	**7,776,218**	**10,939,675**	**18.85**	**19.10**	**37.95**	**7.57**

* Front mower, Lawn & Garden tractors, and rear engine riding mowers have been combined together and labeled “Riding Mowers.” Likewise, shredders have been combined with chippers/stump grinders under the label of “Chippers/Stump Grinders/Shredders.”
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Appendix H – Exhaust Emissions Deterioration

Exhaust Emissions Deterioration Introduction

Deterioration rates are defined as the change in emissions as a function of usage. Pertaining to mobile source emissions inventory, deterioration is reflective of both the natural degradation of an engine (i.e., wear and tear), as well as the increase in emissions resulting from mal-maintenance and emission control system malfunctions. Therefore, it is normal to assume that the deterioration utilized in the emissions inventory will be typically higher as compared to the certification deterioration rates provided by manufactures, since those do not account for mal-maintenance. According to data obtained from the California State University, Fullerton (CSUF) 2018 Survey, approximately 50% of professional users and 40% of residential owners properly maintain their equipment in accordance to the manufacturer recommended maintenance schedule.

Previously in the OFFROAD2007 Model, the exhaust emission factors were derived by initially setting the zero-hour emission factor for $HC+NO_X$, to a level below the emissions standard, due to the lack of available in-use emissions data. As the engine deteriorates over time, the emissions quantified is synonymous to the standard at the end of the durability period, which is the duration (in hours) the manufacturer certified that the engine will not exceed the standard. OFFROAD2007 implements a maximum cap on the deterioration, thus assuming that an engine will only deteriorate up to a certain point. For example, a 4-stroke engine with less than 5 rated horsepower, will not further deteriorate beyond the durability period cap of 300 hours.

While deterioration in internal combustion engines is a well-known phenomenon, quantifying the emissions deterioration requires information on the emission performance of engines at various ages. Such data can be obtained from a longitudinal study, which involves the periodic monitoring of a particular set of engines as they age, or from a sampling study that tests different engines of the same specifications, but with varying ages. In either case, the engines studied should be blindly selected from a population of equipment that are being utilized in the field.

With the limitations on available test data, CARB staff are not currently able to develop unique deterioration rates based on actual engine test data for the countless number of applications and power levels included in the SORE2020 Model. Therefore, the SORE2020 Model will utilize the same approach, as in the OFFROAD2007 Model and in U.S. EPA's NONROAD Model, to estimate the deterioration rates for these engines. Based on this approach, equipment used in residential applications would meet the durability standard at the end of the residential durability period. Similarly, equipment utilized by the commercial/vendor sector would meet the standard at the end of the commercial durability period. CARB staff have also revised the capped deterioration rates to be 1.5 times the median (for residential) and highest (for commercial) durability hours for each respective horsepower group. The previous deterioration hour cap, used in OFFROAD2007, was not representative of engines sold in California, since manufacturers presently certify engines with durability hours greater than the capped values. Due to the lack of in-use durability test data, CARB staff set the capped hours to be above the longest currently available durability period.

While this approach would provide the necessary mechanism to estimate emissions from these engines, stakeholders have requested staff to provide an evidentiary explanation to illustrate how small off-road engines deteriorate beyond their standards. This white paper examines a collection of past studies that were conducted by various entities and exemplify the deterioration of in-use emissions levels exceeding the emissions standard.

Review of Available Emissions Test Data

Gabele (1997)[16] characterized emissions from ten, 4-stroke lawn mower engines, ranging from brand new to 15 years old, by tests conducted using both a 1990, national average gasoline and a reformulated gasoline. Compared to the newer engines, older engines exhibited dramatically higher organic and carbon monoxide emissions and lower nitrogen oxide (NO_x) emissions. This dataset indicated that the average hydrocarbon (HC) emissions increased from 7.0 g/bhp-hr for new lawn mowers to approximately 50 g/bhp-hr for 10 years old lawn mowers, thus indicating a 7x increase in emissions over the course of a span of 10 years as shown in Figure H1 below.

In 2006, the U.S. EPA conducted emissions testing on a number of Class I and II, small off-road engines as part of their safety study[17]. The Class I engines, from several manufacturers containing both overhead valve (OHV) and side valve (SV) designs, were tested in their original configuration and with custom modifications utilizing catalysts and passive secondary air systems. The results, shown in Figure H2 below, demonstrated that in OHV and SV configurations, engine out emissions increased between 10-30%, over the course of 110 hours.

[16] Peter Gabele (1997) Exhaust Emissions from Four-Stroke Lawn Mower Engines, Journal of the Air & Waste Management Association, 47:9, 945-952, DOI:10.1080/10473289.1997.10463951
[17] “EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines <50 Horsepower,” EPA420-R-06-006, March 2006.

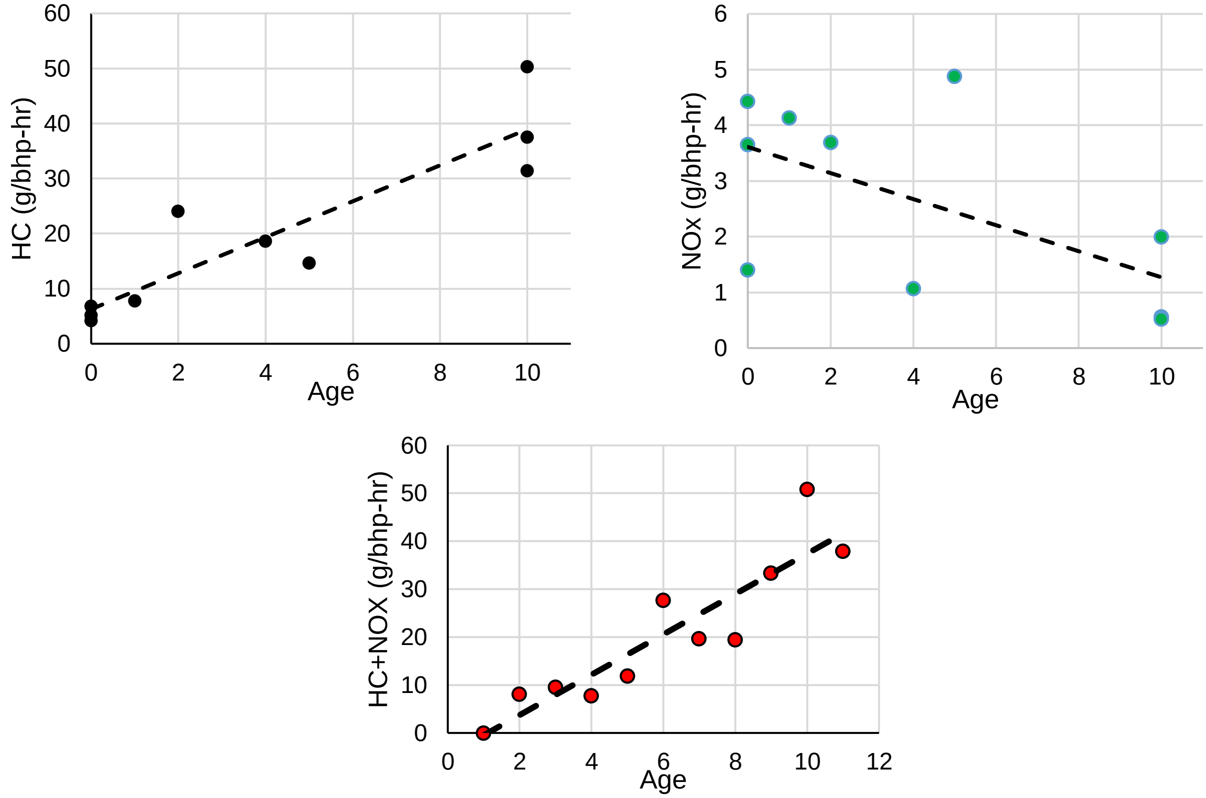


Figure H1. In-Use Emissions Data for 4-Stroke Lawn Mower Engines

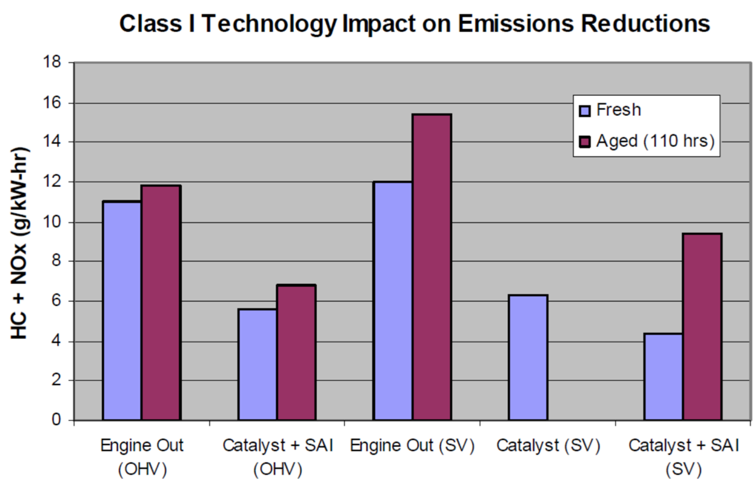


Figure H2. Emissions from Class I Engines with Different Control Technologies (US EPA 2006)

Welch and Durbin (2004)[18] tested two, 2-stroke engines (Stihl trimmer and Echo leaf blower) in brand new condition and again after at least 100 hours of use, to examine the effects of engine deterioration. After 162 hours in the field, the Stihl trimmer had increased CO and PM emissions by 300% and THC emissions increased by 20%. For the Echo leaf blower, significant repairs were required throughout the 100 operating hours which counteracted the effects of the emissions deterioration and resulted in lower CO and THC emissions. Results from this study are shown in Figure H3. The reduction in emissions, for the Echo PB-210E leaf blower engine, was clearly due to the maintenance performed during the testing, which significantly affected the final results and not indicative of engine deterioration.

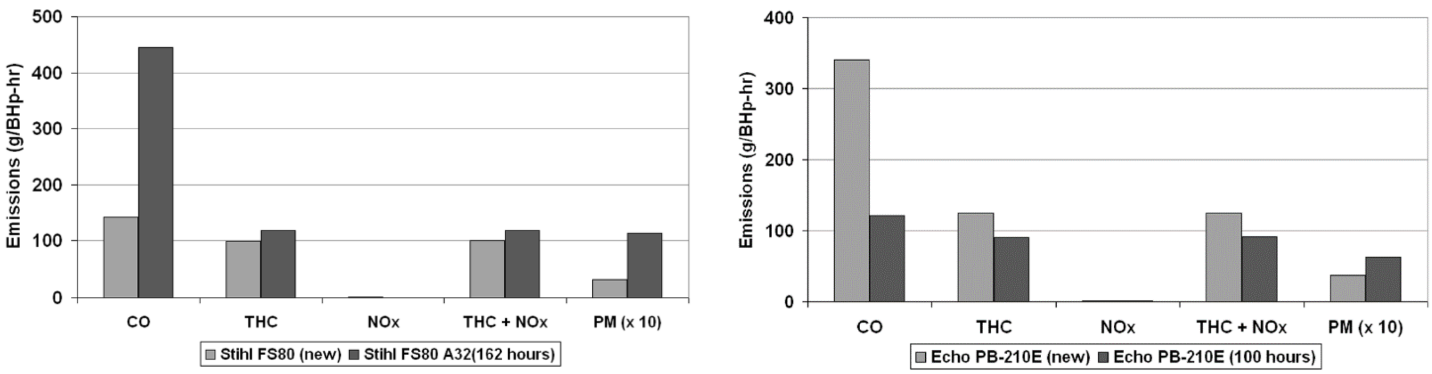


Figure H3. Emissions from Stihl FS80 Trimmer and Echo PB-210E Leaf Blower (New vs Used)

In 2004, Southwest Research Institute (SwRI) conducted a study[19] to determine whether catalyst technology could be applied to small off-road engines (SOREs) and provide 50% or greater reductions in HC+NO_x emissions throughout the useful life of the engines. Six engines, that met current CARB Tier II standards, were evaluated and included two Briggs and Stratton Intek engines, a Tecumseh OVRM 120 engine, two Honda engines (GCV 160 and GX340), and a Kawasaki FH601V engine. Four of the engines were used in a walk-behind mower (WBM), one was used in a riding mower and the other in a constant-speed/generator. The Department of Emissions Research's (DER) small off-road engine test stand was utilized for the tests. It included a 20-hp eddy-current dynamometer, on a movable stand, that was capable of accommodating both horizontal and vertical-shaft engines. A Horiba MEXA 7200D 4-gas emissions bench was employed, which contained a multi-range heated flame ionization detector (HFID) for HC emissions, a chemi-luminescent analyzer for NO_x and non-dispersive infrared analyzers (NDIR) to measure CO and CO_2. The exhaust was collected using an

[18] William Welch & Thomas D. Durbin (2004) Emissions and Demonstration of an Emission Control Technology for Small Two-Stroke Utility Engines, Journal of the Air & Waste Management Association, 54:2, 200-206, DOI: 10.1080/10473289.2004.10470890

[19] Lela, C., and White, J. "Durability of low emissions small off-road engines," Final Report Prepared for California Resources Board, SwRI 08.05734 (2004).

8-inch dilution tunnel, with bag sampling of the diluted exhaust after each mode. All emissions testing was performed with the same batch of California Phase II gasoline.

Engine service accumulation was performed by SwRI's Engine and Vehicle Research Division. The durability site included two, fully-automated, 30-hp eddy current dynamometers with required safety system monitoring for certain engine parameters with automated engine shutdown. The engines were tested on California Phase II gasoline. Maintenance was performed during the service accumulation period in accordance to the manufacturer recommended procedures, with the exception of the first Briggs and Stratton and Tecumseh engines during the first 125 hours of operation. Maintenance included oil changes, air filter cleaning and replacement, and spark plug cleaning and replacement. Figure H4 shows the HC+NO_x emissions (under stock configuration) for the 5 engines at different test intervals, illustrating an increase of 1.1x – 2x in HC+NO_x emissions over 250 hours of operation, with an average increase of 1.4x across all engines.

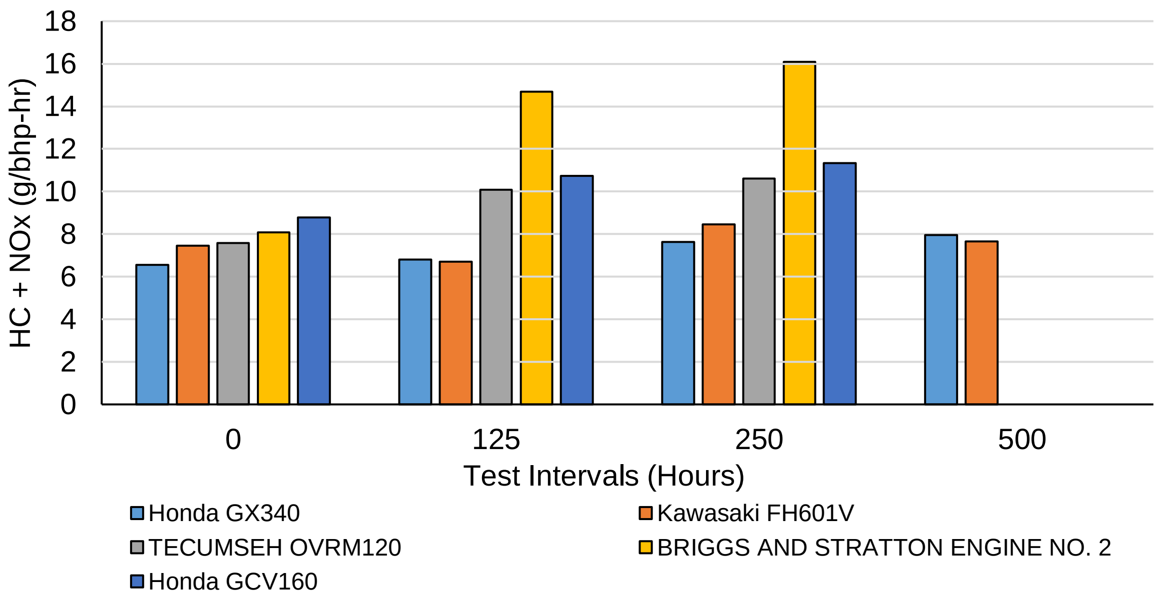


Figure H4. HC + NO_x Emissions from SwRI Engine Study (2004)

In addition to the above mentioned studies, CARB has also conducted a series of emissions testing using both engine dynamometer as well as Portable Emissions Measurement Systems (PEMS). The engine dynamometer testing included equipment tested brand new and at end of its useful life. The aging of the equipment was benched-age (not real-world) by running the engine continuously until the durability hours was reached. According to CARB's test data between 2016 and 2020, both a 2014 riding mower and 2011 string trimmer presented an increase in HC+NO_x emissions of approximately 25% and 68% respectively. The results from this study are shown in Table H1 and indicated that emissions from MY2008+ engines can increase between

25-70%, and brand new engines may also exhibit emissions above the current standards.

Table H1. HC+NO_x Emissions Results from CARB In-House Testing

Equipment Type	Model Year	Durability Period	Power	Displacement (cc)	HC + NO_X (g/kw-hr)		Deterioration Factor
					New	End of Useful Life	
Riding Mower	2014	250	17	603	5.7	7.1	1.25
String Trimmer	2011	300	0.7	25	21.3	35.7	1.68

In another study conducted by CARB in 2019, a new 2005 Honda walk-behind lawn mower, with rated power of 4.4 hp (4-stroke and carbureted), was tested using an AVL 493 Gaseous PEMS system (1065 PEMS with NDUV analyzer for NO_x and NDIR analyzer for CO and CO_2) at Glendora High School as shown in Figure H5. The total test time of approximately 1 hour, included idling time and stop and go mowing. Additional information about this study can be found in Appendix I.

Figure H5. PEMS Testing at Glendora High School (CARB, 2019)

The results from this PEMS study, shown in Table H2, indicated that the mower engine emitted an average HC+NO_x emissions of approximately 13.84 g/bhp-hr (18.5 g/kw-hr), which is above the 12 g/bhp-hr (16 g/kw-hr) engine standard. Although, only one mower was tested in this particular study and the design was not to assess emissions deterioration, the results eluded that emissions from fresh/new mower engines could possibly be higher than the standard, when used in real-world applications.

Table H2. Emission Test Data from *Portable* Emissions Measurement System (CARB 2019)

Pollutant	Real-World Data (Average)		Emissions Standard (HC+ NO_x)	Ratio of Real-World Data to Emission Standard
	(g/hr)	(g/bhp-hr)	(g/bhp-hr)	
HC	21.04	12.66	N/A	N/A
NO_x	1.97	1.18	N/A	N/A
HC + NO_x	23.01	13.84	12	115%
CO_2	904.51	544.24	N/A	N/A

Deterioration Modeling in U.S. EPA's NONROAD Model

Staff has also reviewed the current methodology employed by the U.S. EPA's NONROAD Model. In general, the NONROAD model addresses the effects of deterioration in emissions by multiplying the zero-hour emission levels for a given technology type by a deterioration rate as the engine ages. The following formula describes the basic form of the calculation:

$$EF_{aged} = EF_0 * DF \qquad \textbf{(14)}$$

Where EF_{aged} is the emission factor for an aged engine, EF_0 is the emission factor for a new engine and DF is the deterioration factor. The deterioration factor (DF), which changes as an engine ages, is calculated using the following function:

$$DF = 1 + A * (\text{Age Factor})^b \qquad \textbf{(15)}$$

Where Age Factor is [Cumulative Hours * Load Factor]/[Median Life at Full Load, in Hours].

The "A" values are specific to each technology type in the model. The "b" value is either 1.0 (reflecting a linear deterioration of emissions with the rate of deterioration remaining constant over an engine's life) or 0.5 (reflecting a curvilinear deterioration of emissions with most of the deterioration occurring during the early years of an engine's life).

The "A" values used in the NONROAD Model are determined for each technology type and are intended to represent the deterioration from the whole fleet of in-use engines, which includes engines that are properly maintained as well as engines that are not maintained properly. Because mal-maintained engines generally emit higher levels of pollutants than properly maintained engines, the DF values projected by the NONROAD Model for the entire fleet of engines will generally be higher than a deterioration factor calculated for properly maintained engines. EPA staff believes this would be the case whether the deterioration factors were calculated from properly maintained engines aged in the laboratory on an engine dynamometer (as is typically done for certification purposes) or aged in the field.

In an effort to better characterize the emissions performance of Phase 2 Class I engines, EPA staff tested sixteen walk behind lawn mowers powered by engines that have been certified to the Phase 2 standards. The engines were from five different engine families that represent approximately two-thirds of the Class I engines sold in the United States, excluding those used in snow blowers. Using the information from the in-use testing of walk behind mowers, EPA calculated the multiplicative deterioration factor for each engine based on the average emission levels at the end of the testing (targeted to be the regulatory useful life of 125 hours) divided by the average emission levels at the beginning of the testing (the low-hour emission levels measured after a short break-in period). The deterioration factors were calculated for HC, NO_x and CO for all engines and PM for those engines where data was available at both low-hour and high-hour operation. Table H3 contains the updated "A" values used for Phase 2 non-handheld engines in the NONROAD2005c (used for the modeling in support of the Phase 3 proposal).

Table H3. Updated "A" Values for Phase 2 Non-handheld Engines (NONROAD)

Pollutant	Class I Side-valve Engines	Class I Overhead Valve Engines	Class II Overhead Valve Engines	Class I Side-valve Engines
HC	1.753	1.753	1.095	1.753
NOx	0.180	0.180	0	0.180
CO	0.070	0.070	0.080	0.070
PM	1.753	1.753	1.095	1.753

Based on emissions data collected by the Center for Emission Research & Analysis (CERA) for EPA and a number of other organizations, EPA staff evaluated emissions data of in-use lawn mowers by age of the lawn mowers[20]. Approximately 40 lawn mowers were tested by CERA. The lawn mowers tested covered a wide range of age and maintenance practices. Using the data from those lawn mowers, excluding three outlier engines, EPA staff analyzed the HC, NO_x, and CO emissions by age of the lawn mower. The results of this analysis are presented in Figure H6. Based on this information, EPA staff concluded that HC and CO emissions do not stop deteriorating at the median life of a lawn mower (estimated to be just under 6 years by the NONROAD model), but continue to deteriorate throughout the life of the lawn mowers. NO_x emissions, which are relatively low to begin with, stay fairly constant after the median life.

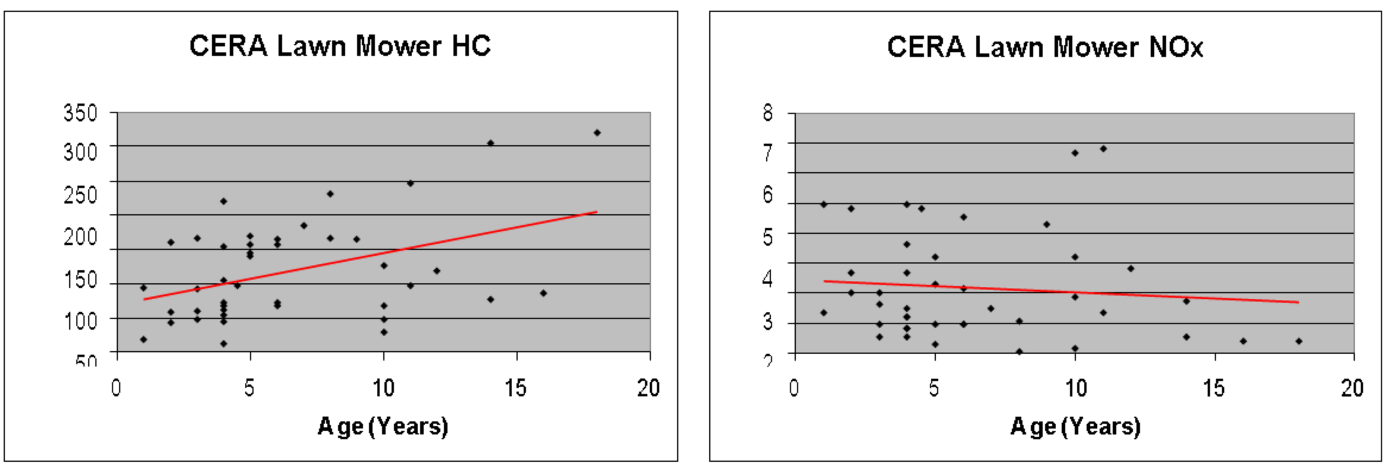


Figure H6. Lawn Mower Emissions Data (CERA - Center for Emission Research & Analysis)

For Phase 3 engines, based on experience with catalyst-equipped non-handheld engines, EPA staff assumed manufacturers will target a zero-hour level that is 70

[20] "Assessment of In- Use Emissions of Gasoline Engine Powered Lawnmowers," The Center for Emissions Research & Analysis, March 1995, Docket Identification EPA-HQ-OAR-2004-0008- 0538.

percent of the proposed HC+NO_x standards to ensure compliance with the proposed Phase 3 standards. Given the levels of the proposed Phase 3 standards, the zero-hour target level was projected to be 7.0 g/kW-hr HC+NO_x for Class I engines and 5.6 g/kW-hr HC+NO_x for Class II engines.

For the mal-maintained engines, EPA based their emission estimates on testing performed on three Phase 2 Class I side-valve engines equipped with catalysts that had high engine-out emissions at high hours. EPA believed the emission levels of these engines would be representative of the emission levels of mal-maintained catalyst-equipped Phase 3 engines (which would be expected to have similarly high engine-out emission levels). Table H4 presents the average engine-out and post-catalyst emissions from these three high-emitting Phase 2 side-valve engines equipped with a catalyst.

Table H4. Projected Emission Levels (g/kW-hr)
(Mal-maintained Phase 3, Class I Side-valve Engines)

Pollutant	Engine-Out Emissions	Post-Catalyst Emissions
HC	16.69	12.01
NO_x	4.91	2.36
CO	310.3	284.4
PM	0.49	0.44

Using the projected median life emission levels for maintained engines and the projected emission levels from mal-maintained engines (based on the post-catalyst emission levels in Table H4), EPA weighted the HC and NO_x results by 60% for maintained engines and 40% for mal-maintained engines to project the emissions at median life for the overall in-use fleet of Class I side-valve engines. Using this data, they back-calculated the “A” values for the entire fleet of in-use Phase 3 engines. Table H5 presents the projected median life emissions for the in-use fleet of Class I side-valve engines and the resulting “A” values (based on the zero-hour emission levels presented earlier in Table H4).

Table H5. Projected HC and NO_x Emission Levels and Deterioration “A” Values
(In-Use Fleet of Phase 3, Class I Sidevalve Engines)

Pollutant	Projected Median Life (145 hours) Emission Levels, g/kW-hr	Resulting “A” Value for In-Use Fleet
HC	10.07	0.797
NO_x	1.82	0.302

Figure H7 shows a comparison of NO_x + HC emission rates for a residential lawn mower between EPA NONROAD and SORE2020 Model.

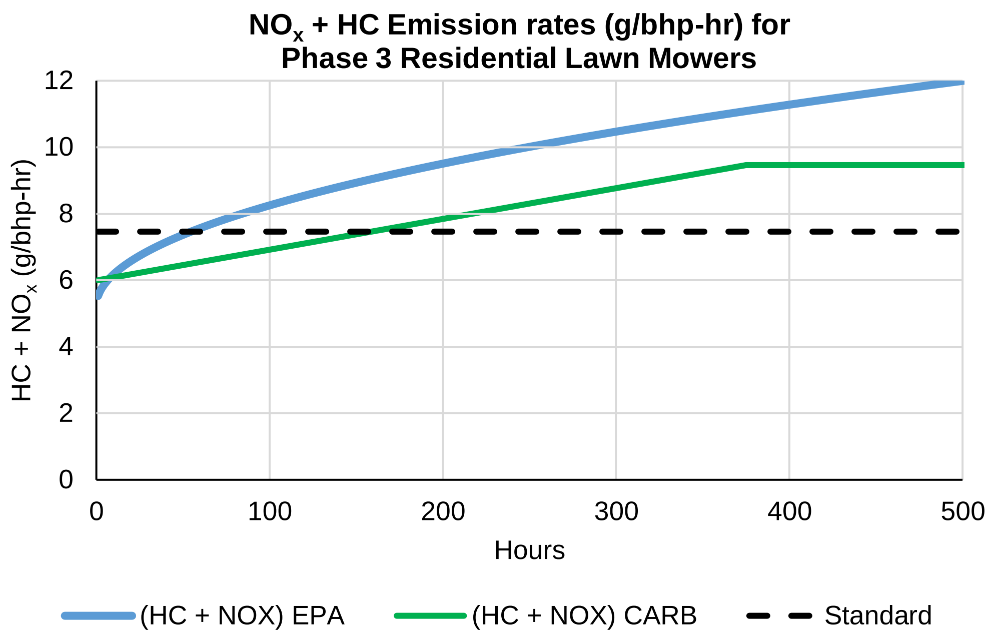


Figure H7. Lawn Mower Emissions Rates (NONROAD vs SORE2020)

As shown in Figure H7, the NONROAD Model assumes that in-use HC+NO_x emissions from phase 3 lawn mowers exceed the standards at around 55 hours of operation, whereas CARB's model assume that in-use emissions stay below the standard up to population weighted durability hours for residential engines. In general, EPA's model assume higher HC+NO_x emissions than CARB as EPA explicitly account for mal-maintained engines. As mentioned earlier, EPA's model assumes that 40% of engines are mal-maintained at 145 hours of operation and emit 44% above the standard at 14.37 g/kW-hr of HC+NO_x.

Conclusions

According to various studies on in-use emissions performance associated with small off-road engines, there is a clear evidence that:

a) In-use emissions from small off-road engines increase over time as they are used in real-world applications. The increase in emissions may vary between 20-600% over the life of the equipment.

b) In-use emissions from small off-road engines may exceed standards even when these engines are new.

Staff concludes that the current assumptions for exhaust emissions deterioration within the SORE2020 Model, are conservative (as compared to EPA's NONROAD Model) and reflect that the average emissions from small off-road engines exceed the standard after they pass their respective useful life.

Appendix I – Lawn Mower Exhaust Emissions Measurement with PEMS

INTRODUCTION

As the emissions trend for on-road vehicles is declining as a result of a series of stringent and effective control measures, the emissions from off-road categories are becoming relatively more significant. As indicated from the on-road portable emission measurement system (PEMS) studies, real-world emissions are typically higher than those measured under laboratory and controlled conditions. In parallel, these observations are also likely in off-road equipment. There is a critical need to collect data and understand real-world emissions from off-road categories in order to improve the emission factors, which are primarily based on certification data.

Since on-road vehicles and off-road diesel equipment have been the primary focus of the majority of past PEMS studies, small off-road gasoline equipment have not been instrumented for data collection. In order to expand the PEMS application, it is necessary to first establish a PEMS test protocol for small off-road gasoline equipment. This pilot study will assist in that establishment for future PEMS testing.

OBJECTIVES

There are several objectives of this pilot study utilizing PEMS to measure the exhaust emissions from small off-road engines. The first objective is to explore the technical feasibility of measuring the emissions from a walk-behind lawn mower with low exhaust flowrate. One challenge in particular is that the PEMS unit is larger and heavier as compared to the lawn mower and must be placed on a golf cart for mobility. Special arrangements must be made for the exhaust data collection, as both the golf cart and lawn mower are moving at a steady speed. The second objective is that staff intends to compare the real-world emissions obtained against both the emissions standard and the emission factor used in the emissions inventory model for small off-road engines or the SORE2020 Model. Thirdly, through the process of measuring the emissions in the field, staff intends to collect the real-world activity and emissions data associated with idling and stop-and-go conditions.

TESTING LOCATION

Staff contacted several local cities in the surrounding area, in attempts to locate available parks in which to perform the PEMS testing. Consequently, due to liability issues, most of the requests were denied. Staff was able to secure a test site at the Glendora High School, in Glendora California. As seen in Figure I1 below, the test location (circled in red) is a grass field located between the parking lot and the football field.

Figure I1. Aerial Map of Glendora High School

TEST EQUIPMENT

The mower used for this pilot study was a 2005 Honda HRR model series, push-behind lawn mower (4 stroke and carbureted) with rated horsepower of 4.4. This brand new, lawn mower was initially purchased for a previous study, but was never used for testing nor removed from the box. Table I1 below lists the various equipment utilized in this pilot study. Note that the AVL 493 Gaseous PEMS, which was used primarily for this study, met the measurement and quality control compliance requirements under the Code of Federal Regulations (CFR) 1065. Other non-compliant PEMS units were used with the intent to compare and confirm the results obtained from the AVL 493 Gaseous PEMS. Typically, the exhaust flowrate for small engines may be inconsistent and contain high fluctuations, thusly, in order to accurately quantify the exhaust flowrate, the AVL PLUtron was specifically used to measure the mass flowrate of the fuel, from which the exhaust flowrate was derived.

Table I1. Equipment Used for Real-World Measurement

AVL 493 Gaseous PEMS* (NDUV analyzer for NOx and NDIR analyzer for CO and CO_2)
AVL heated FID for measuring THC (part of the AVL 493 gaseous PEMS)
AVL PM PEMS with Micro soot sensor and gravimetric filter methods
Eco Physics PEMS (Chemiluminescence analyzer for NOx)
ECM sensor for NOx
ECM sensor for CO_2 and CO
AVL PLUtron (Fuel mass flow meter with CO_2 measurement)
RPM meter

*Meets CFR 1065 Requirements

PREPARATION

The lawn mower was assembled according to the instructions included, filled with engine oil and one-half tank of commercial gasoline (winter grade), and inspected to ensure it was in proper operating condition. Special parts were custom-made in the CARB machine shop to support and connect the sampling probes from the exhaust pipe to the PEMS units, without any impact on the exhaust flow backpressure. At the beginning of April 2019, staff tested the PEMS units and lawn mower in CARB's parking lot to ensure that the golf cart could support the PEMS, while moving simultaneously with the lawn mower.

A second test run was made at a local residence in May 2019, and one staff practiced driving the golf cart parallel to the second staff pushing the lawn mower. During this test run, the PEMS units were taking exhaust measurements as the lawn mower was cutting the grass. From this test run, staff discovered that the built-in batteries may not be sufficient to support all of the PEMS units. As a result, staff proposed to include a portable generator placed on a wagon and towed by the golf cart in order to support the PEMS units. Since the golf cart was also battery powered, special attention was made to ensure that the battery was fully charged and working properly prior to field testing.

TESTING

A team of support staff was stationed at the site for logistical support on May 24, 2019. As seen in Figure I1, the test site was approximately half the size of a football field and the grass was three to five inches in height. The PEMS units were warmed-up and all of the connections and wiring were checked prior to the field test. One staff drove the battery-powered golf cart, towing the small wagon with a portable generator and a second staff operated the lawn mower. The grass catcher was used on the lawn mower for the first 10-15 minutes, but was removed due to the wet grass causing blockages at the catcher outlet. To simulate the typical operation of a lawn mower, the team circled around the field at a comfortable walking speed, determined by the staff pushing the lawn mower. The lawn mower was stopped several times and restarted again, including grass removal from the catcher in the beginning. Since no defined operating cycle currently exists, the team attempted to simulate a typical operating pattern, including mowing, idling, stopping and restarting. Figure I2 below illustrates the team as they circulated the field seven times for the testing duration of approximately one hour.

DATA ANALYSIS

The raw data (NOx) measured with AVL unit contained some negative values, due to the hydrocarbon interference with the NDUV analyzer. To avoid miscalculations in the data, the negative values and/or questionable values were removed if they did not meet the following two criteria: (1) fuel consumption was positive, and (2) CO2 concentration was greater than or equal to 0.1%. Both criteria had to be met to ensure that the "corrected" emissions used in the data analysis occurred while the engine was either idling or moving.

Figure I2. The PEMS Team in Action

LOAD FACTOR

In order to calculate the emissions in gram per brake horsepower-hour, the average load factor associated with operating the lawn mower is required. Since measuring the torque was unfeasible, the two different approaches used to estimate the engine load are detailed below.

Brake Specific Fuel Consumption (BSFC)

Brake-specific fuel consumption is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational or shaft power. It is typically used for comparing the efficiency of internal combustion engines with a shaft output and equal to the rate of fuel consumed divided by the power produced. Though BSFC is a reasonable number to represent a specific engine, it may not fully represent the engines operating in the field and the maximum fuel rate may not always represent the highest power output. The following equations are used to estimate the load using BSFC:

$$Ave\ HP = \frac{Ave\ Fuel\ (\frac{g}{hr})}{BSFC(\frac{g}{bhp-hr})} \qquad \textbf{(16)}$$

$$Load\ Factor = \frac{Ave\ HP}{Rated\ HP}$$

Engine Revolution per Minute (RPM)

The engine rpm may also be used as a surrogate to approximate the load on the engine, however the drawback is that the maximum rpm may not represent the maximum engine output. The load factor can be estimated by normalizing the engine rpm, as shown in the following equation:

$$Load\ Factor = \frac{RPM_i - RPM_{min}}{RPM_{max} - RPM_{min}} \tag{17}$$

Both methods were assessed to reasonably estimate the load factor. Table I2 below summarizes the results of the two methods for comparison. For the BSFC method, the maximum torque, matching a 4.4 hp lawn mower engine, was assumed to be 6.9 lb-ft at 2500 rpm. The resulting BSFC was estimated at 321 g-fuel/bhp-hr and the estimated load factor was 0.38. For the engine RPM method, to eliminate any negative readings, it was assumed that the precision of the rpm, measured in voltage, was 0.001 V and that all negative rpm readings were assumed to be 0.001 V. The estimated load factor from the engine RPM method was 0.48. Although both estimates were in good consensus of each other, due to the magnitude of the rpm estimated by the voltage meter (included negative readings) caused by unstable signal fluctuations, staff decided to use the load factor of 0.38, based on the BSFC method.

Table I2. Estimate of Load Factor

Method	Estimated Load
BSFC	0.38*
RPM Normalization	0.48

*Used in the final data analysis

DATA

As stated in the data analysis section, the raw data was corrected or “cleaned”, to eliminate any questionable negative readings. Figures I3 to I5 illustrate the second-by-second and cumulative exhaust emissions of CO_2, THC, and NO_x, when the lawn mower was either moving or idling.

Figure I3. Glendora High School (CO2)*

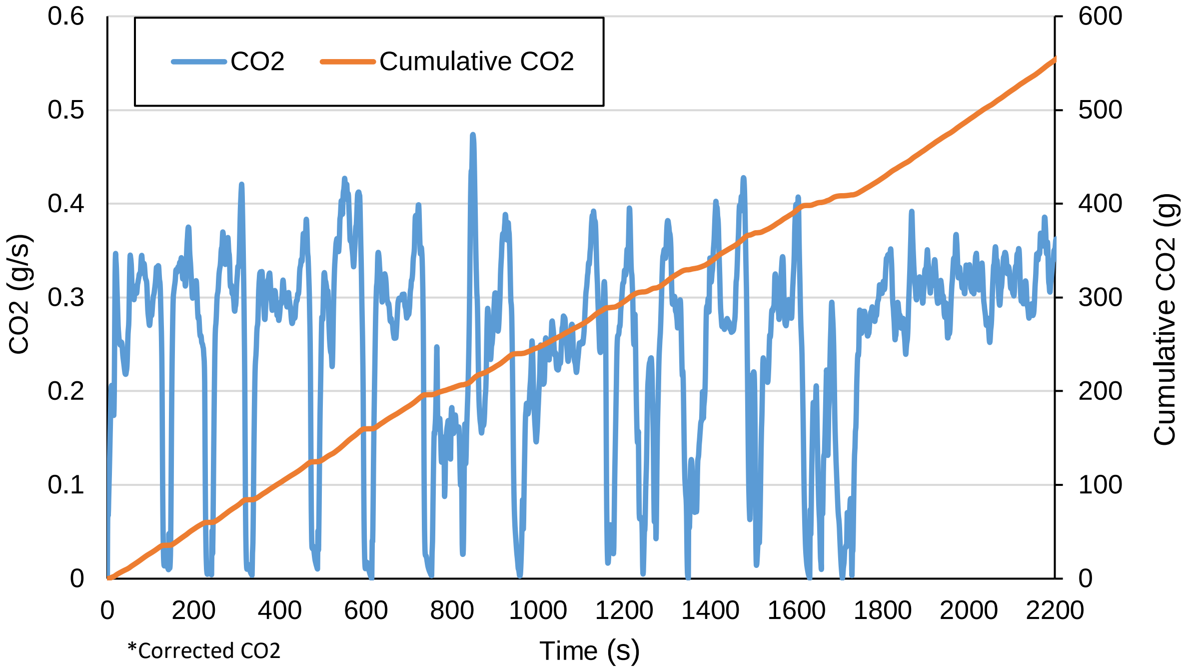


Figure I4. Glendora High School (THC)*

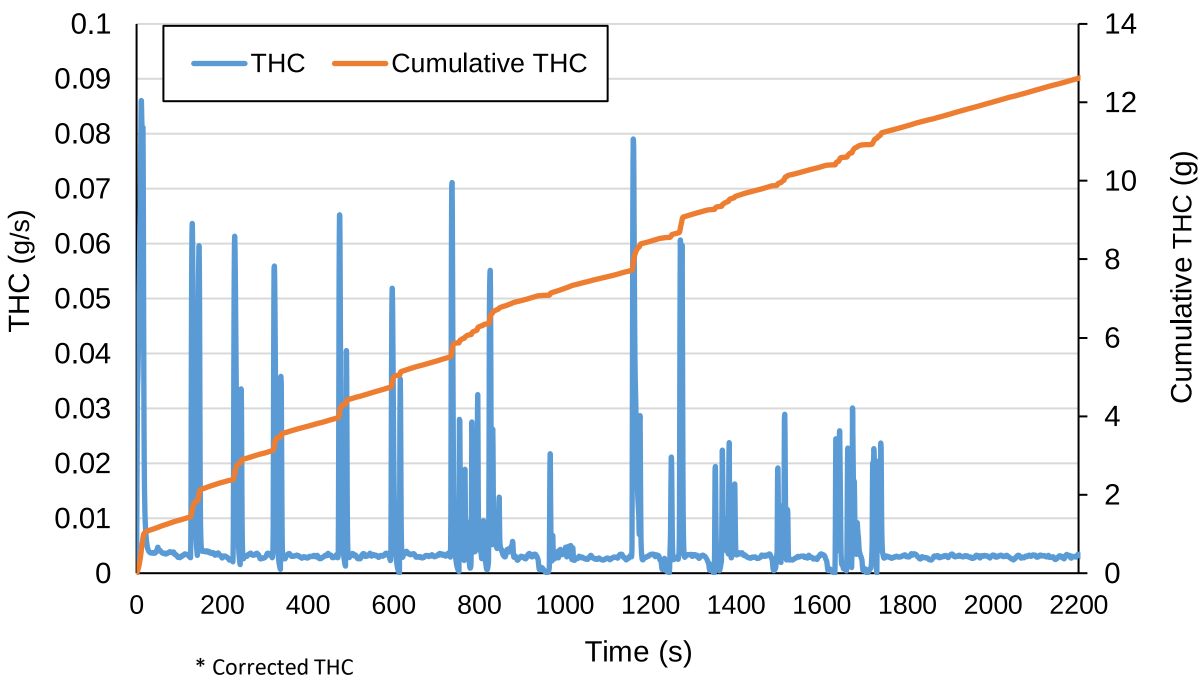
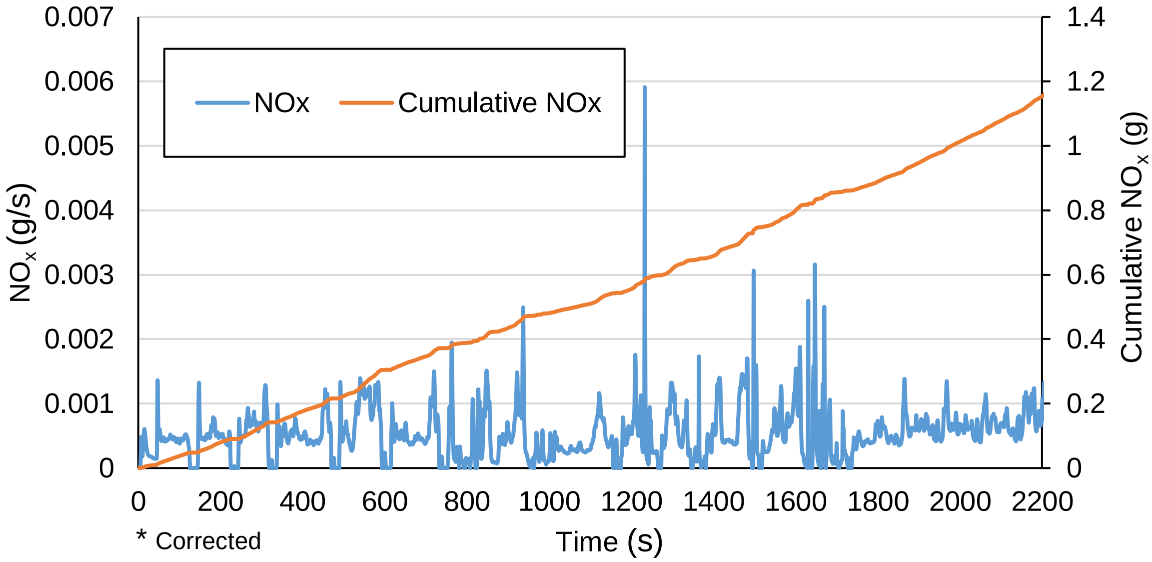


Figure I5. Glendora High School (NOx)*



* Corrected

RESULTS

The PEMS results were compared to the corresponding emissions standards and the emission factors for a 2005 lawn mower (carbureted and 4 stroke) in the SORE2020 Model. As shown in Table I3, the HC+NO_x was estimated to be 13.84 g/bhp-hr, whereas the corresponding emission standard was 12 g/bhp-hr, indicating that the PEMS derived emission factor was higher by 15%. When compared to the zero-hour emission factor (8.7 g/bhp-hr for HC+NO_x) from the SORE2020 Model, the results from the PEMS was 59% higher. Consistently, the emission factors derived from the PEMS data for HC, NO_x and CO2, were higher than those in the SORE2020 Model by 110%, 44% and 27% respectively.

Table I3. Emission Test Data from Portable Emissions Measurement System (PEMS)

Pollutant	Average PEMS Data		SORE2020 Zero-Hour EF (g/bhp-hr)	Emissions Stds. (HC+ NO_x) (g/bhp-hr)	PEMS to SORE Zero-Hour EF Ratio (g/bhp-hr)	PEMS to Emission Stds Ratio
	(g/hr)	(g/bhp-hr)				
HC	21.04	12.66	6.0	N/A	211%	N/A
NOx	1.97	1.18	2.7	N/A	44%	N/A
HC + NOx	23.01	13.84	8.7	12.0	159%	115%
CO2	904.51	544.24	429.4	N/A	127%	N/A

* Alternative estimate for checking (fuel consumption=1.25 lbs./hr, BSFC=0.82 lbs./bhp-hr, load factor=0.35)

CONCLUSION

In conclusion, the pilot study demonstrated the technical feasibility of PEMS in measuring real-world exhaust from a small off-road gasoline engine. As shown in Table I3, the real-world emissions, for a new, out-of-the-box lawn mower, were higher than both the emission standards and the emission factors used in the SORE2020 Model. Since this pilot study collected the exhaust emissions from only one lawn mower, additional studies will need to be conducted to further quantify the real-world emissions from other types of small off-road equipment such as trimmers, blowers and riding mowers. In addition to refining the emissions inventory, these studies may assist in quantifying the exposure levels and health risks to local residents and landscape service providers (gardeners), who operated the equipment and have exposure year around.

Appendix J – Analysis of Survey Responses with High Reported Equipment Usage

Background

The Social Science Research Center (SSRC) of the California State University, Fullerton (CSUF) was established in 1987 and has over 30 years of experience in supporting research activities within the public and private sectors. Due to their expertise, the SSRC was contracted by California Air Resources Board (CARB) in 2018 to conduct a comprehensive phone survey to estimate the population and annual activity of small off-road engines (SORE), covering both the Lawn and Garden and Light Commercial categories. This survey not only focused on the residential and business sectors, but it also reached out to the vendor sector, including any licensed or unlicensed businesses involved in lawn and garden care, landscaping, or landscaping-related activities (such as landscape architecture or design) within California. This was the first time data on SORE were collected and utilized in an emissions inventory model regarding the vendor sector.

While this survey was well designed to be randomized and representative, like any other survey, questionable data may be among the responses due to a variety of reasons. Note that Section 4.2 has already outlined the general criteria for excluding responses that were missing usage information, engines outside the scope of this study (e.g., diesel engine), or equipment with high usage (e.g., residential or commercial responses with ≥ 7 times per week and 8 hours per use for lawn and garden equipment). The objective of this Appendix is to describe CARB's review of industry comments regarding what they describe as "outliers" and summarizing those that were excluded from the final activity estimates. Additionally, staff compared the final activity estimates used in the SORE2020 Model versus those obtained from past surveys, as well as the activity utilized by U.S. EPA's NONROAD Model.

Industry Concerns

On June 30, 2020[21], the Outdoor Power Equipment Institute (OPEI) submitted to CARB comments and concerns regarding the equipment usages reported in the 2018 SORE survey. The comment letter included an evaluation of almost 200 responses, comprised of 64 responses from the residential survey (out of a total of 1,152 responses), 37 responses from the business/commercial survey (out of a total of 1,350 responses), and 93 responses from the vendor survey (out of a total of 629 responses). OPEI identified several major reasons on why they believe these responses should be rejected and removed. Firstly, OPEI indicated that some respondents provided the same activity estimate for different equipment, which they noted as rather unusual. Since the survey was conducted by phone, the interviewers were required to ask the same questions for

[21] OPEI's letter to CARB dated June 30, 2020 *RE: OPEI Comments to CARB 6/9 Potential SORE Regulations Workshop*

each piece of equipment. Having the same answers for different equipment would not jeopardize the validity of the answers. The interviewers were required to record the answers from the respondents and not provide any opinion. Therefore, if there were similar responses for different equipment in the survey, the respondent stated that particular answer multiple times. No evidence suggests that an equipment owner could not own more than one piece of equipment and use each one for similar amounts of time.

Another concern raised by OPEI was related to the long hours of equipment usage, as derived by multiplying the annual activity of an equipment by the equipment's age, as reported by the respondent. OPEI assumes that the annual activity of each individual equipment has been constant over the life of the equipment. For instance, respondent R482 has a gas-powered trimmer that was used once a week for 1 hour each time. For this 15-year-old trimmer, OPEI estimated a total of 780 hours of use. The survey was intended to collect the most recent activity from the past year and should not be assumed constant for all previous years, as external factors may cause variations in past usage. The usage of SORE equipment may be affected if a respondent did not reside at the same property for the life of the equipment or if the property's landscape changed due to a drought, economic downturn, or installation of grass or other flora that require more maintenance. As noted in Appendix E, the usage of SORE equipment varies with age, with newer equipment used more frequently as compared to older equipment. So while using fleet average activity to estimate the cumulative hours of usage for the purpose of emissions deterioration is an appropriate method that has been utilized in different inventory models, assuming that each individual equipment will have the exact same usage across the life of the equipment does not necessary hold true due to the reasons described earlier.

Third, OPEI pointed out the fuel usage (e.g., number of refills of a gas can) for some respondents may not match the expected total fuel consumption associated with the operation of the small off-road engines. Staff recognized such mismatch could indicate an overestimate of equipment activity or an underestimate of gas can filling frequency for a given respondent, but the activity data from that equipment should not be perceived as invalid. This survey was based on the best recollection of the activity of each equipment from the respondent. Staff recognized that respondent may not always remember the number of refills or that they might have used other means to provide the gasoline fuel needed to power their equipment. For example, equipment could be filled directly at a fueling station. This might be expected for equipment that is regularly transported or that is installed in a truck bed. Fuel is also sold in single use containers, with and without oil mixed with the gasoline.

In the business and vendor sector, OPEI expressed concern that the hours of operation for some equipment did not match the total employee work hours or the work hours based on the number of reported regular clients. Staff recognized that this point may has merits, however, business owners may hire part-time workers as the work load fluctuates based on a growing season. As discussed in the survey report (p 556), vendor survey respondents reported on the number of “regular” clients, so clients they didn’t consider “regular” would not have been reported. The clients that weren’t reported as “regular” could also account for part of the difference.

Lastly, as noted in the OPEI & EMA May 20, 2020 “*CARB Survey Outlier Analysis*” presentation[22], one of the major screening methods that OPEI and EMA used to determine outliers is a well-established method called the Interquartile Range (IQR) analysis, or the boxplot method, as developed by Tukey (1977)[23]. In statistical analysis, the IQR (IQR = Q3 – Q1, where Q1 is the 25th percentile and Q3 is the 75th percentile of the data) is simply the range between the first and third quartile of the distribution and is typically used to describe the distribution. Because of this, the IQR may be introduced as the range where the middle half of the data points lie. Tukey (1977) identified Q1-(1.5*IQR) and Q3+(1.5*IQR) as “inner fences”, Q1-(3*IQR) and Q3+(3*IQR) as “outer fences”. The observations between the inner fence and the outer fence are considered to be “potential outliers”, and those beyond the outer fences are considered to be “problematic outliers”[24]. Although the boxplot method can be used as an effective method when working with large data sets that are normally distributed, real-world data may not follow a normal distribution. They can often be highly skewed, usually to the right (i.e., higher values), and as a result, closely resemble that of a lognormal distribution. For example, Hubert and Vandervieren (2008) [25] indicated that while the boxplot method is a very popular graphical tool to visualize the distribution of continuous unimodal data, if the data is skewed, the points exceeding the whiskers are often *erroneously* declared as outliers. In a separate analysis, Seo (2006)[26] supported that Tukey’s method cannot be directly applied to real-world data, which likely deviates from a normal distribution.

Similar to the annual mileage of light-duty vehicles, the annual activity of SORE equipment was found to have a right-skewed distribution. The following two charts, shown in Figure J1, illustrates two different cumulative distributions of activity data for residential lawnmowers. The data represents the annual usage in hours per year from survey respondents. The left panel shows that the cumulative distribution of the raw survey data is not normally distributed. Similarly, the right panel displays the distribution of the data in the logarithmic space and the S-curve indicates that the spread of the data is a log-normal distribution.

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[22] Annex A of OPEI’s letter to CARB dated June 30, 2020 *RE: OPEI Comments to CARB 6/9 Potential SORE Regulations Workshop*

[23] Tukey, John W. Exploratory data analysis. Vol. 2. 1977.

[24] High, R. Dealing with outliers: How to maintain your data’s integrity. University of Oregon, 2000

[25] Hubert, M., & Vandervieren, E. (2008). An adjusted boxplot for skewed distributions. Computational statistics & data analysis, 52(12), 5186-5201.

[26] Seo, S. (2006). A review and comparison of methods for detecting outliers in univariate data sets (Doctoral dissertation, University of Pittsburgh).

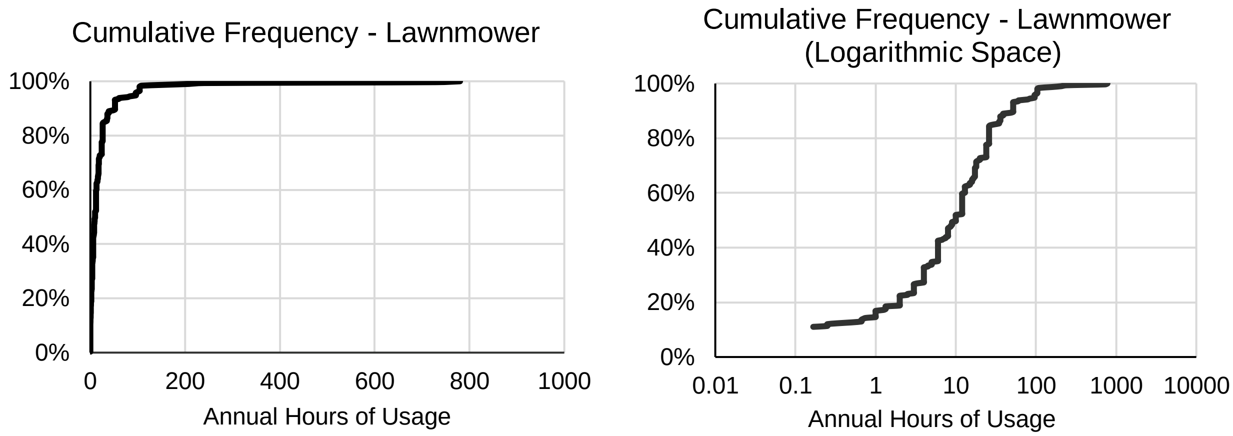


Figure J1. Cumulative Distribution of Annual Residential Lawn Mowers Usage

Therefore, it is evident from Figure J1, that the distribution of SORE equipment usage is highly skewed and closer to a log-normal distribution as opposed to a symmetric, normal distribution. If the IQR analysis was applied to the original distribution, excluding the data above the upper bound, the annual activity would be 13 hours per year. In comparison, if the IQR analysis was applied to the logarithmic distribution (i.e., in the logarithmic space), the annual activity would be 19 hours per year. This illustrates how the final results vary according to the method applied. It is evident that the boxplot method may be a good screening tool, however its application to a log-normal distribution, as utilized by OPEI, is ineffective in determining outliers. As a result, all potential outliers identified by OPEI must be evaluated by staff, before any exclusions are made in the final dataset.

The comments provided by industry assisted significantly in the assessment of all responses from the survey. With the assistance of SSRC from CSUF, staff was able to clearly understand those responses with relatively high usages. For instance, SSRC discovered that respondent R555 owns a large, 3-acre farming property, which correlated with the high annual activity for the various equipment reported. Overall, staff viewed industry's concerns as constructive, since it initiated the further examination of the survey data before inclusion into the SORE2020 Model.

Response Removal

Through the collaboration efforts by both industry and CARB, staff has verified and removed some of the responses identified by OPEI, resulting in a more robust, final data set used to estimate the annual usage of Lawn and Garden and Light Commercial equipment. Table J1 provides a summary of the excluded data in the final activity analysis. Note that some responses have already been removed in the draft SORE2020 inventory, released on May 29, 2020.

Table J1. Summary of Equipment Usage Activity Data Removed from 2018 SORE Survey

Residential Survey

Response #	Proposed Actions
R95	Replace "don't know" with 0 hr/use for chainsaw #2 / Change activity of generator #2 to 0 min/use instead on 30 min/use
R192	Remove air compressor with 7 days/week for 8 hr/use (2912 hr/yr)
R482	Remove lawnmower with 1x/week and 15 hr/use of usage
R616	Remove trimmer with 208 hr/yr of usage
R658	Remove welder with 7x/week and 6 hr/use
R555	Remove riding mower with 7x/week of usage Use 2.25 hr/use for the generator based on the other generator usage
R658	Remove lawn mower with 7x/week of usage
R518	Remove 2nd chainsaw with 24 hr/yr of usage

Business Survey

Response #	Proposed Actions
C26	Remove leaf blower #3
C301	Change the "at least once a week" to "once a week" for lawn mowers and String Trimmers
C1222	Remove pressure washer/compressor with 24 hr/use 6x/yr usage

Vendor Survey

Response #	Proposed Actions
V2-G4	Remove two hedge trimmers that are used at least once a day for more than one hours.
V2-G5	Remove lawnmower/leaf blower/trimmer data
V3-G2	Remove riding mower
V3-G5	Remove trimmer
V18-G4	Remove leaf blower hours due to high usage of 5 hr/use.
V19-G2	Remove string trimmer #2 with 2x/week and 6hrs/use
V59-G2	Remove riding lawnmower
V72-G2	Remove 6 chainsaws/3 lawnmowers/2 leaf blower/4 string trimmer/ 3 hedge trimmer/1 rototiller
V89-G1	Remove lawnmower
V91-G1	Remove 4 leaf blowers that are used 5x/week for 8 hr/use
V96-G1	Remove 1 lawnmower/1 leaf blower/2 trimmers
V127-G1	Remove all leaf blower and all trimmer data
V138-G1	Remove String Trimmer hours due to high usage of 5 hr/use.
V142-G2	Remove 1 lawnmower/1 leaf blower/2 trimmer
V212-G1	Remove 3 leaf blowers - 5x/week; 6-8hr/use
V218-G1	Remove all of the string/hedge trimmers
V271-G1	Remove String trimmer 1
V289-G1	Remove leaf blower

Vendor Survey

Response #	Proposed Actions
V292-G1	Remove first lawn mower used 6x/week for 6 hrs/time
V361-G1	Remove leaf blower
V362-G1	Remove both leaf blowers and both string trimmers
V380-G1	Remove lawnmower #1, leaf blower #1, and string trimmer #1
V401-G1	Remove 1 lawnmower (5x/week*5hr/use)/ 1 leaf blower (5x/week*2hr/use)/ 1 trimmer (4x/week*3hr/use)
V402-G1	Remove 1 trimmer (5x/wk*4hr/use)

In the residential sector, staff removed respondent R192's air compressor which was used 7 times a week and 8 hours per use, or a potential total of 2912 hours per year, as it was atypical, though not impossible, for a compressor to be utilized year around for 8 hours a day. A lawnmower, owned by R482, that was reportedly used once a week for 15 hours per use, was removed due to the atypical run time of the equipment. Respondent R95 had initially provided annual activity for a chainsaw and a generator, however, later commented that these two equipment were stored in the garage and not used. Staff recorded the annual activity as 0 hours.

In the business sector, staff removed respondent C26's leaf blower #3, with usage reported as 2 times a month and 14 hours per use, as it was atypical duration for that equipment. Both a pressure washer and air compressor used 6 times a year and 24 hours each time, owed by respondent C1222, were excluded due to the 24 hours of use.

In the vendor sector, the majority of the equipment had a higher usage due to the nature of the job. Four leaf blowers, owned by respondent V91-G1, were removed as the reported usage was 5 times a week and 8 hours per use. Similarly, for respondent V362-G1, two leaf blowers and two trimmers were removed because the weekly operating hours highly exceeded the total employee work hours.

Discussion

Since surveys are based on the recollection of past events, another way to obtain accurate data on usage would be to install a data logger on a pool of randomly selected SORE equipment for a designated duration period and download the real-world data for analysis. However, such a study would be time-consuming, labor-intensive, and cost-prohibitive for a large sample size.

While staff acknowledges the level of uncertainty associated with surveys, this method is currently considered the best available approach to estimate the equipment usage for the purpose of inventory development. If there are ample resources available in the future, staff may consider adding the data logger component as part of the data collection efforts. In 2001, CARB's Lawn & Garden survey[27] was composed of 224 event loggers, installed on various pieces of Lawn and Garden equipment for a duration of two weeks, to record when and how long each piece of equipment was used. It is noteworthy to mention that in the 2001 survey, more than 85% of the equipment instrumented were lawnmowers, with the inclusion of 2 chainsaws and 3 leaf blowers. Since the 2001 survey was conducted nearly 20 years ago, the equipment usage may not be representative of today's residential Lawn and Garden care practices.

In addition to the 2001 survey, staff looked in the residential Lawn and Garden survey conducted by the Institute of Social Research of California State University Sacramento (ISR) in 2011 – 2012, which was comprised of 2,999 surveys over a two-month period[28]. Since the survey was conducted soon after the 2008 economic recession, when California was experiencing high rates of unemployment (11%-12%), equipment usage may not be representative of today's residential Lawn and Garden maintenance practices. Staff believes that the past surveys can be used as a valuable source of comparison to corroborate the equipment activity in the SORE2020 Model. Please note that staff calculated the total hours of usage over the two week data collection period and multiplied the total hours by 26 (assuming 52 weeks per year) to obtain the annualized activity from the data logger data collected through the 2001 survey. This method differed from the OFFROAD2007 Model and resulted in slightly different estimates. The analyses of the 2012 survey and the 2018 SORE survey utilized the raw data collected and a similar methodology to determine the average annual activity per equipment.

Table J2 summarizes the annual activity from different data sources in comparison to the SORE2020 Model, including the 2001 and 2012 Lawn and Garden surveys, OFFROAD2007 Model, and EPA's NONROAD Model. In addition, the table includes a column with the annual activity from the 2018 Survey, without the removal of any of the responses. In general, the average annual activity, with the inclusion of all responses, was higher than the activity with the responses in Table J1 removed. One exception occurred in the business sector, where the removal of respondent C1222's compressor resulted in an increase in the average annual activity, attributed to a population size of 32 gasoline compressors.

[27] https://ww3.arb.ca.gov/msei/2001_residential_lawn_and_garden_changes_in_eqpt_pop_and_act.pdf
[28] https://ww3.arb.ca.gov/msei/2012_residential_lg_survey_updated_tables.pdf

Table J2. Comparison of Annual Activity with Previous Surveys and US EPA's NONROAD Model

Category	Equipment	SORE2020 - Gas (Final Model)			2018 SORE Survey (All data)			OFFROAD 2007		EPA's NONROAD[29]		2001 Lawn & Garden Survey	2012 Lawn & Garden Survey
		R	B	V	R	B	V	R	B	R	B	R	R
Lawn & Garden	Lawnmower	19	84	240	23	102	249	16	229	25	406	21	15
	Chainsaw	18	53	140	18	53	141	5	289	13	303	22	23
	Trimmer	15	63	162	16	67	172	22	136	9	137	25	14
	Blower	15	149	207	15	151	224	5	196	10	282	13	12
	Other L&G	10	60	126	10	60	126	4	69	61	-	N/A	10
	Riding Lawnmower	83	-	246	152	-	288	29	271	41*	645*	59	28
Light Commercial	Generator	50	146	62	77	146	62	91	134	115		132	N/A
	Pump	10	168	153	10	168	153	174	258	221		N/A	
	Compressor	166	182	176	350	180	176	380	566	484			
	Welder	44	115	25	178	115	25	208	208	408			
	Pressure Washer	29	76	30	29	76	30	90	134	115			

R: Residential **B**: Business/Commercial **V**: Vendor

*Average of Rear Engine Rider and Lawn & Garden Tractor

[29] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf

When compared side-by-side with the other data sources, the annual activity for each equipment, as represented in the SORE2020 Model, was within a comparable range. Figure J2, below, illustrates how most of the residential Lawn and Garden equipment, in the SORE2020 Model, aligned well with OFFROAD2007 and EPA's NONROAD Model, with the exception of the riding mower, which had an increase in annual activity.

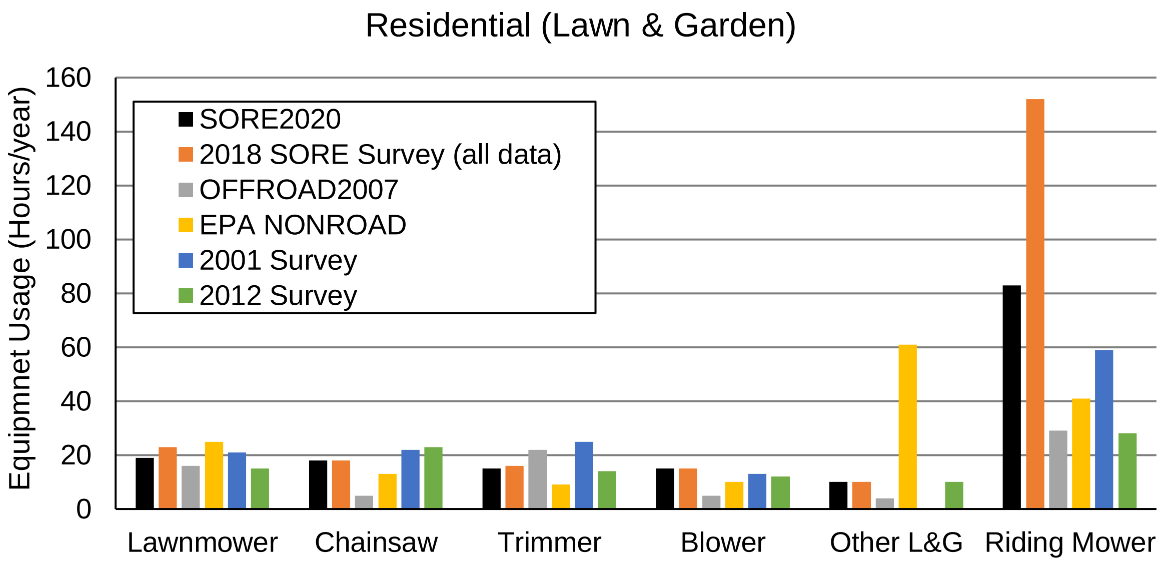
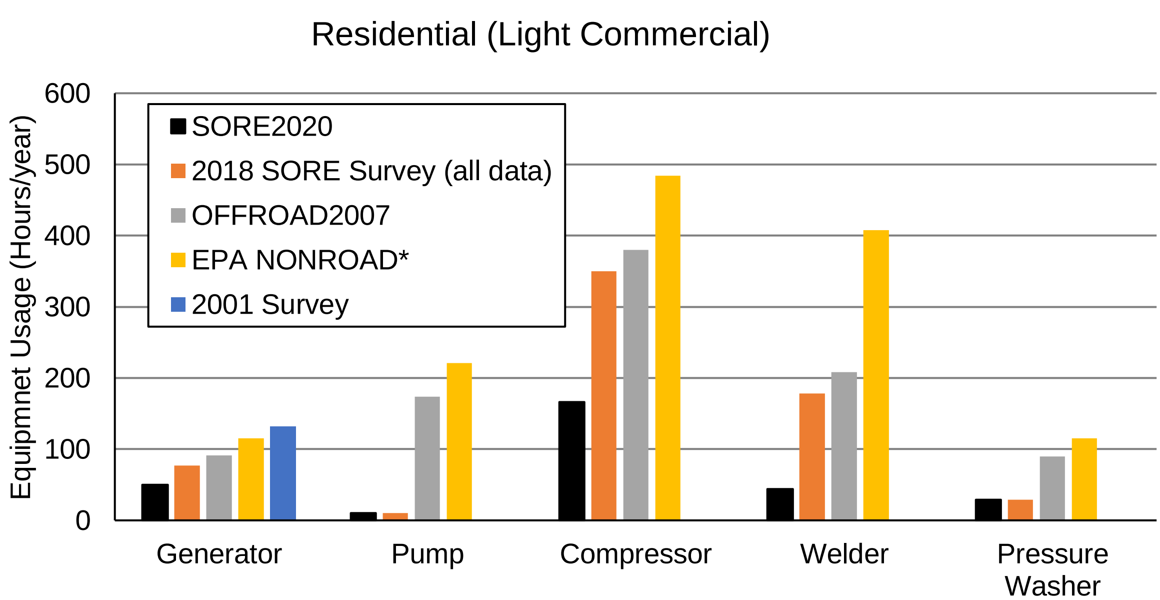


Figure J2. Annual Activity Comparison of Residential Lawn and Garden Equipment (hr/yr)



* Light Commercial Equipment Activities are the same for Residential and Business Sectors

Figure J3. Annual Activity Comparison of Residential Light Commercial Equipment (hr/yr)

As shown in Figure J3, the annual activity, for equipment in the residential Light Commercial category, was less in the SORE2020 Model as compared to the other data sources or previous model inventories.

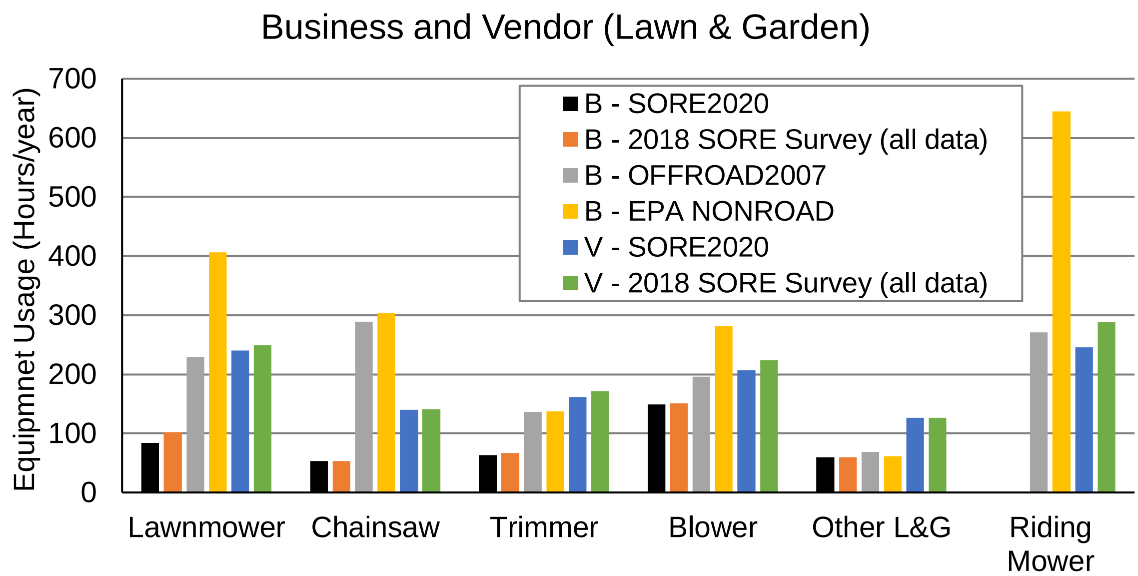


Figure J4. Annual Activity Comparison of Business and Vendor Lawn & Garden Equipment (hr/yr)

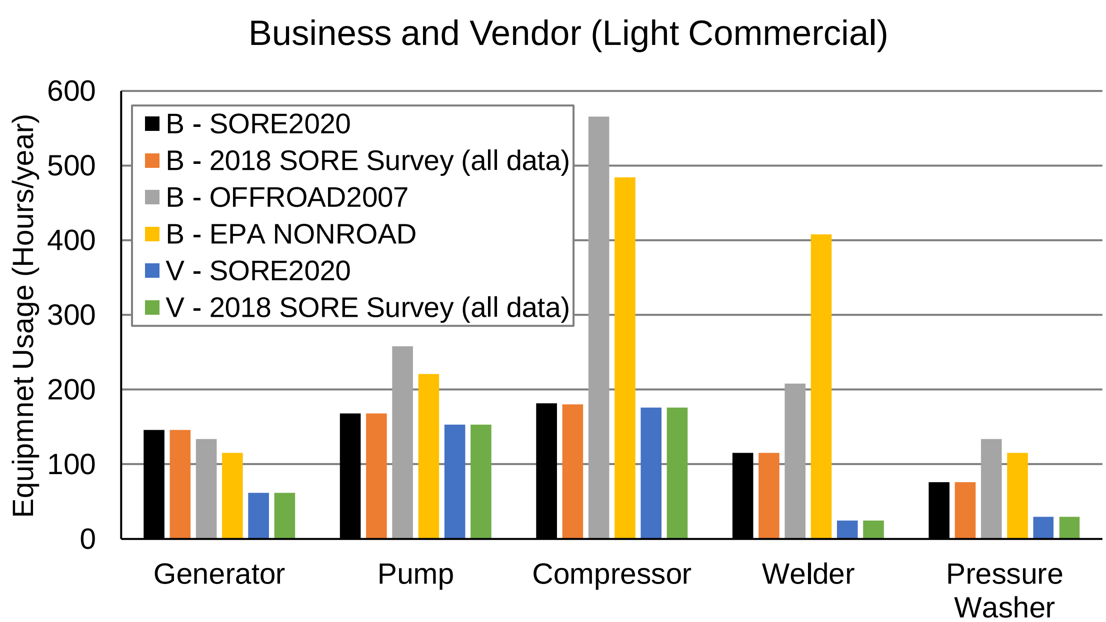


Figure J5. Annual Activity Comparison of Business and Vendor Light Commercial Equipment (hr/yr)

Figure J4 compares the annual activity of Lawn and Garden equipment in the business and vendor sectors. In the business sector, the average activity in the SORE2020 Model for lawnmowers, chainsaws, trimmers, and blowers, were lower than the estimates in both OFFROAD2007 and EPA's NONROAD Model. Similarly, in the vendor sector, the average annual activity for lawnmowers, chainsaws and riding mowers showed a distinctive difference and the SORE2020 Model estimates were less than those in the business sector of the EPA's NONROAD Model.

Figure J5 compares the annual activity of Light Commercial equipment in both the business and vendor sectors. In the business sector, the average activity for pumps, compressors, welders and pressure washers, were lower in the SORE2020 Model as compared to those in EPA's NONROAD Model. Since the vendor sector is a new addition to the SORE2020 Model and no other data sources exist for comparison, the annual activity was placed side-by-side to the equipment in the business sector of OFFROAD2007 and EPA's NONROAD Model. The estimates for the vendor sector were found to be lower for all equipment types.

Overall, the final activity estimates used in the SORE2020 Model, are within a reasonable range when compared to past Lawn and Garden surveys, OFFROAD2007 and EPA's NONROAD Model. Staff recognizes the need for improvement of future data collection efforts of SORE activity and that accurate, real-world data may be obtained through the use of data logging instrumentation. The comparisons illustrated above, in Figures J2 through J5, do not indicate any overestimation of annual usage or emissions by the SORE2020 Model.