Appendix D: 2023 Large Spark Ignition Forklift Emission Inventory

November 2023

CALIFORNIA AIR RESOURCES BOARD

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1 Executive Summary

The California Air Resources Board (CARB) has updated the Large Spark Ignition (LSI) Forklift Emission Inventory (LSI Forklift Emission Inventory or LSI Forklift Inventory), which was last updated in 2007[1]. The 2023 LSI Forklift Emission Inventory covers all propane, natural gas, and gasoline-powered forklifts in California. The purpose of the update is to inform and support the 2023 proposed regulatory measures for LSI forklifts, which includes accelerating the adoption of electric forklifts. This report describes the data inputs, methodology, resulting population and emissions, and impacts of the Proposed Zero-Emission Forklift Regulation (Proposed Regulation).

The main inventory updates include:

- Using forklift data reported to CARB for the Large Spark Ignition Engine Fleet Requirements Regulation (LSI Fleet Regulation)[2] compliance as of December 2020[3],
- Incorporating historical LSI sales data from forklift industry organizations,
- Activity surveys from LSI fleet owners,
- Inclusion of electric forklifts in the emission inventory, and
- Reflecting the latest emission standards, specifically the 2010 emission standard for LSI forklifts (not reflected in the previous inventory).

The largest changes in the LSI forklift emissions baseline due to the updates are:

- Population significantly increased, from 46,099 to approximately 94,725 LSI forklifts,
- Emissions projections between 2020 and 2030 increased significantly (cumulative emissions increase of 50 percent NOx and a doubling of PM) due to the change in population, and
- Over time, NOx emissions decrease due to the inclusion of the 2010 emission standard, which reduced NOx emissions from 2010 and later engines by 70 percent below the previous standard. This change reduces total NOx emissions slightly below the previous emission inventory by 2035.

These trends, and a comparison of the new baseline and impact of the Proposed Regulation, are shown below in Figure 1.

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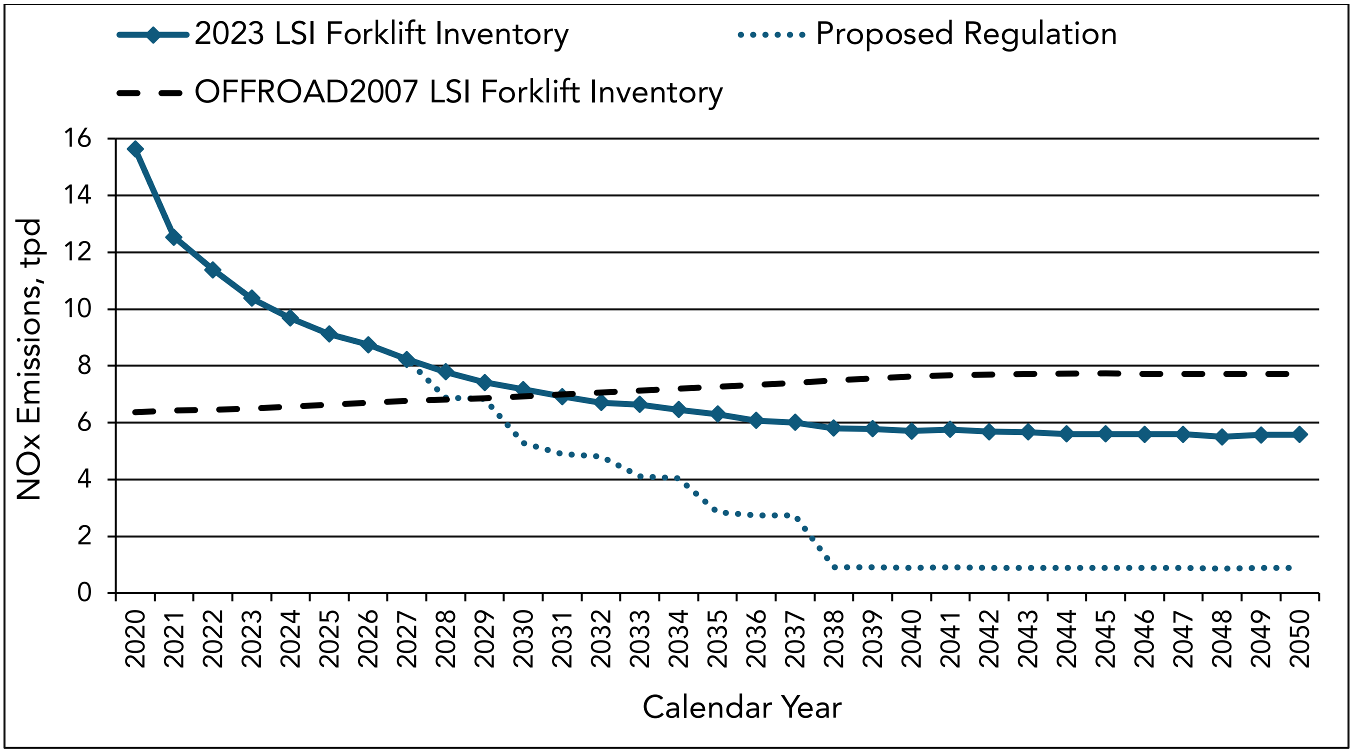
[1] California Air Resources Board, OFFROAD2007 Model Overview, September 13, 2023 (web link: *https://ww2.arb.ca.gov/sites/default/files/2023-06/offroad_overview.pdf*).

[2] LSI Engine Fleet Requirements Regulation, Title 13, California Code of Regulations, Sections 2775, 2775.1, and 2775.2.

[3] California Air Resources Board, Diesel Off-Road Online Reporting System (DOORS) (web link: *https://ssl.arb.ca.gov/ssldoors/doors_reporting/doors_login.html*, last accessed August 2023).

Figure 1. Statewide NOx emissions impacts from LSI Forklift Inventory update and Proposed Regulation



2 Background on Existing Rule

The LSI Fleet Regulation[4], adopted in March 2007, requires owners to report LSI forklifts, floor scrubbers and sweepers (sweeper/scrubbers), airport ground support equipment (GSE), and industrial tow tractors with LSI engines of 25 horsepower or greater. The primary goal of the LSI Fleet Regulation was to establish a series of Fleet Average Emission Level Standards (FAEL) that fleets had to meet from 2009 to 2013, as shown in Table 1. The primary goal of the regulation was to accelerate retirement of the oldest, dirtiest forklifts and other types of LSI equipment.

Table 1. Fleet Average Emission Level Standards (FAEL) in grams per kilowatt-hour (grams per brake-horsepower-hour) of hydrocarbons plus oxides of nitrogen

Fleet Type	Compliance by 2009	Compliance by 2011	Compliance by 2013
Large Forklift Fleet (26+ Forklifts)	3.2 (2.4)	2.3 (1.7)	1.5 (1.1)

[4] LSI Engine Fleet Requirements Regulation, Title 13, California Code of Regulations, Sections 2775, 2775.1, and 2775.2.

Fleet Type	Compliance by 2009	Compliance by 2011	Compliance by 2013
Medium Forklift Fleet (4-25 Forklifts)	3.5 (2.6)	2.7 (2.0)	1.9 (1.4)

3 Data Sources and Methodology

CARB staff used a wide range of data sources when developing the inventory update, including mandatory reporting data, two surveys of industry, working in industry stakeholder groups, and implementing changes based on public workshops and industry feedback. Table 2 lists the data sources used to create the 2023 LSI Forklifts Inventory including population, activity, emissions factors, and regional allocation profiles. The regional allocation profiles determine the portion of the statewide population, activity, and emissions in the inventory that are allocated to each county and air basin in California.

Table 2.Data sources used in 2023 LSI Forklift Inventory

Data Input	Source
Population, Fleets with 4 or more forklifts	DOORS[5] LSI Reporting Database, December 2020
Population, Fleets with 3 forklifts or less	Fullerton Survey[6], May 2016 – Sept 2016
Population, Statewide totals and electric forklifts	ITA[7] California Forklift Sales, 2020
Activity Hours	DOORS Fleet Survey, July 2020
Emission Factors	OFFROAD2021 with 2010 LSI Emission Standards[8]
Regional Allocation	CARB Industrial Warehouse Space Geographic Information System (GIS) Layer, 2019

[5] CARB's Diesel Off-Road Online Reporting System (DOORS) is the online reporting system used by entities subject to the In-Use Off-Road Diesel-Fueled Fleets Regulation (Title 13, California Code of Regulations, Sections 2449, 2449.1, 2449.2, and 2449.3) and the Large Spark-Ignition Engine Fleets Regulation (Title 13, California Code of Regulations, Sections 2775, 2775.1 and 2775.2) to report required company and fleet information.

[6] California State University, Fullerton, Survey of Large Spark-Ignited (LSI) Engines Operating within California, 2017 (web link: *https://ww2.arb.ca.gov/sites/default/files/2020-08/ssrc_2017.pdf*).

[7] Industrial Truck Association, United States Factory Shipments, 1997-2022, September 29, 2023 (web link: *https://www.indtrk.org/wp-content/uploads/2023/04/Factory-Shipments-Table-2023-Directory.pdf*).

[8] California Air Resources Board, Off-Road Emissions Inventory (web link: *https://arb.ca.gov/emfac/offroad/emissions-inventory*, last accessed October 2023).

a. Population

The LSI Forklift Emission Inventory population comes directly from the DOORS LSI Reporting Database (DOORS Database or DOORS), as of December 2020. The DOORS Database included 25,675 reported propane forklifts and 3,842 reported gasoline forklifts.

However, after reviewing the reporting requirements and based on discussions with industry, CARB staff found that the DOORS population does not fully account for the statewide LSI and electric fleet of forklifts.

Three reasons for incomplete representation of forklifts in the DOORS Database are: (1) fleets with 3 or fewer forklifts are not required to report, (2) fleets are not required to report zero-emission forklifts, and (3) non-compliance with the reporting requirements in the LSI Fleet Regulation from fleets with 4 or greater forklifts.

i. Scaling for Small Fleets

To account for fleets with 3 or fewer LSI forklifts, CARB staff developed and used a survey conducted by CSU Fullerton in 2016 (Fullerton Survey) focusing on businesses that use any number of LSI forklifts. The Fullerton Survey was based on phone calls with over 1,200 businesses that owned over 8,800 forklifts in total. This survey showed that 18 percent of the LSI forklift population is owned by fleets with 3 or fewer forklifts, indicating that fleets reporting to DOORS (with 4 or more forklifts) represent 82 percent of all forklifts statewide. Table 3 shows the fleet population represented by the Fullerton Survey.

Table 3. Fullerton Survey populations by fleet size category

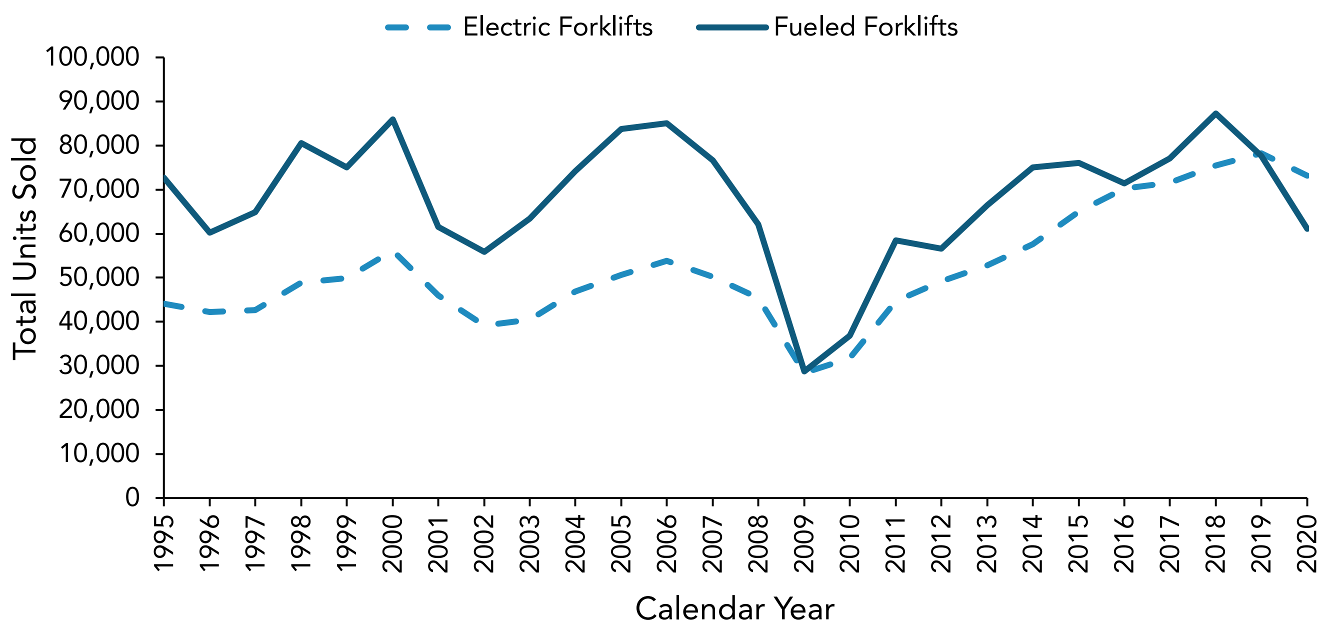
Fleet Category	Population
3 Forklifts and Under (not reported in DOORS)	1,353
Over 3 Forklifts (reported in DOORS)	7,470

Unfortunately, the Fullerton Survey did not provide robust details (horsepower, model year, etc.) that are necessary for an emission inventory. To reflect characteristics of fleets with 3 forklifts and under in the emission inventory, CARB staff randomly selected forklifts from fleets with 4 to 10 forklifts reported in DOORS and applied the same age, activity, and horsepower characteristics on forklifts in fleets with 1 to 3 units. This method used the assumption that fleets with 3 forklifts and under would have identical characteristics to fleets with 4 to 10 forklifts when considering horsepower, annual hours, and model year. The alternative would be scaling up all fleets in the emission inventory to account for the fleets with 3 or fewer forklifts, including fleets with over 1000 forklifts.

ii. Scaling for Other Forklifts Not Reported in DOORS

To determine the statewide population of LSI forklifts, including those that were in fleets with more than 3 forklifts but were not reported in the DOORS Database (i.e., were out of compliance with the reporting requirements), CARB staff used historical data on new forklift sales provided by the Industrial Truck Association (ITA). This data provided (1) the national annual number of LSI sales over the past 25 years, and (2) the fraction of sales in California compared to the national totals. This national ITA data is shown in Figure 2.

Figure 2. Historical national forklift sales reported by ITA from 1995 through 2020



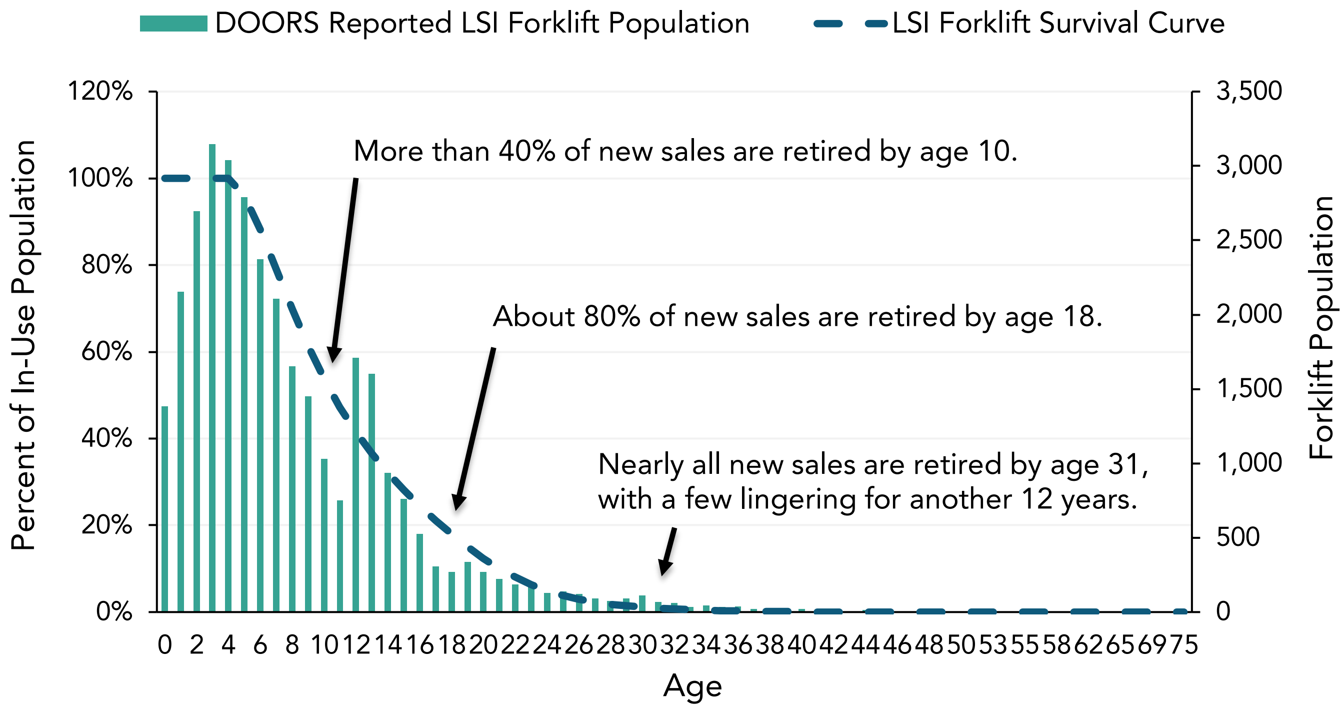
While ITA represents most forklift manufacturers, CARB staff reviewed the DOORS Database for forklifts and found that 10 percent of the forklift population was associated with manufacturers who are not part of ITA. Based on this analysis, the sales numbers shown above were increased by 10 percent.

Based on further discussion with ITA and members, CARB staff found that the California market made up nearly 11 percent of the national sales for recent years where sales data was available. For example, in a year where 70,000 forklifts were sold nationally, the analysis reflects 7,560 forklifts sold in California.

The historical sales data does not directly indicate the number of remaining, active forklifts in the state as a significant fraction may have retired between their sales date and 2020. To estimate the current number of operational forklifts, CARB staff applied a custom survival curve to the sales data.

Survival curves describe the percentage of purchased equipment that is still in service at different equipment ages. Figure 3 shows the DOORS population in 2020 by age, and the survival curve derived from this population. Similar curves were derived for gasoline and electric forklifts as well.

Figure 3. Survival curve applied to Statewide population of propane-powered forklifts



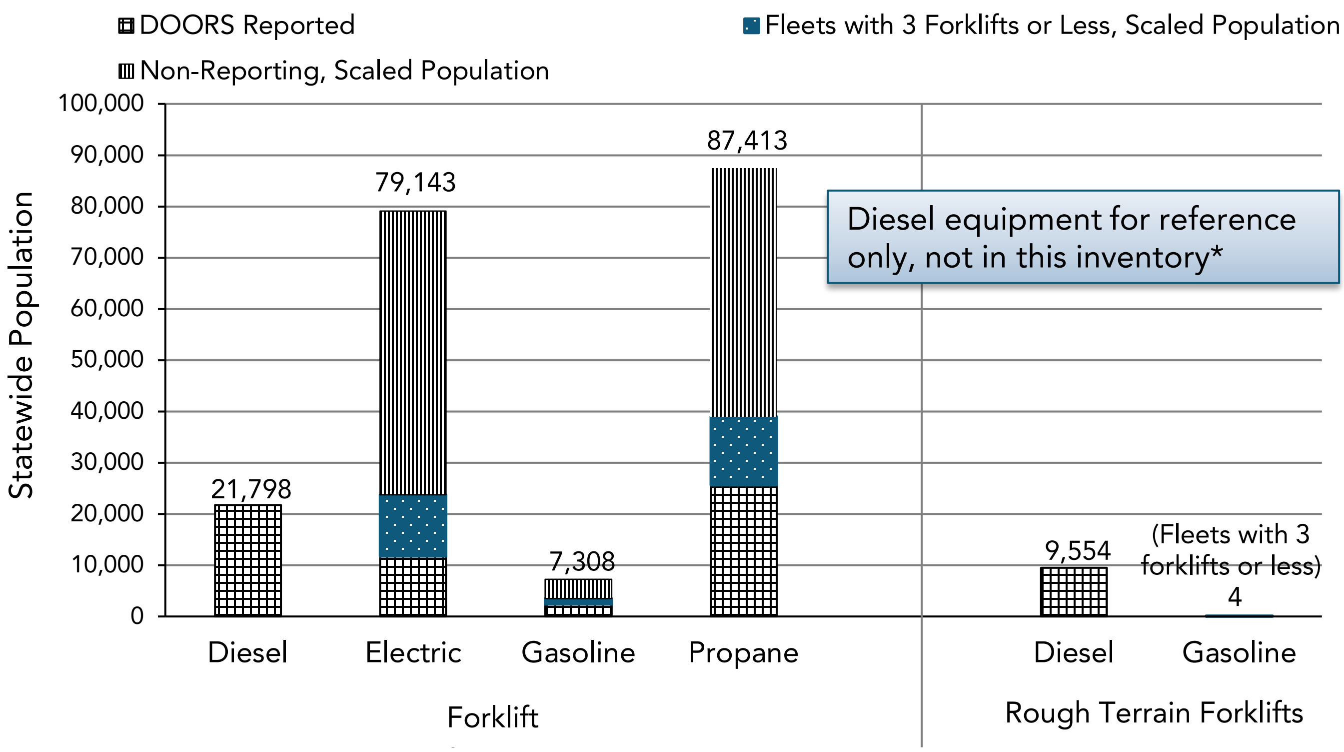
By applying this survival curve to sales, CARB staff estimated the total number of active LSI forklifts in California. For example, consider a model year 2008 LSI forklift, which would be 12 years old in 2020 (the base year of the inventory). Here are the steps taken to estimate those forklifts that remain in 2020:

- First, CARB staff increased the national sales in 2008 of about 62,100 forklifts by 10 percent to account for non-ITA forklift manufacturers, resulting in a total of 68,310 nationwide sales.
- Next, 68,310 was multiplied by 10.8 percent to reflect the California portion of national sales, or a total of 7,377 new forklifts sold statewide in 2008.
- Finally, 7,377 was multiplied by 0.36 to reflect the survival curve value for age 12 equipment, resulting in 2,656 model year 2008 forklifts active in 2020.

This process was completed for all model years and sums to 94,725 LSI forklifts statewide in 2020. This is the expected population of LSI forklifts in the base year 2020, after accounting for both fleets with 3 forklifts or less, and any non-reported forklifts from larger fleets.

Figure 4 shows the base year population in 2020 after scaling adjustments for fleets with 3 forklifts or less, and forklifts that were not reported. Diesel forklifts and rough terrain forklifts are included for reference and scale but are not included in the LSI Forklift Emission Inventory and are not subject to the Proposed Regulation.

Figure 4. 2020 base year forklift population statewide



* It is important to note that the population of diesel forklifts is based on the most recent Construction, Industrial, Mining, and Oil Drilling Emissions Inventory updated in August 2022, which was used to support amendments to the In-Use Off-Road Diesel-Fueled Fleets Regulation considered by the Board in November 2022.

iii. Electric Forklifts

Fleet owners are not required to report electric forklifts operating in California, but may do so in some cases for regulatory credits under the LSI Fleet Regulation. To estimate the total number of electric forklifts operating in California, CARB staff used the national sales data for electric forklifts shown in Figure 2 and applied the same method described above for non-reported LSI forklifts. This results in an estimated population of 79,143 electric forklifts. This methodology is not covered in significant detail here as electric forklifts have no impact on emissions.

iv. Combined Statewide Populations

Table 4 below includes the forklift population for all fuel types after accounting for fleets with 3 or fewer forklifts that did not have to report, as well as non-compliant fleets.

Table 4. 2020 Statewide Forklift Population

Fuel Type	2020 Statewide Population
Propane	87,413
Gasoline	7,312
Electric	79,143
Total, All Types	**173,868**

b. Annual Activity

The emission inventory uses annual activity to estimate the number of hours per year each forklift operates. To collect annual activity, CARB staff conducted a voluntary survey of the DOORS fleet in 2020 which allowed each fleet to report the average annual hours per forklift registered in DOORS. CARB staff sent three separate emails over a period of two months in 2020 requesting survey participation, and ultimately extended the survey period to three months for increased participation.

In the emission inventory, the exact hours reported were maintained for all forklifts. For example, if a fleet owner reported 5,000 hours per year, or 15 hours per year, that value was directly used in the emission calculation, and data was not aggregated or averaged, except to fill in gaps in information.

Where a forklift did not have reported activity data, an average activity was applied in one of two ways:

- Where fleets reported activity for some forklifts but not all, the average activity for the forklifts with activity in that fleet was used to fill in data on those without activity information. This maintained a fleet-specific activity wherever possible.
- In the case where there was no data for the forklifts or any forklifts in the fleet, an average by fleet size was applied, as seen in Figure 5. For example, if a fleet of 7 forklifts did not report, CARB staff would assign them an activity value of 1,044 hours per year, based on the average activity by fleet size. Meanwhile, a fleet with 40 forklifts would receive an average of 2,101 hours per year, etc.

Using population weighted averaging as shown in Figure 6, the inventory shows an overall average of 1,848 hours per forklift unit. However, this average was not applied to any specific forklift. Either the forklift had a specific activity value reported, or the fleet's activity average was used, or the fleet size average was used where no other data was available.

Figure 5. 2020 DOORS annual average activity hours per forklift curve by fleet size

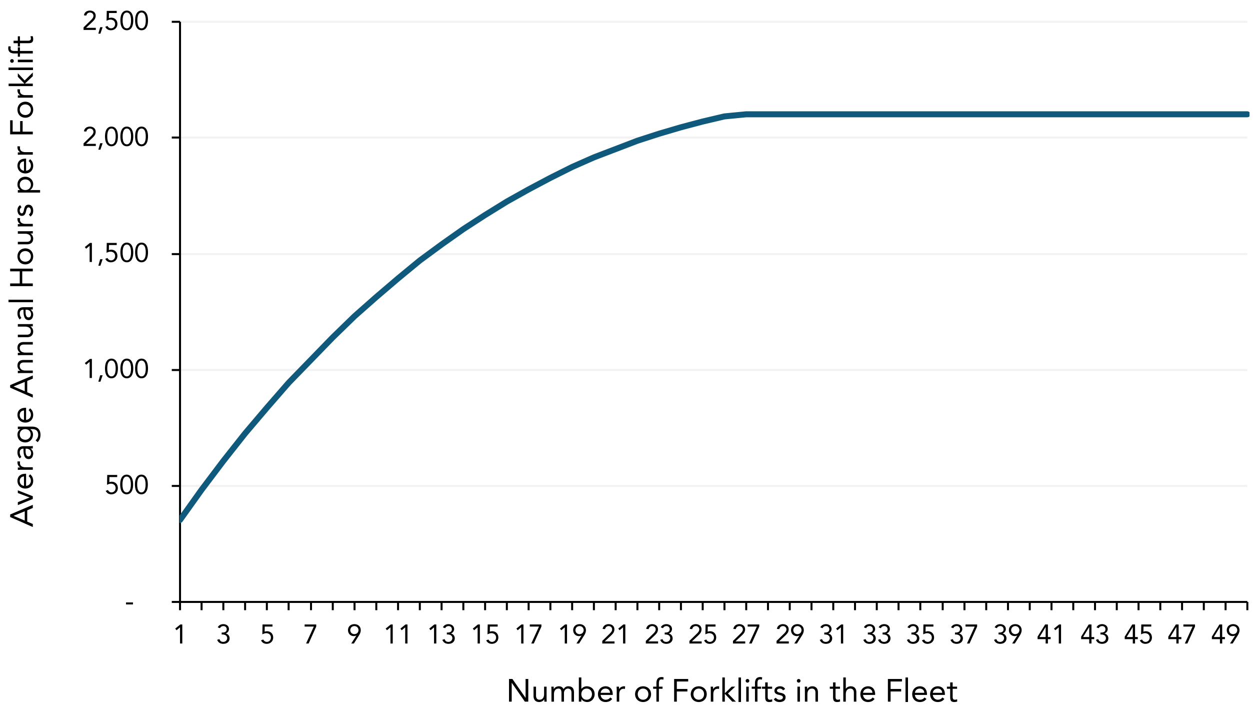
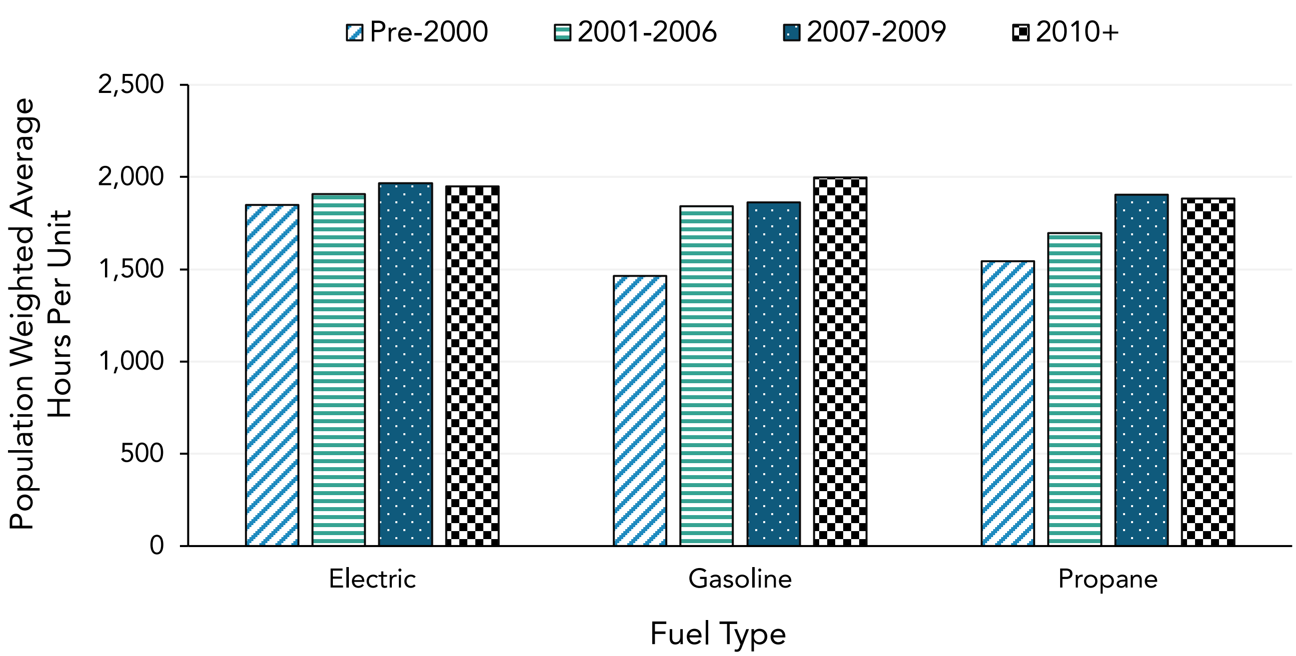


Figure 6. Base year 2020 forklift average hours by engine model year and fuel type



c. Load Factor

A load factor represents the average utilized power of an equipment as compared to its maximum rated power. The load factor is an expression of how hard an engine works on average, ranging from 0 to 100 percent, and is used for calculating emissions from off-road equipment. The last inventory, OFFROAD2007, uses a load factor of 30 percent (or 0.3). CARB staff are not updating forklift load factors at this time as insufficient data exist to support updating existing methodology.

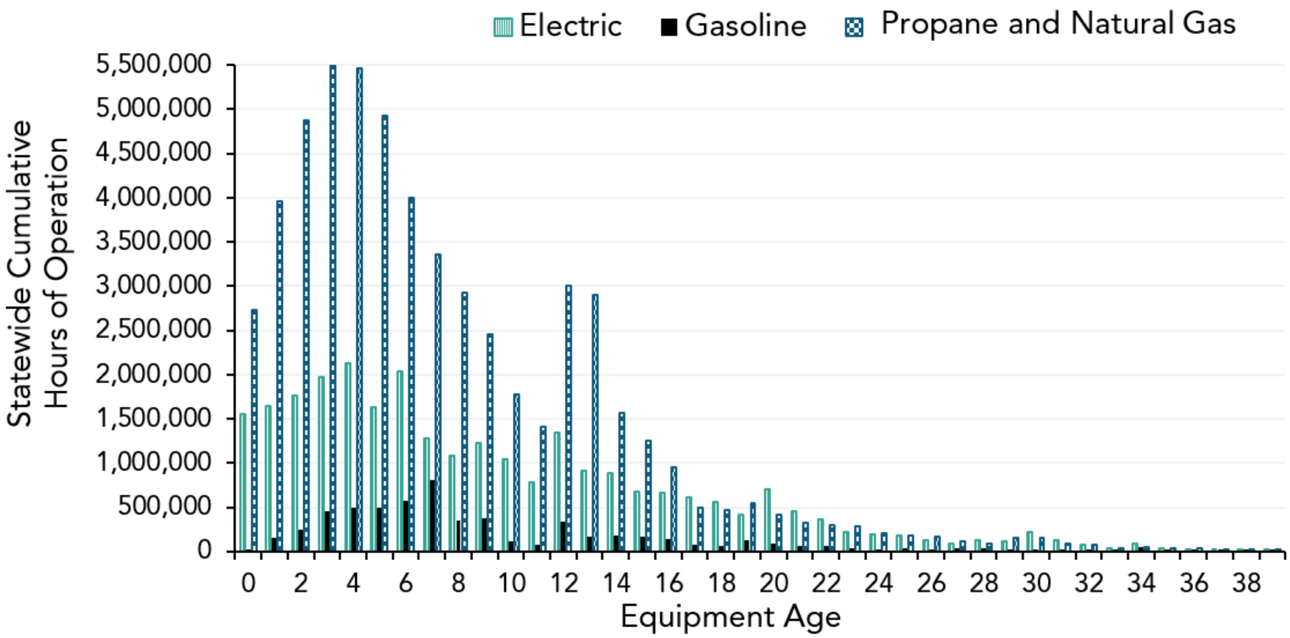
Additional data logging on forklifts or additional reporting on activity and fuel use combined could improve the accuracy of the load factor.

4 Age Distribution Results

Forklifts under 10 years of age represent the majority of population observed in the 2020 base year, as seen in Figure 7, and account for the majority of activity across all fuel types, as seen in Figure 8.

Figure 7. 2020 DOORS LSI forklift population distribution

Figure 8. 2020 base year activity distribution by age and fuel type



d. Forklift Turnover

The emission inventory projects LSI forklift population and emissions in future years based on each fleet's age characteristics observed in the 2020 base year. Fleet operators maintain their base year average age throughout each forecasted year, where fleets exceeding their average age in future years will turn over their oldest forklift until the base year average age is reached. It is assumed that fleets only purchase equipment as new as their youngest forklift observed in the base year, meaning many were modeled as purchasing used equipment. This maintains the assumption that young fleets will continue to purchase newer forklifts in future years, while older fleets will continue to purchase used forklifts in future years.

For example, assume in 2020 a fleet has 5 forklifts, and the average age of these forklifts is 12 years old. As the emission inventory is forecast from 2020 to 2021, each forklift becomes one year older, and the average age of forklifts is now 13 years old. To maintain the average age, the inventory forecasts that the fleet will retire the oldest forklift (16 in the example below), until the average age of all forklifts is once again 12 years old or lower. The fleet turns the oldest forklifts over to match the age of the youngest forklift, in this case age 7. This reflects the trend for some fleets to buy used equipment, and others to buy new equipment. The exact number retired each year can vary as one very old forklift would have more impact on average age than two forklifts that were only moderately older than the average age. For very large fleets, maintaining the average age might require turning over dozens of forklifts per year. On average, the example fleet below would need to turn over about 1 forklift every 2 years to maintain the average age of 12. This concept is further illustrated in Figure 9.

Figure 9. Example fleet replacement for a fleet of 5 forklifts from 2020 through 2025

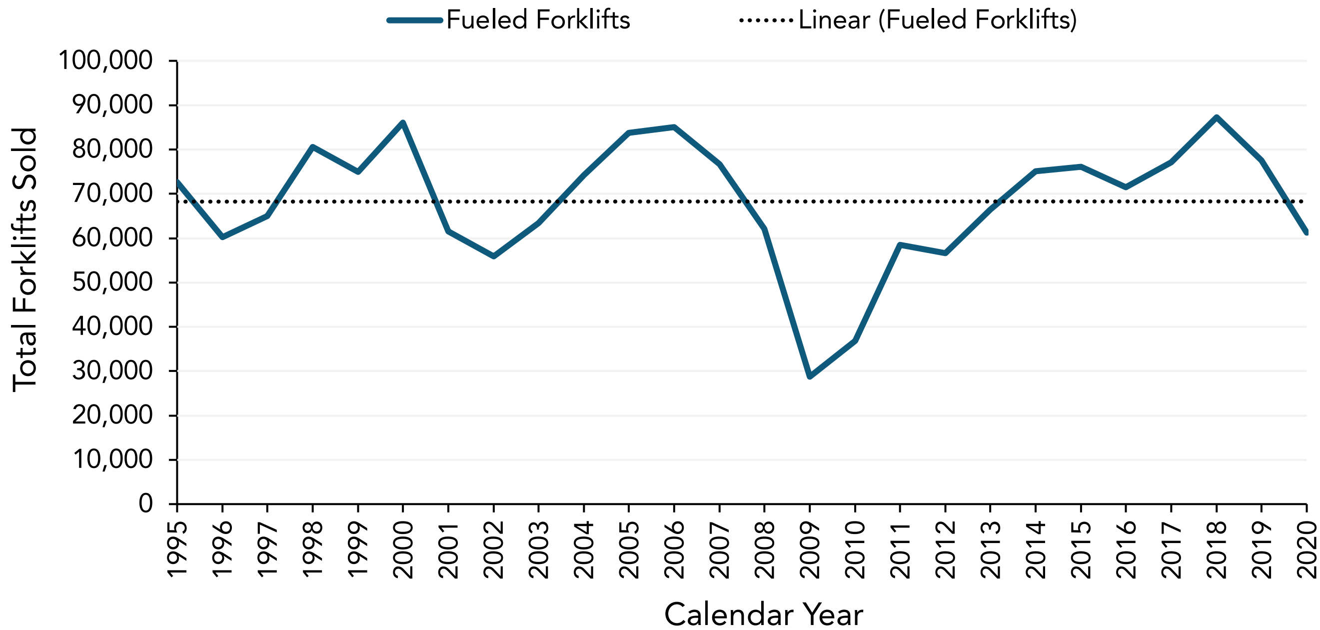
Fleet of 5 forklifts, **12 years old on average**, with an age 7 forklift as the youngest equipment observed in the base year 2020.

Calendar Year						Average Before Turnover	Average After Turnover
2020	Age 7	Age 9	Age 12	Age 16	Age 16	12	-
2021	Age 8	Age 10	Age 13	Age 17	Age ~~17~~ 7	13	11
2022	Age 9	Age 11	Age 14	Age 18	Age 8	12	-
2023	Age 10	Age 12	Age 15	Age ~~19~~ 7	Age 9	13	10.6
2024	Age 11	Age 13	Age 16	Age 8	Age 10	11.6	-
2025	Age 12	Age 14	Age ~~17~~ 7	Age 9	Age 11	12.6	10.6

e. Growth

LSI-fueled forklifts (forklifts which are powered by CNG, propane, or gasoline) have not had substantial historical growth in population, according to forklift sales from 1995 through 2020 depicted in Figure 10. Although there is variation from year to year, the trendline over the period is completely flat and shows no overall trend toward increasing or decreasing into the future. As such, the LSI inventory assumes no growth and the total base year populations are held constant through future forecasted years.

Figure 10: National sales of LSI Forklifts



f. Emission Factors and Group Profiles

Exhaust and evaporative emission factors were maintained from OFFROAD2007 with the addition of the 2010 LSI emission standard, as shown in Figure 11 for propane and natural gas-powered forklifts, and Figure 12 for gasoline powered forklifts.

Figure 11. Exhaust emission factors for propane and natural gas-powered forklifts by engine horsepower bin

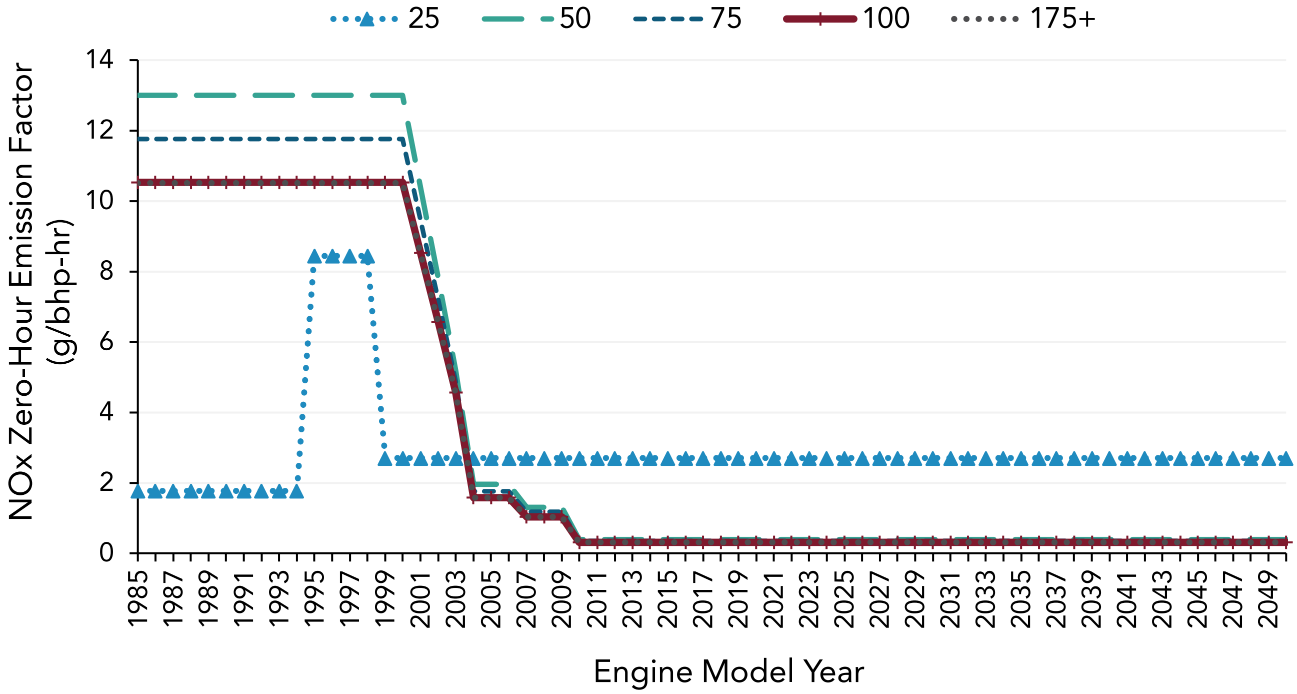
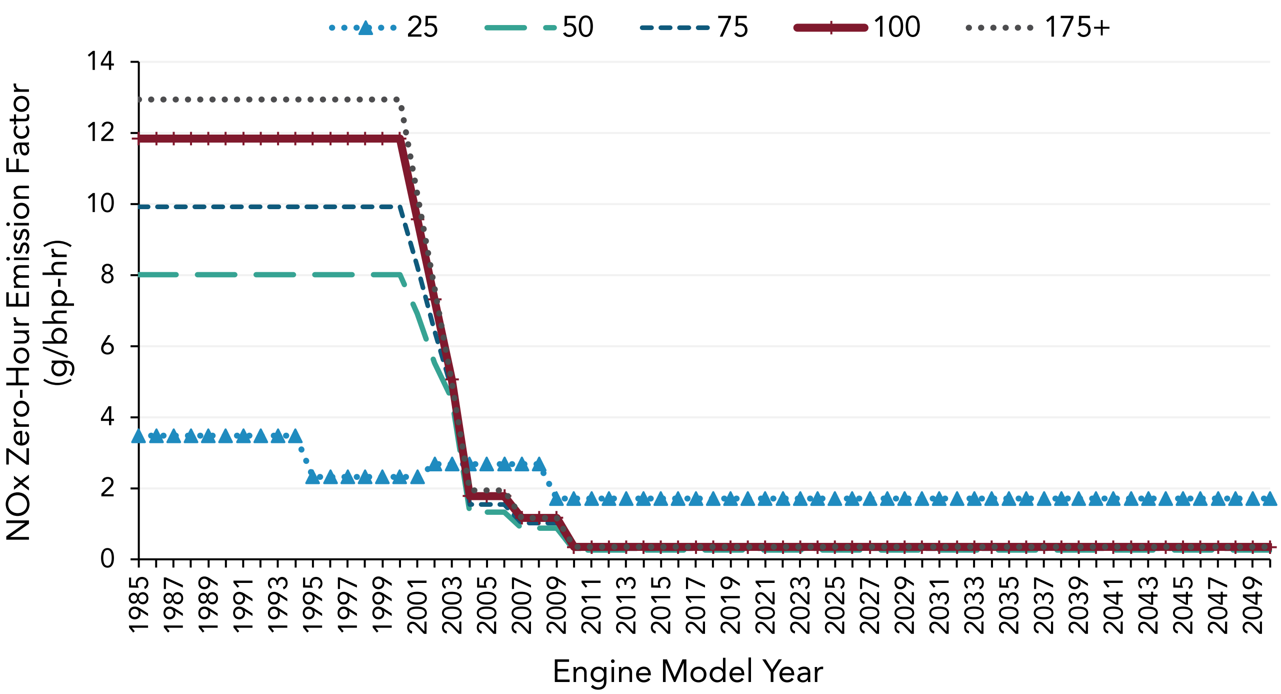


Figure 12. Exhaust emission factors for gasoline-powered forklifts by engine horsepower bin



Emissions factors described in the following sub-sections and applied to each forklift can vary depending on pollutant, engine horsepower, and model year categories.

i. Exhaust Emissions

Exhaust emissions factors represent the amount of pollutant an engine produces from the combustion of fuels, otherwise known as equipment tailpipe emissions. The total exhaust emissions are derived as follows:

Emissions = Population * Activity Hours * Engine Horsepower * Load * Emissions Factor

Engine horsepower reported into the DOORS Database was maintained for all forklifts where available. Where a forklift did not have horsepower included, the average horsepower of all LSI forklifts in DOORS, 63 horsepower, was applied to gap fill missing data. Roughly 3.7 percent of the population did not have horsepower reported.

Zero-hour emissions represent new engines and represents the average emissions from testing on engines with zero or near-zero total running hours accumulated. Over time as engines accumulate more hours, the engine can become less efficient from a variety of factors including natural wear and tear on the engine as well as emissions increases from improper maintenance and malfunctions. The emission increases from degradation are represented in the emissions factors as the deterioration rate.

Both zero-hour emissions and deterioration rates are noted in Appendix D.1 at the end of this report, specifically in Table 10 for gasoline equipment and in Table 11 for propane and natural gas equipment. The resulting emissions factors for each engine are expressed in grams per brake horsepower-hour (g/bhp-hr), as noted in the formula below.

Exhaust Emission Factor (g/bhp-hr) = Zero Hour Emissions + (Deterioration Rate * Accumulated Hours)

ii. Evaporative Emissions

Evaporative emission factors noted in Table 12 of Appendix D.1 represent the amount of pollutants that evaporate or escape from the equipment’s fuel system through various methods such as vapor expansion within the fuel canister, permeation through materials of the system such as through hoses and seals, and liquid leaks which represent the non-vapor emissions that occur when the fuel drips out of the fuel system and evaporates into the atmosphere.

Four evaporative emissions processes are measured in this inventory: hot soak, diurnal, resting loss, and running loss.

- Hot soak emissions occur immediately after the equipment is used and is due to fuel heating as an engine remains hot for an extended time after being switched off, gradually returning to ambient temperatures.
- Diurnal emissions occur when rising ambient temperatures cause fuel evaporation from equipment sitting throughout the day.

- Resting loss emissions occur when decreasing ambient temperatures cause fuel permeation through rubber and plastic fuel components of the system from equipment sitting throughout the day.
- Running loss emissions are a result of hot fuel vapors that escape the fuel canister or overwhelm the carbon canister while the equipment is being operated and the temperature of the fuel systems are above ambient temperatures.

Evaporative emissions are estimated for gasoline-powered equipment only, as propane and natural gas powered offroad equipment are assumed to have insignificant evaporative losses[9]. Each equipment was assumed to have one engine start per day. The following equations will provide evaporative emissions of hydrocarbons (HC):

Hot Soak = Emission Factor * Population * Engine Starts

Diurnal and Resting Loss = Emission Factor * Population

Running Loss = Emission Factor * Population * Annual Activity

g. Geographical Allocation of Statewide Emissions

To regionally allocate statewide emissions from LSI forklifts, an industrial spatial surrogate was used as developed in contract with University of California, Davis in 2019. The parcel information was originally sourced from the Longitudinal Employer-Household Dynamics (LEHD)[10] data for North American Industry Classification System (NAICS)[11] codes 31-33, representing manufacturing square footage in each region. Table 5 below details the percent of statewide emissions allocated to each air district based on industrial warehouse square footage in the region. Additionally, Table 9 in Appendix D.1 notes base year emissions from LSI forklifts by air district.

Table 5. Percent allocation of statewide forklift emissions to local air districts

Air District	Percent Emissions Distribution
South Coast AQMD	47.13 %
Bay Area AQMD	24.82 %
San Diego County APCD	8.29 %
Ventura County APCD	2.41 %

[9] California Air Resources Board, 2020 Emissions Model for Small Off-Road Engines – SORE2020, September 2020 (web link: *https://ww2.arb.ca.gov/sites/default/files/2020-09/SORE2020_Technical_Documentation_2020_09_09_Final_Cleaned_ADA.pdf*).

[10] United States Census Bureau, Longitudinal Employer-Household Dynamics (LEHD) Data (web link: *https://lehd.ces.census.gov/data/*, last accessed August 2023).

[11] United States Census Bureau, Economic Census: NAICS Codes and Understanding Industry Classification Systems, last revised September 28, 2023 (web link: *https://www.census.gov/programs-surveys/economic-census/guidance/understanding-naics.html*).

Air District	Percent Emissions Distribution
San Joaquin Valley Unified APCD	8.19 %
Sacramento Metropolitan AQMD	1.65 %
Monterey Bay Unified APCD	1.12 %
Santa Barbara County APCD	0.96 %
Yolo/Solano AQMD	0.81 %
Antelope Valley AQMD	0.59 %
San Luis Obispo County APCD	0.56 %
Placer County APCD	0.52 %
Mojave Desert AQMD	0.42 %
Northern Sonoma County APCD	0.35 %
Butte County AQMD	0.30 %
El Dorado County APCD	0.20 %
Mendocino County APCD	0.20 %
Shasta County AQMD	0.18 %
Tehama County APCD	0.18 %
Eastern Kern APCD	0.17 %
North Coast Unified AQMD	0.17 %
Feather River AQMD	0.17 %
Northern Sierra AQMD	0.15 %
Imperial County APCD	0.07 %
Amador County APCD	0.07 %
Colusa County APCD	0.07 %
Tuolumne County APCD	0.06 %
Siskiyou County APCD	0.06 %
Glenn County APCD	0.04 %
Calaveras County APCD	0.03 %
Lake County APCD	0.02 %
Great Basin Unified APCD	0.02 %
Mariposa County APCD	0.01 %
Lassen County APCD	0.00 %
Modoc County APCD	0.00 %

5 Results

Overall, the emission inventory projects higher forklift emissions beginning in 2020 through 2030 when compared to the previous OFFROAD2007 emission inventory. Figure 13 illustrates the LSI Forklift Inventory's projected statewide NOx emissions.

The difference in emissions between the update and prior inventory is largely due to a much higher population. The new 2023 inventory includes roughly 94,000 LSI forklifts, compared to roughly 46,000 in the previous inventory, which lacked California-specific reporting or sales numbers. Thus, overall NOx and PM emissions are initially projected to be higher than in OFFROAD2007. Figure 13 shows NOx emissions decrease faster than previously estimated due to the inclusion of updated and significantly lower emission factors for forklifts with MY 2010 and later engines. PM emissions are not expected to decline over time with the introduction of newer equipment, as shown in Figure 14, due to the lack of 2010 emission standards for PM in the LSI engine categories.

Figure 13. Statewide NOx emissions from LSI forklifts projected out to 2050

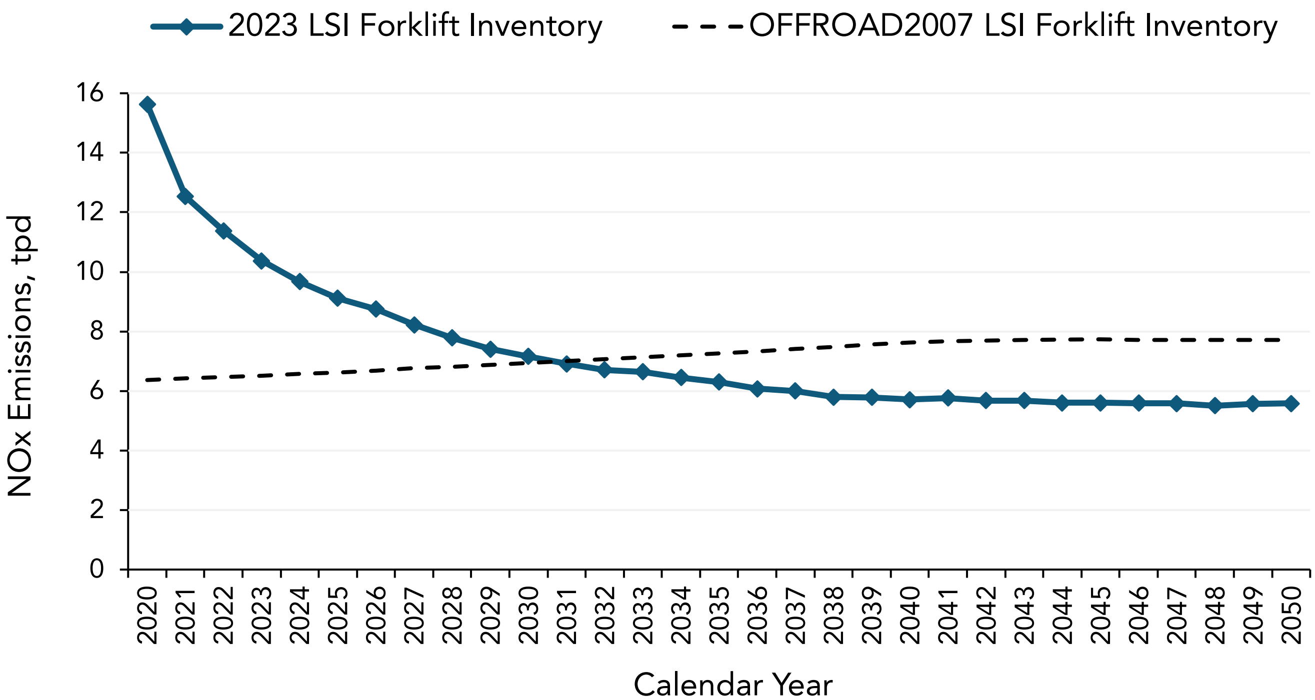
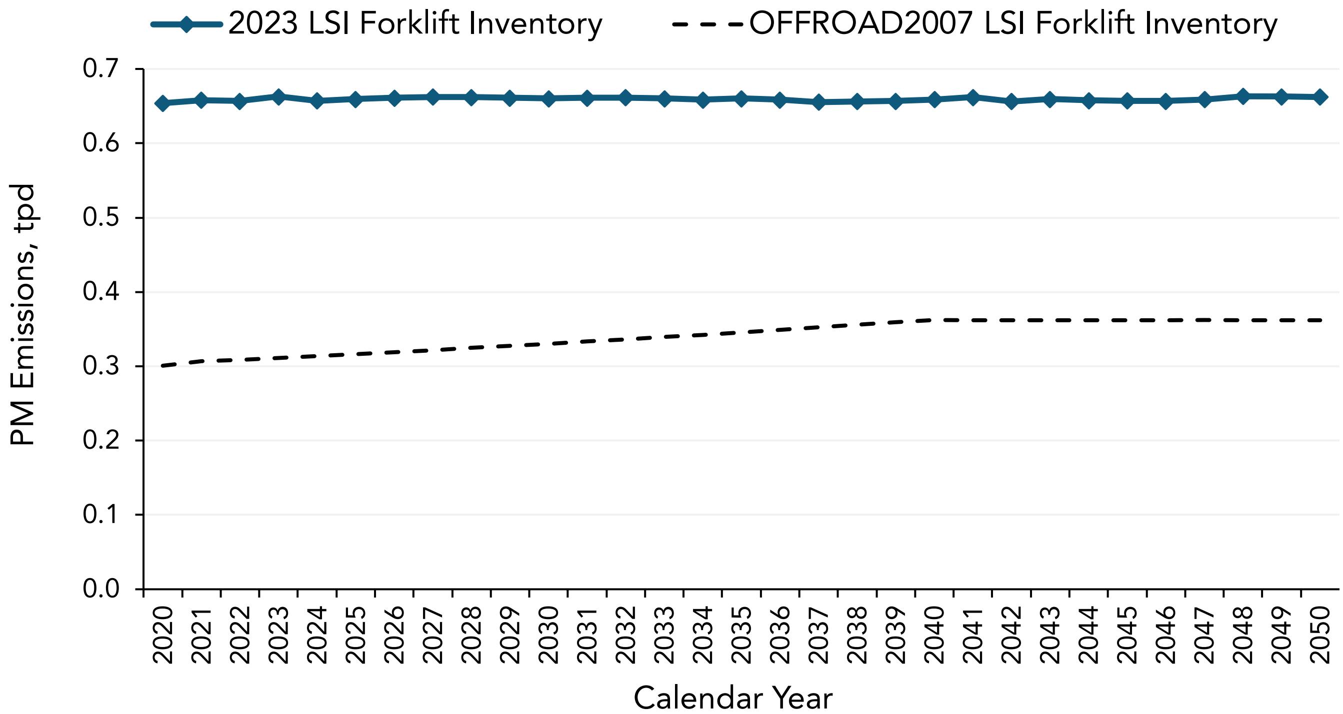


Figure 14. Statewide PM emissions from LSI forklifts projected out to 2050



6 Proposed Regulation

To phase out the use of LSI forklifts and accelerate the transition to zero-emission forklifts throughout the state, this inventory considers the impacts of forklifts subject to the requirements of the Proposed Regulation. The emission inventory provides data on the number of forklifts and fleets impacted by the Proposed Regulation, the emissions benefits, and informs the cost and health impacts analysis for the Proposed Regulation.

a. Statewide Fleet Operators

To determine the number of fleets operating LSI forklifts statewide, the DOORS Database for fleets of 4 or more was used, in addition to the statewide Fullerton Survey of forklift owners for fleets of 3 or less as noted in Table 7.

These distributions were applied to the final statewide populations of the inventory to estimate the total number of fleet operators statewide, as shown in Table 6. Note that in this table, the fleet size designations follow the Proposed Regulation for LSI forklifts, where small fleets are comprised of 25 or fewer forklifts.

Table 6. Statewide Forklift Fleets Overview

Fleet Size	LSI Fleet Size	Number of LSI Fleets	Percent of Fleets	Number of LSI Forklifts
Small Fleets	≤ 25 Forklifts	9,078	80.3%	32,415
Not-Small Fleets	> 25 Forklifts	2,232	19.7%	62,310
Total	**All Forklifts**	**11,310**	**100.0%**	**94,725**

Table 7. Estimate of Statewide fleets with 3 or less forklifts based on Fullerton Survey

Fleet Size	Number of Respondents	Reported Population	Percent of Forklifts	Inventory LSI Forklifts	Number of LSI Fleets
1	417	417	30.53%	4,393	4,393
2	254	508	37.19%	5,352	2,676
3	147	441	32.28%	4,646	1,549

b. Microbusiness

As seen in Table 6, there are approximately 11,310 LSI forklift fleets statewide. According to an analysis by CARB staff and described in Section 4.B of the ISOR (Form 399) for the Proposed Regulation, 98.5 percent of fleets are microbusinesses, or an estimated 11,140 LSI forklift fleets statewide. Beginning in 2031, all microbusiness fleets were modeled as keeping a single low-use (200 annual operating hours or less) LSI forklift indefinitely per the Proposed Regulation.

c. Lift Capacity and Slippage Assumptions

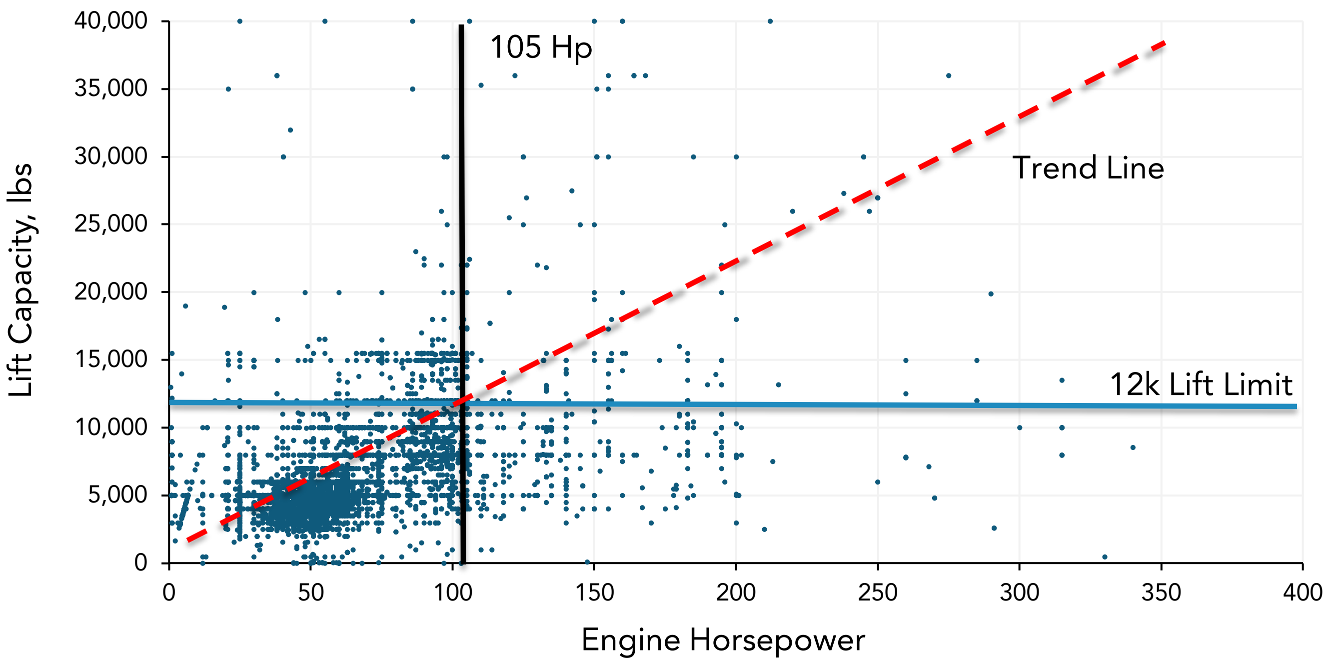
The Proposed Regulation applies to all Class IV forklifts and Class V forklifts up to a 12,000-pound lift capacity limit in the Proposed scenario (or up to 8,000-pound lift capacity in the Alternative Less Stringent scenario). Scenarios were modeled with the assumption that a fraction of businesses that currently use Class V LSI forklifts with a lift capacity just under the lift capacity exemption limit would choose to purchase LSI forklifts just over the 12,000-pound lift capacity limit. This modeling behavior was based on similar behavior observed in CARB's regulation for trailer Transport Refrigeration Units (TRUs), where approximately 40 percent of California TRU owners purchased TRUs that reduced or rerated horsepower, with an average reduction in horsepower of 32 percent. This shift in horsepower (slippage) allowed the TRUs to meet significantly less stringent emissions standards[12].

To understand the potential impact of slippage on forklifts operating statewide, CARB staff analyzed DOORS data to better define the relationship between lift capacity and engine horsepower of LSI forklifts reported into the system. Depicted in Figure 15, a total of 24,206 DOORS LSI forklifts had valid lift capacity and engine horsepower reported. Based on the reporting data summarized in Table 8, DOORS analysis results on forklift lift capacity and engine horsepower, a 12,000-pound lift capacity forklift had approximately 105 horsepower. Using TRUs as an example of shifting horsepower to avoid regulatory requirements, the regulatory scenario was modeled so that 40-percent of Class V forklifts between 71 and 105 horsepower would choose to purchase a 12,001 pound or greater lift capacity LSI forklift instead of switching their forklift to a zero-emission forklift. The cutoff of 71 horsepower was selected because (1) it corresponds to the median horsepower of an 8,000 to 9,000 pound lift capacity forklift, and (2) would result in a similar percentage shift in horsepower to avoid regulatory requirements as was seen in the TRU population.

Note that owners of smaller forklifts, under 8,000 pounds lift capacity, were not modeled as purchasing forklifts over 12,000 pounds lift capacity to avoid regulatory requirements. Although this is a possibility, the shift in size, weight, and cost of a low-capacity forklift to much higher capacity provides a barrier to this behavior. This modeling change results in owners of 4,090 Class V forklifts between 8,000 and 12,000 pounds lift capacity avoiding the regulatory requirements by buying (or in rare cases, converting an existing forklift) to a slightly larger LSI forklift. The emission impact of this change is the loss of approximately 0.6 tpd of NOx emission reductions starting in 2028, or about 6 percent of the total NOx emissions from all LSI forklifts in 2023 (10.4 tpd).

[12] California Air Resources Board, Appendix H of the Staff Report for the Proposed Amendments to the Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities Where TRUs Operate (Approved for Adoption on February 24, 2022): 2021 Update to Emissions Inventory for Transport Refrigeration Units, July 2021 (web link: *https://ww2.arb.ca.gov/sites/default/files/barcu/board/rulemaking/tru2021/apph.pdf*).

Figure 15. DOORS reported LSI forklifts by lift capacity and engine horsepower



The population of forklifts impacted by this exemption is noted below in Table 8. Note that all existing Class V forklifts over 12,000 lb lift capacity are exempted, but only 40 percent of the Class V forklifts between 8,000 and 12,000 lb lift capacity are expected to increase size to avoid other actions.

Table 8. DOORS analysis results on forklift lift capacity and engine horsepower

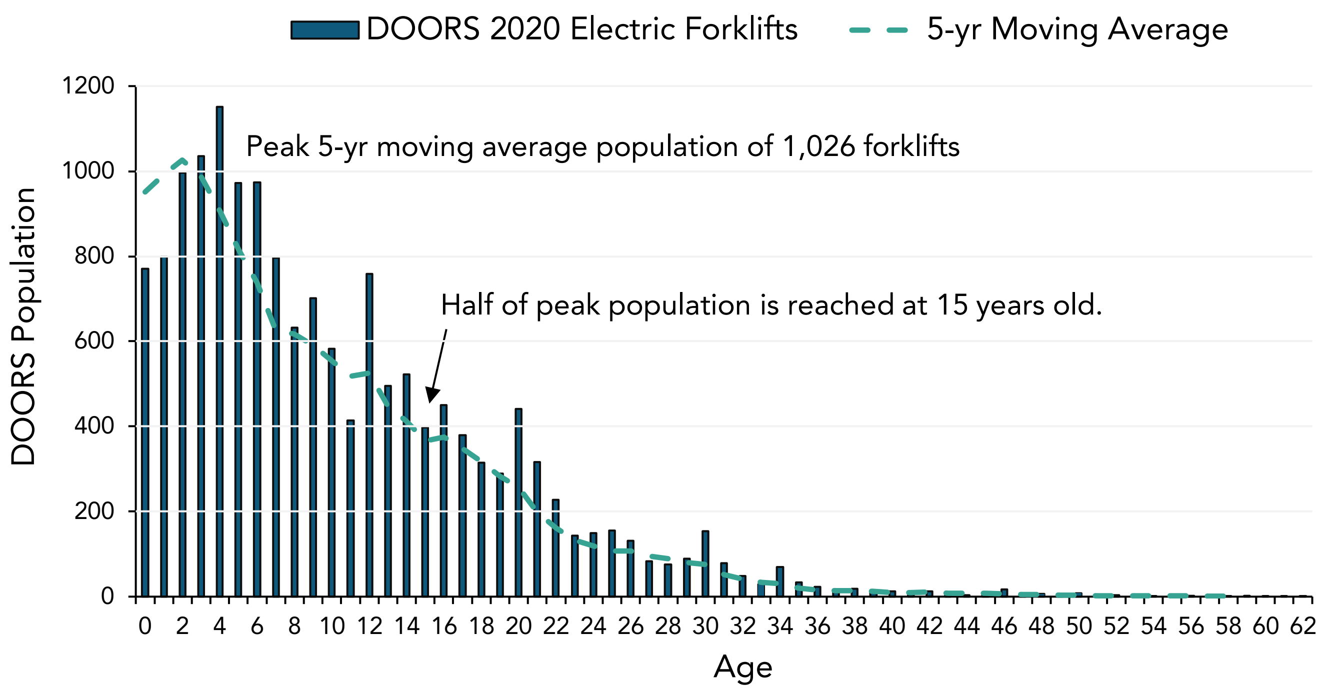
Lift Capacity	Percent of Forklift Population	HP Reg Cutoff	Slippage Range, HP
Over 8,000 lbs	13%	74	50.32 - 74
Over 12,000 lbs	3%	105	71.4 - 105

d. Useful Life of Electric Forklifts

The Proposed Regulation requires retirement of existing LSI forklifts from 2028 to 2038 (with exceptions for Class V based on lift capacity). Fleets were modeled so that each retired LSI forklift subject to the Proposed Regulation would be replaced with an electric forklift with a 15-year useful life. For example, each electric forklift purchased due to the Proposed Regulation would also require a replacement purchase 15 years later.

The 15-year useful life was based on the age distribution of the electric forklifts reported to CARB in DOORS. This age distribution is shown below in Figure 16. Fifteen years represents the median useful life of forklifts, or the age where 50-percent of the electric forklifts appear to be retired from service.

Figure 16. DOORS reported electric forklift population in base year 2020.



e. Emissions and Energy Impacts

Generally, electric forklifts will consume less power overall than a similar fueled forklift completing the same task. An Energy Economy Ratio (EER) of 3.8 was used for estimating the overall reduction in power consumed from an LSI to electric forklift[13], based on data from CARB's Low Carbon Fuel Standard equipment replacement programs. This EER value reflects that an electric forklift would consume 24 percent of the energy of an LSI forklift completing the same work.

Based on this EER value, CARB staff calculated the electric energy consumption of the electric forklifts required by the regulation based on the current consumption of propane or gasoline.

To complete the analysis, CARB staff converted LSI to a gasoline gallon equivalent (GGE), using conversion factors[14]. The conversion factor for LSI equipment powered by propane is 0.758 GGE and for or liquified natural gas 0.666 GGE. To estimate the power necessary from

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[13] California Air Resources Board, Low Carbon Fuel Standard (LCFS) Guidance 20-04: Requesting EER-Adjusted Carbon Intensity Using a Tier 2 Pathway Application, April 2020 (web link: *https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-04.pdf*).
[14] U.S. Department of Energy, Fuel Conversion Factors to Gasoline Gallon Equivalents (web link: *https://epact.energy.gov/fuel-conversion-factors*, last accessed August 2023).

the grid to charge electric forklifts replacing LSI forklifts due to the Proposed Regulation, as summarized in Figure 17, CARB staff used the following equation:

Energy Consumption, kWh = (Fuel Consumption in GPY * GGE Factor) * 126.858 MJ per gallon / 3.6 MJ to kWh / 4.22 EER for LSI to electric.

In the graph below, the solid area at the bottom represents the annual electricity demand from existing electric forklifts, and the top, striped area represents the additional annual electricity demand from electric forklifts that will be required by the Proposed Regulation over the course of implementation. The expected increase in gridded energy demand from electric forklifts after full implementation of the Proposed Regulation is 1,065 MWh, which is roughly 0.4 percent of the statewide gridded energy demand[15].

Figure 17. Proposed Regulation impact on gridded energy demand with full implementation

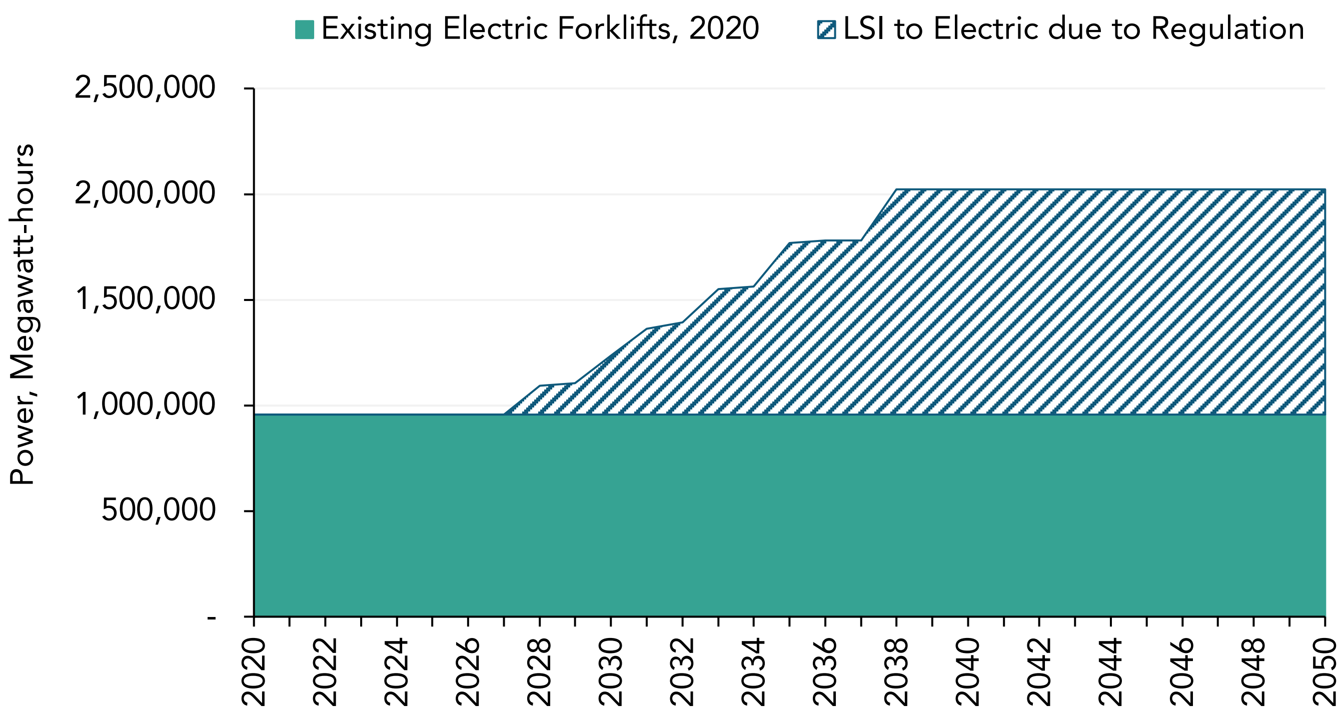


Figure 18 illustrates the LSI forklift inventory's expected NOx emissions under the Proposed Regulation, with Figure 20 comparing emissions with the 2023 LSI forklift base inventory update. Additionally, the transition to zero-emission forklifts under the Proposed Regulation

[15] California Energy Commission, 2021 Total System Electric Generation (web link: *https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2021-total-system-electric-generation#:~:text=Total%20system%20electric%20generation%20is,or%205%2C188%20GWh%2C%20from%202020*, last accessed October 2023).

results in reduced particulate emissions from statewide LSI forklifts over time, as shown in Figure 19.

Figure 18. Proposed Regulation impacts on NOx emissions from the LSI Forklift Inventory by fuel type

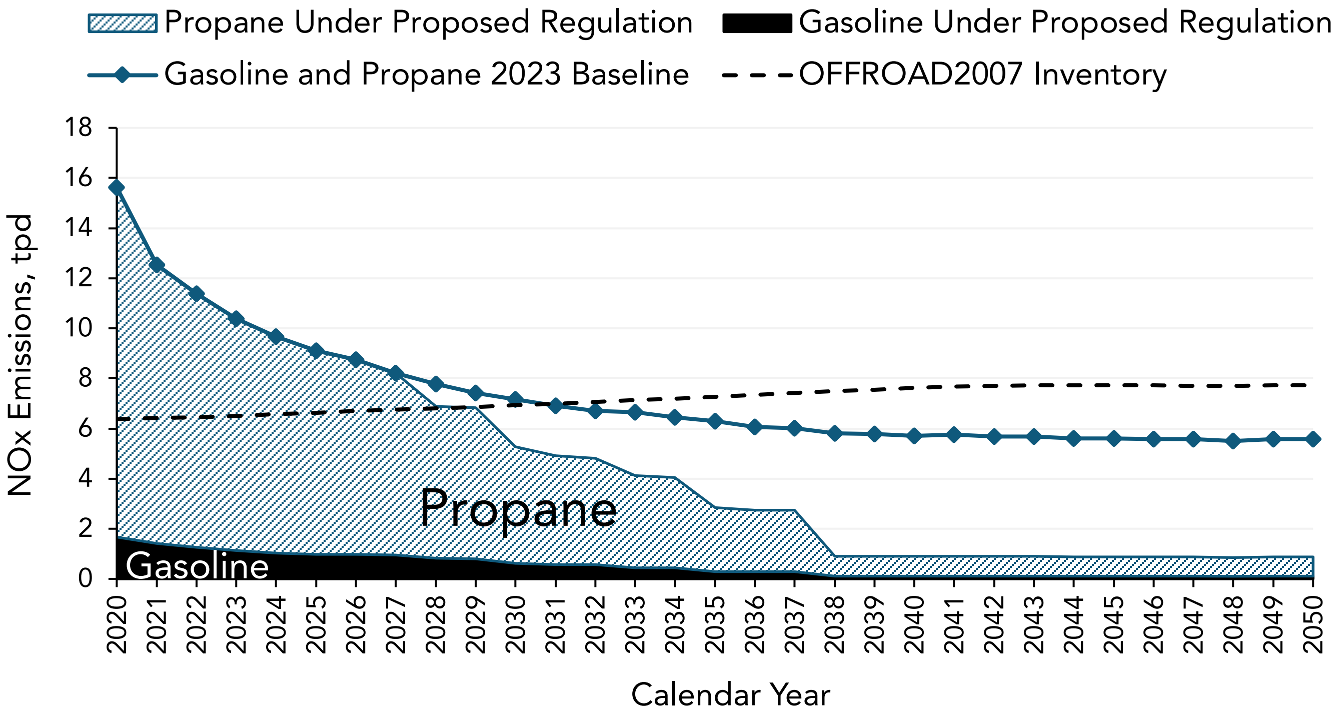


Figure 19. Proposed Regulation impacts on PM emissions from the LSI Forklift inventory by fuel type

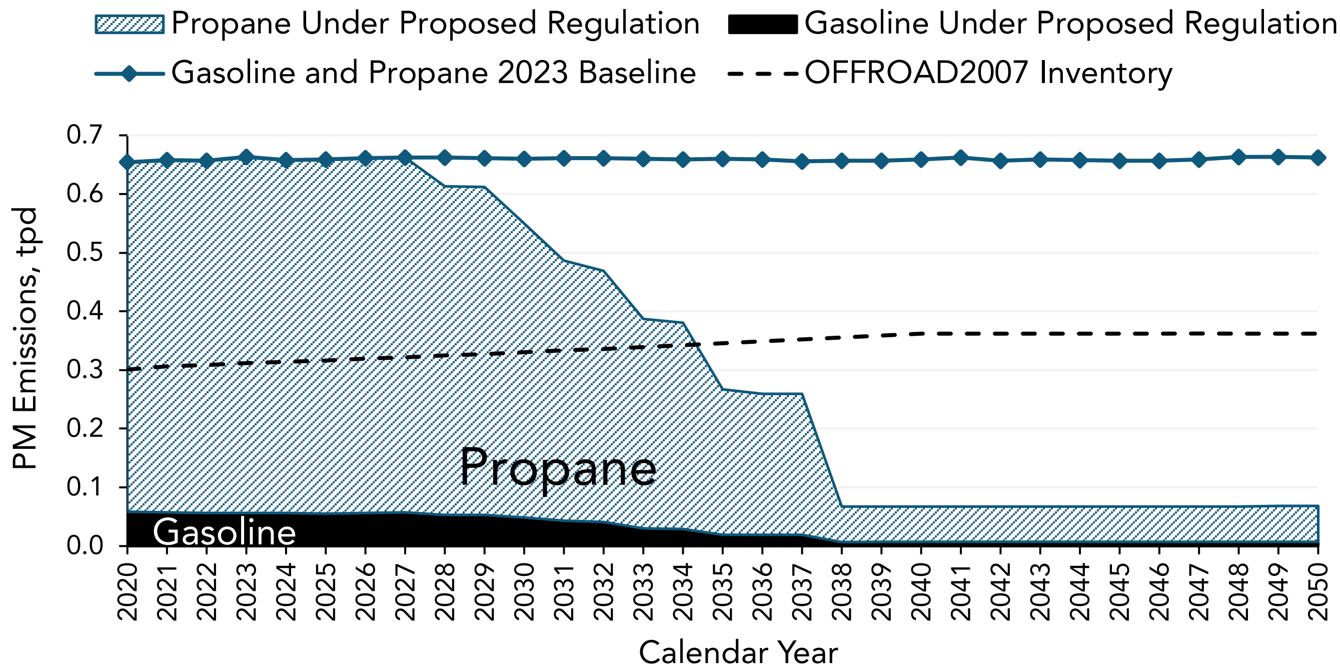
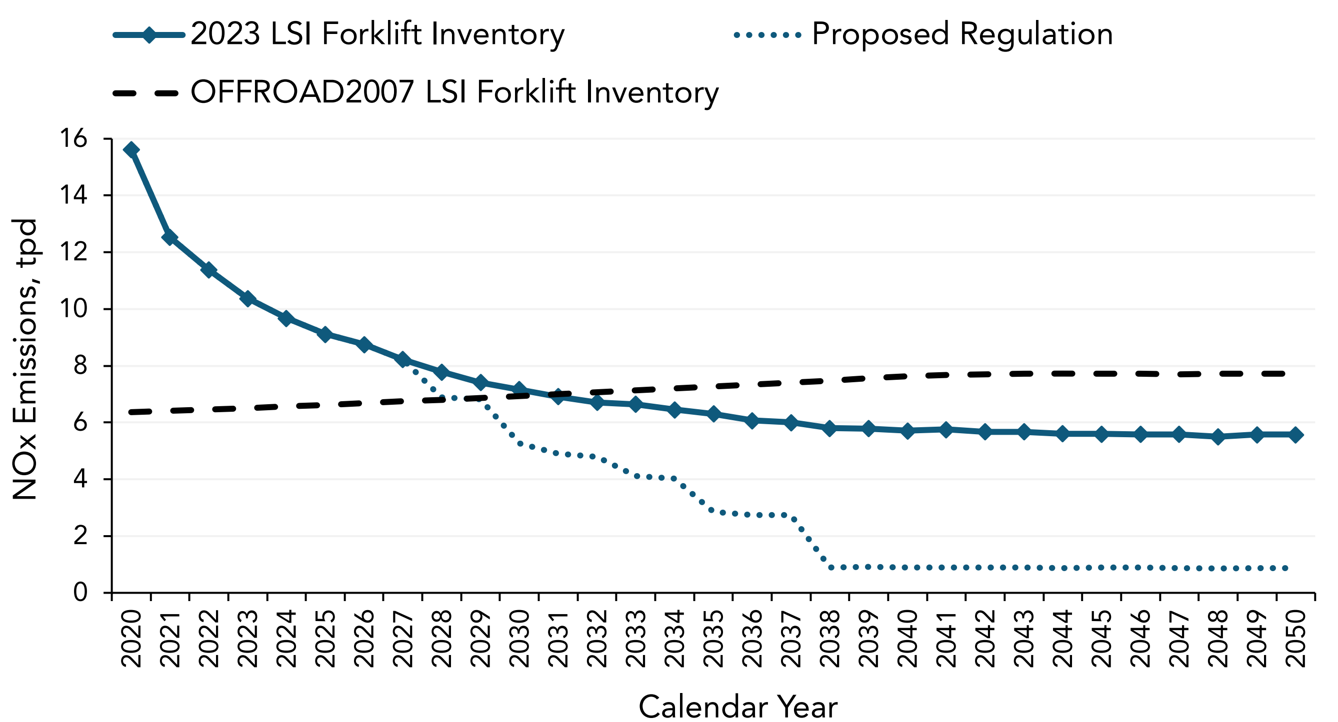


Figure 20. Proposed Regulation impacts on the total LSI Inventory



7 Appendix D.1

a. Emissions Result Tables

Table 9. Regional base year 2020 emissions from LSI forklifts

Year	Air District	LSI Forklift Population	NOx, tpd	PM, tpd	ROG, tpd
2020	Amador County APCD	69	0.0114	0.0005	0.0018
2020	Antelope Valley AQMD	558	0.0921	0.0039	0.0143
2020	Bay Area AQMD	23,514	3.8797	0.1623	0.6022
2020	Butte County AQMD	285	0.0470	0.0020	0.0073
2020	Calaveras County APCD	24	0.0040	0.0002	0.0006
2020	Colusa County APCD	67	0.0110	0.0005	0.0017
2020	Eastern Kern APCD	159	0.0262	0.0011	0.0041
2020	El Dorado County APCD	190	0.0314	0.0013	0.0049
2020	Feather River AQMD	164	0.0271	0.0011	0.0042
2020	Glenn County APCD	40	0.0066	0.0003	0.0010
2020	Great Basin Unified APCD	21	0.0035	0.0001	0.0005
2020	Imperial County APCD	70	0.0116	0.0005	0.0018
2020	Lake County APCD	24	0.0039	0.0002	0.0006
2020	Lassen County APCD	1	0.0002	0.0000	0.0000
2020	Mariposa County APCD	7	0.0012	0.0000	0.0002
2020	Mendocino County APCD	186	0.0307	0.0013	0.0048
2020	Modoc County APCD	1	0.0002	0.0000	0.0000
2020	Mojave Desert AQMD	397	0.0654	0.0027	0.0102
2020	Monterey Bay Unified APCD	1,060	0.1749	0.0073	0.0271
2020	North Coast Unified AQMD	160	0.0264	0.0011	0.0041
2020	Northern Sierra AQMD	140	0.0231	0.0010	0.0036
2020	Northern Sonoma County APCD	331	0.0546	0.0023	0.0085
2020	Placer County APCD	489	0.0806	0.0034	0.0125
2020	Sacramento Metropolitan AQMD	1,563	0.2579	0.0108	0.0400
2020	San Diego County APCD	7,851	1.2954	0.0542	0.2011
2020	San Joaquin Valley Unified APCD	7,759	1.2803	0.0536	0.1987
2020	San Luis Obispo County APCD	535	0.0882	0.0037	0.0137
2020	Santa Barbara County APCD	914	0.1508	0.0063	0.0234
2020	Shasta County AQMD	174	0.0287	0.0012	0.0045
2020	Siskiyou County APCD	55	0.0090	0.0004	0.0014
2020	South Coast AQMD	44,643	7.3660	0.3082	1.1434
2020	Tehama County APCD	168	0.0277	0.0012	0.0043
2020	Tuolumne County APCD	56	0.0093	0.0004	0.0014
2020	Ventura County APCD	2,280	0.3762	0.0157	0.0584

Year	Air District	LSI Forklift Population	NOx, tpd	PM, tpd	ROG, tpd
2020	Yolo/Solano AQMD	770	0.1270	0.0053	0.0197

b. Exhaust Zero-Hour Emissions Factors and Deterioration Rates

Table 10. Gasoline equipment exhaust emissions factors

Engine Model Years	HP Bin	NOx, Zero Hour	NOx, DR	PM, Zero Hour	PM, DR	THC, Zero Hour	THC, DR	CO, Zero Hour	CO, DR
1995	Up to 25	2.32	0.000000	0.14	0.000200	4.42	0.010000	243.17	0.030000
2001	50	6.91	0.000144	0.06	0.000000	2.96	0.000348	78.09	0.020000
2001	75	8.24	0.000154	0.06	0.000000	2.52	0.000302	59.58	0.010000
2001	100	9.58	0.000163	0.06	0.000000	2.08	0.000256	41.08	0.004000
2001	Over 100	10.29	0.000109	0.06	0.000000	1.33	0.000040	20.80	0.000815
2002	50	5.52	0.000308	0.06	0.000000	2.34	0.000374	81.78	0.010000
2002	75	6.42	0.000287	0.06	0.000000	1.94	0.000300	60.75	0.010000
2002	100	7.32	0.000266	0.06	0.000000	1.54	0.000225	39.72	0.004550
2002	Over 100	7.64	0.000092	0.06	0.000000	1.06	0.000038	20.80	0.000815
2003	50	4.52	0.000402	0.06	0.000000	1.62	0.000316	71.03	0.010000
2003	75	4.79	0.000385	0.06	0.000000	1.30	0.000255	54.69	0.010000
2003	100	5.06	0.000368	0.06	0.000000	0.99	0.000194	38.36	0.005100
2003	Over 100	4.98	0.000074	0.06	0.000000	0.78	0.000036	20.80	0.000815
1950-1994	Up to 25	3.48	0.001090	0.14	0.000200	7.46	0.010000	393.10	0.020000
1950-2000	50	8.01	0.000041	0.06	0.000000	3.76	0.000412	89.90	0.005550
1950-2000	75	9.92	0.000050	0.06	0.000000	3.19	0.000350	66.85	0.004230
1950-2000	100	11.84	0.000060	0.06	0.000000	2.63	0.000287	43.80	0.002900
1950-2000	Over 100	12.94	0.000127	0.06	0.000000	1.61	0.000042	20.80	0.000815
1996-2001	Up to 25	2.32	0.000000	0.14	0.000200	4.42	0.010000	283.69	0.030000
2002-2008	Up to 25	2.68	0.003210	0.14	0.000200	4.12	0.004950	238.46	0.000000
2004-2006	50	1.33	0.000471	0.06	0.000000	0.71	0.000169	38.19	0.010000
2004-2006	75	1.55	0.000339	0.06	0.000000	0.48	0.000125	23.47	0.010000
2004-2006	100	1.78	0.000207	0.06	0.000000	0.26	0.000081	8.76	0.005650
2004-2006	Over 100	1.94	0.000278	0.06	0.000000	0.16	0.000102	20.80	0.000815
2007-2009	50	0.88	0.000119	0.06	0.000000	0.47	0.000064	9.54	0.002780
2007-2009	75	1.02	0.000093	0.06	0.000000	0.30	0.000069	5.95	0.001400
2007-2009	Over 75	1.17	0.000066	0.06	0.000000	0.13	0.000074	2.37	0.000019
2009-2050	Up to 25	1.71	0.003240	0.14	0.000200	2.64	0.003360	238.46	0.000000
2010-2050	50	0.26	0.000025	0.06	0.000000	0.14	0.000013	9.54	0.004900
2010-2050	75	0.30	0.000028	0.06	0.000000	0.08	0.000014	5.95	0.003750
2010-2050	Over 75	0.35	0.000030	0.06	0.000000	0.03	0.000014	2.37	0.002600

Table 11. Propane and natural gas equipment exhaust emissions factors

Engine Model Years	HP Bin	NOx, Zero Hour	NOx, DR	PM, Zero Hour	PM, DR	THC, Zero Hour	THC, DR	CO, Zero Hour	CO, DR
2001	50	10.40	0.000156	0.06	0.000000	1.16	0.000159	7.02	0.000475
2001	75	9.47	0.000151	0.06	0.000000	1.22	0.000166	13.37	0.000908
2001	100	8.54	0.000146	0.06	0.000000	1.28	0.000172	19.72	0.001340
2001	Over 100	8.53	0.000091	0.06	0.000000	1.16	0.000036	16.47	0.000862
2002	50	7.79	0.000245	0.06	0.000000	0.93	0.000166	7.02	0.000475
2002	75	7.17	0.000242	0.06	0.000000	0.97	0.000171	13.37	0.000908
2002	100	6.56	0.000239	0.06	0.000000	1.02	0.000175	19.72	0.001340
2002	Over 100	6.54	0.000078	0.06	0.000000	0.94	0.000036	16.47	0.000862
2003	50	5.19	0.000335	0.06	0.000000	0.71	0.000174	7.02	0.000475
2003	75	4.88	0.000333	0.06	0.000000	0.73	0.000176	13.37	0.000908
2003	100	4.57	0.000331	0.06	0.000000	0.75	0.000178	19.72	0.001340
2003	Over 100	4.56	0.000065	0.06	0.000000	0.71	0.000036	16.47	0.000862
1950-1994	Up to 25	1.77	0.000441	0.09	0.000094	3.96	0.004120	240.00	0.010000
1950-2000	50	13.00	0.000066	0.06	0.000000	1.38	0.000151	7.02	0.000475
1950-2000	75	11.76	0.000060	0.06	0.000000	1.46	0.000160	13.37	0.000908
1950-2000	100	10.53	0.000053	0.06	0.000000	1.55	0.000169	19.72	0.001340
1950-2000	Over 100	10.51	0.000104	0.06	0.000000	1.38	0.000035	16.47	0.000862
1995-1998	Up to 25	8.44	0.000441	0.90	0.000094	1.56	0.004120	300.00	0.010000
1999-2050	Up to 25	2.70	0.000441	0.25	0.000094	0.50	0.004120	100.00	0.010000
2004-2006	50	1.95	0.000276	0.06	0.000000	0.14	0.000106	7.02	0.000475
2004-2006	75	1.76	0.000313	0.06	0.000000	0.15	0.000105	13.37	0.000908
2004-2006	100	1.58	0.000350	0.06	0.000000	0.16	0.000103	19.72	0.001340
2004-2006	Over 100	1.58	0.000264	0.06	0.000000	0.14	0.000106	16.47	0.000862
2007-2009	50	1.30	0.000001	0.06	0.000000	0.09	0.000172	2.37	0.000019
2007-2009	75	1.17	0.000007	0.06	0.000000	0.09	0.000109	2.37	0.000019
2007-2009	Over 75	1.04	0.000013	0.06	0.000000	0.10	0.000047	2.37	0.000019
2010-2050	50	0.39	0.000000	0.06	0.000000	0.02	0.000036	7.02	0.000475
2010-2050	75	0.35	0.000019	0.06	0.000000	0.02	0.000025	4.69	0.001540
2010-2050	Over 75	0.31	0.000038	0.06	0.000000	0.03	0.000014	2.37	0.002600

Table 12. Evaporative emissions factors applied to gasoline-powered forklifts

Engine Model Years	Engine Horsepower	HC EF, Hot Soak (grams per start)	HC EF, Diurnal (grams per day)	HC EF, Resting Loss (grams per day)	HC EF, Running Loss (grams per hour)	TOG Ratio of HC	ROG Ratio of HC
Pre-1997	All	10.5	30.61	5.4	4.61	1.04	1.04
1997-2003	All	10.5	30.61	5.4	4.61	1.12	1.12
2004-2005	Up to 25	10.5	30.61	5.4	4.61	1.14	1.14
2006-2050	Up to 25	1.05	1.158	0.651	0.922	1.14	1.14
2004-2050	Over 25	10.5	30.61	5.4	4.61	1.14	1.14