California Air Resources Board's 2022 Class I Switcher Rail Yard Emission Inventory

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CALIFORNIA AIR RESOURCES BOARD

Contents

Figures

Tables

1. CARB's 2022 Class I Switcher Rail Yard Emission Inventory

The California Air Resources Board's (CARB) 2022 Class I Switcher Rail Yard Emission Inventory represents Union Pacific Railroads (UP) and BNSF Railway (BNSF) rail yard activity in California. Switchers are used in and around California's Class I rail yards to move individual railcars or segments of trains. The switcher locomotives work to assemble railroad cars ensuring they are ready for locomotive hauling or disassemble cars that arrive so they can be sorted and stored. This is referred to as 'switching' and the locomotives that perform these operations are called switchers. Switchers are either a locomotive designed for switching work and have lower horsepower than line haul locomotives, or they may be former line haul locomotives removed from long haul service and operating at rail yards.

Switchers in this inventory represent those locomotives operated by UP and BNSF at the 28 Class I rail yards in California. Smaller railroads that have switching activity are included in CARB's short line inventory[1].

These Class I switcher rail yard operations, combined with Line haul (Class I), Short line (Class III), Passenger, and Industrial rail make up California's statewide locomotive emission inventory. Currently, Class I rail yard-produced NOx emissions represent a small portion, approximately 5 percent, of all locomotive NOx emissions in California. However, if dirtier locomotives in the other rail sectors are replaced with cleaner ones, the portion attributed to Class I switcher rail yard emissions will grow.

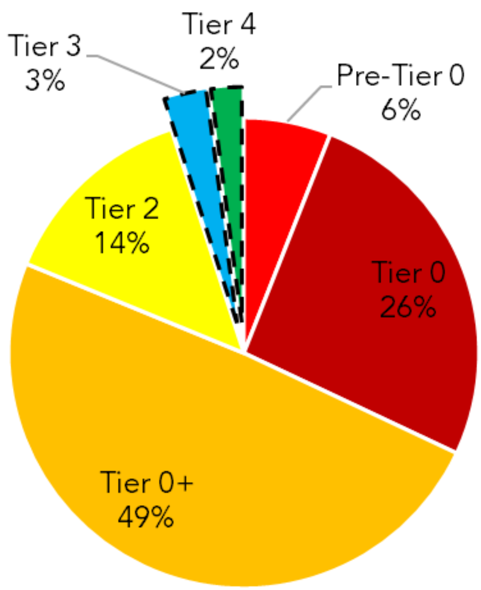
Rail yards are situated in strategic locations, such as near California's ports and industrial areas, so they can link major rail tracks and move cars from smaller regional rail lines to larger national rail lines. The switcher locomotive fleet is not captive, meaning they move all over California, wherever needed, and do not permanently reside at a particular rail yard. The switchers in this inventory are based at 16 UP and 12 BNSF operating rail yards in California, working with a range of conditions and operating hours.

2. Data

CEA Consulting (CEA), the consulting company representing both BNSF and UP, provided CARB with 2017 rail yard data in two parts. First, is a combined statewide tier distribution for both rail companies, shown in Figure 1. Only 5 percent of the statewide switcher locomotives are newer and cleaner Tier 3 or Tier 4 engines, while 80 percent of the state's operating switchers are very old and high emitting Pre-Tier 0, Tier 0, and Tier 0+ locomotives.

[1] CARB's 2017 Short line Emission Inventory Documentation https://ww3.arb.ca.gov/msei/ordiesel/locoshortline2017ei.docx

Figure 1: Statewide 2017 Switcher Tier Distribution



Second, CEA provided each rail yard's number of full-time equivalent (FTE) locomotives. Table 1 lists California's rail companies and their respective rail yards.

Table 1: California Class I Rail yards

BNSF	UP
Bakersfield	Bakersfield
Barstow	Benicia
Fresno	City of Industry
Los Angeles	Fresno
Richmond	LATC
Riverbank	Los Angeles
San Bernardino	Mira Loma
San Diego	Oakland
Stockton	Oakland South
Thenard	Ozol
Vernon	Polk
Watson	Roseville
	South San Francisco
	Stockton
	West Colton
	West Sacramento

FTE is equal to one switcher locomotive operating 24 hours per day, 365 days per year. FTE values at each yard are calculated based on the list of yard jobs (work assignments) at each yard, the number of physical locomotives required for each job, and the hours per day and days per week for each job. To calculate FTE, the total annual locomotive-hours for each yard is divided by 8,760 (8,760 = 24 hours per day x 365 days per year). This is a unitless value that represents FTE Locomotives. To calculate estimated fuel consumption, FTE is multiplied by 82,490 (U.S. EPA assumes that 1 FTE consumes 82,490 gallons of fuel per year[2]).

The combined statewide tier distribution and FTE rail yard data is the foundation of CARB's switcher rail yard emissions inventory, with 2017 as the base year.

3. Activity

Switcher rail yard activity is based on UP and BNSF reported 2017 FTE activity, converted to annual fuel consumption. The U.S. EPA switch locomotive emission factors are based on fuel use, so no adjustment or shift to annual hours is needed in the inventory. The inventory relies on this fuel-based metric for activity and emissions calculation.

4. Growth

The inventory reflects a growth in operations and fuel use of 2.19 percent annually, which is based on freight activity growth estimates for the locomotive sector and is consistent with fuel growth rates calculated in CARB's 2021 Line haul emission inventory[3]. Since line haul traffic flows through rail yards, the switcher inventory assumes rail yards have the same fuel growth rate as line haul locomotives. If the railroads perform significant shifts in operations (i.e., breaking down and assembling fewer trains), then switcher growth rates could differ from line haul growth. However, there is currently no data showing this is happening in a coordinated manner.

5. Equipment Population & Turnover

Switcher locomotives are not captive, which means they are not assigned to one specific rail yard and may be transferred to other yards, as needed. Thus, the tier makeup at any given rail yard may change. As such, UP and BNSF provided an aggregated switcher tier distribution for the entire state that encompasses all rail yards. This data confirms that switchers tend to be older locomotives with approximately 80 percent being Tier 0+ or older, and only 5 percent are Tier 3 or newer.

The supplied data suggests switcher locomotives do not have typical equipment turnover practices. Therefore, the inventory does not assume switchers will turnover to newer and

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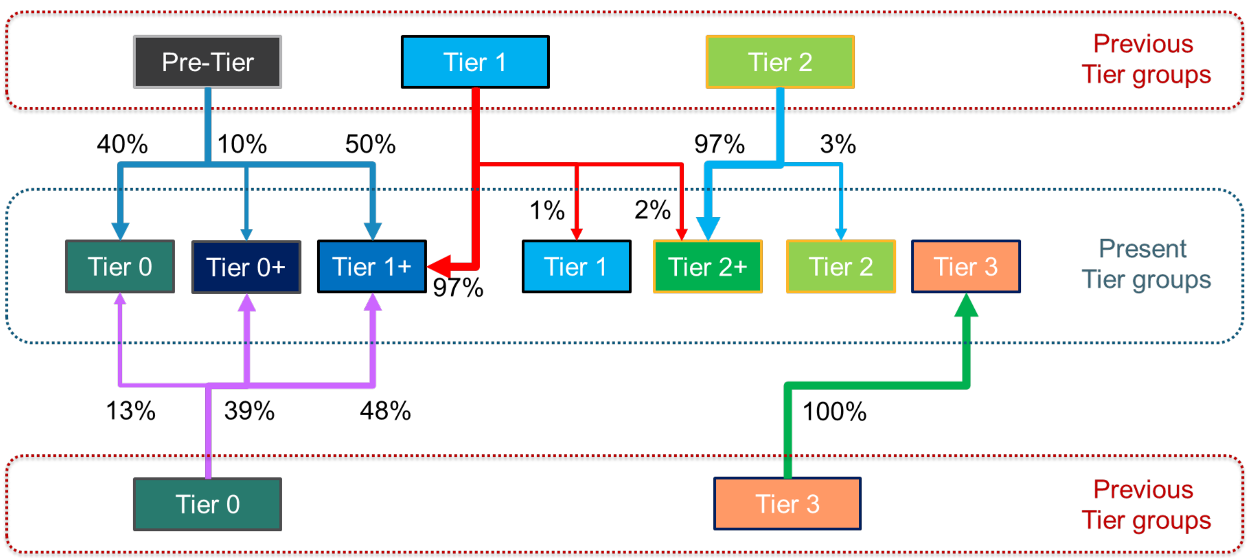
[2] Source: Procedures for Emission Inventory Preparation - Vol IV: Mobile Sources; Publication EPA420-R-92-009, December 1992, p. 207

[3] CARB's 2021 Line haul Emission Inventory Documentation https://ww2.arb.ca.gov/sites/default/files/2021-02/2021_line_haul_locomotive_emission_inventory_final.pdf

cleaner models in the normal course of business, with some exceptions described below. Furthermore, UP and BNSF have not suggested they have plans for future locomotive turnover.

Lack of turnover is further supported by analysis in CARB's 2021 line haul emissions inventory. Figure 2 maps observed turnover practices according to tier from a study of South Coast locomotives between 2010 and 2018. Tier turnover practices are traced according to activity. When Tier 0 locomotives approach replacement age, about 13 percent are rebuilt as Tier 0, 39 percent are remanufactured as Tier 0+, and nearly half are remanufactured as Tier 1+. Considering switch locomotives are currently very old and current railroad practices can move retired line haul locomotives into switching service, along with evidence that a significant portion of Tier 0 South Coast locomotives remain as Tier 0 or Tier 0+, the switcher inventory assumes no turnover.

Figure 2: South Coast Line haul Activity Tier Transition for Remanufacturing[4]



6. Switcher Emissions Factors

This inventory uses the U.S. EPA emission factors reference guide and locomotive conversion factors according to locomotive type (large line haul, small line haul, passenger, and switcher). Table 2 lists the U.S. EPA switcher emission factors, measured in grams per brake horsepower-hour (g/bhp-hr). These values are multiplied by the switcher conversion factor of 15.2 break horsepower-hour per gallon fuel (bhp-hr/gal). This multiplication converts emissions to gram of pollutant per gallon of diesel consumed (g/gal).

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[4] Figure taken from CARB's 2021 Line haul Emission Inventory Documentation https://ww2.arb.ca.gov/sites/default/files/2021-02/2021_line_haul_locomotive_emission_inventory_final.pdf

Table 2: Switcher Emission Factors (g/bhp-hr)[5]

	PM10	HC	NOx	CO
Pre-Tier	0.44	1.01	17.40	1.83
Tier 0	0.44	1.01	12.60	1.83
Tier 0+	0.23	0.57	10.60	1.83
Tier 1	0.43	1.01	9.90	1.83
Tier 1+	0.23	0.57	9.90	1.83
Tier 2	0.19	0.51	7.30	1.83
Tier 2+	0.11	0.26	7.30	1.83
Tier 3	0.08	0.26	4.50	1.83
Tier 4	0.015	0.08	1.00	1.83

For fine particulate matter ($PM_{2.5}$), total pm (PM), total organic gases (TOG), reactive organic gases (ROG), ammonia (NH_3), and carbon dioxide (CO_2), the emission factors are based on the conversions for off-road diesel fuel. The $PM_{2.5}$ emissions are equal to 92 percent of PM_{10}, and the emissions for total PM and PM_{10} are equivalent[6]. Using factors conventional for diesel fuel, the emission factor for total organic gases (TOG) is 1.44 times the emission factor for hydrocarbons (HC), and the emission factor for reactive organic gases (ROG) is 1.21 times the emission factor for hydrocarbons (HC)[7]. The emission factor for NH_3 is 0.0833 g/gal, independent of tier. CO_2 is defined by U.S. EPA as 10,206 g CO_2/gal. Equation 1 provides the combined conversion factor equations.

Equation 1: Additional Emission Conversion Equations

$$PM_{2.5} = 0.92 \times PM_{10}$$

$$PM = PM_{10}$$

$$TOG = 1.44 \times HC$$

$$ROG = 1.21 \times HC$$

$$NH_3 = 0.0833 \left(\frac{\mathrm{g}}{\mathrm{gal}}\right) \times Fuel(gal)$$

$$CO_2 = 10{,}206 \left(\frac{\mathrm{g}}{\mathrm{gal}}\right) \times Fuel(gal)$$

[5] Emission Factors for Locomotives, EPA 420-F-09-025, U.S. EPA, April 2009.
[6] https://ww3.arb.ca.gov/msei/ordiesel/pm25_pm10reference.pdf
[7] https://ww3.arb.ca.gov/msei/ordiesel/rog_tog_hcratio.xlsx

A. Sulfur Adjustment Factor

The sulfur content of diesel fuel affects PM emissions. Equation 2 provides the U.S. EPA equation to quantify the amount of sulfur that needs to be reduced based on the difference between the default sulfur fuel content and the episodic sulfur fuel content[8].

Equation 2: U.S. EPA Sulfur Adjustment Equation

$$S_{\mathrm{PM\ adj}} = \mathrm{BSFC} * 453.6 * 7.0 * \mathrm{soxcnv} * 0.01 * (\mathrm{soxbas} - \mathrm{soxdsl})$$

where:

BSFC = fuel consumption (lb fuel/hp-hr)

453.6 = conversion from lb to grams

7.0 = grams PM sulfate/grams PM sulfur

soxcnv = grams PM sulfur/grams fuel sulfur consumed

0.01= conversion from percent to fraction

soxbas = default certification fuel sulfur weight percent

soxdsl = episodic fuel sulfur weight percent (specified by user)

The SO_x conversion rate (soxcnv) is the amount of sulfur from the diesel fuel that gets converted to PM, specific to an engine's certification. For engines rated below Tier 4, the SO_x conversion rate is 0.02247. The SO_x conversion rate for Tier 4 engines is 0.30.

The sulfur PM adjustment is subtracted from the PM emissions in Equation 3, which yields the corrected PM emissions.

Equation 3: PM Adjusted Emission Calculation

$$PM_{adj} = PM - S_{\mathrm{PM\ adj}}$$

B. Diesel Fuel Adjustment

California has its own standards for diesel fuel, known as CARB diesel, which is an ultra-low sulfur diesel fuel that reduces NO_x emissions by 6 percent and PM emissions by 14 percent[9] compared to national off-road diesel averages. Table 3 shows the sulfur content in fuel by calendar year. Beginning in 2007, CARB regulation required all California locomotives to use CARB diesel with a sulfur fuel content (soxdsl) measuring no more than 500 ppm (parts per

[8] Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression-Ignition, EPA-420-R-10-018, U.S. EPA, July 2010.

[9] Diesel Fuel Effects on Locomotive Exhaust Emissions, *https://www.arb.ca.gov/fuels/diesel/102000swri_dslemssn.pdf*, 2000.

million)[10]. This was a dramatic reduction from the previous sulfur fuel content of 3000 ppm. In 2012, California required the sulfur content in diesel fuel to be further reduced to less than 15 ppm.

Table 3: Diesel Fuel Sulfur Content

Calendar Year	Sulfur Content
Prior to 2007	3000 ppm
2007	500 ppm
2012	15 ppm

This information is utilized in calculating the sulfur adjustments in Equation 2. The term soxbas represents the diesel sulfur content that was reported based on the engine certification level. For example, in 2012, the diesel sulfur content is no more than 15ppm (soxdsl), but a Tier 2 engine (2005 to 2011 Model Year) has an engine certified for 3000 ppm (soxbas). Thus, Equation 2 will make adjustments to reduce the sulfur content.

C. SOx Emissions

The U.S. EPA provides Equation 4, a fuel consumption-based formula SO_2 emissions[11]. This equation adjusts according to the fuel's sulfur content and the engine certification.

Equation 4: U.S. EPA SO_2 Emission equation

$$SO_2 = [BSFC * 453.6 * (1 - soxcnv) - HC] * 0.01 * soxdsl * 2$$

where:

BSFC = fuel consumption (lb fuel/hp-hr)

453.6 = the conversion factor from pounds to grams

soxcnv = the fraction of fuel sulfur converted to direct PM

HC = the in-use adjusted hydrocarbon emissions in g/hp-hr

0.01 = the conversion factor from weight percent to weight fraction

soxdsl = the episodic weight percent of sulfur in nonroad diesel fuel

2 = the grams of SO2 formed from a gram of sulfur

[10] Proposed Extension of the California Standards For Motor Vehicle Diesel Fuel to Diesel Fuel Used For Intrastate Diesel-Electric Locomotives and Harborcraft, California Air Resources Board, https://www.arb.ca.gov/regact/carblohc/rfro.pdf, 2004.

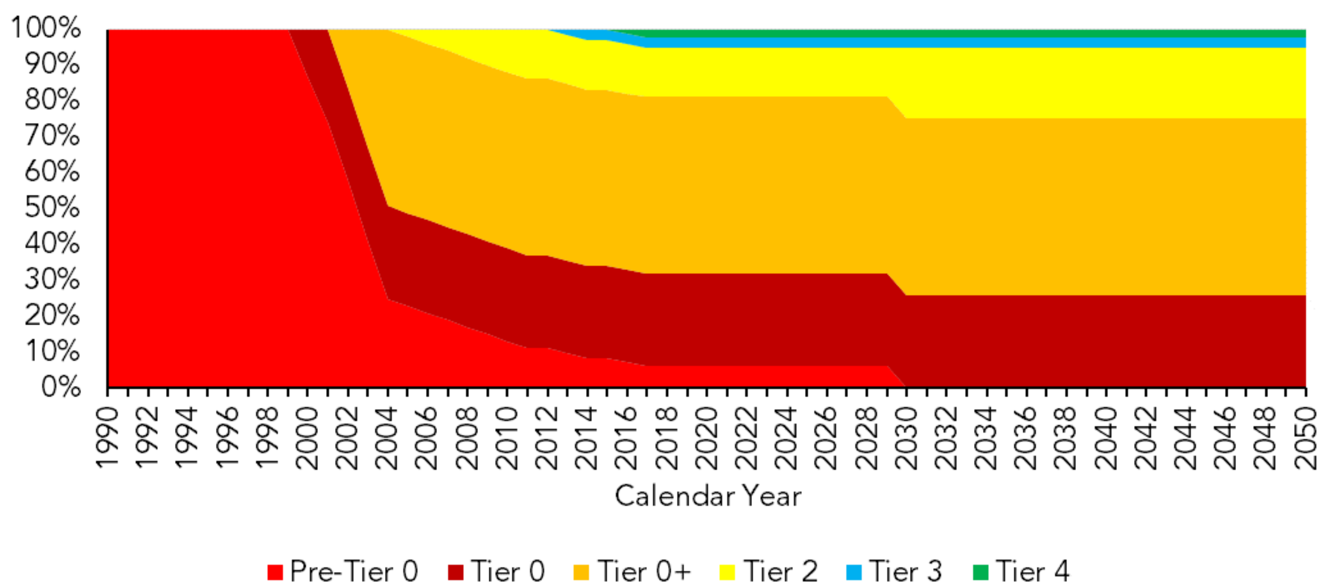
[11] Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression-Ignition, EPA-420-R-10-018, U.S. EPA, July 2010.

7. Results

CARB's 2022 Switcher Rail Yard Emissions Inventory was developed using 2017 base year data supplied by BNSF and UP, to include rail yard specific fuel consumption and FTE locomotive estimates along with statewide aggregated locomotive tier distribution. The combined statewide tier distribution was applied to all rail yards after discussion with the railroads indicated switchers are not permanently assigned to one specific rail yard and move around the state as needed. This distribution is also unlikely to vary significantly between rail yards as nearly all switcher locomotives tend to be older locomotives.

As depicted in Figure 3, the switcher inventory assumes all locomotives begin in 1990 as Pre-Tier 0, as locomotive tier standards had not yet been introduced. These locomotives are replaced according to the tier introduction calendar timeline and build up to the base year 2017 tier distribution. For example, Tier 2 locomotives are introduced in 2005, Tier 3 are introduced in 2013, and Tier 4 are introduced in 2016. These assumptions meet the tier distribution submittal for calendar year 2017. In 2030, the inventory replaces the remaining portion of Pre-Tier locomotives with Tier 2 locomotives assuming they have reached their end-of-life.

Figure 3: Percent Share of Statewide FTE Locomotives



Switchers operate within a rail yard, so their associated emissions are dispersed locally. Fuel growth is assumed to increase at 2.19 percent per year, which is the same rate applied to

CARB's 2021 Line haul Locomotive Emission Inventory and discussed in greater detail in that inventory[12].

The following figures display switcher rail yard emissions from 1990 to 2050, comparing the new 2022 inventory results to the previous inventory. Only results of the previous Switcher Rail Yard inventory, from 2000 to 2035, are available.

Figure 4 compares NOx emissions from the previous inventory (dark blue line) to the new 2020 inventory's emissions by tier. The 2022 inventory results show NOx emissions are increasing, with slight dip in 2000 when it is assumed some Pre-Tier 0 locomotives are replaced with Tier 0 locomotives. Then, there is a constant increase in NOx over time, with a slight dip in 2030 when the Pre-Tier portion is replaced with Tier 2 locomotives. The steady growth reflects the 2.19 percent fuel growth and absence of locomotive turnover to cleaner technologies. The previous inventory shows a decline in NOx over time, with a significant drop from 2007 to 2010 and then a steady decline.

Figure 4: Statewide NOx Emissions

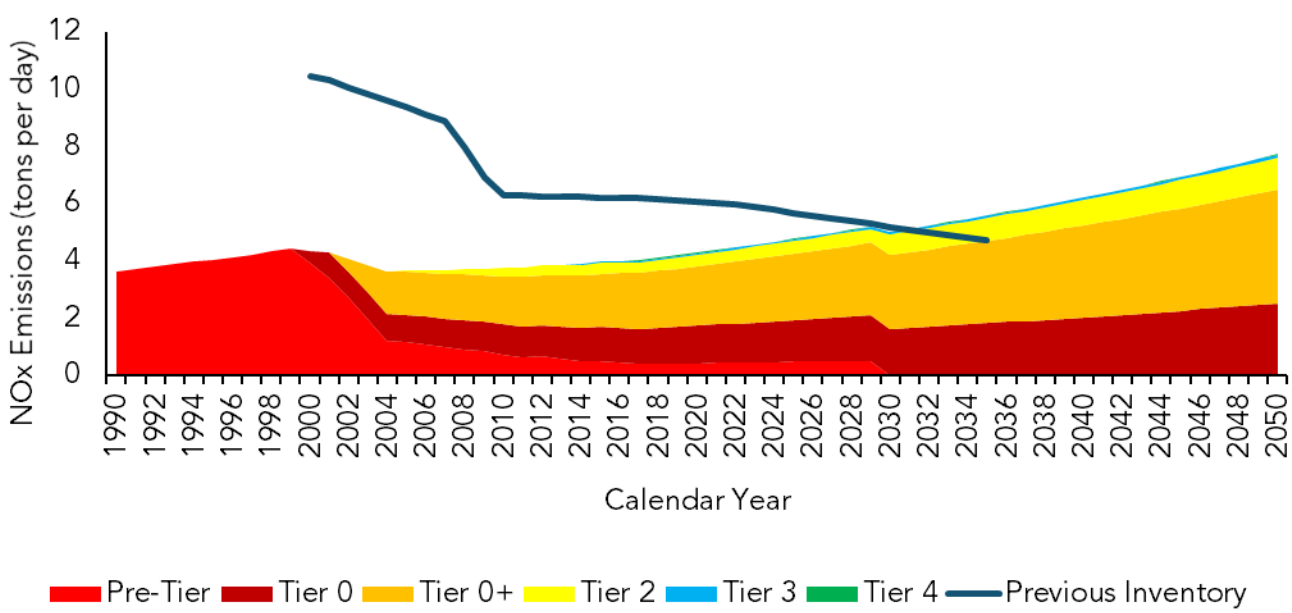


Figure 5 compares the previous PM emissions (dark blue line) and 2020 inventory PM emissions by tier. Both inventories show a drop in PM emissions in 2007, resulting from the introduction of CARB Diesel that lowers the sulfur content in fuel. Again, in 2012, with further fuel sulfur content reductions, the new inventory, in orange, shows a very small dip. Then, PM emissions grow over time as fuel consumption is assumed to increase. PM emissions are not declining as it is assumed there will be no significant turnover to cleaner tiers.

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[12] CARB's 2021 Line haul Emission Inventory Documentation https://ww2.arb.ca.gov/sites/default/files/2021-02/2021_line_haul_locomotive_emission_inventory_final.pdf

Figure 5: Statewide PM Emissions

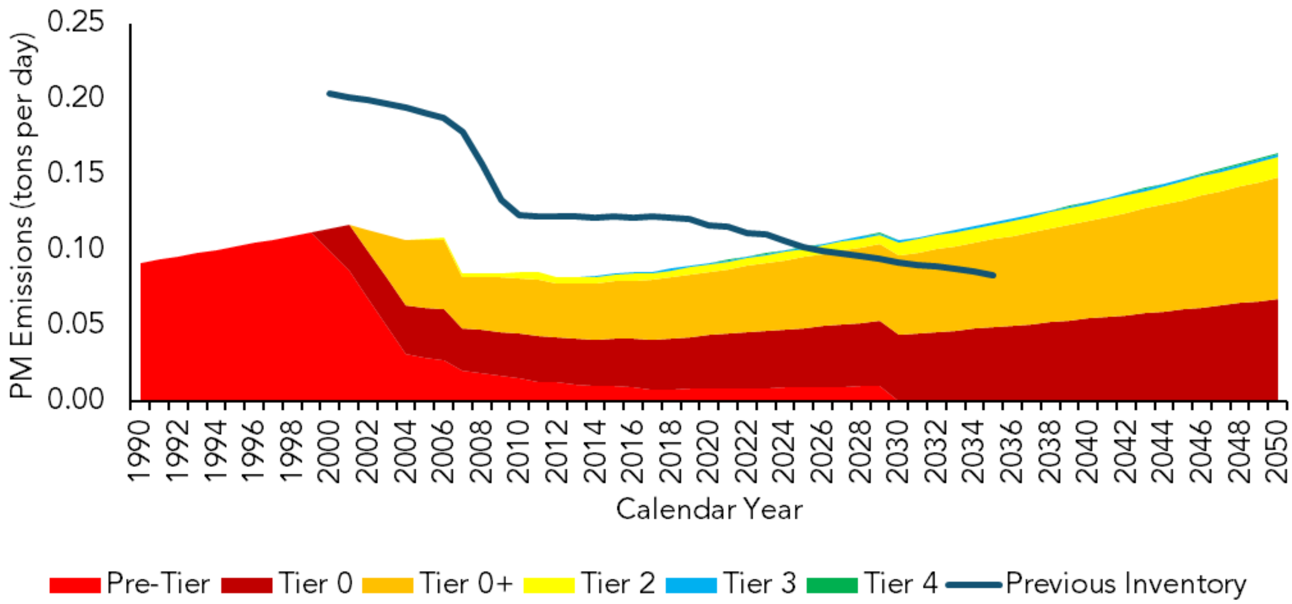


Figure 6 displays statewide NOx emissions by air basin. There are switcher rail yards located within six of California's air basins: the South Coast, San Joaquin Valley, San Francisco Bay Area, Sacramento Valley, Mojave Desert, and San Diego. The South Coast Air Basin reports the largest quantity of NOx emissions, which is not surprising as it is also home to the Ports of Long Beach and Los Angeles, the largest ports on the West Coast.

Figure 6: Statewide Switcher Rail Yard NOx, by Air Basin

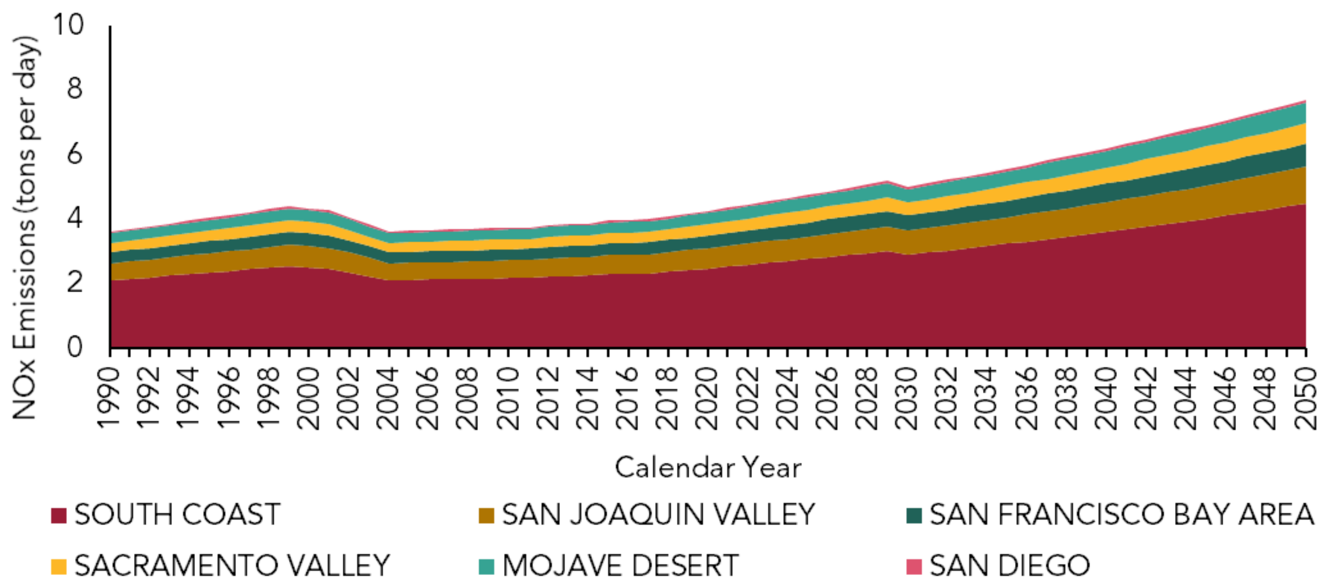
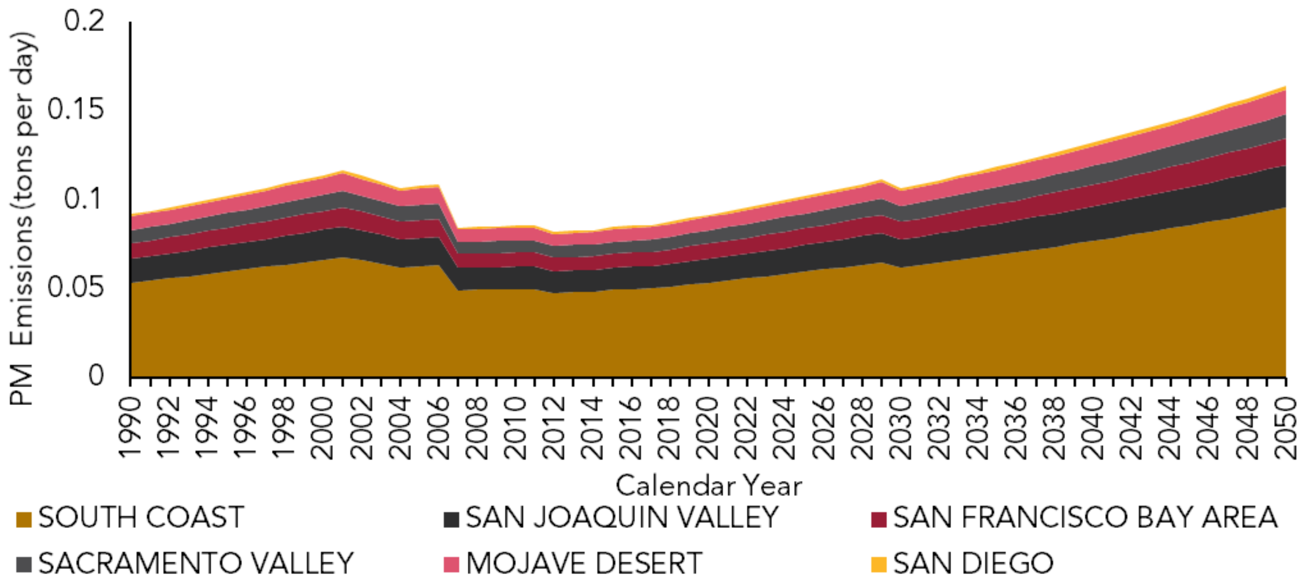


Figure 7 shows statewide PM emissions by air basin. PM emissions decrease significantly in 2007, due to both reductions in fuel sulfur content and the introduction of cleaner locomotives. In 2007, the sulfur content of fuel drops from 3,000 ppm to 500 ppm. Again, in 2012, the sulfur content drops to 15 ppm, showing another drop in PM. The emissions equations (Equation 2 and Equation 3) calculate these adjustments.

Figure 7: Statewide Switcher Rail Yard PM, by Air Basin



8. Conclusion

CARB's 2022 Switcher Rail Yard Emissions Inventory includes the most detailed and current data relating to 28 BNSF and UP Class I rail yards within California with a base year of 2017, thus making this inventory an improvement over the previous inventory. In addition to improved data, the inventory incorporates new growth assumptions from CARB's 2021 Line haul emission inventory. As such, the largest changes in rail yard emissions relate both to (1) a 2.19 percent fuel growth rate that coincides with freight growth assumptions in the 2021 line haul inventory and (2) a lack of evidence supporting locomotive turnover to cleaner technologies. More information on actual population, locomotive turnover and tier distribution at the yard level will enhance the background knowledge and inventory emissions results. Receiving rail yard data on a regular basis will help ensure the accuracy of the inventory, allowing quality assurance verification.