2017 Passenger Rail Emissions Model

California Air Resources Board

Off-Road Diesel Analysis Section

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2017 Passenger Rail Emissions Inventory

# Background

The Passenger Rail Emissions Inventory contains data involving commuter, intercity and interstate passenger rail lines operating within the state of California. Passenger Rail provides an alternative mode of travel, which reduces fuel dependency and congestion, and makes use of rail infrastructure that plays a role in land use decisions. The commuting lines are a relatively new transportation option in California, with service beginning in 1991, while the Amtrak intercity and interstate lines are significantly older.

Table 1.1 provides an overview of Passenger Rail lines operating within California.

Commuter lines include Altamont Commuter Express, Caltrain, Metrolink, and North Coast Transit District. Altamont Commuter Express travels from Stockton to San Jose. Caltrain travels from San Francisco to San Jose and down to Gilroy. Metrolink covers the Los Angeles and Long Beach area, with its southern connection in Oceanside meeting the North Coast Transit District’s Coaster, which travels along the coast of San Diego, from Oceanside to downtown.

Amtrak operates the intercity and interstate lines. Intercity lines include Capitol Corridor and San Joaquin Corridor (both operated by Caltrans), and Pacific Surfliner. The Caltrans line travels from San Jose to Sacramento, and from Stockton to Bakersfield. Pacific Surfliner travels from San Luis Obispo to Los Angeles and on to San Diego. Interstate lines include California Zephyr, Coast Starlight, Southwest Chief, and Sunset Limited. The model covers interstate travel occuring within the California boundary.

Table 1.1 Summary of California Passenger Rail Lines

| Rail Line | Type | Service Begins | Service Locations |
| --- | --- | --- | --- |
| Altamont Commuter Express (ACE) | Commuter | 1998 | Stockton – San Jose |
| California Zephyr | Interstate | 1949 | Emeryville (San Francisco) – Truckee – Denver – Chicago  |
| Caltrain | Commuter | 1992 | San Francisco – San Jose – Gilroy |
| Caltrans (Capitol Corridor and San Joaquin Corridor) | Intercity | 1991 | San Francisco – Sacramento – Bakersfield  |
| Coast Starlight | Interstate | 1971 | Los Angeles – Portland – Seattle  |
| Metrolink | Commuter | 1992 | Oceanside – Long Beach – Los Angeles |
| North Coast Transit District (NCTD) | Commuter | 1995 | Old Town San Diego – Oceanside |
| Pacific Surfliner | Intercity | 1991 | San Luis Obispo – Los Angeles – San Diego |
| Southwest Chief | Interstate | 1974 | Los Angeles – Flagstaff (Arizona) – Chicago  |
| Sunset Limited | Interstate | 1894 | Los Angeles – Tucson (Arizona) – Orlando  |

# Data

Actual data reported from 2008-2015, along with backward projecting, forecasting, and various model assumptions creates the emissions inventory spanning 1990-2050. The passenger rail companies provided various pieces of data, which may include Locomotive ID, Model Year, Tier, horsepower, route mileage, and fuel consumption. The model uses the current railroad rosters to create a baseline and calculates locomotive ages based off this roster. The model assumes each rail company purchased the locomotive engines new, and the model year is the first year it is in service. For example, if a locomotive’s model year is 2005, the model assumes there was no engine prior to 2005 to take this one’s place. The Amtrak interstate data is limited to track-mileage, number of trips per day, and number of days annually.

# Activity

Locomotive activity is based either on reported fuel consumption or track miles. The commuter and intercity rail activities are based on company-provided fuel consumption data from 2008-2015. Each company’s total fuel consumption is distributed equally across all locomotives, on a per company basis.

Amtrak interstate rail fuel consumption is estimated according to track-mile and trip number data. Equation 3.1 provides the fuel calculation.

Equation 3.1 Fuel Consumption Calculation

$$Fuel Use (\frac{gal}{year})=\frac{\# miles}{day}\* \frac{\# operating days}{year}\*\frac{2.2 gal}{mile} $$

The model assumes fuel use is constant. In response to email inquiries, several rail companies answered that they do not expect fuel use to change in the future. An increase in ridership does not correlate to an increase in fuel consumption since additional passengers mean fuller rail cars – not more trips. If there are new tracks or routes, or more trips per day, then fuel use would increase. However, this is not expected. Furthermore, rail companies do not expect a change in fuel use with fleet turnover. Tier 4 locomotives have 4,700 hp, while the older engines typically have 3,300 hp. The new engines will have higher fuel efficiency rates, so the horsepower increase should not increase fuel consumption.

One concern with fuel assumptions pertains to backward projections. The model assumes fuel remains constant and there is no data to suggest different fuel consumption rates in previous years. If the rail lines began with less trips per day, that would mean less fuel use. However, there is no data to support this.

# Electrification

Caltrain has contracts in place to electrify part of their line through the Peninsula Corridor Electrification Project[[1]](#footnote-1). Caltrain will convert about 75% of their diesel engines to electric trains and increase daily trips for this segment[[2]](#footnote-2). The model assumes the transition will occur in 2021. Once Caltrain’s segment is electrified, those segments will no longer require fuel. There are no plans, yet, for other rail companies to electrify.

# Turnover

Many of the rail companies have plans to upgrade portions of their fleet to Tier 4 engines. The model assumes that in 10 years or more, the remaining rail companies will update their long-term plans and retain funding to upgrade to cleaner engines. Caltrain is purchasing electric locomotives. All other engines will eventually be replaced with Tier 4 engines, except for the Amtrak interstate locomotives. Those rely on Federal funding, and there are no long-term plans.

# Emission Factors

The U.S. EPA has an emission factors reference guide where it provides a generalized definition for locomotive emission factors[[3]](#footnote-3). Locomotive engines are separated according to purpose (large line-haul, small line-haul, passenger, and switcher) and tier. Although it is common to use these emission and conversion factors, they are over-simplified when it comes to building an emission inventory.

The inventory expresses emissions in terms of gram of pollutant per gallon of gasoline consumed (g/gal). U.S. EPA line-haul emission factors (Table 6.1), measured in grams per brake horsepower-hour, are multiplied by conversion factors (Table 6.2), measured in break horsepower-hour per gallon fuel. The research report titled “Development of Railroad Emission Inventory Methodologies[[4]](#footnote-4)” provides a better source for emission conversion factors for inventory modeling. These conversion factors are linked directly to the engine, thereby more accurately reflecting emissions.

Table 6.1 Line-haul Emission Factors (g/bhp-hr)[[5]](#footnote-5)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **PM10** |  **HC** |  **NOx**  | **CO** |
| Pre-Tier | 0.32 | 0.48 | 13.00 | 1.28 |
| Tier 0 | 0.32 | 0.48 | 8.60 | 1.28 |
| Tier 0+ | 0.20 | 0.30 | 7.20 | 1.28 |
| Tier 1 | 0.32 | 0.47 | 6.70 | 1.28 |
| Tier 1+ | 0.20 | 0.29 | 6.70 | 1.28 |
| Tier 2 | 0.18 | 0.26 | 4.95 | 1.28 |
| Tier 2+ | 0.08 | 0.13 | 4.95 | 1.28 |
| Tier 3 | 0.08 | 0.13 | 4.95 | 1.28 |
| Tier 4 | 0.02 | 0.04 | 1.00 | 1.28 |

Table 6.2 Conversion Factors (bhp-hr/gal)

|  |  |
| --- | --- |
| Pre-Tier, Tier 0 | 15.2 |
| Tier 0+, Tier 1, Tier 1+ | 18.2 |
| Tier 2, Tier 2+, Tier 3, Tier 4 | 20.8 |

For locomotive operations, the emission factor for PM2.5 is 92% of PM10 and the emission factor for PM and PM10 are equivalent. 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). The emission factor for NH3 is estimated as 0.0833 g/gal of fuel, independent of tier. CO2 is defined by U.S. EPA as 10,206 g CO2/gal of fuel.

## Sulfur Adjustment Factor

The sulfur content of diesel fuel affects PM emissions. Equation 6.1 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[[6]](#footnote-6).

Equation 6.1 U.S. EPA Sulfur adjustment equation

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

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 SOx 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 SOx conversion rate is 0.02247. The SOx conversion rate for Tier 4 engines is 0.30.

The sulfur PM adjustment is subtracted from the PM emissions in Equation 6.2, yielding the corrected PM emissions.

Equation 6.2 PM adjusted emission calculation

$$PM\_{adj}=PM- S\_{PM adj}$$

## Diesel Fuel Adjustment

California has its own standards for diesel fuel. Known as CARB diesel, it is an ultra-low sulfur diesel fuel that reduces NOx emissions by 6% and PM by 14%[[7]](#footnote-7). Beginning in 2007, ARB regulation required all California locomotives to use CARB diesel with a sulfur fuel content (soxdsl) measuring no more than 500 ppm (parts per million)[[8]](#footnote-8). This was a dramatic reduction from the previous sulfur fuel content of 3000 ppm. In 2012, the sulfur content was further reduced measure less than 15 ppm.

In Equation 6.1, 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 (2005-2011 model year) has an engine certified for 3000 ppm (soxbas). Thus, Equation 6.1 will make adjustments to reduce the sulfur content.

## SOx Emissions

The U.S. EPA provides a formula[[9]](#footnote-9) for fuel consumption-based formula for SO2 emission in Equation 6.2. This equation makes adjustments according to the fuel’s sulfur content and the engine certification.

Equation 6.3 U.S. EPA SO2 Emission equation

$$SO\_{2}=[BSFC\* 453.6\* (1 - soxcnv) - HC] \* 0.01 \* soxdsl \* 2$$

where:

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

453.6 is the conversion factor from pounds to grams

soxcnv is the fraction of fuel sulfur converted to direct PM

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

0.01 is the conversion factor from weight percent to weight fraction

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

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

# Results

The passenger rail emissions model consists of commuter, intercity, and interstate rail traffic within California. Many companies have long-term plans to upgrade to either Tier 4 or electric engines. Amtrak has no plans for future upgrades.

The previous passenger model is missing, along with the date of the baseline data, background information, and model assumptions that were used. However, the emissions results are available in CEPAM, from 2000-2035. With no insight on input data, model assumptions, or model design, it would be difficult to compare the models. The figures illustrate the differences between the new model and the prior one on all graphs, except for statewide fuel which was unavailable. The previous model did not distinguish by engine Tier or Air Basin.

Figure 7.1, Figure 7.2, and Figure 7.3 depict the statewide fuel consumption in gallons per year, and NOx and PM in tons per day. In addition to the model forecasts, the graphs illuminate differences between the new model results and those from a previous model (the colored line), except when comparing fuel consumption.

Metrolink leased 40 locomotives from BNSF from 2015 to 2016, which explains a slight increase, and then decrease, in fuel consumption during that time period. In 2021, fuel consumption decreases with the introduction of Caltrain’s electric fleet. Fuel-based emissions also diminish.

Figure 7.1 Statewide fuel consumption (gallons per year), by Tier

The previous model shows statewide NOx and PM increasing over time. This may be a result of the model being built before many of the commuter rail companies began service and prior to implementation of engine tier standards, thus showing a regular growth trend. The new model shows decreases in NOx and PM due to cleaner tier engines and electrification.

Figure 7.2 Statewide NOx (tons per day), by Tier

The decreases in PM are due to both the fuel sulfur content and the introduction of cleaner engines. In 2007, the sulfur content of fuel drops from 3000 ppm to 500 ppm. Again in 2012, the sulfur content drops to 15 ppm. The emissions calculations makes these adjustments (Equation 6.1 and Equation 6.2).

Figure 7.3 Statewide PM (tons per day), by Tier

Figure 7.4 and Figure 7.5 depict NOx and PM emissions forecasts for the South Coast. The previous model shows emissions growth, most likely because the model was created before development of engine tier standards. The new model shows emissions begin to decline with the introduction of cleaner engines, and PM has additional decreases due to the lowered sulfur content of diesel fuel.

Figure 7.4 South Coast NOx (tons per day), by Tier

Figure 7.5 South Coast PM (tons per day), by Tier

In the San Joaquin Valley, Figure 7.6 and Figure 7.7 compare NOx and PM from the previous model. The previous model shows emissions are higher than the new model. This is likely due to the previous model being created before some passenger rail operations began service in the San Joaquin Valley. Here, again, emissions begin to decline with the introduction of cleaner engines, and PM has additional decreases due to the lowered sulfur content of diesel fuel. The two notable spikes correspond to a small increase in reported fuel during those specific years.

Figure 7.6 San Joaquin Valley NOx (tons per day), by Tier

Figure 7.7 San Joaquin Valley PM (tons per day), by Tier

1. Peninsula Corridor Electrification Project http://www.caltrain.com/projectsplans/CaltrainModernization/Modernization/PeninsulaCorridorElectrificationProject.html, 2017. [↑](#footnote-ref-1)
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3. Emission Factors for Locomotives, EPA 420-F-09-025, U.S. EPA, April 2009. [↑](#footnote-ref-3)
4. Development of Railroad emission Inventory Methodologies, prepared for Southeastern States Air Resource Managers, Inc., by Sierra Research, Inc. June 2004. P.28. [↑](#footnote-ref-4)
5. Emission Factors for Locomotives, EPA 420-F-09-025, U.S. EPA, April 2009. [↑](#footnote-ref-5)
6. Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression-Ignition, EPA-420-R-10-018, U.S. EPA, July 2010. [↑](#footnote-ref-6)
7. Diesel Fuel Effects on Locomotive Exhaust Emissions, <https://www.arb.ca.gov/fuels/diesel/102000swri_dslemssn.pdf>, 2000. [↑](#footnote-ref-7)
8. 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. [↑](#footnote-ref-8)
9. Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression-Ignition, EPA-420-R-10-018, U.S. EPA, July 2010. [↑](#footnote-ref-9)