used the total annual GTM from Union Pacific and BNSF R-1 reports for 2019 for both revenue and non-revenue services.[17]

The analysis used annual fuel consumption for the "Freight" category from the Union Pacific and BNSF R-1 reports for 2019 to estimate annual fuel consumption.

The analysis calculated GTM per gallon of diesel consumed using Equation 8.

**Equation 8: GTM per gallon of diesel consumed by locomotives**

$$GTM\ per\ gallon = \frac{annual\ GTM\ [gross\text{-}ton\text{-}miles]}{annual\ fuel\ consumption\ [gallons]}$$

| Where, | | Units |
|---|---|---|
| $GTM\ per\ gallon$ | = Gross-ton-miles from locomotives per gallon of diesel consumed | $GTM/gallon$ |
| $Annual\ GTM$ | = Annual gross-ton-miles reported in R-1 reports | $GTM$ |
| $Annual\ fuel\ consumption$ | = Annual diesel consumption reported in R-1 reports Freight category | $gallons$ |

The analysis used 1,004 GTM per gallon for the analysis calculated from the 2019 Union Pacific and BNSF R-1 report values.

The analysis calculated locomotive fuel consumption from GTM and GTM per gallon using Equation 9.

**Equation 9: Locomotive fuel consumption**

$$fuel\ usage = \frac{GTM}{GTM\ per\ gallon}$$

| Where, | | Units |
|---|---|---|
| $Fuel\ usage$ | = Diesel consumed by locomotives | $gallon$ |
| $GTM$ | = GTM from Equation 7 | $GTM$ |
| $GTM\ per\ gallon$ | = GTM per gallon of diesel consumed, from Equation 8 | $GTM/gallon$ |

Once the amount of fuel usage was determined, the analysis calculated the associated emissions by applying emission factors weighted by the locomotive tier distribution. The analysis calculated total emissions from locomotives using Equation 10.

[17] Non-revenue service accounts for about 1% of the total GTM.

**Equation 10: Emissions from locomotives**

$$
\begin{aligned}
&total\ emissions \\
&\quad = (fuel\ usage) \times CF \\
&\quad \times \left\{ \begin{array}{l} (emission\ factor_{Pre\text{-}Tier\ 0}) \times (Distribution_{Pre\text{-}Tier\ 0}) \\ \quad +(emission\ factor_{Tier\ 0}) \times (Distribution_{Tier\ 0}) \\ \quad +(emission\ factor_{Tier\ 1}) \times (Distribution_{Tier\ 1}) \\ \qquad\qquad + \cdots \\ \quad +(emission\ factor_{Tier\ 4}) \times (Distribution_{Tier\ 4}) \end{array} \right\}
\end{aligned}
$$

| Where, | | Units |
|---|---|---|
| *Total Emissions* | = Total emissions from trains | *pounds* |
| *Fuel usage* | = Total diesel consumption | *gallons* |
| *CF* | = Conversion factor[15] $CF = \frac{20.8\ [bhp\text{-}hr/gallon]}{453.6\ [g/pounds]}$ | |
| $emission\ factor_{Tier\ N}$ | = Emission factor of Tier N locomotives | *g/bhp-hr* |
| $Distribution_{Tier\ N}$ | = MWhr or bhp-hr Tier distribution of Tier N locomotives | - |

The analysis used particulate matter 10 micrometers in diameter or smaller ($PM_{10}$) and $NO_X$ emission factors from the U.S. EPA publication Emission Factors for Locomotives, EPA-420-F-09-025[15] for Tier 4 and older locomotives, and CARB Locomotive Technology Assessment[18] for proposed Tier 5 locomotives, as shown in Table 3. The analysis estimated $PM_{2.5}$ emission factors to be 0.96 times the $PM_{10}$ emission factors consistent with the conversion factor from $PM_{10}$ to $PM_{2.5}$ in the EMFAC2017 data.[19]

**Table 3. Line haul emission factors [grams/bhp-hr]**

| | $PM_{10}$ | $NO_X$ |
|---|---|---|
| **Uncontrolled** | 0.32 | 13.00 |
| **Tier 0** | 0.32 | 8.60 |
| **Tier 0+** | 0.20 | 7.20 |
| **Tier 1** | 0.32 | 6.70 |
| **Tier 1+** | 0.20 | 6.70 |
| **Tier2** | 0.18 | 4.95 |
| **Tier 2+ and Tier 3** | 0.08 | 4.95 |
| **Tier 4** | 0.015 | 1.00 |
| **Tier 5** | 0.006 | 0.15 |

For the baseline scenario, the analysis used tier distribution data from the unpublished draft locomotive line haul emissions inventory dated August 2020 (Appendix B). The baseline scenario only includes projected natural turnover. There is an alternative

[18] CARB. November 2016. Technology Assessment: Freight Locomotives.
[19] U.S. EPA publication Emission Factors for Locomotives, EPA-420-F-09-025 suggests using 0.97 to convert $PM_{10}$ to $PM_{2.5}$.

# Appendix B. Locomotive Inventory Values

The tier distribution in percentage of megawatt hours used for the baseline train scenario in the analysis is shown in Table 6. This data is from the unpublished draft locomotive line haul emissions inventory dated August 2020. Once the locomotive line haul emissions inventory is published, a link will be posted on the CARB Truck vs. Train website.