CalEEMod®

California **E**missions **E**stimator **Mod**el®

Appendix A
Calculation Details for CalEEMod

Prepared for:
**California Air Pollution Control Officers
Association (CAPCOA)**

Prepared by:
**BREEZE Software, A Division of Trinity
Consultants
Dallas, Texas
in collaboration with
South Coast Air Quality Management District
and the California Air Districts**

**May 2021
CalEEMod Version 2020.4.0**

Table of Contents

1 Overview of Program

California Emissions Estimator Model (CalEEMod) calculates both the criteria air pollutant emissions and greenhouse gas (GHG) emissions associated with construction and operational sources as part of development projects. In addition, it calculates GHG emissions associated with one-time changes in vegetation land use. These emission estimates can be used for quantification and reporting as part of the California Environmental Quality Act (CEQA) environmental documentation.

This Appendix serves as the basis for all methods and assumptions and data source references that are used for calculating all emission categories. These category modules include construction, operational energy use, operational mobile sources, operational landscape maintenance, operational consumer product use, operational architectural coating use, operational hearth use, operational stationary sources, indirect emissions from water and wastewater use, vegetation carbon sequestration, and emissions associated with solid waste disposal.

1.1 Structure of this Document

This Appendix will discuss each major module in detail with appropriate subdivisions. The major modules include the following:

- Project Characteristics
- Land Use
- Construction
- Operational Mobile
- Operational Area Sources
- Energy Use
- Water and Wastewater
- Solid Waste
- Stationary Sources
- Vegetation
- Mitigation
- Reports

2 Project Characteristics

The Project Characteristics screen has no calculations associated with it. It is used to provide information on appropriate default values in subsequent screens. A detailed description of this screen and the areas requiring user input is given in the User's Guide main text. Further information regarding some of the inputs are below.

- Mendocino County requested county subdivisions as follows:

    - Inland

    - Coastal

    - Rural Inland North

    - Rural Inland South

- Santa Barbara County requested county subdivisions as follows:

    - North Santa Barbara County: North of Santa Ynez range

    - South Santa Barbara County: South of Santa Ynez range

- Wind speeds are from District supplied information, nearby weather stations if easily identifiable[1] or a default of 2.2 m/s. See Appendix D, Table 1.1 for the values.

- Precipitation Frequency was based on data from the Western Regional Climate Center (WRCC)[2] which is an average of all of the stations found in that county, air basin, or district. See Appendix D, Table 1.1 for the values.

2.1 Utility Information

Several of the modules require an estimation of the indirect GHG emissions associated with supplying electricity to the Project site. The user will need to specify the utility company that will be providing electricity to the Project. The default carbon intensities for the major utility companies as well as a state-wide default are based on the latest public utilities inventory reports. This is consistent with recommendations in the California Air Pollution Control Officer Association (CAPCOA) Quantifying Greenhouse Gas Mitigation Measures document. The complete list of the utilities powering California and the reporting year from which the CO_2 intensity factor currently used in CalEEMod can be found in Table 1.2 in Appendix D. The CH_4 and N_2O values are based on E-grid values for the region since more refined data is not readily available. The user will also be able to provide an alternative value that is recommended by the local agency, if applicable.

---

[1] https://wrcc.dri.edu/
[2] https://wrcc.dri.edu/

2.2 Criteria Pollutants

The criteria pollutants are those pollutants or precursor pollutants to the chemicals that have National Ambient Air Quality Standards (NAAQS) or California Ambient Air Quality Standards (CAAQS). These pollutants are listed below:

- Particulate Matter: The program will define both Particulate Matter with aerodynamic radius less than 10 microns (PM_{10}) and Particulate Matter with aerodynamic radius less than 2.5 microns ($PM_{2.5}$). Since emission factors for $PM_{2.5}$ have not been fully defined, the conversion assumption for each generating source will be described in more detail with the specific modules. Particulate matter will be tracked by subtype which will include fugitive dust and equipment exhaust.

- Carbon Monoxide: The emissions from carbon monoxide (CO) will be calculated for all direct combustion sources associated with the project.

- Lead: The emissions from lead (Pb) will be calculated for all direct combustion sources associated with the project.

- Sulfur Dioxide: The emissions associated with sulfur dioxide (SO_2) will be calculated for all direct combustion sources associated with the project.

- Nitrogen Oxides: The emissions associated with nitrogen oxides (NOx) will be calculated for all direct combustion sources associated with the project or direct emissions associated with area sources. Note that there may be some nitrous oxide (N_2O) emissions that are calculated under the GHG module indirect sources that will not be incorporated into the nitrogen oxide emission tally for criteria pollutants since these emissions may be out of county, air district or air basin the project is located.

- Ozone: The ozone (O_3) emissions are not calculated directly in this program. Instead the emissions associated with ozone precursors are calculated.

- Ozone Precursors: Ozone precursors will be quantified as reactive organic gases (ROG) along with NOx. ROGs when released will interact with NOx in the atmosphere and produce ozone.

A Volatile Organic Compound (VOC) is an organic compound that can evaporate into an organic gas. VOCs can be either reactive or non-reactive. Over the years, non-reactive VOCs have been exempted from regulation. CalEEMod calculates the VOC emissions from the application of architectural coatings based on the locally required VOC content limit of the coatings. ROG is an organic gas that undergoes a photochemical reaction, thus, is reactive. ROG emissions are generated from the exhaust of mobile sources and these combustion emissions are calculated in CalEEMod based on CARB's ROG emission factors. Both VOC and ROGs are precursors to ozone so they are summed in the CalEEMod report under the header ROG. For the purposes of comparing the ROG value to a VOC significance threshold, the terms can be used interchangeably.

2.3 Greenhouse Gas Pollutants

The greenhouse gas (GHG) pollutants are those recognized by the state of California under Assembly Bill 32 (AB32). The most common GHGs emitted in association with land use developments include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). All GHGs will be reported in a common currency of carbon dioxide equivalent (CO_2e). In order to calculate the CO_2e, an individual GHG is multiplied by its global warming potential (GWP). The GWP designates on a pound for pound basis the potency of the GHG compared to CO_2. The program uses GWP from the 2007 IPCC Fourth Assessment Report (SAR)[3], and are consistent with 2017 CARB's Scoping Plan Update[4].

---

[3] Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf
[4] Available at: https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan

3 Land Use

The primary project description data that needs to be entered by the user is all land use types and sizes that make up the project. CalEEMod contains several land use categories that are mainly based on ITE land use classifications. Further division of some land uses (mainly warehouses) has been added. The land use subtype is the basis to define several default values used by the modules. The user-defined land use does not have any default information and the user is required to enter all of the necessary information. CalEEMod currently places a value of 0 for all areas where user defined values would be required for a blank land use.

The land use size has several different size metrics the user can choose from. In order for the information to be cross-compatible, the user can enter all of the metrics for a given land use or default conversions between the metrics will be used. The cross-comparison data generally came from the following sources:

- The value for average dwelling unit square footage is rounded based on the average square footage reported in the Residential Appliance Saturation Survey (RASS). Retirement communities and congregate care facilities are assumed to be similar in size to multifamily units.

- The conversion value is based on taking the ratios of different metrics reported in the Institute of Transportation Engineers (ITE) trip rate manual.

- Equivalent commercial building metrics as noted in Table B1 of the Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS).

Unlike other programs, CalEEMod does not account for additional acreage associated with commercial buildings. This was deemed unnecessary since parking lots have been separated out as a separate land use and multi-story buildings should have their lot acreage known.

3.1 Population

The population data is used to estimate emissions associated with solid waste generation for residential land uses. The population per dwelling unit is based on the statewide default or information supplied by individual air districts. Population data can be found in Appendix D, Table 2.2.

4 Construction

The construction module is used to calculate the emissions associated with the construction of the project. Construction has several different types of sources which contribute to emissions of pollutants. These source types include off-road equipment usage, on-road vehicle travel, fugitive dust, architectural coating, and paving off-gassing. Each of these source types is discussed in more detail in the subsequent sections. These emission sources are associated with various types of construction phases. Typical construction phases include demolition, site preparation, grading, trenching, building construction, paving, and architectural coating. The extent to which these phases occur depends on the specific project. For instance, a demolition phase would only occur if demolition of existing structures was required. Similarly, trenching only occurs if the project requires trenching generally associated with underground utilities. Unique aspects and default assumptions associated with these phases is discussed below in the context of the different emission source calculations.

4.1 Construction Phase

No emission calculations are associated with this sub-screen. The South Coast AQMD construction survey is used to estimate default phase lengths based on total project acreage as calculated from the acreage entered on the land use screen. If the project acreage is in between the acreages in the survey, the next highest acreage tier is used. If the project size defined by the user is between the sizes of two surveyed projects, CalEEMod conservatively uses the phase duration for the larger project. For instance, if the given project is 7 acres, the program will use the phase duration for the 10-acre project rather than that for the 5-acre project. For large acreage sites, the survey was extrapolated by adding additional phase time equivalent to adding phase time from two acreage ranges in the survey. This occurs for sites with acreage larger than 34 acres. In these situations, the user should consider the accuracy of the equipment and phase duration estimations or use site-specific construction schedules and equipment lists.

The date range, work days per week and total days are dynamically linked to each other and will influence one another if the user changes these values.

4.2 Off-road Equipment

Construction consists of several types of off-road equipment. Since the majority of the off-road construction equipment used for construction projects are diesel fueled, CalEEMod assumes all of the equipment operates on diesel fuel. However, there are mitigation measures that can be implemented that will allow for use of alternative fueled equipment.

The South Coast AQMD construction survey is used to estimate default equipment lists based on total project acreage as calculated from the acreage entered on the land use screen. If the project acreage is in between the acreages in the survey, the next highest acreage tier is used. For large acreage sites, the survey was extrapolated by adding additional phase time equivalent to adding phase time from two acreage ranges in the survey. This occurs for sites with acreage larger than 34 acres. In these situations, the user should consider the accuracy of the equipment and phase duration estimations or using site-specific construction schedules and equipment lists.

The calculations associated with this screen include the running exhaust emissions from off-road equipment. Since the equipment is assumed to be diesel, there are no starting or evaporative emissions associated with the equipment as these are *de minimis* for diesel-fueled equipment[5]. CalEEMod calculates the exhaust emissions based on California Air Resources Board (CARB) OFFROAD2011 methodology using the equation presented below.[5]

$$\text{Emission}_{\text{DieselEx}} = \sum_i (EF_i \times Pop_i \times AvgHp_i \times Load_i \times Activity_i)$$

Where:

EF = Emission factor in grams per horsepower-hour (g/bhp-hr) as processed from OFFROAD2011

Pop = Population, or the number of pieces of equipment

$AvgHp$ = Maximum rated average horsepower

$Load$ = Load factor

$Activity$ = Hours of operation

i = equipment type

The program allows the user to enter the number of pieces of equipment, horsepower, load factor, and daily hours of operation for each selected equipment type. CalEEMod assigns default parameters for the construction equipment as explained below:

Emission Factor
OFFROAD2011 was run for statewide with averaging days of MON-SUN for 22 scenario years each. All scenarios were run for three seasons – Annual, Summer, and Winter. The exhaust emission factors for each equipment type at each horsepower range were back calculated from total daily emissions reported in the model output files using the following formula:

$$\text{Emission Factor [g/hp-hr]} = \frac{\text{Total Daily Exhaust x 907,184.74}}{\text{Activity} \times \text{AvgHP} \times \text{LF}}$$

Where:

Total Daily Exhaust	= Total pollutant emissions [tons/day]
Activity	= Total daily statewide usage of equipment [hours/day]
AvgHP	= Average HP of equipment within the horsepower range [HP]
LF	= Load Factor of equipment [unitless]
907,185	= Conversion factor tons to grams (2,000 lbs/ton x 453.6 g/lb)

Total Daily Exhaust and Activity were obtained from OFFROAD2011 model output, while AvgHP and LF were obtained from input files to the model.

---

[5] CARB, 2006. Program Structure of the OFFROAD2007. Available at: http://www.arb.ca.gov/msei/offroad/pubs/offroad_overview.pdf

AvgHP

The default average equipment horsepower is from OFFROAD2011. OFFROAD2011 has an average horsepower for each engine tier which was used in developing the emission factor (from equip.csv). This is different than the default horsepower used for default data which is based on the average horsepower of the mode of populations for the various engine horsepower tiers in OFFROAD.

Load

The load factor is the ratio of the actual output to the maximum output of a piece of equipment. The program uses the OFFROAD2011 load factor as default. Based on OFFROAD2011, the load factor is equipment type-specific and does not vary with horsepower (hp) (e.g., the load factors of a 125-hp dozer and a 500-hp dozer are the same).

Activity

The default hours of operation are 8 hours a day and 5 days a week over the construction phase duration unless specified otherwise in the equipment list. The construction phase length is used from the construction phase screen.

i (Equipment Type) and Pop

The default equipment list and number of pieces of equipment for each equipment type is determined based on the size (i.e., acreage) of the construction project based on the construction activity survey performed by the South Coast AQMD (Appendix E). If the project size defined by the user is between the sizes of two surveyed projects, the program will use the equipment list and number for the larger project. All equipment in the construction category of OFFROAD2011 is included in CalEEMod.

Trenching Emissions

There is no default equipment list associated with trenching emissions at this time. The user must enter site-specific equipment when a project includes trenching.

4.3 Dust from Material Movement

Fugitive dust is generated by the various source activities occurring at a construction site, contributing to. PM_{10} and $PM_{2.5}$ emissions. Fugitive dust emissions are distinguished from exhaust particulate matter emissions. The program calculates fugitive dust associated with the site preparation and grading phases from three major activities: haul road grading, earth bulldozing, and truck loading. As recommended by South Coast AQMD, the fugitive dust emissions from the grading phase are calculated using the methodology in USEPA AP-42 as described in the following paragraphs.

Grading Equipment Passes

Fugitive dust emissions from grading equipment passes are estimated using the methodology described in Section 11.9 - Western Surface Coal Mining of USEPA AP-42[6] which estimates the emission factor of PM_{10} applying a scaling factor to that of PM_{15}. Similarly, the emission factor of

---

[6] Available at: https://www.epa.gov/sites/production/files/2020-10/documents/c11s09.pdf

$PM_{2.5}$ is scaled from that of total suspended particulates (TSP). The following presents the equations used to calculate the emission factors for PM_{15} and TSP and the scaling factor for those of PM_{10} and $PM_{2.5}$:

$$EF_{PM15} = 0.051 \times (S)^{2.0} \text{, and } EF_{PM10} = EF_{PM15} \times F_{PM10}$$

$$EF_{TSP} = 0.04 \times (S)^{2.5} \text{, and } EF_{PM2.5} = EF_{TSP} \times F_{PM2.5}$$

Where:

EF = emission factor (lb/VMT)
S = mean vehicle speed (mph). The AP-42 default value is 7.1 mph.
$F_{PM2.5}$ = PM$_{2.5}$ scaling factor. The AP-42 default value is 0.031.
F_{PM10} = PM$_{10}$ scaling factor. The AP-42 default value is 0.6.

The grading dust emissions are calculated by multiplying the emission factors with the total vehicle miles traveled (VMT) for the grading equipment (i.e., grader). The VMT are estimated based on the dimensions of the grading area and the blade width of the grading equipment.

$$E = EF \times VMT \text{ , and}$$

$$VMT = As / Wb \times 43,560(sqft / acre) / 5,280(ft / mile)$$

Where:

E: emissions (lb)
EF: emission factor (lb/VMT)
VMT: vehicle miles traveled (mile)
A_S: the acreage of the grading site (acre)
W_b: Blade width of the grading equipment. The program uses a default blade width of 12 ft. based on Caterpillar's 140 Motor Grader[7].

Note that the dimensions (e.g., length and width) of the grading site have no impact on the calculation, only the total area to be graded. In order to properly grade a piece of land multiple passes with equipment may be required. The acres value is based on the equipment list and days in grading or site preparation phase according to the anticipated maximum number of acres a given piece of equipment can pass over in an 8-hour workday. The equipment-specific grading rates are given in the following table as determined by South Coast AQMD in consultation with building estimator references.

Equipment Type	Acres/8hr-day
Crawler Tractors	0.5
Graders	0.5
Rubber Tired Dozers	0.5
Scrapers	1

---

[7] https://www.cat.com/en_US/products/new/equipment/motor-graders.html

Bulldozing

Similar to the grading equipment passes emission estimation, the bulldozing emission factors for PM_{10} and $PM_{2.5}$ are scaled from those of PM_{15} and TSP. Based on AP-42 Section 11.9, the dust emission factor for bulldozing is calculated using the following equations:

$$EF_{TSP} = \frac{C_{TSP} \times s^{1.2}}{M^{1.3}}, \text{ and } EF_{PM2.5} = EF_{TSP} \times F_{PM2.5}$$

$$EF_{PM15} = \frac{C_{PM15} \times s^{1.5}}{M^{1.4}}, \text{ and } EF_{PM10} = EF_{PM15} \times F_{PM10}$$

Where:
  EF = emission factor (lb/hr)
  C = arbitrary coefficient used by AP-42
  M = material moisture content (%)
  s = material silt content (%)
  F = scaling factor

C, M, s, and F vary depending on the bulldozed material. The following table summarizes the constants for overburden[8] presented in AP-42[9].

Bulldozing Fugitive Emission Factors

Constant	Overburden
C_{TSP}	5.7
C_{PM15}	1.0
M	7.9%
s	6.9%
F_{PM10}	0.75
$F_{PM2.5}$	0.105

The program uses the constants associated with overburden as default for calculation of bulldozing dust emissions since overburden more closely models the bulldozed materials during land development construction. The dust emissions are calculated by multiplying the emission factor with the hours of operation for the dozers listed in the equipment list using the formula below:

$$E = EF \times Hr$$

Where:
  E = emissions (lb)
  EF = emission factor (lb/hr)
  Hr = hours of operation

---

[8] Overburden is the layer of earth located between the topsoil and the coal seam (USEPA AP-42).
[9] USEPA AP-42, see Tables 11.9-1 and 11.9-3.

Truck Loading

Processes such as truck dumping on the pile or loading out from the pile to a truck with a front-end loader also cause fugitive dust emissions. The program calculates these emissions using the methodology described in Section 13.2, Introduction to Fugitive Dust Sources, of USEPA AP-42. The emission factor, based on the material moisture content and mean wind speed, is calculated using the following formula:

$$EF_D = k \times (0.0032) \times \frac{\left(\dfrac{U}{5}\right)^{1.3}}{\left(\dfrac{M}{2}\right)^{1.4}}$$

Where:

EF = emission factor (lb/ton)

K = particle size multiplier. The AP-42 default value for PM_{10} is 0.35 and that for $PM_{2.5}$ is 0.053

U = mean wind speed. The program selects wind speed based on the value listed on the Project Characteristics screen. It has been converted internally to miles per hour.

M = material moisture content (%). The moisture contents of different materials are listed in Table 13.2.4-1 of AP-42. The program uses the moisture content of cover (12%) as default.

The fugitive dust emissions are calculated by multiplying the emission factor with the throughput of loaded and unloaded material that is entered by the user.

$$E = EF \times TP$$

Where:

E = emissions (lb)

EF = emission factor (lb/ton)

TP = throughput of loaded and unloaded materials (ton)

CalEEMod assumes 1.2641662 tons per cubic yard based on a bulk density of 1.5 grams per cubic centimeter. Typical soil densities range from about 1.25 to about 1.6 and 1.5 is the approximate density of a silty loam soil which is relatively common in most other parts of the state. The density reported above does not account for watering to suppress dust, it only accounts for natural moisture.

4.4 Demolition

The program calculates the demolition dust emissions using the methodology described in the report prepared for the USEPA by Midwest Research Institute (MRI)[10]. The three primary operations that generate dust emission during the demolition phase are mechanical or explosive dismemberment, site removal of debris, and on-site truck traffic on paved and unpaved road. The truck traffic on roads in described with the trips and VMT information.

Mechanical or Explosive Dismemberment

Based on the MRI report, there is no AP-42 emission factor data available for this mechanical or explosive dismemberment. Thus, the emission factor for dismemberment and collapse of a structure is calculated using the following AP-42 equation for batch drop operations:

$$EF_D = k \times (0.0032) \times \frac{\left(\dfrac{U}{5}\right)^{1.3}}{\left(\dfrac{M}{2}\right)^{1.4}}$$

Where:

EF_D = emission factor (lb PM/ton of debris)

EF_{D-PM10} = 0.0011 lb PM_{10}/ton of debris

$EF_{D-PM2.5}$ = 0.00017 lb $PM_{2.5}$/ton of debris

k = particle size multiplier. The AP-42 default value for PM_{10} is 0.35 and that for $PM_{2.5}$ is 0.053.

U = mean wind speed. The program selects the default mean wind speed based on the wind speed (m/s) provided on the project characteristics screen.

M = material moisture content. The program uses 2% as the default based on the MRI report.

The dust emissions are calculated by multiplying the above emission factors with the total weight of building waste using the following equation:

$$E_D = EF_D \times W$$

Where:

E_D = emissions (lb of PM)

EF_D = emission factor (lb of PM/ton of debris)

W = building waste (ton of debris)

---

[10] Midwest Research Institute. 1988. Gap Filling PM10 Emission Factors for Selected Open Area Dust Sources.

If the total building waste weight is not known, the program will estimate the tonnage using the *building waste tonnage – structural floor space* relationship determined from a 1976 analysis by Murphy and Chatterjee of the demolition of 12 commercial brick, concrete, and steel buildings. The following data are cited directly from the MRI report:

> 1 ft^2 floor space = 10 ft^3 original building volume,
> 1 ft^3 building volume = 0.25 ft^3 waste volume,
> 1 yd^3 building waste = 0.5 ton weight,
> Mean truck capacity = 20 yd^3 haulage volume, and therefore
> 1 ft^2 represents 0.046 ton of waste material.

The total building waste is then calculated using the following equation:

$$E_D = EF_D \times SF \times 0.046 (ton / ft^2)$$

Where:
> E_D = emissions (lb of PM)
> EF_D = emission factor (lb of PM/ton of debris)
> SF = building square footage (ft^2)

Debris Loading

The dust emission factor of PM$_{10}$ and PM$_{2.5}$ in pounds per ton building waste is estimated based on the measured total suspended particulates (TSP) emission factor using the following equation:

$$EF_L = k \times EF_{L-TSP}$$

Where:
> EF_L = emission factor (lb/ton)
>
> k = particle size multiplier. The AP-42 default value for PM$_{10}$ is 0.35 and that for PM$_{2.5}$ is 0.053.

The default value for EF_{L-TSP} is 0.058 lb/ton, the average of the two TSP factor (i.e. 0.053 and 0.063 lb/ton) measured from two tests of the filling of trucks with crushed limestone using a front-end loader.

The dust emissions from debris loading are then calculated following the same methodology used for mechanical and or explosive dismemberment:

$$E_L = EF_L \times SF \times 0.046 (ton / ft^2)$$

Where:
> E_L = emissions (lb)
> EF_L = emission factor (lb/ton)
> SF = building square footage (ft^2)

4.5 Trips and VMT

The number of workers, vendor, and hauling trips and associated vehicle miles traveled (VMT) are used to determine both the exhaust emissions associated with on-road vehicle use and fugitive dust emissions.

Trips

Worker trips for all construction phases except building construction and architectural coating is based on 1.25 workers per equipment in that phase resulting in one roundtrip per worker. For building construction workers, the trip number is estimated using the trip generation rate from a survey conducted by SMAQMD. This has been reanalyzed and results in slightly different numbers than used by other programs and that was previously reported in some agency documents. The analysis and data supporting these values can be found in Appendix E.2. The land types selected for the project are grouped into four categories presented in the following table which also presents the associated SMAQMD trip generation rates.

Building Construction Worker and Vendor Trip Rates

Land Use SubType	Rate Metric	Worker Trip Rate	Vendor Trip Rate
Single Family	Daily Trips per DU*	0.36	0.1069
Multi-Family	Daily Trips per DU*	0.72	0.1069
Commercial/Retail	Daily Trips per 1000 sq. ft.	0.32	0.1639
Office/Industrial	Daily Trips per 1000 sq. ft.	0.42	0.1639
Source: South Coast AQMD's analysis of SMAQMD Building Construction Worker and Vendor trip rates found in Appendix E.2.			

*DU = dwelling unit

Architectural coating worker trips are 20% of building construction phase trips. Vendor trips are only associated with building construction and are based on the land uses and trip rate indicated in the table above.

Haul trips are based on the amount of material that is demolished, imported or exported assuming a truck can handle 16 cubic yards of material. For phased trips, the truck is assumed to be full both ways. For non-phased trips, the truck is assumed to be empty one direction and thus results in more haul trips calculated.

VMT

The VMT is estimated from the trip lengths input in this screen. The default trip length for workers is based on the location H-W trip length. The default trip length for vendors is the C-NW trip length. The hauling trip length default is set at 20 miles.

On-Road Vehicle Emissions

Construction generates on-road vehicle exhaust, evaporative, and dust emissions from personal vehicles for worker and vendor commuting, and trucks for soil and material hauling. These emissions are based on the number of trips and VMT along with emission factors from

---

EMFAC2017. The detailed methodology for converting EMFAC2017 emission rates into CalEEMod vehicle emission factors is provided in Section 5.2.

Emission rates of all vehicle categories were obtained from the EMFAC2017 Web Database based on aggregated model year and aggregated speed for all counties, air basins, air districts and statewide average for 31 scenario years that each includes three seasons – Annual, Summer, and Winter[11]. Emission rates of methane (CH4) were provide by CARB directly because they are not included in the web database.

Running emissions for all pollutants, PM emissions from tire and brake wear, and running loss emissions of TOG and ROG were divided by the VMT of each respective vehicle class from each scenario year and adjusted for unit conversions to derive emission factors in units of grams per VMT. All other emissions (including evaporative) were divided by the number of trips to derive emission factors in units of grams per trip.

VMT fractions, calculated as the ratio of VMT for each vehicle class to total VMT for all vehicles were also derived for each scenario year. The emissions from mobile sources were calculated with the trip rates, trip lengths and emission factors for running from EMFAC2017 as follows:

$$\text{Emissions}_{\text{pollutant}} = \text{VMT} * \text{EF}_{\text{running,pollutant}}$$

Where:

$\text{Emissions}_{\text{pollutant}}$ = emissions from vehicle running for each pollutant

VMT = vehicle miles traveled

$\text{EF}_{\text{running,pollutant}}$ = emission factor for running emissions

Evaporative emissions, starting and idling emissions are multiplied by the number of trips times the respective emission factor for each pollutant.

Brake Wear and Tire Wear Emissions

As vehicles are driven, particulate matter is generated from degradation of brakes and tires. This is calculated based on the EMFAC emission factors for each vehicle class and the total VMT traveled by that vehicle class according to the following equation:

$$\text{Emission}_{\text{brakewearo rtirewear}} = \sum_{\text{class}} (\text{E.F.}_{\text{brakewearo rtirewear ,class}} \times \text{VMT}_{\text{class}})$$

Vehicle Mix

The user can select the type of vehicle mix. The EMFAC mix is the total mix of all vehicles provided by EMFAC. The program can also assume that the workers' personal vehicles consist of 50% light-duty auto (or passenger car), 25% light-duty truck type 1 (LDT1), and 25% light-

---

[11] Years 2000, 2005, 2010 to 2035 inclusive, 2040, 2045, and 2050.

duty truck type 2 (LDT2). The equivalent test weight (ETW) from EMFAC2017 for each type of vehicle is presented below[12]:

Gross Vehicle Weights

Vehicle Type	ETW (lb)
LDA	All
LDT1	<= 3,750
LDT2	3,751 - 5,750

For vendor trips, CalEEMod has the option to choose the EMFAC vehicle mix or also choose all HHDT or all MHDT vehicles. The program default assumes that all vendors' vehicles are heavy heavy-duty trucks (HHDT).

For hauling trips, CalEEMod has the option to choose the EMFAC vehicle mix, all MHDT, all HHDT or a 50% mix of MHDT and HHDT vehicles.

4.6 On-Road Fugitive Dust

CalEEMod calculates all on-road fugitive dust associated with paved and unpaved roads consistent with the method discussed in the traffic section. All vehicle miles traveled from worker commuting, vendor commutes, soil hauling, and demolition hauling are accounted for. The same equations described in Section 5.3 are used here with the variables coming from this screen in CalEEMod.

4.7 Architectural Coatings

Volatile organic compounds (VOC)[13] off-gassing emissions result from evaporation of solvents contained in surface coatings. The program calculates the VOC evaporative emissions from application of residential and non-residential surface coatings using the following equation:

$$E_{AC} = EF_{AC} \times F \cdot A_{paint}$$

Where:

    E = emissions (lb VOC)

    EF = emission factor (lb/sq. ft.)

    A = building surface area (sq. ft.).

    The program assumes the total surface for painting equals 2.7 times the floor square footage for residential and two times that for nonresidential square footage defined by the user[14]. All of the land use information provided by a metric other than square footage will be converted to square footage using the default conversions or user defined equivalence. Green area square footage of City Parks and Golf Courses, pool surface area square footage of Recreational Swimming Pools, and parking surface area square footage are

---

[12] CARB. EMFAC2007 version 2.30 User's Guide. Available at:
http://www.arb.ca.gov/msei/downloads/emfac2014/emfac2014-vol1-users-guide-052015.pdf
[13] CalEEMod assumes that all VOCs are reactive organic gases (ROGs).
[14] The factors 2.7 and 2 are based on page A9-124 of South Coast AQMD's 1993 CEQA Air Quality Handbook.

excluded from the floor square footage in calculating VOC emissions due to architectural coatings.

F = fraction of surface area. The default values based on South Coast AQMD methods used in their coating rules are 75% for the interior surfaces and 25% for the exterior shell.

The emission factor (EF) is based on the VOC content of the surface coatings and is calculated estimated using the equation below:

$$EF_{AC} = C_{VOC} / 454(g/lb) \times 3.785(L/Gal)/180(sqft)$$

Where:

EF = emission factor (lb/sq. ft.)

C = VOC content (g/L). This varies by location and year.

The emission factors for coating categories are calculated using the above equation and are based on VOC content data provided by the air districts or ARB's statewide limits, if an air district did not provide VOC content data. VOC content data is available in Appendix D, Table 6.1.

CalEEMod also calculates the VOC emissions from the painting of stripes, handicap symbols, directional arrows and car space descriptions in parking lots. Please refer to Appendix E.7 for the studies conducted to determine a default percent of parking lot square footage that is painted. The equation for striping emission is the same as that for E_{AC} above, but A_{paint} is:

$$A_{paint} = A_{PL} \times P\%$$

Where:

A_{PL} = Parking lot area (sq. ft.)

P% = Default percent of parking lot area that is painted (6%)

The VOC content limit for parking lot area is either provided by local air districts or based on the exterior coating VOC limit of the region where the project is located. Appendix D, Table 6.1 contains the VOC emission factors by region. If the user has more specific VOC content limit on the coating being applied the default can be overridden but the user is expected to explain and justify the change in the "Remarks" box at the bottom of the screen.

4.8 Asphalt Paving Off-Gassing Emissions

While there is no specific screen associated with asphalt paving emissions, CalEEMod estimates VOC off-gassing emissions associated with asphalt paving of parking lots using the following equation:

$$E_{AP} = EF_{AP} \times A_{Parking}$$

Where:

E = emissions (lb)

EF = emission factor (lb/acre). The SMAQMD default emission factor is 2.62 lb/acre[15].

A = area of the parking lot (acre)

The size (acre) of the parking lot is calculated by multiplying the paved area associated with each parking stall with the capacity of the parking lot, or the number of parking stalls.

$$A_{Parking\_lot} = A_{Parking\_Stall} \times Capacity$$

Where the paved area associated with parking stall includes the area of the parking stall and that of the immediate access road, or aisle.

$$A_{Parking\_Stall} = W_{Stall} \times D_{Stall} + W_{Stall} \times W_{Aisle}$$

Where:

A = area (sq. ft.)
W = width (ft)
D = depth (ft)

The dimensions (e.g., width and depth) of a parking stall and the aisle width vary depending on the local government planning guidance. CalEEMod is programmed with a conservative default which assumes 400 square feet (0.009 acre) of paved area per parking stall and a one-way aisle in accordance with city guidance or municipal code for the following cities in California:

Parking Stall Size Estimate

Location	Dimensions									
	Compact					Full Size				
	Width (ft)	Depth (ft)	Aisle Width (ft)	Area (two-way) (sq. ft.)	Area (one-way) (sq. ft.)	Width	Depth	Aisle	Area (two-way) (sq. ft.)	Area (one-way) (sq. ft.)
City of San Jose	8	16	20	208	288	9	18	26	279	396
Menlo Park	8	16.5	23	224	316	9	18	23	265.5	369
Escondido Municipal Code[16]	8.5	16	24	238	340	8.5	18	24	255	357
Davis	8	16	20	208	288	9	18	20	252	342

CalEEMod is designed to allow the user to replace the total acres assumed in the land use screen.

---

[15] Sacramento Metropolitan Air Quality Management District. 1994. Air quality thresholds of significance, first edition. Sacramento, CA.

[16] Available at: http://www.qcode.us/codes/escondido/view.php?topic=33-39-33_768&frames=on

4.9 Maximum Daily Construction Emissions

Since construction phases may or may not overlap in time, the maximum daily construction emissions will not necessarily be the sum of all possible daily emissions. CalEEMod therefore calculates the maximum daily emissions for each construction phase. The program will then add together the maximum daily emissions for each construction phase that overlaps in time. Finally the program will report the highest of these combined overlapping phases as a daily maximum. For fugitive dust calculations during grading, the maximum amount of acres graded in a day is determined by the number of grading equipment which is assumed to operate for 8 hours.

5 Operational Mobile

CalEEMod calculates the emissions associated with on-road mobile sources. These are associated with residents, workers, customers, and delivery vehicles visiting the land use types in the project. The emissions associated with on-road mobile sources includes running and starting exhaust emissions, evaporative emissions, brake and tire wear, and fugitive dust from paved and unpaved roads. Starting and evaporative emissions are associated with the number of starts or time between vehicle uses. The assumptions used in determining these values are described below. All the other emissions are dependent on vehicle miles traveled (VMT). The methods and assumptions used by the program are described in the following sections.

5.1 Vehicle Trips

The first step in determining the number of starts and vehicle miles traveled is to determine the number of trips associated with the various project land uses. These trips are calculated based on either an average daily or a peak daily. The average daily is used when calculating annual emissions from a project, and peak daily is used when calculating peak daily summer or winter emissions. Since CalEEMod has different trip rates for different days of the week, the daily maximum will be determined based on the highest total of either weekday, Saturday, or Sunday trip emissions. To calculate average daily trips, the weekday trips are multiplied by five and added to the Saturday and Sunday trips, then divided by 7. The average daily trip rates for the individual land uses being modeled are used by CalEEMod in the calculation of a project's annual vehicle miles traveled and as just described are determined from the following equation:

$$\text{Average Daily Trip Rate}_i =$$

$$(Triprate_{Weekday} \times 5 + Triprate_{Sat} + Triprate_{Sun})_i / 7 \times LandUse_i$$

Where

Trip Rate = Weekday, Saturday, or Sunday daily trip generation rate

Land Use = Size metric for a land use type (e.g., number of dwelling units)

i = Land use type

For peak daily trips, CalEEMod chooses the highest trip rate amongst weekday, Saturday and Sunday data, and multiplies by the size metric to get total peak daily trips.

Trip rate describes the amount of trips generated by each land use. Multiplying trip rate per unit size of land use (e.g., per dwelling unit, per 1,000 sq. ft., etc.) by land use size yields total daily trips generated by each land use. The trip generation rates from the Institute of Transportation Engineers (ITE) are programmed into CalEEMod as the default values. Like all standard references, it should be noted that ITE has guidance about how their trip rates should be used. For example, some land uses (e.g., electronic superstore, fast food without drive-thru, general heavy industrial, government (civic center), hardware/paint store, movie theater without a matinee) are based on a limited number of survey samples so the user might consider obtaining more

refined trip rate information for their project. For more specific trip rate data than the default trip rates provided by CalEEMod, the user is encouraged to consult with licensed traffic engineers for guidance. CalEEMod allows the user to replace the default trip rates if more accurate, project-specific trip rate information is available. The user will be required to provide justification from alternative sources of data (e.g., project-specific traffic study) that demonstrate that a different trip rate is appropriate for the project being modeled. Metropolitan Planning Organizations (MPOs) may be another source of trip generation rates specific for the given region.

Trip Type

Once the total number of trips for a land use type is determined, the next step is to determine the trip type. The trip type breakdown describes the purpose of the trip generated at each land use. For example, the trip type breakdown indicates the percentage of trips generated at single family home for work, for shopping, and for other purposes. Multiplying the total trips for a land use by trip type breakdown percentage yields trips of a given trip type. Two sets of trip type breakdown are used in CalEEMod – residential breakdown and commercial breakdown.

Residential trip type: These include home-work (H-W), home-shop (H-S), or home-other (H-O). A home-work trip represents the trip from the home to the workplace. A home-shop trip represents the trip from the home to a land use where shopping takes place (generally retail). A home-other represents all other types of trips generated from the resident such as school, entertainment, etc. The default trip type breakdown is either from air district supplied information or the 1999 Caltrans Statewide Travel Survey. The default values are reported in Appendix D, Table 4.2. It is recommended that the District or Project Applicant go to accredited sources such as the regional Metropolitan Planning Organization (MPO) to obtain trip type breakdown specific for the given region. The trip type breakdown can be overwritten if users can provide sufficient justification for alternative sources of data (e.g., project-specific traffic study) that demonstrate a different breakdown.

Commercial trip type: These include commercial-customer (C-C), commercial-work (C-W) and commercial-nonwork (C-NW). A commercial-customer trip represents a trip made by someone who is visiting the commercial land use to partake in the services offered by the site. The commercial-work trip represents a trip made by someone who is employed by the commercial land use sector. The commercial-nonwork trip represents a trip associated with the commercial land use other than by customers or workers. An example of C-NW trips includes trips made by delivery vehicles of goods associated with the land use. The trip type breakdown from the number or workers and or truck trips from ITE and an analysis of information provided for the South Coast Air Basin was used as the default to assign the trip type breakdowns for all land uses and is reported in Appendix D, Table 4.3. If an exact match to a land use was not available, data from a similar land use was used as a surrogate. Trip type breakdown can be overwritten if users can provide justification for alternative sources of data (e.g., project-specific traffic study) that demonstrates different breakdown.

Primary Trip Lengths

Each trip type has a primary trip length associated with it. These trip lengths are based on the location and urbanization selected on the project characteristic screen. These values were supplied by the air districts or use a default average for the state, reported in Appendix D, Table

4.3. Each district (or county) also assigns trip lengths for urban and rural settings. For residential projects, average primary trip lengths of all trip types are determined with the below equation. Commercial and industrial land use types use a similar equation based on their trip types.

Average Primary Trip Length $_i$ =

$$H - W_{miles} \times H - W_{trip\%} + H - S_{miles} \times H - S_{trip\%} + H - O_{miles} \times H - O_{trip\%}$$

Where

H-W$_{miles}$	= Home to Work trip length
H-W$_{trip\%}$	= % of the total primary trips that are Home to Work trips
H-S$_{miles}$	= Home to Shopping trip length
H-S$_{trip\%}$	= % of the total primary trips that are Home to Shopping trips
H-O$_{miles}$	= Home to Other trip length
H-O$_{trip\%}$	= % of the total primary trips that are Home to Other trips
i	= land use type.

Primary, Pass-by and Diverted Trip Links

Trip link types further describe the characteristics of the trip attracted to each land use, whether it's a primary trip, a diverted link trip, or a pass-by trip. For example, a commercial customer pass-by trip could be a person going from home to shop on his/her way to work. In addition, a commercial customer diverted-link trip could be a person going from home to work, and on its way making a diversion to shop. Pass-by trips generate virtually no additional running emissions but could generate additional resting and startup emissions. Diverted trips generate fewer running emissions compared to primary trips, and can also generate additional resting and startup emissions. The average VMT associated with a trip is adjusted by modifying the primary trip length to account for reductions from pass-by and diverted trips. The trip lengths mentioned above are for primary trip links. For pass-by trip links the trip length will be 0.1 miles and diverted trip links the trip length will be 25% of the primary trip length. An average overall trip length can be calculated as follows:

Average Overall Trip Length $_i$ =

$$Link\%_{primary} \times TripLength_{Avg\,Primary} + Link\%_{diverted} \times 0.25 \times TripLength_{Avg\,Primary} + Link\%_{passby} \times 0.1\,mile$$

Where

Link %	= percentage of link types
Trip Length $_{AvgPrimary}$	= Average primary trip length for each trip type
i	= land use type

The trip link percentages from the ITE Trip Generation Manual and SANDAG are used as defaults, reported in Appendix D, Table 4.3. The trip link percentages can be overwritten if users can provide justification for alternative sources of data (e.g., project-specific traffic study) that demonstrate different breakdowns. If diverted or pass-by trips are not desired, the user can change the default percentages to zero for these and have primary trips equal 100%.

Vehicle Miles Traveled

The daily vehicle miles traveled (VMT_d) for a modeled project is calculated using the following equation which relies on the average daily trip rates and lengths calculated from the previous equations. CalEEMod calculates Annual VMT by multiplying VMT_d by 365 days/year.

$$VMT_d = \Sigma(\text{Average Daily Trip Rate }_i * \text{Average Overall Trip Length }_i)_n$$

Where:

n = Number of land uses being modeled.

The following screen shot shows an example of how CalEEMod calculated the Annual VMT for a single residential dwelling in an urban setting.
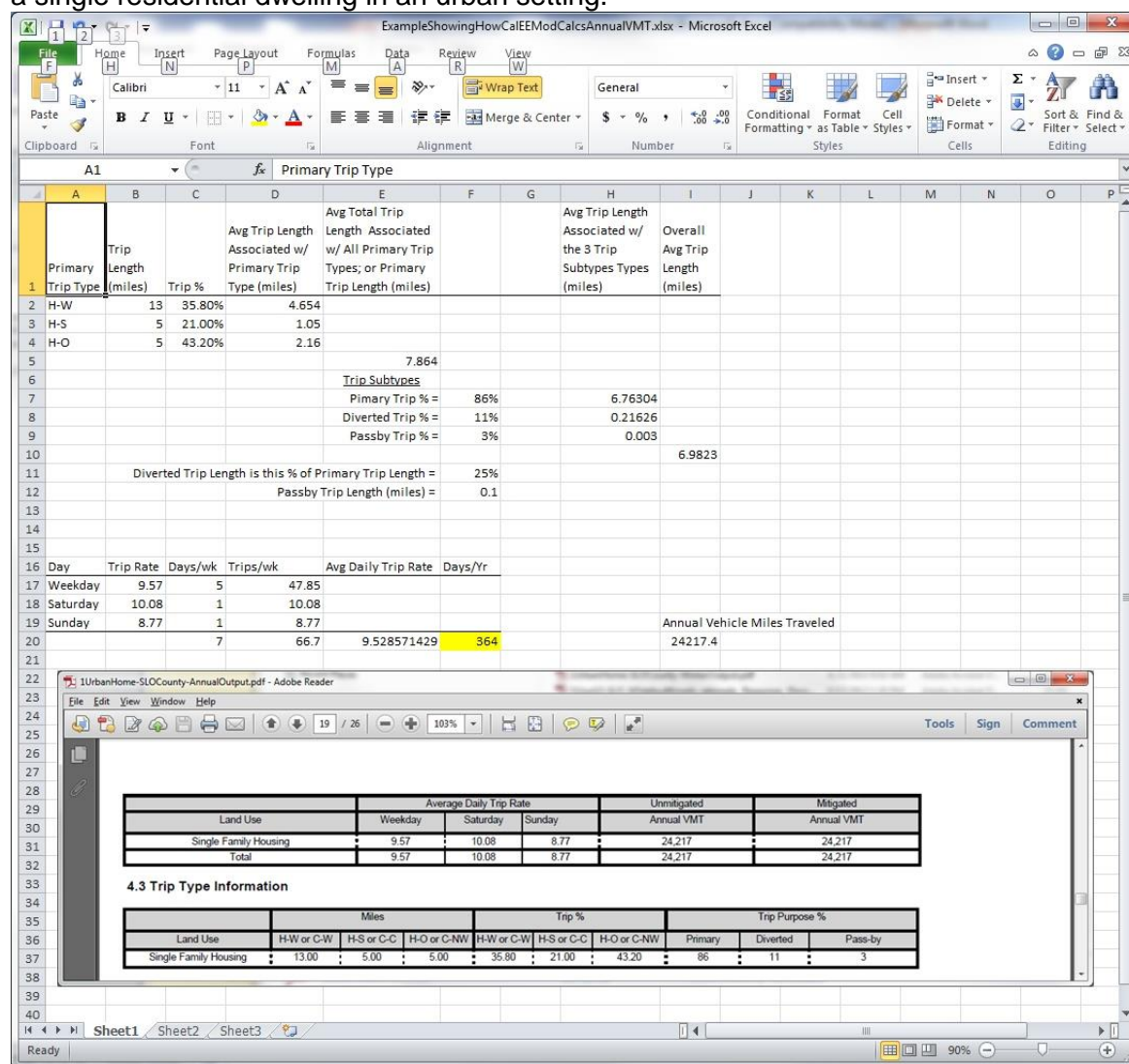
5.2 Methodology for Converting EMFAC2017 Emission Rates into CalEEMod Vehicle Emission Factors

The vehicle emission factors in CalEEMod are extracted from EMFAC2017 emission rate data (https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/msei-modeling-tools; https://www.arb.ca.gov/emfac/2017/). The EMFAC2017 emission rate data for each vehicle class includes multiple types of emissions that are presented with varying units. For example, running emissions are presented in units of grams per mile (g/mile), while starting emissions are presented in units of grams per trip (g/trip) and idling emissions are presented in units of grams per vehicle per day (g/vehicle/day), etc. However, not all of the emission rate data in EMFAC2017 is in a format that is compatible with the formats of CalEEMod vehicle emission factors. In addition, EMFAC2017 emission rate data is presented by both vehicle classes and fuel types while CalEEMod vehicle emission factors are an aggregation of all fuel types for each vehicle class. Thus, in order for all of the EMFAC2017 vehicle emission types to be processed in CalEEMod to yield emission factors for a particular vehicle and land use in the CalEEMod report, EMFAC2017 emission rate data is converted to create CalEEMod vehicle emission factors. After this conversion occurs, all of the emission types are then calculated by CalEEMod vehicle emission factors and vehicle activities and summed to yield one uniform data point with consistent units (e.g., in terms of pounds per day or tons per year). The following describes the methodology for how the EMFAC2017 emission rates are converted for incorporation into CalEEMod.

5.2.1 EMFAC2017 Emission Rate Raw Data

For each vehicle model year and type, the raw emission rate data were obtained from the EMFAC2017 web database for all counties, air basins, air districts and statewide average for all fuel types (e.g., gasoline, diesel, and electric). The emission rate values selected were from EMFAC2017's aggregated speed option.

5.2.2 EMFAC2017 Emission Rate Units versus CalEEMod Emission Factor Units

In CalEEMod, emission factors of running emissions for all pollutants and PM emissions from tire and brake wear are in units of grams per vehicle miles traveled (g/VMT). For all other emission types, the emission factors are in units of g/trip and these emission factors were derived as total emissions divided by the total number of trips.

The following table summarizes the acronyms, descriptions, and units of each vehicle emission type in EMFAC2017 and the corresponding units of the emission factor for each vehicle emission type as it is presented in CalEEMod:

EMFAC2017 Acronyms For Each Vehicle Emission Type	EMFAC2017 Description of Each Vehicle Emission Type	EMFAC2017 Emission Rate Unit	CalEEMod Emission Factor Unit
RUNEX	Running Exhaust	grams/mile	grams/mile
PMBW	PM Brakewear	grams/mile	grams/mile
PMTW	PM Tirewear	grams/mile	grams/mile
STREX	Start Exhaust	grams/trip	grams/trip
HTSK	Hot Soak Evaporative	grams/trip	grams/trip
RUNLS	Running Loss Evaporative	grams/trip	grams/mile
IDLEX	Idle Exhaust	grams/vehicle/day	grams/trip
RESTL	Resting Loss Evaporative	grams/vehicle/day	grams/trip
DIURN	Diurnal Loss Evaporative	grams/vehicle/day	grams/trip
VMT	Vehicle Miles Traveled	miles/day	miles (per day, per season, or per year)
Trip	Total trips per day of a vehicle class	trips/day	trips (per day, per season, or per year)
Population	Vehicle Population	vehicle	vehicle

5.2.3 Conversion from EMFAC2017 to CalEEMod

Because the EMFAC2017 emission rates are associated with vehicle fuel types while CalEEMod vehicle emission factors are aggregated to include all fuel types for each individual vehicle class, the EMFAC2017 emission rates for different fuel types of a vehicle class are averaged by activity or by population and activity to derive CalEEMod emission factors. The equations applied to obtain CalEEMod vehicle emission factors for each emission type are detailed below.

CalEEMod emission factors of all vehicle classes are calculated using data from EMFAC2017 according to the following equations:

$$RUNEX_{CalEEMod} = \sum_{fueltype}(RUNEX\_EmissionRate_i \times VMT_i) / \sum_{fueltype}VMT_i$$

$$PMBW_{CalEEMod} = \sum_{fueltype}(PMBW\_EmissionRate_i \times VMT_i) / \sum_{fueltype}VMT_i$$

$$PMTW_{CalEEMod} = \sum_{fueltype}(PMTW\_EmissionRate_i \times VMT_i) / \sum_{fueltype}VMT_i$$

$$STREX_{CalEEMod} = \sum_{fueltype}(STREX\_EmissionRate_i \times Trip_i) / \sum_{fueltype}Trip_i$$

$$HTSK_{CalEEMod} = \sum_{fueltype}(HTSK\_EmissionRate_i \times Trip_i) / \sum_{fueltype}Trip_i$$

$$RUNLS_{CalEEMod} = \sum_{fueltype}(RUNLS\_EmissionRate_i \times Trip_i) / \sum_{fueltype}VMT_i$$

$$IDLEX_{CalEEMod} = \sum_{fueltype}(IDLEX\_EmissionRate_i \times Population_i) / \sum_{fueltype}Trip_i$$

$$RESTL_{CalEEMod} = \sum_{fueltype}(RESTL\_EmissionRate_i \times Population_i) / \sum_{fueltype}Trip_i$$

$$DIURN_{CalEEMod} = \sum_{fueltype}(DIURN\_EmissionRate_i \times Population_i) / \sum_{fueltype}Trip_i$$

At the left side of the equations, $RUNEX_{CalEEMod}$, $PMBW_{CalEEMod}$, $PMTW_{CalEEMod}$, $STREX_{CalEEMod}$, $HTSK_{CalEEMod}$, $HTSK_{CalEEMod}$, $RUNLS_{CalEEMod}$, $IDLEX_{CalEEMod}$, $RESTL_{CalEEMod}$, and $DIURN_{CalEEMod}$ are CalEEMod vehicle emission factors while the right side of the equations refer to EMFAC2017 data of emission rates, VMT, vehicle population, and vehicle trips per day.

For example, the following equations illustrate how CalEEMod emission factors of RUNEX, STREX, and IDLEX emissions for LDA vehicles are derived from EMFAC2017 data:

$$RUNEX_{CalEEMod} = \frac{(RUNEX_{gas} \times VMT_{gas} + RUNEX_{DSL} \times VMT_{DSL} + RUNEX_{ELEC} \times VMT_{ELEC})}{(VMT_{gas} + VMT_{DSL} + VMT_{ELEC})}$$

$$STREX_{CalEEMod} = \frac{(STREX_{gas} \times Trip_{gas} + STREX_{DSL} \times Trip_{DSL} + STREX_{ELEC} \times Trip_{ELEC})}{(Trip_{gas} + Trip_{DSL} + Trip_{ELEC})}$$

$$IDLEX_{CalEEMod} = \frac{(IDLEX_{gas} \times Population_{gas} + IDLEX_{DSL} \times Population_{DSL} + IDLEX_{ELEC} \times Population_{ELEC})}{(Trip_{gas} + Trip_{DSL} + Trip_{ELEC})}$$

5.2.4 Diesel Fueled Heavy-Heavy Duty and Medium-Heavy Duty Truck Emission Factors

Previous versions of CalEEMod relied upon the EMFAC2011 and EMFAC2014 databases which include population data for the vehicle classes of heavy-heavy duty trucks (HHDT) and medium-heavy duty trucks (MHDT), but without trips per day data for diesel fueled HHDTs and MHDTs. As the equations in section 5.2.3 demonstrate, trips per day data are required for processing the following six emission types: STREX, HTSK, RUNLS, IDLEX, RESTL, and DIURN. As such, trips per day data for diesel heavy duty truck vehicle classes need to be obtained from other sources. In CalEEMod Version 2013.2.2, an estimated approximate 20 trips per day per vehicle of HHDTs and MHDTs was used. In CalEEMod Versions 2016.3.1 and 2016.3.2, a special handling was suggested by CARB and a 2.44 trips per day per vehicle of HHDT and MHDTs was used.[17]

CalEEMod Version 2020.4.0 relies upon the EMFAC2017 database whichincludes total trips per day and total population data such that the average trips per day per vehicle data for the diesel HHDT and MHDT vehicle classes can be directly calculated to approximately 10 trips per day per vehicle.

CalEEMod's trips per day per vehicle data in Version 2020.4.0 is less than the number in Version 2013.2.2 but greater than Versions 2016.3.1 and 2016.3.2 for the HHDT and MHDT vehicle classes. Further, the HHDT and MHDT NOx emission factors and resulting NOx emissions, for example are larger higher in Version 2020.4.0 than in Version 2013.2.2 but are less than Versions 2016.3.1 and 2016.3.2

5.2.5 CalEEMod Vehicle Emissions

The CalEEMod emissions from mobile sources are calculated using the CalEEMod emission factors described in the previous sections and user input trip rates and trip lengths.

For running emissions (RUNEX) and brake wear and tire wear emissions (PMBW and PMTW), pollutant emissions are calculated from VMT as follows:

$$Emissions_{pollutant} = VMT * EF_{pollutant}$$

Where:

$Emissions_{pollutant}$ = emissions for each pollutant

VMT = vehicle miles traveled (per day, per season, or per year)

$EF_{pollutant}$ = CalEEMod emission factor for each pollutant

For all other emission types, pollutant emissions are calculated from vehicle trip rates as follows:

$$Emissions_{pollutant} = Trip * EF_{pollutant}$$

---

[17] Appendix A of the User's Guide for Versions 2016.3.1 and 2016.3.2, which includes a discussion of the special handling procedures in Section 5.2.4 is archived and may be accesed from the Archive tab on www.caleemod.com.

Where:

Emissions$_{pollutant}$	= emissions for each pollutant
Trip	= vehicle trips (per day, per season, or per year)
EF$_{pollutant}$	= CalEEMod emission factor for each pollutant

5.3 Road Dust

Vehicles that drive on both paved and unpaved roads generate fugitive dust by dispersing the silt from the roads. The following equation is used to calculate the fugitive dust emissions associated with <u>paved roads</u>:

$$E_{ext} = [\ k\ (sL)^{0.91} \times (W)^{1.02}\ ]\ (1 - P/4N)$$

Where:

E_{ext} = annual or other long-term average emission factor in the same units as k

k = particle size multiplier for particle size range and units of interest (see below)

sL = road surface silt loading (grams per square meter) (g/m²)

W = average weight (tons) of *all the vehicles* traveling the road (2.4 tons)

P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period

N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly).

The above is the average emission factor by land use for paved roads. The default values for the required parameters are based on recommendations in AP-42. For daily emissions it is assumed to have no precipitation.

The following equation is used to calculate the fugitive dust emissions associated with <u>unpaved roads</u> (if the user does not check the box to select CARB's 2.0 lbs PM$_{10}$/VMT option, which is only for San Luis Obispo County APCD and Sacramento Metropolitan AQMD):

$$E.F._{dust,i} = \left(\frac{k(s/12)^1 (S/30)^{0.5}}{(M/0.5)^{0.2}} - C \right) \left(1 - \frac{P}{365} \right)$$

Where:

k = particle size multiplier for particle size range and units of interest (see below)

s = surface material silt content (%)

M = surface material moisture content (%)

S = mean vehicle speed (mph)

C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear, and

P = number of days in a year with at least 0.254 mm (0.01 in) of precipitation

The above is the average emission factor by land use for unpaved roads. For daily emissions it is assumed to have no precipitation.

By default, CalEEMod assumes the percentage of paved and unpaved roads for each district as provided by the district, noted in Appendix D, Table 4.1. The user is allowed to modify the percentage of unpaved roads if project specific information is available.

Once emission factors are determined, dust emissions can be calculated by

$$\text{Emissions}_{dust} = \sum_i (\text{E.F.}_{dust,i} \times \text{VMT})$$

The VMT is the same used in vehicle trips.

5.4 Operational Off-Road Equipment

CalEEMod also calculates emissions from off-road equipment (e.g., forklifts, cranes, loaders, generator sets, etc.) used during the operation of the land use being analyzed. This is an optional calculation so the user would need to provide the type and number of off-road equipment being used during operation. From that information, CalEEMod provides horsepower, load factor, hours of operation and fuel type. The user has the ability to replace the defaults with project-specific data.

The emission factors are from OFFROAD2011. Please refer to Section 4.2 for the equations used for calculating emissions from off-road equipment.

6 Area Sources

The area source module is used to calculate direct sources of air emissions located at the project site. This includes hearths, consumer product use, architectural coatings, and landscape maintenance equipment. This does not include the emissions associated with natural gas usage in space heating, water heating, and stoves as these are calculated in the building energy use module (see Section 7).

6.1 Hearths

GHG emissions from the combustion of wood or biomass are calculated and are considered biogenic emissions of CO_2. Some protocols do not consider these emissions to be a part of the emission inventory. Therefore, these CO_2 emissions will be kept distinct from the anthropogenic GHG emissions. The method to calculate the criteria and biogenic GHG emissions associated with wood stoves is shown. Emissions from wood stoves are calculated using the formula below for each wood stove type:

$$\text{Wood hearth emissions (MT/year)} = \text{Emission Rate (g } CO_2 \text{ per kg wood burned)} \times \text{Wood Burned (tons per year)} \times \frac{907{,}185}{\text{g/ton}} \times \text{number of stoves} \times \frac{1 \text{ MT } CO2}{1 \times 10^6 \text{ g } CO2}$$

where:

Emission Rate = Based on AP-42[18]

Wood Burned = Weight of wood burned per year per residential unit

Number of stoves = Number of this type of stove in the project

Using the formula above and the number of residential units with wood stoves, it is possible to estimate the GHG emissions from wood stoves. Default values for the emission factors and the amount of wood burned by different hearth types and the percentage of different hearths in various areas of California are based on CARB, USEPA, and air district supplied emission factor values for hearths and woodstoves. The number of wood stoves or hearths is based on percentages supplied by districts or state defaults. Appendix D, Tables 5.1 and 5.2 contain the default data for hearths. If applicable, CalEEMod incorporates the restrictions on the number of wood burning fireplaces and stoves from SJVUAPCD Rule 4901 Amended 10/16/2008. For projects in the San Luis Obispo region, the wood burned per year is 2,016.5 lbs/year (3,081 lbs/cord X 0.6545 cords/year). For visual clarification, a standard cord of wood is defined as a stack of wood with a volume of 128 cubic feet (4 ft. x 4 ft. x 8 ft.)

---

[18] USEPA AP-42, Chapter 1.9 (https://www.epa.gov/sites/production/files/2020-09/documents/1.9_residential_fireplaces.pdf) and Chapter 1.10 (https://www.epa.gov/sites/production/files/2020-09/documents/1.10_residential_wood_stoves.pdf)
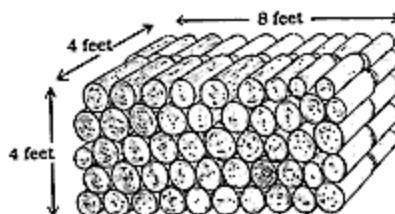
Criteria pollutant emissions from wood stoves or hearths are computed by CalEEMod in a similar manner with emission factors from AP-42.[19]

Natural Gas Fireplaces/Stoves

GHG emissions associated with natural gas fired fireplaces are calculated using emission factors from the California Climate Action Registry (CCAR). The criteria pollutant emission factors are based on AP-42. The average heating rate in British Thermal Units (BTU) per hour for fireplaces in homes is 60,000 BTU/hr.[20] Default values for annual fireplace usage needs to be determined for each county. Natural gas is assumed to have 1,020 BTU per standard cubic foot.[21] Criteria pollutant emissions from natural gas fireplaces/stoves are computed by CalEEMod in a similar manner with emission factors from AP-42.[20]

6.2 Consumer Products

Consumer products are chemically formulated products used by household and institutional consumers, including, but not limited to, degreasers, fertilizers/pesticides, detergents; cleaning compounds; polishes; floor finishes; cosmetics; personal care products; home, lawn, and garden products; disinfectants; sanitizers; aerosol paints; and automotive specialty products; but does not include other paint products, furniture coatings, or architectural coatings. South Coast AQMD conducted an evaluation of consumer product use compared to the total square footage of buildings using data from CARB's consumer products Emission Inventory. Trinity and South Coast AQMD performed an evaluation of degreaser use for parking lots and pesticide/fertilizer use for City Parks/Golf Courses. These analyses can be found in Appendix E.3. To calculate the ROG emissions from consumer product use, the following equation is used:

$$Emissions = EF \ x \ Building \ Area$$

Where:

EF = pounds of VOC per building square foot per day

The emission factor is 2.14×10^{-5} lbs/sq. ft./day for every region except South Coast AQMD.

The factor is 2.04×10^{-5} lbs/sq. ft./day for projects located within the South Coast AQMD jurisdiction.

Building Area = The total square footage of all buildings including residential square footage.

---

[19] USEPA AP-42, Chapter 1.9. Page 3, Table 1.9-1 (https://www.epa.gov/sites/production/files/2020-09/documents/1.9_residential_fireplaces.pdf) and Chapter 1.10 (https://www.epa.gov/sites/production/files/2020-09/documents/1.10_residential_wood_stoves.pdf)

[20] South Coast AQMD Final Environmental Assessment for Proposed Rule 445 – Wood Burning Devices, March 2008. Available at: http://www.aqmd.gov/docs/default-source/ceqa/documents/aqmd-projects/2008/final-environmental-assessment-for-proposed-rule-445.pdf

[21] USEPA. 1998. AP-42 Emission Factors. Chapter 1.4 Natural Gas Combustion, Pages 5-6, Tables 1.4-1 and 1.4-2, https://www.epa.gov/sites/production/files/2020-09/documents/1.4_natural_gas_combustion.pdf.

6.3 Architectural Coatings

VOC off-gassing emissions result from evaporation of solvents contained in surface coatings such as in paints and primers. The program calculates the VOC evaporative emissions from application of residential and non-residential surface coatings using the following equation:

$$E_{AC} = EF_{AC} \times F \cdot A_{paint} \times Reapplication$$

Where:
> E = emissions (lb)
>
> EF = emission factor (lb/sq. ft.)
>
> F = fraction of surface area. The default values are 25% for the exterior surface and 75% for the interior, which are based on an analysis conducted by South Coast AQMD.
>
> A = building surface area (sq. ft.). The program assumes the total surface area for painting equals 2.7 times the floor square footage for residential land use and 2 times the floor square footage for nonresidential land use.[22] All land use information provided by a metric other than square footage will be converted to square footage using the default conversions or user-defined equivalence. Green area of City Parks/Golf Courses, pool surface area of Recreational Swimming Pools, and Parking surface area square footage are excluded from building floor square footage.
>
> Reapplication = Rate at which surfaces are repainted.

The emission factor is based on the VOC content of the surface coatings and is calculated by using the following equation:

$$EF_{AC} = C_{VOC} / 454(g/lb) \times 3.785(L/Gal)/180(sqft)$$

Where:
> EF = emission factor (lb/sq. ft.)
>
> C = VOC content (g/L). This typically varies by air district and year.

CalEEMod also calculates the VOC emissions from the painting of stripes, handicap symbols, directional arrows, and car space descriptions in parking lots. See Appendix E.7 for the studies conducted to determine a default percent of parking lot square footage that is painted. The equation for estimating striping emissions is the same as the equation for E_{AC} above, except that A_{paint} is calculated using the following equation:

$$A_{paint} = A_{PL} \times P\%$$

Where:
> A_{PL} = Parking lot area (sq. ft.)
>
> $P\%$ = Default percent of parking lot area that is painted (6%)

The VOC content limit for parking area coatings is either provided by local air districts or based on the exterior coating VOC limit of the area where the project is located, as noted in Appendix

---

[22] The factors 2.7 and 2 are from Table A9-13-C on page A9-124 of South Coast AQMD's 1993 CEQA Air Quality Handbook.

D, Table 6.1. If the user has more specific VOC content limit on the coating being applied, the default can be overridden but the user is expected to explain and justify the change in the "Remarks" box at the bottom of the screen.

Reapplication rate

All land use buildings are assumed to be repainted at a rate of 10% of area per year, based on the assumptions used by South Coast AQMD.

6.4 Landscape Equipment

Landscape maintenance includes fuel combustion emissions from equipment such as lawn mowers, roto tillers, shredders/grinders, blowers, trimmers, chain saws, and hedge trimmers, as well as air compressors, generators, and pumps. The emissions from landscape equipment use were processed using OFFROAD 2011 and CARB's Technical Memo: Change in Population and Activity Factors for Lawn and Garden Equipment (June 13, 2003[23]). The information was used along with the total building square footage and dwelling units in California to determine two emission factors. The first is for the commercial landscape equipment which is in terms of grams per square foot of non-residential building space per day. The second is the for the residential landscape equipment which is in terms of grams per dwelling unit per day. These emission factors are multiplied by the number of summer days or winter days that represent the number of operational days. For example, pieces of equipment that would typically be used in snow conditions were used with winter days this includes equipment such as snow blowers while all others were used with summer days. For some regions which do not have snow during winter, whereby the number of actual days for the purpose of calculating landscaping emissions is typical of summer weather, at either 330 or 365 days per year (e.g., South Coast, Sacramento, San Joaquin Valley) unless specified by the air district, CalEEMod applies a default of 250 days per year since non-residential (e.g., commercial land uses) landscaping equipment would likely only operate during the week, not weekends (see Appendix D, Table 7.1).

---

[23] https://ww3.arb.ca.gov/msei/2001_residential_lawn_and_garden_changes_in_eqpt_pop_and_act.pdf

7 Energy Use

Criteria pollutants and GHGs are emitted as a result of activities in buildings that consume energy in the form of natural gas and electricity.

Combustion of any type of fuel, including natural gas, emits criteria pollutants and GHGs directly into the atmosphere. When this occurs within buildings, it is considered a direct emission source[24] associated with that building, and the program will calculate emissions of all of criteria pollutants and GHGs accordingly. Fuel oil, kerosene, and liquefied petroleum gas can also be used as fuel in buildings, but are not widely used in California compared to natural gas. As such, CalEEMod does not calculate emissions from combustion of these fuels within buildings. Emissions from wood combustion in wood burning stoves and fireplaces is calculated under the Area Source category of Hearths (See Section 6.1).

Criteria pollutants and GHGs are also emitted during the generation of electricity at fossil fuel power plants. When electricity is used in buildings, the electricity generation typically takes place offsite power plants, the majority of which burn fossil fuels. Because power plants are existing stationary sources permitted by air districts and/or the USEPA, criteria pollutant emissions are generally associated with the power plants themselves, and not individual buildings or electricity users. Additionally, criteria pollutant emissions from power plants are subject to local, state, and federal control measures, which can be considered as the maximum feasible level of mitigation for stack emissions.

In contrast, GHG emissions from power plants are not subject to stationary source permitting requirements to the same degree as criteria pollutants. Likewise, it is difficult to mitigate GHG emissions emitted at power plants using exhaust after treatment control technologies. The most effective way to control GHGs from power plants is to reduce electricity demand. As such, GHGs emitted by power plants may be indirectly attributed to individual buildings and electricity users, who have the greatest ability to decrease usage by applying mitigation measures to individual electricity "end uses." The program therefore calculates GHG emissions (but not criteria pollutant emissions) from regional power plants associated with building electricity use.

Since 1978, the CEC has established building energy efficiency standards with the aim of conserving the state's electricity and natural gas resources. The standards are contained Title 24 of the California Code of Regulations (The Building Standards Code) and are updated periodically. The 2005 standards were relied upon during the formation of CARB's initial AB 32 Scoping Plan and were subsequently revised in 2008[25], 2013[26], 2016[27], and 2019[28].

---

[24] California Climate Action Registry (CCAR) General Reporting Protocol (GRP), Version 3.1 (January). Available at: http://sfenvironment.org/sites/default/files/fliers/files/ccar_grp_3-1_january2009_sfe-web.pdf Chapter 8

[25] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/past-building-energy-efficiency

[26] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/past-building-energy-efficiency

[27] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2016-building-energy-efficiency

[28] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency

CalEEMod 2020.4.0 has the capability of calculating building energy use incorporating only the 2005 Title 24 standards and the capability of calculating building energy use incorporating the 2005, 2008, 2013, 2016 and 2019 Title 24 standards. The option of calculating energy use up to the 2005 Title 24 standards would be used in some air districts that have adopted CEQA thresholds and/or guidance linked to values from CARB's initial AB 32 Scoping Plan. To use this option, users must check the "using historical data" box. Once the box is clicked, the user then must click the "Default" button to download the historical (2005) data. If the "using historical data" box is NOT checked, CalEEMod Version 2020.4.0 estimates the building energy use based on the application of the 2005, 2008, 2013, 2016, and 2019 standards.

Energy use in buildings (both natural gas and electricity) is divided by the program into end use categories subject to Title 24 requirements (end uses associated with the building envelope, such as the HVAC system, water heating system, and integrated lighting) and those not subject to Title 24 requirements (such as appliances, electronics, and miscellaneous "plug-in" uses).

The program will calculate the emissions associated with buildings by multiplying the natural gas use by appropriate emission factors and by multiplying electricity use by the GHG intensity factors of the utility selected on the Project Characteristics screen. The following sections describe the methodologies used to estimate building energy use and emissions.

7.1 Estimating Non-residential Building Energy Use

The program uses the California Commercial End Use Survey (CEUS)[29] database to develop energy intensity values (electricity and natural gas usage per square foot per year) for non-residential buildings.

The CEUS data lists energy use intensity by building type, "end-use," and CEC forecasting climate zone.[30] Each nonresidential land use in CalEEMod is matched to the appropriate CEUS building type. The CEUS end uses are grouped according to whether the end use is subject to Title 24 building requirements or not.

Appendix E.5 describes in detail the method used to analyze the CEUS data.

7.2 Estimating Residential Building Energy Use

The program uses data collected during the Residential Appliance Saturation Survey (RASS) to develop energy intensity values (electricity and natural gas usage per dwelling unit per year) for residential buildings.

Similar to the CEUS, the RASS data[31] lists energy use intensity by building type, "end-use," and CEC forecasting climate zone.[32] Each residential land use in CalEEMod is matched to the

---

[29] California Energy Commission (CEC). California Commercial End-Use Survey Results.
https://www.energy.ca.gov/data-reports/surveys/california-commercial-end-use-survey
[30] A few climate zones were not included in the CEUS data. These climate zones will be mapped to another related climate zone that was included in the data.
[31] Workbooks downloaded from https://www.energy.ca.gov/data-reports/surveys/2019-residental-appliance-saturation-study for all building categories
[32] A few climate zones were not included in the RASS data. These climate zones will be mapped to another related climate zone that was included in the data.

appropriate RASS residence type. The RASS end uses are grouped according to whether the end use is subject to Title 24 building requirements or not.

Appendix E.5 describes in detail the method used to analyze the RASS data.

7.3 Estimating Energy Use from Other Land Uses

There are a few remaining land use categories that are not included in the CEUS or RASS data. These include golf courses, parks, and recreational pools. These currently do not have associated default energy use values within the program; however, users may enter non-default values estimated apart from the program.

For parking lots, several studies have been published regarding the energy use from lighting, ventilation and elevators in parking lots and structures. This data has been incorporated into the program to calculate electricity use, based on the type of parking lot selected by the user: Open Parking Lot, Unenclosed Parking Structure, Unenclosed Parking Structure with Elevators, Enclosed Parking Structure, or Enclosed Parking Structure with Elevators.

Appendix E.6 contains further information regarding the assessment of the electricity usage by parking lots and structures, as well as guidance for overriding the default values (e.g., if the number of elevators is known).

The following table provides a summary of the energy use factors included in CalEEMod for parking lots and structures, depending on the type selected by the user.

Type of Parking Lot	Electricity Use	Annual Energy Use (kWh/sq ft)
Open parking lot	Lighting	0.345
Unenclosed parking structure	Lighting	1.75
Enclosed parking structure	Lighting, ventilation	5.67
Parking structure with elevators	Elevators	0.19

7.4 Calculating Emissions from Energy Use

As previously discussed, natural gas use will contribute to both criteria and GHG emissions. The emission factors for natural gas combustion are from AP-42 and the CCAR. Electricity use will contribute to GHG emissions only.

Emissions from natural gas and electricity use are calculated by the program for each land use using the following equations. (See section 8.2 for further information about electricity carbon intensity).

$$\text{Natural Gas Emissions}_i = \Sigma_j \, (EF_i \times \text{Energy Intensity} \times \text{Size})$$

Where:

EF	= emission factor based on AP-42 or CCAR (lbs/kBTU)
Energy Intensity	= natural gas energy intensity for a land use (kBTU/sq.ft. or kBTU/DU)
Size	= size metric (square feet or dwelling units)
i	= each criteria and GHG pollutant
j	= land use type

$$\text{Electricity Emissions} = \Sigma_i \, (\text{Utility} \times \text{Energy Intensity} \times \text{Size})$$

Where:

Utility	= Carbon intensity of Local Utility (CO_2e/kWh)
Energy Intensity	= electricity energy intensity for a land use (kWh/sq.ft. or kWh/DU)
Size	= size metric Dwelling units (square feet or dwelling units)
i	= land use type

8 Water and Wastewater

The amount of water used and wastewater generated by a project has indirect GHG emissions associated with it. These emissions are a result of the energy used to supply, distribute, and treat the water and wastewater. It will often be the case that the water treatment and wastewater treatment occur outside of the project area. In this case, it is still important to quantify the energy and associated GHG emissions attributable to the water use. In addition to the indirect GHG emissions associated with energy use, wastewater treatment can directly emit both methane and nitrous oxide.

8.1 Annual Indoor and Outdoor Water Use by Land Use Category

Total residential indoor and outdoor water use for all of California for the year 2000 is reported in Table ES-1 of the Pacific Institute "Waste Not Want Not" report.[33] These values were divided by the total number of occupied households in California in the year 2000[34] to give water demand per dwelling unit. The water use values are assumed to be representative of all residential dwelling unit types (single-family, apartment, condo, etc.) and will be used unless alternate values are supplied by the air districts or the user.

Data for most commercial and industrial land uses was obtained from Appendices E and F of the Pacific Institute's "Waste Not Want Not" report.[35] Total gallons of water used per day per metric were reported, where the metric is employee, student, room, acre, or square foot, depending on the land use. For example, water use at office and retail land uses was reported in a metric of gallons per employee per day, while water use at hotels and motels was reported in a metric of gallons per room per day. The total daily water use was converted to annual water use based on the number of days of operation for that land use. For example, it was assumed that schools operate for 180 days per year while offices operate for 225 days per year (excluding weekends and holidays). The figures in Appendices E and F of the Pacific Institute report shows the percent of water use dedicated to landscape irrigation; this percent was multiplied by the total water use to obtain the outdoor water use. The remainder was assigned to indoor water use.

For a few land uses (library, place of worship, movie theater, arena, and civic center), the Pacific Institute report did not provide sufficient data, therefore the American Water Works Association Research Foundation's Commercial and Institutional End Uses of Water report[36] was used. This data is specific to Southern California and was obtained from sample sizes ranging from 1 to 26. In all cases, the total gallons of water used per employee per day was reported.

Specifically, for industrial land use categories, the default indoor water use rate is 231,250 gallons/work-year/ thousand square feet. This value was computed by dividing the annual water

---

[33] Gleick, P.H.; Haasz, D.; Henges-Jeck, C.; Srinivasan, V.; Cushing, K.K.; Mann, A. 2003. Waste Not, Want Not: The Potential for Urban Water Conservation in California. Published by the Pacific Institute for Studies in Development, Environment, and Security. Full report available online at: http://www.pacinst.org/reports/urban_usage/waste_not_want_not_full_report.pdf. Appendices available online at: http://pacinst.org/publication/waste-not-want-not/

[34] US Census Bureau. 2000 Census. Table QT-H1: General Housing Characteristics 2000.

[35] Gleick et al. 2003. Appendices E and F.

[36] Dziegielewski; B.; Kiefer, J.C.; Optiz, E.M.; Porter, G.A.; Lantz, G.L.; DeOreo, W.B.; Mayer, P.W.; Nelson, J.O. 2000. Commercial and Institutional End Uses of Water. Published by the American Water Works Association Research Foundation.

use in California industry (Table ES-6 in Gleick et al. 2002; 963,071,916 gallons/industrial work day) by the industrial work area in California (Dun & Bradstreet, Business Population Report aggregated by Standard Industrial Classification (SIC) and Census Block, May 2002; 1,041,386 thousand square feet). This yields 925 gallons/work-day/thousand square feet and the annual value is derived using 250 workdays in a year. For those industrial projects where the anticipated water use rate is known or can be estimated from similar projects, the project specific indoor water use rate should overwrite the default value and specific rationale needs to be entered in the Remarks section of the Water and Wastewater CalEEMod input page.

Indoor water end-use intensities were also obtained from the Pacific Institute report.[37] End-use categories include toilets, showerheads, bathroom faucets, kitchen faucets, dishwashers, clothes washers, and leaks. End-use intensity is given in terms of percent of total indoor water use. For example, the Pacific Institute estimates that toilets contribute to 33% of indoor residential water use. Water end-use intensity must be known in order to calculate the expected water and GHG savings from installing low-flow or high-efficiency water fixtures.

8.2 Electricity Intensity Factors

Electricity intensity factors were obtained from the 2006 CEC report, "Refining Estimates of Water-Related Energy Use in California." The electricity intensity factors are reported in units of kWh per million gallons (MG) of water used, and represent the amount of electricity needed to: 1) supply and convey the water from the source; 2) treat the water to usable standards; and 3) distribute the water to individual users. The sum of these factors gives the total electricity required to supply, treat, and distribute water for outdoor uses. For indoor uses, the electricity needed to process the resulting wastewater is also included. The program will allow the user to input project specific electricity intensity factors if they are available for the project.

CO_2e emissions associated with *indoor water use* are calculated according to the following equation:

$$\text{GHG emissions} = \text{Water}_{indoor} \times \text{Electricity}_{indoor} \times \text{Utility}$$

Where:

GHG emissions	=	Tonnes CO_2e
Water_{indoor}	=	Total volume of water used indoors (million gallons)
$\text{Electricity}_{indoor}$	=	Electricity required to supply, treat, and distribute water and the resulting wastewater (kWh/million gallons). This is assigned for each location.
Utility	=	Carbon intensity of Local Utility (CO_2e/kWh)

---

[37] Gleick et al. 2003. Residential end-use intensities found in Figure 2-4c of main report. Commercial end-use intensities found in Appendix E.

CO_2e emissions associated with *outdoor water use* are calculated according to the following equation:

$$GHG\ emissions = Water_{outdoor} \times Electricity_{outdoor} \times Utility$$

Where:

GHG emissions	=	Tonnes CO_2e
$Water_{outdoor}$	=	Total volume of water used outdoors (million gallons)
$Electricity_{outdoor}$	=	Electricity required to supply, treat, and distribute water (kWh/million gallons). This is assigned for each location.
Utility	=	Carbon intensity of Local Utility (CO_2e/kWh)

The sum of emissions from indoor and outdoor water use for each land use category gives the total CO_2e emissions associated with water use at the project.

8.3 Wastewater Treatment Methods by County and Air District

Depending on the method, the treatment of wastewater can produce methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions, which are all greenhouse gases. Methane and nitrous oxide emissions are converted to carbon dioxide equivalent (CO_2e) emissions based on their GWP. When a development project generates waste and wastewater, the waste is typically either treated on-site in septic tanks or sent to a centralized wastewater treatment plant to be treated by one of several possible methods. The various wastewater treatment methods employed in each county or air district and the percent of total wastewater treated by each method was used if provided, otherwise the default percentage used in ARB's GHG emission inventories was used. Wastewater treatment methods include on-site septic tanks and centralized wastewater treatment plants which may be composed of aerobic processes or facultative lagoons. The solids from the latter two treatments could be digested anaerobically to produce digester gas. In some cases, the combusted digester gas may be part of a cogeneration system which recovers the heat generated from combustion and generates electricity which is used for on-site processes. Thus, for aerobic and facultative lagoons wastewater treatment, digestion (*listed in the last two columns on the wastewater screen*) should equal 100% percent. For septic systems, the digestion could be zero percent or 100 percent.

The majority of nitrous oxide emissions are generated when treated wastewater is discharged to water bodies as effluent. The default assumption is for non-recycled water. The program calculates total GHG emissions from wastewater treatment based on the region-specific distribution of wastewater treatment methods which the user can modify with project specific data. Default data is provided in Appendix D, Tables 9.3.

8.4 Wastewater Treatment Methods – Calculation of Greenhouse Gas Emissions

The GHGs emitted from each type of wastewater treatment are based on the CARB's Local Government Operations Protocol (LGOP)[38], which are in turn based on USEPA methodologies.[39] The methodologies are summarized below.

Wastewater (or sewage) treatment can occur one of three ways - aerobically, in septic tanks or in facultative lagoons, specifically described below. In CalEEMod, the following defaults for sewage treatment options were used unless an air district provided an alternative percentage of treatment appropriate to the particular project region (see Appendix D, Table 9.3). The user has the ability to replace the defaults with project-specific percentages but the total percentage must equal 100% and must justify the reason for the change in the "Remarks" box at the bottom of the screen.

Statewide Default Treatment Distribution		
Septic Tank (%)	Aerobic (%)	Facultative Lagoons (%)
10.33	87.46	2.21

Solids produced from primary treatment, aerobic processes, or facultative lagoons are typically digested in anaerobic digesters. The gas produced by these digesters may be flared or burned in some other simple device, or sent to a cogeneration process for heat recovery and/or electrical generation. The default condition is to assume no cogeneration; however, CalEEMod allows the user to input an estimate of the percentage of the digester gas combusted in such systems ranging from 0% to 100%.

Anaerobic decomposition in septic tanks and facultative lagoons can produce fugitive emissions of methane. The following figure provides an example of the process flow for a centralized wastewater treatment facility that treats the sewage aerobically, produces digester gas in anaerobic digesters and combusts the gas. The figure also shows where the GHG emissions are occurring in the process.

---

[38] https://www.arb.ca.gov/cc/protocols/localgov/localgov.htm
[39] https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-archive
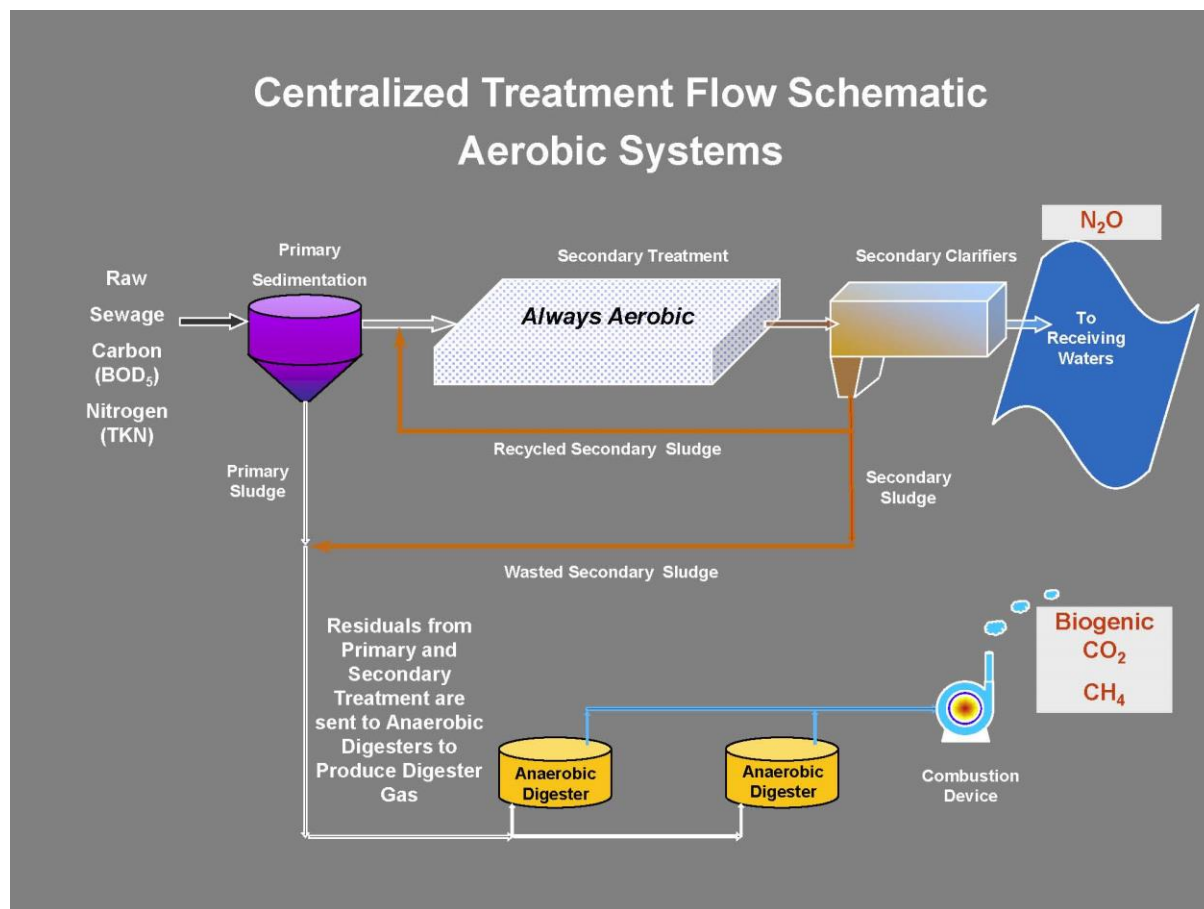
As depicted in the figure above, nitrous oxide is produced when treated wastewater is released as effluent into aquatic environments such as rivers and estuaries. Although the nitrification/denitrification processes within the wastewater treatment plant may also produce nitrous oxide, the USEPA estimated that this contributed to less than 3% of national N_2O emissions associated with wastewater in 2005.[40] Therefore, the program assumes that all N_2O emissions are generated from effluent discharged into aquatic environments.

CO_2 emissions are generated from both aerobic and anaerobic processes, as well as from the combustion of digester gas, but CalEEMod only calculates combustion emissions because there are currently no authoritative emission factors for process CO_2 emissions. When digester gas is combusted to generate electricity, fossil fuel emissions are offset by this renewable power generation. CalEEMod allows the user to provide an estimate of how much renewable power is expected from the project and will debit the biogenic combustion CO_2 with the CO_2 that would otherwise have been sourced from fossil fuel combustion.

---

[40] USEPA. 2008. p. 8-7.

Septic Systems

Developments may use *septic systems* to treat wastewater on-site. These systems utilize microbes to decompose wastewater anaerobically. A by-product of this anaerobic decomposition is methane, which is quantified using Equation 10.5 from LGOP:
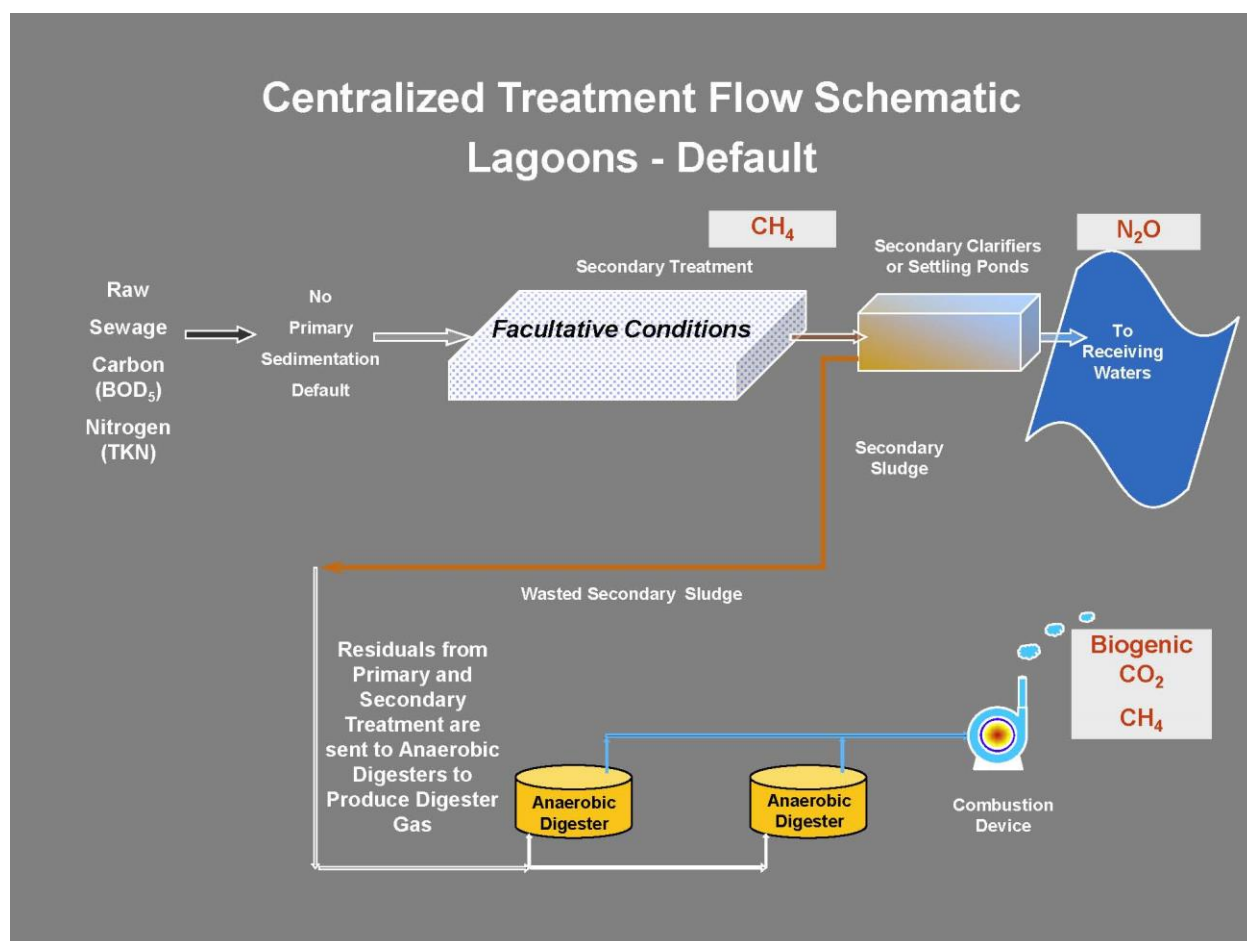
$$CH_4 \text{ emissions (MT)} = \text{Wastewater x } BOD_5 \text{ load x } 10^{-6} \text{ x } Bo \text{ x } MCF_{septic} \text{ x}10^{-3}$$

Term		Description	Value	Unit	Reference
Wastewater	=	volume of wastewater	INPUT	liters	User
BOD_5 load	=	concentration of BOD_5 in wastewater	200	mg / liter wastewater	
10^{-6}	=	conversion factor	--	kg / mg	--
Bo	=	maximum CH4-producing capacity for domestic wastewater	0.6	kg CH_4 / kg BOD_5 removed	LGOP default
MCF_{septic}	=	CH_4 correction factor for septic systems	0.5	--	LGOP default
10^{-3}	=	conversion factor	--	MT / kg	--

The LGOP provides default values for all terms in the equation except BOD_5 load, which is the amount of BOD_5 sent to these decentralized systems per day. BOD, or Biochemical Oxygen Demand, measures the degradable organic component of the wastewater that could deplete dissolved oxygen in receiving waters if left untreated (BOD_5 is the measurement of dissolved oxygen depletion from a liquid sample held for a 5-day test). The program assumes a default BOD_5 load value of 200 mg per liter of wastewater. This value is typical for residential and commercial wastewater. A higher value is typically associated with certain types of industrial wastewater.

Facultative Lagoons

Centralized wastewater treatment facilities may use *facultative lagoons* to treat wastewater. The following figure is an example of the treatment process if facultative lagoons provide the secondary treatment assuming process solids are sent to anaerobic digesters and the digester gas is combusted. In addition, the following figure shows where the GHG emissions are occurring in the process.

The methane emissions expected from facultative lagoons are calculated using Equation 10.3 from LGOP:

$$CH_4 \text{ emissions (MT)} = \text{Wastewater} \times BOD_5 \text{ load} \times 10^{-6} \times (1-F_P) \times Bo \times MCF_{anaerobic} \times F_{removed} \times 10^{-3}$$

Term		Description	Value	Unit	Reference
Wastewater	=	volume of wastewater	INPUT	liters	User
BOD_5 load	=	concentration of BOD_5 in wastewater	200	mg / liter wastewater	
10^{-6}	=	conversion factor	--	kg / mg	--
F_P	=	fraction of BOD_5 removed in primary treatment	0	--	no primary treatment
Bo	=	maximum CH_4-producing capacity for domestic wastewater	0.6	kg CH_4 / kg BOD_5 removed	LGOP default
$MCF_{anaerobic}$	=	CH_4 correction factor for anaerobic systems	0.8	--	LGOP default

$F_{removed}$	=	fraction of overall lagoon BOD_5 removal performance	1	--	LGOP default (see Eq. 10.4)
10^{-3}	=	conversion factor	--	MT / kg	--

The LGOP provides default values for all terms in the equation except BOD_5 load and F_P, the fraction of BOD_5 removed in primary treatment, if present. As before, the program assumes a default BOD_5 load value of 200 mg per liter of wastewater. The program assumes $F_P = 0$, indicating no primary treatment.

Anaerobic Digestion

Anaerobic digesters produce methane-rich biogas which is typically combusted on-site. In some cases the biogas is combusted simply for the purpose of converting methane to CO_2, which has a lower global warming potential than methane. In many cases, a cogeneration system is used to harvest the heat from combustion and use it to generate electricity for on-site energy needs. In both cases, inherent inefficiencies in the system result in incomplete combustion of the biogas, which results in remaining methane emissions. The methane emissions from incomplete combustion of digester gas are quantified using Equation 10.1 from LGOP:

CH_4 emissions (MT) = Wastewater x Digester Gas x F_{CH4} x ρ_{CH4} x (1-DE) x 0.0283 x 10^{-3} x 10^{-3}

Term		Description	Value	Unit	Reference
Wastewater	=	volume of wastewater	INPUT	gallons	User
Digester Gas	=	volume of biogas generated per volume of wastewater treated	0.01	ft^3 biogas / gallon wastewater	USEPA 2008
F_{CH4}	=	fraction of CH_4 in biogas	0.65	--	USEPA 2008
ρ_{CH4}	=	density of CH_4 at standard conditions	662.00	g / m^3	LGOP default
DE	=	CH_4 destruction efficiency	0.99	--	LGOP default
0.0283	=	conversion factor	--	m^3 / ft^3	LGOP default
10^{-3}	=	conversion factor	--	MT / kg	--
10^{-3}	=	conversion factor	--	kg / g	--

The LGOP provides default values for all terms in the equation except the volume of digester gas produced per day (Digester Gas), and the fraction of methane in the biogas (F_{CH4}). The program assumes a digester gas production of 0.01 cubic feet of biogas per gallon of wastewater treated

based on USEPA methodology.[41, 42] The program assumes F_{CH4}= 0.65 based on the USEPA methodology.[43]

The amount of biogenic CO_2 produced from the combustion of biogas is calculated using the following equation based on flow sent to centralized systems (i.e., not sent to septic tanks):

Biogenic CO_2 emissions (MT CO_2) = Wastewater x Digester Gas x F_{CH4} x EF / 2204.623

Where:

Wastewater	=	Volume of Wastewater sent to centralized systems (gallons)
Digester Gas	=	Volume of biogas produced from wastewater treatment 0.01 ft^3 biogas / gallon wastewater treated
F_{CH4}	=	Fraction of CH_4 in biogas 0.65
EF	=	Emission factor for methane combustion[44] 0.120 lb CO_2 / ft^3 CH_4
2204.623	=	Conversion factor from lb CO_2 to MT CO_2

If a *cogeneration system* is used to generate electricity from the combusted biogas, the following equation derived from USEPA's Solid Waste Management and Greenhouse Gases report[45] is used to calculate the amount of electricity generated based on flow sent to centralized systems.

Electricity Generated (kWh) = Wastewater x Digester Gas x F_{CH4} x HHV_{CH4} x ECF x EFF

---

[41] USEPA 2008. Page 8-9. USEPA estimates 1.0 cubic feet of digester gas per person per day and 100 gallons of wastewater per person per day.

[42] USEPA reports 1.0 cubic feet of digester gas per person per day based on Metcalf & Eddy, Inc., 1991, "Wastewater Engineering: Treatment, Disposal, and Reuse," 3rd Ed. McGraw Hill Publishing. USEPA reports 100 gallons of wastewater per person per day based on Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2004, "Recommended Standards for Wastewater Facilities (Ten-State Standards)." USEPA also reports 100 gallons of wastewater per person per day on the USEPA Water & Wastewater Pricing website, based on the U.S. Geological Survey Circular 1200, 1995, "Estimated Use of Water in the United States in 1995."

[43] USEPA. 2008. Page 8-9. USEPA cites Metcalf & Eddy, Inc., 1991, "Wastewater Engineering: Treatment, Disposal, and Reuse," 3rd Ed. McGraw Hill Publishing.

[44] USDOE. 2005. Form EIA-1605: Long Form for Voluntary Reporting of Greenhouse Gases. Available online at: http://www.co2-sachverstaendiger.de/pdf/US%20DOE%20Voluntary%20Reporting%20of%20GHG.pdf

[45] USEPA. 2006. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd Ed. Sections 6.2-6.5. Available online at: https://nepis.epa.gov/Exe/ZyNET.exe/60000AVO.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5CTxt%5C00000000%5C60000AVO.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

Where:

Wastewater	=	Volume of Wastewater sent to centralized systems (gallons)
Digester Gas	=	Volume of biogas produced from wastewater treatment
		$0.01 \ \text{ft}^3$ biogas / gallon wastewater treated
F_{CH4}	=	Fraction of CH_4 in biogas
		0.65
HHV	=	Heating value of methane
		1,012 BTU / ft^3 CH_4
ECF	=	Energy conversion factor
		0.00009 kWh/BTU
EFF	=	Efficiency Factor[46]
		0.85

Since this amount of electricity is generated on-site and no longer needs to be supplied by the local electricity utility, the indirect CO_2e emissions associated with that utility electricity generation are also avoided. The avoided CO_2e emissions are calculated by multiplying the amount of electricity generated (in kWh) by the local utility carbon-intensity factor from Table 2.8.

Net CO_2 emissions are then the difference between the CO_2 produced from the combustion of digester gas and the CO_2 avoided by generating renewable energy, thus:

$$\text{Net } CO_2 \text{ Emissions} = CO_{2 \text{ (digester gas combustion)}} - CO_{2 \text{ (avoided emissions)}}$$

Nitrous oxide is produced when treated wastewater is discharged to aquatic environments such as rivers or estuaries. The nitrogen which remains in treated wastewater effluent is converted to nitrous oxide in a multi-step process accomplished by bacteria which is present in soil and aquatic environments. The nitrous oxide emissions are quantified using Equation 10.9 from the LGOP:

$$N_2O \text{ emissions (MT)} = \text{Wastewater} \times 10^{-6} \times \text{N Load} \times 44/28 \times \text{EF effluent} \times 10^{-3}$$

Term		Description	Value	Unit	Reference
Wastewater	=	volume of wastewater	INPUT	liters	User
10^{-6}	=	conversion factor	--	kg / mg	--
N Load	=	mass of nitrogen discharged per volume of wastewater	26	mg / liter of wastewater	USEPA 2013 (CA Statewide Average)
44/28	=	Ratio of molecular weights for N_2O and N_2			USEPA 2008
EF effluent	=	N_2O effluent emission factor	0.005	kg N_2O / kg N	LGOP default
10^{-3}	=	conversion factor	--	MT / kg	--

---

[46] Ibid. USEPA assumes a 15% system efficiency loss, to account for system down-time. USEPA assumes that methane is flared during down-time.

The LGOP provides default values for all terms in the equation except N Load, the total mass of nitrogen discharged in the wastewater effluent per day. CalEEMod assumes N Load = 26 mg N per liter of wastewater effluent based on the USEPA methodology.[47] This value is appropriate for residential and commercial wastewater. A higher value may be more appropriate for certain types of industrial wastewater.

Methane and nitrous oxide emissions are converted to carbon dioxide equivalent emissions by multiplying by their GWPs. The GWPs for methane and nitrous oxide are 25 and 298, respectively.[48]

---

[47] USEPA. 2013. California Statewide average. USEPA Database at http://cfpub.epa.gov/dmr/ez_search.cfm
[48] Provided in Appendix E, Table E.1 of CARB's LGOP. As specified in Appendix E, Second Assessment Report (SAR) GWPs are still used by international convention and the United States.

9 Solid Waste

Municipal solid waste (MSW) is the amount of material that is disposed of by land filling, recycling, or composting. CalEEMod calculates the indirect GHG emissions associated with waste that is disposed of at a landfill. The program uses annual waste disposal rates from the California Department of Resources Recycling and Recovery (CalRecycle) data for individual land uses. If waste disposal information was not available, waste generation data was used. CalEEMod uses the overall California Waste Stream composition to generate the necessary types of different waste disposed into landfills. The program quantifies the GHG emissions associated with the decomposition of the waste which generates methane based on the total amount of degradable organic carbon. [49] The program will also quantify the CO_2 emissions associated with the combustion of methane, if applicable. Default landfill gas concentrations were used as reported in Section 2.4 of AP-42. The IPCC has a similar method to calculate GHG emissions from MSW in its 2006 Guidelines for National Greenhouse Gas Inventories.

The amount of methane and CO_2 generated is calculated as:

$$Gen = DOC \cdot DANF \cdot 0.5$$

Where:

        Gen   = Amount of CO_2 or methane generated

        DOC   = Degradable organic carbon

        DANF = Degradable anaerobic fraction (0.5)

        0.5   = Assumes half anaerobic carbon is methane and other half is CO_2.

IPCC lists default values for the DOC in its 2006 Guidelines in Table 2.4.

The amount of methane and CO_2 emitted is calculated by assuming collection and destruction efficiencies. The user will be able to select if the landfill the waste is sent to has a landfill gas collection system. The collection efficiency will be assumed to be 75% if this is selected otherwise it will be 0%. The destruction efficiency is assumed to be 98%. The calculations take into account the oxidation of methane to CO_2 as it rises through the landfill. The methane and CO_2 emitted are described as:

$$Emit_{methane} = Gen \cdot [Collect \cdot (1 - destruct) + (1 - Collect) \cdot (1 - ox)]$$

$$Emit_{CO2} = Gen \cdot [Collect \cdot destruct + (1 - Collect) \cdot (ox) + 1]$$

---

[49] Landfill gas generation is dependent upon the amount, type, age and moisture content of the disposed waste. The USEPA has developed emission factors for landfill gas as specified in Section 2.4 of AP-42 which are incorporated in the LANDGEM model. This model uses a first order decay equation that will vary with time. However, there is no need to use a time-varying emissions model, as we are interested in total emissions of gases that could be emitted from a ton of waste. Therefore, instead of using the LANDGEM model, the volume of landfill gas from solid waste will be based on the total amount of degradable organic carbon.

Where:

$Emit_{methane}$ = Methane emitted per ton of green waste

$Emit_{CO2}$ = Carbon dioxide emitted per ton of green waste

Gen = Amount of CO_2 or methane generated

Collect = Collection efficiency of landfill gas (75%)

Destruct = Destruction efficiency of landfill gas (98%)

Ox = Oxidation efficiency of methane (10%)

The CO_2 emissions will be classified as biogenic emissions. The amount of methane emitted will be multiplied by its GWP to convert to CO_2e.

10 Stationary Sources

CalEEMod Version 2016.3.1 was the first version that integrated criteria pollutant emissions and GHG emissions from stationary sources into the project emission totals. The user can either enter stationary sources and their operation conditions, then let the program calculate the emissions, or the user can enter stationary source emissions to the program directly. The second option is provided for stationary equipment that is not included in the program.

10.1 Emergency Generators and Fire Pumps

Emissions for emergency generators and fire pumps are calculated as:

$$Emission = EF * HP * LF * Operation\ Hours$$

Where:

       EF = Emission factor

       HP = Horsepower

       LF = Load factor

In emission calculations, a default emission factor may be adjusted for unit conversion to grams/horsepower-hour.

The following table summarizes source references and assumptions to obtain default emission factors of diesel emergency generators.

Pollutant	Emission Factor Source and Assumptions for Diesel Emergency Generators
TOG	AP42 Table 3.3-1
ROG	AP42 Table 3.3-1 and assumes ROG accounts for 91% of TOG
CO	CCR 2423 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp
NOx	CCR 2423 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp assumes NOx accounts for 95% of (NMHC+NOx)
SO2	Based on diesel fuel sulfur content 15 ppmw, diesel heat value 19300 BTU/lb, Brake specific fuel consumption (BSFC) of 7000 BTU/hp-hr
PM10	CCR 2423 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp
PM2.5	CCR 2423 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp, assumes all PM10 is PM2.5
CO2	AP42 Table 3.3-1
CH4	Based on 0.0014 kg/gallon diesel (California Climate Action Registry General Reporting Protocol), diesel density 6.943 lb/gallon, diesel heat value 19,300 BTU/lb, BSFC of 7,000 BTU/hp-hr

The following table summarizes sources references and assumptions to obtain default emission factors of diesel fire pumps.

Pollutant	Emission Factor Source and Assumptions for Diesel Fire Pumps
TOG	AP42 Table 3.3-1
ROG	AP42 Table 3.3-1 and assumes ROG accounts for 91% of TOG
CO	40 CFR 60.4202 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp
NOx	40 CFR 60.4202 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp, assumes NOx accounts for 95% of (NMHC+NOx)
SO2	Based on diesel fuel sulfer content 15 ppmw, diesel heat value 19,300 BTU/lb, Brake specific fuel consumption (BSFC) of 7,000 BTU/hp-hr
PM10	40 CFR 60.4202 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp
PM2.5	40 CFR 60.4202 for engines < 50 hp, CARB ATCM Final Regulation for engines >= 50 hp, assumes all PM10 is PM2.5
CO2	AP42 Table 3.3-1
CH4	Based on 0.0014 kg/gallon diesel (California Climate Action Registry General Reporting Protocol), diesel density 6.943 lb/gallon, diesel heat value 19,300 BTU/lb, BSFC of 7,000 BTU/hp-hr

The following table summarizes source references and assumptions to obtain default emission factors of natural gas emergency generators.

Pollutant	Emission Factor Source and Assumptions for Natural Gas Emergency Generators
TOG	AP42 Table 3.2-3
ROG	South Coast AQMD Rule 1110.2
CO	South Coast AQMD Rule 1110.2
NOx	South Coast AQMD Rule 1110.2
SO2	AP42 Table 3.2-3, assumes 100% conversion of fuel sulfur to SO2 and sulfur content of 2,000 gr/10^6 scf
PM10	AP42 Table 3.2-3
PM2.5	AP42 Table 3.2-3
CO2	AP42 Table 3.3-1
CH4	AP42 Table 3.3-1

For natural gas emergency generators, conversion from emission factor in pound per MMBTU of fuel input (lb/MMBTU) to emission factor in grams per brake horsepower hour is derived as:

$$\frac{1\ \text{lb}}{\text{MMBTU}} * \frac{1\ \text{MMBTU}}{1{,}000{,}000\ \text{BTU}} * \frac{7{,}000\ \text{BTU}}{1\ \text{hp} - \text{hr}} * \frac{453.6\ \text{grams}}{1\ \text{lb}} = 3.1752\ \text{gram/hp} - \text{hr}$$

Where a BSFC of 7,000 BTU/hp-hr is used.

For natural gas emergency generators, conversion from emission limit of parts per million by volume (ppmv) to emission factor in pound per MMBTU of fuel input (lb/MMBTU) is performed as:

$$\frac{\text{Pollutant lb}}{\text{MMBTU}} = \text{ppmv} * \frac{1}{\text{molar volume}} * \text{MW} * \text{Fd} * 20.9/(20.9 - \%\text{O2})$$

Where:

      Molar Volume = 379.5 dscf/lbmol @ 14.696 psia, 60 deg. F

      Fd = 8,579 dscf/MMBTU for 1020 BTU/scf Natural Gas @60 deg F

      %O2 = Oxygen percentage in emission (South Coast AQMD Rule 1110.2 limits are based on 15% oxygen)

      MW = molecular weight, lb/lb-mol.

      Molecular weight for ROG is set at 86 lb/lb-mol based on Hexane.

Process Boilers

Emissions for process boilers are calculated as:

Emission = Emission Factor * Total Fuel MMBTU input

For this emission calculation, a default emission factor may be adjusted to convert the units to lb/MMBTU.

The following table summarizes source references and assumptions to obtain default emission factors of diesel boilers.

Pollutant	Emission Factor Source and Assumptions for Diesel Boilers
TOG	AP42 Table 1.3-3, Commercial/institutional/residential combustors, Distillate oil
ROG	AP42 Table 1.3-3, assumes ROG = TOG – CH4
CO	AP42 Table 1.3-3, No. 4 oil
NOx	SJVAPCD Rule 4306
SO2	AP42 Table 1.3-3, No. 4 oil, diesel fuel sulfur content 15 ppmw
PM10	AP42 Table 1.3-6
PM2.5	AP42 Table 1.3-6
CO2	AP42 Table 1.3-12
CH4	AP42 Table 1.3-3, Commercial/institutional/residential combustors, Distillate oil

A diesel heat value of 140 MMBTU/10^3 gallon is used to convert emission factor in lb/10^3 gal to emission factor in lb/MMBTU.

The following table summarizes source references and assumptions to obtain default emission factors of natural gas boilers.

Pollutant	Emission Factor Source and Assumptions for Natural Gas Boilers
TOG	AP42 Table 1.4-2
ROG	AP42 Table 1.4-2
CO	AP42 Table 1.4-1
NOx	South Coast AQMD Rules 1146, 1146.1, and 1146.2,
SO2	AP42 Table 1.4-2, assumes 100% conversion of fuel sulfur and sulfur content of 2,000 gr/10^6 scf
PM10	AP42 Table 1.4-2
PM2.5	AP42 Table 1.4-2
CO2	AP42 Table 1.4-2
CH4	AP42 Table 1.4-2

A natural gas heat value of 1,020 BTU/scf is used to convert emission factor in lb/10^6 scf to emission factor in lb/MMBTU.

11 Vegetation

The program calculates GHG emissions associated with the vegetation activities of land use change and the planting of new trees.

The program calculates GHG emissions from vegetation activities according to the IPCC protocol for vegetation since it has default values that work well with the information typically available for development projects. This method is similar to the CAR Forest Protocol[50] and the Center for Urban Forest Research Tree Carbon Calculator[51], but it has more general default values available that will generally apply to all areas of California without requiring detailed site-specific information.[52]

11.1 Land Use Change

A development which changes land use type results in changes in CO_2 sequestration from the atmosphere which would not have been captured had there been no land-type change.

Overall Change in Sequestered CO_2 [MT CO_2]

$$= \sum_i \left(SeqCO_2\right)_i \times \left(area\right)_i - \sum_j \left(SeqCO_2\right)_j \times \left(area\right)_j$$

Where:

$SeqCO_2$	=	mass of sequestered CO_2 per unit area [MT CO_2/acre]
area	=	area of land for specific land use type [acre]
i	=	index for final land use type
j	=	index for initial land use type

Overall change in sequestered CO_2 is the summation of sequestered CO_2 from initial land use type multiplied by area of land for initial land use type subtracted by the summation of sequestered CO_2 from final land use type multiplied by area of land for final land use type. There is no reduction in GHG emissions associated with preservation of a land.

---

[50] CCAR. 2007. Forest Sector Protocol Version 2.1. September. Available at: https://www.climateactionreserve.org/how/protocols/forest/dev/

[51] Available at: https://www.fs.usda.gov/ccrc/tool/cufr-tree-carbon-calculator-ctcc

[52] The CAR Forest Protocol and Urban Forest Research Tree Carbon Calculator are not used since their main focus is annual emissions for carbon offset considerations. As such, they are designed to work with very specific details of the vegetation that is not available at a CEQA level of analysis.

SeqCO₂

The mass of sequestered CO_2 per unit area [MT CO_2/acre] is dependent on the specific land use type. The program uses default CO_2 sequestration values from CCAR for each land use that will be preserved or created:

Land Use	Sub-Category	Default CO_2 accumulation per acre (MT CO_2/ acre)
Forest Land	Scrub	14.3
	Trees	111
Cropland	--	6.20
Grassland	--	4.31
Wetlands	--	0

The default annual CO_2 is calculated by multiplying total biomass (MT dry matter/acre) from IPCC data by the carbon fraction in plant material (0.47), then using the ratio of molecular weights (44/12) to convert from MT of carbon (C) to MT of carbon dioxide (CO_2).

Vegetation Type
Vegetation types are defined by IPCC as follows:

(i) Forest Land
This category includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but *in situ* could potentially reach the threshold values used by a country to define the Forest Land category.

(ii) Cropland
This category includes cropped land, including rice fields, and agro-forestry systems where the vegetation structure falls below the thresholds used for the Forest Land category.

(iii) Grassland
This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions.

(iv) Wetlands
This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

Area

The user must specify area of land in acres for specific final and initial land use types. These area changes include not only the area of land that will be converted to buildings, but also areas disrupted by the construction of utility corridors, water tank sites, and associated borrow and grading areas. Areas temporarily disturbed that will eventually recover to become vegetated will not be counted as vegetation removed as there is no net change in vegetation or land use.[53]

11.2 Sequestration

Planting trees will sequester CO_2 and is considered to result in a one-time carbon-stock change. Trees sequester CO_2 while they are actively growing. The amount of CO_2 sequestered depends on the type of tree.

$$\text{Total Sequestered } CO_2 = \left(\text{Growing Period} \times \sum_{i=1}^{n} [\text{ Sequestration } i \times \text{ Trees } i]\right)$$

Where:

Growing Period = Growing period for all trees, expressed in years (20).

n = Number of broad species classes.

Sequestration i = Default annual CO_2 accumulation per tree for broad species class i.

Trees i = Number of net new trees of broad species class i.

Total Sequestered CO_2 is the growing period for all trees multiplied by the summation of annual CO_2 accumulation multiplied by the number of new trees per broad species class.

Growing Period

The program assumes the IPCC active growing period of 20 years. Thereafter, the accumulation of carbon in biomass slows with age, and will be completely offset by losses from clipping, pruning, and occasional death. Actual active growing periods are subject to, among other things, species, climate regime, and planting density. Note that trees may also be replaced at the end of the 20-year cycle, which would result in additional years of carbon sequestration. However, this would be offset by the potential net release of carbon from the removal of the replaced tree.

---

[53] This assumption facilitates the calculation as a yearly growth rate and CO_2 removal rate does not have to be calculated. As long as the disturbed land will indeed return to its original state, this assumption is valid for time periods over 20 years.

Sequestration

The program uses default annual CO_2 accumulation per tree for broad species class as follows:

Broad species class	Default annual CO_2 accumulation per tree[1] (MT CO_2/ year)
Aspen	0.0352
Soft maple	0.0433
Mixed hardwood	0.0367
Hardwood maple	0.0521
Juniper	0.0121
Cedar/larch	0.0264
Douglas fir	0.0447
True fir/Hemlock	0.0381
Pine	0.0319
Spruce	0.0337
Miscellaneous[2]	0.0354

1. IPCC's carbon (C) values converted to carbon dioxide (CO_2) using ratio of molecular weights (44/12).
2. Average of all other broad species classes. To be assumed if tree type is not known.

12 Mitigation

12.1 Construction Mitigation Measures and Regulatory Adjustments

The section below describes the types of reduction in emissions that CalEEMod incorporates. All information required in this section will require the user to supply a source to support the parameter they select. This source will be displayed in the result output to enhance the communication of the assumptions used in determining the final mitigated emissions reported.

Mitigation Measures for Onsite Off-Road Construction Diesel Equipment

The emissions mitigation measures for onsite off-road construction diesel equipment include use of alternative fuel, electric equipment, diesel particulate filters (DPF), oxidation catalysts, newer tier engines, and dust suppression. The program has options allowing the user to apply mitigation measures to single pieces of equipment or the entire fleet.

Exhaust Emissions Reduction

Alternative Fuel: The use of alternative fuels (i.e., biodiesel, compressed natural gas, propane, etc.) can change both criteria and GHG emissions. Alternative fuels can change emissions (increase or decrease) for each pollutant. Emission factors are based on values for alternative fuels in OFFROAD2011. Therefore, they may not be available for all pieces of equipment. The biodiesel emissions are based on a report from NREL.[54] Biodiesel emissions are separated into both biogenic and non-biogenic CO_2 emissions. These values may be a slight under estimation since no starting or evaporative emissions are calculated in the program.

Electric Equipment: The use of electric equipment reduces emissions by 100% for all criteria pollutants. However, there are indirect GHG emissions associated with the electricity use. This is calculated by converting the horsepower to kilowatts and multiplying by the electricity carbon intensity factor. This is only available for those pieces of equipment where values have been identified as listed in CAPCOA's Quantification of Greenhouse Gas Mitigation Measures.

DPF: The use of DPFs reduces the emissions of PM_{10} and $PM_{2.5}$. The program allows the user to choose filters that meet different CARB standardized abatement and certification levels as needed.[55] The program also allows the user to enter filter specifications in case a filter with a higher abatement level becomes available.

Diesel Oxidation Catalyst: The use of an oxidation catalyst assumes the combination operation of a selective catalytic reduction (SCR) that reduces NOx emissions by 0 to 40% percent. Minor PM emission reductions are also achieved.

Newer Tier Engines: The program allows the user to choose newer engines that meet more stringent USEPA tier emissions standards than is anticipated from the statewide fleet mix. If this option is checked, the user will be required to enter the expected tier level, and CalEEMod will use the emission standard of the selected tier for the emissions calculation.[56]

---

[54] http://www.nrel.gov/docs/fy06osti/37508.pdf (see Table 2)
[55] http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm
[56] https://www.arb.ca.gov/msprog/moyer/guidelines/2011gl/2011cmpgl_20161228.pdf

The mitigation measure-pollutant applicability matrix is presented in the following table:

Mitigation Measure	Applicability						
	VOC	SOx	NOx	PM$_{10}$	PM$_{2.5}$	GHG Anthropogenic	GHG Biogenic
Alternative Fuel		x	x	x	x	X	x
Electric Equipment	x	x	x	x	x	X	x
DPF				x	x		
Diesel Oxidation Catalyst/SCR			x	x	x		
Newer Tier Engines	x	x	x	x	x		
User Input	x	x	x	x	x	X	x

Fugitive Dust Emissions Reduction

The mitigation measures in this section apply the specified percent reduction in PM$_{10}$ or PM$_{2.5}$ to the applicable fugitive dust calculations. Watering of unpaved roads recalculates the unpaved road equations using the updated values supplied by the user in this section. These are based on South Coast AQMD's fugitive dust mitigation measures[57].

12.2 Mobile Mitigation

All mitigation associated with mobile source emissions is consistent with the methods described in CAPCOA's Quantification of Greenhouse Gas Mitigation Measures.

12.3 Hearths Mitigation Measures

The user will be able to change the default percentage of hearths including no hearths or all natural gas hearths. This will recalculate the number of hearths and the corresponding emissions.

12.4 Architectural Coating Mitigation

The user can select lower VOC content in paints than required by regulation. This value will be used instead of the default emission factor.

12.5 Landscape Equipment Mitigation

The user will be able to specify the percentage of landscape equipment that will be electric. This will be incorporated consistent with CAPCOA's Quantification of Greenhouse Gas Mitigation Measures methodology.

12.6 Improve Building Envelope Beyond Title 24 Part 6

The user will enter their commitment to improve building envelope related systems (space heating, space cooling, water heating, and ventilation) beyond current (2019) Title 24 regulations. The user will enter the percentage improvement.

12.7 Install Energy Efficient Appliances

The user can designate the appliances that will be installed that meet USEPAs Energy Star criteria. In order to meet CEQA enforceability criteria, these appliances need to be supplied by the builder. The program will use the average savings for an Energy Star appliance as reported in the Energy Star's most recent annual report. The following appliances will be available: refrigerators, dish washers, fans, and clothes washers. The reduction will only apply to these end uses.

12.8 Install Renewable or Alternative Energy systems

The user will be able to specify the percentage of the electricity use that will be supplied from renewable or alternative energy systems. This includes energy from sources such as photovoltaic cells, wind turbines, geothermal sources, and fuel cells. The user will enter the total annual kilowatt-hours anticipated to be generated or the percentage of the annual building energy that will be supplied by the alternative energy systems. Information on how to calculate these can be found in CAPCOA's Quantification of Greenhouse Gas Mitigation Measures.

12.9 Water Mitigation

All water mitigation methods are consistent with those described in the CAPCOA Quantifying Greenhouse Gas Mitigation Measures document.

12.10 Waste Mitigation

The amount of waste disposed will be reduced by the percentage entered by the user. There is no reallocation of the type of material disposed.