California Air Resources Board

California Climate Investments Quantification Methodology Emission Factor Database Documentation

Appendix C: Natural Resources and Waste Diversion

Note:
This document accompanies the California Climate Investments Quantification Methodology Emission Factor Database available on the California Climate Investments resources webpage. This document explains how emission factors used in California Air Resources Board (CARB) quantification methodologies are developed and updated.

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List of Acronyms and Abbreviations

Acronym	Term
BDT	Bone Dry Ton
CARB	California Air Resources Board
CDFA	California Department of Food and Agriculture
CERF	Compost Emission Reduction Factor document: *CARB Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities (2017)*
CH_4	Methane
C/N	Carbon to Nitrogen Ratio
CO	Carbon Monoxide
CO_2e	Carbon Dioxide Equivalent
Database	California Climate Investments Quantification Methodology Emission Factor Database
DNDC	Denitrification Decomposition
DSCM	Dry Standard Cubic Meter
g	Gram
gal	Gallon
GHG	Greenhouse Gas
GR4	Moderately Course Grass Cover with an Average Depth of about 2 Feet
GWP	Global Warming Potential
HDPE	High density polyethylene
HSP	Healthy Soils Program
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
lb	Pound
LCFS	Low Carbon Fuel Standard
MT	Metric Ton
N_2O	Nitrous Oxide
NH_3	Ammonia
NMOC	Non-Methane Organic Compounds
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
NRCS	Natural Resources Conservation Service
PET	Polyethylene terephthalate
$PM_{2.5}$	Particulate Matter that have a Diameter Less than 2.5 Micrometers
PM_{10}	Particulate Matter that have a Diameter Less than 10 Micrometers
RERF	Recycling Emission Reduction Factor
ROG	Reactive Organic Gas
scf	Standard Cubic Feet
SH2	Shrub Cover with Moderate Fuel Load
SH7	Shrub Cover with Very Heavy Shrub Load

SO_2	Sulfur Dioxide
STIR	Soil Tillage Intensity Rating
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USFS	United States Forest Service
VOC	Volatile Organic Compound
WOR	Whole Orchard Recycling

Introduction

The California Climate Investments Investment Plan identifies natural and working lands and livestock management, and waste diversion as key investment areas to reduce greenhouse gases. Natural and working lands projects can provide particularly cost-effective GHG reductions and carbon sequestration while delivering a variety of other important benefits including improved air and water quality, ecosystem services, increased resilience to climate impacts, and employment opportunities. Reducing methane emissions, considered a short-lived climate pollutant, from livestock and waste management operations is also critical to achieve near-term GHG reductions and carbon neutrality. Emerging opportunities in the natural resources sector include water use and supply, land conservation, forestry, and sustainable agriculture. As for waste management, the reduction, diversion, and reuse of waste continue to be important pathways to reduce and avoid emissions.

This document outlines the generalized calculation approaches used by the suite of California Climate Investments programs to quantify greenhouse gas and air pollutant emission reductions from projects characterized as contributing towards conserving and enhancing natural resources and diverting waste. For more details about how the emission factors are used in specific quantification methodologies and accompanying benefit calculator tools tailored to each California Climate Investments program, the quantification methodologies are available on the California Climate Investments resources webpage. The CARB quantification methodologies estimate both GHGs and select co-benefits utilizing project-specific inputs and emission factors specific to the type of project being quantified. When appropriate, CARB quantification methodologies use the same emission factors across project types.

Natural Resources and Waste Diversion

Investments in the Natural Resources and Waste Diversion sectors result in net GHG benefits in a variety of ways including:

- Sequestering and storing carbon in vegetation and soils,
- Producing biomass-based fuels and energy that displaces fossil fuels,
- Installing biogas control systems on uncontrolled open manure lagoons,
- Diverting organic waste from landfills and manure lagoons,
- Avoiding the use of virgin materials by reducing food waste or using recycled fibers, plastics, and glass in the production of manufactured goods, and
- Reducing VMT through the protection of natural and working lands at risk of expansive, vehicle-dependent development.

Emission Factor Documentation

CARB has developed emission factors to estimate both GHG emission reductions and select criteria and toxic air pollutant emission co-benefits. Methods used to develop emission factors used in Natural Resources and Waste Diversion sector CARB quantification methodologies are described on the subsequent pages. Emission factors for the following project types are currently included in the Database:

- Livestock Manure
- Forest Operations
- Woody Biomass Utilization
- Wetland Restoration
- Food Waste Prevention and Rescue
- Landfills
- Agricultural Soil
- Fiber, Plastics, and Glass Recycling
- Compost Production
- Anaerobic Digestion

Note: Grid electricity and natural gas combustion emission factors used in CARB quantification methodologies for Natural Resources and Waste Diversion sector programs are documented in the Energy Efficiency and Clean Energy sector section of this document.

Livestock Manure

Livestock manure emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 1.

Table 1. Programs Using Livestock Manure Emission Factors

Agency	Program
California Department of Food and Agriculture	Alternative Manure Management Program
California Department of Food and Agriculture	Dairy Digester Research and Development Program
California Department of Resources Recycling and Recovery	Organics Grant Program
California Energy Commission	Low Carbon Fuel Production Program

GHG Emission Factors

Livestock manure GHG emission factors were derived using the following steps:

1. Baseline and project methane emission factors for manure management systems are calculated using the following parameters:
    a. Livestock Manure Characteristics:

       The typical average mass for livestock is used to determine monthly volatile solids production by livestock category. Likewise, volatile solids have a varying capacity to produce methane under anaerobic conditions depending on the livestock category. Values were derived from on the CARB Livestock Protocol where data is available. Factors for volatile solids and methane production for additional livestock categories not included in the Livestock Protocol were obtained from CARB's GHG Emission Inventory.

    b. Percentage of Manure Deposited on Land and not Entering Wet/Anaerobic system:

       Livestock spend a portion of their time in fields, open lots, and other areas where manure is not typically flushed or collected for management in a wet/anaerobic system such as a lagoon or settling pond. Different livestock types spend different amounts of time in these areas. Default values were based on medians of ranges of time spent, by livestock category, with the assumption that the quantity of manure deposited in given areas is proportional to the amount of time livestock spend in each area. Default values were sourced from UC Davis's Managing Dairy Manure in the Central Valley of California.

c. Volatile Solids Separation:

Collected manure often pass through a solids separation system to separate solids from liquids. Different systems have different separation efficiencies. Default values were derived from the CARB Livestock Offset Protocol.

d. Biogas Production and/or Methane Conversion Factors:

The monthly production of biogas from volatile solid digestion in biogas control systems (digesters and anaerobic lagoons) depends on a van't Hoff-Arrhenius relation that is dependent on the activation energy constant for a given temperature, and the monthly average ambient temperature where the digestion occurs. Calculations were derived from the CARB Livestock Offset Protocol.

i. 80% of the volatile solids introduced to a lagoon or digester are available for anaerobic digestion.

ii. Digesters that maintain higher than ambient internal temperatures are expected to result in higher methane production than anaerobic lagoons. Plug-flow and tank/complete mix systems are estimated to produce an additional 12% more methane per animal from volatile solid digestion than anaerobic lagoons or covered lagoons. This is based on UC Davis's Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California.

iii. The van't Hoff-Arrehenius value is based on activation energy constant of 15,175 cal/mol at 303.16 K and has a maximum value of 0.95.

iv. Monthly average ambient temperature is measured at a single weather station for each county, using data from the California Climate Data Archive.

Other forms of manure management use methane conversion factors based on management type and ambient temperature. Values were derived from on the CARB Livestock Offset Protocol.

e. Fugitive Methane Emissions:

All biogas produced from uncovered lagoons reaches the atmosphere. The installation of a biogas control system enables the methane to be collected and then destroyed via a flare or for productive use. The collection efficiency depends on the type of biogas control system and the destruction efficiency depends on the type of device the collected methane is sent to. Collection and efficiency values were derived from the CARB Livestock Offset Protocol.

2. Fuel and energy use may change with the implementation of a new system to collect, transport, treat, and store manure, as well as process any collected biogas. Collected biogas may be utilized to substitute for fossil fuel and energy demand. Emission factors from fuel and energy consumption and displacement were derived from the CARB Livestock Offset Protocol. Other factors include:
    a. The refining of biogas to fuel-grade biomethane uses 10% of the methane in the biogas to power the process, leaving 90% of created methane for use as a renewable fuel, according to a UC Davis study on Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.
    b. The quantification methodology assumes that for the conversion of biogas to electricity, internal combustion engines and turbines are 30% efficient, and fuel cells are 45% efficient, based on a UC Davis study Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.
3. Global Warming Potential: GHG emission reductions related to livestock manure projects are primarily due to reductions in methane emissions. One metric ton of methane is calculated to have the same 100-year global warming potential as 25.0 metric tons of carbon dioxide according to the IPCC Fourth Assessment Report.
4. For dairy manure, a per weight metric based on milk production is calculated using milk energy-correction factors. Cow herds produce milk with variable amounts of fat, true protein, and lactose. Correction factors from a publication on feed efficiency and lactating cows are applied based on these milk characteristics to convert the weight of milk with varying qualities to a single weight standard based on energy value.

See the "Manure GHG" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Livestock manure criteria and toxic air pollutant emission factors were derived using the following steps:

1. Criteria and toxic air pollutant emission factors for the off-road agricultural equipment used at dairies for manure management practices were derived using the following steps:
    a. Statewide emissions were downloaded from OFFROAD2017 (v1.0.1) with the following parameters:
        i. Calendar year: 2018
        ii. Scenario: All Adopted Rules: Exhaust
        iii. Equipment Sector: OFFROAD – Agricultural
        iv. Model Year: Aggregated
        v. Horsepower Bin: Aggregated
        vi. Fuel: All
    b. The tons per day emission factors were converted to pounds per gallon by dividing the daily emissions by the total fuel usage, using Equation 1.

Equation 1: Daily Emissions Conversion to Fuel Use Emission Factors

$$CAGEF = \frac{AGEF \times 365.25 \times 2{,}000}{DFU}$$

Where,			Units
CAGEF	=	The converted exhaust emission factor for the off-road agricultural sector	lbs/gallon
AGEF	=	The off-road agricultural sector pollutant emission factor	tons/day
365.25	=	Unit conversion factor	days/year
2,000	=	Unit conversion factor	lbs/ton
DFU	=	Daily fuel usage	gallon/year

Equation 1. The converted air pollutant exhaust emission factor for the off-road agricultural sector is calculated as the off-road agricultural sector pollutant emission factor divided by the daily fuel usage.

2. Biogas destruction device emission factors were obtained using CARB's CA-GREET 2.0 database and a joint study by UC Davis, U.S. EPA, and National Risk Management Research Lab.
3. Dairy cow annual ammonia and ROG emission factors were obtained using CARB's *Farming Operations Livestock Husbandry* and San Joaquin Valley Air

Pollution Control District's *Air Pollution Control Officer's Revision of the Dairy VOC Emission Factors*.

4. Manure management emission control effectiveness and removal factors were obtained from the South Coast Air Quality Management District's *Final Staff Report Proposed Rule 1127 – Emission Reductions from Livestock Waste*.

Note: While not identical, for the purposes of this estimation, VOC is used as a surrogate for ROG as there are only minor variations of exempted pollutants between the two terms.

See the "Manure Criteria & Toxics" tab of the Database for specific emission factors.

Forest Operations

Forest operations emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 2.

Table 2. Programs Using Forest Operations Emission Factors

Agency	Program
California Department of Forestry and Fire Protection	Forest Health Program

GHG Emission Factors

Forest operations GHG emission factors were derived for the following types of activities:

A. Reforestation site preparation emissions:
   1. GHG emission factors for mobile combustion emissions for reforestation site preparation were derived from the CARB U.S. Forest Offset Protocol.
   2. Carbon (in CO_2e) lost from removal of shrubs and herbaceous understory during reforestation site preparation were derived from a USFS General Technical Report using the following steps:
      a. Tons of biomass per acre by land cover type were determined using:
         i. GR4--Moderate Load, Dry Climate Grass for grass cover
         ii. SH2--Moderate Load Dry Climate Shrub for light to medium shrub cover
         iii. SH7--Very High Load, Dry Climate Shrub for heavy shrub cover
      b. Tons of biomass were converted to $MTCO_2e$/acre using Equation 2.

Equation 2: Carbon (in CO_2e) Lost from Reforestation Site Preparation

$$SHU_{RB} = Biomass \times 0.5 \times 3.67 \times 0.907185$$

			Units
Where,			
SHU_{RB}	=	Shrubs and herbaceous understory carbon removed during site preparation from within the treatment boundary in reforestation project scenario (based on land cover type)	$MTCO_2e$/acre
Biomass	=	Tons biomass per acre by land cover type from USFS General Technical Report	ton biomass/ acre
0.5	=	Biomass carbon concentration	unit of carbon/ unit of biomass
3.67	=	Conversion of carbon to CO_2e based on molar mass	CO_2e/C
0.907185	=	Conversion of tons to metric tons	MT/ton

Equation 2. The carbon lost from reforestation site preparation is calculated as the multiplication of the tons biomass per acre by land cover type, the biomass carbon concentration, and the conversion to carbon dioxide equivalent.

B. Herbicide treatments:

The GHG emission factor for herbicide treatment was derived using the following steps:

1. Emission factor for herbicide treatments ($MTCO_2e$ per hectare) was determined from literature.
2. $MTCO_2e$/hectare was converted to $MTCO_2e$/acre by dividing by 2.47105 acres/hectare.

See the "Forest Operations GHG" tab of the Database for specific emission factors.

Woody Biomass Utilization

Woody biomass utilization emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 3.

Table 3. Programs Using Woody Biomass Utilization Emission Factors

Agency	Program
California Department of Forestry and Fire Protection	Forest Health Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Energy Commission	Renewable Energy for Agriculture Program

GHG Emission Factors

Woody biomass utilization GHG emission reduction factors were derived for electricity generation using the following steps:

1. Determine the MWh produced per BDT.
    a. For electricity generation via combustion, this was derived using values from a 2013 CARB study on biomass conversion.
    b. For electricity generation via gasification, this was derived using values from a Sonoma County Water Agency study.
2. Utilize the California average grid electricity GHG emission factor documented in the Energy Efficiency and Clean Energy sector section of this document.
3. Determine the non-biogenic emissions from the electricity generation.
    a. For electricity generation via combustion, this was derived using values from the same 2013 CARB study on biomass conversion that was previously used.
    b. For electricity generation via gasification, this was derived using values from a CARB LCFS Pathway for Cellulosic Ethanol from Forest Waste.
4. The emission factors were then calculated using Equation 3.

Equation 3: Woody Biomass Electricity Generation Emission Reduction Factor

$$WB\ Elec\ EF = Rate\ of\ Gen\ \times Grid\ EF - Elec\ Gen\ Emissions$$

Where,			Units
WB Elec EF	=	Emission reduction factor for woody biomass electricity generation	$MTCO_2e/BDT$
Rate of Gen	=	Rate of electricity generation from woody biomass feedstock	MWh/BDT
Grid EF	=	California average grid electricity GHG emission factor	$MTCO_2e/MWh$
Elec Gen Emissions	=	Non-biogenic emissions from the woody biomass electricity generation	$MTCO_2e/BDT$

Equation 3. The woody biomass electricity generation emission reduction factor is calculated as the multiplication of the rate of electricity generation from woody biomass feedstock, California average grid electricity GHG emission factor, and the amount of non-biogenic emissions from the woody biomass electricity generation.

Avoided disposal emissions:

The GHG emission factor for landfilling of woody biomass was derived using the landfill emission factor for yard waste from the CARB Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities.

The emission factor for open pile burning of woody biomass was derived using the following steps and Equation 4:

1. Determine the CH_4 and N_2O emissions per BDT from open pile burning of woody biomass using values from the Placer County Biomass Waste for Energy Project Reporting Protocol.
2. Multiply the CH_4 and N_2O emissions by their respective global warming potentials from the IPCC Fourth Assessment Report.
3. Apply the default biomass consumption burn out efficiency of an open pile burn determined from the same Placer County Biomass Waste for Energy Project Reporting Protocol.

Equation 4: Open Pile Burn Emission Factor

$$OPB\ EF = (CH_4 \times GWP_{CH4} + N_2O \times GWP_{N2O}) \times 0.95$$

Where,			Units
OPB EF	=	Emission factor for open pile burning of woody biomass	$MTCO_2e/BDT$
CH_4	=	CH_4 emissions from open pile burning of woody biomass	CH_4/BDT
GWP_{CH4}	=	Global warming potential for CH_4	unitless
N_2O	=	N_2O emissions from open pile burning of woody biomass	N_2O/BDT
GWP_{N2O}	=	Global warming potential for N_2O	unitless
0.95	=	Biomass consumption burn out efficiency of an open pile burn	percent

Equation 4. The emission factor for open pile burning of woody biomass is equal to the sum of the methane and nitrous oxide emission factors for open pile burning, multiplied by the 95% burn out efficiency. The methane and nitrous oxide emission factors for open pile burning are each calculated as their emissions per bone dry ton multiplied by their respective global warming potential.

The emission factor for avoided on-site decay was derived using the following steps and Equation 5:

1. Determine the CH_4 and N_2O emissions per BDT from on-site decay of woody biomass using values from the Placer County Biomass Waste for Energy Project Reporting Protocol.
2. Multiply the CH_4 and N_2O emissions by their respective global warming potentials from the IPCC Fourth Assessment Report.

Equation 5: On-site Decay Emission Factor

$$Decay\ EF = (CH_4\ \times GWP_{CH4} + N_2O \times GWP_{N2O})$$

$$Decay\ EF = (CH_4\ \times GWP_{CH4} + N_2O \times GWP_{N2O})$$

Where,			Units
Decay EF	=	Emission factor for on-site decay of woody biomass	$MTCO_2e$/BDT
CH_4	=	CH_4 emissions from on-site decay of woody biomass	CH_4/BDT
GWP_{CH4}	=	Global warming potential for CH_4	unitless
N_2O	=	N_2O emissions from on-site decay of woody biomass	N_2O/BDT
GWP_{N2O}	=	Global warming potential for N_2O	unitless

Equation 5. The emission factor for on-site decay of woody biomass is equal to the sum of the methane and nitrous oxide emission factors for on-site decay of woody biomass, which are each calculated as their emissions per bone dry ton multiplied by their respective global warming potential.

See the "Woody Biomass Utilization" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Woody biomass electricity generation criteria pollutant emission factors were derived for biomass combustion and gasification using values from a Sonoma County Water Agency study.

Note: While not identical, for the purposes of this estimation, VOC is used as a surrogate for ROG as there are only minor variations of exempted pollutants between the two terms.

See the "Woody Biomass Utilization" tab of the Database for specific emission factors.

Wetland Restoration

Wetland restoration emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 4.

Table 4. Programs Using Wetland Restoration Emission Factors

Agency	Program
California Department of Fish and Wildlife	Wetlands Restoration for Greenhouse Gas Reduction Grant Program

GHG Emission Factors

Wetland restoration GHG emission factors were derived using the following steps:

1. Changes in carbon sequestration, CO_2 emissions, and CH_4 emissions are calculated for different wetland types using the following parameters:
    a. Restoration of Delta Wetlands:

       The change in CO_2 and CH_4 emissions for wetlands in the legal Sacramento-San Joaquin Delta is the difference between calculated project and baseline emission rates.

        i. Organic Soil Subsidence Baseline CO_2 Emissions

           The carbon loss rate for Delta Subsidence in the Sacramento-San Joaquin Delta was calculated by Deverel and Leighton. It is assumed that all carbon loss in the Delta is emitted as carbon dioxide.

        ii. Delta Project CO_2 and CH_4 Emissions

           The Restored Delta Wetland combined Carbon Dioxide and Methane emission rate was calculated by Deverel, et.al.

    b. Restoration of Coastal Tidal Wetlands:

        i. Conversion from farmland

           A land-use change from farmland to be converted to wetland avoids CO_2 emissions due to halting the carbon loss rates in organic soils. The GHG benefit from halting subsidence of organic soils due to farming is estimated by Deverel and Leighton. Carbon sequestration from conversion of the grassland to wetland is discussed in 2.b.ii.

           A land-use change from farmland converted to upland increases the total sequestered carbon dioxide as soil carbon as estimated by the USDA for farmland and grasslands:

- The carbon sequestered in farmland is the product of the carbon reference stock for dry wetland soils in a warm temperate dry climate, the land use factor for warm temperate dry cultivated lands, and the cropland management factor for full till.
- The carbon sequestered in the converted farmland, before it is restored to upland, is the product of the carbon reference stock for dry wetland soils in a warm temperate climate, the land use factor for warm temperate dry grasslands, and the grassland management factor for severely degraded grasslands.

The change in sequestered carbon is the difference between these two products.

ii. Restoration to wetlands

Restoring degraded lands and converted farmland to restored coastal tidal wetlands sequesters CO_2 at rate determined by Callaway, et.al.

Methane emissions occur in wetlands with a salinity less than 18 parts per thousand (ppt) as determined by the 2006 IPCC Guidelines for National Greenhouse Gas Fluxes in Agriculture and Forestry.

iii. Restoration to upland

Restoring degraded lands and converted farmland to uplands increases the total sequestered carbon dioxide as soil carbon as estimated by the USDA for grasslands:

- The carbon sequestered in degraded grasslands is the product of the carbon reference stock for dry wetland soils in a warm temperate dry climate, the land use factor for warm temperate dry grasslands, and the grassland management factor for severely degraded grasslands.
- The carbon sequestered in restored upland is the product of the carbon reference stock for dry wetland soils in a warm temperate climate, the land use factor for warm temperate dry grasslands, the grassland management factor for improved grasslands, and the grassland input factor for high input.

The change in sequestered carbon is the difference between these two products.

c. Restoration of Mountain Meadows:

The carbon sequestration rate due to the restoration of mountain meadows is determined by Drexler, et.al. This is the only quantification for mountain meadows.

2. Changes in N_2O emissions are due to conversion of cropped soils on organic soils to wetlands. Direct N_2O emissions from cropped soils on organic soils are estimated using the IPCC Tier 1 emission rate identified by the USDA for wetlands. Restored wetlands N_2O emissions are not quantified.

See the "Wetland Restoration" tab of the Database for specific emission factors.

Food Waste Prevention and Rescue

Food Waste Prevention and Rescue emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 5.

Table 5. Programs Using Food Waste Prevention and Rescue Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Food waste prevention and rescue GHG emissions factors were derived from a CleanMetric Corp. study, *The Climate Change and Economic Impacts of Food Waste in the United States* and CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*. CARB used the following steps to derive the food waste prevention and rescue emission reduction factor:

1. Determine the total amount of food waste from the distribution, retail, and consumer waste streams.
2. Determine the total GHG emissions from production and processing, packaging, and distribution and retail. Disposal emissions were derived using the CERF for consistency with other CalRecycle programs and California specific factors.
3. Calculate the emission factor using Equation 6.

Equation 6: GHG Emissions Reductions from Food Waste Prevention and Rescue

$$EF_{FW} = \left(\left(\frac{TFWE}{TFW}\right) \times \left(\frac{1}{1.10231}\right) + ALM\right) \times 0.9$$

Where,			Units
EF_{FW}	=	Food waste emission reduction factor	$MTCO_2e$/short ton of food waste
TFWE	=	Total food waste GHG emissions	$MMTCO_2e$/year
TFW	=	Total food waste from all food categories	MMT/year
1.10231	=	Conversion factor from metric ton to short ton	MT/short ton
ALM	=	Avoided landfill methane for food waste	$MTCO_2e$/short ton food waste
0.9	=	10% discount as agreed upon by CARB and CalRecycle	unitless

Equation 6. The food waste GHG emissions reduction factor is calculated as the Total food waste GHG emissions divided by the total food waste from all food categories, then adding the amount of avoided landfill methane, and finally multiplied by 0.90 to take into account a 10%discount rate.

See the "Food Waste" tab of the Database for specific emission factors.

Landfill Emission Factors

Landfill emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 6.

Table 6. Programs Using Landfill Emission Factors

Agency	Program
California Department of Forestry and Fire Protection	Urban and Community Forestry Program
California Department of Resources Recycling and Recovery	Food Waste Prevention and Rescue Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Landfill GHG emission reduction factors were derived from the avoided methane emissions in CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*.

See the "Landfill" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Criteria and toxic air pollutants are formed from the decomposition, volatilization, and off-gas combustion of landfill materials. By diverting organic waste from landfills, pollutants created from the organic waste in landfills are avoided.

Landfill gas is mostly methane and carbon dioxide. However, landfill gas also contains CO, NMOC, and NH_3. Default concentrations for CO and NMOC are given Table 2.4-1 and 2.4-2 of AP-42 Section 2.4, Municipal Solid Waste Landfills. No co-disposal of hazardous wastes is assumed. ROG is a subset of NMOC and is calculated by subtracting from NMOC the non-ROG gases (as defined by the CARB memorandum Definitions of VOC and ROG) found in the list of landfill gas constituents in Table 2.4-1 of AP-42.

Control devices at landfills destroy landfill gas by combustion. The combustion process creates as byproducts additional pollutants that did not previously exist in the landfill gas: $PM_{2.5}$, NO_x, and CO. Emission factors for NO_2, CO, and $PM_{2.5}$ for different control devices are given in Table 2.4-4 of AP-42. In alignment with the CERF and quantification methodology, it is assumed that all control systems are flares, and that 74.3% of the landfill gas is captured. The remaining landfill gas is uncaptured and enters the atmosphere.

Flaring landfill gas converts methane to carbon dioxide and water vapor, but also creates secondary compounds: NO_x, CO, and $PM_{2.5}$. Emission factors for these pollutants from control devices are given in Table 2.4-4 in AP-42. As a control device, flares destroy most but not all ROG that enters the control device; control efficiencies for flares are given in Table 2.4-3 in AP-42.

The total criteria and toxic air pollutants avoided as a result of diverting organic waste from landfills is the sum of the pollutants in the uncaptured landfill gas and the pollutants emitted from the flaring of captured landfill gas. For this quantification, CARB only included NO_x, $PM_{2.5}$, and ROG. CARB used Equation 7 to convert from kg of pollutant per million dscm of methane to lb of pollutant per ton of waste.

Equation 7: Criteria and Toxic Emissions from Landfill Gas

$$EF_{LF,CT} = FL \times \frac{1}{1{,}000{,}000} \times \frac{1}{0.6802} \times 1{,}000 \times 25 \times ALM \times 2.20462$$

Where,			Units
$EF_{LF,CT}$	=	Landfill gas ROG, NO_x, and $PM_{2.5}$ emissions from flare	lb of pollutant/ short ton of waste
FL	=	Flare ROG, NOx, and PM2.5 emission factors	kg of pollutant/ 10^6 dscm of methane
1,000,000	=	Conversion factor from 10^6 dscm methane to dscm methane	10^6 dscm of methane/ dscm of methane
0.6802	=	Conversion factor from dscm methane to kg methane	dscm of methane/ kg of methane
1,000	=	Conversion factor from kg methane to MT methane	kg of methane/ MT of methane
25	=	Conversion from MT methane to $MTCO_2e$	MT of methane/ $MTCO_2e$
ALM	=	CERF avoided landfill methane emission factor	$MTCO_2e$/ short ton of waste
2.20462	=	Conversion from kg pollutant to lb pollutant	kg of pollutant/ lb of pollutant

Equation 7. The air pollutant emissions from landfill gas is calculated as the flare emission factor multiplied by the avoided landfill methane emission factor.

See the "Landfill" tab of the Database for specific emission factors.

Agricultural Soil

Soil emission factors are used in the quantification methodologies for the California Climate Investment programs named in Table 7.

Table 7. Programs Using Agricultural Soil Emission Factors

Agency	Program
California Department of Food and Agriculture	Healthy Soils Program

GHG Emission Factors

GHG emission reduction factors were derived for the following types of soil management practices:

- Cropland Management,
- Herbaceous Cover Establishment on Cropland, and
- Grazing Land Practices.

The COMET-Planner CDFA HSP Calculator Tool estimates net GHG benefits from COMET-Planner implemented conservation practices (consistent with USDA NRCS Conservation Practices Standards) on croplands, grasslands, and croplands converted to herbaceous cover. COMET-Planner is largely derived using a sample-based approach and model runs in COMET-Farm, which utilizes USDA entity-scale GHG inventory methods. Coefficients were generalized by multi-county regions defined by USDA Major Land Resource Areas. Emissions estimates represent field emissions only, including those associated with soils and woody biomass as appropriate, and do not include off-site emissions, such as those from transportation, manufacturing, processing, etc. COMET-Farm is a web-based, whole farm, GHG accounting system that employs methods outlined in the USDA Methods for Entity-Scale Inventory guidance. Estimation methods used for most GHG sources in COMET-Planner rely on advanced methods (commonly referred to as "Tier 3" methodologies in IPCC quantification methods), such as process-based modeling in DayCent and regionally-specific empirical calculations. This is shown in the COMET-Planner companion report for Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning.

See the COMET-Planner CDFA HSP Calculator Tool for specific emission reduction coefficients.

GHG emission reduction estimates in COMET-Planner for woody biomass accumulation in agroforestry systems (i.e., windbreaks, shelterbelts, farm woodlots, silvopasture, riparian buffers and alley cropping) are based on the USDA Forest Service Forest Inventory Analysis database in 2018, using repeated-measures data points at the individual tree species or genus level, aggregated for US Land Resource Regions.

See the COMET-Planner CDFA HSP Calculator Tool for specific emission reduction coefficients.

Compost Application Practices:

GHG emission reduction estimates in the COMET-Planner CDFA HSP Calculator Tool for compost application are based on the DNDC model, a process-based computer simulation model of carbon and nitrogen biogeochemistry that was developed for quantifying carbon sequestration and emissions of GHG in agroecosystems.

See the CARB White Paper "Quantification of Greenhouse Gas Emissions for Compost Application in California Croplands" for specific emission factors.

Whole Orchard Recycling Practice:

GHG reduction estimates in the COMET-Planner CDFA HSP Calculator Tool for whole orchard recycling (WOR) are based on the DNDC model, a process-based computer simulation model of carbon and nitrogen biogeochemistry that was developed for quantifying carbon sequestration and emissions of GHG in agroecosystems.

See the CDFA White Paper "Whole Orchard Recycling" for specific emission factors.

Criteria Pollutant Emission Factors

$PM_{2.5}$ emission reduction factors for agricultural soil are based on the following types of tillage practices (conservation tillage):

- Intensive Till to No Till or Strip Till;
- Intensive Till to Reduced Till; and
- Whole Orchard Recycling.

$PM_{2.5}$ emission reductions from implementation of conservation tillage practices (No Till and Reduced Till) on irrigated and non-irrigated cropland result from the reduction of dust emissions associated with conventional agricultural operations. Emission factors were developed by first creating a conventional soil management scenario (intensive till, including ripping, discing, planting, and harvesting operations) with associated Soil Tillage Intensity Ratings (STIR) from NRCS and PM_{10} emission rates as displayed in Table 8.

Table 8. STIR and PM_{10} Emission Rates for Conventional Agricultural Operations

Operation	STIR	Emission Factor (lbs PM_{10}/acre)
Ripping/Deep Chisel	45.50	4.6
Discing, secondary operation	32.50	1.2
Discing, light finishing	19.50	1.2
Planting (Drill)	2.43	N/A
Harvesting	0.15	5.8
TOTAL (Intensive)	**100.08**	**12.8**

Reduced Till and No Till practice scenarios eliminate particular operations reducing the STIR to below 80 and to below 20, respectively. The removal of dust emissions associated with each eliminated operation is used to estimate the change in PM_{10}, based on the study Computing Agricultural PM10 Fugitive Dust Emissions Using Process Specific Emission Rates and GIS. Reduced Till practices include discing, planting and harvesting for a total PM_{10} emission rate of 8.2 lbs per acre. No Till or Strip Till practices include planting and harvesting for a total PM_{10} emission rate of 5.8 lbs per acre.

$PM_{2.5}$ emission reduction factors are derived from the difference in PM_{10} emission rates between the conventional soil management and conservation tillage scenarios, using Equation 8. For agricultural dust, $PM_{2.5}$ is estimated to be 15% of PM_{10} based on CARB's Miscellaneous Process Methodologies for Agricultural Land Preparation Operations.

Equation 8: $PM_{2.5}$ Emission Reduction Factor for Conservation Tillage Practices

$$ERF_{PM2.5} = (Conv\ ER_{PM10} - Cons\ ER_{PM10}) \times 0.15$$

Where,			Units
$ERF_{PM2.5}$	=	$PM_{2.5}$ emission reduction factor for conservation tillage practices	lb $PM_{2.5}$/acre
Conv ER_{PM10}	=	PM_{10} emission rate for conventional soil management	lb PM_{10}/acre
Cons ER_{PM10}	=	PM_{10} emission rate for conservation tillage practice (reduced till or no till)	lb PM_{10}/acre
0.15	=	Conversion factor from PM_{10} to $PM_{2.5}$	lb $PM_{2.5}$/lb PM_{10}

Equation 8. The $PM_{2.5}$ emission reduction factor for conservation tillage practices is calculated as the conversion factor from PM_{10} to $PM_{2.5}$ multiplied by the difference in PM_{10} emissions from conventional soil management and from the conservation tillage practice.

$PM_{2.5}$ emission reductions from implementation of the WOR practice result from the avoided emissions from orchard removal burning, less the new dust emissions created from WOR implementation: deep ripping and discing. This is based on the San Joaquin Valley Air Control District's 2007 Area Sources Emission Inventory Methodology for Agricultural Burning. Emission factors were developed by identifying the PM2.5 emission factor for orchard removal burning (219 lb-$PM_{2.5}$/acre), and subtracting the emissions from WOR operations (5.8 lb-PM_{10}/acre), using Equation 9.

Equation 9: $PM_{2.5}$ Emission Reduction Factor for Whole Orchard Recycling

$$ERF_{PM2.5} = Burn\ ER_{PM2.5} - 0.15 \times WOR\ ER_{PM10}$$

Where,			Units
$ERF_{PM2.5}$	=	$PM_{2.5}$ emission reduction factor for whole orchard recycling practices	lb $PM_{2.5}$/acre
Burn ER_{PM10}	=	PM_{10} emission rate for avoided orchard removal burning	lb $PM_{2.5}$/acre
0.15	=	Conversion factor from PM_{10} to $PM_{2.5}$	lb $PM_{2.5}$/lb PM_{10}
WOR ER_{PM10}	=	PM_{10} emission rate for whole orchard recycling operations	lb PM_{10}/acre

Equation 9. The $PM_{2.5}$ emission reduction factor for whole orchard recycling is calculated as the conversion factor from PM_{10} to $PM_{2.5}$ multiplied by the reduction in PM_{10} emissions from avoided agricultural burning.

NO_X and NH_3 emission reduction factors for agricultural soil are derived from the following types of practice implementations:

- Add Non-Legume Seasonal Cover Crop to Irrigated Cropland;
- Add Legume Seasonal Cover Crop to Irrigated Cropland;
- Improved nitrogen (N) Fertilizer Management on Irrigated Croplands - Reduce Fertilizer Application Rate by 15%;
- Intensive Till to No Till or Strip Till on Irrigated Cropland;
- Intensive Till to Reduced Till on Irrigated Cropland;
- Compost (C/N ≤ 11) to Annual Crops;
- Compost (C/N > 11) to Annual Crops;
- Compost (C/N ≤ 11) to Perennials, Orchards and Vineyards;
- Compost (C/N > 11) to Perennials, Orchards and Vineyards;
- Compost (C/N > 11) to Grazed, Irrigated Pasture; and
- Compost (C/N > 11) to Grazed Grassland.

NO_X and NH_3 emission reduction factors are estimated using the DNDC model, a process-based computer simulation model of carbon and nitrogen biogeochemistry that was developed for quantifying carbon sequestration and emissions of greenhouse gases in agroecosystems, sourced from CARB's Quantification of Greenhouse Gas Emissions for Compost Application in California Croplands.

NO_x, SO_2, ROG, and CO emission reduction factors for agricultural soil are derived for the following types of practice implementations:

- Whole Orchard Recycling

Nitrous Oxides (NO_x), Sulfur Dioxide (SO_2), Reactive Organic Gases (ROG), and Carbon Monoxide (CO) emission factors for WOR are based on the avoided emissions from burning:

Table 9. Emission Reduction Factors for Whole Orchard Recycling

Pollutant	Emissions (lb/ton)	Fuel Loading (ton/acre)	Emissions (lb/acre)
NO_x	5.2	30	**156**
SO_2	0.1	30	**3**
ROG	6.3	30	**189**
CO	66	30	**1980**

See the "Ag Soil Criteria" tab of the Database for specific emission factors.

Fiber, Plastics, and Glass Recycling

Fiber, plastics, and glass recycling emission reduction factors are used in the quantification methodologies for the California Climate Investment programs named in Table 10.

Table 10. Programs Using Fiber, Plastic, and Glass Recycling Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Recycled Fiber, Plastics, and Glass Grant Program

GHG Emission Factors

GHG emission reduction factors were derived for recycling the following types of fiber, plastics, and glass materials:

- Glass,
- High density polyethylene (HDPE),
- Polyethylene terephthalate (PET),
- Corrugated cardboard,
- Magazines/3rd class mail,
- Newspaper,
- Office paper,
- Phone books,
- Dimensional lumber, and
- Textiles.

The material-specific recycling emission reduction factors (RERFs) were determined using a life-cycle approach to calculate the net avoided emissions from manufacturing using recycled material in place of raw virgin materials. The methods used, results, and discussion of the RERFs are detailed in reports titled *Method for Estimating Greenhouse Gas Emission Reductions from Recycling*, and *Advancing Sustainable Materials Management: Facts and Figures 2013: Assessing Trends in Material Generation, Recycling and Disposal in the United States*. The RERFs are consistent with GHG accounting practices used in California and can be used to accurately and uniformly quantify GHG emission reductions attributable to the diversion of fiber, plastic, and glass for the purpose of manufacturing recycled-content products.

See the "Recycling" tab of the Database for specific emission factors.

Criteria Pollutant Emission Factors

Criteria pollutant emission reductions are estimated based on material specific energy savings from the use of recycled fiber, plastic, and glass in manufacturing. Energy savings for each material are sourced from the U.S. EPA Waste Reduction Model (WARM) and U.S. EPA Advancing Sustainable Materials Management: 2013 Fact Sheet. Criteria pollutant emission factors for electricity are then used to determine the emission reductions from fiber, plastics, and glass recycling.

See the "Grid Electricity" tab of the Database for specific emission factors.

Compost Production Emission Factors

Compost production emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 11.

Table 11. Programs Using Compost Production Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Compost production GHG emission reduction factors were derived from the lifecycle composting production analysis in CARB's *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*.

Based on the boundary developed for the composting projects, the emission reduction factor includes avoided landfill methane and fugitive GHG emissions from processing the compost, however, it does not take into consideration application of compost.

See the "Compost" tab of the Database for specific emission factors.

Anaerobic Digestion Emission Factors

Anaerobic digestion emission factors are used in the quantification methodologies for the California Climate Investments programs named in Table 12.

Table 12. Programs Using Anaerobic Digestion Production Emission Factors

Agency	Program
California Department of Resources Recycling and Recovery	Organics Grant Program

GHG Emission Factors

Anaerobic digestion GHG emission reduction factors were derived from the following LCFS pathways*:*

- *Low Carbon Fuel Standard Pathway for the Production of Biomethane from High Solids Anaerobic Digestion (HSAD) of Organic (Food and Green) Wastes*
- *Low Carbon Fuel Standard Pathway for the Production of Biomethane from the Mesophilic Anaerobic Digestion of Wastewater Sludge at Publicly-Owned Treatment Works (POTW)*

Both pathways analyze the full lifecycle analysis of various digestion pathways to determine the GHG impacts of creating renewable natural gas from an anaerobic digestion system. For the purposes of the Organics Benefits Calculator Tool, the pathway was modified in the following ways:

- Removal of biogenic CO_2 emissions
- Replacement of LCFS factors with CCI default factors where applicable (GHG factors of grid electricity, compost emission reductions factors, vehicle GHG emissions, etc.)
- Included the offset emissions from avoided diesel usage, avoided grid usage, or combustion of biomethane from the natural gas pipeline

See the "Anaerobic Digestion" tab of the Database for specific emission factors.