CALIFORNIA
AIR RESOURCES BOARD

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Calculation of the Lifecycle Greenhouse Gas Emissions Reduction Benchmark for the Organic Waste Reductions Regulation

This document has been revised for clarity and accessibility from its original version. The original version of this document was relied upon in the rulemaking and referred to in the Final Statement of Reasons as "Staff Guidance Memo Prepared for CalRecycle – document explaining calculations related to Article 2." Minor revisions were made to correct typographic errors, clarify the lifecycle system boundary, and to meet CARB's accessibility standards. The methodology and results have not been altered from the original version of the text.

Purpose

This document provides the methodology and calculations used to determine the greenhouse gas (GHG) emissions reduction from diverting organic waste from landfill disposal to composting, 0.30 metric tons carbon dioxide equivalent ($MTCO_2e$) per short ton mixed organic waste (benchmark), as specified in section 18983.2(a)(3) of the *Short-Lived Climate Pollutants: Organic Waste Reduction* Regulation.

Methodology

The quantification methodology used to determine this benchmark follows that used by the California Air Resources Board's (CARB) *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities* (referred to herein as Compost Emission Reduction Factor or "CERF"). The CERF quantification methodology includes GHG emissions from transportation of organic waste to a landfill or composting facility, GHG emissions from energy use during landfilling or composting operations, fugitive GHG emissions from landfilling or composting, and the avoided GHG emissions from fertilizer production (i.e., the GHG emissions that do not occur because synthetic fertilizer is replaced by compost). The resulting benchmark reflects the lifecycle GHG emissions reduction from composting one short ton of mixed organic waste versus depositing the same amount of material into a landfill.

The CERF methodology was modified as follows:

- Calculations utilize CalRecycle's *2014 Waste Characterization Study* to define the characteristics of mixed organic waste. Use of this study is consistent with statutory organic waste reduction targets, which are relative to 2014 levels (Senate Bill 1383,

Lara, Chapter 395, Statutes of 2016). CERF used a previous study, *California 2008 Statewide Waste Characterization Study.*
- Calculations reflect the bioavailability of nutrients from compost application rates used in the California Department of Food and Agriculture's Healthy Soils Incentive (HSI) Program in determining the avoided GHG emissions attributable to displacing the production of synthetic fertilizer.
- The calculations do not reflect any off-site impacts that may occur from using the compost—notably, soil carbon storage. This impact is not incorporated into this calculation because the permanence of soil carbon from compost application depends on many variables, and therefore it is inappropriate to assume permanence. As noted in the *Initial Statement of Reasons to the Regulation* and defined in Regulation section 18982(a)(53.6), GHG emissions reductions must be maintained for the approximate lifetime of carbon dioxide in the atmosphere (~100 years) to be considered permanent.

Emissions Reduction from Composting Organic Waste Benchmark Equation

Emissions Reduction from Composting Organic Waste Benchmark = a + b – c

Where:
a = landfill methane emissions avoided by diverting organic waste from the landfill,
b = GHG emissions associated with avoided product (fertilizer) production, and
c = total compost emissions.

Benchmark Equation Input "a" (Diverting Organic Waste from the Landfill)

The model used to quantify methane emissions from landfills is based on the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines* first-order decay (FOD) method.[1] To calculate the emissions avoided by diverting organic waste from the landfill, the following two parameters were used as inputs in the IPCC FOD model:

1. Decay Rate (k)

Decay rate values are from the U.S. Environmental Protection Agency's (U.S. EPA) *Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM)*,[2] and the *WARM component-specific decay rate methods* memo

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[1] IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. Volume 5, Chapter 3. Solid Waste Disposal.

[2] U.S. Environmental Protection Agency (U.S. EPA) Office of Resource Conservation and Recovery. February 2016. Management Practices Chapters, Exhibit 6-7. Downloaded on July 12, 2018.

to U.S. EPA.[3] The decay rates used to establish this benchmark represent a conservative approach because they represent the driest conditions. While a majority of the State's waste is generated in dry regions, composting in wetter regions of the State is expected to achieve additional GHG emissions reductions. The decay rate (k) is calculated using a proration of 67.8% food (k=0.072), 14.2% grass/leaves (k=0.12, calculated from 50% grass at k=0.15 and 50% leaves at k=0.09), and 18% branches (k=0.01). Staff calculated these waste fractions using data from Table ES-3 of CalRecycle's *2014 Waste Characterization Study*; the applicable organic waste percentages were scaled to 100% to determine the composition of mixed organic waste as shown below in Table 1.

Table 1. Organic waste percentage by material

Material	2014% of Total Waste Disposal	Mixed Organic Waste %
Food	18.1	67.8
Leaves and Grass	3.8	14.2
Branches[4]	3.1 + 1.7 = 4.8	18.0
Totals	**26.7**	**100.0**

The decay rates used for each of the material types (i.e., food, grass/leaves, and branches) is the same between CERF and these calculations; however, the final decay rate for mixed organic waste is 0.068 for this benchmark (as opposed to 0.072 in CERF[5]). This difference is attributable to the updated waste fractions in the *2014 Waste Characterization Study*.

2. Anaerobically Degradable Organic Carbon (ANDOC)

The values used to calculate ANDOC are taken from CARB's *2014 Greenhouse Gas Emission Inventory*.[6]

ANDOC = DOC × DANF

Where:
DOC = degradable organic carbon
DANF = decomposable anaerobic fraction

DOC values were converted from metric tons to short tons basis (i.e., from MT DOC/MT waste to MT DOC/short ton waste) by multiplying by the conversion factor 0.9072. DANF represents the fraction of DOC that is decomposable under anaerobic conditions for each organic waste type. DANF values were taken directly from CARB's *2014 Greenhouse Gas*

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[3] Barlaz, Evans, et al. October 2009. Note that the decay rate value (k) for food was also used in CERF.

[4] This category combines prunings and trimmings (3.1% of total waste disposal) and branches and stumps (1.7%).

[5] Refer to Table 6 on page 15 in CARB's CERF for more details.

[6] Tables 41 and 42 on page 121 in CARB's 2014 Edition of California's 2000-2012 GHG Emission Inventory Technical Support Document.

Emissions Inventory. The resulting DOC and DANF values were then multiplied, yielding a specific ANDOC value for each waste type.

The ANDOC value that was calculated for each waste type was multiplied by the organic waste percentage for the corresponding waste type (67.8%, 14.2%, and 18.0%, respectively, as shown in Table 1) and the results were added together resulting in the final ANDOC value (0.101 MT C/short ton) that represents the composition of the mixed organic waste. The ANDOC value is identical to the CERF ANDOC value that relied on the *2008 Statewide Waste Characterization Study*.

Other IPCC FOD model parameters that are independent of the type of organic waste and remain unchanged between CERF[7] and these calculations include the oxidation factor scenarios (10 and 35 percent), the landfill gas collection scenarios, decomposition delay (6 months), gas combustion efficiency for the flare (99.77 percent), and the global warming potential of methane (25).[8] A summary of the final methane emissions avoided by diverting organic waste from the landfill is shown in Table 2.

Table 2. GHG emission reduction factor for avoided landfill disposal ($MTCO_2e$/short ton mixed organic waste)

	Typical Phased Gas Collection with No Shutdown(1)	Phased Gas Collection with Shutdown after year 60(2)	Average(3)
Oxidation Factor 0.10	0.315	0.450	***a* = 0.33**
Oxidation Factor 0.35	0.228	0.325	

(1) Total 100-year gas collection efficiency is 79.2 percent.
(2) Total 100-year gas collection efficiency is 70.3 percent.
(3) Average 100-year gas collection system efficiency is 74.7 percent.

The values in Table 2 for the four scenarios were computed using k=0.068 and ANDOC=0.101 as the two input parameters within the IPPC FOD model. Results of each of the four scenarios were then averaged.

The resulting value of *a* (methane emissions avoided by diverting organic waste from the landfill) to be used in the benchmark equation is 0.33 $MTCO_2e$ per short ton mixed organic waste (two significant figures) as shown in the last column of Table 2.

Note that in addition to the methane emissions avoided by diverting organic waste from the landfill, CERF also evaluated the emissions from energy use in transportation and processing operations associated with landfilling compared to composting. Transportation includes

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[7] Refer to Table 6 on page 15 in CARB's CERF for more details.

[8] This document uses 100-year global warming potential (GWP) values from the IPCC Fourth Assessment Report, consistent with current international and national GHG inventory practices.

emissions from transporting the waste material to a landfill or composting facility, as well as distribution of the finished compost product to consumers. Landfill process emissions include emissions from landfill construction, waste placement, gas and leachate management, operations, and long-term maintenance; for composting, this includes emissions from use of composting equipment such as shredders, front loaders, and windrow turning equipment. CERF determined that landfilling and composting energy use fall within the same range and can be considered functionally equivalent in regard to process and transportation emissions.

Benchmark Equation Input "b" (Avoided Fertilizer)

The benefit of reduced GHG emissions is attributable to replacing mineral nitrogen (N), phosphorous (P), and potassium (K) fertilizer with compost. The assumption is that compost application displaces NPK fertilizer use based on the nutritional needs of the crop. The GHG emissions benefits are associated with a reduction in NPK fertilizer production.

The emissions benefits for both higher- and lower-N compost were calculated by applying emission factors for mineral NPK[9] fertilizer production used in CERF to the amount of organic NPK provided to the crop from the compost. The compost application rates follow those described in *Compost Application Rates for California Croplands and Rangelands for a CDFA Healthy Soils Incentives Program (Gravuer, 2016)*.[10] Averaging the emissions reductions for the higher- and lower-N compost results in an emissions benefit of 0.0361 $MTCO_2e$ per short ton mixed organic waste.

A stepwise description of the calculations is provided below. The amount of ammonium and nitrate, as well as organically bound N were calculated using data from 1,364 compost samples, the average values of which are provided in Table 1 on page 7 of Gravuer (2016). Gravuer found that only a portion of the organically bound N is bioavailable to the plant, and it remains available for years after application. The initial amount of organically bound nitrogen was quantified for 10 years by applying variable mineralization rates described on page 8 in Gravuer (2016):

- During the first year, mineralization rates after compost application are five percent for lower-N compost and ten percent for higher-N compost.
- During the second year, mineralization rates are about half of the first year's rate—2.5 and 5 percent, respectively, for lower- and higher-N compost.
- During the third year the mineralization rate was 2.5 percent for the higher-N compost and 2 percent for lower-N compost.
- During the fourth and subsequent years, the mineralization rate for both higher- and lower-N compost remained fixed at 2 percent.

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[9] NPK fertilizer used was approximately 24 percent N, 7 percent P, and 3 percent K.

[10] Gravuer, Kelly. Compost Application Rates for California Croplands and Rangelands for a CDFA Healthy Soils Incentives Program. July 22, 2016.

Staff calculated the total amount of N as the sum of the amount of ammonium and nitrate, plus the amount of organically bound N for up to ten years following the mineralization rates listed above. The values are for dry compost, so converting from dry to wet using the moisture content from Gravuer (2016) Table 1 is required. The following equation was used to calculate total N for 10 years into kilogram (kg) N per short ton wet compost. The conversion factor 0.454 converts the mass from pounds to kilograms.

Total N for 10 years (kg N/short ton wet compost) = Total N for 10 years (pounds N/short ton dry compost) * (1/(1-percent moisture)) * 0.454

The total N for 10 years in kg per short ton wet compost is multiplied by the emission factors cited on page 9 of CERF.[11] Because the emission factors are based on finished compost and the benchmark value is based on short tons of mixed organic waste compost feedstock, the same conversion factor of 0.58 must be multiplied to convert the values from finished compost to mixed organic waste.[12] Staff divided the final mass value by 1,000 to convert from kg to metric tons.

Staff assumed the P and K followed the same bioavailability rates as N and used the same procedure to determine the amount of P and K provided to the crop from the compost application. The same procedures were applied to both higher- and lower-N compost. Finally, staff averaged the total amount of GHG emissions from reduced NPK fertilizer production for application of both higher- and lower-N compost. The resulting value of *b* (GHG emissions associated with avoided fertilizer production) is 0.0361, as shown as the average in Table 3 below.

Table 3. GHG emission reduction factor associated with avoided fertilizer production (MTCO$_2$e/short ton mixed organic waste)

Fertilizer Displacement	**N**	**P**	**K**	**NPK**
Lower-N compost (C:N > 11)	0.0220	0.00445	0.00237	0.0288
Higher-N compost (C:N ≤ 11)	0.0331	0.00669	0.00357	0.0434
			Average:	***b* = 0.0361**

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[11] The emission factor used for NPK fertilizer is based on avoided life cycle emissions from fertilizer production that would have occurred in the absence of compost use. The emission factors for N, P, and K are 8.9, 1.8 and 0.96 kg CO$_2$e/kg, respectively.

[12] Refer to Table 9 page 19 of CERF.

Benchmark Equation Input "c" (Total Compost Emissions)

The value for (c) is 0.070 and comes directly from CERF.[13] This value represents the average fugitive methane and nitrous oxide emissions from windrow compost management compiled from various studies. The selected studies represent California composting methods, and include three California-specific studies. The values from the selected papers that discussed methane (n=6) and nitrous oxide (n=4) emissions were averaged together. The average methane and nitrous oxide emissions were converted to $MTCO_2e$ by multiplying by their respective global warming potential values of 25 and 298, then added together.

As noted previously, the energy used in the compost production process is a part of the system boundary. These emissions are not shown as part of total compost emissions, because CERF determined that landfilling and composting energy use can be considered functionally equivalent.

Emissions Reduction from Composting Organic Waste Benchmark Calculation

The final emission reduction factor was determined by adding up the avoided methane emissions from not landfilling the waste (*a*) and the avoided GHG emissions associated with fertilizer production (*b*), then subtracting the compost fugitive emissions (*c*). The value for *a* is 0.33 (Table 2). The value for *b* is 0.0361 (Table 3). The value for *c* is 0.070 and comes directly from CERF. All units for the benchmark values referenced are in $MTCO_2e$ per short ton mixed organic waste.

Benchmark Value = 0.33 + 0.0361 – 0.070 =
0.30 $MTCO_2e$/short ton mixed organic waste

The units in the Regulation are "$MTCO_2e$/short ton organic waste" instead of "$MTCO_2e$/short ton *mixed* organic waste." Through 15-day changes, the word "mixed" was removed from Section 18983.2 Subdivision (a)(3) because recovery may include organic materials of other types that are not mixed.

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[13] Refer to Table 5 on page 14 of CERF.