U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions

Appendix E: Solid Waste Emission Activities and Sources

Version 1.1

July 2013

Developed by
ICLEI – Local Governments for Sustainability USA

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Introduction

Background

Greenhouse gas (GHG) emissions result from management of solid waste of all types and from the natural decay of solid waste with biologic constituents. GHG emissions from the management of solid wastes include those from combustion of fossil and/or biologic fuel in equipment used to transport and process the waste, and, in the case of incinerator and waste-to-energy (WTE) technologies, emissions from combusting the solid waste itself. Typically, combustion emissions include small amounts of nitrous oxide (N_2O) and methane (CH_4), and a larger component of carbon dioxide (CO_2), which will be non-biologic if derived from fossil fuel or non-biologic wastes, and will be biologic if derived from biofuels or biologic wastes. GHG emissions from the natural decay of biologic wastes are associated with landfills, digesters, and compost facilities and they include biologic CO_2, CH_4, and N_2O in differing proportions based upon the type of management process. Upstream emissions associated with solid waste generation are reflected in Appendix H - Emissions Associated with the Community's Use of Materials and Services: Accounting for Trans-boundary Community-Wide Supply-Chains.

GHGs are generated differently from biologic and non-biologic solid wastes. GHGs are generated by non-biologic wastes only if they are combusted. GHGs are generated from biologic wastes whether they are combusted or allowed to decay naturally. Because of the social and health concerns resulting from allowing solid wastes to remain uncontrolled, modern communities typically apply a management method to decaying waste. In the case of combustion and composting, the biologic constituents are broken down into simpler carbon compounds by bacteria in an aerobic (oxygen rich) environment. In the case of digestion and landfilling, the biologic constituents are broken down into simpler carbon compounds by bacteria in an anaerobic (oxygen poor) environment generating roughly equal amounts of CH_4 and CO_2 by volume.

Solid Waste Management

This chapter addresses emissions arising from solid waste *generated* by a community (regardless of where it is disposed of) as well as emissions arising from solid waste *disposed* of inside a community's boundaries (regardless of where it was generated). All communities generate solid waste and have to manage it, even if that management involves transferring the waste to treatment or disposal sites located outside the confines of the community. Not all communities are host to disposal facilities.

Overall, in 2010, waste activities generated emissions of 132.5 Tg CO_2e, or 1.9% of total United States (U.S.) greenhouse gas emissions. Waste activities are listed as landfills, wastewater treatment and composting.[1] Materials use associated with product and food consumption, however, is typically more than 40% of GHG emissions.[2] Some of these emissions can be estimated using methods described in *Appendix H - Emissions Associated with the Community's Use of Materials and Services: Accounting for Trans-boundary Community-Wide Supply-Chains*, using waste generation as a proxy for materials use.

Recycling and composting diversion programs are very important tools for reducing GHG emissions in the community. Protocol-compliant inventories should acknowledge the benefits of programs that lower waste volumes than they would be otherwise. Recycling and composting diversion programs affect a community's emissions in two ways: by reducing landfill or combustion emissions, and by reducing upstream emissions from materials manufacturing when recycled materials displace virgin feedstocks. The reduced emissions from landfills or waste combustion will be reflected in the gross emissions totals for these sources using the Protocol's solid waste accounting methods. However, upstream emissions reductions from materials manufacturing, which are far more significant than landfill/combustion emissions reductions, are more problematic. These emissions would be partially captured through application of methods pertaining to lifecycle emissions analysis in *Appendix H - Emissions Associated with the Community's Use of Materials and Services: Accounting for Trans-boundary Community-Wide Supply-Chains* and *Appendix I - Consumption-based Emission Activities and Sources*, but the emissions reduction benefits will appear small compared to the aggregate emissions from all materials and services used or consumed by the community.

To address the clear need to account for the benefits of recycling and composting programs, ICLEI will publish an accounting standard developed by the Solid Waste Technical Advisory Committee for estimating the specific emissions reductions from recycling and composting (rather than the gross emissions totals that are the subject of this emissions inventory protocol), following release of the Community Protocol in October 2012.

In addition to generating (producing) solid waste, communities may also be home to treatment and disposal facilities. Local governments may own and operate their own solid waste management facilities. However, even if the local government does not own or operate the solid waste management facilities within its jurisdiction, it typically will have a voice in the permitting of such facilities and may even have specific ordinances that address where solid waste may be managed and what types of solid waste can be managed by certain technologies and practices. Local governments also may use facilities that they do not own or operate and may make choices based on facility performance in emissions reduction. Local governments make decisions about how much and what materials to recycle or compost, thereby reducing the amount of waste sent to landfills or combustors. These decisions can reduce facility emissions and avoid emissions from product manufacturing.

[1] Page 86 of 481, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2010, April 15, 2012.
[2] http://www.epa.gov/oswer/docs/ghg_land_and_materials_management.pdf

Solid Waste Disposal Facilities and Equipment

This protocol is intended to cover emissions from the disposal of solid waste within a community, as well as emissions from waste that is generated by a community. This includes emissions from both landfills and waste combustion facilities. Depending on the location of facilities, there may be some overlap between emissions from community-generated waste and emissions from waste facilities within the community. Any given community might host or send waste to more than one facility or a mix of landfills and waste combustion facilities, so the applicable parts of the protocol will depend on the user.

Uncertainties

WTE facilities that do not directly combust waste (such as gasification facilities) are not currently included in this protocol, due to a lack of commercial-scale usage of this technology. If this technology spreads, communities that send waste to these types of facilities will need to include the GHG emissions reported to the United States Environmental Protection Agency (EPA) in accordance with the GHG Mandatory Reporting Rule (40 CFR §98) (MRR), similar to the approach outlined for WTE combustion facilities and landfills.

CH_4 and N_2O default emission factors, from composting activities, were first estimated by the EPA in 2008. These macro-level default emission factors may be appropriate on a national level; however, they are not suitable to estimate fugitive emissions at the individual facility level.

Because of the lack of widely accepted and standardized data and guidance, the Protocol does not include standardized methodologies to estimate fugitive emissions from composting. The Protocol does include Method *SW.3,* which elaborates on the composting process. As direct measurement of these emissions improves that method will be updated with additional guidance.

The emissions calculations do not include CO_2 emissions generated from fugitive sources, such as the landfill surface or compost pile, nor combustion of landfill gas. These CO_2 emissions are considered biologic and thus their inclusion in an emissions inventory is optional (and if included, must be reported separately from fossil CO_2 emissions). The MSW Combustion method in this Appendix (S.W.2 provides optional calculations to estimate biologic emissions.

Significant uncertainties also exist for some parameters used in the calculation of emissions from landfill operations. The processes that determine both methane generation and subsequent emissions resulting from waste deposited in a landfill are a complex mixture of biological, chemical, engineering, and management factors. The accuracy of any calculation varies with knowledge of a particular landfill's operating conditions and those conditions change over time. The values cited in this Community Protocol to calculate methane generation and the portion of that methane that is released to the atmosphere represent the most reasonable factors available as of the writing of this version of the Protocol. These factors are not without controversy, however, and as they are applied consistently across different methods, their weakness becomes apparent.

There are significant controversies about using 75% capture efficiency for landfill gas collection systems applied both as an instantaneous rate for inventory year emissions from an in-jurisdiction landfill (see Method *SW.1*) and as a life-time rate for all future emissions of waste generation in an inventory year (see Method *SW.4*). While these rates cannot be equal in reality, no other widely accepted rates are available at this time and actual emission rates will differ widely between individual landfills. The prevailing practice for many greenhouse gas inventories has been to use this single 75% capture efficiency rate in both methods. During the development of this version of the Community Protocol a viable alternative to deviate from this precedent was not found.

ICLEI-USA recognizes the landfill capture rate issue and will periodically review new research and information that would provide greater precision for solid waste calculations. ICLEI-USA invites the submission of new evidence from academics, other researchers, and public agencies to advance the emissions accounting practices in the solid waste sector (bearing in mind that some regulatory acceptance is needed to be used in this Protocol). Despite uncertainties that exist, a uniform use of the Protocol by communities provides a tool for understanding the level of emissions that can be expected from waste disposal and a means for comparing the results between communities.

Table SW.0 Summary of Solid Waste Greenhouse Gas Emission Sources and Activities			
GHG Source	**GHG Type**	**Data Required**	**Available Methodologies**
Landfills			
Emissions from a community's materials that are disposed of in landfills regardless of where the landfilling occurs	Fugitive CH_4 emissions	- Mass of MSW sent by community to facility	SW.4
In-boundary landfills	Fugitive CH_4 emissions	- Results from the EPA's MRR method	SW.1
OR			
	Fugitive CH_4 emissions	- Year landfill opened - Year landfill closed (if relevant) - Waste-in-place (wet short tons) and/or historical site-specific annual disposal tonnage - Waste characterization (defaults available) - CH_4 fraction in LFG from source testing (defaults available) - Average annual rainfall in operating area (inches/year) - For partial LFG systems: Proportion of landfill surface area under the influence of gas collection system	SW.1.1
Combustion			
Combustion of municipal solid waste (MSW) at facilities inside the community	Fossil CO_2 emissions, N_2O emissions, CH_4 emissions, biologic CO_2 emissions (optional)	- EPA	SW.2.1
Combustion of community-generated at waste combustion facilities, both inside and outside of the community	Fossil CO_2 emissions, N_2O emissions, CH_4 emissions, biologic CO_2 emissions (optional)	- Mass of MSW sent by community to facility (short ton) - Total mass of MSW combusted by facility (short ton) - GHG emissions (fossil CO_2, CH_4, N_2O, and biologic CO_2) reported to EPA	SW.7
OR			
Alternative to SW.2.1 and/or SW.7	Fossil CO_2 emissions, N_2O emissions, CH_4 emissions, biologic CO_2 emissions (optional)	- Mass of MSW sent by community to facility or waste combusted at an in-boundary facility	SW.2.2

Table SW.0 Summary of Solid Waste Greenhouse Gas Emission Sources and Activities (Continued)			
GHG Source	**GHG Type**	**Data Required**	**Available Methodologies**
Composting			
Composting	CO_2 emissions, N_2O emissions, CH_4 emissions	- N/A	SW.3
Collection and Transport			
Collection and transport carbon dioxide emissions	CO_2e emissions	- Mass of solid waste (wet short ton)	SW.6
Process			
Process carbon dioxide emissions associated with community-generated waste sent to landfill(s)	CO_2e emissions	- Mass of solid waste (wet short ton)	SW.5

Figure SW.1 Decision Tree for Solid Waste Emissions from Disposal Sites within a Community

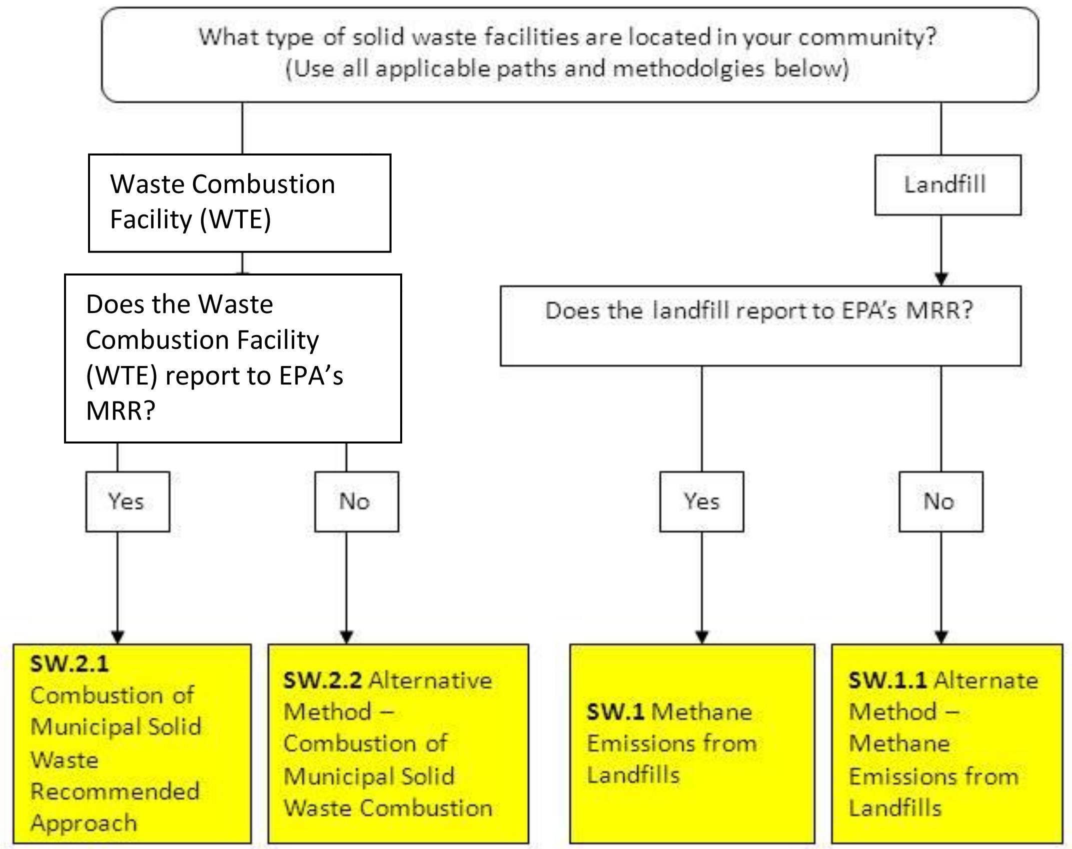
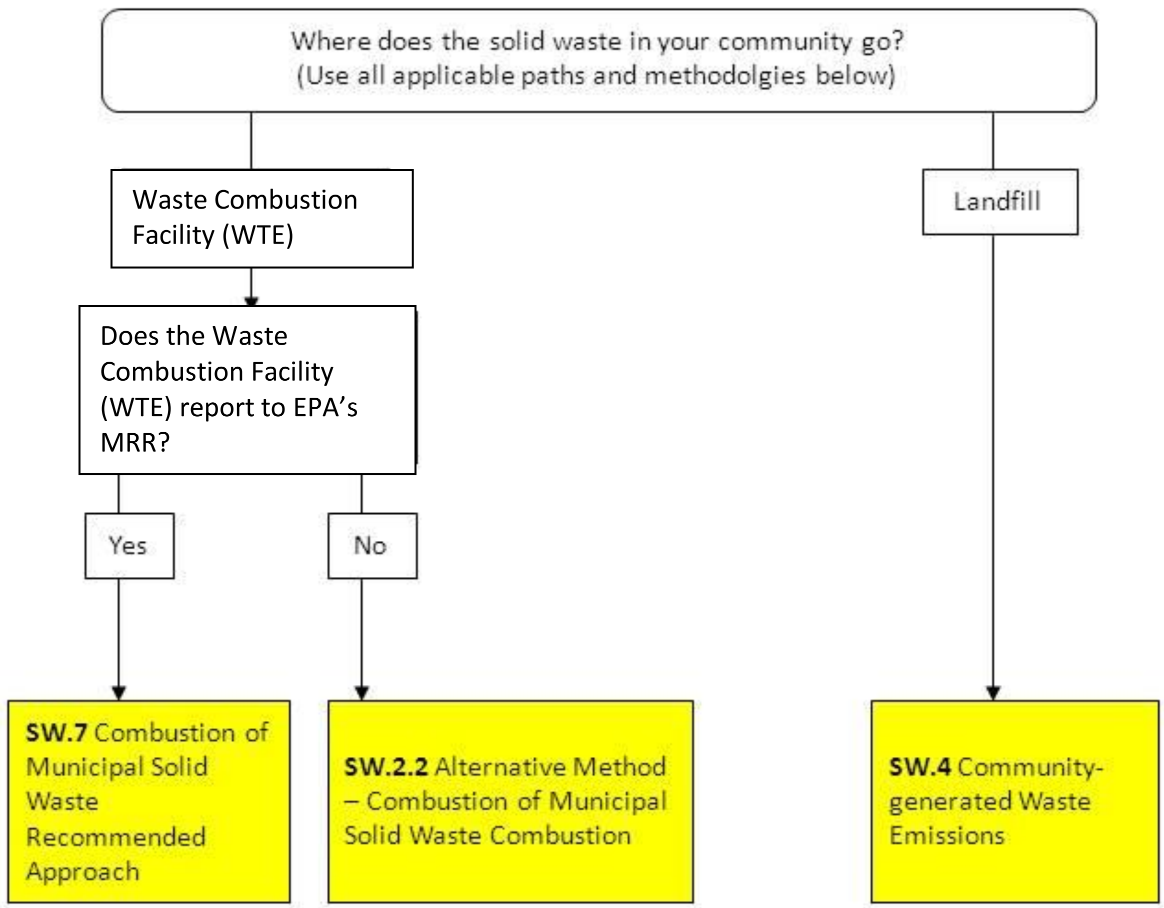


Figure SW.2 Decision Tree for Emissions from Community-generated Solid Waste



Solid Waste Facilities Located in the Community

SW.1 Methane Emissions from Landfills

This method applies to emissions from in-boundary landfills, regardless of where the waste was generated. Emissions associated specifically with community-generated landfill waste are accounted for separately using *SW.4 Community-generated Waste Emissions*. Communities sending their waste to a solid waste landfill in their community, or sending their waste to a solid waste landfill outside of their community, but that are also home to landfills inside their community, may use both of the following methods. The first is Method *SW.1* (for all waste disposed in in-boundary landfills) and the second is Method *SW.4* (for the landfilling of only community-generated waste. This will satisfy the Protocol requirement to estimate the generation of solid waste by the community, one of the "Five Basic Emission Generating Activities" (see section 2.2 of the main Community Protocol document).

The method described in this section applies to all landfills located within the community's borders, regardless of whether the landfills are currently accepting waste or have been closed, and regardless of whether the community contributed all, some, or none of the waste to those landfills. If a community has more than one landfill (closed or open) inside its boundaries and the user chooses to report on these emissions, then the user will need to estimate emissions from each landfill.

How Do Landfills Create Methane Emissions?
After being placed in a landfill, organic waste (such as paper, food scraps, and yard trimmings) is initially decomposed by aerobic bacteria. Once the oxygen has been depleted, anaerobic, non-methanogenic bacteria that convert organic material to simpler forms, such as cellulose, amino acids, sugars, and fats, further decompose the remaining organic material. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH_4-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas that consists of approximately 50% CO_2 and 50% CH_4.

Recommended Reporting Approaches

The recommended approach is to use results obtained from the EPA's MRR methods. If a community's landfill is required to report emissions to the EPA through the MRR, those emissions should be calculated using this method. However, if a community's landfill does not report to the EPA using the MRR and does not prefer to use the MRR method, use of method *SW.1.1 Alternate Method –Methane Emissions from Landfills* is acceptable.

The accounting methods concentrate primarily on emissions of GHG. However, both the IPCC and EPA recognize that landfills can store carbon due to portions of the waste stream (e.g., wood waste) that do not readily decay completely in anaerobic environments. Communities that wish to estimate carbon storage in landfills for informational purposes can refer to the EPA's Waste Reduction Model (WARM) documentation.[3]

If a community has a MSW landfill subject to the MRR within its boundaries, the user should report the GHG emissions generated by this facility in the same manner as they are reported to the EPA pursuant to the MRR. If a MRR report is not yet available for a community's inventory year for a subject landfill, use the most current EPA report available. To obtain the most recent report available, request it from the landfill management agency; if it is not supplied by them, access the report data on the EPA website at http://ghgdata.epa.gov/ghgp/main.do.

The following data relevant to this inventory is included in an EPA GHG MRR Report, and it must be used in the inventory of an EPA GHG MRR-subject MSW landfill:

- **Total facility GHG emissions reported as CO_2e:** (This total includes fugitive GHG emissions from the landfill itself as well as GHG emissions from stationary combustion sources located at the landfill or on adjacent properties owned and/or operated by the landfill. It includes only non-biogenic GHG emissions. This total is found in the MRR report under "Subpart A", "Facility Site Details");
- **Fugitive CH_4 emissions from the landfill reported as CH_4:** (This is the fugitive methane emission number used in the above-referenced total of facility GHG emissions. It is converted to CO_2e for inclusion in the total by multiplying it by the global warming potential for CH_4.[4] These emissions, by definition in the EPA GHG MRR, are non-biogenic. It is found in the MRR report under "Subpart HH" under "Methane Generation and Emission Values" as either the result of Methane Emissions Equation HH6 or HH8. Note that the landfill may select, at their option, the result of Methane Emissions Equation HH6 or HH8 for this value.); and
- **CO_2, CH_4, and N_2O emissions from combustion sources located at the landfill or on adjacent properties owned and/or operated by the landfill:** (This is the GHG emissions from stationary combustion sources located at the landfill or on adjacent properties owned and/or operated by the landfill used in the above-referenced total of facility GHG emissions. It is expressed in CO_2e and includes emissions of non-biogenic CO_2, biogenic CO_2, CH_4 and N_2O…with CH_4 and N_2O converted to CO_2e from all facility stationary combustion sources. It is found in the MRR report under "Subpart C" under "General Stationary Fuel Combustion, Gas Information Details").

[3] http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html
[4] See Appendix GWP for value.

Note that CO_2 from combustion of biologic fuels in combustion sources will be biogenic and CO_2 from combustion of fossil fuels in combustion sources will be non-biogenic. Biogenic CO_2 from flares burning LFG collected from a landfill is not included in MRR reportable data because the EPA GHG MRR rule specifically excludes it from reporting. However, biogenic CO_2 from combustion of landfill gas as a fuel in a stationary combustion device such as an engine, turbine or boiler is included in MRR reportable data as part of Subpart C emissions, if the combustion device is owned and/or operated by the owner/operator of the landfill. However, if such a combustion device is owned and operated by a third party to the landfill, this CO_2 also is excluded from the EPA GHG MRR report by the terms of the rule itself. GHG emissions from the combustion of LFG in flares and/or a third party owned and/or operated LFG-fueled stationary combustion device may be calculated separately using LFG usage data for the combustion device, LFG CH_4 concentration and combustion device efficiency.

SW.1.1 Alternate Method – Methane Emissions from Landfills

If the landfill is not subject to the EPA MRR, then the alternate approach should be utilized. Method *SW.1.1* estimates emissions based on the first order decay (FOD) model and the waste-in-place in the landfill. The FOD model is an exponential equation that estimates the amount of LFG that will be generated in an MSW landfill based upon the amount of MSW in the landfill at the point of time for which LFG generation is to be estimated (or "waste-in-place"), the capacity of that waste to generate CH_4 and a CH_4 generation rate constant which describes the rate at which MSW place in the landfill is expected to decay and produce LFG. An FOD model assumes that LFG generation from MSW peaks shortly after the MSW is placed in a landfill and then decreases exponentially as the organic material in the MSW decays.

SW.1.1 Data Needs

- Year landfill opened
- Year landfill closed (if relevant)
- Waste-in-place (wet short tons) and/or historical site-specific annual disposal tonnage
- Waste characterization, i.e., percentage of each waste type (default values are provided in the FOD model guidance documentation if this data is inaccessible)[5]
- Fraction of CH_4 in LFG from source testing (a default value of 50% may be used if this data inaccessible)
- Average annual rainfall in operating area in inches/year (used to determine appropriate CH_4 generation rate constant)
- For partial LFG systems: The proportion of landfill surface area that is under the influence of a gas collection system.

[5] Use the most recent year's available data. Even though the most current year may not reflect prior years, no single characterization would reflect prior years.

SW.1.1 Calculation Method

The method presented consists of the following five steps:[6]

Step 1: Determine the number of years of operation for the landfill. To do this, subtract the year the landfill opened from the inventory year (if the landfill is still in use) or the year the landfill closed and add one. This will give the number of years the landfill has operated

Years of Landfill Operation = Inventory year (or year landfill closed) – year landfill opened +1

Step 2: Estimate waste deposition. Waste-in-place is a measurement of how much waste is currently in the landfill in wet short tons. To estimate yearly waste deposited in to the landfill, divide the waste-in-place by the years of landfill operation. While it is unlikely that waste was deposited evenly each year as calculated here, this simplification is a way to estimate waste deposition, in the absence of site-specific annual tonnage data, and will not significantly impact the emissions estimation.

Average Yearly Waste Deposition = Waste-In-Place / Years of landfill operation

Step 3: Use the California ARB Landfill Emissions Tool (FOD Model) to calculate the emissions generated by a landfill. The Excel-based FOD model estimates the amount of CH_4 generated for the inventory year, in units of mt of CH_4 generated per year ($mtCH_4/yr$). Many of the inputs', default values are provided; however, the Protocol recommends using site-specific information when possible. The Landfill Emissions Tool is available for download at http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm.

Step 3.a: Calculate fugitive emissions in mt CH_4 and CO_2e. The FOD model estimates annual fugitive CH_4 emissions from a landfill in mt. See Appendix GWP for a global warming potential to convert mt of CH_4 to mt of CO_2 equivalent (CO_2e). Refer to tables *SW.2*, *SW.3*, SW. 3.1, *SW.4* and *SW.5*, in the appendix, for the default factors that can be input into the Excel-tool if facility-specific or local data is inaccessible.

Step 4: For landfills with comprehensive active LFG collection, apply the FOD model to calculate the CH_4 generated by the landfill during the inventory year, multiply the gas generation by (1-0.75) 0.25 to determine fugitive emissions accounting for the efficiency of LFG collection.

Assumptions
Instantaneous Landfill Gas Collection Efficiency: 75%
Oxidation Factor: 10%[7]

[6] If the site-specific annual tonnage is available, skip to Step 3.

[7] If using the California ARB Landfill Emissions Tool oxidation has already been incorporated into landfill outputs therefor you do not have to multiply by 0.9.

Step 5: For landfills with partial, passive or no LFG collection, apply the FOD model to calculate the CH_4 generated by the landfill, multiply the generated CH_4 by the fraction of landfill surface area covered by a collection system (0% for landfills with no LFG collection). Then multiply by 0.25 to correct for the collection efficiency of the LFG collection. Add this number to the emissions from the parts of the landfill not covered by the gas collection system.

Equation SW.1.1 Alternate Method – Methane Emissions from Landfills

Annual fugitive CH_4 emissions =

*Comprehensive LFG Collection: ((TMMG*LFGE)*(Ox))*
Partial or No LFG Collection: ((TMMG(1-%LF)*Ox)+((TMMG*%LF*LFGE)*(Ox)))*
Where:

Term	Description	Value
Annual CH_4 emissions	= Total annual fugitive landfill CH_4 emitted ($mtCO_2e$)	Result
TMMG	= Total modeled CH_4 generated	User Input
OX*	= Account for 10% oxidation rate	(1-.10)
% LF	= Percent of landfill covered by gas collection	User Input
LFGE	= Account for 75% LFG collection efficiency	(1-.75)

Source: 40 CFR 98, Subpart HH, and 40 CFR 60, Subpart WWW

* If using the California ARB Landfill Emissions Tool oxidation has already been incorporated into landfill outputs therefor you do not have to multiply by 0.9.

SW.2 Combustion of Municipal Solid Waste

Introduction

This section provides methods for estimating GHG emissions (fossil CO_2, CH_4, N_2O, and biologic CO_2) from combustion of MSW in municipal waste combustion facilities. These facilities, also called WTE and energy-from-waste (EfW) facilities, burn garbage and typically (but not always) generate steam and/or electricity from the combustion of MSW. The Protocol requires reporting on emissions from all community waste managed at WTE facilities (regardless of location) and separately allows for reporting of emissions from any WTE facilities located within a community boundary. Method SW.2 is specific to in-boundary combustion units (burning waste regardless of where it was originally generated), while Method SW.7 is specific to the combustion of waste generated by the community (regardless of the location of the combustion unit).

CO_2 emissions from the combustion of MSW consist of both fossil and biologic CO_2. Biologic CO_2, if reported at all, should be reported separate from fossil CO_2. The combustion of MSW components originally manufactured from fossil fuels (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) results in fossil based CO_2. The CO_2 emissions from combusting the biomass portion of MSW (e.g., yard waste, paper products) are biologic in origin and are reported separately. The distinction between "fossil derived wastes" and "biologic derived wastes" does not apply to CH_4 and N_2O emissions that occur during combustion; all CH_4 and N_2O emissions are to be reported together. Total CO_2e are reported as the sum of the fossil CO_2 emissions together with the emissions of CH_4 and N_2O multiplied by their respective global warming potentials.

Methods *SW.2.1* and/or *SW.7* are recommended for reporting GHG emissions from MSW combustion using the GHG emissions reported to the EPA in accordance with MRR. Most, if not all, WTE facilities must report their GHG emissions to the EPA. Depending on the size of the facility, continuous emission monitors (CEMs) or an emission factor may be used for EPA reporting. All facilities are required to perform quarterly stack sampling and radiocarbon analysis via ASTM D6866 to determine the percentage of CO_2 emitted that is biologic. For those limited cases where a small facility is not reporting its emissions to the EPA, calculate GHG emissions using method *SW.2.2*.

SW.2.1 Combustion of Municipal Solid Waste Recommended Approach

If a community has MSW WTE combustion facility within its boundaries the user should report the GHG emissions generated by this facility as it was reported to the EPA. This data, reported as total $mtCO_2e$, fossil CO_2, CH_4, N_2O, and biologic CO_2, can be requested directly from the facility or accessed from the EPA website at http://ghgdata.epa.gov/ghgp/main.do. Protocol users may choose not to report on biologic CO_2, and if biologic CO_2 is reported, it should be reported separately (not added with other emissions).

SW.2.2 Alternative Method – Combustion of Municipal Solid Waste

In isolated cases, sufficient information may not be readily available to use methods *SW.2.1* and/or *SW.7*. If this is the case, an alternative method is to calculate CO_2 GHG emissions using the EPA's emission factor for MSW combustion, a default heat content of MSW, and a default MSW biologic percentage (equation *B3.a*). CH_4 and N_2O emissions are calculated similarly using equation *SW.2.2*. In both cases, two versions of the equations are presented, one for community-generated waste, and the second for a MSW combustion facility located in the community. This method, however, does not account for emissions from the combustion of auxiliary fuels (e.g., natural gas, propane).

SW.2.2 Data Needs

- Mass of MSW sent by community to facility *or* waste combusted at an in-boundary facility

SW.2.2.a Method Calculation

The method presented consists of the following five steps:

Step 1: Determine the total tonnage of MSW shipped to the WTE facility from the community and/or received at the in-community facility. If the community ships MSW to more than one facility, or is host to more than one facility, repeat this method for each WTE facility.

Step 2: Calculate the fossil CO_2 emissions from MSW combustion using equation *SW.2.2.a*.

Step 3: If the Protocol user wishes to report on biologic CO_2 emissions, calculate the biologic CO_2 emissions from MSW combustion, repeating Step 2 substituting the biologic fraction for the term (1 – *Biologic fraction*). The result will be the biologic CO_2 emissions from MSW combustion.

Step 4: Use Equation *SW.2.2.b* to calculate the CH_4 and N_2O emissions as CO_2e from the combustion of the MSW.

Step 5: Sum the fossil CO_2 emissions from equation *SW.2.2.a* with the N_2O and CH_4 as CO_2e from equation *SW.2.2.b* to calculate total CO_2e.

Equation SW.2.2.a Calculating MSW CO_2 Emissions of Fossil Fuel Origin		
*Community-generated waste: Fossil CO_2 Emissions = Mass of community MSW combusted*MSW HHV*EF*(1-Biologic Fraction)*(2 x10^{-6})* *In-boundary combustion facility: Fossil CO_2 Emissions = Total mass of combusted MSW*MSW HHV*EF*(1- Biologic Fraction)*(2x10^{-6})* Where:		
Term	Description	Value
Fossil CO_2 emissions	= Total CO_2 emissions from fossil fuel based MSW combustion (metric tons (mt))	Result
Mass of community MSW	= Total mass of MSW generated by community and sent to MWC facility (short ton)	User input
MSW HHV	= Default higher heating value (HHV) of mixed MSW (Btu / lb)	5,000
EF	= Default EPA MSW emission factor (kg CO_2 / mmBtu)	90.7[1]
Biologic Fraction	= Default fraction of biologic carbon in MSW	0.64[2]
2×10^{-6}	= Aggregated conversion factor	2×10^{-6}
[1] 40 CFR 98 Subpart C, Table C-1 [2] Based on the most recent average of radiocarbon testing results for MWCs reporting in accordance with 40 CFR §98.		
Source: Emission factors from Local Government Operations Protocol v.1 May 2010 Table G.1		

Equation SW.2.2.b Calculating Methane and Nitrous Oxide Emissions from MSW		
*CH_4 emissions from MSW = Mass of community MSW*MSW HHV*EF_{CH4}*(2x10^{-6})*GWP_{CH4}* *N_2O emissions from MSW = Mass of community MSW*MSW HHV*EF_{N2O}*(2x10^{-6})*GWP_{N2O}* Where:		
Term	Description	Value
CH_4 emissions from MSW combustion	= Total CH_4 emissions from MSW combustion ($mtCO_2e$)	Result
N_2O emissions from MSW combustion	= Total N_2O emissions from MSW combustion ($mtCO_2e$)	Result
Mass of community MSW	= Total mass of MSW generated by community and sent to WTE facility (short ton)	User input
MSW HHV	= Default higher heating value of mixed MSW (Btu / lb)	5,000
EF_{CH4}	= Default EPA MSW emission factor (kg CH_4 / MMBtu)	0.032[1]
EF_{N2O}	= Default EPA MSW emission factor (kg N_2O / MMBtu)	0.0042[2]
2×10^{-6}	= Aggregated conversion factor	2×10^{-6}
GWP_{CH4}	= CH_4 global warming potential	GWP[8]
GWP_{N2O}	= N_2O global warming potential	GWP[9]
[1] 40 CFR 98 Subpart C, Table C-2 [2] 40 CFR 98 Subpart C, Table C-2		

[8] See Appendix GWP for value.
[9] See Appendix GWP for value.

SW.3 Composting

(Note[10])

Composting of biologic waste, such as food waste, yard and park waste and sludge, is common in the United States. Advantages of composting include reduced volume in the waste material, stabilization of the waste, and destruction of pathogens in the waste material. The end products of composting, depending on its quality, can be recycled as fertilizer or as soil enhancers, or be disposed of in a landfill.

Composting is typically an aerobic process and a large fraction of the degradable biologic carbon in the waste material is converted into CO_2. CH_4 is formed in anaerobic sections of the compost, but is oxidized to a large extent in the aerobic sections of the compost. Anaerobic sections are created in composting piles when there is excessive moisture or inadequate aeration (or mixing) of the compost pile. The estimated CH_4 released into the atmosphere ranges from less than 1% to a few percent of the initial carbon content in the material. Composting can also produce emissions of N_2O. The range of the estimated emissions varies from less than 0.5% to 5% of the initial nitrogen content of the material.

The default CH_4 and N_2O emission factors for composting activities, used by the EPA, are meant to account for emissions from small areas where compost is not aerated and is therefore producing fugitive emissions. These default emission factors are too general to apply at the individual facility level.

The Protocol does not include standardized methodologies to estimate fugitive emissions from composting due to the lack of data and guidance. The EPA is evaluating research suggesting that CH_4 and N_2O emissions also occur during composting as microbial processes decompose compost feedstocks; however, WARM's current assumption is that well-managed piles of compost are adequately aerated and emit negligible non-CO_2 emissions.

In general, as the state of the science for direct measurement of these emissions improves, this chapter will be updated with additional guidance.

[10] From the Local Government Operations Protocol Version 1.1, May 2010

Community-Generated Waste Emissions

SW.4 Community-Generated Waste Sent to Landfills

Introduction

Landfill emissions that result directly from the decomposition of organic material (not process emissions *associated* with fossil fuel use by landfill equipment in Method *SW.5*) are broken up into two parts in this protocol: source emissions from landfills that occur in boundary (Method *SW.1*), and activity emissions that occur as a result of waste disposed of by a community's population (Method *SW.4*).

While communities may want to understand the GHG emissions from landfills located within their boundary (Method *SW.1*), they are required to estimate the emissions that result from waste disposed by the community, regardless of whether or not the receiving landfill or landfills are located inside or outside of the community boundary. As a Basic Emissions Generating Activity, reporting of emissions resulting from waste disposed in the inventory year (Method *SW.4*) is required to be Protocol compliant (note Method *SW.7* is also required for communities that send any waste to combustion units.)

Landfill emissions are unique among sources of emissions in that the emissions are generated over long periods of time from the activity that caused them. Emissions from past generation of solid waste disposed in landfills are still occurring today, and solid waste deposited in a landfill today will continue to produce emissions for many years into the future. This method (*SW.4*) estimates future emissions resulting from solid waste deposited in the inventory year. This is in contrast to Method *SW.1*, which estimates inventory year emissions associated with waste disposal in previous years. Methods *SW.4* and *SW.1* also differ in that Method *SW.4* focuses on waste produced *by* the community, regardless of disposal location, while Method *SW.1* focuses on waste disposed of *within* the community, regardless of where it was produced.

Method *SW.4* attributes future landfill gas generation to the inventory year in which the community's waste was generated and deposited. This perspective is different from others in this Protocol where emissions occur at the same time as the activity that causes them (e.g., combusting natural gas for electrical generation results in immediate emissions from the source's stack as opposed to a landfill where deposited waste decays very slowly over time and results in a release of emissions from that deposited waste also slowly over time), and as such will not be appropriate for practitioners seeking to determine emissions that are physically emitted in an inventory year.

Regardless, the future emissions resulting from disposal of the community's landfilled waste during the inventory year are required for inclusion as a Basic Emissions Generating Activity. This method does have positive attributes in that it allows for more straightforward local decision making with regard to policies that can influence the generation and fate of solid waste from a community and the tracking of progress made to reduce emissions by reducing the landfilling of community-generated waste in subsequent inventory years.

SW.4.1 Calculation of Methane Emissions

SW.4.1 Data Needs

Below are the data inputs needed to collect in order to estimate the community generated waste emissions of MSW:

- Mass of waste from the community entering landfill(s) for inventory year (wet short ton).
- For each landfill that accepted waste from the community, whether a landfill gas collection and control system was in place for the year.
- Waste characterization, i.e. percentage of each waste type (default available if necessary).

SW.4.1 Calculation Method

The method presented consists of the following four steps:

Step 1: Get the total mass of waste entering landfill(s) during the inventory year attributed to the community.

Step 2: If data available, determine the waste characterization i.e., the percentage of each waste type for the inventory year. This data may be available by landfill facility, or at the community, region, or state level. If the data is unavailable, then the factor for Mixed MSW in Table *SW.5*, in the appendix, may be used.

Step 3: Use Equation *SW.4.1* to determine the CH_4 emissions as CO_2e associated with MSW generated in a community that is disposed of in a landfill, regardless of whether that landfill is located inside or outside of the community's boundaries. The equation calculates the CH_4 emissions from each individual waste component (i) and then sums them to obtain the total CH_4 emissions. If waste characterization data cannot be obtained, use the equation with only one waste component, mixed MSW, for all of the community's waste.

Step 4: Repeat step 3 for each landfill that accepted waste from the community in the inventory year. To simplify, simply divide the total MSW sent to landfills into two general categories: shipments to landfills with landfill gas control and collection, and shipments to landfills without landfill gas control and collection.

Equation SW.4.1 Methane Emissions		
$CH_4\ Emissions\ = GWP_{CH4} * (1- CE) * (1- OX) * M * \sum_i P_i\ * EF_i$		
Where:		
Term	Description	Value
CH_4 emissions	= Community generated waste emissions from waste M ($mtCO_2e$)	Result
GWP_{CH4}	= CH_4 global warming potential	
M	= Total mass of waste entering landfill (wet short ton)	User Input
P_i	= Mass fraction of waste component i	User Input
EF_i	= Emission factor for material i ($mtCH_4$/wet short ton)	Table SW.5
CE	= Default LFG Collection Efficiency	No Collection, 0 Collection, 0.75
OX	= Oxidation rate	0.10
Source: As developed by ICLEI staff and Solid Waste Technical Advisory Committee. Emissions factors from U.S. EPA Municipal Solid Waste Publication (2008) available at http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw2008data.pdf		

[11] See Appendix GWP for value.

Box *SW.4.1* Below gives an example of how to calculate CH_4 emissions.

Box SW.4.1	**Example Calculation methane emissions**	
A community sends 10,000 wet short tons of waste to two landfills each in the inventory year. One of the landfills operated landfill gas collection and control equipment during the inventory year. This landfill accepted 6,000 wet short tons of waste from the community. The second landfill has no gas controls. Waste characterization information is not available.		
Term	Description	Value
CH_4 Emissions	= Community generated waste emissions from waste M ($mtCO_2e$)	Result
GWP_{CH4}	= CH_4 global warming potential	GWP[12]
M	= Total mass of waste entering landfill (wet short ton)	10,000
P_i	= Proportion of total waste material i	1
EF_i	= Emission factor for material i ($mtCH_4$/wet short ton)	0.060
CE	= Default LFG collection efficiency	No Collection, 0 Collection, 0.75
OX	= Oxidation rate	0.10
Sample Calculation: $CH_4\ Emissions\ = GWP_{CH4} * (1-CE) * (1-OX) * M * \sum_i P_i\ * EF_i$ $CH_4\ Emissions, LF\#1\ = 21 * (1-0.75) * (1-0.10) * 6{,}000 * 1 * 0.060 = 1701\ MT\ CO_2e$ $CH_4\ Emissions, LF\#2\ = 21 * (1-0) * (1-0.10) * 4{,}000 * 1 * 0.060 = 4536\ MT\ CO_2e$ *Total CH_4 Emissions = 6237 $mtCO_2e$*		

[12] See Appendix GWP for value.

SW.5 Process Emissions Associated with Landfilling

(Note[13] [14])

In order to get a complete picture of the emissions associated with landfilling, it is important to calculate transport emissions (see Method *SW.6*) and process emissions (see *SW.5* here). Process emissions come from CO_2 emissions associated with powering the equipment necessary to manage the landfill. This method may result in double counting of in-boundary process emissions and if so should not be added into an inventory, but can be used as an indicator or for other informational purposes.

Community generated waste process emissions, however, should be calculated for waste delivered to landfills outside a community's boundaries. Emissions factors are presented for both diesel and natural gas (CNG) fueled landfill equipment.

SW.5 Data Needs

- Mass of solid waste (wet short ton)

SW.5 Calculation Method

The method presented consists of the following two steps:

Step 1: Determine the mass of solid waste that enters the landfill in the inventory year

Step 2: Use Equation *SW.5* to calculate landfill process emissions

[13] Natural gas and diesel emissions could be mixed and matched. This section only shows calculations involving all diesel or all natural gas.

[14] While WTE facilities also have minimal process emissions, they are not included because no default values are available.

Equation SW.5 Process Emissions			
*PE_{LF} = M*EFP*			
Where:			
Term	Description	Value (Diesel)	Value (CNG)
PE_{LF}	= Total landfill process emissions ($mtCO_2e$)	Result	Result
M	= Total mass of solid waste that enters the landfill in the inventory year (wet short ton)	User Input	User Input
EFP	= Emissions factor for landfill process emissions (mtCO2e/wet short ton)	0.0164	0.011
Source: U.S. EPA, Waste Reduction Model (WARM), Version 12 and Model Documentation			

SW.6 Collection and Transportation Emissions

In order to get a complete picture of your emissions associated with waste management, it is important to calculate emissions from collection and transportation emissions. Collection emissions consist predominately of CO_2 emissions associated with powering the equipment necessary to collect MSW from within the community. Transportation emissions are similar, but instead cover the transportation of waste from the community to facilities located outside of the community.

Collection emissions may be double counted and should not be added into your inventory, but should be used as an indicator. In contrast, transportation emissions should be calculated for waste delivered to facilities outside your community's boundaries.[15] Communities that manage wastes entirely within their boundaries will not have transportation emissions. Collection emissions factors are presented on a per ton basis for both diesel and natural gas (CNG) fueled vehicles. Transportation emissions factors are presented on a per ton-mile basis for diesel and natural gas (CNG).

SW.6 Data Needs

- Mass of solid waste (wet short ton)
- Transport distance from community center to the waste management facility (miles), if appropriate

SW.6 Calculation Method

The method presented consists of the following three steps:

Step 1: Determine the mass of solid waste managed at a facility in the inventory year

Step 2: Determine the distance traveled to the waste management facility

Step 3: Use the equations in equation *SW.6* to calculate collection and transportation emissions.

[15] Please note that the inclusion of long-haul emissions could result in double counting transportation emissions.

Equation SW.6 Collection and Transportation Emissions			
*CE = M*EFC* *TE = M*MT*EFT* Where:			
Term	Description	Value (Diesel)	Value (CNG)
CE	= Total collection emissions ($mtCO_2e$)	Result	Result
TE	= Total transportation emissions ($mtCO_2e$)	Result	Result
M	= Total mass of solid waste collected and transported in the inventory year (wet short ton)	User Input	User Input
MT	= Miles traveled to disposal site	User Input	User Input
EFC	= Emissions factor for collection emissions ($mtCO_2e$/ wet short ton)	0.020	0.014
EFT	= Emissions factor for transport emissions ($mtCO_2e$/ wet short ton/mile)	0.00014	0.00010

SW.7 Community-Generated Waste Sent to Combustion Facilities

(Note[16])

Method *SW.7* is used for communities that generate waste that is sent to WTE combustion facilities inside or outside of their community boundaries, where those facilities report emissions under EPA's MRR. For very small facilities that do not report emissions to the EPA, use alternative method SW.2.2. Method SW.7 calculates a community's contribution by prorating a facility's reported GHG emissions by the mass of waste generated by the community and sent to the facility for management.

SW.7 Data Needs

- Mass of MSW sent by community to facility (short ton)
- Total mass of MSW combusted by facility (short ton)
- GHG emissions (fossil CO_2, CH_4, N_2O, and biologic CO_2) reported to EPA.

SW.7 Calculation Method

The method presented consists of the following three steps:

Step 1: Determine the total tonnage of MSW shipped to the WTE facility from the community. If the community ships MSW to more than one facility, repeat this method for each WTE facility that receives waste from the community.

Step 2: Calculate the emissions for each GHG (fossil CO_2, CH_4, N_2O, and biologic CO_2 if desired) from community waste using equation *SW.7.1*.

Step 3: Calculate the total GHG emissions as CO_2e using equation *SW.7.2*.

[16] Please note that communities that use energy from WTE facilities could result in double counting energy emissions.

Equation SW.7.1 Calculating Combustion of Municipal Solid Waste Recommended Approach		
*GHG Emissions = (Mass of community MSW / Total MSW Processed by WTE) * Total Emissions of GHG Reported*		
Where:		
Term	Description	Value
GHG Emissions	= Total emissions of each GHG (i.e. fossil CO_2) from combustion of MSW (mt)	Result
Mass of community MSW	= Total mass of MSW generated by community and sent to WTE facility (short ton)	User input
Total MSW Processed by WTE	= Total mass of MSW processed by the WTE facility receiving the community's waste (short ton)	User input
Total Emissions of GHG Reported ($mtCO_2E$)	= Total amount of emissions of GHG reported to EPA in accordance with the MRR (mt)	User input

Equation SW.7.2 Calculating Combustion of Municipal Solid Waste as CO_2 Equivalents		
GHG as $CO_2e = (CH_4*21)+(N_2O*310)+fossil\ CO_2$		
Where:		
Term	Description	Value
GHG as CO_2e	= Total emissions as CO_2e from combustion of MSW ($mtCO_2e$)	Result
GHG from community MSW	= Total emissions of fossil CO_2, CH_4, and N_2O from equation SW.7.1 (mt)	User input

Appendix: Solid Waste

Table SW.2 Default US Waste Characterization (1960-Present)									
Waste Type	*Waste Type by Year (%)*								
	1960 - 1969	**1970 - 1979**	**1980 - 1989**	**1990 - 1999**	**2000 - 2002**	**2003 - 2004**	**2005 - 2006**	**2007**	**2008 – Present**
Newspaper	6.4	6.4	5.9	4.8	3.6	1.9	2.0	1.3	0.6
Office paper	10.7	11.3	12.0	13.1	14.5	13.6	12.8	11.2	11.5
Corrugated boxes	10.8	13.5	11.5	10.5	10.0	9.2	8.8	8.2	7.4
Coated paper	2.2	2.0	2.4	2.1	1.5	1.4	1.5	1.4	1.3
Diapers	0.1	0.3	1.4	1.6	1.9	2.0	2.0	2.2	2.3
Food	14.8	11.3	9.5	12.1	15.4	16.6	17.3	18.1	18.6
Grass	12.1	10.3	10.1	9.0	4.4	3.9	3.6	3.5	3.5
Leaves	6.1	5.1	5.0	4.5	2.2	2.0	1.8	1.7	1.8
Branches	6.1	5.1	5.0	4.5	2.2	2.0	1.8	1.7	1.8
Lumber	3.7	3.3	5.1	7.0	7.0	7.4	7.5	8.5	8.9
Textiles	2.1	1.8	1.7	3.3	5.2	5.9	6.1	6.4	6.9
Construction/ Demolition	2.6	2.5	3.5	3.9	4.7	5.0	5.2	5.5	5.8
Medical waste	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sludge/ Manure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: Developed using national average waste figures and data from US EPA Municipal Solid Waste Publication (2008).
http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw2008data.pdf

The numbers in this table were taken from ICLEI's Local Government Operations Protocol.
http://www.icleiusa.org/search?SearchableText=Local+Government+Operations+Protocol

Note: if available, use the data for the year for which you are doing your inventory, if the data for that year is not available go back to the prior year for which the data is available.

Table SW.3 Default k Values	
Average Rainfall (inches/year)	*K*
< 20	0.020
20 – 40	0.038
> 40	0.057

Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2006, Annex 3.14 (2008).

Table SW.3.1 Total Organic Degradable Carbon per Waste Type (TDOC)		
Waste Type	TDOC	Source
Newspaper	47.0%	EPA
Office paper	39.6%	EPA
Corrugated boxes	44.9%	EPA
Coated paper	33.0%	EPA
Food	14.8%	EPA
Grass	13.3%	EPA
Leaves	29.1%	EPA
Branches	44.2%	EPA
Lumber	43.0%	IPCC
Textiles	24.0%	IPCC
Diapers	24.0%	IPCC
Construction/Demolition	4.0%	IPCC
Medical Waste	15.0%	IPCC
Sludge/Manure	5.0%	IPCC
Sources: 1. EPA Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, Exhibits 6-3 and 6-4 (2006). 2. IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 2, Tables 2.4-2.6 (2006).		

Table SW.4 Default Decomposable Anaerobic Fraction (DANF) of the TDOC		
Waste Type	DANF	Source
Newspaper	15.0%	EPA
Office paper	87.4%	EPA
Corrugated boxes	44.3%	EPA
Coated paper	24.3%	EPA
Food	86.5%	EPA
Grass	32.5%	EPA
Leaves	27.9%	EPA
Branches	23.2%	EPA
Lumber	23.3%	CEC
Textiles	50.0%	IPCC
Diapers	50.0%	IPCC
Construction/Demolition	50.0%	IPCC
Medical Waste	50.0%	IPCC
Sludge/Manure	50.0%	IPCC

Sources:
1. EPA Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, Exhibits 6-3 and 6-4 (2006).
2. CEC Inventory of California Greenhouse Gas Emissions and Sinks: 1990-2004 (2006).
3. IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3, 3.13 (2006).

Table SW.5 CH_4 Yield for Solid Waste Components		
Waste Component	Emissions Factor, EF_i (mt CH_4/wet short ton waste)	Source
Mixed MSW*	0.060	U.S. EPA AP-42
Newspaper	0.043	WARM
Office Paper	0.203	WARM
Corrugated Containers	0.120	WARM
Magazines/Third-Class Mail	0.049	WARM
Food Scraps	0.078	WARM
Grass	0.038	WARM
Leaves	0.030	WARM
Branches	0.062	WARM
Dimensional Lumber	0.062	WARM

* – Mixed MSW factor may be used for entire MSW waste stream if waste composition data is unavailable
U.S. EPA AP-42 – U.S. EPA Emission Factor Database, Chapter 2.4 Municipal Solid Waste Landfills (1998)
WARM—Exhibit 6 of http://epa.gov/epawaste/conserve/tools/warm/pdfs/Landfilling.pdf, February 2012.