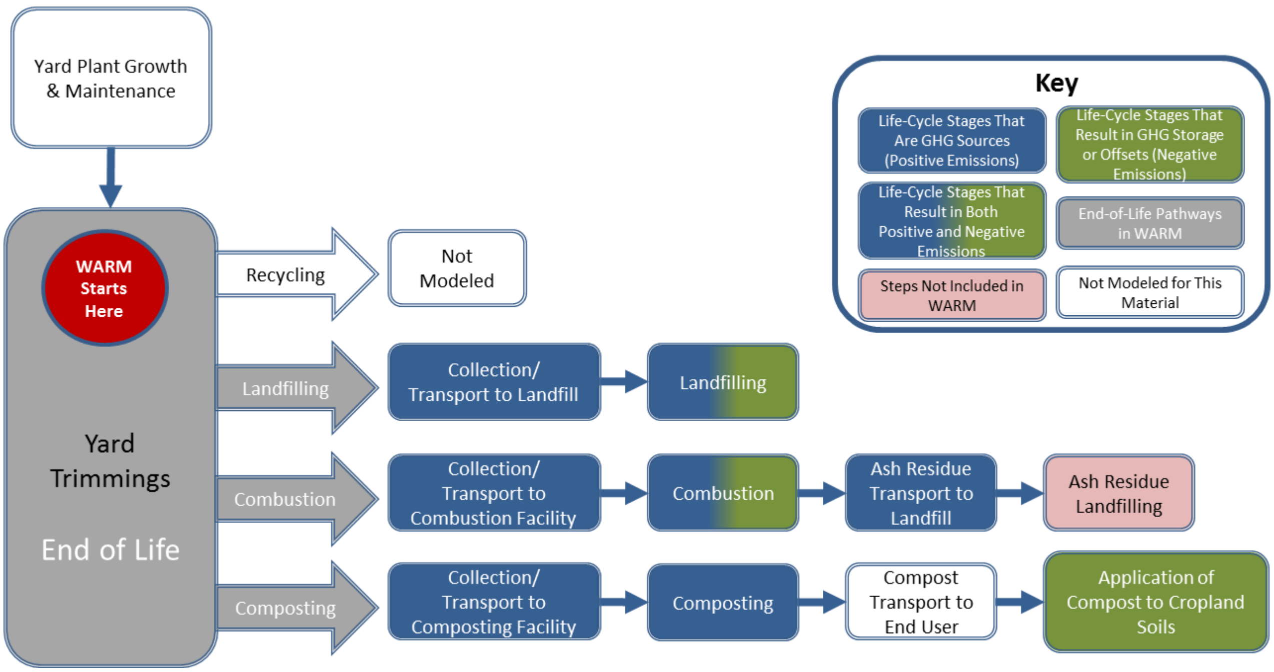
YARD TRIMMINGS

1. INTRODUCTION TO WARM AND YARD TRIMMINGS

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for yard trimmings beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated yard trimmings in the following three materials management options: composting, landfilling, and combustion. Exhibit 1 shows the general outline of materials management pathways for these materials in WARM. For background information on the general purpose and function of WARM emission factors, see the Introduction & Overview chapter. For more information on Composting, Landfilling, and Combustion, see the chapters devoted to those processes. WARM also allows users to calculate results in terms of energy, rather than GHGs. The energy results are calculated using the same methodology described here but with slight adjustments, as explained in the Energy Impacts chapter.

Exhibit 1: Life Cycle of Yard Trimmings in WARM



Yard trimmings fall under the category of "organics" in WARM. Although paper, wood products and plastics are organic materials in the chemical sense, these categories of materials have very different life-cycle and end-of-life characteristics than yard trimmings and are treated separately in the municipal solid waste (MSW) stream. Yard trimmings are grass clippings, leaves and branches. WARM also calculates emission factors for a mixed organics category, which is a weighted average of the food waste and yard trimmings emission factors for the waste management pathways relevant to both materials (i.e., landfilling, combustion, and composting). For more information, see the Food Waste chapter. The weighting is based on the relative prevalence of these two categories in the waste stream, according to the latest (2014b) version of EPA's annual report, *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2012,* and as shown in column (c) of Exhibit 2.[1]

[1] Note that, unlike for other materials in WARM, the "mixed" category is based on organics' relative prevalence among materials *generated* rather than *recovered*. This is because WARM assumes that users interested in

Exhibit 2: Relative Prevalence of Yard Trimmings and Food Waste in the Waste Stream in 2012

(a) Material	(b) Generation (Short Tons)	(c) % of Total Organics Generation	(d) Recovery (Short Tons)	(e) Recovery Rate
Food Waste	36,430,000	52%	1,740,000	4.8%
Yard Trimmings	33,960,000	48%	19,590,000	57.7%

Source: EPA (2014b).

2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The streamlined life-cycle GHG analysis in WARM focuses on the waste generation point, or the moment a material is discarded, as the reference point and only considers upstream GHG emissions when the production of new materials is affected by materials management decisions.[2] Recycling and source reduction are the two materials management options that impact the upstream production of materials, and consequently are the only management options that include upstream GHG emissions. For more information on evaluating upstream emissions, see the chapters on Recycling and Source Reduction.

WARM does not include recycling or source reduction management options for yard trimmings. Yard trimmings cannot be recycled in the traditional sense and sufficient data are not currently available to model the material and energy inputs for trees and grass prior to becoming yard trimmings waste. As Exhibit 3 illustrates, most of the GHG sources relevant to yard trimmings in this analysis are contained in the waste management portion of the life cycle assessment, with the exception of increased soil carbon storage associated with composting of yard trimmings.

Exhibit 3: Yard Trimmings GHG Sources and Sinks from Relevant Materials Management Pathways

Materials Management Strategies for Yard Trimmings	GHG Sources and Sinks Relevant to Yard Trimmings		
	Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**End of Life**
Source Reduction	Not modeled in WARM due to data limitations		
Recycling	Not applicable since yard trimmings cannot be recycled		
Composting	Not applicable	**Offsets** • Increase in soil carbon storage	**Emissions** • Transport to compost facility • Compost machinery
Combustion	NA	NA	**Emissions** • Transport to WTE facility • Combustion-related nitrous oxide **Offsets** • Avoided utility emissions

composting would be dealing with a mixed organics category that is closer to the current rate of generation, rather than the current rate of recovery. Since the fraction of recovered food waste is so low, if the shares of yard trimmings and food waste recovered were used, the mixed organics factor would be essentially the same as the yard trimmings factor, rather than a mix of organic materials.

[2] The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all emissions from materials management.

Materials Management Strategies for Yard Trimmings	GHG Sources and Sinks Relevant to Yard Trimmings		
	Raw Materials Acquisition and Manufacturing	Changes in Forest or Soil Carbon Storage	End of Life
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery • Landfill methane **Offsets** • Avoided utility emissions due to landfill gas combustion • Landfill carbon storage

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 3 to calculate net GHG emissions per short ton of organic materials generated. GHG emissions arising from the consumer's use of any product are not considered in WARM's life-cycle boundaries. Exhibit 4 presents the net GHG emission factors for each materials management strategy calculated in WARM for organic materials.

Additional discussion on the detailed methodology used to develop these emission factors may be found in sections 4.1 through 4.5.

Exhibit 4: Net Emissions for Yard Trimmings and Mixed Organics under Each Materials Management Option ($MTCO_2E$/Short Ton)

Material	Net Source Reduction (Reuse) Emissions for Current Mix of Inputs	Net Recycling Emissions	Net Composting Emissions	Net Combustion Emissions	Net Landfilling Emissions
Yard Trimmings	NA	NA	-0.12	-0.15	-0.19
Grass	NA	NA	-0.12	-0.15	0.17
Leaves	NA	NA	-0.12	-0.15	-0.47
Branches	NA	NA	-0.12	-0.15	-0.65
Mixed Organics	NA	NA	-0.14	-0.14	0.29

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = Not applicable.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

WARM does not consider GHG emissions associated with raw materials acquisition or manufacturing for yard trimmings because this life-cycle stage is only applicable to the source reduction and recycling pathways, which are not modeled in WARM for yard trimmings, as explained previously.

4. MATERIALS MANAGEMENT METHODOLOGIES

Landfilling, composting, and combustion are the three management options used to manage yard trimmings. Residential and commercial land management activities such as landscaping and gardening generate yard trimmings, which are typically either composted onsite, shredded with a mulching mower and used for landscaping onsite, or placed on the curb for transport to central facilities for either combustion, composting or landfilling. Since 1990, many municipalities have implemented programs and policies designed to divert yard trimmings from landfills, and as a result, yard trimmings are increasingly composted or mulched onsite or collected for mulching and composting at a central facility (EPA, 2014a).

4.1 SOURCE REDUCTION

Unlike food waste, yard trimmings do not generally require extensive material or fossil fuel energy inputs prior to becoming waste. While some material and energy inputs are used during the life of trees and grasses (i.e., fuel for lawn mowing, fertilizers), sufficient data needed to model raw material acquisition and production emissions or storage from yard trimmings are not currently available. Therefore, WARM does not consider GHG emissions or storage associated with source reduction of yard trimmings.

4.2 RECYCLING

Recycling, as modeled in WARM (i.e., producing new products using end-of-life materials), does not commonly occur with the yard trimmings materials modeled in WARM. Therefore, WARM does not consider GHG emissions or storage associated with the traditional recycling pathway for yard trimmings. However, yard trimmings can be converted to compost, a useful soil amendment, as described in section 4.3.

4.3 COMPOSTING

4.3.1 Developing the Emissions Factor for the Composting of Yard Trimmings

Composting yard trimmings results in increased carbon storage when compost is applied to soils. The net composting emission factor is calculated as the sum of emissions from transportation, processing of compost, the carbon storage resulting from compost application, and the fugitive emissions of methane (CH_4) and nitrous oxide (N_2O) produced during decomposition.[3] WARM currently assumes that carbon dioxide (CO_2) emissions that occur as a result of the composting process are biogenic and are not counted (for further explanation, see the text box on biogenic carbon in the Introduction and Background chapter). Exhibit 5 details these components for yard trimmings and mixed organics. For additional information on composting in WARM, see the Composting chapter. The two emission sources and one emission sink resulting from the composting of organics are:

- *Nonbiogenic CO_2 emissions from collection and transportation*: Transportation of yard trimmings to the central composting site results in nonbiogenic CO_2 emissions.[4] In addition, during the composting process the compost is mechanically turned, and the operation of this equipment also results in nonbiogenic CO_2 emissions.
- *Fugitive Emissions of CH_4 and N_2O:* Microbial activity during composting decomposes waste into a variety of compounds, which generates small amounts of CH_4 and N_2O gas, a net contributor to the GHG emissions associated with the composting pathway (for more information on fugitive emissions, please refer to the Composting chapter).
- *Carbon Storage*: When compost is applied to the soil, some of the carbon contained in the compost does not decompose for many years and therefore acts as a carbon sink.

Exhibit 5: Components of the Composting Net Emission Factor for Yard Trimmings and Mixed Organics

Composting of Post-Consumer Material (GHG Emissions in $MTCO_2E$/Short Ton)						
Material Type	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Composting	Compost CO_2	Compost CH_4 and N_2O	Soil Carbon Storage	Net Emissions (Post-Consumer)
Yard Trimmings[a]	NA	0.04	–	0.07	-0.24	-0.12

[3] These fugitive emission sources were added in June 2014 to WARM Version 13.

[4] Transportation emissions from delivery of finished compost from the composting facility to its final destination were not counted.

Composting of Post-Consumer Material (GHG Emissions in $MTCO_2E$/Short Ton)						
Material Type	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Composting	Compost CO_2	Compost CH_4 and N_2O	Soil Carbon Storage	Net Emissions (Post-Consumer)
Grass	NA	0.04	–	0.07	-0.24	-0.12
Leaves	NA	0.04	–	0.07	-0.24	-0.12
Branches	NA	0.04	–	0.07	-0.24	-0.12
Mixed Organics	NA	0.04	–	0.07	-0.24	-0.14

NA = Not applicable.
[a] Yard trimmings are a 50%, 25%, 25% weighted average of grass, leaves, and branches, based on U.S. generation data from EPA (2014b).

Transportation energy emissions occur when fossil fuels are used to collect and transport yard trimmings to a composting facility, and then to operate the composting equipment that turns the compost. To calculate these emissions, WARM relies on assumptions from FAL (1994), which are detailed in Exhibit 6.

Exhibit 6: Emissions Associated with Transporting and Turning Compost

	Diesel Fuel Required to Collect and Transport One Ton (million Btu)[a]	Diesel Fuel Required to Turn the Compost Piles (million Btu)[a]	Total Energy Required for Composting (million Btu)	Total CO_2 Emissions from Composting ($MTCO_2E$)
All Material Types	0.36	0.22	0.58	0.04

[a] Based on estimates found on Table I-17 on page I-32 of FAL (1994).

WARM currently assumes that carbon from compost remains stored in the soil through two main mechanisms: direct storage of carbon in depleted soils (the "soil carbon restoration" effect)[5] and carbon stored in non-reactive humus compounds (the "increased humus formation" effect)[6]. The carbon values from the soil carbon restoration effect are scaled according to the percentage of compost that is passive, or non-reactive, which is assumed to be 52 percent (Cole, 2000). The weighted soil restoration value is then added to the increased humus formation effect in order to estimate the total sequestration value associated with composting. The inputs to the calculation are shown in Exhibit 7.

Exhibit 7: Soil Carbon Effects as Modeled in Century Scenarios ($MTCO_2E$/Short Ton of Organics)

Scenario	Soil Carbon Restoration			Increased Humus Formation	Net Carbon Flux[a]
	Unweighted	Proportion of C that is Not Passive	Weighted estimate		
Annual application of 32 tons of compost per acre	-0.04	48%	-0.07	-0.17	-0.24

[a] The net carbon flux sums each of the carbon effects together and represents the net effect of composting a short ton of yard trimmings in $MTCO_2E$.

The nonbiogenic CO_2 emissions from transportation, collection and compost turning are added to the compost carbon sink in order to calculate the net composting GHG emission factors for each

[5] EPA evaluated the soil carbon restoration effect using Century, a plant-soil ecosystems model that simulates long-term dynamics of carbon, nitrogen, phosphorous and sulfur in soils. For more information, see the Composting chapter.

[6] EPA evaluated the increased humus formation effect based on experimental data compiled by Dr. Michael Cole of the University of Illinois. These estimates accounted for both the fraction of carbon in the compost that is considered passive and the rate at which passive carbon is degraded into CO_2. For more information, see the Composting chapter.

organics type. As Exhibit 5 illustrates, WARM estimates that the net composting GHG factor for yard trimmings is the same for all sources of compost.

4.4 COMBUSTION

4.4.1 Developing the Emissions Factor for the Combustion of Yard Trimmings

Combusting organics results in a net emissions offset (negative emissions) due to the avoided utility emissions associated with energy recovery from waste combustion. The combustion net emission factor is calculated as the sum of emissions from transportation of waste to the combustion facility, nitrous oxide emissions from combustion, and the avoided CO_2 emissions from energy recovery in a waste-to-energy (WTE) plant. Although combustion also releases the carbon contained in yard trimmings in the form of CO_2, these emissions are considered biogenic and are not included in the WARM net emission factor. Exhibit 8 presents these components of the net combustion emission factor for each organic material. For additional information on combustion in WARM, see the Combustion chapter. The two emissions sources and one emissions offset that result from the combusting of organics are:

- *CO_2 emissions from transportation of waste.* Transporting waste to the combustion facility and transporting ash from the combustion facility to a landfill both result in transportation CO_2 emissions.
- *Nitrous oxide emissions from combustion.* Waste combustion results in measurable emissions of nitrous oxide (N_2O), a GHG with a high global warming potential (EPA, 2014a).
- *Avoided utility CO_2 emissions*. Combustion of MSW with energy recovery in a WTE plant also results in *avoided* CO_2 emissions at utilities.

Exhibit 8: Components of the Combustion Net Emission Factor for Yard Trimmings and Mixed Organics ($MTCO_2E$/Short Ton)

	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion	N_2O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
Yard Trimmings	NA	0.03	–	0.04	-0.22	–	-0.15
Grass	NA	0.03	–	0.04	-0.22	–	-0.15
Leaves	NA	0.03	–	0.04	-0.22	–	-0.15
Branches	NA	0.03	–	0.04	-0.22	–	-0.15
Mixed Organics	NA	0.03	–	0.04	-0.20	–	-0.14

NA = Not applicable

For the CO_2 emissions from transporting waste to the combustion facility, and ash from the combustion facility to a landfill, EPA used an estimate of 60 lbs CO_2 per ton of MSW for transportation of mixed MSW developed by FAL (1994). EPA then converted the Franklin Associates estimate from pounds of CO_2 per ton of mixed MSW to $MTCO_2E$ per ton of mixed MSW and applied it to estimate CO_2 emissions from transporting one short ton of mixed MSW and the resulting ash. WARM assumes that transportation of yard trimmings and mixed organics uses the same amount of energy as transportation of mixed MSW.

Studies compiled by the Intergovernmental Panel on Climate Change (IPCC) show that MSW combustion results in measurable emissions of N_2O, a GHG with a high global warming potential (IPCC, 2006). The IPCC compiled reported ranges of N_2O emissions, per metric ton of waste combusted, from six classifications of MSW combustors. WARM averages the midpoints of each range and converts the units to $MTCO_2E$ of N_2O per ton of MSW. Because the IPCC did not report N_2O values for combustion of individual components of MSW, WARM uses the same value for yard trimmings and mixed organics.

Most WTE plants in the United States produce electricity and only a few cogenerate electricity and steam (EPA, 2006). In this analysis, EPA assumes that the energy recovered with MSW combustion would be in the form of electricity, as shown in Exhibit 9. The exhibit shows emission factors for mass burn facilities (the most common type of WTE plant). EPA used three data elements to estimate the avoided electric utility CO_2 emissions associated with combustion of waste in a WTE plant: (1) the energy content of each waste material, (2) the combustion system efficiency in converting energy in MSW to delivered electricity, and (3) the electric utility CO_2 emissions avoided per kilowatt-hour (kWh) of electricity delivered by WTE plants.

Exhibit 9: Utility GHG Emissions Offset from Combustion of Yard Trimmings

(a) Material/Product	(b) Energy Content (Million Btu per Short Ton)	(c) Combustion System Efficiency (%)	(d) Emission Factor for Utility-Generated Electricity ($MTCO_2E$/ Million Btu of Electricity Delivered)	(e) Avoided Utility GHG per Short Ton Combusted ($MTCO_2E$/Short Ton) (e = b × c × d)
Yard Trimmings	5.6	17.8%	0.22	0.22

To estimate the gross GHG emissions per ton of waste combusted, EPA sums emissions from combustion N_2O and transportation CO_2. These emissions were then added to the avoided utility emissions in order to calculate the net GHG emission factor, shown in Exhibit 9. WARM estimates that combustion of yard trimmings results in a net emission reduction.

4.5 LANDFILLING

4.5.1 Developing the Emissions Factor for the Landfilling of Yard Trimmings

Landfilling organics can result in either net carbon storage or net carbon emissions, depending on the specific properties of the organic material. The landfilling emissions factor is calculated as the sum of emissions from transportation of waste to the landfill and operation of landfill equipment, methane emissions from landfilling, and the carbon storage resulting from undecomposed carbon remaining in landfills. Exhibit 10 presents the components of the landfilling emission factor for each yard trimmings material. For additional information on landfilling in WARM, see the Landfilling chapter. The two emissions sources and one emissions sink that result from the landfilling of organics are:

- *Transportation of organic waste*. Transportation of yard trimmings to landfill results in anthropogenic CO_2 emissions, due to the combustion of fossil fuels in the vehicles used to haul the wastes.
- *Methane emissions from landfilling*. When yard trimmings are landfilled, anaerobic bacteria degrade the materials, producing CH_4 and CO_2, collectively referred to as landfill gas (LFG). Only the CH_4 portion of LFG is counted in WARM, because the CO_2 portion is considered of biogenic origin and therefore is assumed to be offset by CO_2 captured by regrowth of the plant sources of the material.

- *Landfill carbon storage.* Because yard trimmings are not completely decomposed by anaerobic bacteria, some of the carbon in them remains stored in the landfill. This stored carbon constitutes a sink (i.e., negative emissions) in the net emission factor calculation.

Exhibit 10: Landfilling Emission Factors for Yard Trimmings and Mixed Organics ($MTCO_2E$/Short Ton)

Material Type	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Storage	Net Emissions (Post-Consumer)
Yard Trimmings	–	0.04	0.32	-0.01	-0.54	-0.19
Grass	–	0.04	0.29	-0.01	-0.14	0.17
Leaves	–	0.04	0.30	-0.01	-0.79	-0.47
Branches	–	0.04	0.40	-0.02	-1.06	-0.65
Mixed Organics	–	0.04	0.57	-0.03	-0.30	0.29

Note: The emission factors for landfill CH_4 presented in this table assume that the methane management practices and decay rates at the landfill are an average of national practices.
Negative values denote GHG emission reductions or carbon storage.
NA = Not applicable; upstream raw material acquisition and manufacturing GHG emissions are not included in landfilling since the life-cycle boundaries in WARM start at the point of waste generation and landfilling does not affect upstream GHG emissions.

Transportation energy emissions occur when fossil fuels are used to collect and transport yard trimmings to a landfill, and then to operate the landfill equipment. To calculate these emissions, WARM relies on assumptions from FAL (1994). EPA then converted the Franklin Associates estimate from pounds of CO_2 per ton of mixed MSW to $MTCO_2E$ per ton of mixed MSW and applied it to estimate CO_2 emissions from transporting one short ton of mixed MSW. WARM assumes that transportation of yard trimmings uses the same amount of energy as transportation of mixed MSW.

WARM calculates CH_4 emission factors for landfilled materials based on the CH_4 collection system type installed at a given landfill. There are three categories of landfills modeled in WARM: (1) landfills that do not recover LFG, (2) landfills that collect the LFG and flare it without recovering the flare energy, and (3) landfills that collect LFG and combust it for energy recovery by generating electricity. The Excel version of WARM allows users to select component-specific decay rates based on different assumed moisture contents of the landfill and landfill gas collection efficiencies for a series of landfill management scenarios. The tables in this section show values using the national average moisture conditions, based on the national average precipitation at landfills in the United States and for landfill gas collect efficiency from “typical” landfill operations in the United States. The decay rate and management scenario assumed influences the landfill gas collection efficiency. For further explanation, see the Landfilling chapter.

Exhibit 11 depicts the emission factors for each LFG collection type based on the national average landfill moisture scenario and “typical” landfill management operations. Overall, landfills that do not collect LFG produce the most CH_4 emissions. The emissions generated per short ton of material drop by approximately half for yard trimmings if the landfill recovers and flares CH_4 emissions. These emissions are even lower in landfills where LFG is recovered for electricity generation because LFG recovery offsets emissions from avoided electricity generation.[7]

[7] These values include a utility offset credit for electricity generation that is avoided by capturing and recovering energy from landfill gas to produce electricity. The utility offset credit is calculated based on the non-baseload GHG emissions intensity of U.S. electricity generation, since it is non-baseload power plants that will adjust to changes in the supply of electricity from energy recovery at landfills.

Exhibit 11: Landfill CH_4 Emissions for Three Different Methane Collection Systems, National "Average" Landfill Moisture Conditions, Typical Landfill Management Operations, and National Average Grid Mix ($MTCO_2E$/Wet Short Ton)

Material	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electric Generation
Yard Trimmings	0.59	0.28	0.24
Grass	0.51	0.25	0.23
Leaves	0.59	0.26	0.22
Branches	0.77	0.38	0.26

Note: Negative values denote GHG emission reductions or carbon storage.

A portion of the carbon contained in yard trimmings does not decompose after disposal and remains stored in the landfill. Because this carbon storage would not normally occur under natural conditions (virtually all of the carbon in the organic material would be released as CO_2, completing the photosynthesis/respiration cycle), this is counted as an anthropogenic carbon sink. The carbon storage associated with each material type depends on the initial carbon content, the extent to which that carbon decomposes into CH_4 in landfills, and temperature and moisture conditions in the landfill. The background and details of the research underlying the landfill carbon storage factors are detailed in the Landfilling chapter. As Exhibit 12 illustrates, branches and leaves result in the highest amount of carbon storage.

Exhibit 12: Calculation of the Carbon Storage Factor for Landfilled Yard Trimmings

(a) Material	(b) Ratio of Carbon Storage to Dry Weight (grams of Carbon Stored/dry gram of Material)[a]	(c) Ratio of Dry Weight to Wet Weight	(d) Ratio of Carbon Storage to Wet Weight (grams of Carbon/wet gram of Material) (d = b × c)	(e) Amount of Carbon Stored ($MTCO_2E$ per Wet Short Ton)
Yard Trimmings				0.54
Grass	0.24	0.18	0.04	0.14
Leaves	0.39	0.62	0.24	0.79
Branches	0.38	0.84	0.32	1.06

Note: Yard trimmings are calculated as a weighted average of grass, leaves and branches, currently based on an estimate in the *Facts and Figures* report for 2007 (EPA, 2008, p. 58). This information is not updated annually by EPA.

[a] Based on estimates developed by James W. Levis, Morton Barlaz, Joseph F. DeCarolis, and S. Ranji Ranjithan at North Carolina State University; see Levis et al. (2013).

The landfill CH_4 and transportation emissions sources are added to the landfill carbon sink in order to calculate the net GHG landfilling emission factors for each yard trimmings material, shown in the final three columns of Exhibit 13 for landfills equipped with different LFG collection systems. The final net emission factors indicate that landfilling leaves and branches results in a net carbon sink. This negative net emission factor is due to the fact that these materials do not readily degrade in landfills and a substantial fraction of the carbon in these materials remains in the landfill permanently.

Exhibit 13: Components of the Landfill Emission Factor for the Three Different Methane Collection Systems Typically Used In Landfills ($MTCO_2E$/Short Ton)

(a)	(b) Net GHG Emissions from CH_4 Generation			(c)	(d)	(e) Net GHG Emissions from Landfilling (e = b + c + d)		
Material	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electric Generation	Net Landfill Carbon Storage	GHG Emissions From Transpor-tation	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation
Yard Trimmings	0.59	0.28	0.24	-0.54	0.04	0.10	-0.21	-0.29
Grass	0.51	0.25	0.23	-0.14	0.04	0.41	0.14	0.10
Leaves	0.59	0.26	0.22	-0.79	0.04	-0.16	-0.49	-0.57
Branches	0.77	0.38	0.26	-1.06	0.04	-0.26	-0.64	-0.82

Note: Negative values denote GHG emission reductions or carbon storage.

5. LIMITATIONS

The results of the analysis presented in this chapter are limited by the reliability of the various data elements used. This section details limitations, caveats and areas of current and future research.

5.1.1 Composting

EPA is currently conducting research into process emissions from composting, carbon storage due to compost application, and other issues that are relevant to these calculations.

- As in the other chapters of this report, the GHG impacts of composting reported in this chapter evaluate emissions relative to other possible disposal options for yard trimmings (i.e., landfilling and combustion). This assumes that yard trimmings will be collected for end-of-life management by one of these alternative materials management practices. Yard trimmings, however, can also be simply left on the ground to decompose. This pathway is not modeled in WARM, since EPA would need to analyze the effect of decomposing yard trimmings in their home soil—and the associated soil carbon storage benefits—to develop absolute GHG emission factors for composting yard trimmings at a central facility relative to a baseline of leaving yard trimmings on the ground where they fall.
- Due to data and resource constraints, the analysis considers a small sampling of feedstocks and a single compost application (cropland soil). EPA analyzed two types of compost feedstocks—yard trimmings and food waste—although sewage sludge, animal manure and several other compost feedstocks also may have significant GHG implications. Similarly, it was assumed that compost was applied to degraded agricultural soils growing corn, despite widespread use of compost in specialty crops, land reclamation, silviculture, horticulture and landscaping.

- This analysis did not consider the full range of soil conservation and management practices that could be used in combination with application of compost, and the impacts of those practices on carbon storage. Research indicates that adding compost to agricultural soils in conjunction with various conservation practices enhances the generation of soil organic matter to a much greater degree than applying compost alone. Examples of these conservation practices include conservation tillage, no-till, residue management, crop rotation, wintering and summer fallow elimination.
- In addition to the carbon storage benefits of adding compost to agricultural soils, composting may lead to improved soil quality, improved plant productivity, improved soil water retention and cost savings. As discussed earlier, nutrients in compost tend to foster soil fertility (Brady and Weil, 1999). In fact, composts have been used to establish plant growth on land previously unable to support vegetation. In addition to these biological improvements, compost also may lead to cost savings associated with avoided waste disposal, particularly for feedstocks such as sewage sludge and animal manure.

5.1.2 Landfilling

- WARM currently assumes that 82 percent of MSW landfill CH_4 is generated at landfills with LFG recovery systems (EPA, 2014a). The net GHG emissions from landfilling each material are quite sensitive to the LFG recovery rate, so the application of landfill gas collection systems at landfills will have an effect on lowering the emission factors presented here over time. WARM is updated annually to account for changes in the percent of MSW landfill CH_4 that is collected at U.S. landfills.

5.1.3 Combustion

- Opportunities exist for the combustion system efficiency of WTE plants to improve over time. As efficiency improves, more electricity can be generated per ton of waste combusted (assuming no change in utility emissions per kWh), resulting in a larger utility offset, and the net GHG emissions benefit from combustion of MSW will increase.
- The reported ranges for N_2O emissions from combustion of organics were broad. In some cases, the high end of the range was ten times the low end of the range. Research has indicated that N_2O emissions vary with the type of waste burned. In the absence of better data on the composition and N_2O emissions from organics combustion on a national scale in the United States , the average value used for yard trimmings should be interpreted as an approximate value.
- This analysis used the non-baseload mix of electricity generation facilities as the proxy for calculating the GHG emissions intensity of electricity production that is displaced at the margin from energy recovery at WTE plants and LFG collection systems. Actual avoided utility GHG emissions will depend on the specific mix of power plants that adjust to an increase in the supply of electricity, and could be larger or smaller than estimated in these results.

6. REFERENCES

Barlaz, M.A. (2008). Memorandum to Parties Interested in Carbon Sequestration from Municipal Solid Waste: “Corrections to Previously Published Carbon Storage Factors.” February 27, 2008.

Barlaz, M.A. (2005). Letter to Randy Freed, ICF International: "Decomposition of Leaves." June 29, 2005.

Barlaz, M.A. (1998). Carbon storage during biodegradation of municipal solid waste components in laboratory-scale landfills. *Global Biogeochem. Cycles*, 12 (2): 373–380.

Brady, N., & R. Weil. (1999). *The Nature and Properties of Soils*. Upper Saddle River, NJ: Prentice Hall.

Cole, M. (2000). Personal communication between Dr. Michael Cole, University of Illinois, and Randy Freed, ICF Consulting, July 3, 2000.

EPA (2014a). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012.* (EPA publication no. EPA 430-R-14-003.) Washington, DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs, April. Retrieved from: http://epa.gov/climatechange/emissions/usinventoryreport.html

EPA. (2014b). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012.* Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Retrieved from: http://www.epa.gov/osw/nonhaz/municipal/pubs/2012_msw_dat_tbls.pdf.

EPA. (2008). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007*. United States Environmental Protection Agency, Office of Solid Waste. EPA530-R-08-010. Retrieved from http://www.epa.gov/epawaste/nonhaz/municipal/pubs/msw07-rpt.pdf.

EPA. (2006). *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*. Washington, DC: U.S. Environmental Protection Agency.

EPA. (1998). *AP-42 Emission Factors for Municipal Solid Waste Landfills – Supplement E.* Washington, DC: U.S. Environmental Protection Agency.

FAL. (1994). *The Role of Recycling in Integrated Solid Waste Management to the Year 2000.* Franklin Associates Ltd. (Stamford, CT: Keep America Beautiful, Inc.), September.

Harrington, K. (1997). Personal communication between Karen Harrington, Minnesota Office of Environmental Assistance, and ICF Consulting, October 1997. Value reported by an RDF facility located in Newport, MN.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5: Waste*, Chapter 3: Solid Waste Disposal. Intergovernmental Panel on Climate Change. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html