Recycling and Composting Emissions Protocol

For Estimating Greenhouse Gas Emissions and Emissions Reductions
Associated with Community Level Recycling and Composting

Version 1.0

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Developed by
ICLEI—Local Governments for Sustainability USA

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Recycling and Composting Protocol Advisory Committee

David Allaway	Oregon Department of Environmental Quality
Frank Caponi	Los Angeles County Sanitation Districts
John Davis	Mojave Desert and Mountain Recycling Authority
Shannon Davis	US EPA Region 9
Brian Helmowski	California Department of Resource Recycling and Recovery
Debra Kauffman	StopWaste.org
Nick Lapis	Californians Against Waste
Eric Lombardi	Eco-Cycle
Xico Manarolla	PMC

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1. Introduction

ICLEI-USA has produced this Recycling and Composting Emissions Protocol (RC Protocol) in recognition of the contribution recycling and composting can make to greenhouse gas reduction efforts, and the high degree of influence that local governments have in this area. This Protocol may stand on its own, or it may be used in conjunction with the Community Protocol for Emissions Accounting and Reporting (Community Protocol).[1] It can be used by local government climate program staff, sustainability program staff, and/or solid waste/recovery program staff to document and communicate the climate benefits of recycling and composting. Local governments using the Community Protocol are encouraged to also use this RC Protocol to document and communicate the climate benefits of recycling and composting. The expansion of recycling and composting programs in recent decades has been largely - although not exclusively - driven by decisions made at the city and county level to provide for recycling and composting services. In some cases, programs to increase recycling and composting rates can be among the most cost effective actions local governments can take to reduce community GHG emissions.

This RC Protocol is designed to meet two distinct objectives:

1. **Overall reductions[2]:** Estimate the full greenhouse gas emissions and emissions reductions of community-scale recycling and composting efforts (whether or not some of these emissions are already included in the community's greenhouse gas inventory).
2. **Additional reductions:** Estimate just those emissions and emissions reductions that are not otherwise already accounted for in the community's greenhouse gas inventory, as calculated under the Community Protocol.

Communities may use this Protocol to satisfy either or both of these objectives.

1.1 RC Protocol Organization

This Protocol is laid out in four sections:

1. An overview of key concepts and describes the relationship of this protocol to the Community Protocol, and to EPA's WAste Reduction Model (WARM).
2. Methodologies for estimating the amount of materials collected for recycling and composting in your community. You will need these methods to estimate either overall reductions or additional reductions.
3. Methodologies for overall reductions as defined above.
4. Methodologies for additional reductions as defined above.

If you are only interested in overall reductions, you will not need to refer to the fourth section; however information in both sections 3 and 4 will be useful for estimating additional reductions.

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[1] http://www.icleiusa.org/tools/ghg-protocol/community-protocol

[2] The term 'reductions' is used here for simplicity. In reality, both emissions and emissions and emissions reductions will be calculated as part of either overall reductions or additional reductions. In most cases, the net impact will be an emissions reduction; however it is possible that recycling or composting could cause a net emissions increase.

Estimating additional reductions is more complicated than estimating overall reductions. Overall reductions tell the most complete overall story of the emissions reductions associated with community-scale recycling and composting. Additional reductions provide greater detail on where and how emissions or emissions reductions occur. A comparison of results from the two methods can uncover which emissions and emissions reductions occur inside the community vs. outside of it. This can be helpful for action planning and measuring emissions reduction progress in future inventories. While the total calculated for overall reductions is a valuable contribution to global emissions reductions, only that portion that *is* included in your inventory (the difference between overall reductions and additional reductions) will contribute to local reductions. These reductions are measured by comparing a baseline inventory with a subsequent inventory.

Under the Community Protocol, local governments have the option to include information on GHG benefits associated with activities in their community GHG reporting, so long as this information is presented separately from gross emissions data calculated using the methods provided by the Community Protocol. It is not Protocol-compliant to report net numbers (e.g., subtracting recycling emissions benefits from the gross emissions estimate). However, an inventory can report this information on emissions reduction efforts as a separate line item (or line items), adjacent to (but separate from) gross emissions. Even though recycling benefits are not to be subtracted from gross emissions, communities interested in reporting these two numbers alongside each other may want to use section 4 (additional reductions) in order to report out the “additional” emissions and emissions reductions associated with recycling and composting that are not counted elsewhere in the community’s inventory. It may be most useful to present both overall reductions and additional reductions alongside the community’s gross inventory, as shown in the following hypothetical (and simplified) example:

Example 1.1: Reporting of gross emissions and recycling benefits for hypothetical community

	Reporting Framework	
	Significant Influence	Household Consumption
2012 GHG Gross Emissions	435,000 MTCO2e	540,000 MTCO2e
Additional Benefits of Recycling	-22,000 MTCO2e*	N/A**

*The full benefits of recycling are estimated at 35,000 MTCO2e in emissions reductions. Of these, 13,000 are already reflected in the 2012 gross emissions (these are reduced emissions from community-generated landfill waste and reduced energy use in our city’s steel mill, which has reduced emissions in part due its use of recycled metal from other city households and businesses). The 22,000 MTCO2e of additional benefits result mainly from reduced energy use in manufacturing and materials extraction at sites outside the community, and from increased carbon storage in forests because of reduced harvest.
**Most benefits of community recycling are already included in our consumption-based estimate.

1.2 Relation to Community Protocol

Users of the Community Protocol may wish to use this RC Protocol to estimate the emissions and emissions reductions associated with community-scale recycling and composting. However, use of this RC Protocol is optional. Similarly, the RC Protocol (but not Section 4) can be used independently of the Community Protocol.

Recycling and composting both contribute to emissions and emissions reductions. Recycling and composting can create emissions from collection vehicles, energy use to process/sort recycled material, energy use to operate compost facility equipment, and the long-distance transport of recyclables and compost to distant markets. Significant emissions reductions can occur in the following ways:

- Recycling avoids “upstream” GHGs emitted in raw material acquisition, manufacture and transport of virgin inputs and materials.
- Recycling of wood and paper products increases the amount of carbon stored in forests.
- Recycling and composting reduces emissions associated with landfilling and/or combustion of wastes.

Some of these emissions and emissions reductions may already be fully or partially included in a community inventory developed using ICLEI's Community Protocol. Different communities will have different overlap between their community inventory and recycling/composting net emissions, depending on several factors. These factors include which sources and activities are included in their community inventory, as well as the nature of their recycling processing and location of their end markets.

Box 1.1: Source Reduction

This RC Protocol does not provide methods for estimating the greenhouse gas impacts of source reduction. Also called “waste prevention”, source reduction is preferred over recycling and composting in the waste management hierarchy adopted as policy by EPA and many states. Regardless, few communities attempt to quantify the tons of wastes that are “prevented” through prevention practices, which involve changing how materials are purchased and used. Communities interested in documenting the impacts of these types of programs are encouraged to review ICLEI’s Community Protocol, and specifically Appendices H (Emissions Associated with the Community’s Use of Materials and Services: Accounting for Trans-boundary Community-Wide Supply Chains) and I (Consumption-Based Emission Activities and Sources). These two appendices provide methods for estimating the emissions associated with the use of materials. When source reduction is thought of as avoided use, communities can use these appendices in one of two ways. One way is to estimate pre- and post-source reduction emissions associated with materials use and include these full emissions in their community inventories. Otherwise, communities can use the emissions factors in these appendices to estimate the emissions reductions associated with specific and discrete source reduction initiatives, if the associated reductions in material tonnage or consumption are known.

For the first objective of this RC Protocol—estimating the full emissions impacts/reductions of community-scale recycling and composting—emissions and emissions reductions are estimated independently of the community inventory, and the Community Protocol. However, the second objective involves estimating just those emissions and emissions reductions that are not otherwise already included in a community-wide inventory. In this case, understanding which emissions and reductions are already included in the community's inventory is an essential step in the accounting process. This will be explored in more detail in section 4.

1.3 Relation to EPA's WARM Tool

This RC Protocol draws heavily on the underlying methods, data, and calculations embedded in the U.S. EPA's WAste Reduction Model (WARM). In fact, communities that are only interested in the first objective of this RC Protocol (estimating the full emissions and emissions reductions) may choose to use the WARM tool instead. Differences between this ICLEI RC Protocol and WARM are summarized below:

- WARM can only be used to estimate the full emissions and emissions reductions associated with recycling and composting, while this RC Protocol can also be used to estimate the subset of those emissions and emissions reductions that are not already included in a community-wide inventory.
- This RC Protocol makes a simplifying assumption of lifetime 75% methane collection rate for all landfills with gas collection systems, in order to be consistent with the Community Protocol. The average lifetime efficiency of landfill gas collection is a subject of ongoing research, and may be subject to revision in future protocol versions as new data becomes available. Use of WARM provides for greater flexibility in modeling, such as differences in landfill gas collection efficiencies, as well as distances to end-markets, use of regional electric grids (relevant for energy recovery from waste landfilling and incineration), and other landfill conditions, including rainfall and extent and type of gas collection system.
- This RC protocol differs from WARM in the handling of carbon storage. WARM includes three types of carbon storage:
  1. Increased storage of carbon in forests, when paper and wood products are recycled.
  2. Increased storage of carbon in soils that are treated with finished compost.
  3. Increased storage of carbon in landfills when certain biogenic wastes (such as lumber) are landfilled.

  The ICLEI RC Protocol only accounts for the first type of carbon storage (forests), and not the others (soils and landfills). Storage of carbon in forests is fundamentally different in that it represents "new" or "added" carbon that was not already in circulation in commerce. In contrast, composting and landfilling merely serve to move carbon from one pool (products and/or landscaping) into another pool (compost and/or landfill) and are not effectively removing carbon from the atmosphere. For these reasons, the ICLEI RC Protocol includes increased storage of carbon in forests associated with recycling of paper (consistent with WARM), but excludes consideration of waste and product carbon that merely moves from one carbon pool to another via composting or landfilling. To determine the amount of carbon that remains undegraded in a landfill or finished compost product, a community can refer directly to WARM[3] . This figure should not be added to or subtracted from the greenhouse gas emissions and emissions reductions calculated using this RC Protocol.

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[3] For landfilling, see Exhibit 12, Landfilling, WARM Version 12 (February 2012); http://www.epa.gov/climatechange/waste/downloads/Landfilling.pdf For composting, see Exhibit 8 (both “soil carbon

1.4 Treatment of Emissions over Time

Both the ICLEI RC Protocol and WARM roll-up emissions and reductions over multiple years into a single data point associated with the year in which the waste was generated. In reality, the emissions reductions associated with recycling occur over multiple years. For example, when paper is recycled instead of landfilled, future landfill emissions are reduced, and forest carbon storage increases over time because of decreased harvesting. WARM rolls all of these emissions and emissions reductions into a single data point. EPA explicitly states that WARM should not be used as an inventory tool. However, this is in the context of inventory practice at the international scale, where emissions are only reported in the year in which they actually occur. Since the ICLEI Community Protocol already requires communities to assign to the inventory year the future emissions associated with landfilling of community-generated waste during the inventory year, it is consistent to roll up avoided future landfill emissions as well as other future emissions changes (such as forestry changes) when accounting for the benefits of recycling under this RC Protocol.

1.5 Additional Benefits of Composting

In addition to carbon storage, which is not included in this version of the RC Protocol, composting provides other potential emissions reduction benefits. For example, when finished compost is applied to soils, it improves their water retention capacity, thus conserving water and reducing emissions associated with pumping and applying water. Similarly, some applications of compost result in reduced demand for manufacture of emissions-intensive synthetic fertilizers and/or herbicides. Compost may have less emissions of nitrous oxide than do commercial fertilizers. It may improve crop yield, improve soil workability (thereby reducing energy use in tilling), and decrease soil erosion. Some of these benefits have not yet been quantified, and others have but not sufficiently well. In some cases, quantification of benefits has been performed but the results are limited to certain geographies with specific agricultural practices, climates, and/or irrigation systems, and are not appropriate for use in a nationwide protocol such as this one. As such, most of the potential emissions reductions associated with application of compost are not included in this version of the RC Protocol as research is still underway to develop appropriate emissions factors. Nevertheless, it is important to acknowledge that these potential benefits are real. This approach is largely consistent with WARM at the time of this writing; this RC Protocol will be updated as WARM factors are updated. However, after reviewing the literature, the RC Protocol Advisory Committee agreed to include an estimated emissions reduction factor for one benefit of composting not currently included in WARM: the reduction in emissions associated with producing commercial fertilizers which may be displaced due to the use of compost.

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restoration" and "increased humus formation"); http://www.epa.gov/climatechange/waste/downloads/Composting.pdf. Further background on carbon storage in WARM can be found in "Landfill Carbon Storage in EPA's Waste Reduction Model"; http://epa.gov/epawaste/conserve/tools/warm/pdfs/landfill-carbon-storage-in-warm10-28-10.pdf,
"Composting in WARM" http://epa.gov/epawaste/conserve/tools/warm/pdfs/cmpstng_ovrview.pdf, and
"Forest Carbon Storage" http://epa.gov/epawaste/conserve/tools/warm/pdfs/Forest_Carbon_Storage.pdf

2. Estimating Quantity of Material Recycled and Composted

2.1 Overview

Estimation of emissions reductions associated with recycling and composting starts with an estimate of the quantity and composition of material recycled and composted. Some communities may have high quality data, but many will not have complete data. Local governments frequently operate or oversee collection of recyclable and compostable materials from single-family residences, and sometimes from multi-family residential buildings. As a result, local governments usually have access to good data on materials from these sources. However, most collection from commercial buildings and some from multi-family residential buildings is done by multiple private haulers, making data potentially hard to obtain. Commercial recycling also involves significant back-haul, in which chain retailers, especially big-box retailers and supermarkets collect recyclables from their stores through their own delivery trucks and distribution centers. Also common is direct sale or self-haul recycling (from office complexes or contractors, for example). This makes it challenging to obtain comprehensive community-scale measurement data on amount and composition of materials recycled. This lack of data is made more significant by the fact that, in some communities, the amount of materials recycled from commercial buildings may be greater than the amount from residential buildings.

This section describes what preferred data would look like, and also provides an alternate method(s) for communities without access to the preferred data.

The following data sources are listed in order of preference:

1. Comprehensive local data reflecting actual recycling mass and composition. This could include community-specific information from a hauler or materials recovery facility[4], or a community generation study.
2. An estimate of recycling volume and composition using standardized characterizations provided by a regional or state agency. For example, CalRecycle's 2006 Waste Disposal and Diversion Findings for Select Industry Groups report reflects private commercial recycling activity that may not be reflected in local data.
3. US EPA's Municipal Solid Waste Generation, Recycling and Disposal in the United States report, which is updated annually.[5]

In general, local data will be more *accurate* than EPA or state data, but will typically be less *comprehensive*.[6] As described above, many local governments will have accurate data on single-family

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[4] Note that data from a materials recovery facility alone will not include back-haul and self haul recycling, and may significantly undercount the total mass recycled.

[5] Construction and demolition activity, which generates a significant amount of waste and a significant amount of recycled material, is not included in this report.

[6] It is worth noting that some communities and states do undertake comprehensive recycling quantification studies that are both relatively accurate and comprehensive.

residential and possibly some commercial collection, but may have little data on a significant part of commercial collection. Thus the best data to use will depend in part on your purpose and estimating emissions and reductions. If you want to calculate reductions that can be attributed to a specific local government program, for example your single-family residential collection, then you should use local data. If however you are trying to estimate the total impact of all recycling activity in your community and do not have comprehensive local data, then use the method for adjusting national averages with local data in section 2.4.

2.2 Preferred Data

As noted above, most local governments will not have access to the preferred data for all recycled and composted materials collected in the community. For those local governments that do have that data or wish to start putting systems in place to collect this data, a description of what that data would look like is provided. Access to measured data on amount of materials recycled is essential for communities that want to accurately track the GHG emissions impact of their recycling and composting programs over time.

Two kinds of information are needed to calculate emissions reductions from recycling or composting:

1. The total amount of material recycled or composted
2. The percentage breakdown by material type or amount by material type (note that the composition of the recycled stream will vary significantly from the composition of the landfill bound waste stream for your community).

If you have local data on amount of material recycled and composted, but not on composition, you can use your local quantity data with the ‘Mixed Recyclables’ category in Sections 3 and 4. The Mixed Recyclables category is a weighted average emissions/emissions reduction factor, based on national average composition of materials recycled. For reference, this composition is shown in Table 2.2 below.

2.3 Alternate Data: EPA National Statistics

If you do not have data on local material diversion, you can use national average amounts to estimate the baseline emissions impact of recycling and composting in your community. Table 2.1 shows national average total amounts of waste generated, recycled and composted. This information can be useful to estimate the additional impact of policies to increase recycling and composting rates. For example, if a policy was expected to increase recycling by 50%, you could use the defaults below and methods in sections 3 and 4 to estimate the additional emissions reductions from that policy. However, it is important to note that this approach will not allow you to measure the actual impact over time of increased recycling and composting in your community. To do this, you will need local measured data as outlined in the preferred data section.

In several states, state level data similar to Table 2.1 will be available, and may be used in place of national averages. Some states have data broken down to a county level that can be used. Another potential source of data is the report "The State of Garbage in America[7]," produced by BioCycle and the Earth Engineering Center of Columbia University.

Table 2.1: Average Waste Generated and Diverted per Person

Category	**Amount (lbs/person/day) US Average, 2011[8]**
Total MSW generated	4.40
Diverted for recycling	1.16
Diverted for composting	0.37
Net discarded	2.87

Table 2.2: Average Composition of Recycling in 2010[9]

Material	**Percent of All Materials Recycled**
Paper and paperboard	68.6%
Glass	4.8%
Ferrous metals	8.8%
Aluminum	1.0%
Other non-ferrous metals	2.3%
Plastics	3.9%
Rubber and Leather	1.8%
Textiles	3.0%
Wood	3.5%
Other	2.2%
Material	**Percent of Material Recovered for Composting**
Food Waste	4.8%
Yard Trimmings	95.2%

2.4 Method for estimating materials recycled and composted using national averages

Step 1: Multiply the per person numbers from Table 2.1 by your community population, and by 365 to obtain recycling and composting totals (in pounds) for your community. Divide by 2,000 for an estimate of recycling and composting (in short tons).

Step 2: Use the methods in Section 3 and Section 4 (if calculating additional reductions) to estimate emissions, applying the 'Mixed Recyclables' category to the quantity from step 1.

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[7] http://www.biocycle.net/images/art/1010/bc101016_s.pdf

[8] US EPA. *Municipal Solid Waste in the United States: 2011 Facts and Figures,* Table ES-1. http://www.epa.gov/osw/nonhaz/municipal/pubs/MSWcharacterization_fnl_060713_2_rpt.pdf

[9] US EPA. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States Tables and Figures for 2010.* http://www.epa.gov/epawaste/nonhaz/municipal/pubs/2010_MSW_Tables_and_Figures_508.pdf Calculated from Table 2. This data does not include construction and demolition waste.

2.5 Method for adjusting national averages with local data

Use this method where you are trying to estimate total net emissions reductions associated with all recycling and/or composting activity in your community, and where you do *not* have comprehensive local data on recycling and composting collection.

Step 1: Using local data sources (e.g., collection records, MRF reports, compost facility records, etc.), determine local pounds per person per day for each material.

Step 2: Multiply the material specific recycling and composting percentages in Table 2.2 by the national average pounds per person per day diverted for recycling or composting (Table 2.1.), to obtain an average pounds per person per day for each material.

Step 3: For each material, use whichever result from Step 1 or Step 2 is greater. The reason for this is that where local data shows a higher number, it most likely means a local program is actually diverting more material than the national average. Where the national average number is higher, it is most likely because the local data is not comprehensive. However, if you have local data that you know is comprehensive, use that number, even if it is lower than the national average.

Step 4: Multiply the result of Step 3 by your population and by 365 to obtain annual amounts recycled and composted for each material (in pounds). Divide by 2,000 to convert to tons.

Example 2.1: Adjusting national averages with local data

Step 1: A community has measured glass collection of 0.1 pounds per person per day, and paper and paperboard collection of 0.5 pounds per person per day.

Step 2: national pounds per person per day (ppd)

Glass ppd = (1.15 ppd all recyclables) * (4.8% glass) = 0.055 ppd glass
Paper and paperboard ppd = (1.15 ppd all recyclables) * (68.6% paper and paperboard)
= 0.79 ppd paper and paperboard

Step 3: Since 0.1 is greater than 0.055, use 0.1ppd for glass. Since 0.79 is greater than 0.5, use 0.79 ppd for paper and paperboard.

Step 4: Community population is 100,000.

0.1 ppd glass * 365 * 100,000 = 3,650,000 lbs glass per year
0.79 ppd paper and paperboard *365 * 100,000 = 28,835,000 lbs paper and paperboard per year

The above steps would need to be repeated for each material type. For any material where local data is not available, the national average can be used.

3. Estimating Total Emissions Reductions

3.1 Background

This Protocol provides methods for estimating the emissions reductions associated with recycling and composting at the community scale. This section provides a method for estimating the full, net emissions reductions associated with community recycling and composting, whether or not those emissions and emission reductions (such as reduced landfill emissions) are already reflected in the community's GHG inventory. Section 4 provides a method for identifying and estimating only those emissions and emissions reductions that are not already accounted for in the community's GHG inventory. Both approaches draw on the same basic modeling and data sources for emissions factors, so a short overview is provided.

This Protocol draws extensively on EPA's Waste Reduction Model, or WARM, for overall methodology and material-specific emissions factors. There are some specific difference between this Protocol and WARM, which are identified below.

3.1.1 Recycling Background

Recycling is a process that takes materials or products that are no longer wanted by the original user and either (1) reprocesses them to be used in the manufacture of a similar product or (2) transforms them into a different product (see Box 3.1). When a material is recycled, it is used in place of virgin inputs in the manufacturing process of the new product, rather than being disposed of and managed as waste. Consequently, recycling provides GHG reduction benefits in three ways, depending upon the material recycled: (1) it offsets a portion of "upstream" GHGs emitted in raw material acquisition, manufacture and transport of virgin inputs and materials, (2) it increases the amount of carbon stored in forests when wood and paper products are recycled, and (3) it reduces emissions associated with landfilling and/or combustion of wastes.

Box 3.1: Closed Loop and Open Loop Recycling

Recycling may be either closed loop or open loop, with consequences for the resulting savings of energy and virgin material inputs. In closed loop recycling, a product is turned into a new version of the same product. Aluminum beverage containers are an example of a product that can be recycled in this way. In open loop recycling, a product is turned into a different new product. An example is recycling plastic bottles into plastic lumber.

WARM assesses the GHG emission implications of recycling from the point of waste generation (i.e., starting at the point when the material is collected for recycling) through the point where the recycled material or product has been manufactured into a new product for use. This includes all of the GHG emissions associated with collecting, transporting, processing and recycling or manufacturing the recycled material into a new product for use.

In calculating the first source of GHG reduction benefits, WARM assumes that recycling materials does not cause a change in the amount of materials that would otherwise have been manufactured. Since the amount of product manufactured stays the same, an increase in recycling leads to a displacement of virgin-sourced materials. To account for the emissions associated with virgin manufacture, WARM calculates a “recycled input credit” by assuming that the recycled material avoids—or offsets—the upstream GHG emissions associated with producing material from virgin inputs. This credit represents the difference in emissions that results from using recycled inputs rather than virgin inputs. The credit accounts for U.S. average loss rates in collection, processing and remanufacturing; not all of the material collected for recycling (and estimated using Section 2) actually is used in the manufacture of new product, with associated greenhouse gas reductions. Recycling credit is based on closed- or open-loop recycling, depending on material.

3.1.2 Composting Background

Composting is a materials management option for yard trimmings, food scraps, and mixed organics. During composting, microbial decomposition transforms organic substrates into a stable, humus-like material.

When biodegradable materials such as wood products, food wastes and yard trimmings are placed into a landfill, a fraction of the carbon within these materials degrades into methane (CH4) emissions. The quantity and timing of CH4 emissions released from the landfill depends upon three factors: (1) how much of the original material decays into CH4, (2) how readily the material decays under different landfill moisture conditions, and (3) landfill gas collection practices.

Composted material is not landfilled, so methane emissions are avoided. Compost utilization also reduces water use and associated energy emissions, reduces chemical fertilizer use and associated production emissions, and may result in other benefits as well, such as reduced soil erosion and reduced herbicide use and production. However most of these benefits are not yet sufficiently defined or documented for inclusion in this protocol version. The one exception involves the avoidance of emissions due to displaced chemical fertilizer production. It should be noted that this particular benefit can be highly variable, depending on how the compost is being used and by whom, and to what extent the users of compost from your community will actually reduce their use of chemical fertilizers as a result of using compost. The emissions reduction factor chosen for inclusion in this version of the RC Protocol assumes that while all compost contains nutrients such as nitrogen and phosphorous, the use of compost does not result in reduction in application (and production) of chemical fertilizers on a 1-for-1 basis, but rather that some uses of compost result in some reduction of chemical fertilizer application. This dynamic, which is largely behavioral in nature, would benefit from additional research. In the meantime, the actual benefits of avoided fertilizer production may be higher or lower than those represented by the emissions factor in this Protocol.

Communities in California may consider the Air Resources Board adopted compost emissions reduction factors, which include water benefits, soil erosion benefits, and different chemical emission reductions[10].

This protocol includes reductions of methane emissions that would otherwise occur from landfill disposal, that are identified in WARM. Minimal carbon dioxide (CO_2) emissions from transportation and mechanical turning of the compost piles are also included and are consistent with WARM. However, WARM also includes carbon storage for composting (associated with application of compost to agricultural soils); this RC Protocol does not include soil carbon storage as emission reductions, as explained in Section 1.

Box 3.2: Anaerobic Digestion

Anaerobic digestion is an emerging technology in the United States for disposal of organic wastes, although it is established in other countries, particularly those in Europe. It may involve adding waste to existing digesters at a wastewater treatment plant, or digestion of food and yard wastes in a dedicated facility. Wastes break down in the digester to produce methane, which can be used to displace natural gas, to generate electricity, or as a transportation fuel. Methods for estimating emissions and emissions reductions from anaerobic digestion are not included in this version of the RC Protocol because of limited data availability on facilities in the U.S.

3.1.3 Definitions

The following definitions apply to Tables 3.2 and 3.3. Please note throughout this document that all emissions factors are expressed as positive numbers if recycling or composting cause emissions to occur and negative numbers if they cause a reduction in emissions. For example, "forest carbon storage emissions" of -3.06 MTCO2e/short ton represents a *reduction* in emissions of 3.06 MTCO2e per short ton of waste recycled.

Table 3.1: Definitions of Emissions Types

Recycled input credit	An emissions credit assuming that the recycled material avoids—or offsets—the GHG emissions associated with producing material from virgin inputs
Process energy emissions	Emissions from energy consumption during the acquisition and manufacturing processes
Transportation emissions	Emissions from energy used to transport feedstocks/raw materials to the point of final production

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[10] http://www.arb.ca.gov/cc/protocols/localgov/pubs/compost_method.pdf Note that the ARB factors *do* include soil carbon storage, inconsistent with the RC Protocol. California users of this Protocol, if using the ARB factors, should subtract out the soil carbon storage benefit of compost, in order to avoid inconsistency with the treatment of carbon storage in landfills.

Process non-energy emissions	Emissions occurring during manufacture that are not associated with energy consumption (For example, perfluorocarbons (PFCs) are emitted during the production of aluminum)
Forest carbon storage	Atmospheric CO2 absorbed by growing forests when the rate of uptake exceeds the rate of release
Emissions from using recycled inputs instead of virgin inputs	A sum of the process energy emissions, transportation emissions, process non-energy emissions, and forest carbon storage
Fertilizer production displacement credit	An emissions credit associated with reduced production of chemical fertilizers resulting from the use of compost
Landfill methane	Methane produced from organic matter decaying in anaerobic landfill conditions

Box 3.3: Biogenic carbon emissions. This protocol, consistent with the Community Protocol and other inventory protocols, assumes that emissions from combustion of biomass are carbon neutral. Thinking about biogenic emissions is evolving, and carbon neutrality is not the case in all circumstances. In fact, in a 2012 memo, the EPA Science Advisory Board states: “There are circumstances in which biomass is grown, harvested and combusted in a carbon neutral fashion but carbon neutrality is not an appropriate a priori assumption; it is a conclusion that should be reached only after considering a particular feedstock’s production and consumption cycle.” The assumption of biogenic carbon neutrality affects emissions factors throughout this RC Protocol. For example, the factors in tables 3.2 and 3.3 for emissions benefits of avoiding disposal in a waste combustion facility or in a landfill producing energy from landfill gas are based on an assumption of carbon neutrality for biogenic carbon, and this may lead to underestimating the benefit of that avoided disposal. Changing the treatment of biogenic carbon would have very significant implications for the wider Community Protocol and many other emissions accounting protocols. As available data continues to evolve in the future, treatment of biogenic carbon may be re-evaluated in both the Community Protocol and this RC Protocol.

3.2 Method for Recycling

Step 1. Estimate the quantity (in short tons) of materials collected from the community for recycling during the inventory year, by material type. See Section 2 for a discussion of methods for estimating quantities of material recycled, and Table 3.2 below for a list of material types.

Step 2. For each material recycled, determine the type of facility (landfill with no gas collection, landfill with gas collection but no energy recovery, landfill with gas collection and energy recovery, or combustion facility) that the material would have gone to for disposal, had it not been recycled. If your community sends its wastes to multiple facilities, then a breakdown of waste sent to each type of facility is needed (e.g., 20% to landfills without gas collection, 65% to landfills with gas collection, 15% to waste combustion facilities).

Step 3. For each material recycled, multiply the tonnage recycled during the inventory year by the emissions factor in the column titled "GHG emissions from using recycled inputs instead of virgin inputs" from Table 3.2.

Step 4. For each material recycled, multiply the tonnage recycled during the inventory year by the appropriate emissions factor for avoided disposal in Table 3.2, based on where the material would have been disposed of had it not been recycled.[11]

Step 5. Add the results of Steps 3 and 4 together for each material.

Step 6. Add the results of Step 5 together for all materials.

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[11] Note: if your waste is sent to a landfill with gas collection and energy recovery, the calculation presented in section 4.6.2 will, provide a more accurate local result than the factors based on national averages in table 3.2. If you are calculating additional reductions in section 4, or simply want a more accurate result, you can use the factor for a landfill with gas collection and no energy recovery, and then add emissions for lost energy recovery as calculated in section 4.6.2 (for this overall reduction calculate as if all gas or electricity were used outside your community).

Table 3.2. Life-Cycle Recycling Greenhouse Gas Emissions, by Emission Type (MTCO2e/short ton of material collected for recycling)

Material	Emissions (+) or reductions (-)				
		For Avoided Disposal, by Disposal Facility Type (Step 4)[13]			
	From using recycled inputs instead of virgin inputs[12]	Landfill with no gas collection[14]	Landfill with gas collection but no energy recovery[15]	Landfill with gas collection and energy recovery[16]	Combustion facility[17]
Mixed Recyclables	-2.8	-1.75	-0.47	-0.28	0.42
Aluminum Cans	-8.89	-0.04	-0.04	-0.04	-0.05
Aluminum Ingot	-6.97	-0.04	-0.04	-0.04	-0.05
Steel Cans	-1.8	-0.04	-0.04	-0.04	1.59
Copper Wire	-4.89	-0.04	-0.04	-0.04	-0.05
Glass	-0.28	-0.04	-0.04	-0.04	-0.05
HDPE	-0.86	-0.04	-0.04	-0.04	-1.27
LDPE	NA	-0.04	-0.04	-0.04	-1.28
PET	-1.11	-0.04	-0.04	-0.04	-1.24
LLDPE	NA	-0.04	-0.04	-0.04	-1.27
PP	NA	-0.04	-0.04	-0.04	-1.27
PS	NA	-0.04	-0.04	-0.04	-1.64
PVC	NA	-0.04	-0.04	-0.04	-0.67
PLA	NA	-0.04	-0.04	-0.04	0.62
Corrugated Containers	-3.11	-2.31	-0.61	-0.36	0.48
Magazines/Third-Class Mail	-3.07	-0.96	-0.27	-0.17	0.35
Newspaper	-2.78	-0.85	-0.24	-0.15	0.55
Office Paper	-2.85	-3.87	-1.00	-0.58	0.47
Phone Books	-2.65	-0.85	-0.24	-0.15	0.55
Textbooks	-3.11	-3.87	-1.00	-0.58	0.47
Dimensional Lumber	-2.46	-1.21	-0.33	-0.21	0.58

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[12] Source: http://www.epa.gov/climatechange/waste/downloads/Recycling.pdf, Exhibit 2, column (f).

[13] Please note that these emissions factors are not the emissions from disposal, but rather the reduction in emissions associated with avoided disposal.

[14] Source: http://www.epa.gov/climatechange/waste/downloads/Landfilling.pdf Calculated as values from Exhibit 17 ("landfills without gas recovery") less carbon storage from Exhibit 16.

[15] Ibid. Calculated as negatives of ("transportation to landfill" (Exhibit 16) plus CH4 generation (Exhibit 6) less 75% collection and 10% oxidation).

[16] Calculated as emissions from previous column plus an energy recovery credit calculated as 13% (per EPA exhibit 13) of gas collection (calculated as 75% of CH4 generation).

[17] Source: http://www.epa.gov/climatechange/waste/downloads/Combustion.pdf Calculated as negatives of values in Exhibit 7, column (f).

Table 3.2 Continued

Material	Emissions (+) or reductions (-)				
	From using recycled inputs instead of virgin inputs	For Avoided Disposal, by Disposal Facility Type (Step 4)			
		Landfill with no gas collection	Landfill with gas collection but no energy recovery	Landfill with gas collection and energy recovery	Combustion facility
Medium-Density Fiberboard	-2.47	-1.21	-0.33	-0.21	0.58
Mixed Paper (general)	-3.52	-2.16	-0.57	-0.34	0.49
Mixed Paper (primarily residential)	-3.52	-2.05	-0.54	-0.33	0.48
Mixed Paper (primarily from offices)	-3.59	-2.10	-0.56	-0.33	0.44
Mixed Metals	-3.97	-0.04	-0.04	-0.04	1.06
Mixed Plastics	-0.98	-0.04	-0.04	-0.04	-1.25
Carpet	-2.37	-0.04	-0.04	-0.04	-1.10
Personal Computers	-2.35	-0.04	-0.04	-0.04	0.17
Concrete	-0.01	-0.04	-0.04	-0.04	N/A
Fly Ash	-0.87	-0.04	-0.04	-0.04	N/A
Tires	-0.39	-0.04	-0.04	-0.04	-0.51
Asphalt Concrete	-0.08	-0.04	-0.04	-0.04	N/A
Asphalt Shingles	-0.09	-0.04	-0.04	-0.04	0.34
Drywall	0.03	-0.22	-0.08	-0.07	N/A
Fiberglass Insulation	NA	-0.04	-0.04	-0.04	N/A
Vinyl Flooring	NA	-0.04	-0.04	-0.04	0.30
Wood Flooring	NA	-1.02	-0.29	-0.18	0.76

Note: The factors in Tables 3.2 and 3.3 are intended only for evaluating the benefits of recycling or composting and should not be used for comparing landfill and waste combustion options with each other.

Example 3.1 Emissions Reductions from Recycling

A community recycles 2,000 tons of plastics and 10,000 tons of paper (mixed paper, primarily residential). If not recycled, the waste would have been sent to a landfill with landfill gas collection and energy recovery.

Emissions (MTCO2e) = 2,000 tons *(-0.98 + (-0.04) MTCO2e/ton) + 10,000 tons * (-3.52 + (-0.33) MTCO2e/ton

=2,000 tons *(-1.02 MTCO2e/ton) + 10,000 tons * (-3.85 MTCO2e/ton)

=-2,004 MTCO2e + (-38,500 MTCO2e)

=-40,504 MTCO2e

3.3 Method for Composting

Step 1. Estimate the quantity (in short tons) of materials collected from the community for composting during the inventory year by material type. See Section 2 for a discussion of methods for estimating quantities of material composted, and Table 2 below for a list of material types.

Step 2. For each material composted, determine the type of facility (landfill with no gas collection, landfill with gas collection but no energy recovery, landfill with gas collection and energy recovery, or combustion facility) that the material would have gone to for disposal, had it not been composted. If your community sends it wastes to multiple facilities, then a breakdown of waste sent to each type of facility is needed (e.g., 20% to landfills without gas collection, 65% to landfills with gas collection, 15% to waste incinerators).

Step 3. For each material composted, multiply the tonnage composted during the inventory year by the emissions factor in the column titled "Fertilizer production displacement credit" from Table 3.3. Alternatively, communities in California may consider the Air Resources Board's published compost emissions reduction factors (less carbon storage), which include water and chemical emission reductions as well as reduced soil erosion[18].

Step 4. For each material composted, multiply the tonnage composted during the inventory year by the appropriate emissions factor for avoided disposal in Table 3.3, based on where the material would have been disposed of had it not been composted.

Step 5. Add the results together for all materials.

Note: the factors in Table 3.3 imply that there is a net emissions benefit for sending food and yard waste to a combustion facility rather than composting it. However, a recent meta-analysis of 82 studies[19] found that composting and anaerobic digestion of organics are preferable to disposal in either mass-burn waste-to-energy or landfill gas to energy, from a GHG emissions perspective. As noted previously there are several emissions benefits of composting that are not sufficiently well-quantified at this time for inclusion in this protocol. Thus, while the methods in this protocol are unable to show the emissions benefits of composting over combustion at this time, the best available science indicates that composting (or anaerobic digestion) is the preferable policy option for reducing GHG emissions.

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[18] http://www.arb.ca.gov/cc/protocols/localgov/pubs/compost_method.pdf. These emissions factors are specific to California and should not be used by communities in other states.

[19] Morris, Jeffrey, H. Scott Matthews, and Clarissa Morawski. “Review and meta-analysis of 82 studies on end-of-life management methods for source separated organics.” International Journal of Waste Management, Science and Technology. Volume 33, Issue 3, March 2013.

Table 3.3. Life-Cycle Composting Greenhouse Gas Emissions, by Emission Type (MTCO2e/short ton of material collected for composting)

Material	Emissions (+) or reductions (-)				
	Fertilizer production displacement credit	For Avoided Disposal, by Disposal Facility Type (Step 4)[20]			
		Landfill with no gas collection[21]	Landfill with gas collection but no energy recovery[22]	Landfill with gas collection and energy recovery[23]	Combustion facility[24]
Food Waste	-0.03	-1.47	-0.37	-0.21	0.13
Yard Trimmings	-0.03	-0.79	-0.20	-0.11	0.16
Grass	-0.03	-0.72	-0.18	-0.10	[A]
Leaves	-0.03	-0.56	-0.14	-0.08	[A]
Branches	-0.03	-1.17	-0.29	-0.17	[A]

[A] Emissions factors are not available for combustion of grass, leaves and branches as individual waste types. Use the value for yard trimmings for these materials.

Example 3.2 Emissions Reductions from Composting
A community composts 3,000 tons of food waste and 7,000 tons of yard trimmings. If not recycled, the waste would have been sent to a landfill with landfill gas collection and energy recovery.
Emissions (MTCO2e) = (3,000 tons + 7,000 tons)*(-0.03 MTCO2e/ton) + 3,000 tons *(-0.21 MTCO2e/ton) + 7,000 tons * (-0.11 MTCO2e/ton) =-300 MTCO2e + (-630 MTCO2e) + (-770 MTCO2e) =-1,700 MTCO2e

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[20] Please note that these emissions factors are not the emissions from disposal, but rather the reduction in emissions associated with avoided disposal.

[21] Source: http://www.epa.gov/climatechange/waste/downloads/Landfilling.pdf. Calculated as negatives of CH4 generation (from Exhibit 6) less 10% oxidation.

[22] Ibid. Calculated as negatives of CH4 generation (from Exhibit 6) less 75% collection and 10% oxidation.

[23] Calculated as emissions from previous column plus an energy recovery credit calculated as 13% (per EPA exhibit 13) of gas collection (calculated as 75% of CH4 generation).

[24] Source: http://www.epa.gov/climatechange/waste/downloads/Combustion.pdf Calculated as (negative of the values in Exhibit 7, column (f)) + 0.01. The 0.01 is added because EPA estimates collection-related emissions of 0.04 for composting, compared to 0.03 MTCO2e/ton for combustion.

4: Estimating Additional Emissions

4.1 Background

Some communities may want to estimate just those emissions and emissions reductions associated with community-scale recycling and composting that are not already included or reflected in the community's greenhouse gas inventory. This section provides guidance on how to do this.

This approach is inherently more involved than simply estimating the full, net emissions/reductions associated with community-scale recycling and composting. Section 3 of this Protocol describes the simpler method. The use of this more complex approach is optional, and not required.

To estimate just the emissions that are not already accounted for, the aggregated emissions factors in Section 3 (for example, in Table 3.2) need to be disaggregated into individual components. Then, each component must be evaluated based on whether it is already included, or not, in the community's inventory. To complicate matters further, the Community Protocol encourages communities to use multiple accounting frameworks that will each include (and exclude) emissions associated with different activities and sources. Therefore certain emissions associated with recycling and composting may be included in emissions under one reporting framework but not under another.

Additional background regarding the greenhouse gas impacts of recycling and composting generally is included in Section 3.1 of this Protocol and should be read before proceeding further.

Estimating the emissions/reductions associated with recycling and not accounted for elsewhere in the community inventory is best performed in a series of five parallel elements, each of which is described below. The five elements are:

- Emissions and emissions reductions of recycling collection, processing, transport, and displacement of virgin material. See Section 4.3
- Emissions and emissions reductions associated with composting. See Section 4.4
- Emissions reductions of avoided collection and transport of waste to landfill or combustion facility. See Section 4.5
- Emissions and emissions reductions of avoided landfilling. (This element is only relevant if the community's non-recycled and non-composted waste is landfilled.) See Section 4.6
- Emissions and emissions reductions of avoided combustion. (This element is only relevant if the community's non-recycled and non-composted waste is burned.) See Section 4.7

If the community's emissions inventory includes emissions associated with the community's use of materials and services (trans-boundary community-wide supply chains), as described in Appendix H of the Community Protocol, then this method becomes more complex. The same is true for communities that have included consumption-based emissions, as described in Appendix I of the Community Protocol. Some consumption-based methods include the emissions and emissions reductions of avoided disposal, while some do not. Further, communities using these advanced accounting methods may already be reporting more than one set of emissions as part of their community inventory report. It is important to understand what is being counted in trans-boundary community-wide supply chains and/or consumption-based emissions. This will determine which of the emissions factors and approaches in this section to use, whether and how to aggregate them, and how to report them in the context of community-wide emissions. Some additional guidance on this topic is provided below, but you will also need to apply some critical thinking to determine the best way to tell the story of the emissions impacts and benefits of recycling in the context of your community inventory frameworks.[25]

4.2 Overview of Recycling and Composting Method

Steps 1, 2, and 5 – 8 apply to both recycling and composting. Step 3 is specific to recycling and Step 4 is specific to composting.

1. Estimate the quantity (in short tons) of materials collected from the community for recycling and composting during the inventory year, by material type. (This is the same as Step 1 in Section 3.) See Section 2 for a discussion of methods for estimating quantities of material recycled, and Table 4.2 below for a list of material types.
2. For each material recycled and composted, determine the facility (either landfill or incinerator) that the material would have gone to for disposal, had it not been recycled. (This is the same as Step 2 in Section 3.) If your community sends it wastes to multiple facilities, then a breakdown of waste sent to each type of facility will be needed (e.g., 20% to landfills without gas collection, 65% to landfills with gas collection, 15% to waste incinerators).
3. Refer to Section 4.3 to determine the emissions and emissions reductions associated with recycling collection, processing, transport, and displacement of virgin materials that are not already included in your inventory.
4. Refer to Section 4.4 to determine the emissions and emissions reductions associated with composting.
5. Refer to Section 4.5 to determine the emissions reductions associated with reduced collection and transportation of waste (diverted from landfill or incinerator due to recycling and/or composting) that are not already accounted for in your inventory.
6. If waste from your community is landfilled, refer to Section 4.6 to determine the emissions and emissions reductions associated with avoided landfilling that are not already accounted for in your inventory.
7. If waste from your community is combusted, refer to Section 4.7 to determine which emissions associated with avoided combustion are not already accounted for in your inventory.
8. Add the results of Steps 3, 4, 5, 6 and 7 together.

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[25] For two examples, see emissions inventories from King County, Washington (Appendix C of http://www.kingcounty.gov/environment/climate/climate-change-resources/emissions-inventories/2008-report.aspx) and the State of Oregon (http://www.deq.state.or.us/lq/pubs/docs/SupplementalTechnicalReportTreatmentGHG.pdf).

Example 4.1 shows what Step 8 might look like for a hypothetical community, Sample City.

Example 4.1: Calculation of net emissions/reductions from recycling and composting for Sample City

Type of emissions or reduction	**Emissions (+) or emissions reduction (-) not already included in inventory (Metric tons CO2e)**
Recycling collection and transport and displacement of virgin materials	-37,260
Composting	0
Avoided waste collection and transport	0
Avoided landfilling-methane adjustment	1370
Avoided landfilling-energy recovery	659
Avoided combustion	N/A
Total	**-35,230**

4.3 Emissions and Emissions Reductions of Recycling Transport, and Displacement of Virgin Materials

The relevant emissions and emissions reductions in this element include:

- Emissions associated with collecting and processing recyclables
- Emissions associated with transporting recyclables to market*
- Avoided emissions due to reduced transportation of virgin materials (due to displacement)*
- Energy and process emissions associated with the use of recycled materials in manufacturing*
- Avoided energy and process emissions associated with the reduced use of virgin materials in manufacturing (due to displacement)*
- Increased forest carbon storage due to paper and wood recycling.

The treatment of emissions and reductions noted with an asterisk (*) above depends in part on whether or not each collected recyclable material is used by end-markets located inside the community's boundaries.

Emissions associated with collection of recyclables are almost always included in a community inventory, as part of emissions associated with on-road vehicles. Processing (e.g., sorting) emissions are associated with use of electricity and use of fuels in stationary combustion equipment. These emissions may already be included in your community's inventory, depending on the location of the processing facility. However, they are typically very small and as such are not discussed further here.

Box 4.1: End-market definition

In this context, “end-market” refers to manufacturers that use recycled feedstocks in lieu of virgin feedstocks in the manufacture of materials. Most of the reductions in energy and process emissions occur at this point. “End market” does not mean the customers of the products made by these manufacturers. For example, many communities collect old corrugated containers, which are pulped and made into new corrugated medium or linerboard at paper mills. The medium and linerboard may be shipped in rolls to a box plant that uses them to make boxes, and the boxes may be purchased by local manufacturers of other products. The end market in this example is the paper mill that uses the recycled waste to make new linerboard or medium, *not* the box plant or subsequent users of the boxes.

Steps to calculate emissions and reductions from recycling transport and substitution

Step 3a: For each material recycled, refer to Table 4.1 to determine which emissions and emissions reductions associated with recyclable transport and displacement of virgin materials should be counted in this method (that is, where the emissions or emissions reductions are not already accounted for in your community's inventory). Note that if your inventory looks at supply chain emissions (Community Protocol Appendix H), you should answer yes to Q1 in Table 4.1 for those materials for which supply chain emissions were estimated. You should answer no to Q1 for all other materials. Similarly, for Q2, some materials may have end markets in your community, while others will not.

Step 3b: For each material for which these emissions are to be counted (because they are not already accounted for in your community's inventory), multiply the tonnage recycled during the inventory year by the relevant emissions factor or factors from Tables 4.2 and 4.3. Table 4.1 will identify which emissions factor(s) in Tables 4.2 and 4.3 to use.

Step 3c: Sum across all materials the results from Step 3b.

Table 4.1: Determining Which Emissions and Emissions Reductions from Recycling Transport and Displacement of Virgin Materials are not Included in Inventory

Emissions/Reduction Type	**Q1: Does community inventory include trans-boundary community-wide supply chains for this material or consumption-based emissions:**		
	No		**Yes**
	Q2: Is recycled material end market located in your community or a different community?		
	In your community:	**In a different community:**	
Emissions associated with transporting recyclables to market (Table 4.2, column B)[i]	Do not count this.[ii]	Count this.	The average *use* of recycled materials in production (in lieu of virgin resources) is already reflected in emissions factors (see SC.3.2 and Appendix I). This means that the emissions and emissions reductions of “average” recycling are already reflected in trans-boundary community-wide supply chains and consumption-based emissions. A community could calculate the “additional” (above average) tons of materials recycled when the community’s recycling rate exceeds the national average. For this, they could use emissions factors in Tables 4.2 and 4.3 to estimate the emissions and reductions associated just for these “additional” tons.[iii]
Avoided emissions due to reduced transportation of virgin materials due to displacement (Table 4.3, column B)	Count this, unless already included using an inbound freight accounting method (such as SC.4).	Count this.	
Process energy and non-energy emissions associated with the use of recycled materials in manufacturing (Table 4.2, columns C and D)	Depends - see footnote.[26]	Count this.	
Avoided process energy and non-energy emissions associated with the reduced use of virgin materials in manufacturing[iv] **(Table 4.3, columns C and D)**	Depends - see footnote.[26]	Count this.	
Increased forest carbon storage due to paper and wood recycling (Table 4.3, column E)	Count this		

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[26] For community-generated recyclables that are used by an in-boundary manufacturer, some of the emissions and emissions reductions are already included in the community’s inventory under the basic emissions generating activities ‘use of electricity by the community’ and ‘use of fuel in commercial stationary combustion equipment.’ However, if industrial uses of fuel are excluded from the community’s inventory, then energy and avoided energy related emissions should be counted here. Further, if industrial process (not energy-related) emissions are not included in the community’s inventory (see Community Protocol, BE.8) then process non-energy emissions and emissions reductions also should be counted here.

Table 4.2: Emissions of Recycling Transport and Use of Recycled Materials in Manufacturing (MTCO2e/short ton of material collected for recycling)

A: Material	**Emissions (+) or reductions (-)[v] from:**		
	B: Transporting recyclables to market	**C: Use of recycled materials in manufacturing processes, energy**	**D: Use of recycled materials in manufacturing processes, non-energy**
Mixed Recyclables	0.02	0.23	0.08
Aluminum Cans	0.03	2.02	0
Aluminum Ingot	0.02	0.25	0
Steel Cans	0.29	0.65	0.85
Copper Wire	0.11	0.38	0
Glass	0.02	0.20	0
HDPE	0.16	0.32	0
PET	0.18	0.71	0
Corrugated Containers	0.02	0.38	0
Magazines/Third-Class Mail	0.01	0.81	0
Newspaper	0.02	1.09	0
Office Paper	0.01	0.81	0
Phone Books	0.03	0.99	0
Textbooks	0.03	1.27	0
Dimensional Lumber	0.06	0.15	0
Medium-Density Fiberboard	0.12	0.33	0
Mixed Paper (general)	0.02	0.63	0
Mixed Paper (primarily residential)	0.02	0.63	0
Mixed Paper (primarily from offices)	0.03	2.53	0.01
Mixed Metals	0.21	1.07	0.59
Mixed Plastics	0.17	0.53	0
Carpet	0.02	0.95	0
Personal Computers	0.07	0.63	0.01
Concrete	0.01	0	0
Tires	0.06	0.12	0.04
Asphalt Concrete	0	0.03	0
Asphalt Shingles	0.02	0	0

Table 4.3: Emissions Reductions from Displacement of Virgin Materials (MTCO2e/short ton of material collected for recycling)

A: Material	Emissions (+) or reductions (-)[vi] from:			
	B: Reduced transportation of virgin materials	C: Reduced use of virgin materials in manufacturing processes: energy	D: Reduced use of virgin materials in manufacturing processes: non-energy	E: Change in forest carbon flux due to paper and wood recycling[vii]
Mixed Recyclables	-0.05	-0.48	-0.15	-2.45
Aluminum Cans	-0.07	-7.37	-3.50	NA
Aluminum Ingot	-0.04	-4.24	-2.96	NA
Steel Cans	-0.33	-2.41	-0.85	NA
Copper Wire	-0.02	-5.35	0	NA
Glass	-0.04	-0.32	-0.14	NA
HDPE	-0.16	-1.02	-0.15	NA
PET	-0.10	-1.58	-0.33	NA
Corrugated Containers	-0.07	-0.38	-0.01	-3.06
Magazines/Third-Class Mail	-0.01	-0.82	0	-3.06
Newspaper	-0.05	-1.83	0	-2.02
Office Paper	-0.01	-0.59	-0.02	-3.06
Phone Books	-0.03	-1.62	0	-2.02
Textbooks	-0.03	-1.32	0	-3.06
Dimensional Lumber	-0.06	-0.08	0	-2.53
Medium-Density Fiberboard	-0.11	-0.27	0	-2.53
Mixed Paper (general)	-0.12	-0.99	-0.01	-3.06
Mixed Paper (primarily residential)	-0.12	-0.99	-0.01	-3.06
Mixed Paper (primarily from offices)	-0.14	-2.96	-0.01	-3.06
Mixed Metals	-0.25	-3.93	-1.66	NA
Mixed Plastics	-0.12	-1.31	-0.25	NA
Carpet	-0.03	-2.41	-0.91	NA
Personal Computers	-0.10	-2.18	-0.78	NA
Concrete	-0.02	0	0	NA
Tires	-0.07	-0.51	-0.04	NA
Asphalt Concrete	-0.05	-0.06	0	NA
Asphalt Shingles	-0.04	-0.07	0	NA

Example 4.1 Emissions/Reductions from Recycling Transport and Displacement of Virgin Materials

A community recycles 2,000 tons of plastic and 10,000 tons of paper. The end markets (as defined in Box 4.1) for both materials are outside the community, and the community inventory does not include supply chain or consumption-based emissions.

Plastic

Emissions (metric tons CO2e)= 2,000 tons * (0.17 + 0.53 + 0 + (-0.12) + (-1.31) + (-0.25))MT CO2e/ton
=2,000 tons *(-0.98 MTCO2e/ton)
=-1,960 MTCO2e

Paper

Emissions (metric tons CO2e)= 10,000 tons* (0.02 + 0.63 + 0 + (-0.12) + (-0.99) + (-0.01) + (-3.06) MT CO2e/ton
=10,000 tons * (-3.53 MTCO2e/ton)
=-35,300 MTCO2e

Total = -1,960 MTCO2e + (-35,300 MTCO2e) = -37,260 MTCO2e

4.4 Emissions and Reductions from Composting

There are several different pathways for emissions and emissions reductions associated with composting, but most of these are accounted for elsewhere or excluded from the current version of this RC Protocol, as summarized below:

- Emissions associated with collecting and transporting feedstocks. In-boundary emissions are typically already included in the community's GHG inventory. However, if the compost facility is located outside of the community's boundaries, you need to add emissions associated with transportation. See Section 4.4.1, below.
- Emissions associated with compost facility operations. These emissions include emissions from fuels used by equipment at the compost facility, as well as fugitive emissions of methane and nitrous oxide from the compost pile itself. See Section 4.4.2 below.
- Avoided emissions (and emissions increases) when putrescible materials are diverted away from landfills and/or combustion units. These impacts are addressed in Sections 4.5, 4.6, and 4.7 below.
- Emissions reductions when finished compost is applied to agricultural soils. Potential emissions reductions include soil carbon storage as well as displacement of emissions-intensive fertilizer and/or water use. This version of the RC Protocol only includes an emissions factor for displacement of fertilizer production; see Section 4.4.3 below and Section 1 for additional details.

4.4.1 Transporting Feedstocks to Compost Facility

If composting feedstocks are transported to a compost facility located outside of the community's boundaries, then some of the associated transportation emissions may be excluded; refer to the transportation section of the community's inventory. These excluded emissions can be estimated by using the distance from the community to the compost facility, estimating the tons of feedstock transported in an average vehicle trip and the fuel economy for the relevant travel mode (single-unit truck, tractor/trailer, rail, etc.), and then estimating total fuel use and associated emissions. Fuel use per ton of feedstock transported can be estimated as ((miles round trip)/(miles per gallon))/(tonnage of feedstock delivered).[27] Once the quantity of fuels used is estimated, refer to Community Protocol Appendix D for emissions factors for various transportation fuels.

4.4.2 Emissions from Compost Facility Operations

Emissions associated with compost facility operations include emissions from fuels used by equipment at the compost facility, as well as fugitive emissions of methane and nitrous oxide from the compost pile itself. At this time, EPA's WARM tool does not provide an emissions factor for methane and nitrous oxide emissions from composting operations. Research into these emissions is ongoing, and these emissions may be included in future version of WARM.

Emissions associated with compost facility equipment can be estimated using equation 4.1.

Equation 4.1. Emissions Associated with Turning Compost[28]
Emissions = 0.015 MTCO2E/ton * M_{total}
Where: M_{total} = Total mass of waste composted (wet short tons)

4.4.3 Emissions Reductions associated with Displacement of Chemical Fertilizer Production

One benefit of compost is that it can displace the production of chemical fertilizer production, and associated greenhouse gas emissions. These benefits are estimated in Table 3.3 as approximately 0.03 MTCO2e per ton of feedstock. (This factor accounts for loss of mass as feedstocks are converted to compost, and that the application of finished compost, while providing valuable nutrients such as nitrogen and phosphorous, will not displace the production of chemical fertilizers on a 1-for-1 basis.) These emissions are emissions associated with the *production* of chemical fertilizers. Changes in on-field nitrous oxide emissions as fertilizers and/or compost degrade on site are not included in this emissions factor.

There is one circumstance in which these emissions reductions may already be accounted for in your community's inventory. If this circumstance does not apply, then the full emissions reduction benefit of 0.03 MTCO2e per ton of feedstock should be included in your calculation of "additional emissions".

However, if your community wide inventory already includes the emissions associated with producing fertilizer that is used (Appendix H) and/or consumed (Appendix I) by members of your community, then changes in fertilizer purchase (and production) should (in theory) already be reflected in changes in your

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[27] For example, ((60 miles round trip)/(6 miles per gallon))/5 tons = (10 gallons)/(5 tons) = 2 gallons per ton.

[28] Derived from Exhibit 2 of http://www.epa.gov/climatechange/waste/downloads/Composting.pdf. Calculated as overall emissions factor for transportation and turning compost, multiplied by the percentage of total energy associated just with turning compost piles (0.22 million BTU/0.58 million BTU).

inventory over time. Depending on whether the use/consumption data used is based on actual local data or national extrapolation, this may or may not be the case. If the changes are in fact already being reflected in your inventory over time, then the emissions reductions benefit of using compost should be discounted by a percentage D, where D is the percentage of compost produced that is used (or consumed) by in-boundary community members. Note in this case that the locations of compost and fertilizer production are not relevant, but that the location of the users of compost is. For example, if all of your yard and food waste is sent to a distant compost facility and made into compost that is exclusively used in other communities, then the benefits of using compost (from the perspective of your community) should be included as both overall and additional reductions, even if your community is also accounting for supply chain and/or consumption-based emissions.

4.5 Avoided Emissions (Reductions) Associated with Reduced Collection and Transport of Mixed Waste to Landfills and/or Combustion Facilities

When materials are recycled, rather than landfilled or sent to a combustion facility, there are a resulting reduction in emissions associated with both collecting the wastes, and transporting them to a disposal site. Collection emissions are typically already included in the community's inventory (as part of the required basic emissions generation activity of on-road freight motor vehicle travel), and do not need to be counted again. Further, since the emissions associated with collecting the recyclables or compostables are also not accounted for in this method, it makes sense to not count avoided emissions associated with reduced collection of any discarded material, regardless of disposition.

Transport emissions and reductions in disposal-related transportation are also commonly included in the community's inventory as part of in-boundary movement of freight, and so reductions in transportation-related emissions do not need to be accounted for here, at least to the extent that the disposal facility is located in the community. Similarly, transportation emissions may have been already accounted for using Method SW.6 from Appendix E of the Community Protocol. However, if a community sends its disposed waste to a disposal facility in a different community, and these emissions are not already accounted for using Method SW.6, then the reduction in waste transportation-related emissions has not been accounted for elsewhere and should be estimated here. To estimate these reduced emissions, use the formula for transportation emissions ($TE = M*MT*EFT$) contained in Equation SW.6. For the variable M, use the quantity of materials recycled and composted, not the materials disposed of. Be sure to put a negative sign in front of the results to indicate that the value represents a reduction in emissions (emissions transporting wastes to disposal facilities are reduced due to diversion of wastes to recycling or composting). Note that emissions for transporting recycled materials to a processing facility outside the community were accounted for in Section 4.3.

4.6 Avoided Emissions (Reductions) and Increased Emissions (Avoided Reductions) Associated with Diversion of Recycled and Composted Materials from Landfill

Community-generated waste sent to landfills may have several different types of emissions or emissions reductions associated with it that are already reflected in the community's inventory. When a community recycles or composts wastes that would otherwise be landfilled, the landfill-related emissions are reduced. Any landfill-related emissions reductions (associated with energy recovery) are also reduced, which leads to an increase in emissions (a reduction in emissions reductions is the same as an increase in emissions).

The landfill-related emissions and reductions that may be changed by recycling and composting include:

- Methane emissions from landfills located in the community, if community-generated waste is disposed of in such landfills. These emissions are estimated using method SW.1 in the Community Protocol. Method SW.1 estimates inventory-year emissions from waste that was disposed of historically. Most methane emissions from landfilling do not occur in the same year that the waste is placed in landfill. For these reasons, method SW.1 is not particularly relevant for a community estimating the emissions impacts of recycling and composting occurring during the inventory year.
- Methane emissions from community-generated waste sent to landfills, regardless of landfill location. These emissions are estimated using method SW.4 of the Community Protocol. This method estimates future "lifetime" emissions resulting from waste disposed of during the inventory year. Estimation of these emissions is required as one of the Community Protocol's basic emissions generating activities.
- Landfills that capture methane and use it to produce energy may result in a reduction in fossil fuel combustion elsewhere (and associated emissions). These emissions reductions may or may not already be reflected in the community's inventory.
- Emissions resulting from the use of fossil fuels by landfill equipment. These emissions are estimated using optional method SW.5.
- Collection and transportation emissions are associated with collecting and transporting landfill-bound waste from the community. These emissions are estimated using method SW.6. If the community uses this optional method in their inventory, then reductions in emissions associated with garbage collection and transport are already reflected in the community's inventory.[29] Emissions associated with collection are typically already accounted for as part of on-road freight motor vehicle travel. Potential reductions in these emissions are addressed separately, in Section 4.5, above.

To determine which emissions and emissions reductions associated with avoided landfilling (due to recycling) are to be estimated, and methods for estimating them, use the following steps:

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[29] Emissions associated with transporting recyclables and compostables are accounted for elsewhere. Emissions associated specifically with collecting recyclables and compostables are not included in this protocol, in part because they are presumed to already be included in the community's estimate of all on-road freight motor vehicle travel. Emissions associated with long-haul transport to end-markets located outside of the community are included (see Tables 4.1 and 4.2).

- Step 6a: Use Section 4.6.1 to determine whether avoided landfill methane emissions are accurately reflected in your community's inventory, and if not, to estimate the emissions reductions or increases not reflected in your community's inventory.
- Step 6b: If the landfill accepting waste from your community is recovering energy from methane, use Section 4.6.2 and Figure 4.1 to determine whether the associated reductions in fossil fuels due to energy recovery are already reflected in your community's inventory. If not, use the method indicated by Figure 4.1 to estimate the increase in emissions as recycling and composting diverts material from the landfill.
- Step 6c: Use Section 4.6.3 to determine whether or not to include reductions in emissions associated with landfill equipment.
- Step 6d: Add results from steps 6a, 6b, and 6c together. These are the net emissions reductions and/or increases associated with the reduction in landfilling of waste resulting from your community's recycling and composting that are not already included in your community's inventory. The value from Step C must be negative (a reduction in equipment emissions due to recycling/composting) while the value from Step B will either be zero or positive which represents an increase in net emissions due to reduced displacement of fossil fuels as gas production decreases. The value from Step A may be positive or negative, depending on local circumstances and inventory methods.

4.6.1 Landfill Methane Emissions Adjustment

If the calculation of emissions from generated waste in your community inventory (using Method SW.4) was not based on waste characterization data from your community, then the change in landfill methane emissions over time (calculated using Method SW.4) may be over- or under-estimating the emissions reductions benefits of recycling or composting. This is because the composition of waste collected for recycling and/or composting may be different from the composition of waste used to calculate emissions from community waste disposal.

If the calculation of emissions from generated waste in your community inventory *is* based on waste characterization data from your community, you can skip this section and proceed to 4.6.2. Otherwise, use equation 4.2 to calculate the adjustment.

Equation 4.2: Adjustment to Methane Emissions (+) or Emission Reductions (-) Associated with Avoided Landfilling (No Waste Characterization for Landfilled Waste)

$$\text{Emissions} = GWP * ((1 - CE) * (1 - OX)) * ((M_{total} * EF_{mixed\ waste}) - (\sum_i M_i * EF_i))$$

Where:

GWP = global warming potential of methane

CE = Default LFG Collection Efficiency (see Equation SW.4.1)

OX = Oxidation Rate (0.10)

M_{total} = Total mass of waste recycled (wet short tons)

M_i = Mass of material component i recycled (wet short tons)

$EF_{mixed\ waste}$ = Emissions factor for mixed waste (mtCO2e/wet short ton; from Table 4.4) if this factor was used to calculate emissions from generated waste in your community inventory;

OR, if your community inventory uses a non-local waste characterization

$EF_{mixed\ waste}$=Emissions factor calculated using the waste characterization data used in Method SW.4.1 with waste component-specific emissions factors drawn from Table 4.4, so as to calculate an emissions factor for mixed waste that is specific to the waste composition data used by the community in its inventory

EF_i = Emissions factor for material component i (mtCO2e/wet short ton; from Table 4.4; note that non-putrescible wastes, such as plastic, metal, and glass are not listed in Table 4.4 because they have methane yield of zero)

Table 4.4 CH_4 Yield for Solid Waste Components[30]

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.

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[30] 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.

Example (Equation 4.2)

A community recycles 2,000 tons of plastic and 10,000 tons of newspaper in the inventory year. Had this material not been recycled, it would have gone to a landfill that operates gas collection and control equipment. Emissions from community-generated waste sent to this landfill were estimated using Equation SW.4.1 and no waste characterization data. An emissions factor for mixed waste of 0.060 mtCH4/wet short ton was used.

$$\text{Emissions} = GWP * (1 - CE) * (1 - OX) * ((M_{total} * EF_{mixed\ waste}) - (\sum_i M_i * EF_i))$$

$$= 21 * (1 - 0.75) * (1 - 0.10) * ((12{,}000 \text{ tons} * 0.060 \text{ mtCH4/ton}) - (2{,}000 \text{ tons} * 0 + 10{,}000 \text{ tons} * 0.043 \text{ mtCH4/ton}))$$

$$= 21 * (0.25) * (0.90) * ((720 \text{ mtCH4}) - (0 + 430 \text{ mtCH4}))$$

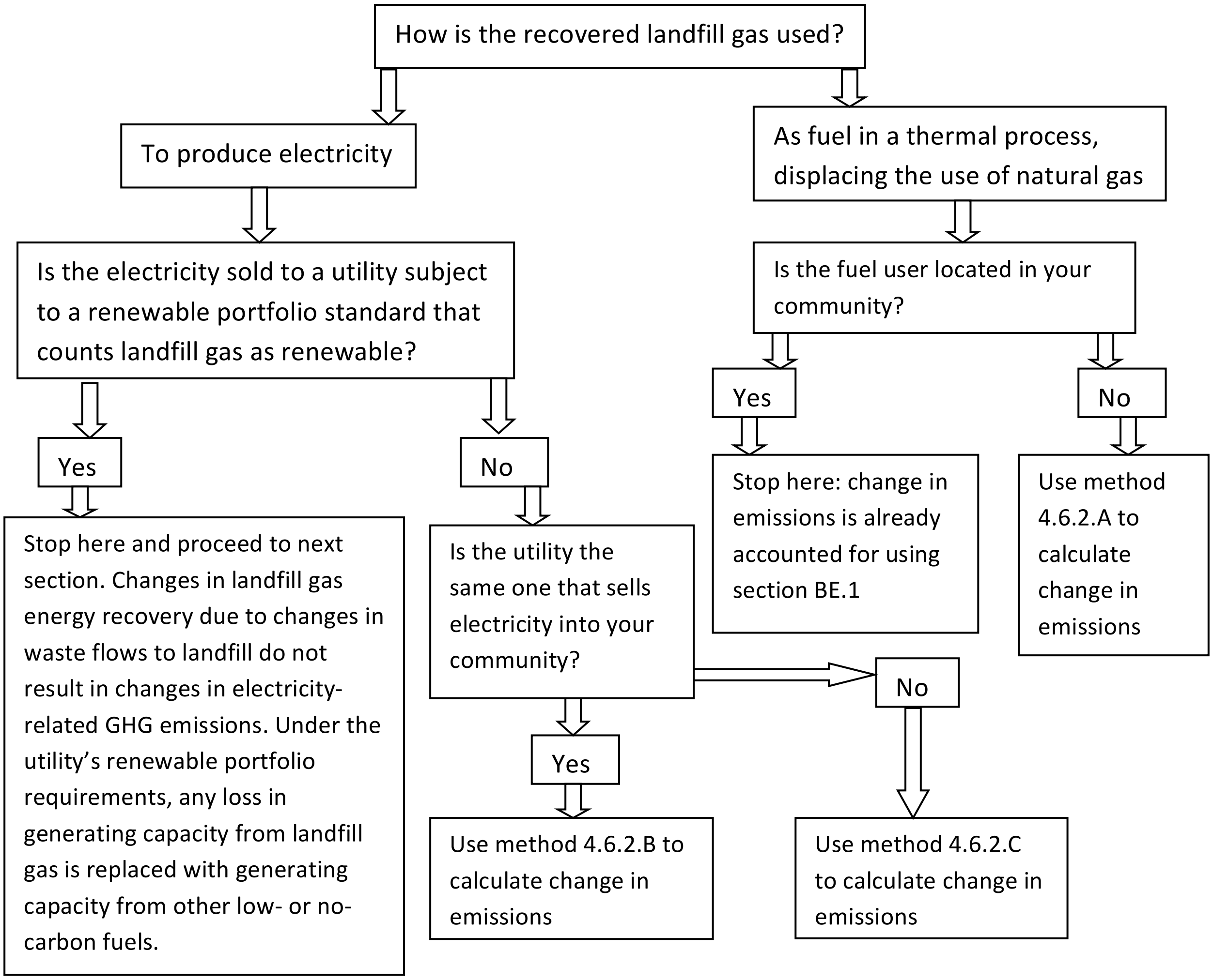
$$= (4.725) * (720 \text{ mtCH4} - 430 \text{ mtCH4}) = 1{,}370 \text{ mtCO2e}$$

Note in this example that the value is positive, so this represents emissions (not emissions reductions) that are not currently reflected in the community's inventory. In this example, 12,000 tons of recycled waste was diverted from landfill, and using an emissions factor for mixed MSW when estimating landfill-related disposal emissions resulted in an overly-large assumed reduction of emissions in the community inventory (12,000 tons of MSW with an "average" methane yield of 0.06 mtCH4/ton). 2,000 of these 12,000 tons produce no methane and the other 10,000 tons produce methane at rate lower than the average for mixed MSW (0.043 mtCH4/ton for newsprint vs. 0.060 mtCH4/ton for mixed MSW). So the reduction in methane generation - and by extension - emissions, is *less than* the community's inventory using method SW.4 (with no waste characterization data) would have predicted. In this case, Method SW.4 is overestimating reductions in GHG emissions due to the diversion of these 12,000 tons from landfill, and the estimated value of +1,370 MT CO2e corrects for this overestimation. Had the material diverted from landfill been *more* putrescible than average waste disposal (that is, had an average methane yield *higher* than 0.06 mtCH4/ton), then changes in emissions estimated using Method SW.4 would be underestimating reductions in GHG emissions, and this method (4.6.1) would generate a negative value, that is, an additional emissions reduction to correct for this underestimation.

4.6.2 Landfill Methane Energy Recovery

When landfills recover energy from gas, this gas displaces - or offsets - the use of some other source of energy, with a potential reduction in greenhouse gas emissions. The extent to which emissions are actually reduced depends on what energy source would be used in the absence of landfill gas. When recycling and composting programs divert waste from landfill and reduce gas generation, less gas is available to recover for energy. This Protocol uses an organizing principle that changes in energy-related emissions associated with changes in landfill gas generation because of recycling and composting are to be fully accounted for. Some of the shift in these emissions may already be reflected in the community's inventory, and some may not. Figure 4.1 provides guidance for determining what to include and how to estimate it.

Figure 4.1: Decision Tree for Changes in Emissions Related to Energy Recovery from Landfill Gas



Method 4.6.2.A

For changes in emissions where landfill gas is used as fuel displacing the use of natural gas:

- Use Equation 4.3 to estimate the energy content of landfill gas *not collected* as a consequence of diversion of recyclables and/or compostables from landfill.
- Use Method B.1 (in the Community Protocol) to estimate the greenhouse gas emissions (in MTCO2e) associated with combustion of natural gas with the same energy content.
- Count the results of these two steps as an increase in emissions associated with community-scale recycling and/or composting.

Method 4.6.2.B

For changes in emissions where landfill gas is used to generate electricity that is sold to a utility that sells electricity to your community.

- Use Equation 4.3 to estimate the energy content (in MMBTU) of landfill gas *not collected* as a consequence of diversion of recyclables and compostables from landfill.

- Use Equation 4.4 to estimate the energy content (in MWh) of electricity *not generated* as a consequence of this reduction in landfill gas collection.
- Determine or estimate the percentage of the utility's overall delivery of electricity (to all communities) that is sold into your community. Call this "S". Multiply (1 – S) by the results from Equation 4.4. This is the energy content (in MWh) of electricity *not generated* as a consequence of reduced landfill gas collection that is not already accounted for in your community's emissions from electricity use.
- Refer to the calculations in Method BE.2 from the Community Protocol. Use the same emissions factors used in your community inventory (for your community's use of electricity) to estimate the GHG emissions associated with this electricity.
- Count the results of these steps as an increase in emissions (not counted elsewhere in your inventory) associated with community scale recycling and composting.

Method 4.6.2.C

For changes in emissions where landfill gas is used to generate electricity that is sold to a utility that does not sell electricity to your community:

- Use Equation 4.3 to estimate the energy content (in MMBTU) of landfill gas *not collected* as a consequence of diversion of recyclables and compostables from landfill.
- Use Equation 4.4 to estimate the energy content (in MWh) of electricity *not generated* as a consequence of this reduction in landfill gas collection.
- Refer to the hierarchy of preferred sources for utility electricity emissions factors contained in Section BE.2 of the Community Protocol. Use the best available emissions factor for this utility.
- Count the results of these steps as an increase in emissions (not counted elsewhere in your inventory) associated with community scale recycling and composting.

Equation 4.3: Energy Content (in MMBTU) of Landfill Gas Not Collected as a Consequence of Diversion of Putrescible Wastes from Landfill to Recycling or Composting

$$\text{Energy Content (in Million BTUs)} = ((50.6\ \text{MMBTU/MT of CH4 collected}) * (CE) * (\textstyle\sum_i M_i * EF_i))$$

Where:

CE = Default LFG Collection Efficiency (see Equation SW.4.1)

M_i = Mass of material component i recycled (wet short tons)

EF_i = Emissions factor for material component i (mtCH4/wet short ton; from Table 4.4; note that non-putrescible wastes, such as plastic, metal, and glass are not listed in Table 4.4 and have methane yield of zero)

Equation 4.4: Electricity (in MWh) not Generated from Landfill Gas not Collected as a Consequence of Diversion of Putrescible Wastes from Landfill to Recycling or Composting

Electricity not generated (in MWh) = E_{E3} * a * GF

Where:
GF = Generation factor of 0.0855 MWh generated/MMBtu gas[31]
E_{E3} = Energy content of gas not collected (MMBTU), taken as result from Equation 4.3
a = Net capacity factor of electricity generation; assumed to be 85 percent

Example, Equations 4.3 and 4.4

A community recycles 2,000 tons of plastic and 10,000 tons of newspaper in the inventory year. Had this material not been recycled, it would have gone to a landfill where landfill gas is used to generate electricity. The electricity is sold to a utility that is not subject to a renewable portfolio standard, and does not sell electricity into the community. The landfill is located in eGrid region FRCC with a 2007 emissions factor of 1225.7 lbs CO2e/MWh.

Step 1: Energy content of landfill gas *not* collected (Equation 4.3)

Energy Content (million BTUs) = (50.6 MMBTU/MT of CH4 collected) * (0.75) *(2,000 tons*0 + 10,000 tons*0.043 mtCH4/ton)
=(50.6 MMBTU/MT of CH4 collected) * (0.75)*(430 MT CH4)
=(16,318 million BTUs)

Step 2: Electricity *not* generated (Equation 4.4)

Electricity not generated (in MWh) = (16,318 MMBTU) *(0.85) * (0.0855 MWh generated/MMBTU)
=1,186 MWh

Step 3: Emissions as a result of recycling, not already included in community inventory

Emissions (metric tons CO2e) = 1,186 MWh *(1225.7 lbs CO2e/MWh) *(1 metric ton/2204.62 lbs)
=659 metric tons CO2e

This represents an increase in emissions because of the recycling and is not already included in the community inventory.

4.6.2.3 Process Emissions from Landfilling

Process emissions are the CO2 emissions associated with powering the equipment necessary to manage the landfill. If process emissions (Community Protocol method SW.5) for community-generated wastes sent to landfill were already included in your community's inventory, then changes in those emissions over time already reflect the reduced landfill tonnage due to recycling and composting. No further

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[31] This factor is a combination of a unit conversion of 0.293 MWh/MMBtu, multiplied by average generation efficiency. The factor of 0.0855 is derived from WARM. If desired, you may use technology-specific generation efficiency as follows: Microturbine: 25%, Combustion Turbine: 32%, Reciprocating Engine: 35%.

calculations are required. However, if your community's inventory did not include process emissions (method SW.5) you may want to include in the benefits of recycling and composting the reduction in process emissions resulting from recycling and composting. To do so, refer to method SW.5 of the Community Protocol. For M (mass of solid waste), use the mass of materials recycled and composted. Put a negative sign in front of the results of Equation SW.5, to indicate that recycling and composting result in a reduction in landfill process emissions.

4.7 Avoided Emissions (Reductions) and Increased Emissions (Avoided Reductions) Associated with Diversion of Recycled and Composted Materials from Combustion

When a community's recycled and composted wastes are diverted from a combustion facility, there are changes in emissions associated with the combustion facility. By way of introduction, combustion-related emissions and reductions that may be changed by recycling and composting include:

- Stack emissions from the combustion unit. These are typically accounted for using Community Protocol Methods SW.2 (for combustion units located in the community) and SW.7 (for the combustion only of community-generated waste, regardless of the location of the combustion unit). For communities using Method SW.7, reductions in emissions associated with reduced combustion of wastes (due to increased recycling and composting) are already (largely) reflected in the community's inventory as combustion of community-generated waste is a basic emission generating activity.[32]
- Most waste combustion units recover energy and use it to generate electricity, which is commonly sold into the grid and displaces the production of electricity using other energy sources.
- Reduced emissions associated with recycling of ferrous metals (most combustion units recover ferrous metals for recycling). As a community recycles more ferrous metals via source separated recycling, less ferrous metal is available for recycling by the combustion unit.[33]

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[32] Technically, users of Method SW.7 are taking total emissions from the combustion facility and pro-rating a fraction of these emissions to the community based on the community's contribution of mixed waste (in tons) relative to the overall throughput of waste from all communities. In reality, emissions change both as overall tonnage changes, as well as the composition of that tonnage changes. Method SW.7 is sensitive to changes in tonnage from the community and overall composition of waste from all sources, but not changes in the composition of waste specific to the community. If the community's waste composition differs from the composition of all wastes being disposed of, and if changes in the community's waste composition due to recycling and/or composting deviate from changes in the waste composition of waste from other communities using the same incinerator, then Method SW.7 may be under- or over-estimating recycling benefits (analogous to Section 4.6.1 for landfills). However, since few communities will know the composition of wastes specific to both their community and the full and unique mix of waste going to the combustion unit, adjustments to the emissions estimated using Method SW.7 are probably not feasible, and so methods for adjusting these emissions are not provided here.

[33] Waste combustion facilities are increasingly installing additional technology to recover non-ferrous metals. As the capture efficiency of these systems is not currently included in the WARM documentation, separate calculations are not provided in this version of the RC Protocol. Communities sending waste to combustion facilities with nonferrous metal recovery may want to replicate the calculations as for ferrous metal, but with capture rates (at the combustion unit) and source-separated recovery tonnages specific to nonferrous metals.

- Emissions associated with collecting mixed waste and transporting it to the combustion facility. Potential reductions in these emissions are addressed separately, in Section 4.5, above.

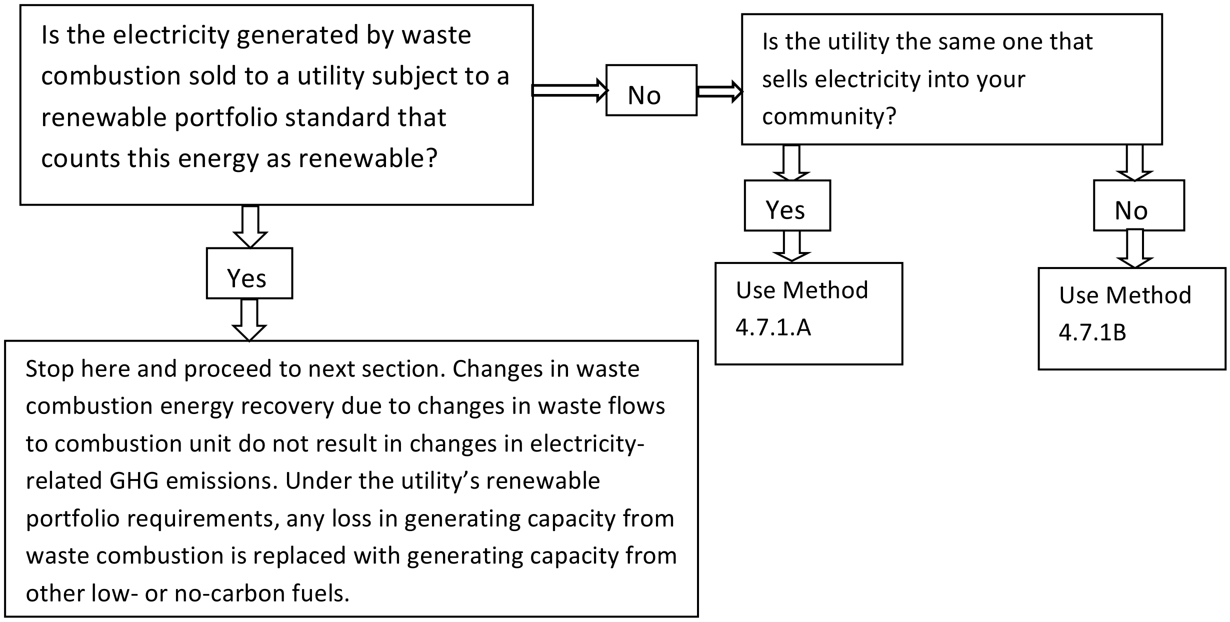
To determine which emissions and emissions reductions associated with avoided combustion (due to recycling and composting) are to be estimated, and methods for estimating them, use the following steps:

- Step 7a: If the combustion unit accepting waste from your community is generating electricity from the energy released during combustion of waste, use Section 4.7.1 and Figure 2 to determine whether the associated reductions in fossil fuels due to energy recovery are already reflected in your community's inventory, and if not, a method for estimating the increase in emissions as recycling and composting diverts material from the combustion unit, reducing energy production and potential fossil fuel displacement.
- Step 7b: Use Section 4.7.2 to determine whether or not to include the effects of reduced recycling of ferrous metal recovered by the combustion unit.
- Step 7c: Add results from steps 7a and 7b together. These are the net increases in emissions associated with the reduction of combustion of community-generated waste resulting from your community's recycling and composting that are not already included in your community's inventory.

4.7.1 Combustion Energy Recovery

When wastes are combusted and heat energy is captured and used to generated electricity, this displaces - or offsets - the use of some other source of energy, with a potential reduction in greenhouse gas emissions. The extent to which emissions are actually reduced depends on what energy source would be used in the absence of waste combustion energy recovery. By extension, when recycling and composting programs divert waste from combustion unit and reduce energy recovery, these emissions reductions may be reduced, and thus count as an increase in emissions (a reduction in reductions is an increase). This Protocol uses an organizing principle that changes in energy-related emissions associated with changes in combustion of community-generated waste are to be fully accounted as a consequence of recycling and composting. Yet some of the shift in these emissions may already be reflected in the community's inventory. Figure 4.2 provides guidance for determining what to include and how to estimate it.

Figure 4.2: Decision for changes in emissions related to energy recovery from combusted wastes



Is the electricity generated by waste combustion sold to a utility subject to a renewable portfolio standard that counts this energy as renewable?

Is the utility the same one that sells electricity into your community?

Stop here and proceed to next section. Changes in waste combustion energy recovery due to changes in waste flows to combustion unit do not result in changes in electricity-related GHG emissions. Under the utility's renewable portfolio requirements, any loss in generating capacity from waste combustion is replaced with generating capacity from other low- or no-carbon fuels.

Method 4.7.1.A

For changes in emissions where waste combustion generates electricity that is sold to a utility that sells electricity into your community.

- Use Equation 4.5 to determine the lost energy value (in MWh) of recyclables and compostables diverted from combustion.
- Determine or estimate the percentage of the utility's overall delivery of electricity (to all communities) that is sold into your community. Call this "S". Multiply (1 – S) by the results from Equation 4.5. This is the energy content (in MWh) of electricity *not generated* as a consequence of reduced waste combustion that is not already accounted for in your community's emissions from electricity use.
- Multiply the results of the preceding step by an appropriate emissions factor for electricity generation by your utility. Refer to the hierarchy of preferred sources for utility electricity emissions factors contained in Section BE.2 of the Community Protocol. Use the best available emissions factor for this utility.

Method 4.7.1.B

For changes in emissions where waste combustion generates electricity that is sold to a utility that does not sell electricity into your community.

- Use Equation 4.5 to determine the lost energy value (in MWh) of recyclables and compostables diverted from combustion.
- Multiply the results of the preceding step by an appropriate emissions factor for electricity generation by the utility. Refer to the hierarchy of preferred sources for utility electricity

emissions factors contained in Section BE.2 of the Community Protocol. Use the best available emissions factor for this utility.

Table 4.5 Energy content (million BTU per ton) of wastes combusted[34]

Material combusted	Energy content (MMBTU/ton)[35]
Aluminum cans	-0.67
Aluminum ingot	-0.70
Steel cans	-0.42
Copper wire	-0.55
Glass	-0.47
HDPE	40.0
LDPE	39.8
PET	21.2
LLDPE	39.9
PP	39.9
PS	36.0
PVC	15.8
PLA	16.7
Corrugated containers	14.1
Magazines/third class mail	10.5
Newspaper	15.9
Office paper	13.6
Phone books	15.9
Textbooks	13.6
Dimensional lumber	16.6
Medium-density fiberboard	16.6
Food scraps	4.7
Yard trimmings	5.6
Carpet	15.2
Personal computers	3.1
Tires	27.8
Asphalt shingles	8.8
Vinyl flooring	15.8
Wood flooring	18.0

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[34] Source: Exhibit 2 of http://www.epa.gov/climatechange/waste/downloads/Combustion.pdf.

[35] Negative values are associated with wastes that give up no energy when combusted but rather consume energy during the combustion of mixed wastes.

Equation 4.5. Lost Energy Content (in MWh) from Avoided Combustion of Waste Due to Diversion via Recycling and Composting

Energy Content (in delivered MWh) = 0.293 MWh/MMBTU * (CSE) * ($\sum_i$ M_i*EC_i))

Where:

CSE = Average mass burn combustion system efficiency (converting energy content in BTUs to electricity as delivered in kWh) = 17.8% per EPA[36]

M_i = Mass of material component i recycled or composted (wet short tons)

EC_i = Energy content (million Btu per ton) of wastes combusted for material component i, from Table 4.5

4.7.2 Ferrous Metal Recovery from Combustion Facilities

Many combustion facilities recover ferrous metal (steel, iron) and send it to recycling. This recycling activity reduces greenhouse gas emissions when the recovered steel displaces virgin steel in manufacturing. These emissions reductions are typically not already accounted for in community greenhouse gas inventories conducted using the Community Protocol.

However, under this supplemental Recycling and Composting Protocol, we are interested in estimating the emissions impacts of community-scale recycling programs, including recycling by waste combustion facilities that serve the community.

When steel is diverted from the waste combustion facility (via traditional source separation collection programs), slightly more steel is actually recycled, as the EPA estimates that combustion facilities recover on average 90 percent of steel sent to them as mixed waste.

If the combustion unit's recycling of steel (generated by your community) is already included in your community's steel recycling total (estimated under Step 3a of Section 4.3), then the impacts of shifting steel recycling away from the combustion facility is already reflected in your recycling totals, and does not require further assessment.

However, if the combustion facility accepting waste from your community is located in some other community, or for some other reason the amount of ferrous metal disposed with mixed waste by your community and subsequently recycled by the combustion facility is not included as part of your community's recycling totals (Step 3a of Section 4.3) then an adjustment is needed to the benefits of community-generated steel recycling. Go back to step 3b in Section 4.3 and identify the non-disposal emissions and emissions reductions associated with ferrous metal recycling by your community. Discount these all of these emissions and emissions reductions by 90% (assuming that 100% of mixed waste from your community is disposed of at a combustion facility; if only Z% is, then discount by (Z% x 90%), to account for the consideration that 90% of the ferrous metal recycled through source separation programs is not actually "new" recycling; the emissions and emissions reductions would have occurred

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[36] This accounts for total system efficiency, translating the energy content of the fuel into the energy content of delivered electricity, after accounting for losses in converting energy in the fuel into steam, converting energy in steam into electricity, and delivering the electricity.

even in the absence of other community recycling programs, had the ferrous metal been sent to the combustion facility instead.

4.8 Endnotes

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[i] Table 4.2 provides estimates of transportation-related emissions for transporting recyclables to market using average U.S. conditions. Communities may also estimate these emissions using a different method, such as estimating the distance from the community to end-markets (where known), estimating fuel economy for the relevant travel mode (single-unit truck, tractor/trailer, rail, etc.), and then estimating total fuel use and associated emissions. See Community Protocol Appendix D for emissions factors for various transportation fuels.

[ii] Since end-market is in-boundary, these transportation emissions are typically already included in the community's inventory (as part of the required basic emissions generation activity of on-road freight motor vehicle travel).

[iii] For consumption-based emissions, the calculation of "additional" recycling is made even more complex since consumption-based emissions methods tend to focus on emissions associated only with household and government consumption (and sometimes business capital/inventory formation). In theory this would require comparing recycling rates not for the whole community but just for the household and government sectors. Given the difficulty most communities would have obtaining the data required to perform this analysis, no further description of it is provided here.

[iv] The manufacturing-related emissions factors in Tables 4.2 and 4.3 combine emissions at primary materials manufacturers (steel and paper mills, etc.) with emissions from their supply chains and there is no easy way to distinguish between them. While supply chain emissions likely do not occur within the community's borders, and so will not be included in the inventories of most communities, (and thereby should, in theory, be counted) there is currently no easy way to isolate just these supply chain emissions, and in the case of primary materials producers (steel mills, paper mills, etc.) the supply chain emissions are assumed to be smaller than direct emissions by the producers.

[v] Emissions factors in Table 4.2 and the first three columns of Table 4.3 are both derived from EPA documentation, but do not exactly conform to virgin- and recycled-product emissions factors contained in EPA documentation. ICLEI's emissions factors for transportation, process energy and process non-energy emissions, for both recycled production (Table 4.2) and virgin production (Table 4.3) are derived as follows: First, transportation, process energy and process non-energy emissions factors for production of one ton of material using recycled feedstocks are drawn from relevant material-specific background papers available on EPA's website at http://www.epa.gov/climatechange/waste/SWMGHGreport.html. In the case of recycled production, EPA's WARM tool treats some recycling processes as "open loop"; for example, some corrugated containers are recycled not back into corrugated containers ("closed loop") but rather into other products (boxboard). As such, the emissions factors for materials in Tables 4.2 and 4.3 should be understood to be the emissions associated with making materials out of the listed recycled wastes, and not necessary making the same material. Second, this step is repeated for production of one ton of material using virgin feedstocks. Third, emissions across the three categories for recycled production are summed, as are emissions across the three categories for virgin production. Fourth, the difference ("emissions reduction from recycling") between virgin and recycled production is calculated from these sums. Fifth, this value is then compared against the total emissions reductions shown in the first data column of Table 3.2 of this protocol. Typically the values in Table 3.2 are lower because they reflect material loss inherent in recycling processes. The ratio of total emissions reductions (Table 3.2 divided by the difference calculated in step four of this process) is then multiplied by all six emissions factors identified in steps 1 and 2. These values are reported in Tables 4.2 and 4.3. The result is that for any given material, the sum of all emissions in Table 4.2 with all emissions reductions in Table 4.3 should equal the same value in the first data column of Table 3.2. For the first row, "mixed recyclables", a somewhat different method was used. First, transportation, process energy and process non-energy emissions for individual materials (or groups of materials, such as mixed paper)

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were identified from elsewhere in Tables 4.2 and 4.3. These were weighted by percentage factors in Table 2.2. The sum (net reductions) was then estimated at -0.76 MTCO2e per ton of mixed recyclables. However, this was determined to be incorrect, since EPA documentation (Recycling, Exhibit 2, columns (b) through (d)) directly estimates these reductions at -0.35 MTCO2e. To comport with EPA documentation, results from the process described above (for mixed recyclables) were scaled downward so that the change in emissions (difference between Table 4.2 and 4.3) for each emission type (transportation, process energy, process non-energy) matches EPA documentation.

[vi] Sources for the first three columns are described in the footnote for Table 4.2.

[vii] Source: http://www.epa.gov/climatechange/waste/downloads/Recycling.pdf, Exhibit 2 column (e).