METHODOLOGY FOR THE QUANTIFICATION AND REGISTRATION OF ENVIRONMENTAL IMPACTS OF GREEN FINANCE FOR

DIVERSION OF ORGANIC WASTE FOR ANAEROBIC DIGESTION PROJECTS

VERSION 1.1

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American Carbon Registry®

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ABOUT AMERICAN CARBON REGISTRY® (ACR)

ACR is a scientific standards body for the creation of environmental assets. This includes tradable assets like carbon offset credits issued by ACR Environmental Markets and the quantification of environmental attributes of financial instruments by ACR Capital Markets. We complement decades of expertise in the development of market-making standards and project measurement methodologies with operational expertise in the verification, registration, issuance, retirement, and reporting of environmental claims.

ACKNOWLEDGEMENTS

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ACRONYMS

ACR	American Carbon Registry
CARB	California Air Resources Board
CH_4	Methane
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DGE	Diesel gallon equivalent
DME	Dimethyl ether
DOE	United States Department of Energy
eGRID	Emissions & Generation Resource Integrated Database
EPA	United States Environmental Protection Agency
GGE	Gasoline gallon equivalent
GHG	Greenhouse gas
GJ	Gigajoule
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
KPI	Key performance indicator
kWh	Kilowatt hour
LFG	Landfill gas
MJ	Megajoule
MSW	Municipal solid waste

MT	Metric ton
MWh	Megawatt hour
N_2O	Nitrous oxide
N/A	Not applicable
RNG	Renewable natural gas
scf	Standard cubic feet
SDG	United Nations Sustainable Development Goals
SMM	Sustainable materials management
SSR	Greenhous gas source, sink, and reservoir
WARM	Waste Reduction Model

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1 METHODOLOGY DESCRIPTION

This Methodology for the Quantification and Registration of Environmental Impacts of Green Finance for Diversion of Organic Waste for Anaerobic Digestion Projects was developed as part of ACR's Green Finance Impact Program.

This Methodology describes the approach and process for quantifying environmental key performance indicators (KPIs) for bond-funded activities related to the diversion of organic waste for anaerobic digestion. It calculates a project's Carbon Return and applies benchmarks to assess a project's impact relative to investments in the same category. This Methodology documents the approach used to quantify the following environmental benefits:

- Greenhouse gas (GHG) emission reductions
- Bioenergy and/or biofuel generation
- Landfill diversion
- Compost or digestate production

In the United States, the total generation of municipal solid waste (MSW) in 2017 was 267.8 million tons, or 4.51 pounds per person per day. Despite advancements in sustainable materials management (SMM), 52 percent of this material ended up in landfills.[1] When organic waste decomposes in a landfill, it produces methane (CH_4) and carbon dioxide (CO_2). Where present, landfill gas (LFG) collection systems reduce such emissions, but adoption of these systems and their efficiency rates vary.[2] As a result, MSW landfills remain the third-largest source of human related methane emissions in both the United States and worldwide.[3,4]

Municipalities are increasingly taking action to promote SMM and prohibit organic materials from entering landfills, thereby creating demand for resource recovery technologies and anaerobic digester operations such as the activities quantified in this Methodology.[5] SMM promotes a circular economy through the use and reuse of materials after they have been discarded and enter the waste stream. Anaerobic digestion is one such end-of-life management practice.

This Methodology quantifies the environmental benefits of diverting food waste, yard waste, and mixed organics from landfills for stand-alone anaerobic digestion. The methods for assessing the environmental impacts of an anaerobic digestion project apply both prior to construction/installation and upon operation. It contains methods for assessing the environmental impacts of an organic waste diversion for anaerobic digestion project funded with bond proceeds, including:

[1] U.S. EPA (2020a), The Current National Picture.

[2] U.S. EPA (2019a), Section 6.2.2.3, pp. 6-11 – 6-13.

[3] U.S. EPA (2020b), p. 1-1.

[4] U.S. EPA (2011), p. 1.

[5] Lystek International (2018).

- Environmental KPIs
- Carbon Return ($MTCO_2e$ per $1,000 bond financing per year)
- Project performance relative to benchmarks, where applicable

This document provides the project eligibility requirements, quantification approach, and project data requirements. Additional resources and requirements applicable to ACR's Green Finance Impact Program are available at www.winrock.org/ms/acr-capital-markets.

2 CALCULATOR TOOL

This Methodology details the technical methods used to calculate environmental KPIs for bond-funded projects. To make these methods accessible to issuers, ACR has created an easy-to-use calculator that embeds the methods and equations found in this document. The accompanying Calculator Tool and instructions for use are available to program participants at www.winrock.org/ms/acr-capital-markets.

3 METHOD APPLICABILITY

Bond-funded activities must satisfy the following conditions for this Methodology to apply:

I. Project reduces GHG emissions through an increase in the amount of organic MSW diverted from a municipal landfill for stand-alone anaerobic digestion by:
   A. Constructing or installing a stand-alone anaerobic digester;
   B. Expanding capacity of an existing stand-alone anaerobic digester;
   C. Constructing, expanding, or purchasing/installing equipment for a waste stream sorting facility; and/or
   D. Initiating or expanding a residential or commercial organics waste program (e.g., collection or source separation technologies).
II. Project diverts organic MSW from the below categories, as defined in this Methodology:
   A. Food waste;
   B. Yard waste; and/or
   C. Mixed organics.
III. Project utilizes organic MSW that would be landfilled in the absence of the project as feedstock for a stand-alone anaerobic digester that meets one of the following descriptions, as defined in this Methodology:
   A. Wet mesophilic digester
   B. Dry mesophilic digester
IV. Project utilizes biogas to produce one of the following bioenergy or biofuels:
   A. Electricity with surplus exported to grid;
   B. Renewable natural gas (RNG) for pipeline injection; or
   C. Vehicle fuel (RNG, hydrogen, or dimethyl ether).
V. Project is located in the United States.
VI. Issuer supplies project data per requirements described in Chapter 11.

Project aggregation for the purpose of reporting is permitted for projects that quantify environmental impacts using this Methodology and accompanying calculator tool, provided that aggregated projects all:

I. Divert organic MSW from the same landfill or landfills that share the same attributes as input into the calculator tool;
II. Are categorized into the same anaerobic digester operation types;
III. Produce the same category of bioenergy or biofuel; and
IV. Have identical project operational lives.

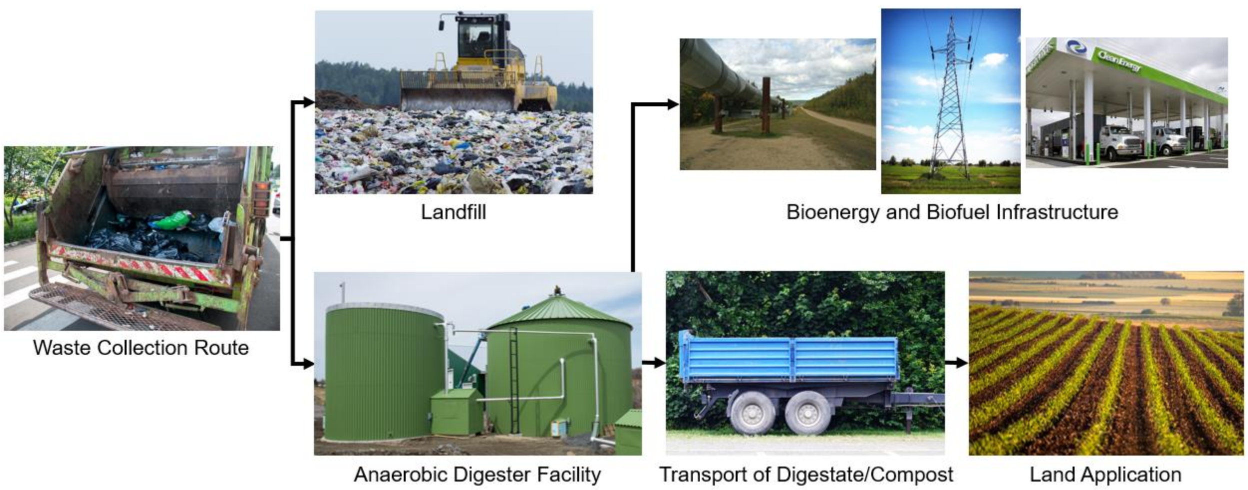
See Chapter 12 for definitions of terms used above and throughout this Methodology.

4 PROJECT BOUNDARIES

4.1 SPATIAL BOUNDARY

The spatial boundary includes the physical and geographical site where the anaerobic digestion takes place, the location of the landfill(s) from which organic material is diverted and at which residual material is disposed, the location of energy generation displaced by the project, the lands on which digestate or finished compost is applied, and the transportation of organic material between these sites, as depicted in Figure 1.

Figure 1: Spatial Boundary



A project proponent may or may not have operational control over all components within the spatial boundary. A diversion of organic waste for anaerobic digestion project's benefits can accrue at a site outside of the operational control – but as a direct result – of a project. This Methodology is designed to capture these benefits as long as they occur within the spatial boundary. This Methodology relies on reasonable assumptions, supported by data and literature, when assessing project impacts that occur upstream or downstream of an anaerobic digestion site.

For this project type, project proponents may have limited information on downstream operations (i.e., transport of byproducts, carbon storage, and displaced fertilizer from the land application of digestate or compost). For this reason, and due to the potential impermanence of carbon storage, the project impacts from the transport and application of digestate or compost are less certain and therefore estimated as a secondary effect while all other impacts are categorized as primary effects (see designations in Table 1).

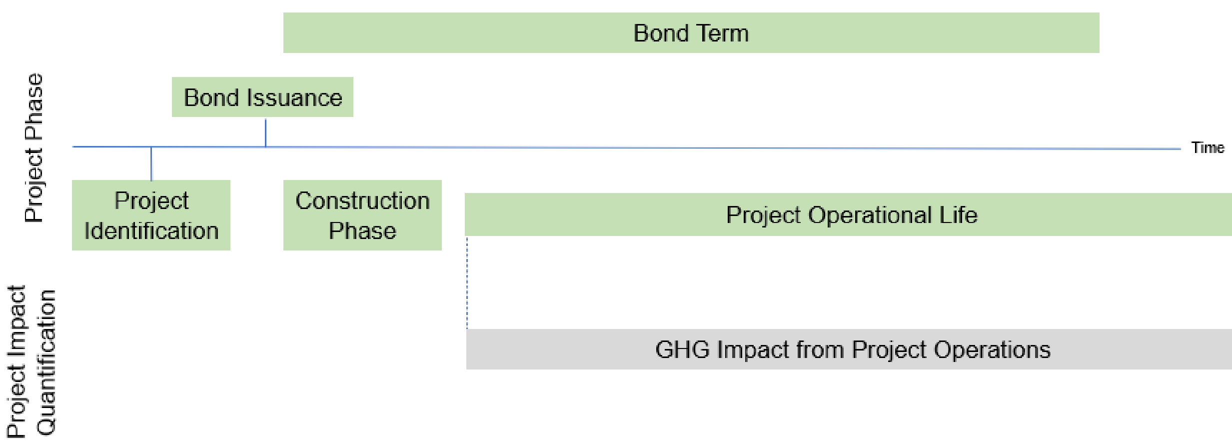
4.2 TEMPORAL BOUNDARY

The temporal boundary is designed to capture impacts associated with the project during its operational life. Figure 2 depicts the project phases, from project identification through the operational life, and how the different phases relate to the quantification of project impacts.

Construction phase emissions (e.g., emissions associated with the construction, installation or expansion of equipment or systems) are omitted for diversion of organic waste for anaerobic digestion projects on account of being small relative to the overall emission reductions and the construction phase being temporary. Moreover, it is anticipated that, without the project, construction emissions would still eventually occur due to the material's contribution toward landfill capacity.

This Methodology assumes an operational life of 25 years for an organic waste diversion for anaerobic digestion project and uses this time period when establishing the benchmarks.[6] This period of time is also consistent with the expected time for food and yard waste to degrade in a landfill, which the EPA estimates at 20-30 years.[7] Individual project operational lives may vary. To apply a different operational life to the quantification of project benefits, project proponents must substantiate the alternative project duration with documentation (i.e., equipment manufacturer specifications, operator's project performance record, or organic waste processing contracts). If a project proponent substantiates a different operational life than that used in the benchmarks, that duration will be used when assessing the project against the benchmarks.

Figure 2: Project Phase Timeline



[6] DiStefano and Belenky (2009), p. 1099.

[7] U.S. EPA (2019b), p. 1-21.

4.3 GHG ASSESSMENT BOUNDARY

The GHG assessment boundary, depicted by Figure 3 and Table 1 below, delineates the sources, sinks, and reservoirs (SSRs) that are included or excluded in quantifying emissions and emission reductions associated with the diversion of organic waste for anaerobic digestion. Table 1 also describes the SSRs used for the quantification of the project impact and the GHG benchmark.

Figure 3 illustrates the GHG assessment boundary for stand-alone anaerobic digestion projects. All SSRs inside the grey box are included and must be accounted for under this Methodology.

Figure 3: GHG Assessment Boundary Diagram

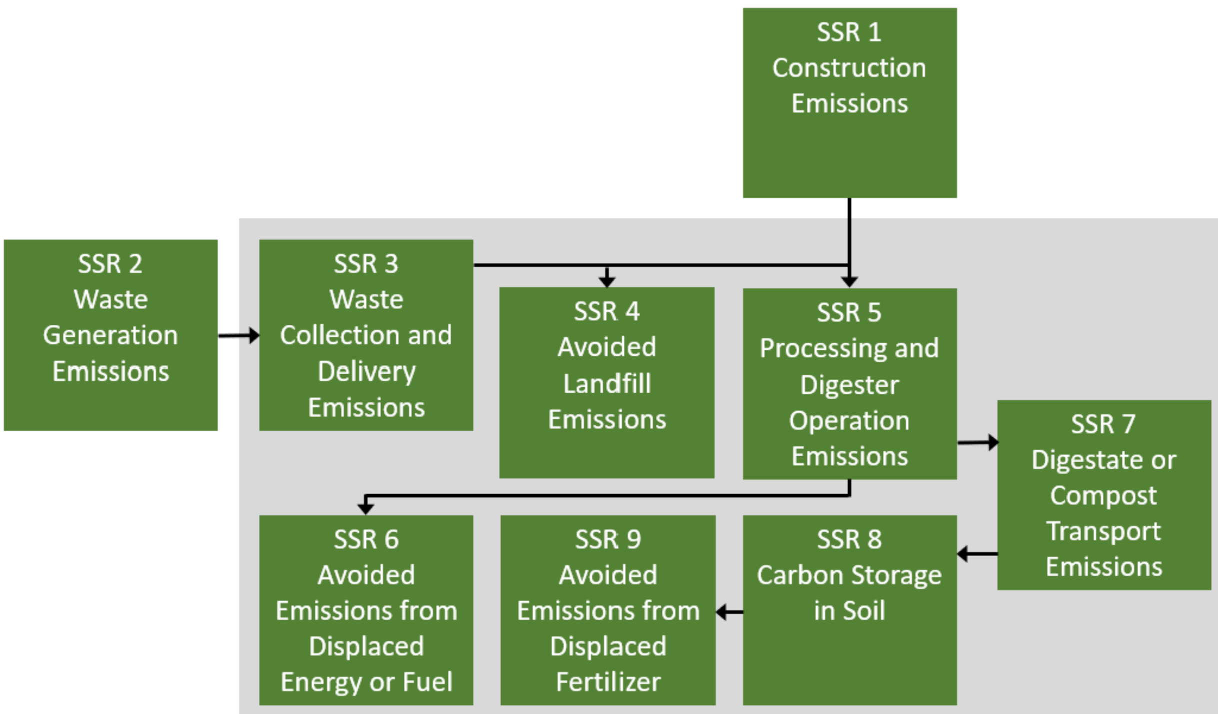


Table 1 lists the SSRs for diversion of organic waste for anaerobic digestion projects, indicating which gases are included in, or excluded from, the GHG assessment boundary.

Table 1: GHG Sinks, Sources, and Reservoirs

SSR	DESCRIPTION	GAS	INCLUDED (I) OR EXCLUDED (E)	JUSTIFICATION / EXPLANATION OF CHOICES
1 Construction Emissions	Stationary and mobile combustion emissions from construction/ installation of an anaerobic digester, construction/expansion of a sorting facility, or installation of equipment at such facilities	CO_2	E	Construction emissions are omitted for diversion of organic waste for anaerobic digestion projects on account of being small relative to the overall emission reductions and the construction phase being temporary. Moreover, it is anticipated that, without the project, construction emissions would still occur due to the material's contribution toward landfill capacity.
		CH_4	E	
		N_2O	E	
2 Waste Generation Emissions	Stationary and mobile combustion emissions from the generation of waste	CO_2	E	Emissions are assumed to be equivalent with and without the project
		CH_4	E	
		N_2O	E	
3 Waste Collection and Delivery Emissions	Mobile combustion emissions from fossil fuel consumed to collect and deliver waste to landfills or digester facilities	CO_2	I	Primary activity of the project
		CH_4	I	
		N_2O	I	

SSR	DESCRIPTION	GAS	INCLUDED (I) OR EXCLUDED (E)	JUSTIFICATION / EXPLANATION OF CHOICES
4 Avoided Landfill Emissions	Net fugitive, stationary combustion, and mobile combustion, emissions avoided from the decomposition of organic material at a landfill, including avoided methane emissions, avoided carbon storage in landfills, reduced bioenergy production from LFG capture systems (if applicable), and landfill equipment emissions	CO_2	I/E	CO_2 emissions from stationary and mobile sources are included Fugitive biogenic CO_2 emissions are excluded[8]
		CH_4	I	Primary activity of the project
		N_2O	I/E	N_2O emission from stationary and mobile sources are included There is insufficient data on fugitive landfill N_2O emissions and this source is conservatively omitted[9]
5 Processing and Digester Operation Emissions	Fugitive, stationary combustion, and mobile combustion emissions from the pre-processing of waste, operation of an anaerobic digester, and post-processing	CO_2	I/E	Primary activity of the project Fugitive biogenic CO_2 emissions are excluded[10]
		CH_4	I	
		N_2O	I	

[8] IPCC (2006), Volume 5, Chapter 3, p. 3.6.
[9] CARB (2017), p. 6.
[10] IPCC (2006), Volume 5, Chapter 3, p. 3.6.

SSR	DESCRIPTION	GAS	INCLUDED (I) OR EXCLUDED (E)	JUSTIFICATION / EXPLANATION OF CHOICES
6 Avoided Emissions from Displaced Energy or Fuel	Stationary and mobile combustion emissions avoided from the displacement of fossil fuels by bioenergy or biofuel	CO_2	I	Primary activity of the project
		CH_4	I	
		N_2O	I	
7 Digestate or Compost Transport Emissions	Mobile combustion emissions from fossil fuel consumed to transport digestate or finished compost	CO_2	I	Secondary effect of project
		CH_4	I	
		N_2O	I	
8 Carbon Storage in Soil	Carbon stored in soils from the land application of digestate or compost	CO_2	I	Secondary effect of project
9 Avoided Emissions from Displaced Fertilizer	Net fugitive, stationary combustion, and mobile combustion emissions avoided from the production and application of synthetic fertilizer displaced by digestate or compost	CO_2	I	Secondary effect of the project
		CH_4	I	
		N_2O	I	

5 PERIODIC REVIEWS

ACR may periodically update (or decide to retire) this Methodology. Such updates occur when significant changes to accounting best practices or the legislative and/or regulatory context justify an update; when sufficient new data is available to revise eligibility requirements, benchmarks, or emission factors; when ACR becomes aware of clarifications that should be made; or for other reasons. Before assessing a project's impacts against the benchmarks contained in this document, the project proponent should ensure that they are using the latest version of the Methodology.

6 QUANTIFICATION OF GHG IMPACT

GHG emission reductions from diverting organic waste for anaerobic digestion are quantified using the methods and equations in the following sections. This chapter describes how to establish the Carbon Return of the project and compare performance relative to the GHG benchmark for stand-alone anaerobic digestion projects.

GHG emissions are converted to carbon dioxide-equivalent (CO_2e) using the 100-year global warming potential (GWP) in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.[11] This methodology may be adjusted to updated GWPs in the future.

6.1 QUANTIFICATION OF NET PROJECT GHG IMPACT & CARBON RETURN

A diversion of organic waste for anaerobic digestion project's GHG emission reductions are assessed using the methods and equations in Subsections 6.1.1 – 6.1.9 below. Each subsection covers a different SSR and the net project GHG impact is calculated in Subsection 6.1.10.

6.1.1 CONSTRUCTION EMISSIONS

Construction emissions refer to the stationary and mobile combustion emissions from construction/installation of an anaerobic digester, construction/expansion of a sorting facility, or installation of equipment at such facilities. This emission source is excluded from the GHG assessment boundary on account of it being small relative to the overall emission reductions and the construction phase being temporary. Moreover, it is anticipated that, without the project, construction emissions would still eventually occur without the project due to the material's contribution toward landfill capacity.

6.1.2 WASTE GENERATION EMISSIONS

Waste generation emissions refer to stationary and mobile combustion emissions from the generation of waste. This emission source is excluded from the GHG assessment boundary on

[11] IPCC (2018), Table 2.14.

account of waste generation emissions being assumed to be equivalent with and without the project.

6.1.3 WASTE COLLECTION & DELIVERY EMISSIONS

Waste collection and delivery emissions refer to the mobile combustion emissions from fossil fuel consumed to collect and deliver waste to landfills or digester facilities. Emissions result from fossil fuel combustion by trucks used to collect and deliver waste to a landfill or digester facility.

Transportation emission factors vary by fuel type, as displayed in Table 2, and electric vehicle emissions vary by grid carbon intensity, as displayed in Appendix A. The diesel ton-mile emission factor is sourced from WARM[12] and the emission factors for alternative fuel types are reduced proportionally based on ACR analysis using fuel economies, energy densities, energy economy ratios and, for electric vehicles, data from the EPA's Emissions & Generation Resource Integrated Database (eGRID)[13]. The difference in transportation emissions for waste collection and delivery between the project and no project scenarios is calculated using Equations 1 and 2.

Table 2: Vehicle Emission Factor

FUEL TYPE	$MTCO_2e$/SHORT TON-MILE
Diesel	0.00016
Biodiesel	0.00004
Compressed Natural Gas (CNG)	0.00016
Renewable Natural Gas (RNG)	0.00006
Hydrogen	0.00009
Electric	See Appendix A

[12] U.S. EPA (2019b), Exhibit 5-1.

[13] U.S. EPA (2021a), column DE in the ST19 tab.

Equation 1: Weighted Vehicle Emission Factor

$$\mathbf{VEF} = \mathbf{VEF_{dsl}} \times (\mathbf{1} - \mathbf{Biodsl} - \mathbf{CNG} - \mathbf{RNG} - \mathbf{Hyd} - \mathbf{EV}) + \mathbf{VEF_{biodsl}} * \mathbf{Biodsl} + \mathbf{VEF_{CNG}} * \mathbf{CNG} + \mathbf{VEF_{RNG}} * \mathbf{RNG} + \mathbf{VEF_{hyd}} * \mathbf{Hyd} + \mathbf{VEF_{EV}} * \mathbf{EV}$$

WHERE	
VEF	Weighted vehicle emission factor
$\mathrm{VEF_{dsl}}$	Vehicle emission factor for diesel from Table 2 ($MTCO_2e$/short ton-mile)
Biodsl	Percentage of waste collection fleet that operates on biodiesel (%)
CNG	Percentage of waste collection fleet that operates on CNG (%)
RNG	Percentage of waste collection fleet that operates on RNG (%)
Hyd	Percentage of waste collection fleet that operates on hydrogen (%)
EV	Percentage of waste collection fleet that operates on electricity (%)
$\mathrm{VEF_{biodsl}}$	Vehicle emission factor for biodiesel from Table 2 ($MTCO_2e$/short ton-mile)
$\mathrm{VEF_{CNG}}$	Vehicle emission factor for CNG from Table 2 ($MTCO_2e$/short ton-mile)
$\mathrm{VEF_{RNG}}$	Vehicle emission factor for RNG from Table 2 ($MTCO_2e$/short ton-mile)
$\mathrm{VEF_{hyd}}$	Vehicle emission factor for hydrogen from Table 2 ($MTCO_2e$/short ton-mile)
$\mathrm{VEF_{EV}}$	Vehicle emission factor for electric vehicles from Appendix A ($MTCO_2e$/short ton-mile)

Equation 2: Waste Collection and Delivery Emissions

$$\mathbf{WCD} = \left\{ \sum_{t} [(\mathbf{TONS}_t + \mathbf{RMR}_t + \mathbf{RML}_t) \times \mathbf{YEARS}_t] \times (\mathbf{VMTD} - \mathbf{VMTL}) + \sum_{t} [(\mathbf{RMR}_t + \mathbf{RML}_t) \times \mathbf{YEARS}_t] \times \mathbf{VMTR} \right\} \times \mathbf{VEF}$$

WHERE	
WCD	Waste collection and delivery emissions (or emission reductions) ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
RMR_t	Residual material initially diverted and later recycled over time interval *t* (short tons/year)
RML_t	Residual material initially diverted but later landfilled over time interval *t* (short tons/year)
$YEARS_t$	Duration of time interval *t* (years)
VMTD	Average vehicle miles traveled to transport diverted waste from curb to digester facility (miles)
VMTL	Average vehicle miles traveled to transport waste from curb to landfill (miles)
VMTR	Average vehicle miles traveled to transport residual material from digester facility to landfill or other facility (miles)
VEF	Vehicle emission factor from Equation 1 ($MTCO_2e$/short ton-mile)

6.1.4 AVOIDED LANDFILL EMISSIONS

Avoided landfill emissions refer to the net fugitive, stationary combustion, and mobile combustion, emissions avoided from the decomposition of organic material at a landfill, including avoided methane emissions, avoided carbon storage in landfills, reduced bioenergy production from LFG capture systems (if applicable), and landfill equipment emissions. Avoided methane emissions from the decomposition of organic material at a landfill is the primary GHG benefit of organic waste diversion. Organic waste diversion also impacts the use of landfilling equipment, the amount of carbon stored at a landfill, and the energy production from LFG recovery. These factors depend on the type of material disposed based on the material's amount of degradable carbon and anaerobically degradable carbon and its decay rate. Landfill conditions such as climate and the existence and efficiency of an LFG gas capture system also impact a landfill's emission profile.

This Methodology incorporates the United States Environmental Protection Agency's (EPA) Waste Reduction Model (WARM)[14] to determine the landfill emissions avoided by a diversion of organic waste for anaerobic digestion project. The emission factors derived from WARM capture reductions in fugitive methane emissions, equipment emissions, biogenic carbon storage, and LFG recovery for energy, if applicable. The accompanying Calculator Tool translates basic landfill management and diverted waste characteristics into WARM emission factors used in Equation 3 to determine the avoided landfill emissions.

[14] U.S. EPA (2019c).

Equation 3: Avoided Landfill Emissions

$$\mathbf{ALE} = \sum_{t} \left[\left(\mathbf{TONS}_{\mathbf{mo},t} \times \mathbf{WARM}_{\mathbf{mo}} + \mathbf{TONS}_{\mathbf{fw},t} \times \mathbf{WARM}_{\mathbf{fw}} + \mathbf{TONS}_{\mathbf{yw},t} \times \mathbf{WARM}_{\mathbf{yw}} + \mathbf{RMR}_{t} \times \mathbf{WARM}_{\mathbf{MR}} \right) \times \mathbf{YEARS}_{t} \right]$$

WHERE	
ALE	Avoided landfill emissions ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
TONS_t	Organic material diverted and sent to anaerobic digester by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) over time interval *t* (short tons feedstock/year) If composition of diverted waste is unknown, material is aggregated together as mixed organics.
RMR_t	Residual material initially diverted and later recycled over time interval *t* (short tons/year)
WARM	WARM GHG emission factor for MSW management in a landfill by waste type: mixed organics (mo), food waste (fw), yard waste (yw), or mixed recyclables (mr) ($MTCO_2e$/short ton feedstock)
YEARS_t	Duration of time interval *t* (years)

6.1.5 PROCESSING & DIGESTER OPERATION EMISSIONS

Processing and digester operation emissions refer to the fugitive, stationary combustion, and mobile combustion emissions from the pre-processing of waste, operation of an anaerobic digester, and post-processing. Electricity and diesel fuel are consumed by mobile and stationary equipment for pre-processing diverted waste (e.g., grinding, screening, and mixing feedstock) and digester operation (e.g., front-end loaders, pumping and mixing within the system, and dewatering). Fugitive emissions also occur from digester operation (e.g., methane leaks) and post-processing (e.g., methane and nitrous oxide leaks from digestate treatment). If the biogas is upgraded for vehicle fuel or injection of RNG into the pipeline, there are additional fossil fuel and fugitive emissions associated with biogas compression. These emissions are calculated below.

When biogas is utilized for vehicle fuel or injection into the pipeline instead of electricity generation,[15] the quantity of electricity consumed to operate the digester is based on digester type (dry or wet) using the assumptions from WARM,[16] as displayed in Table 3.

Table 3: Pre-processing and Digester Operation Electricity Consumption

DRY ANAEROBIC DIGESTION	18.1 kWh/short ton feedstock
WET ANAEROBIC DIGESTION	113.4 kWh/short ton feedstock

GHG emissions associated with the electricity usage are calculated using emission factors from the state electrical grid per eGRID,[17] displayed in Appendix B, and Equation 4.

[15] All anaerobic digestion projects are expected to consume electricity for operations. For projects that produce electricity, this consumption is captured in Subsection 6.1.6 by only crediting the net surplus electricity exported to the electrical grid.

[16] U.S. EPA (2019a), Exhibit 3-4.

[17] U.S. EPA (2021a), column DE in the ST19 tab.

Equation 4: Electricity Emissions from Pre-processing and Digester Operation

$$\mathbf{ELEC} = \sum_{t}[(\mathbf{TONS}_t + \mathbf{RMR}_t + \mathbf{RML}_t) \times \mathbf{YEARS}_t] \times \left(\frac{\mathbf{EC}}{\mathbf{1,000}}\right) \times \left(\frac{\mathbf{eGRID}}{\mathbf{2,204.62}}\right)$$

WHERE	
ELEC	Electricity emissions from pre-processing and digester operation ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
RMR_t	Residual material initially diverted and later recycled over time interval *t* (short tons/year)
RML_t	Residual material initially diverted but later landfilled over time interval *t* (short tons/year)
$YEARS_t$	Duration of time interval *t* (years)
EC	Electricity consumed, depending on digester type from Table 3 (kWh/short ton of feedstock)
1,000	Conversion kWh/MWh
eGRID	eGRID GHG emission factor for electrical grid from Appendix B (lb CO_2e/MWh)
2,204.62	Conversion lb/MT

Diesel fuel combustion emissions vary by digester type (i.e., dry or wet),[18] as displayed in Table 4, and are calculated using Equation 5.

Table 4: Pre-processing and Digester Operation Fuel Emission Factors

DRY ANAEROBIC DIGESTION	0.02 $MTCO_2e$/short ton feedstock
WET ANAEROBIC DIGESTION	0.01 $MTCO_2e$/short ton feedstock

[18] U.S. EPA (2019a), Exhibits 3-13, 3-14, 3-15 and 3-16.

Equation 5: Fuel Emissions from Pre-processing and Digester Operation

$$\mathbf{FUEL} = \sum_{t} [(\mathbf{TONS}_t + \mathbf{RMR}_t + \mathbf{RML}_t) \times \mathbf{YEARS}_t] \times \mathbf{EF}$$

WHERE	
FUEL	Fuel emissions from pre-processing and digester operation ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
TONS_t	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
RMR_t	Residual material initially diverted and later recycled over time interval *t* (short tons/year)
RML_t	Residual material initially diverted but later landfilled over time interval *t* (short tons/year)
YEARS_t	Duration of time interval *t* (years)
EF	Fuel emission factor, depending on digester type from Table 4

Fugitive emissions vary by digester type (i.e., dry or wet), digestate treatment (i.e., aerobically cured or not), and feedstock type (i.e., mixed organics, food waste, yard waste),[19] as displayed in Table 5, and are calculated using Equation 6.

Table 5: Digester Operation and Post-processing Fugitive Emission Factors

FEEDSTOCK TYPE	DRY WITH CURING	DRY WITHOUT CURING	WET WITH CURING	WET WITHOUT CURING
	($MTCO_2e$/SHORT TON)			
Mixed Organics	0.11	0.09	0.10	0.08
Food Waste	0.12	0.12		
Yard Waste	0.09	0.06		

[19] Ibid.

Equation 6: Fugitive Emissions from Digester Operation and Post-processing

$$\mathbf{FUG} = \sum_{t} \left[\left(\mathbf{TONS}_{\mathbf{mo},t} \times \mathbf{EF}_{\mathbf{mo}} + \mathbf{TONS}_{\mathbf{fw},t} \times \mathbf{EF}_{\mathbf{fw}} + \mathbf{TONS}_{\mathbf{yw},t} \times \mathbf{EF}_{\mathbf{yw}} \right) \times \mathbf{YEARS}_{t} \right]$$

WHERE	
FUG	Fugitive emissions from digester operation and post-processing ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) over time interval *t* (short tons feedstock/year) If composition of diverted waste is unknown, material is aggregated together as mixed organics.
EF	Fugitive emission factor for digester operation and post-processing for the digester type (dry or wet), by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) from Table 5 ($MTCO_2e$/short ton feedstock)
$YEARS_t$	Duration of time interval *t* (years)

When biogas is utilized for vehicle fuel or injection into the pipeline instead of electricity generation, additional stationary emissions occur as a result of biogas compression. Biogas compression also results in a reduction in biomethane potential due to fugitive biogas losses. The emission factor for biogas compression associated with vehicle fuel production or pipeline injection was derived from the California Air Resources Board calculator tool for the California Climate Investments Organics Program,[20] and is displayed in Table 6.

Table 6: Biogas Compression Emission Factor

BIOGAS COMPRESSION	**0.0264 $MTCO_2e$/short ton feedstock**

[20] CARB (2020), derived from Table Addendum-1 in the Standalone AD ERF tab, adapted from the Low Carbon Fuel Standard Pathway for the Production of Biomethane from High Solids Anaerobic Digestion (HSAD) of Organic (Food and Green) Wastes. The emission factor is equal to the difference between the process emissions for the fuel or pipeline injection scenarios and the electricity generation scenario, divided by the feedstock tonnage.

If the project utilizes biogas to produce vehicle fuel or for injection into the pipeline, biogas compression emissions are calculated using Equation 7.

Equation 7: Biogas Compression Emissions

$$\mathbf{COMP} = \sum_{t} (\mathbf{TONS}_t \times \mathbf{YEARS}_t) \times \mathbf{BC}$$

WHERE	
COMP	Stationary and fugitive emissions from biogas compression, if applicable ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
BC	Stationary and fugitive emissions from biogas compression from Table 6 ($MTCO_2e$/short ton feedstock)
TONS_t	Organic material diverted for anaerobic digestion over time interval *t* (short tons feedstock/year)
YEARS_t	Duration of time interval *t* (years)

Total processing and digester operation emissions are calculated using Equation 8.

Equation 8: Processing and Digester Operation Emissions

$$\mathbf{PDO} = \mathbf{ELEC} + \mathbf{FUEL} + \mathbf{FUG} + \mathbf{COMP}$$

WHERE	
PDO	Emissions from processing and digester operation ($MTCO_2e$)
ELEC	Electricity emissions from pre-processing and digester operation from Equation 4 (if applicable) ($MTCO_2e$)
FUEL	Stationary and mobile emissions from pre-processing and digester operation from Equation 5 ($MTCO_2e$)
FUG	Fugitive emissions from digester operation and post-processing from Equation 6 ($MTCO_2e$)
COMP	Stationary and fugitive emissions from biogas compression from Equation 7 (if applicable) ($MTCO_2e$)

6.1.6 AVOIDED EMISSIONS FROM DISPLACED ENERGY OR FUEL

Avoided emissions from displaced energy or fuel refers to the stationary and mobile combustion emissions avoided from the displacement of fossil fuels by bioenergy or biofuel. The biogas produced during anaerobic digestion of organic waste can be collected and utilized to generate bioenergy or biofuel that displaces fossil fuels. This Methodology calculates avoided GHG emissions associated with the displacement of fossil fuel from various end-use options for the biogas (i.e., on-site electricity production and export to the grid, upgrading to RNG and injection into the pipeline, or production of vehicle fuel).

These quantities are based on the amount of net surplus energy and/or fuel expected to be produced by the project and available to replace fossil fuels. In the case of electricity production, the net surplus energy available to offset fossil fuels is the energy generated by the project less the amount used for on-site processing and digester operation. For projects that produce pipeline quality renewable natural gas or vehicle fuel, it is expected that the surplus is the entirety of the quantity produced and electricity used for on-site processing and digester operation is calculated separately in Section 6.1.5.

For projects that generate electricity, the emission factor for displaced fossil fuel-based electricity is dependent on the state electrical grid. This Methodology uses the state-specific, non-baseload emissions from eGRID,[21] displayed in Appendix B. Avoided GHG emissions associated with displaced electricity are calculated using Equation 9.

Equation 9: Avoided Emissions from Displaced Electricity

$$\mathbf{DE} = \left(\frac{\sum_t (\mathbf{kWh}_t \times \mathbf{YEARS}_t)}{\mathbf{1,000}}\right) \times \left(\frac{\mathbf{eGRID}}{\mathbf{2,204.62}}\right)$$

WHERE	
DE	Avoided emissions from displaced electricity ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
kWh_t	Net surplus electricity to grid over time interval *t* (kWh/year)
YEARS_t	Duration of time interval *t* (years)
1,000	Conversion kWh/MWh
eGRID	eGRID GHG emission factor for electrical grid from Appendix B (lb/MWh)
2,204.62	Conversion lb/MT

[21] U.S. EPA (2021a) column DE in the ST19 tab.

For projects that upgrade biogas for pipeline injection, the avoided GHG emissions associated with the displaced natural gas are calculated using Equation 10.

Equation 10: Avoided Emissions from Displaced Natural Gas

$$\mathbf{DNG} = \sum_{t} (\mathbf{scf}_t \times \mathbf{YEARS}_t) \times \left(\frac{\mathbf{0.05455}}{\mathbf{1,000}}\right)$$

WHERE	
DNG	Avoided emissions from displaced natural gas ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
scf_t	Renewable natural gas for pipeline injection over time interval *t* (scf/year)
$YEARS_t$	Duration of time interval *t* (years)
0.05455	GHG emission factor for natural gas (kg CO_2e/scf)[22]
1,000	Conversion kg/MT

[22] U.S. EPA (2021b), derived from Table 1.

For projects that produce vehicle fuel, the amount of alternative fuel is first converted to diesel gallon equivalent (DGE) or gasoline gallon equivalent (GGE) and then the avoided GHG emissions associated with displacing those vehicle fuels are calculated using Equation 11.

Equation 11: Avoided Emissions from Displaced Vehicle Fuel

$$\mathbf{DVF} = \left[\frac{\sum_t(\mathbf{RNG_t} \times \mathbf{YEARS_t})}{\mathbf{139.3}}\right] \times \mathbf{0.01016} + \left[\frac{\sum_t(\mathbf{DME_t} \times \mathbf{YEARS_t})}{\mathbf{1.8}}\right] \times \mathbf{0.01016} + \left[\frac{\sum_t(\mathbf{HYD_t} \times \mathbf{YEARS_t})}{\mathbf{1.019}}\right] \times \mathbf{0.00893}$$

WHERE	
DVF	Avoided emissions from displaced vehicle fuel ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
RNG_t	Annual renewable natural gas fuel production over time interval *t* (scf/year)
$YEARS_t$	Duration of time interval *t* (years)
139.3	Conversion scf RNG/DGE[23]
DME_t	Annual dimethyl ether fuel production over time interval *t* (gallons/year)
1.8	Conversion gallon DME/DGE[24]
0.01016	GHG emission factor for diesel fuel ($MTCO_2e$/gallon)[25]
HYD_t	Annual hydrogen fuel production over time interval *t* (kg/year)
1.019	Conversion kg hydrogen/GGE[26]
0.00893	GHG emission factor for gasoline ($MTCO_2e$/gallon)[27]

[23] U.S. DOE (2014).

[24] McKone et al. (2015), p. 24.

[25] Derived from Greenhouse Gas Protocol (2017), Transportation Fuel Use worksheet. Emission factor uses the CH_4 and N_2O values for Heavy Duty Vehicles – Rigid.

[26] U.S. DOE (n.d.).

[27] Derived from Greenhouse Gas Protocol (2017), Transportation Fuel Use worksheet. Emission factor uses the average CH_4 and N_2O values for Heavy Duty Vehicles – Rigid for model years 2000-present.

The avoided GHG emissions associated with the displacement of energy or fuel is calculated using Equation 12.

Equation 12: Avoided emissions from Displaced Energy and Fuel

$$\mathbf{DEF = DE + DNG + DVF}$$

WHERE	
DEF	Avoided emissions from displaced energy and fuel ($MTCO_2e$)
DE	Avoided emissions from displaced electricity from Equation 9 ($MTCO_2e$)
DNG	Avoided emissions from displaced natural gas from Equation 10 ($MTCO_2e$)
DVF	Avoided emissions from displaced vehicle fuel from Equation 11 ($MTCO_2e$)

6.1.7 DIGESTATE OR COMPOST TRANSPORT EMISSIONS

Digestate or compost transport emissions refer to the mobile combustion emissions from fossil fuel consumed to transport digestate or finished compost to the site upon which it is land applied. Anaerobic digestion produces digestate as a byproduct which can be directly land applied or aerobically cured to produce finished compost. For projects that produce digestate, the additional emissions from transportation of the byproduct are calculated using Equation 13. For projects that produce compost, the additional emissions from transportation of the byproduct are calculated using Equation 14.

Equation 13: Digestate Transport Emissions

$$\mathbf{DTE} = \sum_{t} (\mathbf{TONS}_t \times \mathbf{YEARS}_t) \times \mathbf{0.84} \times \mathbf{VMTB} \times \mathbf{0.00016}$$

WHERE	
DTE	Digestate transport emissions from the transportation of digestate ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
TONS_t	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
YEARS_t	Duration of time interval *t* (years)
0.84	Conversion of feedstock to digestate (ton digestate/ton feedstock)[28]
VMTB	Average vehicle miles traveled to transport digestate byproduct from digester facility to land application or landfill (miles)
0.00016	Transportation emission factor from WARM[29] ($MTCO_2e$/short ton-mile)

[28] CARB (2014a), p. 55.
[29] U.S. EPA (2019b), Exhibit 5-1.

Equation 14: Compost Transport Emissions

$$\mathbf{CTE} = \sum_{t} (\mathbf{TONS}_t \times \mathbf{YEARS}_t) \times \mathbf{0.84} \times \mathbf{0.64} \times \mathbf{VMTB} \times \mathbf{0.00016}$$

WHERE	
CTE	Compost transport emissions ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
$YEARS_t$	Duration of time interval *t* (years)
0.84	Conversion of feedstock to digestate (ton digestate/ton feedstock)[30]
0.64	Conversion of digestate to compost (ton compost/ton digestate)[31]
VMTB	Average vehicle miles traveled to transport compost byproduct from digester facility to land application or landfill (miles)
0.00016	Transportation emission factor from WARM[32] ($MTCO_2e$/short ton-mile)

6.1.8 CARBON STORAGE IN SOIL

Carbon storage is soil refers to the potential secondary effect of carbon stored in soils from the land application of compost. Anaerobic digestion produces digestate as a byproduct which can be directly land applied or aerobically cured to produce finished compost.[33] Despite recognition that compost is often used for non-agricultural purposes, the carbon storage factor used in WARM is based only on application to agricultural lands.[34] Consistent with WARM, this Methodology also applies the WARM carbon storage factor for agricultural lands to alternative land application end-uses of compost or digestate. Studies show that benefits observed from agricultural land application would also be expected for various uses in other settings and that this approach is likely to result in conservative soil carbon storage values.[35]

[30] CARB (2014a), p. 55.

[31] CARB (2014a), p. 55.

[32] U.S. EPA (2019b), Exhibit 5-1.

[33] This Methodology applies the soil carbon storage factors used in WARM based on EPA modeling and studies of the fraction of carbon stored in soil after 10 years. Additional information about the soil carbon storage values can be found in WARM Management Practices Chapter (EPA 2019a).

[34] U.S. EPA (2019a), p. 4-16.

[35] Brown and Beecher (2020), p. 227-239.

The amount of carbon stored in soils varies by digester type (i.e., dry or wet), digestate treatment (i.e., aerobically cured or not), and feedstock type (i.e., mixed organics, food waste, yard waste), as displayed in Table 7,[36] and is calculated using Equation 15.

Table 7: Soil Carbon Storage Factor by Feedstock Type

FEEDSTOCK TYPE	DRY WITH CURING	DRY WITHOUT CURING	WET WITH CURING	WET WITHOUT CURING
	($MTCO_2e$/SHORT TON)			
Mixed Organics	0.09	0.22	0.03	0.08
Food Waste	0.03	0.08		
Yard Waste	0.16	0.38		

Equation 15: Carbon Storage in Soil from Land Application

$$\mathbf{CS} = \sum_{t} \left[(\mathbf{TONS}_{\mathbf{mo},t} \times \mathbf{SCSF}_{\mathbf{mo}} + \mathbf{TONS}_{\mathbf{fw},t} \times \mathbf{SCSF}_{\mathbf{fw}} + \mathbf{TONS}_{\mathbf{yw},t} \times \mathbf{SCSF}_{\mathbf{yw}}) \times \mathbf{YEARS}_{t} \right] \times \mathbf{PLA}$$

WHERE	
CS	Carbon stored in soil from land application of digestate or compost ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
TONS_t	Organic material diverted and sent to anaerobic digester by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) over time interval *t* (short tons feedstock/year) If composition of diverted waste is unknown, material is aggregated together as mixed organics.
SCSF	Soil carbon storage factor by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) from Table 7 ($MTCO_2e$/short ton feedstock)
YEARS_t	Duration of time interval *t* (years)
PLA	Percentage of digestate or compost distributed for land application (%)

[36] U.S. EPA (2019a), Exhibits 3-13, 3-14, 3-15 and 3-16.

6.1.9 AVOIDED EMISSIONS FROM DISPLACED FERTILIZER

Avoided emissions from displaced fertilizer refers to the potential secondary effect of avoiding net fugitive, stationary combustion, and mobile combustion emissions from the production and application of synthetic fertilizer displaced by compost. When digestate or finished compost produced by curing digestate is land applied, it may lead to the use of less synthetic fertilizer. Avoided emissions associated with the production and application of displaced fertilizer is calculated using the factors in Table 8[37] and Equation 16.

Table 8: Displaced Fertilizer Emission Factors

<table>
<tr><th rowspan="2">FEEDSTOCK TYPE</th><th>DRY WITH CURING</th><th>DRY WITHOUT CURING</th><th>WET WITH CURING</th><th>WET WITHOUT CURING</th></tr>
<tr><th colspan="4">($MTCO_2e$/SHORT TON)</th></tr>
<tr><td>Mixed Organics</td><td>0.01</td><td>0.01</td><td rowspan="3">0.02</td><td rowspan="3">0.03</td></tr>
<tr><td>Food Waste</td><td>0.01</td><td>0.02</td></tr>
<tr><td>Yard Waste</td><td>0.01</td><td>0.01</td></tr>
</table>

[37] U.S. EPA (2019a), Exhibits 3-13, 3-14, 3-15 and 3-16.

Equation 16: Avoided Emissions from Displaced Fertilizer

$$\mathbf{DF} = \sum_{t} \left[\left(\mathbf{TONS}_{\mathbf{mo},t} \times \mathbf{DFEF}_{\mathbf{mo}} + \mathbf{TONS}_{\mathbf{fw},t} \times \mathbf{DFEF}_{\mathbf{fw}} + \mathbf{TONS}_{\mathbf{yw},t} \times \mathbf{DFEF}_{\mathbf{yw}} \right) \times \mathbf{YEARS}_{t} \right] \times \mathbf{PLA}$$

WHERE	
DF	Avoided emissions from displaced fertilizer ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) over time interval t (short tons feedstock/year) If composition of diverted waste is unknown, material is aggregated together as mixed organics.
DFEF	Displaced fertilizer emission factor by waste type: mixed organics (mo), food waste (fw), or yard waste (yw) from Table 8[38] ($MTCO_2e$/short ton feedstock)
$YEARS_t$	Duration of time interval t (years)
PLA	Percentage of digestate or compost distributed for land application (%)

[38] U.S. EPA (2019a), Exhibits 3-13, 3-14, 3-15 and 3-16.

6.1.10 NET PROJECT GHG IMPACT & CARBON RETURN

The following subsection describes how to calculate the net GHG impact of the project, which includes primary and potential secondary GHG emission reductions, and how to calculate the Carbon Return, cost-effectiveness, and social cost of carbon benefit of the project.

The primary GHG emission reductions from diversion of organic waste for anaerobic digestion projects are calculated using Equation 17.

Equation 17: Primary GHG Emission Reductions from Project Operations

$$\mathbf{GHG_P = (ALE + DEF) - (WCD + PDO)}$$

WHERE	
GHG_P	Primary GHG emission reductions of project ($MTCO_2e$)
ALE	Avoided landfill emissions from Equation 3 ($MTCO_2e$)
DEF	Avoided emissions from displaced energy and fuel from Equation 12 ($MTCO_2e$)
WCD	Waste collection and delivery emissions (or emission reductions) from Equation 2 ($MTCO_2e$)
PDO	Processing and digester operation emissions from Equation 8 ($MTCO_2e$)

The potential secondary GHG emission reductions from diversion of organic waste for anaerobic digestion projects are calculated using Equation 18.

Equation 18: Potential Secondary GHG Emission Reductions of Project Operations

$$GHG_S = CS + DF - DTE - CTE$$

WHERE	
GHG_S	Secondary GHG emission reductions of project ($MTCO_2e$)
CS	Carbon stored in soil from land application of digestate or compost from Equation 15 ($MTCO_2e$)
DF	Avoided emissions from displaced fertilizer from land application of digestate or compost from Equation 16 ($MTCO_2e$)
DTE	Digestate transport emissions from Equation 13 ($MTCO_2e$)
CTE	Compost transport emissions from Equation 14 ($MTCO_2e$)

The net project GHG impact, which is based on the primary and secondary GHG emission reductions from a diversion of organic waste for anaerobic digestion project, is equal to the GHG emission reductions from project operations, as calculated using Equation 19.

Equation 19: GHG Emission Reductions from Project Operations

$$GHG_{PO} = GHG_P + GHG_S$$

WHERE	
GHG_{PO}	GHG emission reductions from project operations ($MTCO_2e$)
GHG_P	Primary GHG emission reductions of project from Equation 17 ($MTCO_2e$)
GHG_S	Secondary GHG emission reductions of project from Equation 18 ($MTCO_2e$)

The Carbon Return of a diversion of organic waste for anaerobic digestion project is the GHG benefit per thousand dollars of bond financing per year of project operation. Carbon Return is calculated using Equation 20.

Equation 20: Carbon Return of Project

$$CR = GHG_{PO} \,/\, \$ \,/\, YEARS$$

WHERE	
CR	Carbon Return of the project ($MTCO_2e$/\$1,000/year)
GHG_{PO}	GHG emission reductions from project operations from Equation 19 ($MTCO_2e$)
$\$$	Total bond financing for the diversion of organic waste for anaerobic digestion project (dollars, in thousands)
$YEARS$	Operational life (years)

The overall cost effectiveness of GHG emission reductions of a diversion of organic waste for anaerobic digestion project is the GHG benefit per thousand dollars of bond financing. GHG cost effectiveness is calculated using Equation 21.

Equation 21: GHG Cost Effectiveness of Project

$$GHG_{\$} = GHG_{PO} \,/\, \$$$

WHERE	
$GHG_{\$}$	GHG cost effectiveness of the project ($MTCO_2e$/\$1,000)
GHG_{PO}	GHG emission reductions from project operations from Equation 19 ($MTCO_2e$)
$\$$	Total bond financing for the diversion of organic waste for anaerobic digestion project (dollars, in thousands)

The social cost of carbon benefit of a project is calculated using the current social cost of carbon rate and Equation 22.

Equation 22: Social Cost of Carbon Benefit

$$\mathbf{SCC = GHG_{PO} \times \frac{51}{1,000}}$$

WHERE	
SCC	Social cost of carbon benefit ($, in thousands)
GHG_{PO}	GHG emission reductions from project operations from Equation 19 ($MTCO_2e$)
51	Social cost of carbon ($ per $MTCO_2e$)[39,40]
1,000	Conversion ($ per $1,000)

[39] Chemnick (2021).
[40] Whitehouse.gov (2021).

6.2 QUANTIFICATION OF GHG BENCHMARK

A benchmark is a representative standard of performance that facilitates measurement and comparison of impacts across investments in the same category. The analysis contained in this Methodology results in a benchmark for GHG emission reductions expected from the typical anaerobic digestion project based on common practice and a comparison of average landfill and digester emissions.

Dry digestion systems are projected to represent the majority of anaerobic digestion growth in the United States[41] and are therefore used for the GHG benchmark. Dry digestion systems can accept both food and yard waste and therefore the GHG benchmark uses the mixed organics category. The mixed organics category is a weighted average of both waste types. Consistent with the WARM default assumption, this Methodology assumes that common practice is to aerobically cure the digestate.[42]

The GHG benchmark for organic waste diversion for anaerobic digestion projects was determined using the methods and equations in Subsections 6.2.1 – 6.2.9 below. Each subsection covers a different SSR, and they are summarized in Subsection 6.2.10.

6.2.1 CONSTRUCTION EMISSIONS

Construction emissions refer to the stationary and mobile combustion emissions from construction/installation of an anaerobic digester, construction/expansion of a sorting facility, or installation of equipment at such facilities. This emission source is excluded from the GHG assessment boundary on account of it being small relative to the overall emission reductions and the construction phase being temporary. Moreover, it is anticipated that construction emissions would still eventually occur without the project due to the material's contribution toward landfill capacity.

6.2.2 WASTE GENERATION EMISSIONS

Waste generation emissions refer to stationary and mobile combustion emissions from the generation of waste. This emission source is excluded from the GHG assessment boundary on account of waste generation emissions being assumed to be equivalent with and without the project.

[41] The Environmental Research & Education Foundation (2015), p. 1.

[42] U.S. EPA (2019c), Analysis Inputs tab.

6.2.3 WASTE COLLECTION & DELIVERY EMISSIONS

Waste collection and delivery emissions refer to the mobile combustion emissions from fossil fuel consumed to collect and deliver waste to landfills or digester facilities. Emissions result from fossil fuel combustion by trucks used to collect and deliver waste and by the equipment used to process the material at a landfill or digester facility. For this GHG benchmark, transportation emissions from waste collection and delivery are assumed to be equivalent with and without the anaerobic digestion project (i.e., whether delivered to a landfill or digester facility) and are therefore excluded.

6.2.4 AVOIDED LANDFILL EMISSIONS

Avoided landfill emissions refer to the net fugitive, stationary combustion, and mobile combustion, emissions avoided from the decomposition of organic material at a landfill, including avoided methane emissions, avoided carbon storage in landfills, reduced bioenergy production from LFG capture systems (if applicable), and landfill equipment emissions. As organic waste decomposes in landfills, some of the carbon portion of these materials does not completely decompose and is stored in the landfill. The portion that does decompose is emitted as LFG, composed of CO_2 and CH_4. The CO_2 portion of the gas is biogenic and therefore not accounted for, consistent with IPCC guidance,[43] while the methane emissions are accounted for. Most methane generated at municipal landfills is from landfills with LFG recovery and electricity generation[44] so avoided emissions from fossil fuel-based energy displaced by the biogas is also accounted for.

WARM identifies the national average net GHG emissions from landfilling based on the typical LFG collection practices, average landfill moisture conditions, and U.S.-average non-baseload electricity grid mix,[45] as displayed in Table 9. The mixed organics category is a weighted average of the two organic waste types and is therefore used in the GHG benchmark calculations.

[43] IPCC (2006), Volume 5, Chapter 3, p. 3.6.

[44] U.S. EPA (2019a), Exhibit 6-1.

[45] U.S. EPA (2019a), Exhibit 6-16.

Table 9: Avoided Landfill Emissions

LANDFILL COMPONENT	MIXED ORGANICS ($MTCO_2e$/SHORT TON)
Collection and Processing Fuel Emissions	-0.02
Landfill CH_4 Emissions	-0.53
Landfill Carbon Storage	0.30
Avoided CO_2 from Energy Recovery	0.04
AVOIDED LANDFILL EMISSIONS	**-0.21 $MTCO_2e$/short ton feedstock**

6.2.5 PROCESSING & DIGESTER OPERATION EMISSIONS

Processing and digester operation emissions refer to the fugitive, stationary combustion, and mobile combustion emissions from the pre-processing of waste, operation of an anaerobic digester, and post-processing. For an anaerobic digester, fossil fuel is consumed[46] for pre-processing (e.g., grinding, screening, and mixing feedstock) and digester operation (e.g., front-end loaders, pumping and mixing within the system, and dewatering). Fugitive emissions also occur from digester operation (e.g., methane leaks) and post-processing (e.g., methane and nitrous oxide leaks from digestate treatment). The emission factor for processing and digester operation for the anaerobic digestion of mixed organics in a dry digester with curing of digestate, as assumed for this GHG benchmark, is displayed in Table 10.[47]

Table 10: Processing and Digester Operation Emissions

PROCESSING AND DIGESTER OPERATION EMISSIONS	**0.13 $MTCO_2e$/short ton feedstock**

[46] Anaerobic digestion operation also requires electricity. For the benchmark, which assumes electricity generation with the surplus being exported to the grid, this energy consumption is captured in Subsection 6.2.6 when determining the net surplus electricity exported to the electrical grid.

[47] U.S. EPA (2019a), Exhibit 3-13.

6.2.6 AVOIDED EMISSIONS FROM DISPLACED ENERGY OR FUEL

Avoided emissions from displaced energy or fuel refers to the stationary and mobile combustion emissions avoided from the displacement of fossil fuels by bioenergy or biofuel. A majority of currently operational digesters beneficially use biogas.[48] This GHG benchmark follows the typical pathway of combusting biogas in an on-site internal combustion engine to generate electricity and heat. The heat is captured and used to heat the reactor while electricity is used for digester operation. Surplus electricity is exported to the regional electrical grid.[49]

The net surplus electricity to the grid is the difference between the electricity generated and consumed in the anaerobic digestion process. To determine the quantity of net surplus electricity, WARM considers the amount of methane generated, leaked, flared, and combusted by digester type and feedstock. The net surplus electricity from the anaerobic digestion of mixed organics in a dry digester, as assumed for this GHG benchmark, is displayed in Table 11.[50]

Table 11: Net Surplus Electricity to the Grid

NET SURPLUS ELECTRICITY TO THE GRID	**121.76 kWh/short ton feedstock**

The avoided emissions associated with the offset of electricity generation in the power sector depends on the regional electrical grid. This GHG benchmark uses the eGRID national average[51] and, consistent with WARM, assumes that the surplus electricity offsets non-baseload electricity generation.[52] The resulting avoided emissions are displayed in Table 12.

Table 12: Avoided Emissions from Displaced Energy

DISPLACED ENERGY	**-0.079 $MTCO_2e$/short ton feedstock**

6.2.7 DIGESTATE OR COMPOST TRANSPORT EMISSIONS

Digestate or compost transport emissions refer to the mobile combustion emissions from fossil fuel consumed to transport digestate or finished compost to the site upon which it is land applied or landfilled. To determine the amount of byproduct to be transported, this GHG benchmark

[48] U.S. EPA (2019a), Exhibit 6-1.
[49] The Environmental Research & Education Foundation (2015), Table 8.
[50] U.S. EPA (2019a), Exhibit 3-7.
[51] U.S. EPA (2021c) column N in the Table 1 tab.
[52] U.S. EPA (2019a), p. 3.6.

assumes that common practice is to aerobically cure the digestate to produce compost.[53] It also assumes a transport distance of 40 miles[54] and uses the same ton-mile emission factor applied to waste collection and delivery in a diesel vehicle.[55] The resulting emission factor for transport of the compost byproduct, as assumed for this GHG benchmark, is displayed in Table 13.

Table 13: Digestate or Compost Transport Emissions

DIGESTATE OR COMPOST TRANSPORT EMISSIONS	**0.0034 MTCO$_2$e/short ton feedstock**

6.2.8 CARBON STORAGE IN SOIL

Carbon storage in soil refers to the potential secondary effect of carbon stored in soils from the land application of digestate or compost. Anaerobic digestion produces digestate as a byproduct which can be directly land applied or aerobically cured to produce finished compost. The soil carbon storage factor for mixed organics sent to a dry digester with curing of digestate, as assumed for this GHG benchmark, is displayed in Table 14.[56]

Table 14: Carbon Storage in Soil

CARBON STORAGE IN SOIL	**-0.09 MTCO$_2$e/short ton feedstock**

6.2.9 AVOIDED EMISSIONS FROM DISPLACED FERTILIZER

Avoided emissions from displaced fertilizer refers to the potential secondary effect of avoiding net fugitive, stationary combustion, and mobile combustion emissions from the production and application of synthetic fertilizer displaced by digestate or compost. The avoided fertilizer emission rate for mixed organics sent to a dry digester with curing of digestate, as assumed for this GHG benchmark, is displayed in Table 15.[57]

Table 15: Avoided Emissions from Displaced Fertilizer

AVOIDED EMISSIONS FROM DISPLACED FERTILIZER	**-0.01 MTCO$_2$e/short ton feedstock**

[53] U.S. EPA (2019c), Analysis Inputs tab.
[54] CARB (2014b), p. 29.
[55] U.S. EPA (2019b), Exhibit 5-1.
[56] U.S. EPA (2019a), Exhibit 3-13.
[57] U.S. EPA (2019a), Exhibit 3-13.

6.2.10 SUMMARY OF GHG BENCHMARK

The GHG benchmark for a project that diverts organic waste from a landfill for stand-alone anaerobic digestion is summarized in Table 16 below. The GHG benchmark represents both primary and secondary effects of the project.

Table 16: GHG Benchmark

SSR	EMISSIONS (+)/ EMISSION REDUCTIONS (-)
1 Construction Emissions	N/A
2 Waste Generation Emissions	N/A
3 Waste Collection & Delivery Emissions	0 $MTCO_2e$/short ton feedstock
4 Avoided Landfill Emissions	-0.21 $MTCO_2e$/short ton feedstock
5 Processing & Digester Operation Emissions	0.13 $MTCO_2e$/short ton feedstock
6 Avoided Emissions from Displaced Energy or Fuel	-0.079 $MTCO_2e$/short ton feedstock
GHG Benchmark for Primary Effects	-0.159 $MTCO_2e$/short ton feedstock
7 Digestate or Compost Transport Emissions	0.003 $MTCO_2e$/short ton feedstock
8 Carbon Storage in Soil	-0.09 $MTCO_2e$/short ton feedstock
9 Avoided Emissions from Displaced Fertilizer	-0.01 $MTCO_2e$/short ton feedstock
GHG Benchmark for Potential Secondary Effects	-0.097 $MTCO_2e$/short ton feedstock
GHG BENCHMARK FOR DIVERSION OF ORGANIC WASTE FOR ANAEROBIC DIGESTION PROJECTS	**-0.256 $MTCO_2e$/short ton feedstock**

A project's emission reductions, quantified per Section 6.1, will be assessed against this GHG benchmark using the methods in Section 6.3.

6.3 COMPARISON OF PROJECT GHG IMPACT TO BENCHMARK

This Section describes how project performance is assessed relative to the GHG benchmark. After calculating the total project emission reductions from the diversion of organic waste for anaerobic digestion in Section 6.1, the project GHG emission reductions are compared to the GHG benchmark determined in Section 6.2. To do this, the GHG benchmark must first be converted from the $MTCO_2e$/short ton of feedstock unit to $MTCO_2e$ using project-specific inputs and Equation 23.

Equation 23: GHG Benchmark Unit Conversion

$$\mathbf{GHG_B} = \left[\frac{\sum_t (\mathbf{TONS}_t \times \mathbf{YEARS}_t)}{\sum_t \mathbf{YEARS}_t}\right] \times \mathbf{0.256} \times \mathbf{25}$$

WHERE	
GHG_B	Benchmark GHG emission reductions ($MTCO_2e$)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
$YEARS_t$	Duration of time interval *t* (years)
0.256	Benchmark GHG emission reduction rate ($MTCO_2e$/short ton)
25	Operational life assumed for benchmark (years)

The resulting calibrated GHG benchmark is then compared to the project GHG impact to determine the project's relative performance. The project's emission reductions are compared to the GHG benchmark using Equation 24.

Equation 24: Comparison of Project GHG Impact to Benchmark

$$\mathbf{GHG_C} = \mathbf{GHG_{PO}} - \mathbf{GHG_B}$$

WHERE	
GHG_C	Project GHG impact compared to benchmark ($MTCO_2e$)
GHG_{PO}	GHG emission reductions from project operations from Equation 19 ($MTCO_2e$)
GHG_B	Benchmark GHG emission reductions from Equation 23 ($MTCO_2e$)

The project's emission reductions are also compared to the GHG benchmark on a percentage basis (e.g., project performance is X% relative to benchmark) using Equation 25.

Equation 25: Percentage Comparison of Project GHG Impact to Benchmark

$$\mathrm{GHG}_{\%} = \frac{\mathrm{GHG}_{\mathrm{PO}}}{\mathrm{GHG}_{\mathrm{B}}}$$

WHERE	
$\mathrm{GHG}_{\%}$	Project GHG impact compared to benchmark (%)
$\mathrm{GHG}_{\mathrm{PO}}$	GHG emission reductions of project operations from Equation 19 ($MTCO_2e$)
$\mathrm{GHG}_{\mathrm{B}}$	Benchmark GHG emission reductions from Equation 23 ($MTCO_2e$)

7 QUANTIFICATION OF BIOENERGY PRODUCTION IMPACT

Anaerobic digestion projects produce bioenergy and/or biofuel. In this Chapter, the quantity of bioenergy and/or biofuel produced by a project is compared to a bioenergy production benchmark representing the production expected from the typical anaerobic digestion project based on common practice. This Chapter also evaluates the project's bioenergy and/or biofuel production per thousand dollars invested.

7.1 PROJECT BIOENERGY IMPACT

For projects that generate electricity, the net surplus electricity is converted to megawatt hours (MWh) for comparability across sectors using Equation 26.

Equation 26: Project Net Surplus Electricity

$$\mathbf{MWh_P} = \frac{\sum_t (\mathbf{kWh}_t \times \mathbf{YEARS}_t)}{\mathbf{1,000}}$$

WHERE	
$\mathrm{MWh_P}$	Net surplus electricity production by the project (MWh)
t	Time interval (initial start-up period or remainder of operational life)
kWh_t	Net surplus electricity to grid over time interval *t* (kWh/year)
YEARS_t	Duration of time interval *t* (years)
1,000	Conversion kWh/MWh

In order to quantify the bioenergy and biofuel impact of the project, the net surplus energy or fuel produced by a project must first be converted to the comparable unit using Equation 27. Megajoules (MJ) conversion rates are sourced from the United States Energy Information Administration[58] and then converted to gigajoules (GJ) for comparability across sectors.

[58] U.S. EIA (2020).

Equation 27: Project Net Surplus Bioenergy and Biofuel Unit Conversion

$$
\begin{aligned}
GJ_P = & \sum_t (kWh_t \times YEARS_t) \times \left(\frac{3.6}{1,000}\right) + \sum_t (scf_t \times YEARS_t) \times \left(\frac{1.093}{1,000}\right) \\
& + \frac{\sum_t (RNG_t \times YEARS_t)}{139.3} \times \left(\frac{144.945}{1,000}\right) + \frac{\sum_t (DME_t \times YEARS_t)}{1.8} \times \left(\frac{144.945}{1,000}\right) \\
& + \left(\frac{\sum_t (HYD_t \times YEARS_t)}{1.019}\right) \times \left(\frac{126.958}{1,000}\right)
\end{aligned}
$$

WHERE	
GJ_P	Net surplus energy production by the project (GJ)
t	Time interval (initial start-up period or remainder of operational life)
kWh_t	Net surplus electricity to grid over time interval *t* (kWh/year)
$YEARS_t$	Duration of time interval *t* (years)
3.6	Conversion MJ/kWh
1,000	Conversion MJ/GJ
scf_t	Natural gas for pipeline injection over time interval *t* (scf/year)
1.093	Conversion MJ/scf
RNG_t	Annual renewable natural gas fuel production over time interval *t* (scf/year)
139.3	Conversion scf RNG/DGE[59]
DME_t	Annual dimethyl ether fuel production over time interval *t* (gallons/year)
1.8	Conversion gallon DME/DGE[60]
144.945	Conversion MJ/DGE
HYD_t	Annual hydrogen fuel production over time interval *t* (kg/year)
1.019	Conversion kg hydrogen/GGE[61]
126.958	Conversion MJ/GGE

[59] U.S. DOE (2014).
[60] McKone et al. (2015), p. 24.
[61] U.S. DOE (n.d.).

The bioenergy production per thousand dollars of bond financing invested in the project is calculated using Equation 28.

Equation 28: Net Surplus Bioenergy Production per $1,000 Invested

$$GJ_{\$} = \frac{GJ_P}{\$}$$

WHERE	
$GJ_{\$}$	Net surplus bioenergy production per $1,000 invested (GJ/$1,000)
GJ_P	Net surplus energy production by the project from Equation 27 (GJ)
$\$$	Total bond financing for the diversion of organic waste for anaerobic digestion project (dollars, in thousands)

7.2 QUANTIFICATION OF BIOENERGY BENCHMARK

A benchmark is a representative standard of performance that facilitates measurement and comparison of impacts across investments in the same category. The analysis contained in this section results in a benchmark for the bioenergy production expected from the typical anaerobic digestion project based on common practice. Consistent with the GHG benchmark described in Section 6.2, the bioenergy benchmark assumes that common practice is a dry digestion system using mixed organics and combusting biogas in an on-site internal combustion engine to generate electricity and heat. The heat is captured and used to heat the reactor while electricity is used for digester operation. Surplus electricity is exported to the regional electrical grid.[62]

The bioenergy benchmark uses the WARM net surplus electricity to grid value for mixed organics of 121.76 kWh/short ton feedstock.[63] The bioenergy benchmark must then be converted from a kWh/short ton of feedstock unit to GJ using project-specific inputs and Equation 29.

[62] The Environmental Research & Education Foundation (2015), Table 8.

[63] U.S. EPA (2019a), Exhibit 3-7.

Equation 29: Bioenergy and Biofuel Benchmark Unit Conversion

$$\mathbf{GJ_B} = \left[\frac{\sum_t (\mathbf{TONS}_t \times \mathbf{YEARS}_t)}{\sum_t \mathbf{YEARS}_t}\right] \times \mathbf{121.76} \times \left(\frac{\mathbf{3.6}}{\mathbf{1,000}}\right) \times \mathbf{25}$$

WHERE	
GJ_B	Bioenergy benchmark for net surplus energy (MJ)
t	Time interval (initial start-up period or remainder of operational life)
$TONS_t$	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
$YEARS_t$	Duration of time interval *t* (years)
121.76	Benchmark net surplus electricity to grid (kWh/short ton feedstock)
3.6	Conversion MJ/kWh
1,000	Conversion MJ/GJ
25	Operational life assumed for benchmark (years)

7.3 COMPARISON OF PROJECT BIOENERGY IMPACT TO BENCHMARK

This Section describes how project performance is assessed relative to the bioenergy benchmark. After calculating the project bioenergy production from the diversion of organic waste for anaerobic digestion in Section 7.1, the project bioenergy production is compared to the calibrated bioenergy benchmark determined in Section 7.2 to determine the project's relative performance using Equation 30.

Equation 30: Comparison of Project Bioenergy Production to Benchmark

$$\mathbf{GJ_C} = \mathbf{GJ_P} - \mathbf{GJ_B}$$

WHERE	
GJ_C	Net surplus bioenergy production by project compared to benchmark (GJ)
GJ_P	Net surplus energy production by the project from Equation 27 (GJ)
GJ_B	Bioenergy benchmark for net surplus energy from Equation 29 (GJ)

The project's bioenergy production is also compared to the bioenergy benchmark on a percentage basis (e.g., project performance is X% relative to benchmark) using Equation 31.

Equation 31: Percentage Comparison of Project Bioenergy Production to Benchmark

$$\mathbf{GJ_{\%}} = \frac{\mathbf{GJ_P}}{\mathbf{GJ_B}}$$

WHERE	
$GJ_{\%}$	Net surplus bioenergy production by project as a percentage of the benchmark (%)
GJ_P	Net surplus energy production by the project from Equation 27 (MJ)
GJ_B	Bioenergy benchmark for net surplus energy from Equation 29 (MJ)

8 QUANTIFICATION OF LANDFILL DIVERSION IMPACT

In addition to GHG emission reductions, anaerobic digestion projects reduce the amount of waste entering landfills, thereby avoiding tipping fees and reducing pressure on limited land. Net organic material diverted from landfills is calculated using Equation 32.

Equation 32: Net Organic Material Diverted from Landfills

$$\mathrm{NOMD} = \sum_t \mathrm{TONS}_t \times \mathrm{YEARS}_t$$

WHERE	
NOMD	Net organic material diverted by the project (short tons)
t	Time interval (initial start-up period or remainder of operational life)
TONS_t	Organic material diverted and sent to anaerobic digester over time interval *t* (short tons feedstock/year)
YEARS_t	Duration of time interval *t* (years)

The total net material diverted from landfills is calculated using Equation 33.

Equation 33: Net Material Diverted from Landfills

$$\mathrm{NMD} = \mathrm{NOMD} + \sum_t (\mathrm{RMR}_t \times \mathrm{YEARS}_t)$$

WHERE	
NMD	Net material diverted by the project (short tons)
NOMD	Net organic material diverted by the project (short tons)
t	Time interval (initial start-up period or remainder of operational life)
RMR_t	Residual material initially diverted and later recycled over time interval *t* (short tons/year)
YEARS_t	Duration of time interval *t* (years)

The waste diversion per thousand dollars of bond financing invested in the project is calculated using Equation 34.

Equation 34: Landfill Diversion per $1,000 Invested

$$\mathbf{NDD} = \frac{\mathbf{NMD}}{\$}$$

WHERE	
NDD	Net material diverted per $1,000 invested (short tons/$1,000)
NMD	Net material diverted by the project from Equation 33 (short tons)
$	Total bond financing for the diversion of organic waste for anaerobic digestion project (dollars, in thousands)

9 QUANTIFICATION OF DIGESTATE OR COMPOST PRODUCTION

In addition to diverting organic material from landfills and producing bioenergy, anaerobic digestion projects produce digestate or finished compost for land application. For projects that produce digestate, the quantity of digestate produced is calculated using Equation 35.

Equation 35: Digestate Produced

$$\mathbf{DP = NOMD \times 0.84}$$

WHERE	
DP	Digestate produced by project (short tons)
$NOMD$	Net organic material diverted by the project from Equation 32 (short tons)
0.84	Conversion of feedstock to digestate (ton digestate/ton feedstock)[64]

The digestate produced per thousand dollars of bond financing invested in the project is calculated using Equation 36.

Equation 36: Digestate Produced per $1,000 Invested

$$\mathbf{DPD = \frac{DP}{\$}}$$

WHERE	
DPD	Digestate produced per $1,000 invested (short tons/$1,000)
DP	Digestate produced by project from Equation 35 (short tons)
$\$$	Total bond financing for the diversion of organic waste for anaerobic digestion project (dollars, in thousands)

[64] CARB (2014a), p. 55.

For projects that produce compost, the quantity of compost produced is calculated using Equation 37.

Equation 37: Compost Produced

$$\mathbf{CP = NOMD \times 0.84 \times 0.64}$$

WHERE	
CP	Compost produced by project (short tons)
NOMD	Net organic material diverted by the project from Equation 32 (short tons)
0.84	Conversion of feedstock to digestate (ton digestate/ton feedstock)[65]
0.64	Conversion of digestate to compost (ton compost/ton digestate)[66]

The compost produced per thousand dollars of bond financing invested in the project is calculated using Equation 38.

Equation 38: Compost Produced per $1,000 Invested

$$\mathbf{DPD = \frac{DP}{\$}}$$

WHERE	
CPD	Compost produced per $1,000 invested (short tons/$1,000)
CP	Compost produced by project from Equation 37 (short tons)
$	Total bond financing for the diversion of organic waste for anaerobic digestion project (dollars, in thousands)

[65] CARB (2014a), p. 55.
[66] CARB (2014a), p. 55.

10 KEY PERFORMANCE INDICATORS

The KPIs resulting from this Methodology are shown in Table 17. Projects funded with bond proceeds may align with the United Nations Sustainable Development Goals (SDGs).[67] Diversion of organic waste for anaerobic digestion project KPIs map to particular SDGs, as signified by their icons.[68]

Table 17: Key Performance Indicators

KEY PERFORMANCE INDICATOR	EQUATION REFERENCE	SDG[69]
GHG Emission Reductions from Project Operations ($MTCO_2e$)	Equation 19	13 CLIMATE ACTION
Primary GHG Emission Reductions from Project Operations ($MTCO_2e$)	Equation 17	
Potential Secondary GHG Emission Reductions from Project Operations ($MTCO_2e$)	Equation 18	
Carbon Return ($MTCO_2e$/$1,000/year)	Equation 20	
GHG Cost Effectiveness ($MTCO_2e$/$1,000)	Equation 21	
Social Cost of Carbon Benefit ($, in thousands)	Equation 22	
Project GHG Impact Compared to Benchmark ($MTCO_2e$)	Equation 24	
Project GHG Impact Compared to Benchmark (%)	Equation 25	

[67] United Nations (2015).

[68] Nordic Public Sector Issuers (2020), p. 17.

[69] An anaerobic digestion project may contribute to the following individual SDG targets: 7.2, 11.6, 12.5, 13.3, and 15.3.

KEY PERFORMANCE INDICATOR	EQUATION REFERENCE	SDG[69]
Surplus Electricity Produced (MWh)	Equation 26	7 AFFORDABLE AND CLEAN ENERGY
Surplus Bioenergy or Biofuel Produced (GJ)	Equation 27	
Surplus Bioenergy or Biofuel Produced per $1,000 Invested (GJ/$1,000)	Equation 28	
Project Bioenergy or Biofuel Production Compared to Benchmark (GJ)	Equation 30	
Project Bioenergy or Biofuel Production Compared to Benchmark (%)	Equation 31	
Net Organic Material Diverted from Landfills (short tons)	Equation 32	11 SUSTAINABLE CITIES AND COMMUNITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Net Material Diverted from Landfills (short tons)	Equation 33	
Net Material Diverted per $1,000 Invested (short tons/$1,000)	Equation 34	
Digestate Produced (short tons)	Equation 35	15 LIFE ON LAND
Digestate Produced per $1,000 Invested (short tons/$1,000)	Equation 36	
Compost Produced (short tons)	Equation 37	
Compost Produced per $1,000 Invested (short tons/$1,000)	Equation 38	

11 DATA REQUIREMENTS

In order to assess the impacts of a diversion of organic waste for anaerobic digestion project against the benchmarks contained in this Methodology, project-specific data is required. Data requirements fall into two categories: data required at the time of ex-ante reporting prior to the project becoming operational and data required for ex-post reporting once the project is operational. These data are necessary inputs to quantify environmental impacts using this Methodology and the accompanying tool.

11.1 EX-ANTE REPORTING

The project-specific data required to quantify the environmental impacts of a diversion of organic waste for anaerobic digestion project prior to the project becoming operational are displayed in Table 18. Metrics with an asterisk (*) after them have default values available for use if project-specific data is unavailable.

Table 18: Data Requirements for Ex-Ante Quantification and Reporting

METRIC	UNIT	REFERENCE
GENERAL PROJECT INFORMATION		
Total bond financing for the diversion of organic waste for anaerobic digestion project	Dollars	Equations 20, 21, 28, 34, 36 & 38
LANDFILL INFORMATION		
Location of landfill from which material is diverted	State	Subsection 6.1.4
Existence of LFG capture system at the landfill from which material is diverted.	Yes or No	
• If yes, moisture conditions at location of landfill from which material is diverted. Select from: ◈ Dry: <20 inches of precipitation/year ◈ Moderate: 20-40 inches of precipitation/year ◈ Wet: >40 inches of precipitation/year ◈ Bioreactor: Water is added until the moisture content reaches 40 percent moisture on a wet weight basis	N/A	

METRIC	UNIT	REFERENCE
• If yes, select gas collection efficiency, as defined in WARM: ◈ Worst-case scenario ◈ Typical operation ◈ Aggressive gas collection ◈ California regulatory collection	%	
• If yes, select primary and, if applicable, secondary end-use for gas: ◈ Gas is recovered for energy ◈ Gas is flared	N/A	
• If yes, percentage of gas sent to: ◈ Primary end-use for gas ◈ Secondary end-use for gas, if applicable	%	
ANAEROBIC DIGESTER INFORMATION		
If different from 25 years assumed by this Methodology,[70] project operational life*	Years	Section 4.2 Equations 2, 3, 4, 5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 20, 23, 26, 27, 29, 32 & 33
Duration of initial start-up period prior to full operation	Years	
Anaerobic digestion operation type. Select from: • Wet mesophilic digester with curing of digestate • Wet mesophilic digester without curing of digestate • Dry mesophilic digester with curing of digestate • Dry mesophilic digester without curing of digestate	N/A	Equations 4, 5, 6, 13, 14, 15 & 16

[70] To apply a different operational life to the quantification of project benefits, project proponents must substantiate the alternative project duration with documentation (i.e., equipment manufacturer specifications or organic waste processing contracts).

METRIC	UNIT	REFERENCE
Type of bioenergy or biofuel produced. Select from: • Electricity for export to grid • Natural gas for pipeline injection • Vehicle fuel (RNG) • Vehicle fuel (hydrogen) • Vehicle fuel (DME)	N/A	Equations 4, 7, 9, 10, 11 & 26
Quantity of bioenergy or biofuel produced annually • Electricity for export to grid • Natural gas for pipeline injection • Vehicle fuel (RNG) • Vehicle fuel (hydrogen) • Vehicle fuel (DME)	 kWh/year scf/year scf/year kg/year gallons/year	Equations 9, 10, 11, 26 & 27
DIVERTED MATERIAL INFORMATION		
Quantity of organic material annually diverted from a landfill and sent to anaerobic digester If known, quantity by material type* • Mixed organics • Food waste • Yard trimmings	Short tons feedstock/year	Equations 2, 3, 4, 5, 6, 7, 13, 14, 15, 16, 23, 29 & 32
Quantity of residual material initially diverted and later recycled	Short tons/year	Equations 2, 3, 4, 5 & 33
Quantity of residual material initially diverted but later landfilled	Short tons/year	Equations 3, 4 & 5
DIGESTATE / FINISHED COMPOST INFORMATION		
Percent of digestate or compost distributed for land application	%	Equations 15 & 16

METRIC	UNIT	REFERENCE
TRANSPORTATION INFORMATION		
Average distance traveled to transport waste from curb to: • Anaerobic digester facility* • Landfill* For each location, select from: ◈ ≤50 miles ◈ 51-100 miles ◈ 101-150 miles ◈ 151-200 miles ◈ >200 miles	Miles	Equation 2
Average distance traveled to transport residual material from digester facility to landfill or other facility Select from: ◈ ≤50 miles ◈ 51-100 miles ◈ 101-150 miles ◈ 151-200 miles ◈ >200 miles	Miles	Equation 2
Average distance traveled to transport digestate/compost from digester facility to land application site or landfill Select from: ◈ ≤50 miles ◈ 51-100 miles ◈ 101-150 miles ◈ 151-200 miles ◈ >200 miles	Miles	Equation 13

METRIC	UNIT	REFERENCE
Existence of alternative fueled vehicles for waste collection and delivery. • If yes, percentage of fleet that is biodiesel • If yes, percentage of fleet that is CNG • If yes, percentage of fleet that is RNG • If yes, percentage of fleet that is hydrogen • If yes, percentage of fleet that is electric	Yes/No %	Equation 1

11.2 EX-POST REPORTING

The project-specific data required to quantify the environmental impacts of a diversion of organic waste for anaerobic digestion project once the project becomes operational are displayed in Table 19. Metrics with an asterisk (*) after them have default values available for use if project-specific data is unavailable.

Table 19: Data Requirements for Ex-post Quantification and Reporting

METRIC	UNIT	REFERENCE
Quantity of bioenergy or biofuel produced annually • Electricity for export to grid • Natural gas for pipeline injection • Vehicle fuel (RNG) • Vehicle fuel (hydrogen) • Vehicle fuel (DME)	 kWh/year scf/year scf/year kg/year gallons/year	Equations 9, 10, 11, 26 & 27
Quantity of organic material annually diverted from a landfill and sent to anaerobic digester If known, quantity by material type* • Mixed organics • Food waste • Yard trimmings	Short tons feedstock/year	Subsection 6.1.4 Equations 2, 3, 4, 5, 6, 7, 13, 14, 15, 16, 23, 29 & 32
Quantity of residual material initially diverted and later recycled	Short tons/year	Equations 2, 3, 4, 5 & 33
Quantity of residual material initially diverted but later landfilled	Short tons/year	Equations 3, 4 & 5
Percent of digestate or compost distributed for land application	%	Equations 15 & 16
UPDATED INFORMATION (ONLY IF DIFFERENT FROM INFORMATION USED FOR EX-ANTE REPORTING)		
Total bond financing for the diversion of organic waste for anaerobic digestion project	Dollars	Equations 20, 21, 28, 34, 36 & 38
Duration of initial start-up period prior to full operation	Years	2, 3, 4, 5, 6, 7, 9, 10, 11, 13, 14, 15, 16, 23, 26, 27, 29, 32 & 33

METRIC	UNIT	REFERENCE
Average distance traveled to transport waste, from curb to: • Anaerobic digester facility* • Landfill* For each location, select from: ◈ ≤50 miles ◈ 51-100 miles ◈ 101-150 miles ◈ 151-200 miles ◈ >200 miles	Miles	Equation 2
Average distance traveled to transport residual material from digester facility to landfill or other facility Select from: ◈ ≤50 miles ◈ 51-100 miles ◈ 101-150 miles ◈ 151-200 miles ◈ >200 miles	Miles	Equation 2
Average distance traveled to transport digestate/compost from digester facility to land application site or landfill Select from: ◈ ≤50 miles ◈ 51-100 miles ◈ 101-150 miles ◈ 151-200 miles ◈ >200 miles	Miles	Equation 13

METRIC	UNIT	REFERENCE
Existence of alternative fueled vehicles for waste collection and delivery. • If yes, percentage of fleet that is CNG • If yes, percentage of fleet that is RNG • If yes, percentage of fleet that is hydrogen • If yes, percentage of fleet that is electric	Yes/No %	Equation 1

12 DEFINITIONS

Anaerobic digestion	Anaerobic digestion is a biological process in which microorganisms break down biodegradable organic material in the absence of oxygen. The process produces biogas and digested solids, referred to as digestate.
Benchmark	A representative standard of performance that facilitates measurement and comparison of impacts across investments in the same category.
Carbon Return	A project's GHG benefit ($MTCO_2e$) per unit of investment (thousand dollars) per year of project operation.
Curing of digestate	An aerobic composting treatment for digestate solids before land application resulting in the stabilization of organics in the finished compost.
Dry mesophilic digester	A digester that typically operates between 20° and 40°C and is designed to process materials with a solids content between 25 and 40% and process solid substrates without the addition of water. These digesters can accept food and yard waste.
End-use option	A method of biogas utilization. This Methodology calculates benefits of projects that utilize biogas for electricity generation, pipeline injection, and vehicle fuel production.
Food waste	Uneaten food from residences, commercial establishments such as grocery stores and restaurants, institutional sources such as school cafeterias, and industrial sources such as factory lunchrooms.
GHG source, sink, or reservoir (SSR)	• GHG Source: Physical unit or process that releases a GHG into the atmosphere. • GHG Sink: Physical unit or process that removes a GHG from the atmosphere. • GHG Reservoir: Physical unit or component of the biosphere, geosphere or hydrosphere with the capability to store or accumulate a GHG removed from the atmosphere by a GHG sink or captured from a GHG source.
Mixed organics	Mixed food and yard waste, weighted as 53 percent food waste and 47 percent yard waste.

Mixed recyclables	Weighted average of approximately 1 percent aluminum cans, 2 percent steel cans, 6 percent glass, 1 percent high density polyethylene (HDPE), 2 percent polyethylene terephthalate (PET), 57 percent corrugated cardboard, 7 percent magazines/third-class mail, 10 percent newspaper, 8 percent office papers, <1 percent phonebooks, <1 percent textbooks, and 5 percent dimensional lumber.
Municipal solid waste (MSW)	Waste materials from households, commercial, institutional, and light industrial facilities collected and managed by a municipality. MSW generally includes metals and glass, plastics, paper and wood, organics, mixed categories, and composite products. MSW does not include construction and demolition, industrial, or agricultural waste.
Residual material	Solid waste material initially diverted for anaerobic digestion and later sent for disposal at a landfill.
Stand-alone anaerobic digestion	Stand-alone anaerobic digestion is a specific type of digester that primarily uses food waste as a feedstock and is distinguished from on-farm digesters or digesters at water resource recovery facilities.
Wet mesophilic digester	A digester that typically operates between 20° and 40°C and is designed to process pumpable slurries. These digesters cannot accept yard waste.
Yard waste	Yard trimmings from residential, institutional, and commercial sources weighted as 50 percent grass, 25 percent leaves, and 25 percent tree and brush trimmings.

APPENDIX A: ELECTRIC VEHICLE EMISSION FACTORS

The table below provides the emission factors used in Equation 1 for quantifying emissions from electric vehicles used for waste collection and delivery.

STATE	ELECTRIC VEHICLE ($MTCO_2e$/SHORT TON-MILE)
Alabama	0.00004
Alaska	0.00004
Arizona	0.00005
Arkansas	0.00005
California	0.00003
Colorado	0.00005
Connecticut	0.00002
Delaware	0.00003
District of Columbia	0.00002
Florida	0.00003
Georgia	0.00005
Hawaii	0.00005
Idaho	0.00003
Illinois	0.00006
Indiana	0.00006
Iowa	0.00006
Kansas	0.00007
Kentucky	0.00006
Louisiana	0.00004
Maine	0.00002

STATE	ELECTRIC VEHICLE ($MTCO_2e$/SHORT TON-MILE)
Maryland	0.00005
Massachusetts	0.00003
Michigan	0.00006
Minnesota	0.00005
Mississippi	0.00003
Missouri	0.00006
Montana	0.00007
Nebraska	0.00007
Nevada	0.00003
New Hampshire	0.00003
New Jersey	0.00003
New Mexico	0.00006
New York	0.00003
North Carolina	0.00005
North Dakota	0.00007
Ohio	0.00006
Oklahoma	0.00004
Oregon	0.00003
Pennsylvania	0.00004
Rhode Island	0.00003
South Carolina	0.00004
South Dakota	0.00005
Tennessee	0.00005
Texas	0.00004
Utah	0.00005

STATE	ELECTRIC VEHICLE ($MTCO_2e$/SHORT TON-MILE)
Vermont	0.00001
Virginia	0.00003
Washington	0.00004
West Virginia	0.00007
Wisconsin	0.00005
Wyoming	0.00007

APPENDIX B: eGRID2019 STATE NON-BASELOAD ELECTRICITY EMISSION FACTORS

The table below provides the state non-baseload electricity emission factors used in Equation 4 for quantifying emissions from electricity usage for pre-processing and digester operations and in Equation 9 for quantifying avoided emissions from electricity produced by the project and exported to the grid.

STATE	NON-BASELOAD EMISSIONS (lb CO_2e / MWh)
Alabama	1,162.299
Alaska	1,371.377
Arizona	1,467.457
Arkansas	1,565.806
California	864.334
Colorado	1,584.879
Connecticut	771.868
Delaware	849.823
District of Columbia	664.27
Florida	1,050.429
Georgia	1,630.601
Hawaii	1,674.126
Idaho	859.966
Illinois	1,889.278
Indiana	1,848.58
Iowa	1,802.295
Kansas	2,192.467

STATE	NON-BASELOAD EMISSIONS ($lb\ CO_2e$ / MWh)
Kentucky	1,828.187
Louisiana	1,152.779
Maine	622.581
Maryland	1,647.189
Massachusetts	903.664
Michigan	1,756.348
Minnesota	1,553.885
Mississippi	1,051.861
Missouri	1,874.669
Montana	2,225.371
Nebraska	2,117.833
Nevada	1,069.497
New Hampshire	957.585
New Jersey	975.324
New Mexico	1,814.461
New York	1,021.243
North Carolina	1,450.284
North Dakota	2,069.934
Ohio	1,856.679
Oklahoma	1,400.752
Oregon	1,085.509
Pennsylvania	1,362.902
Rhode Island	915.083
South Carolina	1,418.033
South Dakota	1,515.503

STATE	NON-BASELOAD EMISSIONS ($lb\ CO_2e$ / MWh)
Tennessee	1,595.009
Texas	1,326.109
Utah	1,677.47
Vermont	402.414
Virginia	1,062.64
Washington	1,426.656
West Virginia	2,079.335
Wisconsin	1,684.541
Wyoming	2,346.914

APPENDIX C: REFERENCES

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