American Carbon Registry
AT WINROCK INTERNATIONAL

METHODOLOGY FOR THE QUANTIFICATION MONITORING, REPORTING AND VERIFICATION OF GREENHOUSE GAS EMISSIONS REDUCTIONS AND REMOVALS FROM

LANDFILL GAS DESTRUCTION AND BENEFICIAL USE PROJECTS

VERSION 2.0

July 2020

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ABOUT AMERICAN CARBON REGISTRY® (ACR)

A leading carbon offset program founded in 1996 as the first private voluntary GHG registry in the world, ACR operates in the voluntary and regulated carbon markets. ACR has unparalleled experience in the development of environmentally rigorous, science-based offset methodologies as well as operational experience in the oversight of offset project verification, registration, offset issuance and retirement reporting through its online registry system.

ACKNOWLEDGEMENTS

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Version 2.0 of this Methodology was developed in cooperation with Loci Controls, Inc.

ACRONYMS

CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
Offsets	Carbon Offset Credits
CAA	Clean Air Act
CNG	Compressed Natural Gas
ERT	Emission Reduction Tonne
GCCS	Gas Collection and Control System
SSR	GHG Source, Sink, or Reservoir
GWP	Global Warming Potential
LFG	Landfill Gas
LFGTE	Landfill Gas-to-Energy
LNG	Liquefied Natural Gas
CH_4	Methane
MSW	Municipal Solid Waste Landfill
NMOC	Non-Methane Organic Compound
NSPS	New Source Performance Standard
RCRA	Resource Conservation & Recovery Act
WIP	Waste in Place

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1 BACKGROUND AND APLICABILITY

1.1 SUMMARY DESCRIPTION OF THE METHODOLOGY

Table 1: Eligible LFG Activities

PROJECT ACTIVITY	DESCRIPTION
Destruction in a flare	Burning LFG onsite in an open or an enclosed flare.
Landfill gas to energy	Converting LFG in an engine, turbine or boiler to energy to be used on- or off-site.
Natural gas pipeline injection	Processing of LFG for injection into a natural gas pipeline.

The collection and combustion of landfill gas (LFG) is an effective method for decreasing the greenhouse gas (GHG) emissions from landfills that would have otherwise been vented to the atmosphere. This Methodology provides the quantification and accounting frameworks, including eligibility and monitoring requirements, for the creation of carbon offset credits from the reductions in GHG emissions resulting from the destruction or utilization of landfill gas at eligible landfills. The Methodology is intended to be used as an incentive to increase these activities and utilizes a flexible additionality framework which is based on either a performance standard or ACR's three-prong additionality test, as stipulated in Section 3.

1.2 APPLICABILITY CONDITIONS

Projects that reduce methane emissions as a result of the combustion or beneficial use of landfill gas in any of the following activities are considered a "project activity" under this Methodology:

- The destruction of landfill gas in an open or closed flare;
- The conversion of landfill gas in a turbine, boiler or generator to energy;

- The enhancement of landfill gas for injection into a natural gas pipeline;
- The enhancement of landfill gas for use in fleet vehicles, trucks and cars;
- The installation of an automated collection system that increases landfill gas collection efficiency above that obtained with standard collection methods with methane destruction, conversion, or enhancement occurring in any of the above “project activities”.
  - To qualify as an automated collection system that increases landfill gas collection efficiency, the system must deploy automated control and measurement devices which result in an incremental increase in the aggregate methane volume that is captured and which is shown to be attributable to the automated collection system as determined by Equations 2-10 set forth below. An automated collection system must include equipment installed on individual collection wells as part of the gas collection system that can measure, at minimum, O_2, CH_4, and CO_2 concentrations in the landfill gas being collected, pressure applied to the wellhead, and include an actuated valve where the valve can be operated remotely with automation.

In addition to satisfying the latest ACR program eligibility requirements as found in the *ACR Standard*, project activities must satisfy the following conditions for this Methodology to be applicable:

- The project is located in the United States; and
- The project is not required by any regulatory agency.

1.3 START DATE

The Start Date is the date that the landfill gas project became operational. For purposes of this Methodology, a project is considered to be operational when methane is continuously destroyed following a start-up period which may be a maximum of 6 months after the date of project commissioning[1]. Project commissioning is the first day which the GCCS and respective destruction device(s) are fully operational and either destroying or enhancing landfill gas.

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[1] For projects that install an automated collection system that increases landfill gas collection efficiency as a stand-alone project activity, a project is considered to be operational upon commissioning of the automated collection system which may be up to 6 months after the system has been deployed. For clarity, the start date of a project that installs an automated collection system that increases landfill gas collection efficiency as a stand-alone project activity is not tied to the date when the landfill gas destruction device(s) began operation.

1.4 CREDITING PERIOD

A Crediting Period is the finite length of time for which a GHG Project Plan is valid, and during which a project can generate offsets against its baseline scenario. The crediting period for a project activity shall be ten years.

Projects that have previously generated carbon offsets in a GHG Program other than ACR and whose crediting period has expired may apply for a new crediting period under the ACR program. As with all projects, the requirements of this Methodology must be met and the project must receive a positive validation opinion.

1.5 REPORTING PERIOD

A Reporting Period is the portion of time during the crediting period for which the project is reporting emission reductions to be verified and issued. Reporting periods shall not exceed five (5) years.

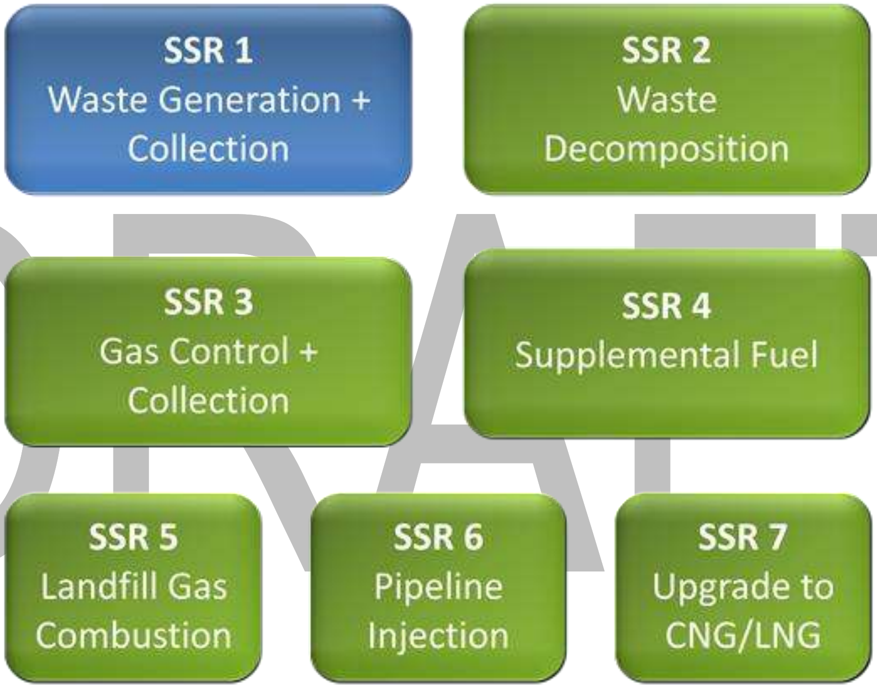
1.6 PERIODIC REVIEWS AND REVISIONS

ACR may require revisions to this Methodology to ensure that monitoring, reporting, and verification systems adequately reflect project activities. This Methodology may also be periodically updated to reflect regulatory changes, emission factor revisions, or expanded applicability criteria. Before beginning a project, the project proponent should ensure that they are using the latest version of the Methodology.

2 PROJECT BOUNDARIES

2.1 GEOGRAPHIC BOUNDARY

Figure 1: Project Boundary Diagram for Landfill Gas Projects



The Blue SSR represents emission sources outside of the project boundary while the green SSRs are those included in the project boundary. Within the boundaries, the sources of GHG emissions and removals are from the waste decomposition, landfill gas collection and control system, the maintenance or operations of the destruction or combustion device(s), and any emissions associated with the enhancement of LFG. Table 2 lists the GHG sources included and excluded depending on whether the sources are within or outside project boundaries.

Table 2: Greenhouse Gases and Sources

SSR		SOURCE DESCRIPTION	GAS	INCLUDED (I) OR EXCLUDED (E)	COMMENTS
1	Waste Generation & Collection	Emissions from the generation and hauling of waste to the landfill	CO_2	E	Emissions resulting from this SSR should be equivalent in both the project and baseline scenarios.
			CH_4	E	
			N_2O	E	
2	Waste Decomposition	Emissions from the decomposition of waste at the landfill	CO_2	E	Emissions are assumed to be de minimis.
			CH_4	I	Primary GHG affected by the project.
			N_2O	E	Emissions are assumed to be de minimis.
3	Gas Collection & Control	Emissions associated with the energy consumed to collect and process LFG	CO_2	I	Emissions resulting from the GCCS shall be included.
			CH_4	E	Emissions are assumed to be de minimis.
			N_2O	E	
4	Supplemental fuel	Combustion of fossil fuels to supplement the destruction or use of LFG	CO_2	I	Emissions resulting from the use of supplemental fuel shall be included.
			CH_4	I	
			N_2O	E	Emissions are assumed to be de minimis.
5	Landfill Gas Combustion	The combustion of LFG in an eligible destruction device	CO_2	E	Emissions are assumed to be de minimis.
			CH_4	I	Emissions resulting from the incomplete combustion of LFG shall be included.
			N_2O	E	Emissions are assumed to be de minimis.

SSR		SOURCE DESCRIPTION	GAS	INCLUDED (I) OR EXCLUDED (E)	COMMENTS
6	Pipeline Injection	The enhancement of LFG to be injected into a natural gas pipeline	CO_2	I	Emissions resulting from the enhancement of LFG shall be included.
			CH_4	I	
			N_2O	E	Emissions are assumed to be de minimis.
7	CNG/LNG Upgrade	The enhancement of LFG to be used in fleet vehicles, trucks or cars.	CO_2	I	Emissions resulting from the enhancement of LFG shall be included.
			CH_4	E	Emissions are assumed to be de minimis.
			N_2O	E	

3 BASELINE DETERMINATION AND ADDITIONALITY

3.1 BASELINE DETERMINATION

The baseline for a project activity is determined utilizing industry standards and represents the most commonly used practices and technologies. Landfill gas destruction and beneficial use projects are not eligible to generate Emission Reduction Tons (ERT) in instances where the collection and destruction of landfill gas can be considered a standard business practice or is required by law or as a result of any other legally binding framework. The baseline determination shall be consistent with the pre-project activity prior to the start date.

For projects that are or have previously employed ineligible project activities, such as a passive flare, or have an eligible project activity that was implemented prior to the specified start date, emission reductions associated with these activities shall be accounted for in the baseline emission calculations[2]. Project proponents shall submit a proposed method for quantifying pre-project emission reductions to ACR for approval. Emission reductions resulting from ineligible project activities shall be accounted for in Equation 2 as NE_{device}.

3.2 ADDITIONALITY ASSESSMENT

Emission reductions from the project must be additional, or deemed not to occur in the "business-as usual" scenario. Assessment of the additionality of a project will be made based on passing a practice-based performance standard and a regulatory surplus test OR ACR's three-prong additionality test (which, as a first step, includes a regulatory surplus test).

Projects shall demonstrate conformance with the full requirements found in Section 3.2.1 OR 3.2.2 only once at the beginning of a crediting period. However, projects shall demonstrate regulatory surplus during verification activities for each reporting period. For more information on the development of the practice-based performance standard, please see Appendix A.

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[2] For projects that install an automated collection system that increases landfill gas collection efficiency as a stand-alone project activity, a landfill gas destruction device(s) may be operational prior to the start date of the automated collection system. In these situations, a deduction for baseline pre-project emission reductions is not required.

3.2.1 Practice-Based Performance Standard

Projects with the characteristics described below may apply the practice-based performance standard to demonstrate that the project activity is not common practice and is therefore considered additional pending the outcome of the regulatory surplus test:

- Project activities located in non-arid counties (defined as counties with more than 25 inches of precipitation historically) implemented at landfills with equal to or less than 500,000 tons of waste in place; or
- Project activities located in arid counties (defined as counties with less than 25 inches of precipitation historically) implemented at landfills with equal to or less than 1,500,000 tons of waste in place.
- Project activities involving the installation of an automated collection system that increases landfill gas collection efficiency.

Appendix A shall be used to determine if a project is located in a non-arid or arid county. Further, Appendix A provides a discussion of the performance standard for projects deploying an automated collection system that increases landfill gas collection efficiency.

3.2.1.1 REGULATORY SURPLUS TEST

For projects applying the performance standard discussed in Section 3.2.1, a regulatory surplus test shall also be applied. To pass the regulatory surplus test, a project must not be mandated by existing laws, regulations, statutes, legal rulings, or any other regulatory frameworks that directly or indirectly affect the GHG emissions associated with a project such as the CAA or RCRA. The project proponent must demonstrate that there is no existing law, regulation, statute, legal ruling, or other regulatory framework that mandates the project or effectively requires the GHG emission reductions associated with the installation of a destruction device, the infrastructure necessary for enhancing the landfill gas, or the installation of an automated collection system that increases landfill gas collection efficiency[3]. The project proponent shall provide evidence including all supporting documentation necessary to prove that landfill gas destruction, abatement, mitigation, or increased collection efficiency is not required.

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[3] For projects that install an automated collection system that increases landfill gas collection efficiency at a landfill that is required to install a GCCS under NSPS, only the incremental landfill gas collected through the use of the automated collection system is eligible, per section 4 below.

3.2.2 ACR's Three-Prong Additionality Test

For project activities that do not automatically qualify under the practice-based performance standard outlined in Section 3.2.1, ACR's Three-Prong additionality test shall be applied. The first step in the Three-Prong additionality test, as stated above, is the application of a regulatory surplus test which is followed by a common practice assessment and description of implementation barriers. Landfill gas projects may only demonstrate a financial implementation barrier(s) and may not apply technological or institutional barriers. For a complete description of the ACR Three-Prong Additionality Test, please refer to the *ACR Standard*.

4 QUANTIFICATION OF GHG EMISSION REDUCTIONS

Quantification of project emission reductions requires calculation of baseline emissions and project emissions.

4.1 BASELINE EMISSIONS[4]

Equation 1: Volume of CH_4 Combusted

This is the amount of GHG emissions that would take place without the destruction or beneficial use of the landfill gas. Records of continuous landfill gas flows (in standard cubic feet per minute) shall be matched with continuous methane content data using Equation 1.

$$\mathbf{CH_{4combusted}} = [(\mathbf{LFG_{captured}} \times \%\mathbf{CH_{4,continuous}}) + (\mathbf{LFG_{captured}} \times \%\mathbf{CH_{4,weekly}} \times (\mathbf{1} - \mathbf{DF_{weekly}}))] \times (\mathbf{1} - \mathbf{OF})$$

WHERE

$CH_{4combusted}$	Total volume of methane combusted (scf)
$LFG_{captured}$	LFG captured (scf)
$\%CH_{4,\ continuous}$	Methane content of LFG for continuous methane monitoring (%)
$\%CH_{4,\ weekly}$	Methane content LFG for duration weekly methane monitoring (%)
DF_{weekly}	Discount factor for weekly methane content monitoring (a value of 0.1 shall be applied only when weekly readings occurred)

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[4] Projects that do not deploy an automated collection system as a stand-alone project activity shall not use equations 2-10 and will skip to equation 11 after quantifying $CH_{4combusted}$ in equation 1. Projects that deploy an automated collection system that increases landfill gas collection efficiency as a stand-alone project activity shall utilize all relevant equations (i.e., inclusive of equations 1-10). This is to ensure that only the additional landfill gas captured and attributed to automated control system operation is considered in the emission reduction calculations. For these projects, equations 2-7 are calculated and validated once and are used for the duration of the project's crediting period. Equations 8-10 are calculated for each reporting period. For a case study example on the use of equations 2-9, see Appendix C.

OF	Oxidation factor

The oxidation factor is based on the recommended oxidation rates by the U.S. EPA. The following values shall be applied based on the type of landfill cover and methane flux within the project boundary:

- A value of 0.0 shall be applied to landfills with a synthetic cover;
- A value of 0.10 shall be applied to landfills without a synthetic cover that are not required to determine methane flux or for landfills that do not have a soil cover of at least 24 inches for the majority of landfill area containing waste;
- A value of 0.35 shall be applied to landfills have a soil cover of at least 24 inches for a majority of the landfill area containing waste and for which the methane flux rate is less than 10 grams per square meter per day (g/m^2/d);
- A value of 0.25 shall be applied to landfills have a soil cover of at least 24 inches for a majority of the landfill area containing waste and for which the methane flux rate is 10 - 70 grams per square meter per day (g/m^2/d); or
- A value of 0.10 shall be applied to landfills have a soil cover of at least 24 inches for a majority of the landfill area containing waste and for which the methane flux rate is greater than 70 grams per square meter per day (g/m^2/d).

Equation 2: Historic Modeled Methane Generation Rate[5]

The modeled methane generation rate is quantified for the three years preceding the installation of the automated collection system using the below equation. Each year is to be quantified separately.

$$G_{CH4} = \left[\sum_{x=S}^{T-1} \left\{ W_x \, L_{o,x} \left(e^{-k(T-x-1)} - e^{-k(T-x)} \right) \right\} \right]$$

WHERE

G_{CH4}	Modeled methane generation rate in year T (metric tons)
X	Year in which waste was disposed
S	Start year of calculation

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[5] From Equation HH-1 of the US EPA 40 CFR Part 98 Subpart HH

T	Year for which emissions are calculated
W_x	Quantity of waste disposed in the landfill, in year x (metric tons, as received net weight)
L_o	Methane generation potential (metric tons/metric ton waste)
k	Rate constant year^{-1} from table HH-1 from US EPA 40 CFR Part 98 Subpart HH

Equation 3: Historic Measured CH_4 Collection

Historic measured methane collection is quantified for the three years preceding the installation of the automated collection system using the below equation. Each year is to be quantified separately.

$$C_{CH4,T} = HLFG_{captured} \times H\%CH_4 \div 385 \times 16.04 \div 2204.62$$

WHERE

$C_{CH4,T}$	Measured methane collected in year T (metric tons)
$HLFG_{captured}$	Historic LFG captured (scf)
$H\%CH_4$	Historic methane content of LFG (%)
385	Gas conversion factor (scf/lb-mole CH_4)
16.04	Molecular weight of CH_4
2204.62	lbCO_2/tCO_2

Equation 4: Measured Landfill Gas Collection Efficiency

Measured landfill gas collection efficiency is quantified for the three years preceding installation of the automated collection system using the below equation. Each year is to be quantified separately.

$$CE_{measured} = C_{CH4,T} \div G_{CH4}$$

WHERE

$\mathbf{CE_{measured}}$	Measured baseline collection efficiency (%)
$\mathbf{C_{CH4,T}}$	Measured methane collected in year T (metric tons) – as calculated in Equation 3
$\mathbf{G_{CH4}}$	Modeled methane generation rate in year T (metric tons) – as calculated in Equation 2

Equation 5: Modeled Gas Collection System Efficiency

Modeled landfill gas collection efficiency is quantified for the three years preceding installation of the automated collection system using the below equation. This equation utilizes landfill gas collection efficiencies from Table HH-3 of US EPA 40 CFR Part 98, Subpart HH. Each year is to be quantified separately.

$$\mathbf{CE_{modeled} = (A2_T \times CE2 + A3_T \times CE3 + A4_T \times CE4 + A5_T \times CE5) \div (A2_T + A3_T + A4_T + A5_T)}$$

WHERE

$\mathbf{CE_{modeled}}$	Modeled baseline collection efficiency (%)
$\mathbf{A2_T}$	Area of landfill without active gas collection in year T (square meters)
$\mathbf{CE2}$	Regardless of cover type, collection efficiency for area without active gas collection (CE2) = 0%
$\mathbf{A3_T}$	Area of landfill with daily soil cover and active gas collection in year T (square meters)
$\mathbf{CE3}$	Collection efficiency for area with daily soil cover and active gas collection (CE3) = 60%
$\mathbf{A4_T}$	Area of landfill with intermediate soil cover and active gas collection in year T (square meters)
$\mathbf{CE4}$	Collection efficiency for area with intermediate soil cover and active gas collection (CE4) = 75%
$\mathbf{A5_T}$	Area of landfill with final soil and geomembrane cover system and active gas collection in year T (square meters)

CE5	Collection efficiency for area with final soil and geomembrane cover system and active gas collection (CE5) = 95%

Equation 6: Calibrated Collection Efficiency based on Landfill Area

The calibrated collection efficiency for each landfill area, by cover type, is quantified for the three years preceding installation of the automated collection system using the below equation. The US EPA LFG collection efficiencies by landfill area are adjusted by the same proportion for each landfill area: A2-A5 (see Equation 5). Specifically, US EPA LFG collection efficiencies are multiplied by the ratio of the measured collection efficiency (Equation 4) divided by the modeled collection efficiency (Equation 5) to calculate the calibrated collection efficiencies by area. This results in an overall calibrated collection efficiency set equal to the measured collection efficiency at the landfill. Note that the same calculation is performed based on each cover type and the associated collection efficiency and is quantified for each year separately.

$$CCE2 = CE2 \times CE_{measured} \div CE_{modeled}$$

$$CCE3 = CE3 \times CE_{measured} \div CE_{modeled}$$

$$CCE4 = CE4 \times CE_{measured} \div CE_{modeled}$$

$$CCE5 = CE5 \times CE_{measured} \div CE_{modeled}$$

WHERE

CCE2	Calibrated collection efficiency for area without active gas collection (%)
CE2	Regardless of cover type, collection efficiency for area without active gas collection (CE2) = 0%
$CE_{measured}$	Measured baseline collection efficiency (%) – as calculated in Equation 4
$CE_{modeled}$	Modeled baseline collection efficiency (%) – as calculated in Equation 5
CCE3	Calibrated collection efficiency for area with daily soil cover and active gas collection (%)
CE3	Collection efficiency for area with daily soil cover and active gas collection (CE3) = 60%
CCE4	Calibrated collection efficiency for area with intermediate soil cover and active gas collection (%)

CE4	Collection efficiency for area with intermediate soil cover and active gas collection (CE4) = 75%
CCE5	Calibrated collection efficiency for area with final soil and geomembrane cover system and active gas collection (%)
CE5	Collection efficiency for area with final soil and geomembrane cover system and active gas collection (CE5) = 95%

Equation 7: Average Calibrated Collection Efficiencies

The average of the three years of calibrated collection efficiencies (Equation 6) for each landfill area, by cover type, is quantified using the below equation. Note that the same calculation is performed based on each cover type and the associated calibrated collection efficiency.

$$\mathrm{ACCE2} = \sum \mathrm{CCE2} \div 3$$

$$\mathrm{ACCE3} = \sum \mathrm{CCE3} \div 3$$

$$\mathrm{ACCE4} = \sum \mathrm{CCE4} \div 3$$

$$\mathrm{ACCE5} = \sum \mathrm{CCE5} \div 3$$

WHERE

ACCE2	Average calibrated collection efficiency for area without active gas collection (%)
CCE2	Calibrated collection efficiency for area without active gas collection (%) – as calculated in Equation 6
3	Number of years preceding installation of automated collection system
ACCE3	Average calibrated collection efficiency for area with daily soil cover and active gas collection (%)
CCE3	Calibrated collection efficiency for area with daily soil cover and active gas collection (%) – as calculated in Equation 6

ACCE4	Average calibrated collection efficiency for area with intermediate soil cover and active gas collection (%)
CCE4	Calibrated collection efficiency for area with intermediate soil cover and active gas collection (%) – as calculated in Equation 6
ACCE5	Average calibrated collection efficiency for area with final soil and geomembrane cover system and active gas collection (%)
CCE5	Calibrated collection efficiency for area with final soil and geomembrane cover system and active gas collection (%) – as calculated in Equation 6

Equation 8: Updated Calibrated Collection Efficiency

Following the installation of the automated collection system, the calibrated collection efficiencies are updated annually to reflect changes in the landfill's cover and collection system.

$$\mathrm{UCCE} = (\mathrm{A2_T} \times \mathrm{ACCE2} + \mathrm{A3_T} \times \mathrm{ACCE3} + \mathrm{A4_T} \times \mathrm{ACCE4} + \mathrm{A5_T} \times \mathrm{ACCE5}) \div (\mathrm{A2_T} + \mathrm{A3_T} + \mathrm{A4_T} + \mathrm{A5_T})$$

WHERE

UCCE	Updated Calibrated Collection efficiency (%)
$\mathrm{A2_T}$	Area of landfill without active gas collection in year T (square meters)
ACCE2	Average calibrated collection efficiency for area without active gas collection (%) – as calculated in Equation 7
$\mathrm{A3_T}$	Area of landfill with daily soil cover and active gas collection in year T (square meters)
ACCE3	Average calibrated collection efficiency for area with daily soil cover and active gas collection (%) – as calculated in Equation 7
$\mathrm{A4_T}$	Area of landfill with intermediate soil cover and active gas collection in year T (square meters)
ACCE4	Average calibrated collection efficiency for area with intermediate soil cover and active gas collection (%) – as calculated in Equation 7

$A5_T$	Area of landfill with final soil and geomembrane cover system and active gas collection in year T (square meters)
$ACCE5$	Average calibrated collection efficiency for area with final soil and geomembrane cover system and active gas collection (%) – as calculated in Equation 7

Equation 9: ACS Increment

The incremental collection efficiency attributable to the automated collection system is quantified using the below equation.

$$ACSI = \left(CH_{4total} - (UCCE \times G_{CH4})\right) \div CH_{4total}$$

WHERE

$ACSI$	Incremental collection efficiency attributable to automated collection system (%)
CH_{4total}	Total methane combusted (metric tons) – as calculated in Equation 11; projects shall use the $CH_{4combusted}$ parameter when quantifying Equation 11 for use as the CH_{4total} parameter in Equation 9
$UCCE$	Updated Calibrated Collection efficiency (%) – as calculated in Equation 8
G_{CH4}	Modeled methane generation rate in year T (metric tons) – calculated for the current reporting year based on Equation 2

Equation 10: Increase in Volume of CH_4 Combusted

For projects deploying an automated collection system that increases landfill gas collection efficiency, the below equation is used to determine the increase in landfill gas captured attributable to system deployment.

$$ICH_{4combusted} = CH_{4combusted} \times ACSI$$

WHERE

$ICH_{4combusted}$	Increase in methane combusted using automated collection system (scf)
$CH_{4combusted}$	Total volume of methane combusted (scf) – as calculated in Equation 1

ACSI	Incremental collection efficiency attributable to automated collection system (%) as calculated in Equation 9

Equation 11: Net Mass of CH_4 Destroyed[6]

In order to estimate the amount of methane combusted in metric tons, methane combusted needs to be converted to weight using Equation 11.

$$CH_{4total} = (\Big((CH_{4combusted}\ \mathbf{OR}\ ICH_{4combusted} \times CF) \times 16.04 \times \left[\frac{1}{10^6}\right] \times \left[\frac{1}{24.04}\right] \times 28.32\Big) \times 95\%) - NE_{device}$$

WHERE

CH_{4total}	Total methane combusted (metric tons)
$CH_{4combusted}$	Methane combusted (scf – as calculated in Equation 1)
$ICH_{4combusted}$	Increase in methane combusted using automated collection system (scf) – as calculated in Equation 10
CF	Correction factor – calculated per Equation 12[7]
16.04	Molecular weight of CH_4
$1/10^6$	Conversion to metric tons (MT/g)
1/24.04	Gas constant (mol/L – measured at standard temperature and pressure – defined as 68ºF and 14.7psi)
28.32	Conversion factor (L/cf)
95%	Destruction efficiency of the destruction device[8]

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[6] Projects deploying an automated collection system as a stand-alone project activity, shall use the $ICH_{4combusted}$ parameter in Equation 11. Projects that do not deploy an automated control system as a stand-alone project activity shall use the $CH_{4combusted}$ parameter in Equation 11.

[7] The correction factor shall only be applied in instances where the project flow meter does not use a standard temperature of 68ºF. Where project flow meters do apply a standard temperature of 68ºF, CF = 1.

[8] In lieu of the default 95% destruction efficiency, project proponents may apply the results of a third-party source test conducted by an organization meeting or exceeding the U.S. Environmental Protection

NE_{device}	Emissions from a pre-project, non-eligible device

Equation 12: Correcting LFG Flow Temperature

If the monitoring equipment is set to record landfill gas flow at a temperature other than that defined in Equation 2 (68ºF), the project proponent must normalize the landfill gas flow by using the correction factor calculated in Equation 3.

$$CF = \frac{527.67}{T + 459.67}$$

WHERE

CF	Correction factor
T	Temperature as measured by project flow meters

4.2 PROJECT EMISSIONS

Depending on project-specific circumstances, certain emission sources shall be subtracted from total project emission reductions using the equations below.

Equation 13: CO_2 Emissions from Fossil Fuel Combustion

$$Dest_{CO2} = \sum y \left(FF_y \times EF_y\right)$$

WHERE

$Dest_{CO2}$	CO_2 emissions from fossil fuel used in methane destruction process (tCO_2)
FF_y	Total quantity of fossil fuel,y, consumed (volume of fuel)
EF_y	Fuel specific emission factor for fuel, y (tCO_2/fuel quantity) – See Appendix B

Agency's *Minimum Competency Requirements for Air Emission Testing* rule to determine the actual destruction efficiency of the device.

Equation 14: Emissions from Project Specific Electricity Consumption

$$\mathbf{Elec_{CO2}} = \frac{\mathbf{EL_{total}} \times \mathbf{EF_{EL}}}{\mathbf{2204.62}}$$

WHERE

$\mathbf{Elec_{CO2}}$	Project specific electricity emissions (tCO_2)
$\mathbf{EL_{total}}$	Total grid connected electricity consumption (MWh)
$\mathbf{EF_{EL}}$	Carbon emission factor for grid electricity ($lbCO_2/MWh$) - See Appendix B
2204.62	$lbCO_2/tCO_2$

Equation 15: Project Emissions

$$\mathbf{PE} = \mathbf{Elec_{CO2}} + \mathbf{Dest_{CO2}}$$

WHERE

PE	Project emissions (tCO_2)
$\mathbf{Elec_{CO2}}$	Project specific electricity emissions (tCO_2)
$\mathbf{Dest_{CO2}}$	CO_2 emissions from fossil fuel used in methane destruction or transportation process (tCO_2)

4.3 LEAKAGE

Leakage is a term that refers to secondary effects where the GHG emission reductions of a project may be negated by shifts in market activity or shifts in materials, infrastructure, or other physical assets associated with the project. ACR does not expect landfill methane projects to result in any additional activities that would augment GHG emissions outside of the project boundary and, therefore, no leakage assessment is required.

4.4 EMISSION REDUCTIONS

Equation 16: GHG Emission Reductions

$$\mathbf{ER} = [\mathbf{CH}_{\mathbf{4total}} \times \mathbf{GWP}_{\mathbf{CH4}}] - \mathbf{PE}$$

WHERE

ER	Total Emission Reductions (tCO_2e)
CH_{4total}	Methane combusted (MT)
GWP_{CH4}	Global warming potential of methane[9]
PE	Project emissions (tCO_2)

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[9] Project proponents shall refer to the ACR Program Standard for the approved IPCC GWP for methane value, which will be updated periodically as new information becomes available.

5 MONITORING AND DATA COLLECTION

Each project shall include a GHG project plan sufficient to meet the requirements of the *ACR Standard*. The plan shall collect all data required to be monitored and in a manner that meets the requirements for accuracy and precision of this Methodology. Project Proponents shall use the template for GHG project plans available at www.americancarbonregistry.org. Additionally, projects are required to submit a GHG monitoring report for each reporting period. Project Proponents shall use the template for GHG monitoring reports available at http://americancarbonregistry.org/carbon-accounting/tools-templates.

5.1 DESCRIPTION OF THE GHG PROJECT PLAN

These are expanded upon in the sections below. The project proponent must prepare a GHG project plan describing (for each separately) the following: a) project implementation; b) technical description of the monitoring task; c) data to be monitored and collected; d) overview of data collection procedures; e) frequency of the monitoring; f) quality control and quality assurance procedures; g) data archiving; and h) organization and responsibilities of the parties involved in all the above.

The rationale of monitoring project implementation is to document all project activities implemented by the project that could cause an increase in GHG emissions compared to the baseline scenario.

5.2 DATA COLLECTION AND PARAMETERS TO BE MONITORED

Project monitoring and recording shall include the following parameters:

- Continuous monitoring of landfill gas flow to each destruction device,
- Methane content analysis using a continuous gas analyzer or gas chromatograph
- Electricity production records, if applicable,
- Quantity of transport fuel or pipeline quality gas generated, if applicable,
- Destruction device operating hours, if applicable,
- Before and after results of field checks

- Project-related emission data (grid electricity consumed and/or fossil fuels used by the project), and
- A GCCS downtime log that includes the duration and cause of a GCCS shutdown or malfunction.
- For projects that deploy an automated collection system either as a stand-alone project activity or as a component of a project:
  - A record of the changes to the gas collection system, including (at the start and end of each reporting period):
    - total number of active collection wells and area of coverage, by cover type,
    - number of collectors with automated control system by area and cover type,
    - number of any new collection wells drilled including date of start of operation and area covered,
    - any collection wells that are de-commissioned,
    - quantity of waste disposed in the landfill by year, and
    - L_o and k parameters to model methane generation.

5.2.1 Flow Monitoring

Landfill gas flow shall be continuously monitored using an adequate flow meter. Continuous monitoring is defined as one data point recorded at least every 15 minutes. The flow meter shall be installed along the header pipe at a location that provides a straight section of pipe sufficient to establish laminar gas flow, in order to mitigate any turbulence resulting from bends, obstructions, or constrictions in the pipe. This turbulence may result in inaccurate flow measurements. The flow meter shall be located downstream of the blower and upstream of the destruction device. All flow data used to calculate emission reductions must be corrected for standard temperature (68ºF) and standard pressure (14.7psi).

5.2.2 Methane Content Analysis

The methane fraction in the landfill gas shall be continuously monitored using a methane analyzer. Continuous monitoring is defined as one data point at least every 15 minutes.

Weekly readings may be taken using a handheld gas analyzer for no more than two (2) months with a 10% discount for the duration of the weekly readings if the continuous methane analyzer fails or is being serviced. The discount shall be applied in Equation 1 only for the period in which weekly readings were taken in place of continuous readings. Handheld gas analyzers shall meet the calibration and maintenance requirements of Section 5.2.3.

5.2.3 Monitoring Equipment Calibration/Quality Assurance

The following information regarding flow meter and gas analyzer performance shall be maintained:

- Proof of initial calibration for flow meters and gas analyzers;
- Capability to record flow or methane concentration every 15 minutes;
- Means to correct for temperature and pressure (for flow meter, if necessary); and
- Manufacturer's recommended factory calibration frequency.

It is essential that flow meters and gas analyzers operate properly in order to accurately quantify GHG emission reductions. To ensure proper equipment function, annual field checks for flow meter and methane analyzer accuracy shall be performed by a qualified third-party. Annual field checks must meet the following conditions[10]:

- Field checks must be performed in accordance with manufacturer's specifications and methodologies;
- Field checks must be performed by the manufacturer or other appropriately trained third-party personnel;
- All field checks must be documented and made available for review during the validation and verification process. Documentation must include specific results of the field checks including the percent error demonstrated by the instrumentation capturing the before (as-found) and after (as-left) status;
- Should the instrumentation demonstrate an error in the reading or output of either landfill gas flow or methane content that is greater than or equal to 5%, written documentation must be provided as to the correction applied during the field check and the resulting accuracy of the instrumentation. In situations where the flow meter or methane analyzer percent error is greater than or equal to 5%, all data from the previous field check through to the most recent field check shall be scaled by the percent error documented in the most recent field check.

Projects may choose to conduct more than one field check to ensure that the monitoring equipment continuously meets the requirements of Section 5.2.3. If a project elects to conduct more frequent field checks, they must adhere to the requirements of Section 5.2.3. Additionally, manufacturer specifications regarding instrument calibration shall be followed. No ERTs will be granted for periods where the flow meter or gas analyzer have not been maintained in accordance with manufacturer calibration requirements.

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[10] Annual field checks must be separated by an elapsed time frame of a minimum of 10 months from the date of the preceding field check but must not exceed 12 months.

5.2.4 Destruction Device Operating Hours

The operating hours for each destruction device must be monitored to ensure that landfill gas destruction is claimed for landfill gas destroyed only during periods when the device(s) was/were operational. Emission reductions may not be claimed for time periods where the destruction device(s) is not operating or thermocouple readings are below 500 degrees Fahrenheit. Operating hours must be continuously monitored and recorded except for non-flare destruction devices (e.g. boilers or engines) that are equipped with an operable safety shut off valve and that impede the flow of landfill gas to the device when it is not in operation. In general, operating hours for a flare are tracked through the use of a thermocouple which monitors the presence and temperature of the flame. Operating hours for other destruction devices such as engines should be tracked through operator logs, electricity production records, or other verifiable means.

Projects that treat landfill gas and inject it into a natural gas pipeline shall only provide evidence of the quantity of gas delivered to the pipeline and are not required to provide evidence of landfill methane destruction.

5.2.5 Project-Related Emissions

Project-related emissions may result from the used of imported electricity or from the use of fossil fuels. Information related to electricity usage and relevant fossil fuel consumption may be obtained from sources such as on-site electricity meters, utility invoices, and fuel purchase records.

5.2.6 Parameters Monitored

PARAMETER	CH_4%
UNIT	Percentage
DESCRIPTION	Percent methane in landfill gas
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	1
SOURCE OF DATA	Gas analyzer/data acquisition device
MEASUREMENT FREQUENCY	Continuous or using a handheld analyzer during calibration

PARAMETER	$LFG_{captured}$
UNIT	scfm
DESCRIPTION	Landfill gas flow
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	1
SOURCE OF DATA	Flow meter(s)/data acquisition device
MEASUREMENT FREQUENCY	Continuous

PARAMETER	Flare Operating Hours
UNIT	Degrees Fahrenheit
DESCRIPTION	Monitoring of operational activity of destruction device to ensure destruction of landfill gas. Not applicable for pipeline injection projects.
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	1
SOURCE OF DATA	Thermocouple/data acquisition device
MEASUREMENT FREQUENCY	Continuous

PARAMETER	Flare Temperature
UNIT	Degrees Fahrenheit
DESCRIPTION	Monitoring of temperature of destruction device to ensure destruction of landfill gas. Not applicable for pipeline injection projects.
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	1
SOURCE OF DATA	Thermocouple/data acquisition device
MEASUREMENT FREQUENCY	Continuous

PARAMETER	Wx
UNIT	Metric tons
DESCRIPTION	Quantity of waste disposed in the landfill in year x from measurement data, tipping fee receipts, or other company records (metric tons, as received wet weight)
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	2
SOURCE OF DATA	US EPA 40 CFR Part 98 Subpart HH: Variable for HH-1 equation
MEASUREMENT FREQUENCY	Annual

PARAMETER	x
UNIT	Year
DESCRIPTION	Year in which waste was disposed
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	2
SOURCE OF DATA	US EPA 40 CFR Part 98 Subpart HH: Variable for HH-1 equation
MEASUREMENT FREQUENCY	Annual

PARAMETER	T
UNIT	Year
DESCRIPTION	Reporting year in which emissions are calculated
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	2
SOURCE OF DATA	US EPA 40 CFR Part 98 Subpart HH: Variable for HH-1 equation
MEASUREMENT FREQUENCY	Annual

PARAMETER	L_o
UNIT	Metric tons methane per metric ton waste
DESCRIPTION	Methane generation potential
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	2
SOURCE OF DATA	US EPA 40 CFR Part 98 Subpart HH: Variable for HH-1 equation
MEASUREMENT FREQUENCY	Annual

PARAMETER	K
UNIT	Yr-1
DESCRIPTION	Rate constant from Table HH-1 (0.02 to 0.057)
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	2
SOURCE OF DATA	US EPA 40 CFR Part 98 Subpart HH: Variable for HH-1 equation
MEASUREMENT FREQUENCY	Annual

PARAMETER	$HLFG_{captured}$
UNIT	scf
DESCRIPTION	Historic LFG captured
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	3
SOURCE OF DATA	Flow meter/data acquisition device
MEASUREMENT FREQUENCY	Minimum flow reading once per day

PARAMETER	$H\%CH_4$
UNIT	Percentage
DESCRIPTION	Historic percent methane
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	3
SOURCE OF DATA	Gas analyzer/data acquisition device
MEASUREMENT FREQUENCY	Minimum once per week

PARAMETER	A2, A3, A4, and A5
UNIT	Square meters
DESCRIPTION	Landfill Areas A2: Area without active gas collection, regardless of cover type A3: Area with daily soil cover and active gas collection A4: Area with an intermediate soil cover, or a final soil cover and active gas collection A5: Area with a final soil cover of 3 feet or thicker of clay and/or geomembrane cover system and active gas collection
RELEVANT SECTION	4.1
RELEVANT EQUATION(S)	5
SOURCE OF DATA	US EPA 40 CFR Part 98 Subpart HH Table HH-3 - Landfill gas collection efficiencies. Variable for establishing Baseline Collection Efficiencies.
MEASUREMENT FREQUENCY	Annual

PARAMETER	FF_y
UNIT	Volume of fuel
DESCRIPTION	Total quantity of fossil fuel,y, consumed
RELEVANT SECTION	4.2
RELEVANT EQUATION(S)	13
SOURCE OF DATA	Utility or fuel Invoices
MEASUREMENT FREQUENCY	Collected annually

PARAMETER	EL_{total}
UNIT	MWh
DESCRIPTION	Total grid connected electricity consumption
RELEVANT SECTION	4.2
RELEVANT EQUATION(S)	14
SOURCE OF DATA	Electricity Invoices
MEASUREMENT FREQUENCY	Collected annually

DEFINITIONS

If not explicitly defined here, the definitions in the latest version of the American Carbon Registry (ACR) Standard apply.

Automated collection system that increases landfill gas collection efficiency	A system deploying automated control and measurement devices which result in an incremental increase in the aggregate methane volume that is captured. An automated collection system must include equipment installed on individual collection wells as part of the gas collection system that can measure, at minimum, O_2, CH_4, and CO_2 concentrations in the landfill gas being collected, pressure applied to the wellhead, and include an actuated valve where the valve can be operated remotely with automation.
Clean Air Act	A comprehensive federal law designed to regulate both stationary and mobile air emissions in order to improve air quality and human health.
Compressed Natural Gas	Natural gas under pressure, typically used a fuel substitute.
Gas Collection and Control System	A system of wells and pipes designed to collect landfill gas that can be conveyed under vacuum to a combustion device such as a flare or engine.
Landfill Gas	Landfill gas is a product of the decomposition of organic material contained in municipal solid waste landfills.[11]
Landfill Gas-to-Energy	The process of converting landfill gas to electricity, steam or natural gas for fuel.
Liquefied Natural Gas	Natural gas in a liquid state for ease of use or storage.
Municipal Solid Waste Landfill	A designation for landfills that accept household trash.

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[11] As defined by the U.S. EPA's Landfill Methane Outreach Project. Found at http://www3.epa.gov/lmop/faq/landfill-gas.html.

Non-Methane Organic Compound	Non-methane organic compounds consist of hazardous air pollutants and volatile organic compounds, which when exposed to sunlight may form ground-level ozone or smog.
New Source Performance Standard	Federal rules for U.S. landfills, codified in 40 CFR Subpart WWW, that govern emissions from existing landfills with a design capacity greater than 2.5 million megagrams that began receiving waste or began construction or made modifications after May 30, 1991.

APPENDIX A: DEVELOPMENT OF PRACTICE-BASED PERFORMANCE STANDARD

A.1 LOCATION BASED PERFORMANCE STANDARD

While the total number of landfills in the U.S. has declined over time, the amount of waste sent to landfills has increased. As of 2015, landfills accounted for approximately 18%[12] of anthropogenic methane emissions in the U.S. The Environmental Protection Agency's (EPA) Landfill Methane Outreach Program (LMOP) maintains a database of the 2,434 landfills in the U.S. of which there are approximately 1,000 municipal solid waste (MSW) landfills that are subject to the existing New Source Performance Standards (NSPS). Of the 1,000 MSW landfills subject to NSPS, greater than 50 percent of these landfills have installed gas collection and control systems (GCCS) as a result of the regulatory requirement, while the remainder are only required to report their annual emissions to the EPA[13]. Only landfills that have a design capacity of 2.5 million metric tons and 2.5 million cubic meters of waste are subject to federal NSPS requirements and landfills are only required to abate emissions if they are found to reach or surpass the 50 megagrams per year of non-methane organic compounds (NMOC) emission threshold or 34 megagrams per year beginning in 2025.

For landfills that have reached or have exceeded the allowable NMOC emission threshold, no credits may be claimed once the landfill is required to install a GCCS. However, these landfills can participate in a voluntary carbon offset program if an automated collection system is voluntarily used which increases gas collection system efficiency. In addition, landfills that are not subject to NSPS regulations or have not reached the allowable NMOC threshold may participate in a voluntary carbon offset program for the totality of their captured emissions.

While past landfill gas carbon offset protocols have been predicated upon a low adoption rate for LFG GCCS nationally the number of voluntary landfill gas projects has steadily increased to

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[12] EPA's Air Rules for Municipal Solid Waste Landfills, Proposed Emission Guidelines for Existing Landfills: Fact Sheet. Found at http://www3.epa.gov/ttn/atw/landfill/20150814egfs.pdf.

[13] EPA's Air Rules for Municipal Solid Waste Landfills, Proposed Emission Guidelines for Existing Landfills: Fact Sheet. Found at http://www3.epa.gov/ttn/atw/landfill/20150814egfs.pdf.

the point where a national, practice-based performance standard is no longer applicable. However, based on analysis of the LMOP database along with assistance from several state or local permitting authorities, ACR has identified that there are still criteria that define landfills with low penetration rates for voluntary landfill gas projects. ACR began by identifying candidate landfills which consisted of the following criteria:

- Landfills that were currently open or had closed within in the last 5 years;
- Landfills that are currently under the waste in place (WIP) threshold for the region (i.e. arid versus non-arid locations, see Table 3; and
- Landfills that are not subject to NSPS or other state/local requirements to install a GCCS.

It should be noted that recently closed landfills may generate enough landfill gas to facilitate a project which is why candidate landfills closed in the last 5 years were included.

Given the above criteria, ACR has calculated that voluntary projects at landfills in non-arid regions (regions with more than 25 inches of rain in the last five years) and less than 500,000 tons of WIP, and at landfills in arid regions (regions with less than or equal to 25 inches of rain in the last five years) with less than 1,500,000 tons of WIP, account for less than 15% of candidate landfills in each region (Table 3)[14]. As these adoption rates are low, landfills that meet the criteria stipulated in Section 3.2.1 automatically qualify under the practice-based performance standard. The historical precipitation map in Figure 2 below shall be used to determine if a project is located in an arid or non-arid region.

Table 3: Penetration Rate of Candidate Landfills

	NON-ARID	ARID
WIP Limit	**500,000**	**1,500,000**
Candidate Landfills	90	92
Candidates Landfills with a Voluntary GCCS	13	12
Percent Adoption	14.44%	13.04%

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[14] Precipitation zones defined by the EPA (Section 2.4.4.1). Found at https://www3.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.

Figure 2: U.S. Historic Precipitation Map

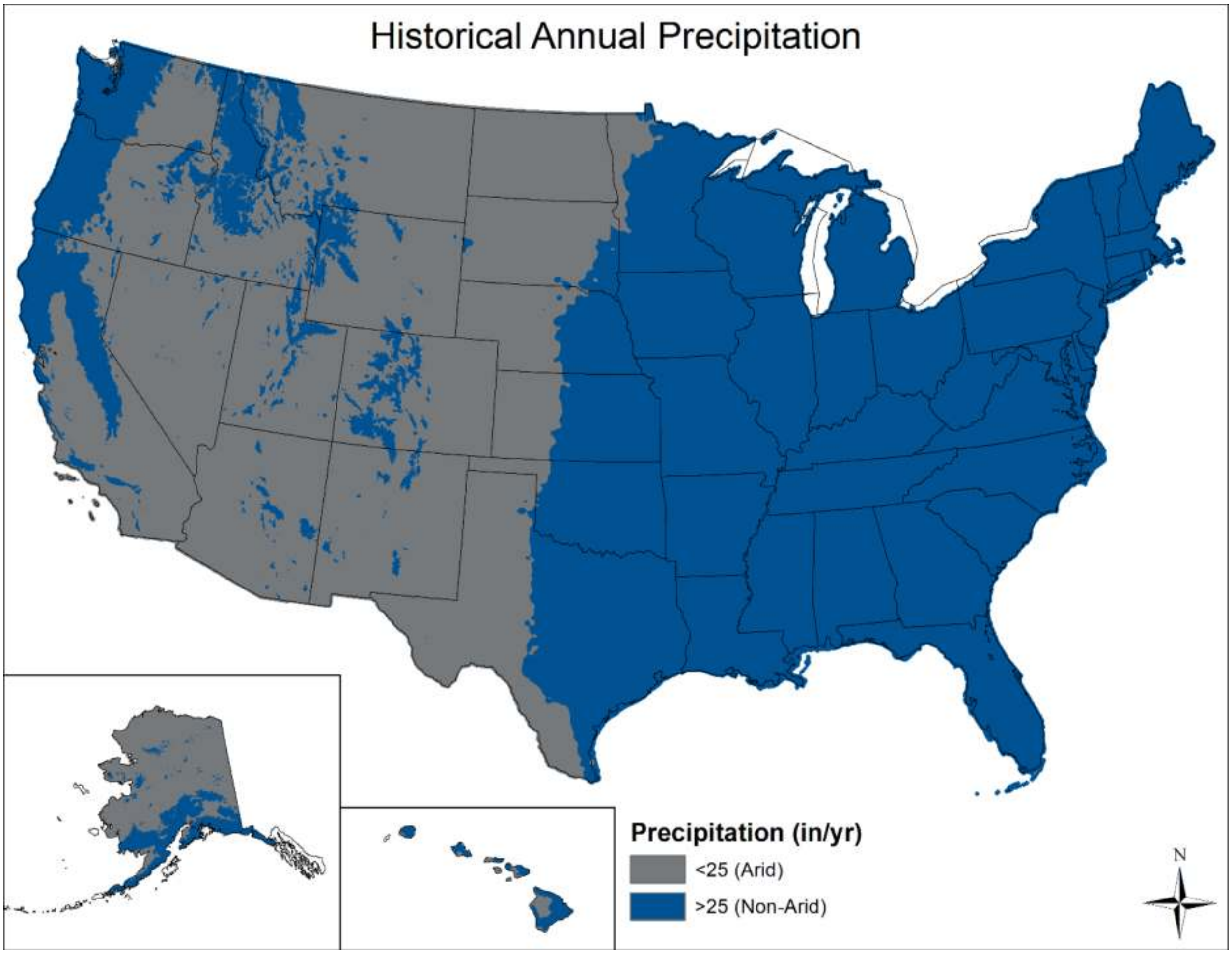

Figure 2 precipitation data sources by region include:

- Continental U.S.: PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created Feb 4, 2004.
- Alaska: Arctic Landscape Conservation Cooperative, 2012. Baseline (1961-1990) average total precipitation (mm) for Alaska and Western Canada. Created by Arctic Landscape Conservation Cooperative staff; data provided by Scenarios Network for Alaska and Arctic Planning. http://arcticlcc.org/products/spatial-data/show/baseline-1961-1990-rasters.
- Hawaii: Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte, 2013: Online Rainfall Atlas of Hawai‘i. Bull. Amer. Meteor. Soc. 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

A.2 PERFORMANCE STANDARD FOR AUTOMATED COLLECTION SYSTEMS THAT INCREASE LANDFILL GAS COLLECTION EFFICIENCY

Industry standard landfill gas collection systems are designed to meet minimum requirements established by regulations. NSPS regulations require at least monthly measurements of each collection well for pressure applied to the wellhead (static pressure), landfill gas temperature, and Oxygen or Nitrogen concentrations. These measurements are traditionally taken manually, with a handheld device, designed for this purpose.

Historically, the control of the individual landfill gas collection well can only be made by a manual adjustment to a mechanical valve located on the wellhead above ground. Opening of the manual valve will increase the vacuum applied to the collection well. Closing the valve, will reduce the vacuum applied to the collection well. Higher applied vacuum generally results in increased landfill gas collection and also results in increased concentration of oxygen and nitrogen in the landfill gas. Reducing the applied vacuum generally reduces gas collection and lowers the amount of oxygen and nitrogen in the landfill gas. Too little applied vacuum to a collector, or positive pressure applied to a collection well, will result in excessive emissions and odors. If too much vacuum is applied to a collection well, elevated oxygen concentrations in the landfill gas can result in sub-surface oxidation which can lead to unwanted and difficult to control sub-surface thermal activity. Because of the varying positive and negative impacts of valve adjustments, it is difficult to maintain optimum valve opening given varying conditions during any month when only one or two adjustments are made monthly.

The majority of landfills in the US control individual collection wells based on minimum required once per month compliance measurements, accompanied by a manual valve adjustment. At landfill gas to energy projects with higher value beneficial use, such as current landfill gas to pipeline projects, other refinements to the manual control process have occasionally been used. Most often the method used is to increase the frequency of measurements on individual collections wells to once per week to try to improve collection system efficiency. However, considering that an average large landfill will have approximately 150 collection wells, this process is very time and labor intensive. Approximately 10 landfills with pipeline projects have increased collection well density and substituted much more expensive portable gas chromatographs in lieu of more commonly used and lower cost, but less accurate, handheld gas analyzers, to try to improve measurement accuracy along with increased collection well density, to improve collection system efficiency. In a few cases some operators have tried to incorporate variable speed motors to change overall system vacuum, but this has proven to have little benefit as increasing or decreasing vacuum to the entire collection system indiscriminately affects all collection wells, irrespective of actual collection process conditions on each collector.

Automated landfill gas collection systems allow for near continuous gas collection well measurements and valve adjustments using cellular connections to cloud based computing and data storage systems in order to improve gas collection system efficiency. These automated systems typically deploy collection well mounted hardware, which reproduces the manual, monthly measurements taken traditionally with a handheld, along with remotely actuated valves that allow for continuous gas collection system measurement, control, and optimization. Algorithms are used to automate the valve adjustments to maximize collection efficiency, and reduce GHG emissions, based on individual collection well operating thresholds, along with aggregate gas composition thresholds for the entire collection system. This type of system is an example of an automated collection system that increases landfill gas collection efficiency beyond regulatory requirements.

As of the spring of 2020, there were over 60 operational landfill gas to pipeline projects in the US, and since the introduction of automated collection systems to the market in 2017, current adoption is 9 of the operational projects, or just under 15% of the addressable market. Faster penetration of this market has been slowed due to general industry reluctance to adopt new technology, and an uncertain financial value proposition, due to volatility of the value of renewable natural gas.

There are approximately 500 large landfills in the country, most are NSPS regulated according to the EPA LMOP database, with landfill gas to electricity or other beneficial use projects. In general, automated collection systems have made virtually no penetration into this market, due to the cost of the new automated collection systems versus the value of the electricity being generated in landfill gas to electricity markets.

The opportunity to generate voluntary carbon offsets through use of an automated collection system to increase gas collection system efficiency, and reduce GHG emissions, has the potential to expand the addressable market, and accelerate adoption for a large number of landfills where the system is not financially justified by the incremental increase of gas collection made possible through automated control.

APPENDIX B: EMISSION FACTORS

Project proponents shall use the current version of the U.S. Environmental Protection Agency's Power Profiler (http://oaspub.epa.gov/powpro/ept_pack.charts) to determine what regional emission factor should be used in accordance with the Emissions & Generation Resource Integrated Database (eGRID) for EF_{EL}. eGRID emission factors are available at http://www.epa.gov/energy/egrid.

To calculate $Dest_{CO2}$, project proponents shall use the below emission factors for EF_y which will be revised periodically based on updated information.

	CO_2 EF_y					
FOSSIL FUEL TYPE	**POUNDS (LBS.) CO_2**	**PER UNIT**	**KILOGRAMS (KG) CO_2**	**PER UNIT**	**LBS. CO_2/ MMBTU**	**KG CO_2/ MMBTU**
GASES						
Propane	12.70	Gallon	5.76	Gallon	139.05	63.07
Butane	14.80	Gallon	6.71	Gallon	143.20	64.95
Butane/ Propane Mix	13.70	Gallon	6.21	Gallon	141.12	64.01
Home Heating and Diesel Fuel	22.40	Gallon	10.16	Gallon	161.30	73.16
Kerosene	21.50	Gallon	9.75	Gallon	159.40	72.30
Coal (All types)	4,631.50	Short ton	2,100.82	Short ton	210.20	95.35
Natural Gas	117.10	Thousand cubic feet	53.12	Thousand cubic feet	117.00	53.07
Gasoline	19.60	Gallon	8.89	Gallon	157.20	71.30

FOSSIL FUEL TYPE	POUNDS (LBS.) CO_2	PER UNIT	KILOGRAMS (KG) CO_2	PER UNIT	LBS. CO_2/ MMBTU	KG CO_2/ MMBTU
Residual Heating Fuel (Businesses only)	26.00	Gallon	11.79	Gallon	173.70	78.79
Flared natural gas	120.70	Thousand cubic feet	54.75	Thousand cubic feet	120.60	54.70
Petroleum coke	32.40	Gallon	14.70	Gallon	225.10	102.10
Other petroleum & miscellaneous	22.09	Gallon	10.02	Gallon	160.10	72.62
			COALS			
Anthracite	5,685.00	Short ton	2,578.68	Short ton	228.60	103.70
Bituminous	4,931.30	Short ton	2,236.80	Short ton	205.70	93.30
Subbituminous	3,715.90	Short ton	1,685.51	Short ton	214.30	97.20
Lignite	2,791.60	Short ton	1,266.25	Short ton	215.40	97.70
Coke	6,239.68	Short ton	2,830.27	Short ton	251.60	114.12

Source: U.S. Energy Information Administration, published February 2, 2016.

APPENDIX C: INCREMENTAL METHANE COLLECTION FOR AUTOMATED COLLECTION SYSTEMS

Improving landfill gas collection system efficiency has the benefit of reducing GHG emissions from landfills. Equations 2-10 provide the methods to determine the incremental increase in landfill gas collection that is achieved by the installation and operation of an automated collection system compared to traditional manual data measurement and gas collection well “tuning”.

These equations utilize data that landfills report to the US EPA under the Greenhouse Gas Reporting Program and the formulas and assumptions developed by the US EPA for predicting landfill gas collection system performance based on manual well-field measurement and tuning. Use of this data, which is required by law to be reported annually, allows for a consistent method to be used to calculate historical landfill gas generation and gas collection system efficiency. This data can then be compared to the actual measured and reported landfill gas collection to establish historical gas collection system efficiency for any landfill.

As described in the following case study, using the proposed method will establish the historical baseline collection system efficiency for manual well-field tuning for any landfill. The method allows for this baseline to be updated based on changes to the landfill and the gas collection system in the future. This historical collection system efficiency baseline can then be compared to measured gas collection system efficiencies when enhanced landfill gas collection system technology is used. The result is a consistent method to calculate the incremental increase in gas collection system efficiency through the use of automated collection technology when compared to manual well-field tuning.

C.1 CASE STUDY LANDFILL DESCRIPTION

During 2014-2016, the subject landfill had a 400,000 square meter (99 acre) footprint that commenced operation in 1995. 500,000 tons of municipal solid waste (MSW) are disposed in the landfill annually. In 2000, the landfill exceeded the 2.75-million-ton size threshold for NSPS reporting and testing of non-methane organic compounds (NMOCs). In 2002, the landfill exceeded the 30 megagram threshold for NMOC emissions and therefore became subject to the control and monitoring requirements of NSPS.

To comply with the NSPS for landfills, a gas collection system was installed during 2003 and continued to expand into new areas of waste disposed. The wells were monitored and adjusted manually by landfill technicians in accordance with the NSPS requirements. The gas collection system continued to expand and operate manually through 2016.

During 2017, an automated collection system was installed and operated on 50% of the wells evenly throughout each of the landfill areas that were covered by the gas collection system. Those wells were automatically adjusted to maximize the collection of methane. The remaining 50% of the wells continued to be operated manually through 2017.

During 2018, the automated collection system was expanded to 100% of the wells throughout the landfill areas that were covered by the gas collection system. All the wells were automatically adjusted to maximize the collection of methane.

The remainder of this case demonstrates how the collection efficiencies from the gas collection system operated manually and automatically are calculated to determine the increase in collection efficiency due to the automated collection system when compared to manual control of the gas collection system. This incremental improvement to gas collection system efficiency is the basis for determining the quantity of methane that is collected and combusted above the regulatory requirements under NSPS. The calculations use data, algorithms, and results from the US EPA GHG Reporting protocols.

C.2 CASE STUDY EQUATION APPLICATIONS

Step 1 Determine historic modeled methane generation rate using Equation 2 for the three years preceding the installation of the automated control system (calculate the three years separately using Equation 2). Below is an example calculation for 2014.

$$G_{CH4} = \left[\sum_{x=S}^{T-1} \left\{ W_x \, L_{o,x} \left(e^{-k(T-x-1)} - e^{-k(T-x)} \right) \right\} \right]$$

WHERE	VALUE USED IN THIS CASE
G_{CH4} = Modeled methane generation rate in reporting year T (metric tons)	Calculation result
X = Year in which waste was disposed	Each year from 1995 through baseline years 2014, 2015, 2016 and

	then ACS Increment years 2017 and 2018
S = Start year of calculation.	1995
T = Reporting year for which emissions are calculated.	Year of calculation including baseline years 2014, 2015, 2016 and then ACS Increment years 2017 and 2018
W_x = Quantity of waste disposed in the landfill in year x from measurement data, tipping fee receipts, or other company records (metric tons, as received wet weight).	For 2014: 453,590 metric tons (500,000 short tons)
L_o = Methane generation potential (metric tons methane/metric ton waste)	0.067, which corresponds to bulk MSW disposed
k = Rate constant year $^{-1}$ from Table HH-1 from EPA 40 CFR Part 98 Subpart HH: Variable for HH-1 equation.	0.038, which corresponds to a landfill existing in climate that receives 10 to 40 inches of precipitation annually (for this example).

The calculation for modeled methane generation in T = 2014 is shown below. The same calculation is performed for each of the subsequent years (2015 and 2016) to establish the baseline for use of manual gas collection. The same calculation is used for 2017 and 2018 to establish the increment for use of the automated collection system.

YEAR	CALCULATION FOR MODELED METHANE GENERATION IN T = 2014		RESULTS, METHANE METRIC TONS
1995	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-1-1)) - EXP ((-0.038 year $^{-1}$) × (20-1))]	=	571.8

1996	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-2-1)) - EXP ((-0.038 year $^{-1}$) × (20-2))]	=	593.9
1997	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-3-1)) - EXP ((-0.038 year $^{-1}$) × 20-3))]	=	616.9
1998	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-4-1)) - EXP ((-0.038 year $^{-1}$) × (20-4))]	=	640.8
1999	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-5-1)) - EXP ((-0.038 year $^{-1}$) × (20-5))]	=	665.7
2000	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-6-1)) - EXP ((-0.038 year $^{-1}$) × (20-6))]	=	691.4
2001	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-7-1)) - EXP ((-0.038 year $^{-1}$) × (20-7))]	=	718.2
2002	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-8-1)) - EXP ((-0.038 year $^{-1}$) × (20-8))]	=	746.0
2003	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-9-1)) - EXP ((-0.038 year $^{-1}$) × (20-9))]	=	774.9
2004	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-10-1)) - EXP ((-0.038 year $^{-1}$) × (20-10))]	=	804.9
2005	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-11-1)) - EXP ((-0.038 year $^{-1}$) × (20-11))]	=	836.1

2006	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-12-1)) - EXP ((-0.038 year $^{-1}$) × (20-12))]	=	868.5
2007	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-13-1)) - EXP ((-0.038 year $^{-1}$) × (20-13))]	=	902.1
2008	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-14-1)) - EXP ((-0.038 year $^{-1}$) × (20-14))]	=	937.1
2009	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-15-1)) - EXP ((-0.038 year $^{-1}$) × (20-15))]	=	973.4
2010	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-16-1)) - EXP ((-0.038 year $^{-1}$) × (20-16))]	=	1,011.1
2011	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-17-1)) - EXP ((-0.038 year $^{-1}$) × (20-17))]	=	1,050.2
2012	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-18-1)) - EXP ((-0.038 year $^{-1}$) × (20-18))]	=	1,090.9
2013	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-19-1)) - EXP ((-0.038 year $^{-1}$) × (20-19))]	=	1,133.2
2014	G_{CH4} = (453,590 Mtons waste) × (0.067 MTons methane/MTons waste) × [(EXP ((-0.038 year $^{-1}$) × (20-20-1)) - EXP ((-0.038 year $^{-1}$) × (20-20))]	=	1,177.1
TOTAL	G_{CH4}	=	**16,804.0**

Step 2 Determine historic measured methane collection using Equation 3 for the three years preceding the installation of the automated control system (calculate the three years separately using Equation 3). Below is an example calculation for 2014 with assumptions for the standard cubic feet of landfill gas captured as well as the methane content of that gas.

$$\mathbf{C_{CH4,T} = HLFG_{captured} \times H\%CH_4 \div 385 \times 16.04 \div 2204.62}$$

$C_{CH4,\ 2014}$= 1,050,000,000 scf × 52% / 385 × 16.04 ÷ 2204.62 = 10,318 metric tons C

Step 3 Determine measured landfill gas collection efficiency using Equation 4 for the three years preceding the installation of the automated control system (calculate the three years separately using Equation 4). Below is an example calculation for 2014.

$$\mathbf{CE_{measured} = C_{CH4,T} \div G_{CH4}}$$

$CE_{measured}$ = 10, 318 ÷ 16,804 = 61.4%

Step 4 Determine modeled landfill gas collection system efficiency using Equation 5 for the three years preceding the installation of the automated control system (calculate the three years separately using Equation 5). Below is an example calculation for 2014 with assumptions for the cover area at the landfill that corresponds to each collection efficiency from Table HH-3 of US EPA CFR Part 98, Subpart HH.

A1: Areas with no waste in-place, CE 1 is not applicable
A2: Area without active gas collection, regardless of cover type, CE 2 = 0%
A3: Area with daily soil cover and active gas collection, CE 3 = 60%
A4: Area with an intermediate soil cover and active gas collection, CE 4 = 75%
A5: Area with a final soil and geomembrane cover system and active gas collection, CE 5 = 95%

The landfill areas (A2-A5) shown below are inputs for each specific cover area in the example for year 2014.

LF AREA, SQ METERS		COLLECTION EFFICIENCIES	
A2 =	25,000	**CE2 =**	0%
A3 =	100,000	**CE3 =**	60%
A4 =	135,000	**CE4 =**	75%
A5 =	140,000	**CE5 =**	95%

$$\mathbf{CE_{modeled} = (A2_T \times CE2 + A3_T \times CE3 + A4_T \times CE4 + A5_T \times CE5) \div (A2_T + A3_T + A4_T + A5_T)}$$

$$CE_{modeled} = (25{,}000 \times 0 + 100{,}000 \times 60\% + 135{,}000 \times 75\% + 140{,}000 \times 95\%) \div (25{,}000 + 100{,}000 + 135{,}000 + 140{,}000) = 73.6\%$$

Step 5 Calibrate the collection efficiencies based on landfill area using Equation 6 for the three years preceding the installation of the automated control system (calculate the three years separately using Equation 5). Below is an example calculation for 2014.

$$\mathbf{CCE2 = CE2 \times CE_{measured} \div CE_{modeled}}$$

$$\mathbf{CCE3 = CE3 \times CE_{measured} \div CE_{modeled}}$$

$$\mathbf{CCE4 = CE4 \times CE_{measured} \div CE_{modeled}}$$

$$\mathbf{CCE5 = CE5 \times CE_{measured} \div CE_{modeled}}$$

$$CCE2 = 0\% \times 61.4\% \div 73.6\% = 0$$

$$CCE3 = 60\% \times 61.4\% \div 73.6\% = 50\%$$

$$CCE4 = 75\% \times 61.4\% \div 73.6\% = 63\%$$

$$CCE5 = 95\% \times 61.4\% \div 73.6\% = 79\%$$

Step 6 Calculate the average of the three years for each calibrated collection efficiency based on landfill area using Equation 7. The same calculation is performed based on each cover type and the associated calibrated collection efficiency for the three years preceding the installation of the automated control system. Below is the example calculation with CCE values for 2014 taken from Step 5 as well as example values provided in the table for 2015 and 2016

	2014	2015	2016
CCE2 =	0	0	0
CCE3 =	50	49	48
CCE4 =	63	62	60
CCE5 =	79	78	76

$$\mathbf{ACCE2} = \sum \mathbf{CCE2} \div \mathbf{3}$$

$$\mathbf{ACCE3} = \sum \mathbf{CCE3} \div \mathbf{3}$$

$$\mathbf{ACCE4} = \sum \mathbf{CCE4} \div \mathbf{3}$$

$$\mathbf{ACCE5} = \sum \mathbf{CCE5} \div \mathbf{3}$$

ACCE2 = (0 + 0 +0) ÷ 3 = 0%

ACCE3 = (50 + 49 +48)/3 = 49%

ACCE4 = (63 + 62 + 60)/3 = 61.7%

ACCE5 = (79 + 78 + 76)/3 = 77.7%

Step 7 Following the installation of the automated collection system (in this example, in 2017), calculate the updated calibrated collection efficiency to reflect changes in the landfill's cover and collection systems. The below example uses the updated landfill areas by cover in the below table.

LF AREA, SQ METERS	
A2 ' =	5,000
A3 ' =	110,000
A4 ' =	145,000
A5 ' =	140,000

$$\mathbf{UCCE} = (\mathbf{A2_T} \times \mathbf{ACCE2} + \mathbf{A3_T} \times \mathbf{ACCE3} + \mathbf{A4_T} \times \mathbf{ACCE4} + \mathbf{A5_T}) \times \mathbf{ACCE5} \div (\mathbf{A2_T} + \mathbf{A3_T} + \mathbf{A4_T} + \mathbf{A5_T})$$

For 2017, the UCCE is calculated as follows:

UCCE = (5,000 × 0 + 110,000 × 49% + 145,000 × 61.7% + 140,000 × 77.7%)
÷ (5,000 + 110,000 + 145,000 + 140,000) = 63%

Step 7 Calculate the incremental efficiency improvement that is attributable to the automated collection system in 2017. To do this, $CH_{4combusted}$ is calculated in accordance with Equation 1 and CH_{4total} is calculated in accordance with Equation 11. In this example and for simplicity, assume that $CH_{4combusted}$ is calculated appropriately and is used to calculate CH_{4total} in Equation 11 with the resulting CH_{4total} set to 13,478 metric tons. Also, assume that G_{CH4} is calculated per Equation 2 for 2017 and is set equal to 18,395 metric tons.

$$\mathbf{ACSI} = \left(\mathbf{CH_{4total}} - (\mathbf{UCCE} \times \mathbf{G_{CH4}})\right) \div \mathbf{CH_{4total}}$$

$$\text{ACSI} = (13{,}478 - (63\% \times 18{,}395)) \div 13{,}478 = 14\%$$

The ACSI is then used as an input to Equation 10.

This case study has been included to provide an illustrative example of the application of Equations 2-9 for projects that install an automated collection system as a stand-alone project activity.

APPENDIX D: REFERENCES

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