

February 4, 2009

**TECHNICAL SUPPORT DOCUMENT
FOR THE LANDFILL SECTOR:
PROPOSED RULE FOR
MANDATORY REPORTING OF
GREENHOUSE GASES**

Office of Air and Radiation
U.S. Environmental Protection Agency

February 4, 2009

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1. Industry Description

The New Source Performance Standard (NSPS) for municipal solid waste (MSW) landfills (40 CFR 60 subpart WWW) includes the following definition for landfills:

“Landfill means an area of land or an excavation in which wastes are placed for permanent disposal, and that is not a land application unit, surface impoundment, injection well, or waste pile as those terms are defined under §257.2 of this title.”
(Note: 40 CFR 257 is the Criteria for Classification of Solid Waste Disposal Facilities and Practices)

The landfill NSPS also includes the following definition for MSW landfills:

“Municipal solid waste landfill or MSW landfill means an entire disposal facility in a contiguous geographical space where household waste is placed in or on land. An MSW landfill may also receive other types of RCRA Subtitle D wastes (§257.2 of this title) such as commercial solid waste, nonhazardous sludge, conditionally exempt small quantity generator waste, and industrial solid waste. Portions of an MSW landfill may be separated by access roads. An MSW landfill may be publicly or privately owned. An MSW landfill may be a new MSW landfill, an existing MSW landfill, or a lateral expansion.”

After being placed in a landfill, waste is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH₄-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas.

Methane generation from a given landfill is a function of several factors, including: (1) the total amount of waste disposed of in the landfill each year (annual waste acceptance rate); (2) the age of the landfill (or the total quantity of waste in-place); (3) the characteristics of the waste (i.e., composition and organic content of waste); and (4) the climatic conditions (temperature and soil moisture content – wet soils promote anaerobic degradation). The amount of methane emitted is dependent on the amount of CH₄ generated less the amount of CH₄ that is recovered (and either flared or used for energy purposes); and the amount of CH₄ oxidized near the landfill surface prior to being released into the atmosphere.

There are two important federal standards that require MSW landfills to capture and control landfill gas: the NSPS for MSW Landfills (40 CFR 60 subpart WWW) and the Emission Guidelines for MSW Landfills (40 CFR 60 subpart Cc). The landfill NSPS requires landfills that have a design capacity of 2.5-million cubic meters or greater and 2.5-million megagrams (Mg) or greater and that commenced construction, reconstruction, or modification on or after May 30, 1991, to capture and control the landfill gas if the non-methane organic compound (NMOC) emissions exceed 50 Mg per year (Mg/yr). The Emission Guidelines are applicable to landfills that commenced construction, reconstruction, or modification prior to May 30, 1991,

but that received waste (or have remaining capacity to receive waste) after November 8, 1987. The Emission Guidelines, like the NSPS, requires applicable landfills that have a design capacity of 2.5-million cubic meters or greater and 2.5-million Mg to capture and control the landfill gas if the non-methane organic compound (NMOC) emissions exceed 50 Mg per year (Mg/yr). While these two standards focus on NMOC, they effectively require capture and control of landfill-generated methane.

In addition to these two standards, the EPA has promoted the beneficial use of landfill gas for energy (electricity or heat) production through its voluntary Landfill Methane Outreach Program. This program helps to identify and promote cost-effective landfill gas-to-energy (LFGTE) projects.

2. Total Emissions

There were approximately 7,800 active MSW landfills in the United States in 1988; in 2004, the number of active MSW landfills had dropped to about 1,600 (Simmons, et al., 2006). MSW landfills emitted 111.2 million metric tons of carbon dioxide equivalent (mmtCO₂e) in 2006. Generation of methane at these landfills was 246.8 mmtCO₂e; however, 65.3 mmtCO₂e was recovered and used in energy projects, 59.8 mmtCO₂e was reduced by flaring, and 12.4 mmtCO₂e was oxidized in cover soils (U.S. EPA, 2008b). Based on the decrease in the number of landfills reported over the past 16 years, it is estimated that there are approximately 6,200 closed MSW landfills in the U.S. that have been closed less than 20 years. Data on these landfills were unavailable at the time of this analysis.

The majority of the CH₄ emissions from on-site industrial landfills occur at pulp and paper facilities and food processing facilities. In 2006, these landfills emitted 14.6 mmtCO₂e.

Approximately 180 pulp and paper facilities have on-site landfills. These landfills emitted 7.3 mmtCO₂e in 2006. Approximately 189 food processing facilities have on-site landfills. These landfills emitted 7.2 mmtCO₂e in 2006.

3. Review of Existing Programs and Methodologies

In developing GHG monitoring and reporting options for landfills, a number of existing programs and guideline methodologies were reviewed. In addition to the NSPS and Emission Guidelines for MSW landfills, the following resources were examined:

1. 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Volume 5, *Waste*.
2. U.S. Department of Energy (DOE). 2007. Technical Guidelines: Voluntary Reporting Of Greenhouse Gases (1605(B)) Program.

3. CARB (California Air Resource Board). 2008. *Regulation For The Mandatory Reporting of Greenhouse Gas Emissions: Second 15-Day Modified Regulatory Language For Public Comment*. May 15.
4. Environment Canada (2006). Guidance Manual for Estimating Greenhouse Gas Emissions. <http://www.ghgreporting.gc.ca/GHGInfo/Pages/page15.aspx?lang=E>.

Additional programs and methodological guidance reviewed included: U.S. GHG Inventory, California Climate Action Registry, EPA Climate Leaders, EU Emissions Trading System, The Climate Registry, EPA's Landfill Methane Outreach Program, Australia's National Mandatory GHG Reporting Program (draft), NSPS/NESHAP, and the WRI/WBCSD GHG Protocols.

Each of these sources was reviewed to determine the types of emissions to be reported, the facility reporting thresholds, and the monitoring methodologies recommended. The reporting and monitoring options presented in Sections 4, 5, and 6 are commensurate with the methodologies used in these existing programs and guidelines.

4. Types of Emissions Information to be Reported

4.1 Types of Emissions to be Reported

Based on the review of existing programs and the emission sources at landfills, GHG reporting for landfills is limited to CH₄ because the CO₂ produced from the landfills is considered biogenic. There are potentially other sources of GHG emissions at facilities that operate landfills. For reporting options for stationary combustion (including landfill gas combustion for energy and combustion of fossil fuels used to assist gas combustion efficiency), refer to EPA-HQ-OAR-2008-0508-004. Biogenic emissions of CO₂ from flaring without energy recovery are not reported.

In the case of industrial facilities with onsite landfills, industrial process emissions of greenhouse gases may be occurring onsite as well. Reporting options for landfill emissions are detailed here, but for reporting options for other sources of industrial process emissions, refer to sections for that industry in the respective Background Technical Support Documents.

4.2 Other Information to be Reported

In order to check the reported GHG emissions for reasonableness and for other data quality considerations, additional information about the emission sources is needed. It is recommended that, in addition to methane emissions, each reporting landfill should also report methane generation and, if applicable, methane combustion annual quantities. Additionally, it is recommended that the following data also be submitted with the annual report:

Data to report—all landfills

- a. Waste disposal for each year of landfilling
- b. Method for estimating waste disposal
- c. Waste composition, if available
- d. Method for estimating waste composition
- e. Fraction of CH₄ in landfill gas (most will use IPCC default)

- f. Oxidation rate (most will use IPCC default)
- g. Degradable organic carbon (DOC) (most will use inventory default)
- h. Decay rate (most will use inventory default)
- i. Fraction of DOC dissimilated (most will use IPCC default)
- j. MCF used (most will use IPCC)
- k. Methane generation using FOD method
- l. Methane emissions using FOD method (and deducting methane recovery)
- m. Landfill design capacity
- n. Estimated year of landfill closure
- o. Cover system description
- p. Acreage and quantity of waste covered by intermediate cap
- q. Acreage and quantity of waste covered by final cap

Additional data to report—landfills with gas collection systems

- a. Total volumetric flow
- b. CH₄ concentration
- c. Temperature at which flow is measured
- d. Pressure at which flow is measured
- e. Destruction efficiency used
- f. Methane destruction
- g. Estimated gas collection system efficiency
- h. Methodology for estimating gas collection system efficiency for landfills with gas collection systems
- i. Number of wells in gas collection system
- j. Methane generation using recovery data
- k. Methane emissions using recovery data

5. Options for Reporting Threshold

5.1 Emissions-based thresholds

Data were collected and analyzed to evaluate several potential reporting thresholds. The primary options were based on the CH₄ generation at a landfill minus oxidation (“generation threshold”) and CH₄ emissions from a landfill, minus oxidation after any destruction of landfill gas at a combustion device (“emissions threshold”). The generation threshold refers to the methane generated at the landfill, minus oxidation in landfill cover soils that are expected to occur in the absence of a landfill gas collection system. The emissions threshold refers to the methane that is actually emitted to the atmosphere from these landfills taking into account recovered methane combustion and methane oxidation at the landfill surface. Emissions-based thresholds evaluated were:

- i. An emissions threshold of 1,000 mtCO₂e
- ii. An emissions threshold of 10,000 mtCO₂e
- iii. An emissions threshold of 25,000 mtCO₂e
- iv. An emissions threshold of or 100,000 mtCO₂e
- v. A generation threshold of 1,000 mtCO₂e
- vi. A generation threshold of 10,000 mtCO₂e

- vii. A generation threshold of 25,000 mtCO₂e
- viii. A generation threshold of 100,000 mtCO₂e

In addition to these emissions-based thresholds, landfills were also categorized as active MSW landfills, closed MSW landfills, and industrial landfills. The emissions based thresholds were evaluated for each of these classes of landfills and certain combinations of these classes; the results of this analysis are presented in Table 1.

Table 1. Summary of Threshold Analysis for Landfills

Source Category	Threshold Level	Facilities Covered		Emissions Covered	
		Number	Percent	MMTCO ₂ e/year	Percent
"Active" MSW Landfills	>1,000 mtCO ₂ e (generation)	1560	98	57.3	99.7
	>1,000 mtCO ₂ e (emissions)	1557	97	57.3	99.7
	>10,000 mtCO ₂ e (generation)	1314	82	54.0	94
	>10,000 mtCO ₂ e (emissions)	1200	75	53.2	93
	>25,000 mtCO ₂ e (generation)	1001	63	47.2	82
	>25,000 mtCO ₂ e (emissions)	686	43	42.6	74
	>100,000 mtCO ₂ e (emissions)	131	8	20.3	35
Closed MSW Landfills	>1,000 mtCO ₂ e (generation)	5270	85	53.4	99.6
	>1,000 mtCO ₂ e (emissions)	5270	85	53.4	99.6
	>10,000 mtCO ₂ e (generation)	2170	35	50.4	94
	>10,000 mtCO ₂ e (emissions)	1860	30	49.6	93
	>25,000 mtCO ₂ e (generation)	1550	25	44.0	82
	>25,000 mtCO ₂ e (emissions)	1240	20	39.8	74
	>100,000 mtCO ₂ e (emissions)	310	5	18.9	35
Industrial Landfills, Pulp and Paper	>1,000 mtCO ₂ e (generation)	180	100	7.3	100
	>1,000 mtCO ₂ e (emissions)	180	100	7.3	100
	>10,000 mtCO ₂ e (generation)	170	94	7.0	96
	>10,000 mtCO ₂ e (emissions)	170	94	7.0	96
	>25,000 mtCO ₂ e (generation)	100	56	5.0	68
	>25,000 mtCO ₂ e (emissions)	100	56	5.0	68
	>100,000 mtCO ₂ e (emissions)	10	6	1.5	21
Industrial Landfills, Food Processing	>1,000 mtCO ₂ e (generation)	189	100	7.2	100
	>1,000 mtCO ₂ e (emissions)	189	100	7.2	100
	>10,000 mtCO ₂ e (generation)	170	90	7.0	97
	>10,000 mtCO ₂ e (emissions)	170	90	7.0	97
	>25,000 mtCO ₂ e (generation)	100	53	5.0	69
	>25,000 mtCO ₂ e (emissions)	100	53	5.0	69
	>100,000 mtCO ₂ e (emissions)	10	5	1.5	21

Source Category	Threshold Level	Facilities Covered		Emissions Covered	
		Number	Percent	MMTCO ₂ e/year	Percent
Total All MSW Landfills	>1,000 mtCO ₂ e (generation)	6,830	88	110.7	100
	>1,000 mtCO ₂ e (emissions)	6,827	88	110.7	100
	>10,000 mtCO ₂ e (generation)	3,484	45	104.4	94
	>10,000 mtCO ₂ e (emissions)	3,060	39	102.8	93
	>25,000 mtCO ₂ e (generation)	2,551	33	91.1	82
	>25,000 mtCO ₂ e (emissions)	1,926	25	82.4	74
	>100,000 mtCO ₂ e (generation)	1,038	13	65.6	59
	>100,000 mtCO ₂ e (emissions)	441	6	39.2	35
Total All MSW and Industrial Landfills	>1,000 mtCO ₂ e (generation)	7199	88	125.2	100
	>1,000 mtCO ₂ e (emissions)	7196	88	125.2	100
	>10,000 mtCO ₂ e (generation)	3824	47	118.4	94
	>10,000 mtCO ₂ e (emissions)	3400	42	116.8	93
	>25,000 mtCO ₂ e (generation)	2751	34	101.1	81
	>25,000 mtCO ₂ e (emissions)	2126	26	92.4	74
	>100,000 mtCO ₂ e (generation)	1058	13	68.6	55
	>100,000 mtCO ₂ e (emissions)	461	6	42.2	34

5.2 Other threshold options

In addition to these general landfill classes, other specific reporting thresholds were evaluated. For example, reporting of only NSPS landfills was considered, but this would only result in the reporting of 36% of the emissions from the landfill sector. Reporting of only landfills that do not have landfill gas collection systems would require reporting from approximately 6,900 landfills many of which have very small emissions and would still exclude a significant fraction of the landfill sector emissions. Excluding closed landfills would mean that 48% of emissions from all landfills in the United States would not be reported. Consequently, none of these options were considered further as part of the reporting threshold.

Commensurate with other reporting programs, a generation threshold of 25,000 mtCO₂e per year is recommended. The emissions threshold would exclude reporting from large facilities with gas collection systems. A generation threshold level of 1,000 or 10,000 mtCO₂e increases the number of reporters by several thousand and this level would likely capture numerous small landfills that only contribute 5 to 10 percent of the nationwide CH₄ emissions. An emissions threshold level of 100,000 mtCO₂e would require reporting by far fewer landfills, but capture only about 50 percent of emissions from this source.

At the recommended reporting threshold, it is estimated that 1001 active MSW landfills would report. This would represent around 63% of active MSW landfills, but 82% of methane emitted from active MSW landfills. Data are not available to calculate the amount of methane emitted from specific closed landfills, but it is estimated that approximately 1,550 (or approximately 25 percent of) closed landfills would need to report at this threshold and that approximately 82 percent the methane emissions from closed landfills would be included. Overall, approximately 2,551 MSW landfills would report and these facilities would include 91.1 MMTCO₂e or 82 percent of the total U.S. CH₄ emissions from MSW landfills (see Table 2).

For industrial landfills, at a generation threshold of 25,000 mtCO₂e per year, it is estimated that approximately 100 landfills at pulp and paper facilities (56% of such landfills) and 100 landfills at food processing facilities (53% of such landfills) would report emissions. As seen in Table 2, it is estimated that approximately 68 percent of CH₄ emissions from pulp and paper landfills and 69 percent of CH₄ emissions from food processing landfills would be accounted for at the recommended reporting threshold. Data were not available for landfills that may occur at other industrial facilities (e.g., petroleum refineries).

Table 2. Estimated Number of Facilities Reporting and Emissions Reported at the Recommended Reporting Threshold

Operation	Estimated Number Facilities Reporting	Percent of All Facilities of this Type of Operation	Emissions (mtCO₂e)	Percent of All Emissions from this Type of Operation
MSW Landfills	2551	33	91.1	82
Pulp and Paper on-site Landfills	100	56	5.0	68
Food Processing onsite landfills	100	53	5.0	69

6. Options for Monitoring Methods

There are three potential monitoring methods: (1) calculation of methane generation using the IPCC waste model for landfills that do not have landfill gas collection systems; (2) use of gas flow and composition metering for landfills that have gas collection systems, in addition to calculating methane generation with the IPCC waste model; and (3) direct emission measurements from the landfill surface. Direct surface emission measurement techniques are expensive, they typically provide only short-term measures of emissions, and they often suffer from high uncertainty.

6.1 Calculating Methane Generation using the First-order Decay (FOD) Model

The 2006 IPCC Guidelines' Waste Model produces emissions estimates that reflect the degradation rate of wastes in a landfill (IPCC, 2006). To assist in developing CH₄ emission estimates for solid waste disposal sites (SWDS), the IPCC developed the Waste Model and improved default values for the organic content and degradation rate constants for different types of waste materials. The basic FOD equation for the methane generation rate in the IPCC Waste Model using the "bulk waste" option and a time delay of 6 months is presented below (see Equation 1). This is the simplest calculation performed by the model.

Equation 1.

$$A = CH_4 \text{ Generation}_T \text{ (Mg / yr)} = \left[\sum_{x=S}^{T-1} \{W_x L_{0,x} (e^{-k(T-x-1)} - e^{-k(T-x)})\} \right]$$

where,

x = the year in which waste was disposed;

S = the start year of inventory calculation;

T = the inventory year for which emissions are calculated;

W_x = the quantity of waste disposed at SWDS (metric tons);

L_0 = CH_4 generation potential = $MCF \cdot DOC \cdot DOC_F \cdot F \cdot 16 / 12$ (Mg CH_4 /Mg waste);

MCF = methane correction factor (fraction);

DOC = degradable organic carbon [fraction (Mg C/Mg MSW)];

DOC_F = fraction of DOC dissimilated (fraction);

F = fraction by volume of CH_4 in landfill gas; and

k = reaction rate constant (yr^{-1}).

The model includes the delay time (in months) for CH_4 generation as an input parameter to the model, and adjusts the emission inventory calculations accordingly.

The model also provides an option in which CH_4 generation can be estimated for different types of waste materials (wood, food, garden, paper, textiles, etc.) by repeating the above calculation for each type of waste. This approach requires waste-specific disposal quantities and values of DOC and k by waste type; the IPCC Guidelines provides default values for DOC and k by waste type.

To accurately estimate emissions using this method, waste disposal data are needed for the 50 year period prior to the year of the emissions estimate.

Annual waste disposal data are to be estimated using receipts for disposal where available and extrapolation for years where these data are not available.

For years where waste composition data are available, emissions are estimated using waste composition. When waste composition data are unavailable, composition estimates are to be developed by extrapolating/interpolating with available waste composition data, by using regional composition data (as available) or by using bulk waste values developed for the United States.

The model will calculate emissions using the appropriate values for DOC, DOC_F , and k based on the waste composition entered. The selection of appropriate k values should also consider regional rainfall amounts.

6.2 Monitoring Methane Combustion at Flares or Energy Projects

Direct measurement for methane combustion methods depend on two measurable parameters: 1) the rate of gas flow to the combustion device; and 2) the CH₄ content in the gas flow. These can be quantified by directly measuring the gas stream to the destruction device(s).

Continuous Metering. The instrumentation recommended for continuous measurement measures both flow and gas concentration. Several direct measurement instruments also use a separate recorder to store and document the data. A fully integrated system that directly reports CH₄ content requires no other calculation than summing the results of all monitoring periods for a given year. Internally, the instrumentation is performing its calculations using algorithms similar to the equation below.

Monthly Sampling. The two primary instruments used in the monthly monitoring method are a gas flow meter and a gas composition meter. The gas flow meter must be installed as close to the landfill gas combustion device as possible to measure the amount of gas reaching the device. Two procedures are used for data collection in the monthly monitoring method:

1. Calibrate monitoring instrument in accordance with the manufacturer's specifications.
2. Collect four sets of data: flow rate (scfm); CH₄ concentration (%); temperature (°R); and pressure (atm) from the inlet landfill gas (before any treatment equipment using a monitoring meter specifically for CH₄ gas.)

The amount of CH₄ destroyed during the year is calculated using Equation 2. This equation can be used for either monthly sampling or for continuous monitoring systems that are not integrated.

Equation 2.

$$R = \sum_{n=1}^N \left\{ V_n \times \left(\frac{Conc_n}{100\%} \right) \times 0.0423 \times \left(\frac{520}{T_n} \right) \times \left(\frac{P_n}{1} \right) \times t_n \times \left(\frac{0.454}{1000} \right) \right\}$$

Where:

R = quantity of recovered CH₄ (Mg/yr)

V_n = average volumetric flow rate over time period n (acfm)

Conc_n = average CH₄ concentration in gas flow over time period n (in %)

0.0423 = lb. CH₄/scf (at 520°R or 60°F and 1 atm)

T_n = average temperature at which flow is measured over time period n (°R)

P_n = average pressure at which flow is measured over time period n (atm)

t_n = Time period since last measurement (min)

0.454/1000 = Conversion factor (Mg/lb)

6.3 Calculating Generation and Emissions using the IPCC Model

Generation, adjusted for oxidation, is calculated from the methane generation rate and the assumed oxidation factor according to Equation 3.

Equation 3.

$$\text{Adjusted Generation} = A \times (1 - \text{OX})$$

Where:

OX = oxidation, default rate is 0.1 (10%)

For landfills with gas collections systems, the emissions are reduced by the amount of gas recovered while considering the destruction efficiency of the control system. Emissions are calculated using Equation 4. Equation 4 reduces to Equation 3 when R = 0. That is, for landfills that do not have gas collection systems, the emissions calculated are equal to the adjusted generation.

Equation 4.

$$\text{Emissions} = (A - R) \times (1 - \text{OX}) + R \times (1 - \text{DE})$$

Where:

DE = destruction efficiency, default rate is 0.99

OX = oxidation, default rate is 0.1 (10%)

6.4 Calculating Generation and Emissions using Gas Collection Data and Collection Efficiency

For landfills with gas collection systems, an alternative method for estimating the methane generation rate and subsequently the adjusted generation and emissions is to use the gas collection data and estimated gas collection system efficiency. The methane generation rate estimated from gas collection data is the quantity of methane recovered divided by the collection efficiency (CE) of the landfill gas collection system ($A = R/CE$). Substituting for this expression for A in Equations 3 and 4 yield equations for the adjusted generation and emissions as calculated using the gas collection data and estimated gas collection system efficiency, which are provided here as Equations 5 and 6, respectively.

Equation 5.

$$\text{Adjusted generation} = R / \text{CE} \times (1 - \text{OX})$$

Where:

OX = oxidation, default rate is 0.1 (10%)

CE = collection efficiency, estimated at landfill

Equation 6.

$$\text{Emissions} = [R \times (1/\text{CE} - 1)] \times (1 - \text{OX}) + R \times (1 - \text{DE})$$

Where:

OX = oxidation, default rate is 0.1 (10%)

CE = collection efficiency, estimated at landfill

6.5 Monitoring Landfill Emissions from the Landfill Surface

A variety of measurement techniques have been used to measure the flux of methane gas at the surface of the landfill. One commonly used approach is flux chamber measurements. A flux chamber is a small enclosure used to collect gas as it is released from the surface of the landfill. The flux chamber covers a small area of the landfill and the methane concentration and quantity of gas collected and swept from the chamber is measured to calculate a flux of methane per area of the landfill. Difficulties associated with flux chamber measurements include the limited time and area over which measurements can be made. The surface of the landfill is not perfectly homogeneous and landfill gas will be released at different rates at different areas across the landfill. A significant fraction of the landfill gas releases may be focused in very limited areas where larger fissures in the surface soil exist. As such, it is difficult to get representative measurements across the entire landfill area. Additionally, flux chamber measurements are generally short-term tests. Variations in short-term emissions may occur due to barometric pumping, unusually dry or wet weather, etc. Consequently, there is significant uncertainty associated with a short-term, one-time test.

Open-Path Fourier Transform Infrared Spectroscopy (OP-FTIR) systems have also been used to measure emissions from large area sources such as landfills. OP-FTIR systems use multiple beams to determine vertical and horizontal gradients. Radial scanning techniques can be used to locate potential hot spots; vertical gradient measurements are used for determining mass flux rates. OP-FTIR monitoring requires significant capital investment and is a complicated system to maintain and operate correctly. The accuracy of the plume flux measurements are dependent on acceptable wind conditions. While the OP-FTIR system can more easily obtain an integrated flux rate from a relatively large landfill area, these systems are typically used to assess emission over a relatively short study period, and the hourly or daily measurements made during a one-time test may not be representative of the annual average emissions.

7. Options for Estimating Missing Data

For missing waste quantity data, it is recommended that reporters use historical waste disposal data or historical population served by the landfill and per capita waste disposal data (can be derived from current year waste acceptance and population). For missing gas recovery data, the average gas recovery rate measured over the previous week should be used. If gas recovery data are missing for more than one week, gas recovery rate of zero must be used until the monitoring system is operational. EPA considered not deducting CH₄ combustion that was not recorded, but not including CH₄ recovery could greatly overestimate an entity's emissions. On the other hand, allowing extended periods of missing data provides little incentive to repairing the monitoring system.

8. QA/QC Requirements

In order to ensure the quality of the reported GHG emissions, the following quality assurance/quality control (QA/QC) activities are recommended:

- (1) Reporters are to maintain annual records on waste acceptance quantities and waste composition, and records on daily gas flow and methane content to combustion device.
- (2) Reporters are to maintain records of Waste Model input values used (historical waste disposal quantities, DOC values, k values, etc.)
- (3) All fuel flow meters and gas composition monitors, and/or heating value monitors that are used to provide data for the GHG emissions calculations should be calibrated prior to the first reporting year, using a suitable method published by a consensus standards organization (e.g., ASTM, ASME, API, AGA, etc.). Alternatively, calibration procedures specified by the flow meter manufacturer may be used. Fuel flow meters and gas composition monitors should be recalibrated either annually or at the minimum frequency specified by the manufacturer.
- (4) Documentation of the procedures used to ensure the accuracy of the estimates of fuel usage, gas composition, and/or heating value including, but not limited to, calibration of weighing equipment, fuel flow meters, and other measurement devices should be maintained. The estimated accuracy of measurements made with these devices should also be recorded, and the technical basis for the estimates should be provided.

9. References

- CARB (California Air Resource Board). 2008. *Regulation For The Mandatory Reporting of Greenhouse Gas Emissions: Second 15-Day Modified Regulatory Language For Public Comment*. Available at: <http://www.arb.ca.gov/regact/2007/ghg2007/ghgattachment1.pdf>. May 15.
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Appendix A. Assumptions Used in Landfill Threshold Analysis

This appendix summarizes the key assumptions and methodologies used to estimate the number of landfills and the emissions included for various landfill emission reporting thresholds. The assumptions and methodologies used for municipal solid waste (MSW) landfills are presented first, and then the assumptions and methodologies used for industrial waste landfills are presented.

A.1 Municipal Solid Waste (MSW) Landfills

Number of MSW Landfills

- i The number of active and recently closed landfills was estimated from data presented in “The State of Garbage in America” (*BioCycle*, 47(4), April 2006, pp. 26-43). A graph on page 27 indicates that there were approximately 7,800 landfills in 1988 and 1,654 landfills in 2004. It was assumed that in 2006, the active landfills were approximately 1,600, so that there are approximately 6,200 (7,800 – 1,600) landfills that closed over the past 18 years (i.e., since 1988), and approximately 460 landfills active landfills that are not included in the landfill-specific model.

Methane Generation

- i A landfill-specific model developed by RTI was used to estimate methane generation rates in 2006. This model includes 1,142 landfills from the LMOP database that did not report gas collection in 2003, or were projected to close prior to 2003. Based on the waste acceptance rates (WAR), these landfills accounted for 88.5 percent of the waste landfilled annually in the United States. The landfill specific model used the first order decay model with an L_0 of 100 m³/mt and three different k values based on rainfall levels (identical to what is used in the U.S. GHG Inventory). More details of the landfill specific model are provided elsewhere.¹
- i Total active landfill methane generation was estimated by taking the model’s estimated methane generation and dividing it by 88.5% (proportion of total WAR covered by these landfills). This total was then multiplied by 11.5% to estimate the total methane generation for the “missing” active landfills. These “missing” landfills are generally assumed to be small or to be construction and demolition debris landfills.
- i Methane generation from closed landfills was estimated from the 2006 inventory methane generation rates minus methane generation from active landfills.

Generation adjusted for oxidation

- i Adjusted generation was estimated as methane generation less 10% oxidation of methane near the landfill surface. This was used for all landfills (both open and closed). Adjusted generation = Generation × (1-OX), where OX = oxidation fraction = 0.1 or 10%.

Emissions

- i For the landfills included in the landfill-specific model, methane recovery was assumed to be 75 percent of the methane generation rate under the following 3 conditions:
 - o The landfill is known to have a flare or landfill gas-to-energy (LFGTE) project based on data available in the LMOP, EIA, or flare vendor databases used to estimate CH₄ recovery for the U.S. GHG Inventory.

¹ “Development of Landfill-specific Methane Inventory Model” Memorandum from Jeff Coburn and Marvin Branscome, RTI, to Elizabeth Scheele, EPA, dated May 6, 2005.

- The landfill is projected to be subject to the NSPS: design capacity greater than 2.5-million Mg AND Year Open is 1991 or more recent AND 2006 methane generation exceeds 1,174 mtCH₄/yr (estimated to be equivalent to 50 Mg NMOC/yr).
- The landfill is projected to be subject to the Emission Guidelines: design capacity greater than 2.5-million Mg AND accepted waste in 1988, 1989, or 1990 AND 2006 methane generation exceeds 1,174 mtCH₄/yr.
- ¡ Emissions were than estimated as: $(\text{Generation} - \text{Recovery}) \times (1 - \text{OX})$, where OX = oxidation fraction = 0.1 or 10%.
- ¡ For active landfills not in the landfill-specific model, it was assumed that none had recovery, so that emissions = adjusted generation.
- ¡ For closed landfills, the total methane recovery estimate from the U.S. GHG inventory was subtracted from the recovery estimated for the active landfills included in the landfill-specific model. The emissions from closed landfills was then calculated to be $(\text{Generation} - \text{Recovery}) \times (1 - \text{OX})$, where OX = oxidation fraction = 0.1 or 10%. This yields nationwide methane emissions from both open and closed landfills of 111.1 MMTCO₂e (commensurate with the inventory).
- ¡ Threshold analyses for the active landfills included in the landfill specific model were performed directly on the model predictions for each landfill.
- ¡ Threshold analyses for the active landfills not included in the landfill specific model were estimated based on expert judgment from the average size of the landfills.
 - For the roughly 460 active landfills not included in the landfill-specific model, the average adjusted generation per landfill was 39,000 mtCO₂e. Based on this average emissions rate, it was assumed 95% of these landfills exceed the 1K threshold; 80% of these landfills exceed the 10K threshold, 50% exceed the 25K threshold, and 10 percent exceed the 100K threshold. The proportion of generation covered by a threshold was assumed to be the same as the portion of emissions over the threshold as calculated for the modeled landfills. For the 460 active landfills not in the landfill specific model, the landfill counts and emissions covered by the emission thresholds were set equal to the counts and emissions calculated for the generation threshold because these landfills were assumed not to have recovery.
 - For the closed landfills, the average adjusted generation per landfill was estimated to be approximately 10,800 mtCO₂e and the average emissions per landfill was approximately 8,600 mtCO₂e. Based on these average emissions rates, it was assumed:
 - § 85% of these landfills exceed the 1K generation threshold
 - § 85% exceed the 1K emissions threshold
 - § 35% of these landfills exceed the 10K generation threshold
 - § 30% exceed the 10K emissions threshold
 - § 25% exceed the 25K generation threshold
 - § 20% exceed the 25K emissions threshold
 - § 10% exceed the 100K generation threshold
 - § 5% exceed the 100K emissions threshold.

- The percentage of the emissions covered by a threshold level for the closed landfills was assumed to be the same as the percentage of emissions covered by the threshold for all active landfills.

A.2 Industrial Waste Landfills

- ! The number of industrial landfills was estimated based on 1987 screening survey of industrial Subtitle D waste management practices.
- ! Methane generation and methane emissions were estimated based on U.S. GHG Inventory estimates.
- ! The number of landfills and percentage of waste covered by each threshold was estimated based on expert judgment and the average methane emissions potential for the industrial landfills.
- ! Industrial landfills were assumed not to have recovery, so there is no difference in the generation versus emissions thresholds.