TECHNICAL SUPPORT DOCUMENT FOR THE INDUSTRIAL WASTE LANDFILL SECTOR: FINAL RULE FOR MANDATORY REPORTING OF GREENHOUSE GASES

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Contents

1. Industry Description

An industrial waste landfill is a landfill containing industrial solid wastes. The New Source Performance Standard (NSPS) for municipal solid waste (MSW) landfills (40 CFR 60 subpart WWW) and the Greenhouse Gas (GHG) Mandatory Reporting Rule (MRR) (40 CFR 98 subpart A) include 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. Only the MSW landfill rule includes the bracketed phrase "of this title.")

An MSW landfill is a landfill in which household waste is placed. An MSW landfill may receive industrial or commercial wastes, but if the landfill receives household waste, then the landfill is an MSW landfill. There are two basic types of industrial wastes: 1) hazardous wastes such as those defined in Subtitle C of the Resource Conservation and Recovery Act (RCRA) or defined in the Toxic Substance Control Act (TSCA); and 2) non-hazardous wastes as those regulated in Subtitle D of RCRA. A hazardous waste landfill may accept non-hazardous wastes, but a non-hazardous waste landfill cannot accept hazardous wastes. As RCRA and TSCA have a significant restrictions on the types of hazardous wastes that can be landfilled and significant containment requirements on the landfill, methane production from these hazardous waste landfills is expected to be negligible. Consequently, a reasonable definition of industrial waste landfills is:

> "Industrial waste landfill means any landfill other than a municipal solid waste landfill, a RCRA Subtitle C hazardous waste landfill, or a TSCA hazardous waste landfill, in which industrial solid waste, such as RCRA Subtitle D wastes (non-hazardous industrial solid waste, defined in 40 CFR 257.2), commercial solid wastes, or conditionally exempt small quantity generator wastes, is placed. An industrial waste landfill includes all disposal areas at a facility."

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 CH_4-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 CH_4 generated less the amount of CH_4 that is recovered (and either flared or used for energy purposes) and the amount of CH_4 oxidized near the landfill surface prior to being released into the atmosphere.

Although federal standards require some MSW landfills to capture and control landfill gas, industrial waste landfills are not subject to similar federal standards.

2. Total Emissions

According the *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2006* (US EPA, 2008a), the majority of the CH_4 emissions from on-site industrial waste landfills occur at pulp and paper facilities and food processing facilities. In 2006, these landfills emitted 14.6 Tg CO_2e of methane, with pulp and paper facilities emitting 7.3 Tg CO_2e of methane and food processing facilities emitting 7.2 Tg CO_2e of methane. Based on the *Report to Congress: Solid Waste Disposal in the United States* (US EPA, 1988), there were 180 pulp and paper facilities and 189 food processing facilities with onsite landfills in 1985. Other industry sectors that are expected to landfill organic waste materials that contribute to methane emissions (and the number of facilities within the sector that had onsite landfills in 1985) include: organic chemical manufacturers (13); plastics and resins manufacturers (29), water treatment facilities (67); petroleum refineries (31); rubber and miscellaneous product manufacturers (24); selected chemical and allied product manufacturers (15); textile manufacturers (10); and leather and leather product manufacturers (7). [U.S. EPA, 1988]

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 for solid waste landfills. 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: *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2006* (US EPA, 2008a) and *1990-2007* (US EPA 2009a), California Climate Action Registry, EPA Climate Leaders, EU Emission Trading System, The Climate Registry, EPA's Landfill Methane Outreach Program, Australia's National Mandatory GHG Reporting Program (draft), 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 CH_4 because the CO_2 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 sources (including landfill gas combustion for energy and combustion of fossil fuels used to assist gas combustion efficiency), refer to the Technical Support Document for Stationary Fuel Combustion Emissions. Biogenic emissions of CO_2 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 industrial waste landfill emissions are detailed here, but for reporting options for other industrial process emissions, refer to the Technical Support Document for that industry sector.

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. In addition to actual methane emissions, each reporting landfill should also report methane generation and, if applicable, methane combustion annual quantities. Additionally, the following data should also be submitted with the annual report:

Data to report—industrial waste landfills

- General information about the landfill, such as an indication of the landfill as "open" or "closed," the year in which the landfill first started accepting waste for disposal, the last year the landfill accepted waste or the projected year of landfill closure, the capacity of the landfill, and an indication of whether leachate recirculation is used at the landfill.
- Waste characterization information, such as the number of waste steams or waste stream types accepted at the landfill and a description of each waste stream.
- Waste stream-specific information, such as the decay rate (k) value used in the calculations, the method(s) for estimating historical waste disposal quantities, and the range of years for which each method applies. When historical disposal rates are estimated based on production or filled capacity, the production or filled capacity parameters needed to estimate the historical disposal rates must also be reported.

- Historic and current annual landfill operating information, such as the quantity of waste disposed of in the landfill for each waste stream type for each year, the degradable organic carbon content value for each waste stream or waste stream type for each year and an indication as to whether this was the default value or a value determined through sampling and analysis, and the fraction of CH_4 in the landfill gas for each year and an indication as to whether this was the default value or a value determined through measurement data.
- Description of the landfill cover, such as the type(s) of cover material used, and the landfill surface area at the start of the reporting year associated with each cover type.
- Modeled CH_4 generation rate for the reporting year.
- Methane generation (MG), which is the modeled CH_4 generation rate adjusted for oxidation (landfills with gas collection systems must report both MG from modeled CH_4 generation and MG back-calculated from CH_4 recovery).
- Annual CH_4 emissions (landfills with gas collection systems must report both CH_4 emissions from modeled CH_4 generation adjusted for recovery and CH_4 emissions back-calculated from CH_4 recovery).
- Annual quantity of CH_4 recovered (for landfills with landfill gas collection systems).
- An indication of whether passive vents and/or passive flares are present at the landfill.
- Information about active landfill gas collection systems (if present), such as the total volumetric flow of landfill gas collected for destruction, the measured CH_4 concentration, monthly average measured temperature, pressure, and moisture content, a description of the gas collection system (manufacture, capacity, number of wells, etc.), the gas collection efficiency, annual operating hours of gas collection system, and the surface area, waste depth and cover type for areas within the landfill serviced by the landfill gas collection system.
- Information about landfill gas destruction devices (for landfills with gas collection system), such as an indication of whether destruction occurs onsite or offsite, the destruction device efficiency, an indication of whether a back-up destruction device is available and the annual operating hours for primary destruction and back-up destruction devices.

5. Options for Reporting Threshold

The precise impacts of the facility-wide reporting threshold (in terms of tCO_2e emissions) could not be directly evaluated, because many of the industrial waste landfills are expected to be co-located at facilities that have other reportable GHG emissions. In fact, most facilities that have industrial waste landfills will also have stationary combustion sources or other regulated sources that would cause the facility to exceed a facility-wide 25,000 reporting threshold regardless of how little or how much emissions are generated from the landfill. For example, all pulp and paper facilities (U.S. EPA, 2009c), 97 percent of petroleum refineries (U.S. EPA, 2008b), and 99 percent of petrochemical production facilities (U.S. EPA, 2008c), which includes certain organic chemical and plastic manufacturers, are projected to exceed the 25,000 reporting threshold based on sources other than landfills at the facility. Food processing facilities are the exception wherein the industrial waste landfill is the primary GHG emissions source at the facility (U.S. EPA, 2009d). Consequently, we did not differentiate between options for all industrial landfills to report and options for industrial landfills to report if they are located at a facility that exceed a facility-wide reporting threshold (in terms of tCO_2e emissions). Instead, different reporting "threshold" options were identified and evaluated to determine the relative impacts of the different options assuming all industrial landfills were located at facilities that already exceeded a facility-wide reporting threshold of 25,000 tCO_2e.

Based on the analysis that is described in greater detail in the remainder of this section, two of these options were inferior to other similar options (higher costs with less of the nationwide GHG emissions reported). Consequently, the following four reporting "threshold" options were identified as viable alternatives.

- All industrial landfills report (i.e., assumes all industrial landfills are co-located at facilities that exceed the 25,000 tCO_2e threshold).
- Only "organic" waste industrial landfills report.
- Only "organic" waste industrial landfills with design capacity of 300,000 Mg or more report.
- Only "organic" waste industrial landfills that accept 20,000 tons/yr or more of waste report

5.1 Summary of Results
Table 1 provides a summary of the alternatives that were considered viable.

Table 1. Threshold Analysis of Potential Alternatives for Industrial Landfills

Alternative No.	Description	Number of facilities reporting	Percent of total number of facilities	Total GHG emissions reported (10^6 $mtCO_2e$)	Percent of total GHG emissions reported
1	All industrial landfills report	2,310	100%	15.4	100%
2	Only "organic" waste industrial landfills report	607	26.3%	14.8	96.1%
3	Only "organic" waste industrial landfills with design capacity of 300,000 Mg or more report	200	8.7%	13.7	89.0%
4	Only "organic" waste industrial landfills that accept 20,000 tons/yr or more of waste report	100	4.3%	13.0	84.4%

5.2 Approach
Data from the 1988 *Report to Congress: Solid Waste Disposal in the United States* (US EPA, 1988), which contains data regarding 1985 waste management practices, was used to characterize the number of industrial landfills, the landfill capacities, and the annual waste disposal rates for various industry categories. While these data are 25 years old, they represent the only complete industrial waste survey data available. Tables 2 through 4 provide key data taken from the 1988 *Report to Congress*.

Table 2. Characteristics of Industrial Landfills by Industry Category

Industry Category	Number of active landfill units[1]	Number of facilities with active landfills[1]	Number of facilities with closed landfills[1]	Waste quantities disposed in landfills[2] (1000 tons)	Total design capacity[3] (1000 tons)	Remaining design capacity[3] (1000 tons)
Organic chemicals	17	13	39	263	6,284	4,011
Primary iron and steel	201	177	104	3,687	61,056	42,870
Fertilizer and agricultural chemicals	31	30	45	5,789	149,252	63,307
Electric power generation	155	126	89	53,449	999,469	874,358
Plastics and resins manufacturing	32	28	46	86	2,200	1,514
Inorganic chemicals	120	81	115	3,220	69,167	8,593
Stone, clay, glass, and concrete	1257	1153	454	7,571	8,883,934	8,538,009
Pulp and paper	259	180	179	5,873	108,457	229,337
Primary nonferrous metals	111	90	93	1,375	21,460	13,818
Food and kindred products	194	189	140	3,595	23,758	13,078
Water treatment	121	69	29	157	3,374	1,782
Petroleum refining	61	41	66	272	9,200	2,357
Rubber and misc. products	77	36	93	520	18,456	5,657
Transportation equipment	63	56	127	172	7,335	2,003
Selected chemicals and allied products	21	19	33	112	3,056	3,285
Textile manufacturing	28	25	84	69	697	728
Leather and leather products	9	9	23	9	178	120
Totals	**2,757**	**2,322**	**1,759**	**86,219**	**10,367,333**	**9,804,827**

[1]From Table 4-3 of US EPA, 1988.

[2]From Table 4-8 of US EPA, 1988.

[3]From Table 4-13 of US EPA, 1988.

Table 3. Waste Disposal Rates for Industrial Landfills by Industry Category[1]

Industry Category	Number of establishments by quantity of waste landfilled in 1985 (1,000 tons)						
	Less than 0.5	0.5 - 5	5.1 - 20	21 - 100	101 – 1000	More than 1000	Totals
Organic chemicals	2	4	4	2	1	0	13
Primary iron and steel	69	55	29	13	9	0	175
Fertilizer and agricultural chemicals	25	2	0	0	2	1	30
Electric power generation	23	13	6	23	57	3	125
Plastics and resins manufacturing	18	6	2	2	0	0	28
Inorganic chemicals	30	31	10	9	0	1	81
Stone, clay, glass, and concrete	873	129	85	46	10	0	1,143
Pulp and paper	26	14	83	44	12	0	179
Primary nonferrous metals	32	35	7	13	2	0	89
Food and kindred products	127	22	17	12	11	0	189
Water treatment	33	33	0	3	0	0	69
Petroleum refining	21	9	8	1	1	0	40
Rubber and misc. products	2	22	2	10	0	0	36
Transportation equipment	37	8	7	7	1	0	60
Selected chemicals and allied products	6	6	6	1	0	0	19
Textile manufacturing	12	6	7	0	0	0	25
Leather and leather products	8	0	1	0	0	0	9
Totals	**1,344**	**395**	**274**	**186**	**106**	**5**	**2,310**

[1]From Table 4-9 of US EPA, 1988.

Table 4. Design Capacity for Industrial Landfills by Industry Category[1]

	Number of establishments by landfill design capacity (1000 tons)						
	Less than 0.5	0.5 - 5	5.1 - 20	21 - 100	101 – 1000	More than 1000	Totals
Organic chemicals	1	0	2	5	4	1	13
Primary iron and steel	3	24	51	25	49	11	163
Fertilizer and agricultural chemicals	19	1	4	2	0	3	29
Electric power generation	6	5	5	12	21	74	123
Plastics and resins manufacturing	8	2	8	4	7	0	29
Inorganic chemicals	1	12	20	18	20	3	74
Stone, clay, glass, and concrete	177	234	176	127	162	71	947
Pulp and paper	0	1	17	47	79	26	170
Primary nonferrous metals	9	13	26	8	20	3	79
Food and kindred products	91	33	4	18	39	1	186
Water treatment	24	3	28	7	4	1	67
Petroleum refining	2	5	8	9	6	1	31
Rubber and misc. products	0	0	0	2	11	11	24
Transportation equipment	31	1	2	10	5	2	51
Selected chemicals and allied products	0	1	4	5	4	1	15
Textile manufacturing	1	2	0	5	2	0	10
Leather and leather products	0	3	3	0	1	0	7
Totals	**373**	**340**	**358**	**304**	**434**	**209**	**2,018**

[1]From Table 4-12 of US EPA, 1988.

The industrial categories were characterized as either producing "organic" waste or "inorganic" waste. The following industrial categories were assumed to produce inorganic wastes:

- Primary iron and steel
- Fertilizer and agricultural chemicals
- Electric power generation
- Inorganic chemicals
- Stone, clay, glass, and concrete
- Primary nonferrous metals
- Transportation equipment

The wastes produced by these industries would generally have minimal degradable organic content (DOC). Note that it is assumed the "fertilizer and agricultural chemicals" industry does not include agricultural wastes (such as those produced in animal feeding operations, which could contain significant organic matter); this category is expected to include primarily fertilizers, herbicides, and pesticides. Plastics, metals, glass, and other "inert" wastes are generally considered to have negligible DOC (IPCC, 2006). At DOC levels below approximately 0.5 wt%, even the largest industrial landfills would not generate enough methane to exceed a 25,000 tonne CO_2 equivalent (tCO_2e) emissions threshold. Consequently, while there is no industry accepted definition of "inorganic waste," for the purposes of this analysis, "inorganic waste" (i.e., waste generated by the above 7 industry categories) was assumed to have a DOC of 0.5 weight percent (wt%) or less.

Of the remaining industries that are expected to produce "organic waste," the majority of landfills are located at either pulp and paper facilities or food and kindred products facilities. Industrial wastes at these industries in the U.S. have been evaluated and are expected to contain approximately 20 to 26 wt% DOC measured on a wet basis (US EPA, 2009a). Consequently, it was assumed that the waste generated by the "organic" industry categories listed in Tables 1 through 3 (industries other than the 7 listed "inorganic" industries) has an average DOC of approximately 20 wt%.

Industrial landfills are not known to have gas collection systems. Therefore, methane emissions from industrial landfills can be estimated from the modeled methane generation by accounting for the fraction of the generated methane that is oxidized near the soil surface, which is assumed to be 10% (IPCC, 2006 and U.S. EPA 2009a). Methane emissions (modeled methane generation less 10% soil oxidation) were projected for various sizes of landfills based on the waste disposal rate ranges and the design capacity ranges reported in the 1988 *Report to Congress* (see Tables 3 and 4, respectively) using the IPCC waste model (IPCC, 2006). Each of these differently sized landfills was assumed to contain 25 years of waste within the range of values reported for that group of landfills. An average DOC value of 0.0025 was used for inorganic waste, and an average DOC value of 0.20 was used for organic waste. The decay rate of 0.057 yr^{-1} was used for modeling purposes because only 25 years of waste was used and much of the organic industrial waste is expected to have high water content.

Model landfill sizes were initially selected from a midpoint in each range, and nationwide emissions were projected based on the number of landfills in that range. The size of the model landfill (and consequently the projected emissions) for selected ranges were subsequently adjusted (but well within the range limits for a given range) so that nationwide industrial landfill emissions were estimated to be 15.4 teragrams per year (Tg/yr) of carbon dioxide equivalence (CO_2e); this is the quantity of methane emissions projected for 2007 in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007* (US EPA, 2009a). This methodology was done both considering the annual waste disposal rates and the landfill design capacity (essentially assuming the landfills are now nearing capacity). Although the number of landfills responding to the two different survey questions for the 1988 Report to Congress were slightly different, the response rate for these questions was quite high (99.3 percent for annual quantity of waste landfilled in 1985 and 87 percent for the design capacity).

This analysis only considers the landfills that were active in 1985 based on the assumption that, like MSW landfills, it would be impractical to require reporting of landfills that closed prior to 1980. Although some of the landfills that reported that they were closed in 1985 may have operated past 1980, the number of active landfills in 1985 provides the best number of likely affected sources. No attempt was made to delineate what fraction of landfills may still be operating; all landfills that operated in 1985, whether still operating or closed were assumed to be potentially subject to a GHG reporting rule for industrial landfills. While the industrial waste disposal practices may have shifted over the past 25 years and, this “model landfill” approach provides a reasonable means by which to estimate the impacts of different regulatory alternatives for industrial landfills.

5.3 Discussion of Results

Table 5 presents the estimated emissions for the model landfills, the number of landfills, and the cumulative emissions for each landfill range. Using the data in Table 5, various applicability levels or thresholds can be evaluated. While certain industrial facilities may have landfills as the only reportable GHG emissions source (so that only landfills with emissions greater than the 25,000 tCO_2e reporting threshold would need to report), it is anticipated that nearly all industrial landfills will be co-located at facilities that already exceed the reporting threshold. As such, alternatives to the facility-wide 25,000 tCO_2e reporting threshold were evaluated. There are three obvious parameters that can be used to affect the applicability of the industrial landfill rule: 1) the type of waste disposed (organic versus inorganic); 2) the annual quantity of waste disposed; and 3) the design capacity of the landfill.

Modeling results indicate that wastes that have an organic content of 0.5 wt% or less do not contribute significantly to the total emissions from industrial sources; therefore, an exemption or applicability exclusion for waste with an organic content less than 0.5 wt% appears reasonable. Modeling results also indicate that smaller organic waste industrial landfills will generally have emissions of less than 25,000 tCO_2e. Specifically, organic waste landfills that dispose of 20,000 tons/year of waste annually or less will generally have emissions less than 25,000 tCO_2e as do organic waste landfills with a capacity of 300,000 Mg (330,000 tons) or less.

Based on the data in Table 5, the number of industrial establishments (reporting entities) and the quantity of emissions that would be reported under different applicability or threshold levels were estimated. The inorganic waste and 20,000 tons of annual waste quantity thresholds are directly evaluated by the data in Table 5. The 300,000 Mg landfill design capacity threshold requires additional assumptions for the landfills within the 101,000 to 1,000,000 ton capacity range. For this capacity range, it was assumed that two-thirds of the landfills within this range are over the 300,000 Mg capacity threshold simply based on the given range (i.e., assuming the landfills are fairly evenly dispersed within the range). However, because the larger landfills in this range will have higher emissions than the smaller landfills within this range, the emissions distribution will tend to be weighted toward the larger landfills. As such, it was assumed that landfills greater than 300,000 Mg capacity accounted for 85% of the cumulative emissions from the overall range.

Table 5. Emission Projections for Model Industrial Landfills

Parameter	Less than 0.5	0.5 - 5	5.1 - 20	21 - 100	101 – 1000	More than 1000	Totals
	Parameter values for specified ranges of the annual quantity of waste landfilled (annual waste quantities in 1,000 tons)						
Number of organic waste landfills	255	122	130	75	25	0	607
Number of inorganic waste landfills	1089	273	144	111	81	5	1,703
GHG emissions per organic waste landfill (tCO_2e/yr)	257	2,570	11,200	40,000	400,000	2,400,000	N/A
GHG emissions per inorganic waste landfill (tCO_2e/yr)	3.2	32	150	500	5000	20,000	N/A
Cumulative GHG emissions for organic waste landfills (1,000 tCO_2e/yr)	65.5	313.5	1,456	3,000	10,000	0	14,800
Cumulative GHG emissions for inorganic waste landfills (1,000 tCO_2e/yr)	3.5	8.7	22	55	405	100	600
Cumulative GHG emissions for all landfills (1,000 tCO_2e/yr)	69	322	1,478	3,055	10,405	100	15,400
	Parameter values for specified ranges of landfill design capacity (1000 tons)						
	Less than 0.5	**0.5 - 5**	**5.1 - 20**	**21 - 100**	**101 – 1000**	**More than 1000**	**Totals**
Number of organic waste landfills	127	50	74	102	157	42	552
Number of inorganic waste landfills	246	290	284	202	277	167	1,466
GHG emissions per organic waste landfill (tCO_2e/yr)	15	90	600	3,050	30,500	230,000	N/A
GHG emissions per inorganic waste landfill (tCO_2e/yr)	0.2	1.5	7	36	360	3,000	N/A
Cumulative GHG emissions for organic waste landfills (1,000 tCO_2e/yr)	1.9	4.5	44.4	311	4,790	9,660	14,800
Cumulative GHG emissions for inorganic waste landfills (1,000 tCO_2e/yr)	0.05	0.4	2.0	7.3	100	500	600
Cumulative GHG emissions for all landfills (1,000 tCO_2e/yr)	2	5	46	318	4,890	10,160	15,400

Notes: N/A = not applicable

tCO_2e = tonnes (or metric tons) of carbon dioxide equivalence

The precise impacts of the facility-wide 25,000 tCO_2e reporting threshold could not be directly evaluated, but it was assumed that very few, if any, industrial landfills would be excluded from the reporting requirements based on the facility-wide threshold. Consequently, no differentiation was made between options for all industrial landfills to report and options for industrial landfills to report if they are located at a facility that exceed a facility-wide reporting threshold (in terms of tCO_2e emissions). The following six "threshold" options were initially identified and evaluated to determine the relative impacts of the different option (beyond a facility-wide reporting threshold of 25,000 tCO_2e).

- All industrial landfills report (i.e., assumes all industrial landfills are co-located at facilities that exceed the 25,000 tCO_2e threshold).
- Only industrial landfills with design capacity of 300,000 Mg or more report.
- Only "organic" waste industrial landfills report.
- Only industrial landfills that accept 20,000 tons/yr or more of waste report.
- Only "organic" waste industrial landfills with design capacity of 300,000 Mg or more report.
- Only "organic" waste industrial landfills that accept 20,000 tons/yr or more of waste report

Table 6 summarizes number of reporting facilities and the projected industrial landfill emissions that would be reported for these six different regulatory alternatives.

Table 6. Threshold Analysis Results for Industrial Landfills

Option No.	Description	Number of facilities reporting	Percent of total number of facilities	Total GHG emissions reported (10^6 $mtCO_2e$)	Percent of total GHG emissions reported
1	All industrial landfills report	2,310	100%	15.4	100%
1a	Only industrial landfills with design capacity of 300,00 Mg or more report	730	31.6%	14.3	92.9%
2	Only "organic" waste industrial landfills report	607	26.3%	14.8	96.1%
2a	Only landfills that accept more than 20,000 tons/yr of waste report	292	12.6%	13.5	87.7%
3	Only "organic" waste industrial landfills with design capacity of 300,00 Mg or more report	200	8.7%	13.7	89.0%
4	Only "organic" waste industrial landfills that accept more than 20,000 tons/yr of waste report	100	4.3%	13.0	84.4%

Assuming that the costs associated with each threshold is proportional to the number of landfills in the threshold, the number of applicable landfills included for a given alternative provides a good estimate of the relative costs of the alternative. On this basis, Option 1a (300,000 Mg capacity threshold) is inferior to Option 2 (inorganic waste exclusion) because it impacts more facilities while including less GHG emissions than Option 2 (i.e., Option 1a costs more for less reported GHG emissions than Option 2). Similarly, Option 2a (20,000 tons/yr annual waste disposal rate threshold) is inferior to Option 3 (combination of inorganic waste exclusion and 300,000 Mg capacity threshold). Consequently, these options (Options 1a and 2a) can be excluded from further analysis. The remaining four options (Options 1, 2, 3, and 4) are recommended for further analysis. Note that the options that include an annual waste disposal threshold (Options 2a and 4) intrinsically put more importance on the annual waste disposal quantities than the other options. As such, these options would likely require a more accurate (and costly) monitoring method for waste disposal quantities than the other options to simply determine applicability to the rule.

6. Options for Monitoring Methods

There are two cost-effective potential monitoring methods: (1) calculation of methane generation using the IPCC waste model for landfills that do not have landfill gas collection systems; and (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. Direct methane emission measurement from the landfill surface using optical remote sensing technologies is also a potential monitoring method. However, these techniques are expensive, and they typically provide only short-term measures of emissions. Using optical remote methods for a one-time or annual test to estimate annual methane emissions has a high level of uncertainty as short-term emissions from a landfill are expected to vary with temperature and barometric pressure fluctuations, soil moisture content, and rainfall events. Even though remote sensing methods may accurately measure the methane emissions from the landfill over the course of several hours, the uncertainty of this method in estimating annual average emissions is comparable to the other monitoring methods identified above, but the costs are much higher.

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 CH_4 emission estimates for solid waste disposal sites (SWDS), the IPCC developed the Waste Model and improved default values for degradable organic content (DOC) 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.

$$A = CH_4\ Generation_T\ \ (Mg/yr)$$

$$= \left[\sum_{x=S}^{T-1} \left\{ W_x \times DOC_x \times MCF \times DOC_F \times F_x \times \frac{16}{12} \times \left(e^{-k(T-x-1)} - e^{-k(T-x)} \right) \right\} \right]$$

Where:

A	=	Modeled methane generation rate in reporting year T (metric tons CH_4).
X	=	Year in which waste was disposed.
S	=	Start year of calculation.
T	=	Reporting year for which emissions are calculated.
W_x	=	Quantity of waste disposed in the industrial waste landfill in year X (metric tons, as received (wet weight)).
DOC_x	=	Degradable organic carbon for year X [fraction (metric tons C/metric ton waste)].
DOC_F	=	Fraction of DOC dissimilated (fraction).
MCF	=	Methane correction factor (fraction).
F_x	=	Fraction by volume of CH_4 in landfill gas (fraction, dry basis).
k	=	Decay rate constant (yr^{-1}).

The IPCC model includes the delay time (in months) for CH_4 generation as an input parameter to the model, and adjusts the emission calculations accordingly. The IPCC default value for this delay time is 6 months, so that Equation 1 effectively implements the IPCC Waste Model at the recommended value for the delay time.

Waste disposal quantities are occasionally directly measured at industrial waste landfill facilities, but the waste quantities are more commonly estimated based on other company records, such as process unit feed rates less production rates (i.e., mass balances around the process unit) or vehicle load counts. Waste generation rates may also be estimated as a percentage of production rate. As methane generation occurs slowly over a number of years, waste disposal data are needed for approximately a 50 year period prior to the year of the emissions estimate.

The FOD model can also be applied to different waste streams that are land disposed by applying Equation 1 to each landfilled waste stream and sum of the modeled methane generation across all of the waste streams. This approach requires disposal quantities for each individual waste stream and appropriate values of DOC and k by waste type.

6.2 Developing Appropriate Input Parameters for the FOD Model

As appropriate values for DOC and k are critical to the application of the FOD model, a literature review was conducted to develop default parameters for these model parameters. Also, potential measurement methods were evaluated. The results of these investigations are summarized in this section

6.2.1 Review of Values for DOC

The IPCC Guidelines provides default values for DOC for several different types of industrial wastes (IPCC, 2006); the IPCC default DOC values are provided in Table 7. The IPCC notes that DOC values can vary widely by facility within a given industry. Flores et al. (1999) conducted analyses of food waste in Iowa. The carbon content (assumed to be all degradable) calculated from the non-aqueous waste streams analyzed by Flores et al. (1999) are provided in Table 8. The data from Flores et al. suggests that the average moisture content of food wastes in the may U.S. may be approximately 40 to 45 percent rather than 60 percent used in the default values for IPCC. Other things being equal, the IPCC DOC content of food waste at 40 to 45 percent moisture content would be 22 percent. This value compares well with the median and average values as well as for raw scrap, cooked scrap, and sausage casings. While Table 8 shows that different waste streams may have significantly different DOC values, a central tendency DOC value for food processing waste of 22 percent (or 0.22) is recommended.

Table 7. IPCC Default Values for Degradable Organic Content (DOC) for Industrial Waste Streams (IPCC, 2006)

Industry Type	DOC (wt%, wet)	Total Carbon (wt%, wet)	Water Content (wt%)
Food, beverages and tobacco (other than sludge)	15	15	60
Textile	24	40	20
Wood and wood products	43	43	15
Pulp and paper (other than sludge)	40	41	10
Plastics	-	80	0
Rubber	(39)[a]	56	16
Construction and demolition	4	24	0

[a] Natural rubbers would likely not degrade under anaerobic conditions.

Table 8. Carbon Content of Food Industry Waste Derived from Data Reported by Flores et al. (1999)

Originating SIC	Description	Moisture (%)[a]	Carbon (% Dry Basis)[b]	Carbon (% Wet Basis)
2013	Raw Scrap	55.81	64.93	28.69
2013	Cooked Scrap	69.28	69.45	21.34
2013	Rendering Grease I	17.47	90.96[c]	75.07
2013	Rendering Grease II	86.55	20.13	2.71
2015	Offal	68.47	72.42	22.83
2096	Popcorn feed and tailings, REC	13.93	46.4	39.94
2087	Spent diatomaceous earth	42.89	7.18	4.10
2096	Corn and chip waste	3.94	54.49	52.34
2096	Wet waste solid (corn)	78.33	38.02	8.24
2052	Egg shell	32.98	8.77	5.88
2013	Sausage casings	46.06	50.6	27.29
2048	Dust collection	2.38	11.09	10.83
2048	Floor sweepings	2.46	12.17	11.87
	Median—all	**42.9**	**46.4**	**21.3**
	Mean—all	**40.0**	**42.0**	**23.9**

[a] As reported by Flores et al. (1999).
[b]Carbon content was not directly reported, but the % Nitrogen (dry basis) and the carbon to nitrogen ratio were reported. Carbon content was calculated as the %Nitrogen (dry basis) times the carbon to nitrogen ratio, except where noted otherwise.

[c]Carbon content calculated from carbon to nitrogen ratio lead to unrealistic value (102%). Calculated carbon content as %Fat+%Fiber+%Protein-%Nitrogen-%Ash.

Pulp and paper waste, the IPCC default DOC value is based on 10 percent moisture content. However, Kraft and Orender (1993) present data for some pulp and paper waste streams suggesting the moisture content is commonly 50 percent, so that the carbon content (wet weight) is between 12 and 25 percent (see Table 9). National Council for Air and Stream Improvement, Inc. (NCASI) calculated methane generation potential of four different pulp and paper wastes. The methane generation potential ranged from 70 to 101 m^3 of methane per Mg waste (Miner, 2008); this translates into DOC values of 0.14 to 0.20. Correcting the IPCC default DOC value for pulp and paper waste to be on a wet basis of 50 percent moisture, the IPCC value would be 0.22. Considering all of these data, a default DOC value of 0.20 is recommended for the pulp and paper industry.

Table 9. Sludge and Bark Analysis Data from Kraft and Orender (1993)

Material	Moisture (% by Wt)	Carbon (% by Wt)
Deinking Sludge 1	58	12.1
Deinking Sludge 2	58	13.07
Pulp Mill Sludge	58	21.66
Bark	50	25.15
	Average	**18.0**

Bronstein and Coburn (2010) evaluated available U.S. data for construction and demolition (C&D) wastes. The average wood content in C&D waste from a number of studies ranged from 10 to 33 percent. Combined with the DOC content of wood and wood product waste of 0.43 (IPCC, 2006), this wood content in C&D waste suggests that bulk C&D waste could have DOC value between 0.04 and 0.14. Not all of the wood waste in C&D waste would be degradable, as some of the wood is pressure treated. Nevertheless, these data suggest that the IPCC default value for DOC for C&D waste may be low compared to typical U.S. C&D waste. The weighted average wood content of all of the C&D waste studies reviewed by Bronstein and Coburn was 22.6 wt%, suggesting a DOC of approximately 0.10. Assuming 20 percent of the wood is pressure treated, the DOC value of 0.08 is recommended for C&D waste.

6.2.2 Review of Values for Decay Rate Constant (k)

The IPCC Guidelines also provides recommended ranges and default values for the decay rate constant (k). These values vary by type of waste and climate (average temperature and soil moisture in the landfill). The ranges for k for temperate regions (i.e., annual average temperature less than or equal to 68°F), which should be applicable for most parts of the U.S., are provided in Table 10. Note that IPCC encourages countries using its methods to collect and use national data, where available, and also comments that the default data are very uncertain.

The U.S. EPA has also defined 3 different values for k in its greenhouse gas inventories (U.S. EPA, 2009a) for "bulk wastes" depending on precipitation range. These k values were determined by statistical best fit of methane generation rates calculated from U.S. landfills with landfill gas collection and destruction systems. The EPA inventory k values follow:

$k = 0.02\ yr^{-1}$ for areas where the precipitation is <20 inches/year;

k = 0.038 yr^{-1} for areas with precipitation between 20 and 40 inches/year; and
k = 0.057 yr^{-1} for areas where precipitation is greater than 40 inches/year.

Table 10. Ranges of k Values by Waste Type for Temperate Climates (IPCC, 2006)

Waste Type (and examples)	k Values (yr^{-1})	
	Dry Climates[a]	Wet Climates[a]
Slowly degrading wastes (paper, textiles, wood or straw)	0.01 to 0.05	0.02 to 0.07
Moderately degrading wastes (Other [non-food] organic putrescible/garden and park waste)	0.04 to 0.06	0.06 to 0.1
Rapidly degrading wastes (food waste and sewage sludge)	0.05 to 0.08	0.1 to 0.2
Bulk wastes	0.04 to 0.06	0.08 to 0.1

[a]Dry climate is defined as areas where the annual average precipitation rate is less than the potential evapotranspiration rate, and a wet climate is one where the annual average precipitation rate is greater than the potential evapotranspiration rate.

For the pulp and paper industry, NCASI derived k values for 4 types of pulp and paper wastewater treatment residuals through field testing and best fit analysis (Miner, 2008); these values are presented in Table 11.

Table 11. NCASI k Values for Pulp and Paper Wastes (Miner 2008)

Residual Description	k, yr^{-1}
Bleached Kraft, combined	0.0034
Deinked, combined	0.020
Deinked, primary	0.014
Nonintegrated, primary	0.016
Average	**0.013**

Comparisons between these different sources of k values are not easy, because the values do not represent the same waste materials or climate. The bulk waste decay rates from the U.S. data appear to be slower than indicated by the IPCC defaults. The pulp and paper waste decay rates from the NCASI study is within the range (albeit the lower end of the range) of the decay rates for slowly degrading wastes provided by IPCC.

6.2.3 Recommended Values for DOC and k for Industrial Solid Wastes

Based on a review of all of the available data as described above, recommended values for DOC and k were developed. As described in Section 6.2.1, the central tendency DOC values of 0.22 for food processing waste and 0.20 for pulp and paper wastes are recommended. The IPCC Guideline's DOC value of 0.43 for wood and wood product wastes is recommended (IPCC, 2006). For C&D waste, the DOC value of 0.08 is recommended based on the mass fraction of wood waste in C&D waste in the U.S. (Bronstein and Coburn, 2010) and the default DOC value for wood waste. Inert wastes, such as glass, concrete, metals, and plastics, are expected to have negligible DOC; the recommended DOC value for these waste materials is zero. Data are not readily available for other types of industrial wastes, but the average DOC value for bulk wastes in an MSW landfill is 0.20. MSW landfills may also accept industrial solid wastes, so this bulk waste DOC value may also represent other industrial solid wastes. Given that inert materials are assumed to have no DOC, and seeing other industrial wastes appear to have a DOC value of 0.20, this value is recommended for "other" industrial solid wastes. However, we note that there is significant variability in DOC content for different types of waste streams. As such, measurement methods for determining waste stream-specific DOC values should provide as good or better estimates of the DOC content of industrial wastes than the default values provided in Table 12.

Table 12 also provides recommended values for the decay rate constant, k. As the soil moisture content (which is generally related to rainfall amounts) are an important driver for the value of k, three rainfall categories (dry, moderate, and wet) are recommended for assessing the appropriate value for k. This approach prevents the significant shift in k for moderate rainfall areas (where the annual average precipitation rate is approximately equal to the potential evapotranspiration rates) caused by the two rainfall category system suggested by IPCC. The use of direct rainfall data should also be easier to implement by reporters, as they would not need to determine or find potential evapotranspiration rates applicable to their landfill site. To account for the effect of leachate recirculation (to the extent it is used at industrial waste landfills), leachate recirculation rates are added to precipitation rates for determining the appropriate rainfall category. Values of k for food processing wastes were selected from the IPCC ranges for rapidly degrading wastes. Values of k for pulp and paper wastes, wood and wood product wastes, and C&D wastes were selected from the IPCC ranges for slowly degrading wastes. The k values for other industrial wastes were selected from the default values for bulk wastes, rounded to one significant digit. Inert wastes have no DOC, so these wastes do not need to be modeled at all, but default k values of zero are included in Table 12 for these wastes for completeness.

Table 12. Recommended DOC and Decay Rate Values for Industrial Waste Landfills

Industry/Waste Type	DOC (weight fraction, wet basis)	k [dry climate[a]] (yr^{-1})	k [moderate climate[a]] (yr^{-1})	k [wet climate[a]] (yr^{-1})
Food Processing	0.22	0.06	0.12	0.18
Pulp and Paper	0.20	0.02	0.03	0.04
Wood and Wood Product	0.43	0.02	0.03	0.04
Construction and Demolition	0.08	0.02	0.03	0.04
Inert Waste (glass, metal, plastic)	0	0	0	0
Other Industrial Solid Waste (not otherwise listed)	0.20	0.02	0.04	0.06

[a] The applicable climate classification is determined based on the annual rainfall plus the recirculated leachate application rate. Recirculated leachate application rate (in inches/year) is the total volume of leachate recirculated and applied to the landfill divided by the area of the portion of the landfill containing waste [with appropriate unit conversions].

- Dry climate = precipitation plus recirculated leachate less than 20 inches/year
- Moderate climate = precipitation plus recirculated leachate from 20 to 40 inches/year (inclusive)
- Wet climate = precipitation plus recirculated leachate greater than 40 inches/year

6.2.4 Measurement Methods for DOC and k for Industrial Solid Wastes

Various test methods for determining DOC and k values were assessed. Traditionally, DOC values (or "methane generation potential, Lo" values) are estimated from landfills with gas collection systems or from long-term laboratory studies. Values for k are generally estimated using a best fit regression analysis of the methane generated over time once the "measured" methane generation potential is established. Unfortunately, these methods are not suitable for reasonably quick and repeatable determinations of DOC and k values for specific waste streams. As such other approaches for determining these parameters were investigated.

There are a variety of test methods for determining the total organic carbon (TOC) content, the chemical oxygen demand, or the biological oxygen demand of a waste material. Any of these measured parameters would be a reasonable proxy for estimating DOC; however, these methods appear to be only applicable to wastewaters or dilute sludges. The tests are targeted to the dissolved organic compounds and the waste must be able to pass through a pipette for the analyses. As such, these methods are generally not applicable to industrial solid wastes.

Method 2540G "Total, Fixed, and Volatile Solids in Solid and Semisolid Samples" of the *Standard Methods for the Examination of Water and Wastewater* (21^{st} edition, 2005) [available on-line (to subscribers) at http://www.standardmethods.org/store/] may be a reasonable, quick, and inexpensive means to estimate the DOC content of solid wastes. Particularly, degradable organic carbon is expected to be a primary component of the volatile solids content. Das et al. (1998) measured the volatile solids and carbon content of pulp and paper wastes used in a composting test. Zhang et al. (2007) performed similar measurements of chicken wastes, and Barlaz (1998) measured these parameters for components of MSW. Pertinent data from these studies are summarized in Table 13. As seen from the data in Table 13, except for the one ratio of 0.41 for office paper, the carbon content to volatile solids content ratios ranged from 0.46 to 0.61. The average ratio of all values is 0.53. As the carbon-to-volatile solids content ratio for different types of wastes is consistently within a fairly narrow range, the use of volatile solids content as a proxy for DOC appears to be reasonable. A ratio of 0.6 appears to be a reasonable high-range estimate of the DOC content per mass of volatile solids, while 0.53 is the central tendency of the data identified from the literature.

No reasonable test methods were identified for determining values for k, the decay rate constant. As such, the recommended default values for the decay rate constant presented previously in Table 12 should be used.

6.3 Calculating Potential and Actual Emissions using the IPCC Model

Potential emissions are calculated from the methane generation rate and the assumed oxidation factor according to Equation 2.

Equation 2.

Potential emissions = A x (1 – OX)

Where,

A = modeled methane generation rate (derived in Equation 1)

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

For landfills without gas collections systems, which include nearly all industrial waste landfills, the potential and actual emissions are identical. That is, Equation 2 also provides the actual emissions for landfills without gas collection systems. Few, if any, industrial waste landfills have landfill gas collection systems. For landfills with gas collection systems, measurement of the quantity and quality (i.e., methane content) of landfill gas generated at the landfill provides a second and often more accurate means of determining methane generation rates. Measurement methods associated with landfill gas collection systems were covered in the general landfill technical support document (EPA, 2009b). As landfill gas collection systems are not typically used in conjunction with industrial waste landfills, the reader is referred to EPA, 2009b if more information on measurement methods for gas collection systems is desired.

Table 13. Volatile Solids (VS) and Carbon (C) Content of Waste Materials

Parameter	%VS (dry basis)	%C (dry basis)	Carbon to VS Ratio	Reference
Seed1	48.2	27.37	0.57	Barlaz (1998)
Seed2	42.4	25.93	0.61	Barlaz (1998)
Grass	85	44.87	0.53	Barlaz (1998)
Leaves	90.2	49.4	0.55	Barlaz (1998)
Branches	96.6	49.4	0.51	Barlaz (1998)
Food	93.8	50.8	0.54	Barlaz (1998)
Coated paper	74.3	34.3	0.46	Barlaz (1998)
Newsprint	98.5	46.2	0.47	Barlaz (1998)
Corrugated container	98.2	46.9	0.48	Barlaz (1998)
Office paper	98.6	40.3	0.41	Barlaz (1998)
Sludge	57	35	0.61	Das et al. (1998)
Bark	90.8	45.3	0.50	Das et al. (1998)
Grit	90.8	48.9	0.54	Das et al. (1998)
Ash	34.2	20.8	0.61	Das et al. (1998)
Poultry Litter	87.6	43.4	0.50	Das et al. (1998)
Chicken waste	54.7	29.1	0.53	Zhang et al. (2007)

7. Options for Estimating Missing Data

As only annual measurement quantities are required for Equation 1, these values must be measured or estimated. For gas collection systems, if present, the missing value for the CH_4 content and/or the missing gas flow rates should be the arithmetic average of the values immediately before and immediately after the missing data incident.

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 quantity measurements and waste composition.

(2) Reporters are to maintain records of Waste Model input values used (historical waste disposal quantities, DOC values, k values, etc.) and the procedures used to develop those values.

(3) Reporters are to maintain records on daily or weekly gas flow and methane content to the combustion device, if applicable.

(4) 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 maintained. The estimated accuracy of measurements made with these devices should also be recorded, and the technical basis for the estimates should be provided.

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