~~2.4 MUNICIPAL SOLID WASTE LANDFILLS~~

2.4 Municipal Solid Waste Landfills

Disclaimer: Emission factors in AP-42 are neither EPA-recommended emission limits (e.g., best available control technology or BACT, or lowest achievable emission rate or LAER) nor standards (e.g., National Emission Standard for Hazardous Air Pollutants or NESHAP, or New Source Performance Standards or NSPS). Use of these factors as source-specific permit limits and/or as emission regulation compliance determinations is **NOT** recommended by EPA. Because emission factors essentially represent an average of a range of emission rates, approximately half of the subject sources are expected to have emission rates greater than the emission factor, and the other half are expected to have emission rates less than the emission factor. As such, EPA does not recommend using emission factors as limits or standards. This could cause, for example, a permit limit using an AP-42 emission factor resulting in approximately half of the sources being in noncompliance. We recommend source testing be done for the best possible emission values. For more information on the use of emission factors, please refer to the AP-42 Introduction.

2.4.1 General[1-4]

A municipal solid waste (MSW) landfill unit is a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile. An MSW landfill unit may also receive other types of wastes, such as commercial solid waste, nonhazardous sludge, and industrial solid waste. The municipal solid waste types potentially accepted by MSW landfills include (most landfills accept only a few of the following categories):

- MSW,
- Household hazardous waste,
- Municipal sludge,
- Municipal waste combustion ash,
- Infectious waste,
- Waste tires,
- Industrial non-hazardous waste,
- Conditionally exempt small quantity generator (CESQG) hazardous waste,
- Construction and demolition waste,
- Agricultural wastes,
- Oil and gas wastes, and
- Mining wastes.

In the United States in 2018, approximately ~~57 percent~~50% of solid waste ~~is~~was landfilled, ~~16 percent is incinerated~~12% was combusted for energy recovery, and ~~27 percent is~~32% was recycled or composted.[5] There were an estimated ~~2,500~~1,274 active MSW landfills in the United States in ~~1995~~2021. These landfills were estimated to receive ~~189~~339 million megagrams (Mg) (~~208~~373 million tons) of waste annually~~, with~~.[6] In 1998, 55 to ~~60 percent~~65% of MSW was reported as household waste~~,~~ and 35 to 45 ~~percent~~% of MSW was reported as commercial waste.[7]

References for this AP-42 section are available electronically here. The reader is referred to Sections 13.2.2 (Unpaved Roads), and 11.2.4 (Heavy Construction Operations) of the Electronic AP-42: Compilation of Air Emissions Factors from Stationary Sources, and Section II-7 (Construction Equipment) of Volume II, of the AP-42 document for determination of associated fugitive dust and exhaust emissions from these emission sources at MSW landfills. In addition to this, Section 3.1 (Stationary Gas Turbines) and Section 13.5 (Industrial Flares) of the Electronic AP-42: Compilation of Air Emissions Factors from Stationary Sources also contains emission factors for landfill gas (LFG) fired turbines and open flares, respectively.

2.4.2 Process Description[2,~~5~~8]

There are three major designs for municipal landfills. These are the area, trench, and ramp methods. All of these methods utilize a three-step process, which includes spreading the waste, compacting the waste, and covering the waste with soil. The trench and ramp methods are not commonly used~~,~~ and are not the preferred methods when liners and leachate collection systems are utilized or required by law. The area fill method involves placing waste on the ground surface or landfill liner, spreading it in layers, and compacting with heavy equipment. A daily soil cover is spread over the compacted waste. The trench method entails excavating trenches designed to receive a day's worth of waste. The soil from the excavation is often used for cover material and wind breaks. The ramp method is typically employed on sloping land, where waste is spread and compacted similar to the area method, however, the cover material obtained is generally from the front of the working face of the filling operation.

Modern landfill design often incorporates liners constructed of soil (i.e., recompacted clay), or synthetics (i.e., high density polyethylene), or both to provide an impermeable barrier to leachate (i.e., water that has passed through the landfill) and gas migration from the landfill.

2.4.3 Control ~~Technology[1]~~Technology [1,2,~~6~~9]

The Resource Conservation and Recovery Act (RCRA) Subtitle D regulations promulgated on October 9, 1991, require that the concentration of methane generated by MSW landfills not exceed 25 ~~percent~~% of the lower explosive limit (LEL) in on-site structures, such as scale houses, or the LEL at the facility property boundary.

The original New Source Performance Standards (NSPS) and Emission Guidelines (EG) for air emissions from MSW landfills for certain new and existing landfills were published in the Federal Register on March ~~1~~12, 1996. Since then, the MSW NSPS/EG were updated on August 29, 2016. Additionally, a National Emission Standard for Hazardous Air Pollutants (NESHAP) was promulgated on January 16, 2003, and the residual risk and technology review (RTR) was promulgated on March 26, 2020, with technical corrections to the RTR promulgated on February 3, 2022. A history of MSW landfills can be found on the EPA's Municipal Solid Waste Landfills: New Source Performance Standards (NSPS), Emission Guidelines (EG) and Compliance Times website. The ~~regulation requires~~ NSPS, EG, and NESHAP for MSW landfills are similar in that ~~Best Demonstrated Technology (BDT) be used to reduce MSW landfill~~ they regulate emissions ~~from affected new and existing MSW landfills emitting greater than or equal to 50 Mg/yr (55 tons/yr) of~~ of landfill gas using non-methane organic compounds (~~NMOCs). The MSW landfills that are affected by the NSPS/Emission Guidelines are each new MSW landfill, and each existing MSW landfill that has accepted waste since November 8, 1987, or that has capacity available for future use. The NSPS/Emission Guidelines affect landfills with~~ NMOC) as an estimate for VOC emissions. These regulations established a design capacity of 2.5 million Mg (2.75 million tons) ~~or more.~~and 2.5 million cubic meters and NMOC emission rate thresholds that if exceeded require landfills to install a gas collection and control system (GCCS). Control systems require: (1) a well-designed and well-operated ~~gas collection system~~GCCS, and (2) a control device capable of reducing NMOCs in the collected gas by 98 weight-percent.

Landfill gas (LFG) collection systems, also referred to as GCCS, are either active or passive systems. Active collection systems provide a pressure gradient in order to extract LFG by use of mechanical blowers or compressors. Passive systems allow the natural pressure gradient created by the increase in pressure created by LFG generation within the landfill to mobilize the gas for collection.

LFG control and treatment options include (1) combustion of the LFG, and (2) purification of the LFG. Combustion techniques include techniques that do not recover energy (i.e., flares and thermal incinerators), and techniques that recover energy (i.e., gas turbines and internal combustion engines) and generate electricity from the combustion of the LFG. Boilers can also be employed to recover energy from LFG in the form of steam. Flares involve an open combustion process that requires oxygen for combustion~~,~~ and can be open or enclosed. Thermal incinerators heat an organic chemical to a high enough temperature in the presence of sufficient oxygen to oxidize the chemical to carbon dioxide (CO_2) and water. Purification techniques can also be used to process raw landfill gas to pipeline quality natural gas by using adsorption, absorption, and membranes.

2.4.4 Emissions[2,~~7~~10]

Methane (CH_4) and CO_2 are the primary constituents of landfill gas~~,~~ and are produced by microorganisms within the landfill under anaerobic conditions. Transformations of CH_4 and CO_2 are mediated by microbial populations that are adapted to the cycling of materials in anaerobic environments. Landfill gas generation, including rate and composition, proceeds through four phases. The first phase is aerobic [i.e., with oxygen (O_2) available] and the primary gas produced is CO_2. The second phase is characterized by O_2 depletion, resulting in an anaerobic environment, where large amounts of CO_2 and some hydrogen (H_2) are produced. In the third phase, CH_4 production begins, with an accompanying reduction in the amount of CO_2 produced. Nitrogen (N_2) content is initially high in landfill gas in the first phase~~,~~ and declines sharply as the landfill proceeds through the second and third phases. In the fourth phase, gas production of CH_4, CO_2, and N_2 becomes fairly steady. The total time and phase duration of gas generation varies with landfill conditions (i.e., waste composition, design management, and anaerobic state).

Typically, LFG also contains a small amount of ~~non-methane organic compounds (NMOC).~~NMOC. This NMOC fraction often contains various organic hazardous air pollutants (HAP), greenhouse gases (GHG), and compounds associated with stratospheric ozone depletion. The NMOC fraction also contains volatile organic compounds (VOC). The weight fraction of VOC can be determined by subtracting the weight fractions of individual compounds that are non-photochemically reactive (i.e., negligibly ~~-~~reactive organic compounds as defined in 40 CFR 51.100).

Other emissions associated with MSW landfills include combustion products from LFG control and utilization equipment (i.e., flares, engines, turbines, and boilers). These include carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur dioxide (SO_2), hydrogen chloride (HCl), particulate matter (PM) and other combustion products (including HAPs). PM emissions can also be generated in the form of fugitive dust created by mobile sources (i.e., garbage trucks) traveling along paved and unpaved surfaces. The reader should consult AP-42 Volume I Sections 13.2.1 and 13.2.2 for information on estimating fugitive dust emissions from paved and unpaved roads.

The rate of emissions from a landfill is governed by gas production and transport mechanisms. Production mechanisms involve the production of the emission constituent in its vapor phase through vaporization, biological decomposition, or chemical reaction. Transport mechanisms involve the transportation of a volatile constituent in its vapor phase to the surface of the landfill, through the air boundary layer above the landfill, and into the atmosphere. The three major transport mechanisms that enable transport of a volatile constituent in its vapor phase are diffusion, convection, and displacement.

2.4.4.1 Uncontrolled Emissions ~~—~~

EPA notes that fugitive emissions include those emissions not gathered by collection devices (uncollected). Here, fugitive, uncollected, and uncontrolled emissions are synonymous terms. One way to estimate uncontrolled emissions of ~~the various compounds present~~a pollutant in landfill gas~~, total landfill gas emissions must first be estimated. Uncontrolled CH_4 emissions~~ is to begin by determining the annual volume of landfill methane generation, accounting for air infiltration as necessary, and to use the ideal gas law to provide pollutant mass per year. Methane generation may be estimated for individual landfills by ~~using a~~multiplying the result of Equation HH-1, found at 40 CFR 98.343(a)(1), by 1474.83 to obtain methane generation for the reporting year for which emissions are calculated in terms of cubic meters per year. The equation is as follows:

$$Q_{CH4} = G_{CH4} \frac{1000}{(0.0192)(35.3147)} = G_{CH4} \times 1474.83 \quad (1)$$

where:

Q_{CH_4}	=	Methane generation rate for the reporting year, m^3/yr;
G_{CH_4}	=	Result of Equation HH-1, metric tons CH_4/yr;
1000	=	Conversion, kilograms to metric tons;
0.0192	=	Density of methane at 60° F and 14.7 psia, kg/ft^3; and
35.3147	=	conversion, ft^3 to m^3.

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate generation or emissions rates for total landfill gas, methane, carbon dioxide, and NMOCs, and individual air pollutants from municipal solid waste landfills. Version 3.1, available from the following EPA website: https://www.epa.gov/system/files/other-files/2023-12/landgem-v3.1beta-dec-2023.xlsm, was updated in December 2023 and includes Equation HH-1 from 40 CFR 98.343(a)(1) and its selectable parameters, as well as the theoretical first-order kinetic model of methane production found in LandGEM Version 3.03. Note that the regulatory defaults for the equations in LandGEM Version 3.03 must be used when required by programs such as 40 CFR Part 60 subpart XXX, 40 CFR Part 60 Subpart Cf (Emission Guideline), or 40 CFR Part 63 AAAA.

developed by the EPA.[8] This model is known as the Landfill Air Emissions Estimation model, and can be accessed from the Office of Air Quality Planning and Standards Technology Transfer Network Website (OAQPS TTN Web) in the Clearinghouse for Inventories and Emission Factors (CHIEF) technical area (URL http://www.epa.gov/ttn/chief). The Landfill Air Emissions Estimation model equation is as follows:

$$Q_{CH_4} = L_o R (e^{-kc} - e^{-kt}) \quad (1)$$

where:

Q_{CH_4}	=	Methane generation rate at time t, m^3/yr;
L_o	=	Methane generation potential, m^3 CH_4/Mg refuse;
R	=	Average annual refuse acceptance rate during active life, Mg/yr;
e	=	Base log, unitless;
k	=	Methane generation rate constant, yr^{-1};
c	=	Time since landfill closure, yrs (c = 0 for active landfills); and
t	=	Time since the initial refuse placement, yrs.

It should be noted that the model above was designed to estimate LFG generation and not LFG emissions to the atmosphere. Other fates may exist for the gas generated in a landfill, including capture and subsequent microbial degradation within the landfill's surface layer. Currently, there are no data that adequately address this fate. It is generally accepted that the bulk of the gas generated will be emitted through cracks or other openings in the landfill surface.

Site-specific landfill information is generally available for variables R, c, and t. When refuse acceptance rate information is scant or unknown, R can be determined by dividing the refuse in place by the age of the landfill. If a facility has documentation that a certain segment (cell) of a landfill received *only* nondegradable refuse, then the waste from this segment of the landfill can be excluded from the calculation of R. Nondegradable refuse includes concrete, brick, stone, glass, plaster, wallboard, piping, plastics, and metal objects. The average annual acceptance rate should only be estimated by this method when there is inadequate information available on the actual average acceptance rate. The time variable, t, includes the total number of years that the refuse has been in place (including the number of years that the landfill has accepted waste and, if applicable, has been closed).

Values for variables L_o and k must be estimated. Estimation of the potential CH_4 generation capacity of refuse (L_o) is generally treated as a function of the moisture and organic content of the refuse. Estimation of the CH_4 generation constant (k) is a function of a variety of factors, including moisture, pH, temperature, and other environmental factors, and landfill operating conditions. Specific CH_4 generation constants can be computed by the use of EPA Method 2E (40 CFR Part 60 Appendix A).

The Landfill Air Emission Estimation model includes both regulatory default values and recommended AP-42 default values for L_o and k. The regulatory defaults were developed for compliance purposes (NSPS/Emission Guideline). As a result, the model contains conservative L_o and k default values in order to protect human health, to encompass a wide range of landfills, and to encourage the use of site-specific data. Therefore, different L_o and k values may be appropriate in estimating landfill emissions for particular landfills and for use in an emissions inventory.

Recommended AP-42 defaults include a k value of 0.04/yr for areas recieving 25 inches or more of rain per year. A default k of 0.02/yr should be used in drier areas (<25 inches/yr). An L_o value of 100 m^3/Mg (3,530 ft^3/ton) refuse is appropriate for most landfills. Although the recommended default k and L_o are based upon the best fit to 21 different landfills, the predicted methane emissions ranged from 38 to 492% of actual, and had a relative standard deviation of 0.85. It should be emphasized that in order to comply with the NSPS/Emission Guideline, the regulatory defaults for k and L_o must be applied as specified in the final rule.

When gas generation reaches steady state conditions, LFG consists of approximately 40 percent% by volume CO_2, 55 percent% CH_4, 5 percent% N_2 (and other gases), and trace amounts of NMOCs. Therefore, the estimate derived for CH_4 generation using the Landfill Air Emissions Estimation modelLandGEM can also be used to represent CO_2 generation. Addition of the CH_4 and CO_2 emissions will yield an estimate of total landfill gas emissions. If site-specific information is available to suggest that the CH_4 content of landfill gas is not 55 percent,%, then the site-specific information should be used, and the CO_2 emission estimate should be adjusted accordingly.

For landfills, volatile organic compound (VOC) emissions are equivalent to NMOC emissions minus the emissions from compounds with low to no photochemical reactivity. Predominant compounds with low to no photochemical reactivity found in landfills include methyl chloroform, acetone, methylene chloride, tetrachloroethylene, chlorodifluoromethane, dichlorodifluoromethane, and ethane. When the contribution of emissions from these compounds with low to no photochemical reactivity is low, then NMOC emissions are a good surrogate for VOC emissions. Recent data review shows that the contribution of these seven predominant compounds with low to no photochemical reactivity to be less than 6.5% of NMOC.[11-38]

Most of the NMOC emissions result from the volatilization of organic compounds contained in the landfilled waste. Small amounts may be created by biological processes and chemical reactions within the landfill. The current version of the Landfill Air Emissions Estimation modelLandGEM contains a proposed regulatory default value for total NMOC of 4,000 ppmv, expressed as hexane. However, available data show that there is a range of over 4,400 ppmv for total NMOC values from landfills. The proposedThe regulatory default value for NMOC concentration was developed for regulatory compliance purposes (40 CFR Part 60, Subpart XXX) and to provide the most cost-effective default values on a national basis. For emissions inventory purposes, site-specific information should be taken into account when determining the total NMOC concentration. In the absence of site-specific information, a value of 2,420400 ppmv as hexane is suggested for landfills known to have co-disposal of MSW and non-residential waste. If the landfill is known to contain only MSW or have very little organic commercial/industrial wastes, then a total NMOC value of 595for default values before 1992, 600 ppmv as hexane should be used, and for default values on and after 1992, 550 ppmv as hexane should be used. In addition, as with the landfill model defaults, the regulatory default value for NMOC content must be used in order to comply with the NSPS/Emission Guideline. According to NSPS (40 CFR Part 60, Subpart XXX) and Emission Guideline (40 CFR Part 60, Subpart Cf), the landfills with annual NMOC emissions greater than 34 megagrams must consider further emission measurement efforts or installation of a gas collection system.

IfBefore a site-specific totaldefault pollutant concentration is available (i.used (e., as measured by EPA Reference Method 25C.g. from Table 2.4-1), it must be correctedreviewed for potential air infiltration whichcorrection. from Table 2.4-1), it must be reviewed for potential air infiltration correction. Air infiltration can occur by two different mechanisms: LFG sample dilution, and air intrusion into the landfill. These corrections require site-specific data for the LFG CH_4, CO_2, nitrogen (N_2), and oxygen (O_2) content. If the ratio of N_2 to O_2 is less than or equal to 4.0 (as found in ambient air), then the total pollutant concentration is adjusted for sample dilution by assuming that CO_2 and CH_4 are the primary (100 percent)%) constituents of landfill gas, and the following equation is used:

$$C_p \text{ (ppmv) (corrected for air infiltration)} = \frac{C_p \text{ (ppmv) } (1 \times 10^6)}{C_{CO_2} \text{ (ppmv)} + C_{CH_4} \text{ (ppmv)}} \quad (2)$$

where:

C_p = Concentration of pollutant P in landfill gas (i.e., NMOC as hexane), ppmv;
C_{CO_2} = CO_2 concentration in landfill gas, ppmv;
C_{CH_4} = CH_4 Concentration in landfill gas, ppmv; and
1×10^6 = Constant used to correct concentration of P to units of ppmv.

$$C_P(ppmv)\ (corrected\ for\ air\ infiltration) = \frac{C_P(ppmv)(1\times10^6)}{C_{CO_2}(ppmv)+C_{CH_4}(ppmv)} \quad (2)$$

where:

C_P = Concentration of pollutant P in landfill gas (e.g., NMOC as hexane), ppmv;
C_{CO_2} = CO_2 concentration in landfill gas, ppmv;
C_{CH_4} = CH_4 Concentration in landfill gas, ppmv; and
1×10^6 = Constant used to correct concentration of P to units of ppmv.

If the ratio of N_2 to O_2 concentrations (i.e., C_{N_2}, C_{O_2})C_{N_2}, C_{O_2}) is greater than 4.0, then the total pollutant concentration should be adjusted for air intrusion into the landfill by using equation 2 and adding the concentration of N_2 (i.e., C_{N_2}) to the denominator. Values for C_{CO_2}, C_{CH_4}, C_{N_2}, and C_{O_2}, can usually be found in the source test report for the landfill along with the total pollutant concentration data.
concentration of N_2 (i.e., C_{N_2}) to the denominator. Values for C_{CO_2}, C_{CH_4}, C_{N_2}, C_{O_2}, can usually be found in the source test report for the particular landfill along with the total pollutant concentration data.

To estimate emissions of NMOC or other landfill gas constituents, the following equation should be used:

$$Q_p = 1.82\ Q_{CH_4} * \frac{C_p}{(1 \times 10^6)} \quad (3)$$

where:

Q_p = Emission rate of pollutant P (i.e. NMOC), m^3/yr;
Q_{CH_4} = CH_4 generation rate, m^3/yr (from the Landfill Air Emissions Estimation model);
C_p = Concentration of P in landfill gas, ppmv; and

1.82 = Multiplication factor (assumes that approximately 55 percent of landfill gas is CH_4 and 45 percent is CO_2, N_2, and other constituents).

$$Q_P = \frac{1}{F} Q_{CH_4} \times \frac{C_P}{(1 \times 10^6)} \quad (3)$$

where:

Q_P = Emission rate of pollutant P (e.g., NMOC), m^3/yr;
F = Fraction by volume of CH_4 in landfill gas from measurement data for the current reporting year, if available (fraction, dry basis, corrected to 0% oxygen); otherwise, use the default of 0.5;
Q_{CH_4} = CH_4 generation rate, m^3/yr (from equation 1 or LandGEM); and
C_P = Concentration of P in landfill gas, ppmv.

Uncontrolled mass emissions per year of total NMOC (as hexane), CO_2, CH_4, and speciated organic and inorganic compounds can be estimated by the following equation:

$$UM_p = Q_p * \left[\frac{MW_p * 1 \text{ atm}}{(8.205 \times 10^{-5} \text{ m}^3\text{-atm/gmol-°K})(1000 \text{g/kg})(273 + T \text{ °K})} \right] \quad (4)$$

where:

UMp = Uncontrolled mass emissions of pollutant P (i.e., NMOC), kg/yr;
MWp = Molecular weight of P, g/gmol (i.e., 86.18 for NMOC as hexane);
Qp = NMOC emission rate of P, m^3/yr; and

T = Temperature of landfill gas, °C.

$$UM_P = Q_P \times \frac{MW_P \times 1\ atm}{(8.205\times10^{-5}\frac{m^3\ atm}{gmol\ °K})(1000\frac{g}{kg})(273+T\ °K)} \quad (4)$$

where:

UM_P = Uncontrolled mass emissions of pollutant P (e.g., NMOC), kg/yr;
MW_P = Molecular weight of P, g/gmol (e.g., 86.18 for NMOC as hexane);
Q_P = NMOC emission rate of P, m^3/yr; and
T = Temperature of landfill gas, °C.

This equation assumes that the operating pressure of the system is approximately 1 atmosphere. If the temperature of the landfill gas is not known, a temperature of 25°C (77°F25°C (77°F) is recommended.

Uncontrolled default concentrations of speciated organics along with some inorganic compounds are presented in Table 2.4-1. These default concentrations have already been corrected for air infiltration and can be used as input parameters to equation 3 or the Landfill Air Emission Estimation model for estimating speciated emissions from landfills when site-specific data are not available. An analysis of the data, based on the co-disposal history (with non-residential wastes) of the individual landfills from which the concentration data were derived, indicates that for benzene, NMOC, and toluene, there is a difference in the uncontrolled concentrations. Table 2.4-2 presents the corrected concentrations for benzene, NMOC, and toluene to use based on the site's co-disposal history.

It is important to note that the compounds listed in Tables 2.4-1 and 2.4-2 are not the only compounds likely to be present in LFG. The listed compounds are those that were identified through a review of the available literature. The reader should be aware that additional compounds are likely present, such as those associated with consumer or industrial products. Given this information, extreme caution should be exercised in the use of the default VOC weight fractions and concentrations given at the bottom of Table 2.4-2. These default VOC values are heavily influenced by the ethane content of the LFG. Available data have shown that there is a range of over 1,500 ppmv in LFG ethane content among landfills.

2.4.4.12.4.4.2 Controlled Emissions

Emissions from landfills are typically controlled by installing a gas collection system, and combusting the collected gas through the use of internal combustion engines, flares, or turbines. Gas collection systems are not 100 percent% efficient in collecting landfill gas, so emissions of CH_4 and NMOC at a landfill with a gas recovery system still occur. To estimate controlled emissions of CH_4, NMOC, and other constituents in landfill gas, the collection efficiency of the system must first be estimated. Reported collection efficiencies typically range from 60 to 85 percent, with an average of 75 percent most commonly assumed.should first be estimated. Different models exist to provide a better estimate for uncontrolled emissions that are more appropriate for emission inventory development (e.g. LandGEM) that incorporates waste degradation parameters which include the potential to generate methane and the waste degradation decay rate. The potential to generate methane is a function of waste type, and age of waste. The waste degradation decay rate is a function of waste type, age of waste, and waste moisture. Waste moisture might be changed by leachate recirculation and rainfall rates. Higher collection efficiencies may be achieved at some sites (i.e., those engineered to control gas emissions). If site-specific collection efficiencies are available (i.e., through a comprehensive surface sampling program), then they should be used instead of the 75 percent average. If a user lacks site-specific collection efficiencies, use the appropriate values in Table HH-3 to Subpart HH of Part 98 - Landfill Gas Collection Efficiencies for calculations. See section III.T.2 of the preamble of the GHGRP final rule (89 FR 31853 April 25, 2024) for more information on the finalized collection efficiencies in Table HH-3 and default collection efficiency.

Controlled emission estimates should also ~~need to~~ take into ~~account~~consideration the control efficiency of the control device. Control efficiencies based on test data for the combustion of CH_4, NMOC, and some speciated organics with differing control devices are presented in Table 2.4-3. Emissions from the control devices need to be added to the uncollected emissions to estimate total controlled emissions.

Controlled CH_4, NMOC, and speciated emissions can be calculated with equation 5. It is assumed that the landfill ~~gas collection and control system~~GCCS operates 100 ~~percent~~% of the time. Minor durations of system downtime associated with routine maintenance and repair (i.e., 5 to 7 ~~percent) will~~%) should not appreciably ~~effect~~affect emission estimates. The first term in equation 5 accounts for emissions from uncollected landfill gas, while the second term accounts for emissions of the pollutant that were collected but not combusted in the control or utilization device:

$$CM_p = \left[UM_p * \left(1 - \frac{\eta_{col}}{100} \right) \right] + \left[UM_p * \frac{\eta_{col}}{100} * \left(1 - \frac{\eta_{cnt}}{100} \right) \right] \qquad (5)$$

~~where:~~

~~CMp = Controlled mass emissions of pollutant P, kg/yr;~~
~~UMp = Uncontrolled mass emissions of P, kg/yr (from equation 4 or the Landfill Air Emissions Estimation Model);~~
~~η_{col} = Collection efficiency of the landfill gas collection system, percent; and~~
~~η_{cnt} = Control efficiency of the landfill gas control or utilization device, percent.~~

$$CM_P = \left[UM_P \times \left(1 - \frac{\eta_{col}}{100}\right)\right] + \left[UM_P \times \frac{\eta_{col}}{100} \times \left(1 - \frac{\eta_{cnt}}{100}\right)\right] \quad (5)$$

where:

CM_P = Controlled mass emissions of pollutant P, kg/yr;
UM_P = Uncontrolled mass emissions of P, kg/yr (from equation 4 or LandGEM);
η_{col} = Collection efficiency of the landfill gas collection system, percent; and
η_{cnt} = Control efficiency of the landfill gas control or utilization device, percent.

Emission factors for the secondary compounds, CO and NO_X, exiting the control device are presented in Tables 2.4-4 and 2.4-5. These For convenience, emission factors shouldare also presented for NMOC, although most of this NMOC is presumed to be from incomplete combustion of NMOC generated from the landfill rather than NMOC generated by combustion. These default values can be used when equipment vendor guarantees are not available.

Consistent with the language in the Introduction to AP-42, using source-specific data is preferred for estimating a source's emissions, while controlled emissions of CO_2 and sulfur dioxide (SO_2) are best estimated using site-specific landfill gas constituent concentrations and, along with mass balance methods.[68][39] If site-specific data are not available, the data in Tables 2.4-1 through 2.4-3 can be used with the mass balance methods that follow.

Controlled CO_2 emissions include emissions from the CO_2 component of landfill gas (equivalent to uncontrolled emissions) and additional CO_2 formed during the combustion of landfill gas. The bulk of the CO_2 formed during landfill gas combustion comes from the combustion of the CH_4 fraction. Small quantities will be formed during the combustion of the NMOC fraction,; however, this typically amounts to less than 1 percent% of total CO_2 emissions by weight. Also, the formation of CO through incomplete combustion of landfill gas will result in small quantities of CO_2 not being formed. This contribution to the overall mass balance picture is also very small and does not have a significant impact on overall COCO$_2$ emissions.[68][39]

The following equation, which assumes a 100 percent% combustion efficiency for CH_4, can be used to estimate CO_2 emissions from controlled landfills:

$$CM_{CO_2} = UM_{CO_2} + \left[UM_{CH_4} * \frac{\eta_{col}}{100} * 2.75\right] \quad (6)$$

where:

CM_{CO_2} = Controlled mass emissions of CO_2, kg/yr;
UM_{CO_2} = Uncontrolled mass emissions of CO_2, kg/yr (from equation 4 or the Landfill Air Emission Estimation Model);
UM_{CH_4} = Uncontrolled mass emissions of CH_4, kg/yr (from equation 4 on the Landfill Air Emission Estimation Model);
η_{col} = Efficiency of the landfill gas collection system, percent; and

2.75 = Ratio of the molecular weight of CO_2 to the molecular weight of CH_4.

$$CM_{CO_2} = UM_{CO_2} + (UM_{CH_4} \times \frac{\eta_{col}}{100} \times 2.75) \quad (6)$$

where:

CM_{CO_2} = Controlled mass emissions of CO_2, kg/yr;
UM_{CO_2} = Uncontrolled mass emissions of CO_2, kg/yr (from equation 4 or LandGEM);
UM_{CH_4} = Uncontrolled mass emissions of CH_4, kg/yr (from equation 4 or LandGEM);
η_{col} = Efficiency of the landfill gas collector on system, percent; and
2.75 = Ratio of the molecular weight of CO_2 to the molecular weight of CH_4.

To prepare estimates of SO_2 emissions, data on the concentration of reduced sulfur compounds within the landfill gas are needed. The best way to prepare this estimate is with site-specific information on the total reduced sulfur content of the landfill gas. Often these data are expressed in ppmv as sulfur (S). Equations 3 and 4 should be used first to determine the uncontrolled mass emission rate of reduced sulfur compounds as sulfur. Then, the following equation can be used to estimate SO_2 emissions:

$$CM_{SO_2} = UM_S * \frac{\eta_{col}}{100} * 2.0 \quad (7)$$

where:

CM_{SO_2} = Controlled mass emissions of SO_2, kg/yr;
UM_S = Uncontrolled mass emissions of reduced sulfur compounds as sulfur, kg/yr (from equations 3 and 4);
η_{col} = Efficiency of the landfill gas collection system, percent; and
2.0 = Ratio of the molecular weight of SO_2 to the molecular weight of S.

$$CM_{SO_2} = UM_S \times \frac{\eta_{col}}{100} \times 2.0 \quad (7)$$

where:

CM_{SO_2} = Controlled mass emissions of SO_2, kg/yr;
UM_S = Uncontrolled mass emissions of reduced sulfur compounds as sulfur, kg/y (from equations 3 and 4);
η_{col} = Efficiency of the landfill gas collection system, percent; and
2.0 = Ratio of the molecular weight of SO_2 to the molecular weight of S.

The next best method to estimate SO_2 concentrations, if site-specific data for total reduced sulfur compounds as sulfur are not available, is to use site-specific data for speciated reduced sulfur compound concentrations. These data can be converted to ppmv as S with equation 8. After the total reduced sulfur as S has been obtained from equation 8, then equations 3, 4, and 7 can be used to derive SO_2 emissions.

$$C_S = \sum_{i=1}^{n} C_P * S_P \qquad (8)$$

where:

C_S = Concentration of total reduced sulfur compounds, ppmv as S (for use in equation 3);
C_P = Concentration of each reduced sulfur compound, ppmv;
S_P = Number of moles of S produced from the combustion of each reduced sulfur compound (i.e., 1 for sulfides, 2 for disulfides); and
n = Number of reduced sulfur compounds available for summation.

$$C_S = \sum_{i=1}^{n} C_P \times S_P \qquad (8)$$

where:

C_S	=	Concentration of total reduced sulfur compounds, ppmv as S (for use in equation 3);
C_P	=	Concentration of each reduced sulfur compound, ppmv;
S_P	=	Number of moles of S produced from the combustion of each reduced sulfur compound (e.g., 1 for sulfides, 2 for disulfides); and
n	=	Number of reduced sulfur compounds available for summation.

If no site-specific data are available, a value of 46.9 ppmv can be assumed for C_s (for use in equation 3). This value was obtained by using the default concentrations presented in Table 2.4-1 for reduced sulfur compounds and equation 8.

Hydrochloric acid [Hydrogen Chloride (HCl)] emissions are formed when chlorinated compounds in LFG are combusted in control equipment. The best methods to estimate emissions are mass balance methods that are analogous to those presented above for estimating SO_2 emissions. Hence, the best source of data to estimate HCl emissions is site-specific LFG data on total chloride [expressed in ppmv as the chloride ion (Cl^-)]. If these data are not available, then total chloride can be estimated from data on individual chlorinated species using equation 9 below. However, emission estimates may be underestimated, since not every chlorinated compound in the LFG will be represented in the laboratory report (i.e., only those that the analytical method specifies).

$$C_{Cl} = \sum_{i=1}^{n} C_P * Cl_P \qquad (9)$$

where:

C_{Cl} = Concentration of total chloride, ppmv as Cl^- (for use in equation 3);
C_P = Concentration of each chlorinated compound, ppmv;
Cl_P = Number of moles of Cl^- produced from the combustion of each chlorinated compound (i.e., 3 for 1,1,1-trichloroethane); and
n = Number of chlorinated compounds available for summation.

$$\left(\frac{n_{cnt}}{100}\right)$$

$$C_{Cl} = \sum_{i=1}^{n} C_P \times Cl_P \qquad (9)$$

where:

C_{Cl}	=	Concentration of total chloride, ppmv as Cl^- (for use in equation 3);
C_P	=	Concentration of each chlorinated compound, ppmv;
Cl_P	=	Number of moles of Cl^- produced from the combustion of each chlorinated compound (e.g., 3 for 1,1,1-trichloroethane); and
n	=	Number of chlorinated compounds available for summation.

After the total chloride concentration (C_{Cl}) has been estimated, equations 3 and 4 should be used to determine the total uncontrolled mass emission rate of chlorinated compounds as chloride ion (UM_{Cl}). This value is then used in equation 10 below to derive HCl emission estimates:

$$CM_{HCl} = UM_{Cl} * \frac{\eta_{col}}{100} * 1.03 * \qquad (10)$$

where:

CM_{HCl}	=	Controlled mass emissions of HCl, kg/yr;
UM_{Cl}	=	Uncontrolled mass emissions of chlorinated compounds as chloride, kg/yr (from equations 3 and 4);
η_{col}	=	Efficiency of the landfill gas collection system, percent;
1.03	=	Ratio of the molecular weight of HCl to the molecular weight of Cl^-; and
η_{cnt}	=	Control efficiency of the landfill gas control or utilization device, percent.

$$CM_{HCl} = UM_{Cl} \times \frac{\eta_{col}}{100} \times 1.03 \times \frac{\eta_{cnt}}{100} \quad (10)$$

where:

CM_{HCl}	=	Controlled mass emissions of HCl, kg/yr;
UM_{Cl}	=	Uncontrolled mass emissions of chlorinated compounds as chloride, kg/yr (from equations 3 and 4);
η_{col}	=	Efficiency of the landfill gas collection system, percent;
1.03	=	Ratio of the molecular weight of HCl to the molecular weight of Cl^-; and
η_{cnt}	=	Control efficiency of the landfill gas control or utilization device, percent.

In estimating HCl emissions, it is assumed that all of the chloride ion from the combustion of chlorinated LFG constituents is converted to HCl. If an estimate of the control efficiency, θ_{cnt} η_{cnt}, is not available, then the high end of the control efficiency range for the equipment listed in Table 92.4-3 should be used. This assumption is recommended to assume that HCl emissions are not under-estimated.

If site-specific data on total chloride or speciated chlorinated compounds are not available, then a default value of 42.0 ppmv can be used for C_{Cl}. This value was derived from the default LFG constituent concentrations presented in Table 2.4-1. As mentioned above, use of this default may produce underestimates of HCl emissions since it is based only on those compounds for which analyses have been performed. The constituents listed in Table 2.4-1are1 are likely not all of the chlorinated compounds present in LFG.

~~The reader is referred to Sections 11.2-1 (Unpaved Roads, SCC 50100401), and 11-2.4 (Heavy Construction Operations) of Volume I, and Section II-7 (Construction Equipment) of Volume II, of the AP-42 document for determination of associated fugitive dust and exhaust emissions from these emission sources at MSW landfills.~~

2.4.5 Source Classification Codes

The Source Classification Codes for Municipal Solid Waste Landfills are:

- 50100401 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Unpaved Road Traffic
- 50100402 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Fugitive Emissions
- 50100403 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Area Method
- 50100404 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Trench Method
- 50100405 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Ramp Method
- 50100406 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Gas Collection System: Other
- 50100407 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Storage Piles
- 50100408 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Conveying of Cover material
- 50100409 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Spreading of Daily Cover
- 50100410 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Dump: Waste Gas Destruction: Waste Gas Flares
- 50100411 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Incinerator
- 50100412 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Other Not Elsewhere Classified
- 50100420 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Turbine

- 50100421 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Internal Combustion Engine
- 50100422 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Other Not Elsewhere Classified
- 50100423 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Boiler
- 50100424 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Microturbine
- 50100425 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Direct Use
- 50100426 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Industrial Use
- 50100427 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Automobile Fuel
- 50100433 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Purification
- 50100440 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Bioreactor
- 50100441 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Final Cover
- 50100442 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Hazardous Fugitive Emissions
- 50300601 – Waste Disposal; Solid Waste Disposal – Industrial; Solid Waste Landfill; Waste Gas Destruction
- 50300602 – Waste Disposal; Solid Waste Disposal – Industrial; Solid Waste Landfill; Other Not Elsewhere Classified
- 50300603 – Waste Disposal; Solid Waste Disposal – Industrial; Solid Waste Landfill; Hazardous; Fugitive Emissions
- 50300604 – Waste Disposal; Solid Waste Disposal – Industrial; Solid Waste Landfill; Hazardous Fugitive Emissions
- 50300607 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Storage Piles
- 50300608 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Conveying of Cover material
- 50300609 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Spreading of Daily Cover
- 50301001 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Unpaved Road Traffic
- 50301002 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Area method
- 50301003 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Trench Method
- 50301004 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Ramp Method
- 50301005 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Gas Collection System: Other Not Elsewhere Classified
- 50301010 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Incinerator
- 50301011 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Other Not Elsewhere Classified
- 50301020 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Turbine
- 50301021 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Internal Combustion Engine
- 50301022 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Other Not Elsewhere Classified
- 50301023 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Boiler
- 50301024 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Microturbine
- 50301025 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Direct Use
- 50301026 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG)

Energy Recovery: Industrial Use

- 50301027 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Automobile Fuel
- 50301030 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Purification
- 50301040 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Bioreactor
- 50301041 – Waste Disposal; Solid Waste Disposal – Industrial; Municipal Solid Waste Landfill; Final Cover
- 50600601 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Fugitive Emissions
- 50600602 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Hazardous Fugitive Emissions
- 50600603 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Unpaved Road Traffic Area Method
- 50600604 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Area Method
- 50600605 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Trench Method
- 50600606 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Ramp Method
- 50600607 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Gas Collection System: Other Not Elsewhere Classified
- 50600610 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Incinerator
- 50600611 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Other Not Elsewhere Classified
- 50600620 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Turbine
- 50600621 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Internal Combustion Engine
- 50600622 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Other Not Elsewhere Classified
- 50600623 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Boiler
- 50600624 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Microturbine
- 50600625 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Direct Use
- 50600626 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Industrial Use
- 50600627 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Automobile Fuel
- 50600630 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Landfill Gas (LFG) Purification
- 50600640 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Bioreactor
- 50600641 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Final Cover
- 50600642 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Conveying of Cover Material
- 50600643 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Storage Piles
- 50600644 – Waste Disposal; Solid Waste Disposal – Commercial; Municipal Solid Waste Landfill; Spreading of Daily Cover
- 50700601 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Fugitive Emissions
- 50700602 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Hazardous Fugitive Emissions
- 50700603 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Unpaved Road Traffic Area Method

- 50700604 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Area Method
- 50700605 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Trench Method
- 50700606 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Ramp Method
- 50700607 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Gas Collection System: Other Not Elsewhere Classified
- 50700610 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Incinerator
- 50700611 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Destruction: Other Not Elsewhere Classified
- 50700620 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Turbine
- 50700621 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Internal Combustion Engine
- 50700622 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Other Not Elsewhere Classified
- 50700623 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Boiler
- 50700624 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Microturbine
- 50700625 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Direct Use
- 50700626 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Industrial Use
- 50700627 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Automobile Fuel
- 50700630 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Landfill Gas (LFG) Purification
- 50700640 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Bioreactor
- 50700641 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Final Cover
- 50700642 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Conveying of Cover Material
- 50700643 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Storage Piles
- 50700644 – Waste Disposal; Solid Waste Disposal – Institutional; Municipal Solid Waste Landfill; Spreading of Daily Cover

~~2.4.5~~2.4.6 Major Updates Since the Fifth Edition

~~The Fifth Edition was released in January 1995. Supplemnt D (8/98) is a major revision of the text and recommended emission factors conained in the section. The most significant revisions to this section since publication in the Fifth Edition are summarized below.~~

August 1998 (Supplement D):

- The equations to calculate the CH_4, CO_2 and other constituents were simplified.
- The default L_0 and k were revised based upon an expanded base of gas generation data.
- The default ratio of CO_2 to CH_4 was revised based upon averages observed in available source test reports.
- The default concentrations of LFG constituents were revised based upon additional data.
- Additional control efficiencies were included, and existing efficiencies were revised based upon additional emission test data.

- ~~Revised and expanded~~ The recommended emission factors for secondary compounds emitted from typical control devices were revised and expanded.

November 1998 (Supplement E ~~(11/98) includes~~):

- A correction ~~in~~was made to equation 10 ~~and a very minor change~~.
- Minor changes in the molecular weights for 1,1,1-Trichloroethane (methyl chloroform), 1,1-Dichloroethane, 1,2-Dichloropropane, and Trichloroethylene (trichloroethene) presented in Table 2.4-1 were made to agree with values presented in Perry's Handbook.[40]

Table 2.4-1.

August 2024:

- A disclaimer was added on the use of AP-42 emission factors.
- Equation 1 was replaced by Equation HH-1 from 40 CFR 98.343(a)(1) and a conversion factor so that consistent values for methane generation are provided across programs.
- Equation 3 was updated to account for a site-specific fraction of volume of methane in landfill gas.
- The default average collection efficiency was changed from 75% to referring the reader to Table HH-3 to Subpart HH of Part 98, Landfill Gas Collection Efficiencies for calculations.
- The complete list of Source Classification Codes (SCCs) for MSW landfills were specified and updated in the chapter.
- LandGEM was revised to include Equation HH-1 and its parameter choices.
- SCCs were updated for Tables 2.4-1 – 2.4-5.
- Default concentrations were rounded to two significant figures in Tables 2.4-1 and 2.4-2 to be consistent with the rest of the chapter and with LandGEM.

The default concentration for CO was updated (DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS[a] (SCC 50100402, 50300603)

Compound	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
1,1,1-Trichloroethane (methyl chloroform)[a]	133.41	0.48	B
1,1,2,2-Tetrachloroethane[a]	167.85	1.11	C
1,1-Dichloroethane (ethylidene dichloride)[a]	98.97	2.35	B
1,1-Dichloroethene (vinylidene chloride)[a]	96.94	0.20	B
1,2-Dichloroethane (ethylene dichloride)[a]	98.96	0.41	B
1,2-Dichloropropane (propylene dichloride)[a]	112.99	0.18	D
2-Propanol (isopropyl alcohol)	60.11	50.1	E
Acetone	58.08	7.01	B
Acrylonitrile[a]	53.06	6.33	D
Bromodichloromethane	163.83	3.13	C
Butane	58.12	5.03	C
Carbon disulfide[a]	76.13	0.58	C
Carbon monoxide[b]	28.01	141	E
Carbon tetrachloride[a]	153.84	0.004	B
Carbonyl sulfide[a]	60.07	0.49	D
Chlorobenzene[a]	112.56	0.25	C
Chlorodifluoromethane	86.47	1.30	C
Chloroethane (ethyl chloride)[a]	64.52	1.25	B
Chloroform[a]	119.39	0.03	B
Chloromethane	50.49	1.21	B
Dichlorobenzene[c]	147	0.21	E
Dichlorodifluoromethane	120.91	15.7	A
Dichlorofluoromethane	102.92	2.62	D
Dichloromethane (methylene chloride)[a]	84.94	14.3	A
Dimethyl sulfide (methyl sulfide)	62.13	7.82	C
Ethane	30.07	889	C
Ethanol	46.08	27.2	E
Ethyl mercaptan (ethanethiol)	62.13	2.28	D
Ethylbenzene[a]	106.16	4.61	B
Ethylene dibromide	187.88	0.001	E
Fluorotrichloromethane	137.38	0.76	B
Hexane[a]	86.18	6.57	B
Hydrogen sulfide	34.08	35.5	B
Mercury (total)[a,d]	200.61	2.92×10^{-4}	E

- Table 2.4-1. (Concluded)).
- NMOC default concentrations were split into pre 1992 and 1992 or later (1992+) to account for co-disposal in landfills in Table 2.4-2 and added an additional default concentration was added for NMOC 1992+.
- Affirmed that NMOC is a good surrogate for VOC emissions when NMOC compounds with negligible photochemical reactivity are low, removed default reference to 39% ratio of VOC to NMOC compounds for non-regulatory programs, and reminded users to develop their own ratios or to use extreme caution if default values were selected (footnote c in Table 2.4-2).
- Tables 2.4-4 and 2.4-5 were rearranged and factors for CO from flares and internal combustion engines have been updated, the NO_2 factors from flares and internal combustion engines have been replaced with factors for NO_X from flares and internal combustion engines, a factor for NMOC, as hexane, for flares has been added and 4 factors for NMOC, as hexane, varying by percent load have been added for internal combustion engines.
- Footnote e in Table 2.4-4 was corrected.
- New quality ratings have been given to new/revised factors based on approaches contained in the revised Emissions Factors Procedures Document (January 2023). Factors are given quality ratings based on representativeness of factor (e.g., Highly, Moderately, or Minimally Representative).

Table 2.4-1. DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS[a]

(SCC 50100402, 50300603, 50600601, 50700601)

Compound	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
~~Methyl ethyl ketone[a]~~1,1,1-Trichloroethane (methyl chloroform)[a]	~~72.11~~133.41	~~7.09~~0.48	~~A~~B
~~Methyl isobutyl ketone[a]~~1,1,2,2-Tetrachloroethane[a]	~~100.16~~167.85	1.~~87~~1	~~B~~C
1,1-Dichloroethane (ethylidene dichloride)[a]	98.97	2.4	B
1,1-Dichloroethene (vinylidene chloride)[a]	96.94	0.20	B
1,2-Dichloroethane (ethylene dichloride)[a]	98.96	0.41	B
1,2-Dichloropropane (propylene dichloride)[a]	112.99	0.18	D
~~Methyl mercaptan~~2-Propanol (isopropyl alcohol)	~~48~~60.11	~~2.49~~50	~~C~~E
Acetone	58.08	7.0	B
~~Pentane~~Acrylonitrile[a]	~~72.15~~53.06	6.3.~~29~~	~~C~~D
~~Perchloroethylene (tetrachloroethylene)[a]~~Bromodichloromethane	~~165~~163.83	3.~~73~~1	~~B~~C
Butane	58.12	5.0	C
Carbon disulfide[a]	76.13	0.58	C
Carbon monoxide[b]	28.01	110[e]	Minimally Representative[f]
Carbon tetrachloride[a]	153.84	4.0×10^{-3}	B
Carbonyl sulfide[a]	60.07	0.49	D
Chlorobenzene[a]	112.56	0.25	C
Chlorodifluoromethane	86.47	1.3	C
~~Propane~~Chloroethane (ethyl chloride)[a]	~~44.09~~64.52	~~11.~~1.3	B
Chloroform[a]	119.39	3.0×10^{-2}	B
~~t-1,2-dichloroethene~~Chloromethane	50.49~~96.94~~	1.2.~~84~~	B
Dichlorobenzene[c]	147	0.21	E
Dichlorodifluoromethane	120.91	16	A
~~Trichloroethylene (trichloroethene)[a]~~Dichlorofluoromethane	~~131.40~~102.92	2.~~82~~6	~~B~~D
Dichloromethane (methylene chloride)[a]	84.94	14	A
~~Vinyl chloride[a]~~Dimethyl sulfide (methyl sulfide)	62.~~50~~13	7.~~34~~8	~~B~~C
Ethane	30.07	890	C
Ethanol	46.08	27	E
Ethyl mercaptan (ethanethiol)	62.13	2.3	D
~~Xylenes[a]~~Ethylbenzene[a]	106.16	~~12.1~~4.6	B
Ethylene dibromide	187.88	1.0×10^{-3}	E
Fluorotrichloromethane	137.38	0.76	B
Hexane[a]	86.18	6.6	B
Hydrogen sulfide	34.08	36	B
Mercury (total)[a,d]	200.61	2.9×10^{-4}	E

Table 2.4-1. (Continued)

Compound	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
Methyl ethyl ketone[a]	72.11	7.1	A
Methyl isobutyl ketone[a]	100.16	1.9	B
Methyl mercaptan	48.11	2.5	C
Pentane	72.15	3.3	C
Perchloroethylene (tetrachloroethylene)[a]	165.83	3.7	B
Propane	44.09	11	B
t-1,2-dichloroethene	96.94	2.8	B
Trichloroethylene (trichloroethene)[a]	131.4	2.8	B
Vinyl chloride[a]	62.5	7.3	B
Xylenes[a]	106.16	12	B

NOTE: This is not an all-inclusive list of potential LFG constituents, only those for which test data were available at multiple sites. References 10-6741-97. Source Classification Codes in parentheses.

[a] Hazardous Air Pollutants listed in Title III of the 1990 Clean Air Act Amendments.

[a] [b] Carbon monoxide is not a typical constituent of LFG, but doescan exist in instances involving landfill (underground) combustion. Therefore,LFG, typically in small quantities. This default value should be used with caution. Just 2 of 18 sites where CO was measured, only 2 showed detectable levels of CO. Note that large values – on the order of 1,000 ppm and greater – can indicate underground combustion or other atypical conditions.

[c] Source tests did not indicate whether this compound was the para- or ortho- isomer. The para isomer is a Title III-listed HAP.

[d] No data were available to speciate total Hg into the elemental and organic forms.

[e] Reference 98.

[f] Emission factor is minimally representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).

Table 2.4-2. DEFAULT CONCENTRATIONS OF BENZENE, NMOC, AND TOLUENE BASED ON WASTE DISPOSAL HISTORY[a]
(SCC 50100402, 50300603, 50600601, 50700601)

Pollutant	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
Benzene[b]	78.11		
Benzene[b] - Co-disposal	78.11	11.1	D
Benzene[b] - No or Unknown co-disposal	78.11	1.919	B
NMOC (as hexane)[c] - Co-disposal (pre 1992)[d]	86.18	2400	D
NMOC (as hexane)[c] - No or Unknown co-disposal (pre 1992)[d]	86.18	2420600	DB
NMOC (as hexane)[c] - No or Unknown co-disposal (1992+)[d]	86.18	595550[e]	BModerately Representative[f]
Toluene[b] - Co-disposal	92.13	170	D
Co-disposal		165	D
Toluene[b] - No or Unknown co-disposal	92.13	39.3	A

[a] References 10-5441-85. Source Classification Codes in parentheses.
[b] Hazardous Air Pollutants listed in Title III of the 1990 Clean Air Act Amendments.
[c] For NSPS/Emission Guideline compliance purposes, the default concentration for NMOC as specified in the final rule must be used. For other purposes not associated with NSPS/Emission Guideline compliance, the default VOC content at co-disposal sites = 85 percent by weight (2,060 ppmv as hexane); at No or Unknown sites = 39 percent by weight 235 ppmv as hexane)., users should develop and use their own-site specific data.
[d] Emission factors are split into pre 1992 and 1992 or later (1992+) to account for co-disposal in landfills. The 1992+ factor is based on data from landfills that did not accept co-disposed waste and from landfills that opened in 1992 or later because current landfills do not allow co-disposal. The pre 1992 factors are based on data from landfills that opened before and during 1992, when some landfills allowed co-disposal.
[e] Reference 113.
[f] Emission factor is moderately representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).

Table 2.4-3. CONTROL EFFICIENCIES FOR LFG CONSTITUENTS[a]

Control Device	Constituent[b]	Typical Control Efficiency (%)	Range of Control Efficiency (%)	Emission Factor Rating
Gas Turbine (50100420, 50301020, 50600620, 50700620)	Halogenated Species	99.7	98-99+	E
IC Engine (50100421, 50301021, 50600621, 50700621)	Halogenated Species	93	90-99+	E
Gas Turbine (50100420, 50301020, 50600620, 50700620)	Non-Halogenated Species	98.2	97-99+	E
IC Engine (50100421, 50301021, 50600621, 50700621)	Non-Halogenated Species	86.1	25-99+	E
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC	97.2	94-99+	E
Boiler/Steam Turbine (50100423, 50301023, 50600623, 50700623)	NMOC	98	96-99+	D
Boiler/Steam Turbine (50100423, 50301023, 50600623, 50700623)	Halogenated Species	99.6	87-99+	D
Boiler/Steam Turbine (50100423, 50301023, 50600623, 50700623)	Non-Halogenated Species	99.8	67-99+	D
Flare[c] (50100410, 50300601)	NMOC	99.2	90-99+	B
Flare[c] (50100410, 50300601)	Halogenated Species	98	91-99+	C
Flare[c] (50100410, 50300601)	Non-Halogenated Species	99.7	38-99+	C
Gas Turbine (50100420, 50301020, 50600620, 50700620)	NMOC	94.4	90-99+	E

[a] References 41-97. Source Classification Codes in parentheses.
[b] Halogenated species are those containing atoms of chlorine, bromine, fluorine, or iodine. For any equipment, the control efficiency for mercury should be assumed to be 0. See section 2.4.4.2 for methods to estimate emissions of SO_2, CO_2, and HCl.
[c] Where information on equipment was given in the reference, test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

Table 2.4-4. (Metric Units) EMISSION FACTORS FOR SECONDARY COMPOUNDS EXITING CONTROL DEVICES[a]

Control Device	Pollutant[b]	kg/10^6 dscm Methane	Emission Factor Rating
~~Flare~~[c]Boiler/Steam Turbine[c] (50100423, 50301023, 50600623, 50700623)	Nitrogen dioxide	~~650~~530	~~C~~D
~~(50100410)~~Boiler/Steam Turbine[c] (50100423, 50301023, 50600623, 50700623)	Carbon monoxide	~~12,000~~90	~~C~~E
~~(50300601)~~Boiler/Steam Turbine[c] (50100423, 50301023, 50600623, 50700623)	Particulate matter	~~270~~130	D
~~IC Engine~~Gas Turbine (50100420, 50301020, 50600620, 50700620)	Nitrogen dioxide	~~4,000~~1,400	D
~~(50100421)~~Gas Turbine (50100420, 50301020, 50600620, 50700620)	Carbon monoxide	~~7,500~~3,600	~~C~~E
Gas Turbine (50100420, 50301020, 50600620, 50700620)	Particulate matter	~~770~~350	E
Enclosed Combustor/Flare[d] (50100410, 50300601)	Particulate matter	270	D
~~Boiler/Steam Turbine~~[d]Enclosed Combustor/Flare[d] (50100410, 50300601)	Nitrogen ~~dioxide~~oxides	~~530~~610[e,f]	~~D~~Highly Representative[g]
Enclosed Combustor/Flare[d] (50100410, 50300601)	NMOC, as hexane (VOC)[j]	66[e,h]	Highly Representative[g]
~~(50100423)~~Enclosed Combustor/Flare[d] (50100410, 50300601)	Carbon monoxide	~~90~~920[e,i]	~~E~~Highly Representative[g]
	~~Particulate matter~~	~~130~~	~~D~~
~~Gas Turbine~~IC Engine (50100421, 50301021, 50600621, 50700621)	Nitrogen ~~dioxide~~oxides	1,~~400~~500[e,k]	~~D~~Highly Representative[g]
~~(50100420)~~IC Engine (50100421, 50301021, 50600621, 50700621)	Carbon monoxide	~~3,600~~4,600[e,l]	~~E~~Highly Representative[g]
IC Engine (50100421, 50301021, 50600621, 50700621)	Particulate matter	~~350~~770	E
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 100% Load	250[e,m]	Moderately Representative[n]
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 80% Load	250[e,m]	Moderately Representative[n]
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 60% Load	270[e,m]	Moderately Representative[n]
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 30% Load	140[e,m]	Moderately Representative[n]

[a] Source Classification Codes in parentheses. Divide kg/10^6 dscm methane by 16,~~700~~666.7 to obtain kg/hr/dscmm~~.~~ methane.

[b] No data on PM size distributions were available, however for other gas-fired combustion sources, most of the particulate matter is less than 2.5 microns in diameter. Hence, this emission factor can be used to provide estimates of PM-10 or PM-2.5 emissions. See section 2.4.4.2 for methods to estimate CO_2, SO_2, and HCl. As mentioned in *Basic Information about NO_2*, available at https://www.epa.gov/no2-pollution/basic-information-about-no2, nitrogen dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_X), and it is used as the indicator for the larger group of nitrogen oxides.

~~[c] Where information on equipment was given in the reference, test data were taken from enclosed flares.~~

~~[c] Control efficiencies are assumed to be equally representative of open flares.~~

~~[d]~~ All source tests were conducted on boilers, however emission factors should also be representative of steam turbines. Emission factors are representative of boilers equipped with low-NO_X burners and flue gas recirculation. No data were available for uncontrolled NO_X emissions.

[d] Test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

[e] Factors were converted from lb/mmbtu. To convert back to lb/mmbtu, divide by 16.02 and then divide by 1020 (the heat

content of methane in ft^3/Btu). Note that these factors will have units of lb/mmbtu in WebFIRE.
[f] Reference 99.
[g] Emission factor is highly representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).
[h] Reference 100.
[i] Reference 101.
[j] NMOC = VOC because review of data from references 11-21, 23-24, 26,27, 29,30, 32,36,38,102-109 affirm the effect of compounds with low or no photochemical reactivity is less than 50 ppm LFG.
[k] Reference 110.
[l] Reference 111.
[m] Reference 112.
[n] Emission factor is moderately representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).
[o] During its review, the EPA investigated whether the NMOC emission factors at varying loads could be combined but found that they should remain separate. All per-load heat input values were found to be from differing data sets via a two sample t-test at a 95% confidence coefficient.

Table 2.4-5. (English Units) EMISSION RATES FOR SECONDARY COMPOUNDS EXITING CONTROL DEVICES[a]

Control Device	Pollutant[b]	lb/10^6 dscf Methane	Emission Factor Rating
~~Flare[c]~~Boiler/Steam Turbine[c] (50100423, 50301023, 50600623, 50700623)	Nitrogen dioxide	~~40~~33	~~C~~E
~~(50100410)~~Boiler/Steam Turbine[c] (50100423, 50301023, 50600623, 50700623)	Carbon monoxide	~~750~~5.7	~~C~~E
~~(50300601)~~Boiler/Steam Turbine[c] (50100423, 50301023, 50600623, 50700623)	Particulate matter	~~17~~8.2	~~D~~E
~~IC Engine~~Gas Turbine (50100420, 50301020, 50600620, 50700620)	Nitrogen dioxide	~~250~~87	D
~~(50100421)~~Gas Turbine (50100420, 50301020, 50600620, 50700620)	Carbon monoxide	~~470~~230	~~C~~D
Gas Turbine (50100420, 50301020, 50600620, 50700620)	Particulate matter	~~48~~22	E
Enclosed Combustor/Flare[d] (50100410, 50300601)	Particulate matter	17	D
~~Boiler/Steam Turbine[d]~~Enclosed Combustor/Flare[d] (50100410, 50300601)	Nitrogen ~~dioxide~~oxides	~~33~~38[e,f]	~~E~~Highly Representative[g]
Enclosed Combustor/Flare[d] (50100410, 50300601)	NMOC, as hexane (VOC)[j]	4.1[e,f]	Highly Representative[g]
~~(50100423)~~Enclosed Combustor/Flare[d] (50100410, 50300601)	Carbon monoxide	~~5.7~~58[e,f]	~~E~~Highly Representative[g]
	~~Particulate matter~~	~~8.2~~	~~E~~
~~Gas Turbine~~IC Engine (50100421, 50301021, 50600621, 50700621)	Nitrogen ~~dioxide~~oxides	~~87~~96[e,k]	~~D~~Highly Representative[g]
~~(50100420)~~IC Engine (50100421, 50301021, 50600621, 50700621)	Carbon monoxide	~~230~~290[e,l]	~~D~~Highly Representative[g]
IC Engine (50100421, 50301021, 50600621, 50700621)	Particulate matter	~~22~~48	E
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 100% Load	15[e,m]	Moderately Representative[n]
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 80% Load	15[e,m]	Moderately Representative[n]
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 60% Load	17[e,m]	Moderately Representative[n]
IC Engine (50100421, 50301021, 50600621, 50700621)	NMOC, as hexane (VOC)[j,o] 30% Load	9[e,m]	Moderately Representative[n]

[a] Source Classification Codes in parentheses. Divide lb/10^6 dscf by 16,700 to obtain lb/hr/dscfm.

[b] Based on data for other combustion sources, most of the particulate matter will be less than 2.5 microns in diameter. Hence, this emission rate can be used to provide estimates of PM-10 or PM-2.5 emissions. See section 2.4.4.2 for methods to estimate CO_2, SO_2, and HCl. As mentioned in *Basic Information about NO_2*, available at https://www.epa.gov/no2-pollution/basic-information-about-no2, nitrogen dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_X), and it is used as the indicator for the larger group of nitrogen oxides.

~~PM-2.5 emissions. See section 2.4.4.2 for methods to estimate CO_2, SO_2, and HCl.~~

[c] Where information on equipment was given in the reference, test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

[d][c] All source tests were conducted on boilers, however emission factors should also be representative of steam turbines. Emission factors are representative of boilers equipped with low-NO_X burners and flue gas recirculation. No data were available for uncontrolled NO_X emissions.

[d] Test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

[e] Emission Factors were converted from lb/mmbtu. To convert back to lb/mmbtu, divide by 1020. Note that these factors will have units of lb/mmbtu in WebFIRE.

[f] Reference 99.

[g] Emission factor is highly representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).

[h] Reference 100.

[i] Reference 101.

[j] NMOC = VOC because review of data from references 11-21, 23-24, 26,27, 29,30, 32,36,38,102-109 affirm the effect of compounds with low or no photochemical reactivity is less than 50 ppm LFG.

[k] Reference 110.

[l] Reference 111.

[m] Reference 112.

[n] Emission factor is moderately representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).

[o] During its review, the EPA investigated whether the NMOC emission factors at varying loads could be combined but found that they should remain separate. All per-load heat input values were found to be from differing data sets via a two sample t-test at a 95% confidence coefficient.

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* Test data from these reports are in the Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997 (reference 115). The documentation reference number and page citations in the document are listed. The appendices have data from the reports.

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