2.4 Municipal Solid Waste Landfills

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 50% of solid waste was landfilled, 12% was combusted for energy recovery, and 32% was recycled or composted.[5] There were an estimated 1,274 active MSW landfills in the United States in 2021. These landfills were estimated to receive 339 million megagrams (Mg) (373 million tons) of waste annually.[6] In 1998, 55 to 65% of MSW was reported as household waste and 35 to 45% of MSW was reported as commercial waste.[7]

2.4.2 Process Description[2,8]

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 [1,2,9]

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% 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, 1996. Since then, the MSW NSPS/EG were updated on August 16, 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. These regulations are similar in that they regulate emissions of landfill gas using non-methane organic compounds (NMOC) as an estimate for VOC emissions. These regulations established a design capacity of 2.5 million Mg (2.75 million tons) 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 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[2,10]

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 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

To estimate uncontrolled emissions of the various compounds, present in landfill gas, total landfill gas emissions must first be estimated. Uncontrolled CH_4 emissions may be estimated for individual landfills by 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.

It should be noted that the equation above was designed to estimate methane generation and not methane emissions to the atmosphere.

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate 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 to comply with other programs, such as NSPS 40 CFR Part 60 subpart WWW, Emission Guideline Cc, or NESHAP 40 CFR Part 63 AAAA, the regulatory defaults for the equation found in LandGEM Version 3.03 must be applied.

When gas generation reaches steady state conditions, LFG consists of approximately 40% by volume CO_2, 55% CH_4, 5% N_2 (and other gases), and trace amounts of NMOCs. Therefore, the estimate derived for CH_4 generation using LandGEM 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%, 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 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 to be less than 0.005% of LFG and less than 0.25% of NMOC.

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 LandGEM contains a regulatory default value for total NMOC of 4,000 ppmv, expressed as hexane. The regulatory default value for NMOC concentration was developed for regulatory compliance purposes 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 2,420 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 600 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.

If a site-specific total pollutant concentration is available (i.e., as measured by EPA Reference Method 25C), it must be corrected for air infiltration which 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%) constituents of landfill gas, and the following equation is used:

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

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
$1x10^6$	=	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}) 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.

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

$$Q_P = 1.82 Q_{CH_4} \times \frac{C_P}{(1\times10^6)} \quad (3)$$

where:

Q_P	=	Emission rate of pollutant P (e.g., 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).

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

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

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°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 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.

2.4.4.2 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% 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%, with an average of 75% most commonly assumed. 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% average.

Controlled emission estimates also need to consider 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 operates 100% of the time. Minor durations of system downtime

associated with routine maintenance and repair (i.e., 5 to 7%) should not appreciably 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:

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

where:

CM_P = Controlled mass emissions of pollutant P, kg/yr;
UM_P = Uncontrolled mass emissions of P, kg/yr (from equation 4 or 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.

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 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, along with mass balance methods.[11] 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% 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 is also very small and does not have a significant impact on overall CO_2 emissions.[11]

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

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

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.

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:

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

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.

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

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).

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

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:

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

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, η_{cnt}, is not available, then the high end of the control efficiency range for the equipment listed in Table 2.4-3 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 2.4-1 are likely not all of the chlorinated compounds present in LFG.

References 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.

2.4.5 Source Classification Codes

The Source Classification Codes for Municipal Solid Waste Landfills are:

- 20300802 – Internal Combustion Engines – Commercial/Institutional - Landfill Gas – Reciprocating
- 50100402 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Fugitive Emissions
- 50100410 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Dump: Waste Gas Destruction: Waste Gas Flares
- 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
- 50100423 – Waste Disposal; Solid Waste Disposal – Government; Municipal Solid Waste Landfill; Landfill Gas (LFG) Energy Recovery: Boiler
- 50300601 – Waste Disposal; Solid Waste Disposal – Industrial; Solid Waste Landfill; Waste Gas Destruction
- 50300603 – Waste Disposal; Solid Waste Disposal – Industrial; Solid Waste Landfill; Fugitive Emissions

2.4.6 Updates Since the Fifth Edition

August 1998 (Supplement D):
- The equations to calculate the CH_4, CO_2 and other constituents were simplified.
- The default L0 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.
- The recommended emission factors for secondary compounds emitted from typical control devices were revised and expanded.

November 1998 (Supplement E):
- A correction was made to equation 10.
- 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.[12]

January 2024:
- Source Classification Codes (SCCs) for MSW landfills were specified.
- 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.
- LandGEM was revised to include Equation HH-1 and its parameter choices.
- Three new emission factors have been added for SCC 50300601 (Tables 2.4-4 and 2.4-5).
- 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)

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	0.2	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	1.3	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. (Continued)

Compound	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
Methyl ethyl ketone[a]	72.11	7.09	A
Methyl isobutyl ketone[a]	100.16	1.87	B
Methyl mercaptan	48.11	2.49	C
Pentane	72.15	3.29	C
Perchloroethylene (tetrachloroethylene)[a]	165.83	3.73	B
Propane	44.09	11.1	B
t-1,2-dichloroethene	96.94	2.84	B
Trichloroethylene (trichloroethene)[a]	131.4	2.82	B
Vinyl chloride[a]	62.5	7.34	B
Xylenes[a]	106.16	12.1	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 13-70. Source Classification Codes in parentheses.

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

[b] Carbon monoxide is not a typical constituent of LFG, but does exist in instances involving landfill (underground) combustion. Therefore, this default value should be used with caution. Of 18 sites where CO was measured, only 2 showed detectable levels of CO.

[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.

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

Pollutant	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
Benzene[b] - Co-disposal	78.11	11.1	D
Benzene[b] - No or Unknown co-disposal	78.11	1.91	B
NMOC (as hexane)[c] - Co-disposal	86.18	2420	D
NMOC (as hexane)[c] - No or Unknown co-disposal	86.18	600	B
Toluene[b] - Co-disposal	92.13	165	D
Toluene[b] - No or Unknown co-disposal	92.13	39.3	A

[a] References 13-57. 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 purposes not associated with NSPS/Emission Guideline compliance, the default VOC content at co-disposal sites = 85% by weight (2,060 ppmv as hexane); at No or Unknown sites = 39% by weight 235 ppmv as hexane).

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

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

[a] References 13-70. 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] (50100410, 50300601)	Nitrogen dioxide	650	C
Flare[c] (50100410, 50300601)	Carbon monoxide	12,000	C
Flare[c] (50100410, 50300601)	Particulate matter	270	D
IC Engine (50100421)	Nitrogen dioxide	4,000	D
IC Engine (50100421)	Carbon monoxide	7,500	C
IC Engine (50100421)	Particulate matter	770	E
Boiler/Steam Turbine[d] (50100423)	Nitrogen dioxide	530	D
Boiler/Steam Turbine[d] (50100423)	Carbon monoxide	90	E
Boiler/Steam Turbine[d] (50100423)	Particulate matter	130	D
Gas Turbine (50100420)	Nitrogen dioxide	1,400	D
Gas Turbine (50100420)	Carbon monoxide	3,600	E
Gas Turbine (50100420)	Particulate matter	350	E
Enclosed Combustor/Flare (50300601)	Nitrogen oxides[j]	613[e,f]	Highly Representative[g]
Enclosed Combustor/Flare (50300601)	NMOC, as hexane (VOC) [j]	3[e,h]	Highly Representative[g]
Enclosed Combustor/Flare (50300601	Carbon monoxide[j]	630[e,i]	Highly Representative[g]

[a] Source Classification Codes in parentheses. Divide kg/10^6 dscm methane by 16,666.7 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. 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.
[e] Factors were converted from lb/mmbtu. To convert back to lb/mmbtu, divide by 16.02. Note that these factors will have units of lb/mmbtu in WebFIRE.
[f] Reference 71.
[g] Emission factor is highly representative of the population. Emission factor quality ratings based on the Emissions Factors Procedures Document (January 2023).
[h] Reference 72.
[i] Reference 73.
[j] NMOC = VOC because review of data from references 74-104 affirm the effect of compounds with low or no photochemical reactivity is less than 50 ppm LFG.

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] (50100410, 50300601)	Nitrogen dioxide	40	C
Flare[c] (50100410, 50300601)	Carbon monoxide	750	C
Flare[c] (50100410, 50300601)	Particulate matter	17	D
IC Engine (50100421)	Nitrogen dioxide	250	D
IC Engine (50100421)	Carbon monoxide	470	C
IC Engine (50100421)	Particulate matter	48	E
Boiler/Steam Turbine[d] (50100423)	Nitrogen dioxide	33	E
Boiler/Steam Turbine[d] (50100423)	Carbon monoxide	5.7	E
Boiler/Steam Turbine[d] (50100423)	Particulate matter	8.2	E
Gas Turbine (50100420)	Nitrogen dioxide	87	D
Gas Turbine (50100420)	Carbon monoxide	230	D
Gas Turbine (50100420)	Particulate matter	22	E
Enclosed Combustor/Flare (50300601)	Nitrogen oxides[j]	38[e,f]	Highly Representative[g]
Enclosed Combustor/Flare (50300601)	NMOC, as hexane (VOC)[j]	0.2[e,f]	Highly Representative[g]
Enclosed Combustor/Flare (50300601)	Carbon monoxide[j]	39[e,f]	Highly Representative[g]

[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.

[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] 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.

[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 71.

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

[h] Reference 72.

[i] Reference 73.

[j] NMOC = VOC because review of data from references 74-104 affirm the effect of compounds with low or no photochemical reactivity is less than 50 ppm LFG.

References for Section 2.4

1. "Criteria for Municipal Solid Waste Landfills," 40 CFR Part 258, Volume 56, No. 196, October 9, 1991.

2. Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Office of Air Quality Planning and Standards, EPA-450/3-90-011a, Chapters 3 and 4, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1991.

3. Characterization of Municipal Solid Waste in the United States: 1992 Update, Office of Solid Waste, EPA-530-R-92-019, U. S. Environmental Protection Agency, Washington, DC, NTIS No. PB92-207-166, July 1992.

4. Eastern Research Group, Inc., List of Municipal Solid Waste Landfills, Prepared for the U. S. Environmental Protection Agency, Office of Solid Waste, Municipal and Industrial Solid Waste Division, Washington, DC, September 1992.

5. US EPA, Advancing Sustainable Materials Management: 2018 FACT Sheet, December 2020.

6. US EPA, *LMOP Landfill and Project Database*. <https://www.epa.gov/lmop/lmop-landfill-and-project-database>

7. US EPA. Characterization of Municipal Solid Waste in the United States: 1998 Update. US EPA Office of Solid Waste Report No. EPA 530-R-98-007. July 1999.

8. Suggested Control Measures for Landfill Gas Emissions, State of California Air Resources Board, Stationary Source Division, Sacramento, CA, August 1990. (book – Stanford library)- (Reference #4 in chapter 2 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997)*

9. "Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills; Proposed Rule, Guideline, and Notice of Public Hearing," 40 CFR Parts 51, 52, and 60, Vol. 56, No. 104, May 30, 1991.

10. S.W. Zison, Landfill Gas Production Curves: Myth Versus Reality, Pacific Energy, City of Commerce, CA, [Unpublished] (Reference #47 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp.4-1, 4-3, 4-6)*

11. Letter and attached documents from C. Nesbitt, Los Angeles County Sanitation Districts, to K. Brust, E.H. Pechan and Associates, Inc., December 6, 1996.

12. Perry, J.H., Chemical Engineers' Handbook, New York :McGraw-Hill, 1984

13. Engineering-Science, Inc., Report of Stack Testing at County Sanitation District Los Angeles Puente Hills Landfill, Los Angeles County Sanitation District, August 15, 1984. (Reference #4 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32) *

14. J.R. Manker, Vinyl Chloride (and Other Organic Compounds) Content of Landfill Gas Vented to an Inoperative Flare, Source Test Report 84-496, David Price Company, South Coast Air Quality Management District, November 30, 1984. (Reference #5 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32, B-1, B-3, B-5, B-6, B-9, B-14, B-16, B-17, B-18, B-20) *

15. S. Marinoff, Landfill Gas Composition, Source Test Report 85-102, Bradley Pit Landfill, South Coast Air Quality Management District, May 22, 1985. (Reference #6 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32, B-1, B-3, B-4, B-6, B-8, B-11, B-12, B-14, B-15, B-17, B-18, B-19, B-21) *

16. J. Littman, Vinyl Chloride and Other Selected Compounds Present in A Landfill Gas Collection System Prior to and after Flaring, Source Test Report 85-369, Los Angeles County Sanitation District, South Coast Air Quality Management District, October 9, 1985. (Reference #7 in chapter 4 of Emission Factor Documentation for

AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32, B-1, B-3, B-4, B-6, B-7, B-8, B-11, B-12, B-14, B-15, B-17, B-18, B-19, B-22) *

17. W.A. Nakagawa, Emissions from a Landfill Exhausting Through a Flare System, Source Test Report 85-461, Operating Industries, South Coast Air Quality Management District, October 14, 1985. (Reference #8 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32, B-5, B-16, B-18, B-20, B-22) *

18. S. Marinoff, Emissions from a Landfill Gas Collection System, Source Test Report 85-511. Sheldon Street Landfill, South Coast Air Quality Management District, December 9, 1985. (Reference #9 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32, B-2, B-5, B-7, B-9, B-14, B-16, B-19, B-20, B-22) *

19. W.A. Nakagawa, Vinyl Chloride and Other Selected Compounds Present in a Landfill Gas Collection System Prior to and after Flaring, Source Test Report 85-592, Mission Canyon Landfill, Los Angeles County Sanitation District, South Coast Air Quality Management District, January 16, 1986. (Reference #10 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-32, B-1, B-5, B-6, B-9, B-14, B-18, B-20) *

20.California Air Resources Board, Evaluation Test on a Landfill Gas-Fired Flare at the BKK Landfill Facility, West Covina, CA, ARB-SS-87-09, July 1986. (Reference #12 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-1, B-3, B-4, B-6, B-7, B-8, B-10, B-11, B-12, B-13, B-14, B-15, B-18, B-19, B-22) *

21. S. Marinoff, Gaseous Composition from a Landfill Gas Collection System and Flare, Source Test Report 86-0342, Syufy Enterprises, South Coast Air Quality Management District, August 21, 1986. (Reference #13 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-1, B-4, B-6, B-8, B-14, B-15, B-18, B-19, B-21) *

22. Analytical Laboratory Report for Source Test, Azusa Land Reclamation, June 30, 1983, South Coast Air Quality Management District. (Reference #15 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-1, B-3, B-4, B-6, B-7, B-8, B-10, B-12, B-13, B-15, B-17, B-18, B-19, B-21, C3-Flares-1) *

23. J.R. Manker, Source Test Report C-84-202, Bradley Pit Landfill, South Coast Air Quality Management District, May 25, 1984. (Reference #17 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-1, B-3, B-4, B-14, B-15, B-18, B-19, B-21, B-22, C3-Flares-1) *

24. S. Marinoff, Source Test Report 84-315, Puente Hills Landfill, South Coast Air Quality Management District, February 6, 1985. (Reference #18 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1 4-5, 4-16, 4-17, 4-18, 4-33, B-2, B-3, B-5, B-6, B-9, B-14, B-16, B-17, B-19, B-20, B-21) *

25. P.P. Chavez, Source Test Report 84-596, Bradley Pit Landfill, South Coast Air Quality Management District, March 11, 1985. (Reference #19 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-1, B-3, B-6, B-8, B-14, B-15, B-17, B-19, B-21) *

26. S. Marinoff, Source Test Report 84-373, Los Angeles By-Products, South Coast air Quality Management District, March 27, 1985. (Reference #20 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-2, B-3, B-5, B-7, B-9, B-14, B-16, B-17, B-19, B-20, B-22) *

27. J. Littman, Source Test Report 85-403, Palos Verdes Landfill, South Coast Air Quality Management District, September 25, 1985. (Reference #22 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-1, B-2, B-3, B-5, B-7, B-9, B-14, B-16, B-18, B-19, B-20, B-22, C3-Flares-1) *

28. S. Marinoff, Source Test Report 86-0234, Pacific Lighting Energy Systems, South Coast Air Quality Management District, July 16, 1986. (Reference #23 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-3, B-6, B-9, B-15, B-16, B-19, B-21) *

29. South Coast Air Quality Management District, Evaluation Test on a Landfill Gas-Fired Flare at the Los Angeles County Sanitation District's Puente Hills Landfill Facility, [ARB/SS-87-06], Sacramento, CA, July 1986. (Reference #24 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-33, B-2, B-5, B-6, B-7, B-9, B-11, B-14, B-16, B-19, B-20, B-21) *

31. Browning-Ferris Industries, Source Test Report, Lyon Development Landfill, August 21, 1990. (Reference #27 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-34, B-2, B-3, B-5, B-7, B-8, B-9, B-11, B-17, B-18, B-20, B-22) *

32. X.V. Via, Source Test Report, Browning-Ferris Industries, Azusa Landfill. (Reference #28 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-3 data excluded because no data support, 4-34) *

33. M. Nourot, Gaseous Composition from a Landfill Gas Collection System and Flare Outlet. Laidlaw Gas Recovery Systems, to J.R. Farmer, OAQPS: ESD, December 8, 1987. (Reference #41 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-35, B-1, B-4, B-6, B-8, B-10, B-11, B-12, B-13, B-14, B-15, B-16, B-17, B-18, B-20, B-22, B-23) *

34. D.A. Stringham and W.H. Wolfe, Waste Management of North America, Inc., to J.R. Farmer, OAQPS: ESD, January 29, 1988, Response to Section 114 questionnaire.

35. V. Espinosa, Source Test Report 87-0318, Los Angeles County Sanitation District Calabasas Landfill, South Coast Air Quality Management District, December 16, 1987. (Reference #48 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-35, A-7, C3-Turbines-1) *

36. C.S. Bhatt, Source Test Report 87-0329, Los Angeles County Sanitation District, Scholl Canyon Landfill, South Coast Air Quality Management District, December 4, 1987. (Reference #49 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-35, A-8) *

37. V. Espinosa, Source Test Report 87-0391, Puente Hills Landfill, South Coast Air Quality Management District, February 5, 1988. (Reference #50 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-35, A-8, B-2, B-5, B-6, B-11, B-13, B-14, B-16, B-19, B-20, B-21, B-23, C3-Engines-1) *

38. V. Espinosa, Source Test Report 87-0376, Palos Verdes Landfill, South Coast Air Quality Management District, February 9, 1987. (Reference #51 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-5, 4-16, 4-17, 4-18, 4-35, A-8, B-2, B-5, B-7, B-13, B-14, B-16, B-19, B-20, B-22, B-23, C3-Engines-1) *

39. Bay Area Air Quality Management District, Landfill Gas Characterization, Oakland, CA, 1988.

40. Steiner Environmental, Inc., Emission Testing at BFI's Arbor Hills Landfill, Northville, Michigan, September 22 through 25, 1992, Bakersfield, CA, December 1992.

41. PEI Associates, Inc., Emission Test Report - Performance Evaluation Landfill-Gas Enclosed Flare, Browning Ferris Industries, Chicopee, MA, 1990.

42. Kleinfelder Inc., Source Test Report Boiler and Flare Systems, Prepared for Laidlaw Gas Recovery Systems, Coyote Canyon Landfill, Diamond Bar, CA, 1991.

43. Bay Area Air Quality Management District, McGill Flare Destruction Efficiency Test Report for Landfill Gas at the Durham Road Landfill, Oakland, CA, 1988.

44. San Diego Air Pollution Control District, Solid Waste Assessment for Otay Valley/Annex Landfill. San Diego, CA, December 1988.

45. PEI Associates, Inc., Emission Test Report - Performance Evaluation Landfill Gas Enclosed Flare, Rockingham, VT, September 1990.

46. Browning-Ferris Industries, Gas Flare Emissions Source Test for Sunshine Canyon Landfill. Sylmar, CA, 1991.

47. Scott Environmental Technology, Methane and Nonmethane Organic Destruction Efficiency Tests of an Enclosed Landfill Gas Flare, April 1992.

48. BCM Engineers, Planners, Scientists and Laboratory Services, Air Pollution Emission Evaluation Report for Ground Flare at Browning Ferris Industries Greentree Landfill, Kersey, Pennsylvania. Pittsburgh, PA, May 1992.

49. EnvironMETeo Services Inc., Stack Emissions Test Report for Ameron Kapaa Quarry, Waipahu, HI, January 1994.

50. Waukesha Pearce Industries, Inc., Report of Emission Levels and Fuel Economies for Eight Waukesha 12V-AT25GL Units Located at the Johnston, Rhode Island Central Landfill, Houston TX, July 19, 1991.

51. Mostardi-Platt Associates, Inc., Gaseous Emission Study Performed for Waste Management of North America, Inc., CID Environmental Complex Gas Recovery Facility, August 8, 1989. Chicago, IL, August 1989.

52. Mostardi-Platt Associates, Inc., Gaseous Emission Study Performed for Waste Management of North America, Inc., at the CID Environmental Complex Gas Recovery Facility, July 12-14, 1989. Chicago, IL, July 1989.

53. Browning-Ferris Gas Services, Inc., Final Report for Emissions Compliance Testing of One Waukesha Engine Generator, Chicopee, MA, February 1994.

54. Browning-Ferris Gas Services, Inc., Final Report for Emissions Compliance Testing of Three Waukesha Engine Generators, Richmond, VA, February 1994.

55. South Coast Environmental Company (SCEC), Emission Factors for Landfill Gas Flares at the Arizona Street Landfill, Prepared for the San Diego Air Pollution Control District, San Diego, CA, November 1992.

56. Carnot, Emission Tests on the Puente Hills Energy from Landfill Gas (PERG) Facility - Unit 400, September 1993, Prepared for County Sanitation Districts of Los Angeles County, Tustin, CA, November 1993.

57. Pape & Steiner Environmental Services, Compliance Testing for Spadra Landfill Gas-to-Energy Plant, July 25 and 26, 1990, Bakersfield, CA, November 1990.

58. AB2588 Source Test Report for Oxnard Landfill, July 23-27, 1990, by Petro Chem Environmental Services, Inc., for Pacific Energy Systems, Commerce, CA, October 1990.

59. AB2588 Source Test Report for Oxnard Landfill, October 16, 1990, by Petro Chem Environmental Services, Inc., for Pacific Energy Systems, Commerce, CA, November 1990.

60. Engineering Source Test Report for Oxnard Landfill, December 20, 1990, by Petro Chem Environmental Services, Inc., for Pacific Energy Systems, Commerce, CA, January 1991.

61. AB2588 Emissions Inventory Report for the Salinas Crazy Horse Canyon Landfill, Pacific Energy, Commerce, CA, October 1990.

62. Newby Island Plant 2 Site IC Engine's Emission Test, February 7-8, 1990, Laidlaw Gas Recovery Systems, Newark, CA, February 1990.

63. Landfill Methane Recovery Part II: Gas Characterization, Final Report, Gas Research Institute, December 1982.

64. Letter from J.D. Thornton, Minnesota Pollution Control Agency, to R. Myers, U.S. EPA, February 1, 1996.

65. Letter and attached documents from M. Sauers, GSF Energy, to S. Thorneloe, U.S. EPA, May 29, 1996.

66. Landfill Gas Particulate and Metals Concentration and Flow Rate, Mountaingate Landfill Gas Recovery Plant, Horizon Air Measurement Services, prepared for GSF Energy, Inc., May 1992.

67. Landfill Gas Engine Exhaust Emissions Test Report in Support of Modification to Existing IC Engine Permit at Bakersfield Landfill Unit #1, Pacific Energy Services, December 4, 1990. (Reference #98 in chapter 4 of Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, August 1997, pp. 4-1, 4-2, 4-5, 4-16, 4-17, 4-18, 4-39, A-21)*

68. Addendum to Source Test Report for Superior Engine #1 at Otay Landfill, Pacific Energy Services, April 2, 1991.

69. Source Test Report 88-0075 of Emissions from an Internal Combustion Engine Fueled by Landfill Gas, Penrose Landfill, Pacific Energy Lighting Systems, South Coast Air Quality Management District, February 24, 1988.

70. Source Test Report 88-0096 of Emissions from an Internal Combustion Engine Fueled by Landfill Gas, Toyon Canyon Landfill, Pacific Energy Lighting Systems, March 8, 1988.

71. NOx stack test data submitted to CEDRI for SCC/control device combination. Each individual test report can be obtained via WebFIRE.

72. NMOC, as hexane, stack test data submitted to CEDRI for SCC/control device combination. Each individual test report can be obtained via WebFIRE.

73. CO stack test data submitted to CEDRI for SCC/control device combination. Each individual test report can be obtained via WebFIRE.

74. TRC Environmental Corporation, TR-145: Compliance Testing of a Landfill Flare at Browning-Ferris Gas Services, Inc.'s Facility in Halifax, Massachusetts, May 1996.

75. Horizon Air Measurement Services, Inc., TR-196: Results of the Biennial Criteria and AB 2588 Air Toxics Source Test on the Simi Valley Landfill Flare, Simi Valley, CA, April 1997.

76. EMCON, TR-258: Source Test Report City of Sacramento Landfill Gas Flare, Sacramento, CA, June, 1996.

77. Blue Sky Environmental, LLC, TR-457: Compliance Source Emissions Test Report, Sunnyvale, CA, October 2006.

78. Blue Sky Environmental, LLC, TR-458: Waste Management: Altamont Landfill Annual Compliance Emissions Test Report # 08097 Landfill Gas Flare - Source A-15, Livermore, CA, September 2008.

79. SCEC, TR-461: Allied Waste Forward Inc. Landfill Flare 2006 Source Test Results, Diamond Bar, CA, August 2006.

80. SCEC, TR-462: Compliance Source Test Report Austin Road Landfill, Stockton, CA, June 2007.

81. Blue Sky Environmental, LLC, TR-463: Compliance Source Emissions Test Report # 07115 for Keller Canyon Landfill, Pittsburg, CA, December 2007.

82. Blue Sky Environmental, LLC, TR-464: Source Test Emission Report for One Calledus Flare (A-1) Located at Keller Canyon Landfill, Pittsburg, CA, November 2006.

83. Best Environmental, TR-466: City of Palo Alto Landfill Compliance Emissions Test Report, Palo Alto, CA, October 2008.

84. Best Environmental, TR-467: City of Palo Alto Landfill Compliance Emissions Test Report, Palo Alto, CA, October 2007.

85. Blue Sky Environmental, LLC, TR-468: Compliance Source Emissions Test Report for Republic Services – Potrero Hills Landfill, Inc, Suisun, CA, September 2007.

86. Blue Sky Environmental, LLC, TR-469: Annual Compliance Emissions Test Report #08058 Source Test for Landfill Gas Flare-Source A-51 for Redwood Landfill, Inc, Novato, CA, July 2008.

87. Best Environmental, TR-470: Vasco Road Landfill Compliance Emissions Test Report, Livermore, CA, October 2006.

88. SCEC, TR-488: 2008 Compliance Source Test Central Maui Municipal Landfill Gas Collection and Control System (FLARE), Puunene, Maui, January 2009.

89. Horizon Air Measurement Services, Inc., TR-530: Emission Compliance Test on Two Landfill Gas Flares San Marcos Landfill, San Marcos, CA, November 1994.

90. Horizon Air Measurement Services, Inc., TR-534: Emission Compliance Test on a Landfill Gas Flare for Sunshine Canyon Landfill, Sylmar, California, October 2007.

91. Horizon Air Measurement Services, Inc., TR-535: Emission Compliance Test on a Landfill Gas Flare After Louver Altercation for Sunshine Canyon Landfill, Sylmar, California, October 2007.

92. Horizon Air Measurement Services, Inc., TR-538: Emission Compliance Test on a Landfill Gas Flare for Simi Valley Landfill and Recycling Center, Simi Valley, CA, February 2008.

93. Horizon Air Measurement Services, Inc., TR-540: Results of the Criteria and AB 2588 Air Toxics Source Test on Simi Valley Landfill Flare #1 (McGill), Simi Valley, CA, December 2005.

94. Horizon Air Measurement Services, Inc., TR-541: Results of the Criteria and AB 2588 Air Toxics Source Test on Simi Valley Landfill Flare #2 (John Zink), Simi Valley, CA, December 2005.

95. Horizon Air Measurement Services, Inc., TR-546: Emissions Compliance Test Results on a Landfill Gas Flare, Palmdale, CA, March 2006.

96. Horizon Air Measurement Services, Inc., TR-579: Source Evaluation Report Waste Management Disposal Services of Washington, Inc., Greater Wenatchee Regional Landfill and Recycling Center, East Wenatchee, WA, February 2007.

97. Alaska Source Testing, LLC, TR-582: Summary of Test Results Municipality of Anchorage, Solid Waste Services Anchorage Landfill Gas Collection and Control System, Anchorage, AK, January 2007.

98. SCEC, TR-603: Waimanalo Gulch Solid Waste Landfill Flare Compliance Source Test Report 2005, Kapolei, HI, January 2006.

99. Blue Sky Environmental, LLC, TR-632: TriCities Recycling Disposal Facility Annual Compliance Emissions Test Report #08071 Source Test for Landfill Gas Flare – Source A-3, Fremont, CA, July 2008.

100. Shaw EMCON/OWT, Inc., TR-635: 2005 Annual Source Test Report - Redwood Landfill, Novato, CA, August 2005.

101. Shaw Environmental, Inc., TR-639: 2007 Source Test Report – Anderson Landfill, Anderson, CA, June 2007.

102. Shaw Environmental, Inc., TR-662: 2005 Annual Source Test Report – Guadalupe Rubbish Disposal Company, Inc., San Jose, CA, December 2005.

103. Shaw EMCON/OWT, Inc., TR-663: 2005 Annual Source Test Report – Kirby Canyon Recycling and Disposal Facility Landfill Gas Control - Flare, Morgan Hill, CA, February 2005.

104. Cornerstone Environmental Group LLC, TR-665: Guadalupe Rubbish Disposal Company, Inc. 2008 Annual Source Test Report Landfill Gas Control Flare A-9, San Jose, CA, October 2008.

105. Shaw Environmental, Inc., TR-668: 2006 Annual Source Test Report, Guadalupe Rubbish Disposal Company, Inc., Landfill Gas Control Flare A-9, San Jose, CA, November 2006.

106. Blue Sky Environmental, LLC, TR-678: Kirby Canyon Recycling and Disposal Facility Annual Compliance Emissions Test Report #07116 Landfill Gas Flare Source A-11, San Jose, CA, January 2008.

107. Blue Sky Environmental, LLC, TR-679: Kirby Canyon Recycling and Disposal Facility Annual Compliance Emissions Test Report #08004 Initial Source Test for Landfill Gas Flare Source A-12, San Jose, CA, March 2008.

108. Shaw Environmental, Inc., TR-711: 2006 Source Test Report Emissions Monitoring of Two Landfill Gas Fired Flares at the Redwood Landfill, Novato, CA, July 2006.

109. Shaw Environmental, Inc., TR-716: 2007 Source Test Report Emissions Monitoring of Two Landfill Gas Fired Flares at the Redwood Landfill, Novato, CA, May 2007.

110. Shaw Environmental, Inc., TR-717: 2007 Source Test Report Annual Emission Monitoring of a Landfill Gas Fired Flare at the Tri-Cities Recyling and Disposal Facility, Fremont, CA, August 2007.

111. Shaw Environmental, Inc., TR-718: 2005 Annual Source Test Report for Kirby Canyon Recyling and Disposal Facility, Morgan Hill, CA, February 2006.

112. Shaw Environmental, Inc., TR-738: 2006 Annual Source Test Report for Tri-Cities Recycling and Disposal Facility, Fremont, CA, August 2006.

113. Metco Environmental, TR-768: Source Emissions Survey of BFI Sunset Farms Landfill Enclosed Flare Outlet Stack and Inlet Duct, Austin, TX, November 2002.

114. Metco Environmental, TR-769: Source Emissions Survey of BFI Tessman Road Landfill Enclosed Flare Outlet Stack and Inlet Duct, San Antonio, TX, November 2002.

115. Office of Air Quality Planning and Standards, Office of Air and Radiation, US Environmental Protection Agency, Emission Factor Documentation for AP-42 Section 2.4 Municipal Solid Waste Landfills Revised, Research Triangle Park, North Carolina, August 1997.

* 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.

References are available electronically at: https://gaftp.epa.gov/ap42/ch02/s04/reference/Draft%202024%20Update/