

2.4 Municipal Solid Waste Landfills

2.4.1 General¹⁻⁴

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. In addition to household and commercial wastes, the other waste types potentially accepted by MSW landfills include (most landfills accept only a few of the following categories):

- Municipal sludge,
- Municipal waste combustion ash,
- Infectious waste,
- Small-quantity generated hazardous 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.

The information presented in this section applies only to landfills which receive primarily MSW. This information is not intended to be used to estimate emissions from landfills which receive large quantities of other waste types such as industrial waste, or construction and demolition wastes. These other wastes exhibit emissions unique to the waste being landfilled.

In the United States in 2006, approximately 55 percent of solid waste was landfilled, 13 percent was incinerated, and 32 percent was recycled or composted. There were an estimated 1,754 active MSW landfills in the United States in 2006. These landfills were estimated to receive 138 million tons of waste annually, with 55 to 60 percent reported as household waste, and 35 to 45 percent reported as commercial waste.⁷⁹

2.4.2 Process Description^{2,5}

The majority of landfills currently use the “area fill” method which involves placing waste on a landfill liner, spreading it in layers, and compacting it with heavy equipment. A daily soil cover is spread over the compacted waste to prevent wind-blown trash and to protect the trash from scavengers and vectors. The landfill liners are constructed of soil (i.e., recompacted clay) and synthetics (i.e., high density polyethylene) to provide an impermeable barrier to leachate (i.e., water that has passed through the landfill) and gas migration from the landfill. Once an area of the landfill is completed, it is covered with a “cap” or “final cover” composed of various combinations of clay, synthetics, soil and cover vegetation to control the incursion of precipitation, the erosion of the cover, and the release of gases and odors from the landfill.

2.4.3 Control Technology^{2,5,6}

The New Source Performance Standards (NSPS) and Emission Guidelines for air emissions from MSW landfills for certain new and existing landfills were published in the Federal Register on March 1, 1996. Current versions of the NSPS and Emission Guidelines can

be found at 40 CFR 60 subparts WWW and Cb, respectively. The regulation requires that Best Demonstrated Technology (BDT) be used to reduce MSW landfill emissions from affected new and existing MSW landfills if (1) the landfill has a design capacity of 2.5 million Mg (2.75 million tons) and 2.5 million cubic meters or more, and (2) the calculated uncontrolled emissions from the landfill are greater than or equal to 50 Mg/yr (55 tons/yr) of nonmethane 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. Control systems require: (1) a well-designed and well-operated gas collection system, and (2) a control device capable of reducing non-methane organic compounds (NMOCs) in the collected gas by 98 weight-percent (or to 20 ppmv, dry basis as hexane at 3% oxygen for an enclosed combustion device). Other compliance options include use of a flare that meets specified design and operating requirements or treatment of landfill gas (LFG) for use as a fuel. The National Emission Standards for Hazardous Air Pollutants (NESHAP) for MSW landfills was published in the Federal Register on January 16, 2003. It requires control of the same landfills, and the same types of gas collection and control systems as the NSPS. The NESHAP also requires earlier control of bioreactor landfills and contains a few additional reporting requirements for MSW landfills.

Landfill gas collection systems consist of a series of vertical or horizontal perforated pipes that penetrate the waste mass and collect the gases produced by the decaying waste. These collection systems are classified as either active or passive systems. Active collection systems use mechanical blowers or compressors to create a vacuum in the collection piping to optimize the collection of LFG. Passive systems use the natural pressure gradient established between the encapsulated waste and the atmosphere to move the gas through the collection system.

LFG control and treatment options include: (1) combustion of the LFG, and (2) treatment of the LFG for subsequent sale or use. Combustion techniques include techniques that do not recover energy (i.e., flares and thermal incinerators), and techniques that recover energy and generate electricity from the combustion of the LFG (i.e., gas turbines and reciprocating engines). Boilers can also be employed to recover energy from LFG in the form of steam. Flares combust the LFG without the recovery of energy, and are classified by their burner design as being either open or enclosed. Purification techniques are used to process raw LFG to either a medium-BTU gas using dehydration and filtration or as a higher-BTU gas by removal of inert constituents using adsorption, absorption, and membranes.

2.4.4 Emissions^{2,7}

Methane (CH₄) and carbon dioxide (CO₂) are the primary constituents of LFG, and are produced by microorganisms within the landfill under anaerobic conditions. Transformations of CH₄ and CO₂ are mediated by microbial populations that are adapted to the cycling of materials in anaerobic environments. Landfill gas generation proceeds through four phases. The first phase is aerobic [i.e., with oxygen (O₂) available from air trapped in the waste] and the primary gas produced is CO₂. The second phase is characterized by O₂ depletion, resulting in an anaerobic environment, where large amounts of CO₂ and some hydrogen (H₂) are produced. In the third phase, CH₄ production begins, with an accompanying reduction in the amount of CO₂ produced. Nitrogen (N₂) content is initially high in LFG in the first phase, and declines sharply as the landfill proceeds through the second and third phases. In the fourth phase, gas production of CH₄, CO₂, and N₂ becomes fairly steady. The duration of each phase and the total time of gas generation vary with landfill conditions (i.e., waste composition, design management, and anaerobic state).

Typically, LFG also contains NMOC and volatile organic compounds (VOC). NMOC result from either decomposition by-products or volatilization of biodegradable wastes. Although NMOC are considered trace constituents in LFG, the NMOC and VOC emission rates could be “major” with respect to Prevention of Significant Deterioration (PSD) and New Source Review (NSR) requirements. This NMOC fraction often contains various organic hazardous air pollutants (HAP), greenhouse gases (GHG), compounds associated with stratospheric ozone depletion and volatile organic compounds (VOC). However, in MSW landfills where contaminated soils from storage tank cleanups are used as daily cover, much higher levels of NMOC have been observed. As LFG migrates through the contaminated soil, it adsorbs the organics, resulting in the higher concentrations of NMOC and any other contaminant in the soil. In one landfill where contaminated soil was used as daily cover, the NMOC concentration in the LFG was 5,870 ppm as compared to the AP-42 average value of 838 ppm. While there is insufficient data to develop a factor or algorithm for estimating NMOC from contaminated daily cover, the emissions inventory developer should be aware to expect elevated NMOC concentrations from these landfills.

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 (SO₂), 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.

One pollutant that can vary greatly between landfills is hydrogen sulfide (H₂S). H₂S is normally present in LFG at levels ranging from 0 to 90 ppm, with an average concentration of 33 ppm. However, a recent trend at some landfills has been the use of construction and demolition waste (C&D) as daily cover. Under certain conditions that are not well understood, some microorganisms will convert the sulfur in the wall-board of C&D waste to H₂S. At these landfills, H₂S concentrations can be significantly higher than at landfills that do not use C&D waste as daily cover. While H₂S measurements are not available for landfills using C&D for daily cover, the State of New Hampshire among others have noted elevated H₂S odor problems at these landfills and have assumed that H₂S concentrations have increased, similarly. In a series of studies at 10 landfills in Florida where a majority of the waste is composed of C&D material, the concentration of H₂S concentration spanned a range from less than the detection limit of the instrument (0.003 ppmv) up to 12,000 ppmv.⁸ Another study that was conducted used flux boxes to measure uncontrolled emissions of H₂S at five landfills in Florida. This study reported a range of H₂S emissions between 0.192 and 1.76 mg/(m²-d).⁹ At any MSW landfill where C&D waste was used as daily cover or was comingled with the MSW, it is recommended that direct H₂S measurements be used to develop specific H₂S emissions for the landfill.

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.

Although relatively uncommon, fires can occur on the surface of the landfill or underground. The smoke from a landfill fire frequently contains many dangerous chemical

compounds, including: carbon monoxide, particulate matter and hazardous gases that are the products of incomplete combustion, and very elevated concentrations of the many gaseous constituents normally occurring in LFG. Of particular concern in landfill fires is the emission of dioxins/furans. Accidental fires at landfills and the uncontrolled burning of residential waste are considered the largest sources of dioxin emissions in the United States.¹⁰ The composition of the gases from landfill fires is highly variable and dependent on numerous site specific factors, including: the composition of the material burning, the composition of the surrounding waste, the temperature of the burning waste, and the presence of oxygen. The only reliable method for estimating the emissions from a landfill fire involves testing the emissions directly. More information is available on landfill fires and their emissions from reference 11.

2.4.4.1 Uncontrolled Emissions -

Several methods have been developed by EPA to determine the uncontrolled emissions of the various compounds present in LFG. The newest measurement method is optical remote sensing with radial plume mapping (ORS-RPM). This method uses an optical emission detector such as open-path Fourier transform infrared spectroscopy (FTIR), ultraviolet differential absorption spectroscopy (UV-DOAS), or open-path tunable diode laser absorption spectroscopy (OP-TDLAS); coupled with radial plume mapping software that processes path-integrated emission concentration data and meteorological data to yield an estimate of uncontrolled emissions. More information on this newest method is described in *Evaluation of Fugitive Emissions Using Ground-Based Optical Remote Sensing Technology* (EPA/600/R-07/032).¹² Additional research is ongoing to provide additional guidance on the use of optical remote sensing for application at landfills. Evaluating uncontrolled emissions from landfills can be a challenge. This is due to the changing nature of landfills, scale and complexity of the site, topography, and spatial and temporal variability in emissions. Additional guidance is being developed for application of EPA's test method for area sources emissions. This is expected to be released by the spring of 2009. For more information, refer to the Emission Measurement Center of EPA's Technology Transfer Network (<http://www.epa.gov/ttn/emc/tmethods.html>). Additional information on ORS technology can also be found on EPA's website for Measurement and Monitoring Technologies for 21st Century (21M²) which provided funding to identify improved technologies for quantifying area source emissions (<http://www.clu-in.org/programs/21m2/openpath/>).

Often flux data are used to evaluate LFG collection efficiency. The concern with the use of this data is that it does not capture emission losses from header pipes or extraction wells. The other concern is that depending upon the design of the study, the emission variability across a landfill surface is not captured. Emission losses can occur from cracks and fissures or difference in landfill cover material. Often, alternative cover material is used to help promote infiltration, particularly for wet landfill operation. This can result in larger loss of fugitive emissions. Another loss of landfill gas is through the leachate collection pumps and wells. For many of these potential losses, a flux box is not considered adequate to capture the total loss of fugitive gas. The use of ORS technology is considered more reliable.

When direct measurement data are not available, the most commonly used EPA method to estimate the uncontrolled emissions associated with LFG is based on a biological decay model. In this method, the generation of CH₄ must first be estimated by using a theoretical first-order kinetic model of CH₄ production developed by the EPA¹³:

$$Q_{CH_4} = 1.3 L_o R (e^{-kc} - e^{-kt}) \quad (1)$$

where:

- Q_{CH_4} = Methane generation rate at time t , m^3/yr ;
- L_o = Methane generation potential, $m^3 CH_4/Mg$ of “wet” or “as received” refuse;
- R = Average annual refuse acceptance rate during active life, Mg of “wet” or “as received” refuse /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.

When annual refuse acceptance data is available, the following form of Equation (1) is used. This is the general form of the equation that is used in EPA’s Landfill Gas Emissions Model (LandGEM). Due to the complexity of the double summation, Equation (1 alt) is normally implemented within a computer model. Equation (1 alt.) is more accurate because it accounts for the varying annual refuse flows and it calculates each year’s gas flow in $1/10$ th year increments.

$$Q_{CH_4} = 1.3 \sum_{i=1}^n \sum_{j=0.1}^1 k L_o \frac{R_i}{10} e^{-kt_j} \quad (1 \text{ alternate})$$

where:

- Q_{CH_4} = Methane generation rate at time t , m^3/yr ;
- L_o = Methane generation potential, $m^3 CH_4/Mg$ of “wet” or “as received” refuse;
- R_i = Annual refuse acceptance rate for year i , Mg of “wet” or “as received” refuse /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.
- i = year in life of the landfill
- j = $1/10$ th year increment in the calculation.

It should be noted that Equation (1) is provided for estimating CH_4 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 CH_4 generated will be emitted through cracks or other openings in the landfill surface and that Equation (1) can be used to approximate CH_4 emissions from an uncontrolled landfill. It should also be noted that Equation (1) is different from the equation used in other models such as LandGEM by the addition of the constant 1.3 at the front of the equation. This constant is included to compensate for L_o which is typically determined by the amount of gas collected by LFG collection systems. The design of these systems will typically result in a gas capture efficiency of only 75%. Therefore, 25% of the gas generated by the landfill is not captured and included in the development of L_o . The ratio of total gas to captured gas is a ratio of 100/75 or equivalent to 1.3.

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 are normally 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.

Recommended AP-42 defaults for k are:

k Value	Landfill Conditions
0.02	Areas receiving <25 inches/yr rainfall
0.04	Areas receiving >25 inches/yr rainfall
0.3	Wet landfills¹⁴

For the purpose of the above table, wet landfills are defined as landfills which add large amounts of water to the waste. This added water may be recycled landfill leachates and condensates, or may be other sources of water such as treated wastewater.

The CH_4 generation potential, L_o , has been observed to vary from 6 to 270 m^3/Mg (200 to 8670 ft^3/ton), depending on the organic content of the waste material. A higher organic content results in a higher L_o . Food, textiles, paper, wood, and horticultural waste have the highest L_o value on a dry basis, while inert materials such as glass, metal and plastic have no L_o value.² Since moisture does not contribute to the value of L_o , a high moisture content waste, such as food or organic sludge, will have a lower L_o on an “as received” basis. When using Equation 1 to estimate emissions for typical MSW landfills in the U.S., a mean L_o value of 100 m^3/Mg refuse (3,530 ft^3/ton , “as received” basis) is recommended.

There is a significant level of uncertainty in Equation 2 and its recommended defaults values for k and L_o . The recommended defaults k and L_o for conventional landfills, based upon the best fit to 40 different landfills, yielded predicted CH_4 emissions that ranged from ~30 to 400% of measured values and had a relative standard deviation of 0.73 (Table 2-2). The default values for wet landfills were based on a more limited set of data and are expected to contain even greater uncertainty.

When gas generation reaches steady state conditions, LFG consists of approximately equal volumes of CO_2 and CH_4 . LFG also typically contains as much as five percent N_2 and other gases, and trace amounts of NMOCs. Since the flow of CO_2 is approximately equal to the flow of CH_4 , the estimate derived for CH_4 generation using Equation (1) can also be used to estimate CO_2 generation. Addition of the CH_4 and CO_2 emissions will yield an estimate of total LFG emissions. If site-specific information is available on the actual CH_4 and CO_2 contents of the LFG, then the site-specific information should be used.

Most of the NMOC emissions from landfills result from the volatilization of organic compounds contained in the landfilled waste. Small amounts may also be created by biological

processes and chemical reactions within the landfill. Available data show that the range of values for total NMOC in LFG is from 31 ppmv to over 5,387 ppmv, and averages 838 ppmv. The proposed regulatory default of 4,000 ppmv for NMOC concentration was developed for regulatory compliance purposes and is considered more conservative. For emissions inventory purposes, site-specific information should be taken into account when determining the total NMOC concentration, whenever available. Measured pollutant concentrations (i.e., as measured by EPA Reference Method 25C), 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 CH₄, CO₂, N₂, and O₂ content. If the ratio of N₂ to O₂ 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 CO₂ and CH₄ are the primary constituents of LFG (assumed to account for 100% of the LFG), and the following equation is used:

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

where:

- C_p = Concentration of pollutant P in LFG (i.e., NMOC as hexane), ppmv;
- C_{CO₂} = CO₂ concentration in LFG, ppmv;
- Q_{CH₄} = CH₄ Concentration in LFG, ppmv; and
- 1 x 10⁶ = Constant used to correct concentration of P to units of ppmv.

If the ratio of N₂ to O₂ concentrations (i.e., C_{N₂}, C_{O₂}) 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 N₂ (i.e., C_{N₂}) to the denominator. Values for C_{CO₂}, C_{CH₄}, C_{N₂}, C_{O₂}, can usually be found in the source test report for the particular landfill along with the total pollutant concentration data.

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

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

where:

- Q_p = Emission rate of pollutant P (i.e., NMOC), m³/yr;
- Q_{CH₄} = CH₄ generation rate, m³/yr (from Equation 1);
- C_p = Concentration of pollutant P in LFG, ppmv; and
- C_{CH₄} = Concentration of CH₄ in the LFG (assumed to be 50% expressed as 0.5)

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

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

where:

UM_p = Uncontrolled mass emissions of pollutant P (i.e., NMOC), kg/yr;
 MW_p = Molecular weight of P, g/gmol (i.e., 86.18 for NMOC as hexane);
 Q_p = Emission rate of pollutant P, m^3 /yr; and
 T = Temperature of LFG, °C.

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

Uncontrolled default concentrations of VOC, NMOC and speciated compounds are presented in Table 2.4-1 for landfills having a majority of the waste in place on or after 1992 and in Table 2.4-2 for landfills having a majority of the waste in place before 1992. These default concentrations have already been corrected for air infiltration and can be used as input parameters to Equation (3) for estimating 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.

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 landfill test reports. 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 emission concentrations given in Tables 2.4-1 and 2.4-2. Available data have shown that there is a range of over two orders of magnitude in many of the pollutant concentrations among gases from various MSW landfills.

2.4.4.2 Controlled Emissions —

Emissions from landfills are typically controlled by installing a gas collection system, and either combusting the collected gas through the use of internal combustion engines, flares, or turbines, or by purifying the gas for direct use in place of a fuel such as natural gas. Gas collection systems are not 100% efficient in collecting LFG, 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 LFG, the collection efficiency of the system must first be estimated. Reported collection efficiencies typically range from 50 to 95%, with a default efficiency of 75% recommended by EPA for inventory purposes. The lower collection efficiencies are experienced at landfills with a large number of open cells, no liners, shallow soil covers, poor collection system and cap maintenance programs and/or a large number of cells without gas collection. The higher collection efficiencies may be achieved at closed sites employing good liners, extensive geomembrane-clay composite caps in conjunction with well engineered gas collection systems, and aggressive operation and maintenance of the cap and collection system. If documented site-specific collection efficiencies are available (i.e., through a comprehensive surface sampling program), then they may be used instead of the 75% average. An analysis showing a range in the gas collection system taking into account delays from gas collection from initial waste placement is provided in Section 2.0.

Estimates of controlled emissions may also need to account for the control efficiency of the control device. Control efficiencies for NMOC and VOC based on test data for the combustion of LFG with differing control devices are presented in Table 2.4-3. As noted in the table, these control efficiencies may also be applied to other LFG constituents. Emissions from

the control devices need to be added to the uncollected emissions to estimate total controlled emissions.

Controlled CH₄, NMOC, VOC, and speciated emissions can be determined by either of two methods developed by EPA. The newest method is the optical remote sensing with radial plume mapping (ORS-RPM). This method uses an optical emission detector such as open-path Fourier transform infrared spectroscopy (FTIR), ultraviolet differential absorption spectroscopy (UV-DOAS), or open-path tunable diode laser absorption spectroscopy (OP-TDLAS); coupled with radial plume mapping software that processes path-integrated emission concentration data and meteorological data to yield an estimate of uncontrolled emissions. More information on this newest method is described in *Evaluation of Fugitive Emissions Using Ground-Based Optical Remote Sensing Technology* (EPA/600/R-07/032).¹²

Historically, controlled emissions have been calculated with Equation 5. In this equation it is assumed that the LFG collection and control system operates 100 percent of the time. Minor durations of system downtime associated with routine maintenance and repair (i.e., 5 to 7 percent) will not appreciably effect emission estimates. The first term in Equation 5 accounts for emissions from uncollected LFG, while the second term accounts for emissions of the pollutant that were collected but not fully 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);
 - η_{col} = Efficiency of the LFG collection system, % (recommended default is 75%);
- and
- η_{cnt} = Efficiency of the LFG control or utilization device, %.

Emission factors for the secondary compounds, CO, PM, NO_x and dioxins/furans exiting the control device are presented in Table 2.4-4. These emission factors should be used when equipment vendor emission guarantees are not available.

Controlled emissions of CO₂ and sulfur dioxide (SO₂) are best estimated using site-specific LFG constituent concentrations and mass balance methods.¹⁵ If site-specific data are not available, the data in Tables 2.4-1 and 2.4-2 can be used with the mass balance methods that follow.

Controlled CO₂ emissions include emissions from the CO₂ component of LFG and additional CO₂ formed during the combustion of LFG. The bulk of the CO₂ formed during LFG combustion comes from the combustion of the CH₄ fraction. Small quantities will be formed during the combustion of the NMOC fraction. However, this typically amounts to less than 1 percent of total CO₂ emissions by weight. Also, the formation of CO through incomplete combustion of LFG will result in small quantities of CO₂ not being formed. This contribution to the overall mass balance picture is also very small and does not have a significant impact on overall CO₂ emissions.¹⁵

The following equation which assumes a 100% combustion efficiency for CH₄ can be used to estimate CO₂ 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_{CO₂} = Controlled mass emissions of CO₂, kg/yr;
- UM_{CO₂} = Uncontrolled mass emissions of CO₂, kg/yr (from Equation 4);
- UM_{CH₄} = Uncontrolled mass emissions of CH₄, kg/yr (from Equation 4);
- η_{col} = Efficiency of the LFG collection system, % (recommended default is 75%);
- and
- 2.75 = Ratio of the molecular weight of CO₂ to the molecular weight of CH₄.

To prepare estimates of SO₂ emissions, data on the concentration of reduced sulfur compounds within the LFG are needed. The best way to prepare this estimate is with site-specific information on the total reduced sulfur content of the LFG. 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 SO₂ emissions:

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

where:

- CM_{SO₂} = Controlled mass emissions of SO₂, kg/yr;
- UM_S = Uncontrolled emissions of reduced sulfur compounds as sulfur, kg/yr (from Equations 3 and 4);
- η_{col} = Efficiency of the LFG collection system, %; and
- 2.0 = Ratio of the molecular weight of SO₂ to the molecular weight of S.

The next best method to estimate SO₂ 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 SO₂ 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 (i.e., 1 for sulfides, 2 for disulfides); and
- n = Number of reduced sulfur compounds available for summation.

If no site-specific data are available, values of 47 and 33 ppmv can be used for C_S in the gas from landfills having a majority of the waste in place before 1992 and from landfills having a majority of the waste in place after 1992, respectively. These values were obtained by using the default concentrations presented in Tables 2.4-1 and 2.4-2 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 HCl 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^-)]. However, emission estimates may be underestimated, since not every chlorinated compound in the LFG will be represented in the site test report (i.e., only those that the analytical method specifies). If these data are not available, then total chloride can be estimated from data on individual chlorinated species using Equation 9 below.

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

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 mole of chlorinated compound (i.e., 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 LFG 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 LFG 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 control efficiency for the equipment listed in Table 2.4-3 should be used. This assumption is recommended to assume that HCl emissions are not underestimated.

If site-specific data on total chloride or speciated chlorinated compounds are not available, then default values of 42 and 74 ppmv can be used for C_{Cl} in the gas from landfills having a majority of the waste in place before 1992 and from landfills having a majority of the

waste in place after 1992, respectively. These values were derived from the default LFG constituent concentrations presented in Tables 2.4-1 and 2.4-2. 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 and 2.4-2 are likely not all of the chlorinated compounds present in LFG.

The reader is referred to AP-42 Volume I, Sections 13.2.1 and 13.2.2 for information on estimating fugitive dust emissions from paved and unpaved roads, and to Section 13.2.3 for information on estimating fugitive dust emissions from heavy construction operations; and to AP-42 Volume II Section II-7 for estimating exhaust emissions from construction equipment.

2.4.5 Updates Since the Fifth Edition

The Fifth Edition was released in January 1995. The November 1998 revision includes major revisions of the text and recommended emission factors contained in the section. The most significant revisions to this section since publication in the Fifth Edition are summarized below.

- The equations to calculate the CH₄, CO₂ 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 CO₂ to CH₄ was revised based upon averages observed in available source test reports.
- The default concentrations of LFG constituents were revised based upon additional data. References 16-148 are the emission test reports from which data were obtained for this section.
- 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.

The current (i.e., 2008) update includes text revisions and additional discussion, as well as revised recommended emission factors contained within the section. The more significant revisions are summarized below:

- Default concentrations of LFG constituents were developed for landfills with the majority of their waste in place on or after 1992 (proposal of RCRA Subtitle D). The LFG constituent list from the last update reflects data from landfills with waste in place prior to 1992, so Table 2.4-2 was renamed to reflect this.
- Control efficiencies were updated to incorporate additional emission test data and the table was revised to show the NMOC and VOC control efficiencies.
- Revised and expanded the recommended emission factors for secondary compounds emitted from typical control devices.
- The description of modern landfills and statistics about waste disposition in the U.S. were updated with 2006 information.

- EPA's newest measurement method for determining landfill emissions, Optical Remote Sensing with Radial Plume Mapping (ORS-RPM), was added to the discussion of available options for measuring landfill emissions.
- A factor of 1.3 was added to Equation (1) to account for the fact that L_0 is typically determined by the amount of CH_4 collected at landfills using equipment that typically has a capture efficiency of only 75%.
- A k value of 0.3 was added to the list of recommended k values for use in Equation (1).

Table 2.4-1. DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE ON OR AFTER 1992

Compound	CAS Number	Molecular Weight	Default Concentration (ppmv)	Recommended Emission Factor Rating
NMOC (as hexane) ^a		86.18	8.38E+02	A
VOC ^b		NA	8.35E+02	A
1,1,1-Trichloroethane ^c	71556	133.40	2.43E-01	A
1,1,2,2-Tetrachloroethane ^c	79345	167.85	5.35E-01	E
1,1,2,3,4,4-Hexachloro-1,3-butadiene (Hexachlorobutadiene) ^c	87683	260.76	3.49E-03	D
1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113)	76131	187.37	6.72E-02	C
1,1,2-Trichloroethane ^c	79005	133.40	1.58E-01	D
1,1-Dichloroethane ^c	75343	98.96	2.08E+00	A
1,1-Dichloroethene (1,1-Dichloroethylene) ^c	75354	96.94	1.60E-01	A
1,2,3-Trimethylbenzene	526738	120.19	3.59E-01	D
1,2,4-Trichlorobenzene ^c	120821	181.45	5.51E-03	C
1,2,4-Trimethylbenzene	95636	120.19	1.37E+00	B
1,2-Dibromoethane (Ethylene dibromide) ^c	106934	187.86	4.80E-03	B
1,2-Dichloro-1,1,2,2-tetrafluoroethane (Freon 114)	76142	170.92	1.06E-01	B
1,2-Dichloroethane (Ethylene dichloride) ^c	107062	98.96	1.59E-01	A
1,2-Dichloroethene	540590	96.94	1.14E+01	E
1,2-Dichloropropane ^c	78875	112.99	5.20E-02	D
1,2-Diethylbenzene	135013	134.22	1.99E-02	D
1,3,5-Trimethylbenzene	108678	120.19	6.23E-01	C
1,3-Butadiene (Vinyl ethylene) ^c	106990	54.09	1.66E-01	C
1,3-Diethylbenzene	141935	134.22	6.55E-02	D
1,4-Diethylbenzene	105055	134.22	2.62E-01	D
1,4-Dioxane (1,4-Diethylene dioxide) ^c	123911	88.11	8.29E-03	D
1-Butene / 2-Methylbutene	106989 / 513359	56.11 / 70.13	1.22E+00	D
1-Butene / 2-Methylpropene	106989 / 115117	56.11	1.10E+00	E

Table 2.4-1 (CONTINUED). DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE ON OR AFTER 1992

Compound	CAS Number	Molecular Weight	Default Concentration (ppmv)	Recommended Emission Factor Rating
1-Ethyl-4-methylbenzene (4-Ethyl toluene)	622968	120.19	9.89E-01	C
1-Ethyl-4-methylbenzene (4-Ethyl toluene) + 1,3,5-Trimethylbenzene	622968 / 108678	120.19	5.79E-01	D
1-Heptene	592767	98.19	6.25E-01	E
1-Hexene / 2-Methyl-1-pentene	592416 / 763291	84.16	8.88E-02	D
1-Methylcyclohexene	591491	96.17	2.27E-02	D
1-Methylcyclopentene	693890	82.14	2.52E-02	D
1-Pentene	109671	70.13	2.20E-01	D
1-Propanethiol (n-Propyl mercaptan)	107039	76.16	1.25E-01	A
2,2,3-Trimethylbutane	464062	100.20	9.19E-03	D
2,2,4-Trimethylpentane ^c	540841	114.23	6.14E-01	D
2,2,5-Trimethylhexane	3522949	128.26	1.56E-01	D
2,2-Dimethylbutane	75832	86.18	1.56E-01	D
2,2-Dimethylpentane	590352	100.20	6.08E-02	D
2,2-Dimethylpropane	463821	72.15	2.74E-02	E
2,3,4-Trimethylpentane	565753	114.23	3.12E-01	D
2,3-Dimethylbutane	79298	86.18	1.67E-01	D
2,3-Dimethylpentane	565593	100.20	3.10E-01	D
2,4-Dimethylhexane	589435	114.23	2.22E-01	D
2,4-Dimethylpentane	108087	100.20	1.00E-01	D
2,5-Dimethylhexane	592132	114.23	1.66E-01	D
2,5-Dimethylthiophene	638028	112.19	6.44E-02	E
2-Butanone (Methyl ethyl ketone) ^c	78933	72.11	4.01E+00	C
2-Ethyl-1-butene	760214	84.16	1.77E-02	D
2-Ethylthiophene	872559	112.19	6.29E-02	E
2-Ethyltoluene	611143	120.19	3.23E-01	D
2-Hexanone (Methyl butyl ketone)	591786	100.16	6.13E-01	E
2-Methyl-1-butene	563462	70.13	1.79E-01	D
2-Methyl-1-propanethiol (Isobutyl mercaptan)	513440	90.19	1.70E-01	E
2-Methyl-2-butene	513359	70.13	3.03E-01	D
2-Methyl-2-propanethiol (tert-Butylmercaptan)	75661	90.19	3.25E-01	E
2-Methylbutane	78784	72.15	2.26E+00	D
2-Methylheptane	592278	114.23	7.16E-01	D
2-Methylhexane	591764	100.20	8.16E-01	D
2-Methylpentane	107835	86.18	6.88E-01	D
2-Propanol (Isopropyl alcohol)	67630	60.10	1.80E+00	C

Table 2.4-1 (CONTINUED). DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE ON OR AFTER 1992

Compound	CAS Number	Molecular Weight	Default Concentration (ppmv)	Recommended Emission Factor Rating
3,6-Dimethyloctane	15869940	142.28	7.85E-01	D
3-Ethyltoluene	620144	120.19	7.80E-01	D
3-Methyl-1-pentene	760203	84.16	6.99E-03	D
3-Methylheptane	589811	114.23	7.63E-01	D
3-Methylhexane	589344	100.20	1.13E+00	D
3-Methylpentane	96140	86.18	7.40E-01	D
3-Methylthiophene	616444	98.17	9.25E-02	E
4-Methyl-1-pentene	691372	84.16	2.33E-02	E
4-Methyl-2-pentanone (MIBK) ^c	108101	100.16	8.83E-01	C
4-Methylheptane	589537	114.23	2.49E-01	D
Acetaldehyde ^c	75070	44.05	7.74E-02	D
Acetone	67641	58.08	6.70E+00	C
Acetonitrile ^c	75058	41.05	5.56E-01	A
Acrylonitrile ^{c,d}	107131	53.06	BDL	
Benzene ^c	71432	78.11	2.40E+00	A
Benzyl chloride ^c	100447	126.58	1.81E-02	A
Bromodichloromethane	75274	163.83	8.78E-03	E
Bromomethane (Methyl bromide) ^c	74839	94.94	2.10E-02	C
Butane	106978	58.12	6.22E+00	C
Carbon disulfide ^c	75150	76.14	1.47E-01	A
Carbon monoxide	630080	28.01	2.44E+01	C
Carbon tetrachloride ^c	56235	153.82	7.98E-03	A
Carbon tetrafluoride (Freon 14)	75730	88.00	1.51E-01	E
Carbonyl sulfide (Carbon oxysulfide) ^c	463581	60.08	1.22E-01	A
Chlorobenzene	108907	112.56	4.84E-01	A
Chlorodifluoromethane (Freon 22) ^c	75456	86.47	7.96E-01	D
Chloroethane (Ethyl chloride) ^c	75003	64.51	3.95E+00	B
Chloromethane (Methyl chloride) ^c	74873	50.49	2.44E-01	B
cis-1,2-Dichloroethene	156592	96.94	1.24E+00	B
cis-1,2-Dimethylcyclohexane	2207014	112.21	8.10E-02	D
cis-1,3-Dichloropropene	10061015	110.97	3.03E-03	D
cis-1,3-Dimethylcyclohexane	638040	112.21	5.01E-01	D
cis-1,4-Dimethylcyclohexane / trans-1,3-Dimethylcyclohexane	624293 / 2207036	112.21	2.48E-01	D
cis-2-Butene	590181	56.11	1.05E-01	D
cis-2-Heptene	6443921	98.19	2.45E-02	E
cis-2-Hexene	7688213	84.16	1.72E-02	D
cis-2-Octene	7642048	112.21	2.20E-01	D
cis-2-Pentene	627203	70.13	4.79E-02	D

Table 2.4-1 (CONTINUED). DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE ON OR AFTER 1992

Compound	CAS Number	Molecular Weight	Default Concentration (ppmv)	Recommended Emission Factor Rating
cis-3-Methyl-2-pentene	922623	84.16	1.79E-02	D
Cyclohexane	110827	84.16	1.01E+00	B
Cyclohexene	110838	82.14	1.84E-02	D
Cyclopentane	287923	70.13	2.21E-02	D
Cyclopentene	142290	68.12	1.21E-02	D
Decane	124185	142.28	3.80E+00	D
Dibromochloromethane	124481	208.28	1.51E-02	D
Dibromomethane (Methylene dibromide)	74953	173.84	8.35E-04	E
Dichlorobenzene ^{c,e}	106467	147.00	9.40E-01	A
Dichlorodifluoromethane (Freon 12)	75718	120.91	1.18E+00	B
Dichloromethane (Methylene chloride) ^c	75092	84.93	6.15E+00	A
Diethyl sulfide	352932	90.19	8.62E-02	E
Dimethyl disulfide	624920	94.20	1.37E-01	A
Dimethyl sulfide	75183	62.14	5.66E+00	A
Dodecane (n-Dodecane)	112403	170.33	2.21E-01	D
Ethane	74840	30.07	9.05E+00	D
Ethanol	64175	46.07	2.30E-01	D
Ethyl acetate	141786	88.11	1.88E+00	C
Ethyl mercaptan (Ethanediol)	75081	62.14	1.98E-01	A
Ethyl methyl sulfide	624895	76.16	3.67E-02	E
Ethylbenzene ^c	100414	106.17	4.86E+00	B
Formaldehyde ^c	50000	30.03	1.17E-02	D
Heptane	142825	100.20	1.34E+00	B
Hexanec	110543	86.18	3.10E+00	B
Hydrogen sulfide	7783064	34.08	3.20E+01	A
Indane (2,3-Dihydroindene)	496117	34.08	6.66E-02	D
Isobutane (2-Methylpropane)	75285	58.12	8.16E+00	D
Isobutylbenzene	538932	134.22	4.07E-02	D
Isoprene (2-Methyl-1,3-butadiene)	78795	68.12	1.65E-02	D
Isopropyl mercaptan	75332	76.16	1.75E-01	A
Isopropylbenzene (Cumene) ^c	98828	120.19	4.30E-01	D
Mercury (total) ^c	7439976	200.59	1.22E-04	B
Mercury (elemental) ^c	7439976	200.59	7.70E-05	C
Mercury (monomethyl) ^c	51176126	216.63	3.84E-07	C
Mercury (dimethyl) ^c	627441	258.71	2.53E-06	B
Methanethiol (Methyl mercaptan)	74931	48.11	1.37E+00	A
Methyl tert-butyl ether (MTBE) ^c	1634044	88.15	1.18E-01	D
Methylcyclohexane	108872	98.19	1.29E+00	D

Table 2.4-1 (CONTINUED). DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE ON OR AFTER 1992

Compound	CAS Number	Molecular Weight	Default Concentration (ppmv)	Recommended Emission Factor Rating
Methylcyclopentane	96377	84.16	6.50E-01	D
Naphthalene ^c	91203	128.17	1.07E-01	D
n-Butylbenzene	104518	134.22	6.80E-02	D
Nonane	111842	128.26	2.37E+00	D
n-Propylbenzene (Propylbenzene)	103651	120.19	4.13E-01	D
Octane	111659	114.23	1.08E+00	D
p-Cymene (1-Methyl-4-Isopropylbenzene)	99876	134.22	3.58E+00	D
Pentane	109660	72.15	4.46E+00	C
Propane	74986	44.10	1.55E+01	C
Propene	115071	42.08	3.32E+00	D
Propyne	74997	40.06	3.80E-02	E
sec-Butylbenzene	135988	134.22	6.75E-02	D
Styrene (Vinylbenzene) ^c	100425	104.15	4.11E-01	B
Tetrachloroethylene (Perchloroethylene) ^c	127184	165.83	2.03E+00	A
Tetrahydrofuran (Diethylene oxide)	109999	72.11	9.69E-01	C
Thiophene	110021	84.14	3.49E-01	E
Toluene (Methyl benzene) ^c	108883	92.14	2.95E+01	A
trans-1,2-Dichloroethene	156605	96.94	2.87E-02	C
trans-1,2-Dimethylcyclohexane	6876239	112.21	4.04E-01	D
trans-1,3-Dichloropropene	10061026	110.97	9.43E-03	D
trans-1,4-Dimethylcyclohexane	2207047	112.21	2.05E-01	D
trans-2-Butene	624646	56.11	1.04E-01	D
trans-2-Heptene	14686136	98.19	2.50E-03	E
trans-2-Hexene	4050457	84.16	2.06E-02	D
trans-2-Octene	13389429	112.21	2.41E-01	D
trans-2-Pentene	646048	70.13	3.47E-02	D
trans-3-Methyl-2-pentene	616126	84.16	1.55E-02	D
Tribromomethane (Bromoform) ^c	75252	252.73	1.24E-02	D
Trichloroethylene (Trichloroethene) ^c	79016	131.39	8.28E-01	A
Trichlorofluoromethane (Freon 11)	91315616	137.37	2.48E-01	B
Trichloromethane (Chloroform) ^c	8013545	119.38	7.08E-02	A
Undecane	1120214	156.31	1.67E+00	D
Vinyl acetate ^c	85306269	86.09	2.48E-01	C
Vinyl chloride (Chloroethene) ^c	75014	62.50	1.42E+00	A
Xylenes (o-, m-, p-, mixtures)	8026093	106.17	9.23E+00	A

NOTE: This is not an all-inclusive list of potential LFG constituents, only those for which test data were available at multiple sites. References 83-148.

^a For NSPS/Emission Guideline compliance purposes, the default concentration for NMOC as specified in the final rule must be used.

^b Calculated as 99.7% of NMOC, based on speciated emission test data.

^c Hazardous Air Pollutant listed in Title III of the 1990 Clean Air Act Amendments.

^d All tests below detection limit. Method detection limits are available for three tests, and are as follows: MDL = 2.00E-04, 4.00E-03, and 2.00E-02 ppm

^e Many source tests did not indicate whether this compound was the ortho-, meta-, or para- isomer. The para isomer is a Title III listed HAP.

Draft

Table 2.4-2. DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE PRIOR TO 1992

Compound	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
NMOC (as hexane) ^c	86.18		
Co-disposal (SCC 50300603)		2,420	D
No or Unknown co-disposal (SCC 50100402)		595	B
1,1,1-Trichloroethane (methyl chloroform) ^a	133.42	0.48	B
1,1,2,2-Tetrachloroethane ^a	167.85	1.11	C
1,1-Dichloroethane (ethylidene dichloride) ^a	98.95	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	112.98	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
Benzene ^a	78.11		
Co-disposal (SCC 50300603)		11.1	D
No or Unknown co-disposal (SCC 50100402)		1.91	B
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

Table 2.4-2 (CONTINUED). DEFAULT CONCENTRATIONS FOR LFG CONSTITUENTS FOR LANDFILLS WITH WASTE IN PLACE PRIOR TO 1992

Compound	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating
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	2.92x10 ⁻⁴	E
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
Toluene ^a	92.13		
Co-disposal (SCC 50300603)		165	D
No or Unknown co-disposal (SCC 50100402)		39.3	A
Trichloroethylene (trichloroethene) ^a	131.38	2.82	B
Vinyl chloride ^a	62.50	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 16-82. 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.

^e 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 can be estimated by 85 percent by weight (2,060 ppmv as hexane); at No or Unknown sites can be estimated by 39 percent by weight 235 ppmv as hexane).

Table 2.4-3. CONTROL EFFICIENCIES FOR LFG NMOC and VOC^a

Control Device	Control Efficiency (%) ^b		
	Typical	Range	Rating
Boiler/Steam Turbine (50100423)	98.6	96-99+	D
Flare ^c (50100410) (50300601)	97.7	86-99+	A
Gas Turbine (50100420)	94.4	92-97	E
IC Engine (50100421)	97.2	95-99+	D

^a References 16-148. Source Classification Codes in parentheses.

^b Control efficiency may also be applied to LFG constituents in Tables 2-4.1 and 2.4-2, except for mercury. For any combustion equipment, the control efficiency for mercury should be assumed to be 0.

^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. EMISSION FACTORS FOR SECONDARY COMPOUNDS EXITING CONTROL DEVICES^a

Control Device	Pollutant ^b	Typical Rate, kg/10 ⁶ dscm CH ₄	Typical Rate, lb/10 ⁶ dscf CH ₄	Emission Factor Rating
Flare ^c (50100410) (50300601)	Nitrogen dioxide	631	39	A
	Carbon monoxide	737	46	A
	Particulate matter	238	15	A
	Dioxin/Furan	6.7x10 ⁻⁶	4.2x10 ⁻⁷	E
IC Engine (50100421)	Nitrogen dioxide	11,620	725	C
	Carbon monoxide	8,462	528	C
	Particulate matter	232	15	D
Boiler/Steam Turbine ^d (50100423)	Nitrogen dioxide	677	42	D
	Carbon monoxide	116	7	D
	Particulate matter	41	3	D
	Dioxin/Furan	5.1x10 ⁻⁶	3.2x10 ⁻⁷	D
Gas Turbine (50100420)	Nitrogen dioxide	1,400	87	D
	Carbon monoxide	3,600	230	E
	Particulate matter	350	22	E

^a Source Classification Codes in parentheses.

^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 CO₂, SO₂, 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 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.

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. *Municipal Solid Waste in the United States: 2006 Facts and Figures*, Office of Solid Waste, U. S. Environmental Protection Agency, Washington, DC, December 2007. <http://www.epa.gov/osw/nonhaz/municipal/msw99.htm>
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. *Suggested Control Measures for Landfill Gas Emissions*, State of California Air Resources Board, Stationary Source Division, Sacramento, CA, August 1990.
6. "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.
7. U.S. DOE, National Renewable Energy Laboratory, Comparison of Models for Predicting Landfill Methane Recovery, March 1997, Available online: <http://www.nrel.gov/docs/legosti/fy97/26041.pdf>
8. Eun, Sangho, Debra R. Reinhart, C. David Cooper, Timothy G. Townsend, Ayman Faour. Hydrogen sulfide flux measurements from construction and demolition debris (C&D) landfills. *Waste Management* 27 (2007) 220-227. Available online: <http://www.sciencedirect.com>
9. Lee, Sue, Qiyong Xu, Matthew Booth, Timothy G. Townsend, Paul Chadik and Gabriel Bitton. *Reduced sulfur compounds in gas from construction and demolition debris landfills*. Department of Environmental Engineering Sciences, University of Florida, P.O. Box 116450, Gainesville, FL 32611-6450, United States. October 2005. Available online: <http://www.sciencedirect.com>
10. Gullett, B.K., P.M. Lemieux, C.C. Lutes, C.K. Winterrowd and D.L. Winters, 2001. Emissions of PCDD/F from uncontrolled, domestic waste burning, *Chemosphere, Volume 43, Issues 4-7, May 2001, Pages 721-725*
11. *Landfill Fires, Their Magnitude, Characteristics, and Mitigation*, prepared by TriData Corporation, 1000 Wilson Boulevard Arlington, Virginia 22209, for Federal Emergency Management Agency, United States Fire Administration, National Fire Data Center, May 2002, <http://www.usfa.dhs.gov/downloads/pdf/publications/fa-225.pdf>
12. *Evaluation of Fugitive Emissions Using Ground-Based Optical Remote Sensing Technology*, Office of Research and Development, U. S. Environmental Protection Agency, Washington, DC, (EPA/600/R-07/032), February 2007.
13. R.L. Peer, et al., Memorandum *Methodology Used to Revise the Model Inputs in the Municipal Solid Waste Landfills Input Data Bases (Revised)*, to the Municipal Solid Waste Landfills Docket No. A-88-09, April 28, 1993.

14. Debra R. Reinhart, Ayman A. Faour, and Huaxin You, *First-Order Kinetic Gas Generation Model Parameters for Wet Landfills*, U. S. Environmental Protection Agency, (EPA-600/R-05/072), June 2005.
15. Letter and attached documents from C. Nesbitt, Los Angeles County Sanitation Districts, to K. Brust, E.H. Pechan and Associates, Inc., December 6, 1996.
16. A.R. Chowdhury, *Emissions from a Landfill Gas-Fired Turbine/Generator Set, Source Test Report C-84-33*, Los Angeles County Sanitation District, South Coast Air Quality Management District, June 28, 1984.
17. Engineering-Science, Inc., *Report of Stack Testing at County Sanitation District Los Angeles Puente Hills Landfill*, Los Angeles County Sanitation District, August 15, 1984.
18. 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.
19. S. Mainoff, *Landfill Gas Composition, Source Test Report 85-102*, Bradley Pit Landfill, South Coast Air Quality Management District, May 22, 1985.
20. 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.
21. 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.
22. 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.
23. 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.
24. 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.
25. 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.
26. *Analytical Laboratory Report for Source Test*, Azusa Land Reclamation, June 30, 1983, South Coast Air Quality Management District.
27. J.R. Manker, *Source Test Report C-84-202*, Bradley Pit Landfill, South Coast Air Quality Management District, May 25, 1984.
28. S. Marinoff, *Source Test Report 84-315*, Puente Hills Landfill, South Coast Air Quality Management District, February 6, 1985.

29. P.P. Chavez, *Source Test Report 84-596*, Bradley Pit Landfill, South Coast Air Quality Management District, March 11, 1985.
30. S. Marinoff, *Source Test Report 84-373*, Los Angeles By-Products, South Coast Air Quality Management District, March 27, 1985.
31. J. Littman, *Source Test Report 85-403*, Palos Verdes Landfill, South Coast Air Quality Management District, September 25, 1985.
32. S. Marinoff, *Source Test Report 86-0234*, Pacific Lighting Energy Systems, South Coast Air Quality Management District, July 16, 1986.
33. 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.
34. D.L. Campbell, et al., *Analysis of Factors Affecting Methane Gas Recovery from Six Landfills*, Air and Energy Engineering Research Laboratory, EPA-600/2-91-055, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1991.
35. Browning-Ferris Industries, *Source Test Report*, Lyon Development Landfill, August 21, 1990.
36. X.V. Via, *Source Test Report*, Browning-Ferris Industries, Azusa Landfill.
37. 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.
38. 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.
39. V. Espinosa, *Source Test Report 87-0318*, Los Angeles County Sanitation District Calabasas Landfill, South Coast Air Quality Management District, December 16, 1987.
40. 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.
41. V. Espinosa, *Source Test Report 87-0391*, Puente Hills Landfill, South Coast Air Quality Management District, February 5, 1988.
42. V. Espinosa, *Source Test Report 87-0376*, Palos Verdes Landfill, South Coast Air Quality Management District, February 9, 1987.
43. Bay Area Air Quality Management District, *Landfill Gas Characterization*, Oakland, CA, 1988.
44. Steiner Environmental, Inc., *Emission Testing at BFI's Arbor Hills Landfill, Northville, Michigan*, September 22 through 25, 1992, Bakersfield, CA, December 1992.
45. PEI Associates, Inc., *Emission Test Report - Performance Evaluation Landfill-Gas Enclosed Flare, Browning Ferris Industries*, Chicopee, MA, 1990.
46. Kleinfelder Inc., *Source Test Report Boiler and Flare Systems*, Prepared for Laidlaw Gas Recovery Systems, Coyote Canyon Landfill, Diamond Bar, CA, 1991.

47. Bay Area Air Quality Management District, *McGill Flare Destruction Efficiency Test Report for Landfill Gas at the Durham Road Landfill*, Oakland, CA, 1988.
48. San Diego Air Pollution Control District, *Solid Waste Assessment for Otay Valley/Annex Landfill*. San Diego, CA, December 1988.
49. PEI Associates, Inc., *Emission Test Report - Performance Evaluation Landfill Gas Enclosed Flare*, Rockingham, VT, September 1990.
50. Browning-Ferris Industries, *Gas Flare Emissions Source Test for Sunshine Canyon Landfill*. Sylmar, CA, 1991.
51. Scott Environmental Technology, *Methane and Nonmethane Organic Destruction Efficiency Tests of an Enclosed Landfill Gas Flare*, April 1992.
52. 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.
53. EnvironMETeo Services Inc., *Stack Emissions Test Report for Ameron Kapaa Quarry*, Waipahu, HI, January 1994.
54. 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.
55. 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.
56. 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.
57. Browning-Ferris Gas Services, Inc., *Final Report for Emissions Compliance Testing of One Waukesha Engine Generator*, Chicopee, MA, February 1994.
58. Browning-Ferris Gas Services, Inc., *Final Report for Emissions Compliance Testing of Three Waukesha Engine Generators*, Richmond, VA, February 1994.
59. 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.
60. 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.
61. Pape & Steiner Environmental Services, *Compliance Testing for Spadra Landfill Gas-to-Energy Plant, July 25 and 26, 1990*, Bakersfield, CA, November 1990.
62. 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.

63. AB2588 Source Test Report for Oxnard Landfill, October 16, 1990, by Petro Chem Environmental Services, Inc., for Pacific Energy Systems, Commerce, CA, November 1990.
64. Engineering Source Test Report for Oxnard Landfill, December 20, 1990, by Petro Chem Environmental Services, Inc., for Pacific Energy Systems, Commerce, CA, January 1991.
65. AB2588 Emissions Inventory Report for the Salinas Crazy Horse Canyon Landfill, Pacific Energy, Commerce, CA, October 1990.
66. Newby Island Plant 2 Site IC Engine's Emission Test, February 7-8, 1990, Laidlaw Gas Recovery Systems, Newark, CA, February 1990.
67. Landfill Methane Recovery Part II: Gas Characterization, Final Report, Gas Research Institute, December 1982.
68. Letter from J.D. Thornton, Minnesota Pollution Control Agency, to R. Myers, U.S. EPA, February 1, 1996.
69. Letter and attached documents from M. Sauers, GSF Energy, to S. Thorneloe, U.S. EPA, May 29, 1996.
70. 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.
71. 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.
72. Addendum to Source Test Report for Superior Engine #1 at Otay Landfill, Pacific Energy Services, April 2, 1991.
73. 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.
74. 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.
75. Determination of Landfill Gas Composition and Pollutant Emission Rates at Fresh Kills Landfill, revised Final Report, Radian Corporation, prepared for U.S. EPA, November 10, 1995.
76. Advanced Technology Systems, Inc., *Report on Determination of Enclosed Landfill Gas Flare Performance*, Prepared for Y & S Maintenance, Inc., February 1995.
77. Chester Environmental, *Report on Ground Flare Emissions Test Results*, Prepared for Seneca Landfill, Inc., October 1993.
78. Smith Environmental Technologies Corporation, *Compliance Emission Determination of the Enclosed Landfill Gas Flare and Leachate Treatment Process Vents*, Prepared for Clinton County Solid Waste Authority, April 1996.

79. AirRecon®, Division of RECON Environmental Corp., *Compliance Stack Test Report for the Landfill Gas FLare Inlet & Outlet at Bethlehem Landfill*, Prepared for LFG Specialties Inc., December 3, 1996.
80. ROJAC Environmental Services, Inc., *Compliance Test Report, Hartford Landfill Flare Emissions Test Program*, November 19, 1993.
81. Normandeau Associates, Inc., *Emissions Testing of a Landfill Gas Flare at Contra Costa Landfill, Antioch, California, March 22, 1994 and April 22, 1994*, May 17, 1994.
82. Roe, S.M., et. al., *Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization*, Prepared for U.S. EPA, Office of Air and Radiation, Air and Energy Engineering Laboratory, EPA-600/R-95-089, July 1995.
83. TR-076. New Source Performance Standards Tier 2 Sampling and Analysis for the Flying Cloud Landfill, Browning-Ferris Industries, 6/30/98.
84. TR-084. Tier 2 NMOC Emission Rate Report for the Buncombe County Landfill, Buncombe County Solid Waste Services, 5/12/99.
85. TR-086. Tier 2 NMOC Emission Rate Report for the White Street Landfill, Duke Engineering and Services, City of Greensboro Solid Waste Management Division, 5/18/99.
86. TR-114. Summary Report of Tier 2 Sampling, Analysis, and Landfill Emissions Estimates for Non-Methane Organic Compounds Chrin Brothers Landfill, Chrin Brothers Sanitary Landfill, 4/24/98.
87. TR-115. Seneca Landfill - Revised Tier 2 NMOC Emission Rate Report, Seneca Landfill, Inc., 12/5/96.
88. TR-134. New Source Performance Standards Tier 2 Sampling, Analysis, and Landfill NMOC Emission Estimates for the Fort Worth Landfill, Laidlaw Waste Systems, Inc., 4/15/97.
89. TR-141. Tier 2 NMOC Emission Rate Report for the SPSA Regional Landfill, Southeastern Public Service Authority, MSA Consulting Engineers, 6/10/97.
90. TR-145. Compliance Testing of a Landfill Flare at Browning-Ferris Gas Services, Inc.'s Facility in Halifax, Massachusetts, BFI Waste Systems of North America, Inc., May 1996.
91. TR-146. Compliance Source Testing of a Landfill Flare at Northern Disposal, Inc. East Bridgewater Landfill, Northern Disposal, Inc., June 1994.
92. TR-147. Compliance Emissions Test Program for BFI of Ohio, Inc., BFI of Ohio, Inc., 6/26/98.
93. TR-148. Compliance Testing of Landfill Flare at Browning-Ferris Gas Services, Inc.'s Fall River Landfill Flare, BFI Waste Systems of North America, Inc., March 1995.
94. TR-153. Results of the Emission Compliance Test on the Enclosed Flare System at the Carbon Limestone Landfill, Browning-Ferris Industrial Gas Services, Inc., 8/8/96.
95. TR-156. Results of the Emission Compliance Test on the Enclosed Flare System at the Lorain County Landfill No. 2, Browning-Ferris Industrial Gas Services, Inc., 9/5/96.

96. TR-157. Emission Compliance Testing Browning-Ferris Gas Services, Inc. Willowcreek Landfill, BFI-Willowcreek, 2/2/98.
97. TR-159. Compliance Stack Sampling Report, Monmouth County Reclamation Center, SCS Engineers (Reston, VA), 9/8/95.
98. TR-160. Source Emission Testing of an Enclosed Landfill Gas Ground Flare, SCS Engineers (Reston, VA), September 1997.
99. TR-163. Compliance Testing for SPADRA Landfill Gas-to-Energy Plant, Ebasco Constructors, Inc., November 1990.
100. TR-165. 1997 Annual Compliance Source Testing Results for the Coyote Canyon Landfill Gas Recovery Facility Flare No. 1, Laidlaw Gas Recovery Systems, January 1998.
101. TR-167. 1997 Annual Compliance Source Testing Results for the Coyote Canyon Landfill Gas Recovery Facility Boiler, Laidlaw Gas Recovery Systems, January 1998.
102. TR-168. Colton Sanitary Landfill Gas Flare No. 2 (John Zink) 1998 Source Tests Results, Bryan A. Stirrat & Associates, 9/29/98.
103. TR-169. Colton Sanitary Landfill Gas Flare No. 1 (McGill) 1998 Source Tests Results, Bryan A. Stirrat & Associates, 9/29/98.
104. TR-171. High Landfill Gas Flow Rate Source Test Results from One Landfill Gas Flare at FRB Landfill in Orange County, California, Bryan A. Stirrat & Associates, July 1997.
105. TR-173. Annual Emissions Test of Landfill Gas Flare #3 Bradley Landfill, Waste Management Recycling and Disposal Services of California, Inc., 4/12/99.
106. TR-175. Emissions Tests on Flares #2, #4 and #6 at the Lopez Canyon Landfill, City of Los Angeles, August 1997.
107. TR-176. Emissions Test Results on Flares #1, #4 and #9 Calabasas Landfill, County Sanitation Districts of Los Angeles County, February 1998.
108. TR-178. Annual Emission Test of Landfill Gas Flare #3 Bradley Landfill, Waste Management Recycling and Disposal Services of California, Inc., 5/21/98.
109. TR-179. Annual Emissions Test of Landfill Gas Flare #1 Bradley Landfill, Waste Management Recycling and Disposal Services of California, Inc., 4/13/99.
110. TR-181. The Mid-Valley Sanitary Landfill Gas Flare No.1 (McGill) 1998 Source Test Results, Bryan A. Stirrat & Associates, 9/29/98.
111. TR-182. The Mid-Valley Sanitary Landfill Gas Flare No.2 (SurLite) 1998 Source Test Results, Bryan A. Stirrat & Associates, 9/29/98.
112. TR-183. Annual Emissions Test of Landfill Gas Flare #2 Bradley Landfill, Waste Management Recycling and Disposal Services of California, Inc., 4/13/99.
113. TR-187. Emissions Test of a Landfill Gas Flare - Lowry Landfill/Denver-Arapohoe Disposal Site, Sur-Lite Corporation, February 1997.
114. TR-188. Characterization of Emissions from a Power Boiler Fired with Landfill Gas, Environment Canada Emissions Research and Measurement Division, March 2000.

115. TR-189. Characterization of Emissions from 925 kWe Reciprocating Engine Fired with Landfill Gas, Environment Canada Emissions Research and Measurement Division, December 2000.
116. TR-190. Characterization of Emissions from 812 kWe Reciprocating Engine Fired with Landfill Gas, Environment Canada Emissions Research and Measurement Division, December 1999.
117. TR-191. Characterization of Emissions from Enclosed Flare - Trail Road Landfill, Environment Canada Emissions Research and Measurement Division, August 2000.
118. TR-194. Characterization of Emissions from 1 MWe Reciprocating Engine Fired with Landfill Gas, Environment Canada Emissions Research and Measurement Division, January 2002.
119. TR-195. Characteristics of Semi-volatile Organic Compounds from Vented Landfills, Environment Canada Environmental Technology Advancement Directorate, August 1996.
120. TR-196. Results of the Biennial Criteria and AB 2588 Air Toxics Source Test on the Simi Valley Landfill Flare, Simi Valley Landfill and Recycling Center, April 1997.
121. TR-199. Emission Compliance Test on a Landfill Flare, City of Los Angeles, January 1999.
122. TR-205. The Mid-Valley Sanitary Landfill Gas Flare No. 3 (John Zink) 1998 Source Test Results, Bryan A. Stirrat & Associates, 9/29/98.
123. TR-207. Compliance Source Test Report Landfill Gas-fired Flare Stations I-4 and F-2, BKK Landfill, 12/12/97.
124. TR-209. Emission Test Report Volumes I and II - Source/Compliance Emissions Testing for Cedar Hills Landfill, King County Solid Waste Division, 1/20/05.
125. TR-211. Determination of Total and Dimethyl Mercury in Raw Landfill Gas with Site Screening for Elemental Mercury at Eight Washington State Landfills, Washington State Department of Ecology, July 2003.
126. TR-212. Determination of Total, and Monomethyl Mercury in Raw Landfill Gas at the Central Solid Waste Management Center, Delaware Solid Waste Authority, February 2003.
127. TR-220. SCAQMD Performance Tests on the Spadra Energy Recovery from Landfill Gas (SPERG) Facility, County Sanitation Districts of Los Angeles County, April 1992.
128. TR-226. Methane and Nonmethane Organic Destruction Efficiency Tests of an Enclosed Landfill Gas Flare, Newco Waste Systems, April 1992.
129. TR-229. Scholl Canyon Landfill Gas Flares No. 9, 10 11 and 12 Emission Source Testing April 1999, South Coast Air Quality Management District, April 1999.
130. TR-236. Landfill Gas Flare Hydrogen Chloride Emissions Atascocita Landfill, Waste Management of Houston, 4/20/99.
131. TR-241. Performance Evaluation, Enclosed Landfill Gas Flare, Valley Landfill, Waste Energy Technology, November 1991.

132. TR-251. Emission Compliance Test on a Landfill Gas Flare - Flare #1, Frank R. Bowerman Landfill, Orange County, 1/25/99.
133. TR-253. Emission Source Testing on Two Flares (Nos. 3 and 6) at the Spadra Landfill, Los Angeles County Sanitation Districts, 7/21/98.
134. TR-255. Emission Compliance Test on a Landfill Gas Flare -Olinda Alpha Landfill, Orange County Integrated Waste Management Department, No Report Date Given.
135. TR-258. Source Test Report, City of Sacramento Landfill Gas Flare, City of Sacramento, 6/26/96.
136. TR-259. The Millikan Sanitary Landfill Gas Flare No. 1 (Surlite) 1998 Source Test Results, South Coast Air Quality Management District, 9/29/98.
137. TR-260. The Millikan Sanitary Landfill Gas Flare No. 2 (John Zink) 1998 Source Test Results, South Coast Air Quality Management District, 9/29/98.
138. TR-261. The Millikan Sanitary Landfill Gas Flare No. 3 (John Zink) 1998 Source Test Results, South Coast Air Quality Management District, 9/29/98.
139. TR-264. Emission Compliance Test on a Landfill Gas Flare, Orange County Integrated Waste Management Department, No Report Date Given.
140. TR-266. Compliance Source Test Report - Landfill Gas-Fired Engine, Minnesota Methane, 3/3/98.
141. TR-268. Emission Testing at PERG - Maximum Boiler Load, County Sanitation Districts of Los Angeles County, December 1986.
142. TR-272. Source Testing Final Report - Landfill A, US EPA Air Pollution Prevention and Control Division, 10/6/05.
143. TR-273. Source Testing Final Report - Landfill B, US EPA Air Pollution Prevention and Control Division, 10/6/05.
144. TR-284. Source Testing Final Report - Landfill C, US EPA Air Pollution Prevention and Control Division, 10/6/05.
145. TR-287. Source Testing Final Report - Landfill D, US EPA Air Pollution Prevention and Control Division, 10/6/05.
146. TR-290. San Timoteo Sanitary Landfill 1998 Source Test Results, San Bernardino County Solid Waste Management, 9/29/98. TR-291. PCDD/PCDF Emissions Tests on the Palos Verdes Energy Recovery from Landfill Gas (PVERG) Facility, Unit 2, County Sanitation Districts of Los Angeles County, February 1994.
147. TR-292. Source Testing Final Report - Landfill E, US EPA Air Pollution Prevention and Control Division, October 2005
148. TR-293. *Quantifying Uncontrolled Air Emissions From Two Florida Landfills* – Draft Final Report. U.S. EPA Air Pollution Prevention and Control Division, March 26, 2008.