United States Environmental Protection Agency
Office of Air and Radiation
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Frequently Asked Questions About Landfill Gas and How It Affects Public Health, Safety, and the Environment

Approximately 60% of all municipal solid waste (MSW) generated in the U.S. is currently being disposed of in over 2,100 operational MSW landfills, as referenced in EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000. Landfills are the largest single human source of methane emissions in the U.S., accounting for 33% of all methane sources. Uncontrolled MSW landfills also emit nonmethane organic compounds (NMOC), which include volatile organic compounds (VOC) that contribute to ozone formation and hazardous air pollutants (HAP) that can affect human health when exposed. However, combustion of landfill gas significantly reduces emissions of methane and NMOC. Over 330 MSW landfills in the U.S. recover and combust landfill gas to generate heat or electricity, and more than 500 other MSW landfills flare the gas. EPA's air quality requirements and advances in landfill gas energy technologies have encouraged the combustion of landfill gas to benefit human health, safety, and the environment, as well as provide economic opportunities. The following questions and answers are provided to inform interested parties about compounds found in landfill gas and about how combusting landfill gas can significantly reduce emissions of these compounds to the atmosphere.

The answers provided in this document are not rules nor are they binding upon the EPA in any context. Should you have questions related to information provided in this document, please call EPA's Landfill Methane Outreach Program hotline toll-free at 1-888-782-7937 or JoLynn Collins at EPA's Office of Air Quality Planning and Standards (919-541-5671, collins.jolynn@epa.gov).

How Is Landfill Gas Generated?

Landfill gas is generated during the natural process of bacterial decomposition of organic material contained in MSW landfills. A number of factors influence the quantity of gas that a MSW landfill generates and the components of that gas. These factors include, but are not limited to, the types and age of the waste buried in the landfill, the quantity and types of organic compounds in the waste, and the moisture content and temperature of the waste. Temperature and moisture levels are influenced by the surrounding climate.

What Components Make Up Landfill Gas?

By volume, landfill gas is about 50 percent methane and 50 percent carbon dioxide and water vapor. It also contains small amounts of nitrogen, oxygen, and hydrogen, less than 1 percent NMOC, and trace amounts of inorganic compounds. Some of these compounds have strong, pungent odors (for example, hydrogen sulfide, or H_2S). Nonmethane organic compounds consist of certain HAP and VOC, which can react with sunlight to form ground-level ozone (smog) if uncontrolled. Nearly 30 organic HAP have been identified in uncontrolled landfill gas, including benzene, toluene, ethyl benzene, and vinyl chloride. Exposure to these HAP can lead to adverse health effects. Thermal treatment of NMOC (including HAP and VOC) and methane through flaring or combustion in an engine, turbine, or other device greatly reduces the emission of these compounds.

How Are Nonmethane Organic Compounds Generated in Landfill Gas?

Nonmethane organic compounds are contained in discarded items such as household cleaning products, materials coated with or containing paints and adhesives, and other items. During the waste decomposition process, NMOC can be stripped from the waste by methane, carbon dioxide, and other gases and carried in landfill gas. Three different mechanisms are responsible for the production of NMOC and their movement into landfill gas: (1) vaporization (the change of state from liquid or solid to vapor) of organic compounds until the equilibrium vapor concentration is reached, (2) chemical reaction of materials present in the landfill, and (3) biological decomposition of heavier organic compounds into lighter, more volatile constituents.

At What Concentrations Are Nonmethane Organic Compounds Typically Found in Uncontrolled Landfill Gas?

Concentrations of NMOC in uncontrolled landfill gas can vary depending on several factors, including the type of waste discarded in the landfill, the climate surrounding the landfill, and the physical properties of the individual organic compound. A default concentration of 595 parts per million by volume (ppmv) of NMOC is presented in EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Of this total NMOC, 110 ppmv are considered HAP compounds, according to default concentrations in *AP-42*. Therefore, total uncontrolled concentrations of organic HAP at MSW landfills are typically less than 0.02 percent of the total landfill gas. The *Standards of Performance for New Stationary Sources* (NSPS) and *National Emission Standards for Hazardous Air Pollutants* (NESHAP) regulations require combustion of NMOC, a surrogate for organic HAP, at a destruction efficiency of 98 percent, or to an outlet concentration of 20 ppmv NMOC.

What Are the Public Health, Safety, and Environmental Concerns Associated with Landfill Gas?

The public health, safety, and environmental concerns fall into three categories: subsurface migration, surface emissions/air pollution, and odor nuisance.

Subsurface Migration

Subsurface migration is the underground movement of landfill gas from landfills to other areas within the landfill property or outside the landfill property. (Note: Most subsurface migration occurs at older, unlined landfills because there is minimal barrier for lateral migration. The Resource Conservation and Recovery Act began requiring all new or expanded landfills be lined as of October 9, 1993. This requirement decreases the likelihood of subsurface migration.) Since landfill gas contains approximately 50 percent methane (a potentially explosive gas) it is possible for landfill gas to travel underground, accumulate in enclosed structures, and ignite. There have been incidences of subsurface migration causing fires and explosions on both landfill property and private property.

Surface Emissions

Possibly the biggest health and environmental concerns are related to the uncontrolled surface emissions of landfill gas into the air. As previously mentioned, landfill gas contains carbon dioxide, methane, VOC, HAP, and odorous compounds that can adversely affect public health and the environment. For example, carbon dioxide and methane are greenhouse gases that contribute to global climate change. Methane is of particular concern because it is 21 times more effective at trapping heat in the atmosphere than carbon dioxide. Emissions of VOC contribute to ground-level ozone formation (smog). Ozone is capable of reducing or damaging vegetation growth as well as causing respiratory problems in humans. Finally, exposure to HAP can cause a variety of health problems such as cancerous illnesses, respiratory irritation, and central nervous system damage. Thermal treatment of NMOC (including HAP and VOC) and methane through flaring or combustion in an engine, turbine, or other device greatly reduces the emission of these compounds.

Odors

The final concern related to uncontrolled landfill gas emissions is their unpleasant odor. Compounds found in landfill gas are associated with strong, pungent odors. These smells can be transmitted off-site to nearby homes and business. Unpleasant odors can lower the quality of life for individuals that live near landfills and potentially reduce local property values.

What Is EPA Doing to Protect Public Health, Safety, and the Environment?

The EPA promulgated *Criteria for Municipal Solid Waste Landfills* (40 CFR Part 258) under the Resource Conservation and Recovery Act (RCRA) on October 9, 1991. The criteria contain location restrictions, design and operating standards, groundwater monitoring requirements, corrective actions, financial assurance requirements, landfill gas migration control, closure requirements, and post closure requirements. Under the design standards new landfills and lateral expansions that occur on or after October 9, 1993 are required to line the bottom and sides of the landfill prior to waste deposition. In addition, all landfills operating after October 9, 1991 must place a final cap over the landfill surface. The placement of liners and caps reduces the potential for subsurface and surface landfill gas migration and groundwater contamination. Recovery and combustion of landfill gas will reduce emissions of organic compounds that would otherwise be released from the landfill. Because of the benefits of collecting and controlling landfill gas, the 1996 EPA *Standards of Performance for New Stationary Sources* (NSPS) and *Guidelines for Control of Existing Sources*, and the recently published *National Emission Standards for Hazardous Air Pollutants* (NESHAP) require "large" MSW landfills to collect landfill gas and combust it to reduce NMOC by 98 percent (or to an outlet concentration of 20 ppmv). A "large" landfill is defined as having a design capacity of at least 2.5 million metric tons and 2.5 million cubic meters and a calculated or measured uncontrolled NMOC emission rate of at least 50 metric tons (megagrams) per year. Landfills are meeting these gas destruction standards using flares or energy recovery devices including reciprocating engines, gas turbines, and boilers. In addition to gas destruction requirements, the NSPS and NESHAP require that gas collection systems be well designed and well operated. They require gas collection from all areas of the landfill, monthly monitoring at each collection well, and monitoring of surface methane emissions to ensure that the collection system is operating properly and to reduce fugitive emissions. Smaller MSW landfills are not required to control emissions by the NSPS or NESHAP, but can still greatly reduce emissions of NMOC by collecting and combusting landfill gas for energy recovery or in a flare.

EPA's Landfill Methane Outreach Program (LMOP) is a voluntary assistance and partnership program that promotes the use of landfill gas as a renewable energy source. By preventing emissions of methane through the development of landfill gas energy projects, LMOP helps businesses, states, and communities protect the environment and build a sustainable future. The LMOP Partnership program helps communities and landfill owner/operators learn more about the benefits of using landfill gas as an alternative energy source and helps them develop or participate in landfill gas energy projects. In addition, LMOP provides information, software tools, and marketing assistance, and access to technical experts to facilitate development of landfill gas energy projects. For more information about LMOP, please visit the LMOP Web site at http://www.epa.gov/lmop or call the LMOP hotline toll-free at 1-888-782-7937.

Can Landfill Gas Combustion Be Used as an Energy Source?

Landfill gas can be an asset when it is used as a source of energy to create electricity or heat. It is classified as a medium-Btu gas with a heating value of 350 to 600 Btu per cubic foot, approximately one-half that of natural gas. Landfill gas can often be used in place of conventional fossil fuels in certain applications. It is a reliable source of energy because it is generated 24 hours a day, 7 days a week. By using landfill gas to produce energy, landfills can significantly reduce their emissions of methane and avoid the need to generate energy from fossil fuels, thus reducing emissions of carbon dioxide, sulfur dioxide, nitrogen oxides, and other pollutants from fossil fuel combustion.

How Do Landfill Gas Energy Projects Reduce Greenhouse Gas Emissions?

Landfill gas recovery projects provide a highly effective means of reducing overall greenhouse gas emissions from landfills, whether the landfill gas is combusted by flare, electricity generation equipment, or other end use system. By using the otherwise wasted methane contained in the collected landfill gas to generate electricity or directly as a fuel, fossil fuels such as oil and coal are displaced. This displacement of fossil fuels is an environmental benefit, the magnitude of which would depend on the actual amount of electricity generated or landfill gas used.

For example, if a 3 MW landfill gas electricity project starts up at a landfill with previously uncontrolled landfill gas, the project would have a direct methane reduction of approximately 6,000 tons per year (125,000 tons of carbon dioxide equivalents (CO_2E) per year) and a fossil fuel displacement of approximately 700 tons of methane per year (15,000 tons of CO_2E per year). The combined emissions reduction of 6,700 tons of methane per year (140,000 tons of CO_2E per year) would be equivalent to any of the following annual environmental benefits for 2003:

- Removing emissions equivalent to 28,000 cars
- Planting 38,000 acres of forest
- Offsetting the use of 630 railroad cars of coal
- Preventing the use of 300,000 barrels of oil

How Do Landfill Gas Energy Projects Reduce Emissions of Nonmethane Organic Compounds?

Landfill gas energy projects involve collecting and combusting landfill gas. The process of combustion destroys organic compounds, including methane and NMOC. During combustion, these organic compounds chemically react with oxygen in the presence of heat, breaking apart to form water vapor, carbon dioxide, and other, less volatile, compounds. Combusting the gas in a reciprocating engine, gas turbine, or boiler to generate energy also reduces pollution associated with the extraction and use of fossil fuels to produce the same amount of energy.

What Are Dioxins and Furans and Are They Released from Landfill Gas Combustion?

Dioxins and furans are a group of toxic chemical compounds, known as persistent organic pollutants, that share certain similar chemical structures and biological characteristics. Dioxins/furans are released into the air as byproducts of many combustion processes such as incinerating municipal waste, burning fuels (like wood, coal, or oil), and some industrial processes such as bleaching pulp and paper. Some of the conditions that are conducive to dioxin/furan formation are the combustion of organic material in the presence of chlorine and particulate matter under certain thermodynamic conditions such as low combustion temperatures and brief combustion times. Sources of dioxin/furan include but are not limited to: MSW combustors (incinerators), residential and commercial coal combustion, residential and commercial oil combustion, backyard trash burning, residential fireplaces, cars, cigarettes, forest and brush fires, and the combustion of landfill gas. However, relative to many of these combustion sources, the characteristics of landfill gas combustion are less conducive to dioxin/furan formation.

EPA's review of the available data indicates that dioxins/furans can be released in small amounts when landfill gas is combusted by flare or for recovering energy. Based on national and international source tests, the concentration of dioxins from landfill gas combustion ranges from non-detectable to 0.1 nanograms (10^{-9} grams) of toxic equivalents (TEQ) per dry standard cubic meter of exhaust, at 7 percent oxygen. Because of the health threat from uncontrolled emissions of other organic compounds in landfill gas, EPA found, in developing emissions standards, that landfill gas destruction in a proper control device (e.g., flare or energy recovery unit) with minimal by-product generation of dioxins/furans is preferable to the release of uncontrolled landfill gas. In summary, EPA believes that the potential for dioxin emissions from the combustion of landfill gas is small.

How Does Landfill Gas Combustion Affect Mercury Emissions?

Mercury, although present throughout the environment, is a health concern because it can bioaccumulate through the food chain as methylated mercury, an organic, more toxic form of mercury. Sources of mercury in MSW landfills can include batteries, fluorescent light bulbs, electrical switches, thermometers, and paints. Once mercury enters the waste stream, it will ultimately be released from the landfill and is contained in uncontrolled landfill gas. However, combustion of landfill gas reduces the toxicity of landfill gas emissions by converting the organic mercury compounds, including methylated mercury, to less toxic, less hazardous, inorganic mercury compounds. According to EPA's 1997 *Mercury Study Report to Congress*, MSW landfills contributed less than 0.1 percent of the total mercury released from all man-made sources in the U.S. in 1994. When compared on an annual basis, mercury emissions from landfill gas are significantly less than mercury emissions generated by small oil-fired boilers used in homes and apartments.

Where Can I Get Additional Information About the Types and Amounts of Compounds Found in Landfill Gas?

- *Compilation of Air Pollutant Emission Factors (AP-42), Fifth Edition, Volume I: Stationary Point and Area Sources, Chapter 2.4*. U.S. EPA, Office of Air Quality Planning & Standards. November 1998. AP-42 Chapter 2.4: *ttp://www.epa.gov/ttn/-chief/ap42/ch02/final/c02s04.pdf*. Background Document: *http://www.epa.gov/ttn/-chief/ap42/ch02/bgdocs/b02s04.pdf*.

  This chapter of AP-42 provides typical concentrations for individual compounds from uncontrolled landfill gas (Tables 2.4-1 and 2.4-2); the default concentrations are based on test data from multiple landfill sites. The background document provides the concentrations observed in the individual tests. Table 2.4-3 contains control efficiencies for several combustion devices. [It is important to note that default concentrations and control efficiencies in Chapter 2.4 of AP-42 are assigned quality ratings reflecting the limited data that were available when the chapter was developed in 1998. Therefore, minor differences in emission reductions for different combustion devices should not necessarily be considered significant. EPA is collecting additional test data in 2002 and 2003 and plans to use these data to make recommendations for changes to the current AP-42 emission factors for MSW landfills.]

- Landfill Gas Emissions Model (LandGEM) and User's Manual, Version 2.01. U.S. EPA, Clean Air Technology Center. EPA/600/R-98-054. January 6, 1999. *http://www.epa.gov/ttn/catc/products.html#software*.

  This software model can be used to estimate emissions of methane, NMOC, and several other compounds from individual MSW landfills based on the default concentrations in AP-42.

- Emission Reduction Benefits of Landfill Gas Combustion, Final Report. Prepared for Environment Canada, National Office of Pollution Prevention, by Cheminfo Services Inc. February 2002.

  This report interprets the Environment Canada test results for the emissions of 19 selected compounds measured at 4 landfill sites. The study summarizes the pollutant emissions before and after the landfill gas combustion process.

- A Review of the Literature Regarding Non-Methane and Volatile Organic Compounds in Municipal Solid Waste Landfill Gas. H. Soltani-Ahmadi, University of Delaware, Department of Civil and Environmental Engineering. Featured in the September/October 2002 issue of MSW Management (Forester Communications, Inc.). *http://www.forester.net/nmocvoc.pdf*.

  This paper reviews and compiles information from the current literature regarding concentrations of NMOC and VOC from landfill gas. Various potential techniques for VOC treatment with their advantages and disadvantages are described. In addition, a critical review of sample source, concentration, and flux measurement techniques is presented. Where can I Get Additional Information about the Potential Health Effects of Landfill Gas?

- Landfill Gas Primer: An Overview for Environmental Health Professionals. U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. November 2001. *http://www.atsdr.cdc.gov/HAC/landfill/html/preface.html*.

  This primer was designed to provide environmental health professionals with a general understanding of landfill gases and to help them in responding to community concerns that may be related to landfill gas issues. It provides basic information about the composition, formation, and movement of landfill gas. The primer also discusses health and safety issues related to landfill gas, and it provides information about landfill gas monitoring methods and control measures.

Where Can I Get Additional Information About Standards for MSW Landfills?

- Standards of Performance for New Stationary Sources (NSPS) and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills. U.S. EPA, Office of Air Quality Planning & Standards. 61 FR 9905. March 12, 1996.

  As required under the Clean Air Act (CAA), this document contains the final emission standards for new MSW landfills and the final emission guidelines for existing MSW landfills. These standards and guidelines require certain MSW landfills to control NMOC emissions using flares or other combustion devices. Minor amendments have been made since 1996, and the latest versions of the standards and guidelines are contained in the Code of Federal Regulations at 40 CFR part 60, subparts Cc and WWW (*http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr60_00.html*).

- National Emission Standards for Hazardous Air Pollutants (NESHAP): Municipal Solid Waste Landfills, Final Rule. U.S. EPA, Office of Air Quality Planning & Standards. 68 FR 2227. January 16, 2003. *http://a257.g.akamaitech.net/7/257/2422/14mar20010800/edocket.access.gpo.gov/2003/pdf/0 3-88.pdf*

  This final rule outlines the emission standards for reducing HAP from MSW landfills. These standards contain the same requirements as the NSPS and Guidelines for Control of Existing Sources for MSW landfills with added requirements for bioreactor landfills.

- Criteria for Municipal Solid Waste Landfills. U.S. EPA, Office of Solid Waste. 40 CFR Part 258. October 9, 1991. *http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr258_00.html*.

  As required under the Resource Conservation and Recovery Act (RCRA), the purpose of this regulation is to establish minimum national criteria for all MSW landfill units. As stated previously, the criteria contain location restrictions, design and operating standards, groundwater monitoring requirements, corrective actions, financial assurance requirements, migration control, closure requirements, and post closure requirements.

Where Can I Get Additional Information About Releases of Mercury Compounds or Dioxins/Furans?

- Mercury Study Report to Congress, Volume II: An Inventory of Anthropogenic Mercury Emissions in the United States. U.S. EPA, Office of Air Quality Planning & Standards and Office of Research and Development. EPA/452/R-97-004. December 1997. *http://www.epa.gov/oar/mercury.html*.

  This report provides an assessment of the magnitude of U.S. mercury emissions by source, the health and environmental implications of those emissions, and the availability and cost of control technologies.

- Database of Sources of Environmental Releases of Dioxin-Like Compounds in the United States: Version 3.0 for Reference Years 1987 and 1995. U.S. EPA, Office of Research and Development, National Center for Environmental Assessment. EPA/600/C-01-012. March 2001. *http://www.epa.gov/NCEA/dioxindb.htm*.

  This database serves as a repository for dioxins/furans emissions data from all known sources in the U.S. The information contained in the database is associated with two reference years – 1987 and 1995. This database provides the technical basis for the derivation of emission factors used to estimate dioxin/furan releases by source in the draft final report below.

- Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds. Volume 2: Sources of Dioxin-Like Compounds in the U.S., Draft Final Report. U.S. EPA, National Center for Environmental Assessment. EPA/600/P-00/001Bb. September 2000. *http://www.epa.gov/ncea/pdfs/dioxin/part1/volume2/volume2.pdf*.

  This document is the ultimate reference for sources of dioxin-like compounds (including furans) in the U.S. This report is part of EPA's Dioxin Reassessment effort, which began in 1991, to conduct a scientific reassessment of the health risks resulting from exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and chemically similar compounds collectively known as dioxins/furans.

- Summary of Readily Available Information and Conclusions Drawn Regarding the By-product Production of Dioxin from the Combustion of Landfill Gas. U.S. EPA. Memorandum from M. Laur, Office of Air Quality Planning & Standards, to the Air and Radiation Docket and Information Center. Publicly available in Docket No. A-98-28, Item No. II-B-23. March 20, 2000.

  This memorandum summarizes readily available information on the by-product production of dioxin from the combustion of landfill gas.

Where Can I Get Additional Information About National Greenhouse Gas Emissions?

- Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000, Final Version. U.S. EPA, Office of Atmospheric Programs. EPA/430/R-02-003. April 15, 2002. *http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2002.html.*

  This report presents estimates by the United States government of U.S. human-related greenhouse gas emissions and sinks for the years 1990 through 2000. The information provided in this inventory is presented in accordance with the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories.