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Landfill Gas and Its Influence on Global Climate Change

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ABSTRACT

Landfills are considered a major source of methane (CH_4) which is a potent greenhouse gas. Because this source is amenable to cost effective control measures, research designed to reduce the uncertainty associated with CH_4 emissions estimates has been given a high priority. The CH_4 can be either flared or utilized for its energy potential. Bingemer and Crutzen (1987) estimated that landfills contribute 30 to 70 teragrams per year (Tg/yr) of CH_4. Recent United States Environmental Protection Agency (EPA) estimates suggest that this source contributes 20 to 40 Tg/yr. There are major sources of uncertainty with estimating CH_4 emissions from landfills. EPA is working toward reducing these uncertainties and developing more reliable estimates.

This chapter describes the relative importance of landfills to global warming and identifies the major sources of uncertainty with current emission estimates. This chapter also provides an overview of EPA's research program on global landfill CH_4. This includes developing more reliable estimates of global landfill CH_4 emissions, characterizing the current state of technology for controlling and utilizing landfill CH_4, and demonstrating innovative technologies for mitigating and utilizing landfill CH_4.

The research that is described in this paper was funded through the EPA's Global Climate Change Research Program. This research is part of a larger EPA research program to develop more reliable emission estimates for the major sources of greenhouse gas emissions. This research is being conducted in support of the goals established at the United Nations Conference on Environment and Development in 1992. *This chapter has been reviewed in accordance with EPA's peer and administrative review policies and approved for presentation and publication.*

INTRODUCTION

Methane (CH_4) produced by the decomposition of waste buried in landfills and open dumps is a significant contributor to global CH_4 emissions. Current estimates range from 30 to 70 teragrams per year (Tg/yr) (IPCC, 1992). Global anthropogenic sources emit 360 Tg/yr (IPCC, 1992) which suggests that landfills may account for 8 to 20 percent of the total. Waste management practices vary globally and this affects CH_4 emissions. Landfill gas typically consists of approximately 50 percent CH_4, 50 percent carbon dioxide (CO_2), and trace constituents of non-methane organic compounds (NMOCs). Primarily due to the ability to utilize the CH_4 for its energy potential, this is a relatively cost-effective source of greenhouse gas emissions to control.

The potential control of CH_4 emissions from municipal solid waste (MSW) landfills has been targeted by the United States (U.S.) and other countries as part of greenhouse gas reduction programs designed to meet the goals of treaties signed at the United Nations Conference on Environment and Development (UNCED) held in 1992. In May 1991, the U.S. proposed Clean Air Act regulations for new and existing MSW landfills. These regulations are expected to be promulgated by February 1994. These regulations are estimated to result in a CH_4 emission reduction of 7 to 10 Tg/yr. The control of U.S. landfill CH_4 is considered a significant step toward realizing the goals established at UNCED.

Methane and Its Importance to Climate Change

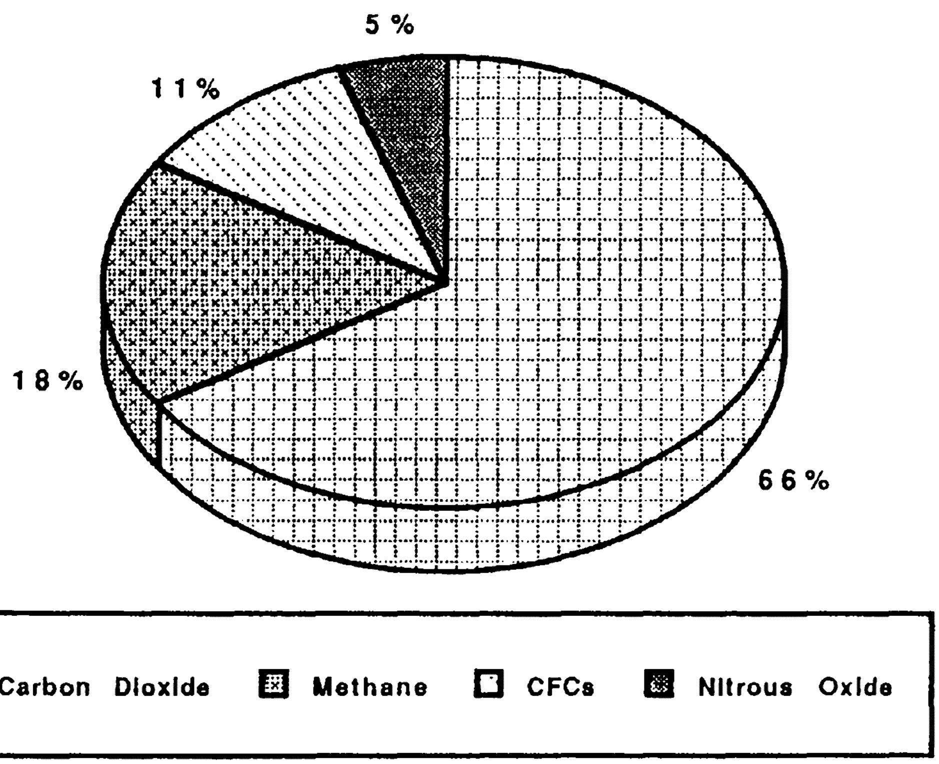
The Intergovernmental Panel on Climate Change (IPCC) has concluded that emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases (GHGs) (CO_2, CH_4, chlorofluorocarbons, and nitrous oxide) (IPCC, 1990 and 1992). General circulation models (GCMs) project that an increase in GHG concentrations, equivalent to a doubling of the preindustrial level of atmospheric CO_2, would produce global average temperature increases between 1.9 and 5.2°C (3.4 and 9.4°F) (NAS, 1991). Currently, there are many uncertainties in the predictions, particularly with regard to timing, magnitude, and regional patterns of climate change.

The IPCC has concluded that the average global temperature has increased between 0.3 to 0.6°C (0.5 to 1.1°F) over the last 100 years (IPCC, 1992). This could be attributed to climate change or to natural climate variability. With our limited understanding of the underlying phenomena, neither can be ruled out. If the higher GCM projections prove to be accurate, substantial responses would be needed, and the stresses on this planet and its inhabitants would be serious (NAS, 1991).

The UNCED was held in 1992 to reach agreements on steps that can be taken to reduce GHG emissions. The general consensus is that, despite the great uncertainties, greenhouse warming is a potential threat sufficient to justify action now. Opportunities for cost-effective adaptation or mitigation are being considered (U.S. EPA, 1989a,b).

Methane is a potent GHG due to its radiative forcing ability. It is second to CO_2 in its global contribution to radiative forcing (Figure 1).

Figure 1. Global Contribution to Integrated Radiative Forcing by Gas for 1990[1,2]



Estimated on a carbon dioxide equivalent basis using IPCC (1990) global warming potentials (GWPs) for a 100-year time horizon. Anthropogenic emissions only.

[1]This chart is used to present a general understanding of CH_4's contribution to future warming based on the GWPs presented in IPCC (1990). However, these GWPs are continually being revised due to a variety of scientific and methodological issues. It is likely that the contribution of CFCs presented will decrease and that the contribution of other gases will be about the same or greater upon further investigation.
[2]U.S.EPA, 1993.

Methane is 20 times more effective at trapping heat in the atmosphere than CO_2 over a 100 year time period[1] (U.S. EPA, 1993). The atmospheric concentration of CH_4 was 1.72 ppmv in 1990 or slightly more than twice that before 1750. It is rising at a rate of 0.9 percent per year. The doubling of the CH_4 concentration over the last 200 years is attributed to increasing emissions from anthropogenic (human related) sources. Anthropogenic emissions currently constitute about 70 percent of total emissions. The contribution of major anthropogenic CH_4 sources to global emissions is provided in Figure 2.

Waste CH_4 emissions--from landfills, digesters, coal mines, and natural gas systems--are being targeted as potential sources for control because they are amenable to cost-effective control through the utilization of the CH_4. The U.S. regulations for air emissions for MSW landfills are expected to result in requiring about 10 to 15 percent of all MSW landfills to collect and control. These regulations are expected to result in a reduction of 7 to 10 Tg of CH_4 by 2000 and ~250,000 Mg per year of NMOC. The contribution of landfill CH_4 in the U.S. to other anthropogenic sources is provided in Figure 3. The landfill regulation is anticipated to result in a reduction of 40 to 45 percent of the CH_4 emissions from U.S. MSW landfills.

It is hoped that this gas will be utilized, as opposed to flared, because of the increased environmental benefits resulting from an offset in power plant emissions and the conservation of global fossil fuel resources. However, barriers exist that may result in landfill owners/operators choosing to flare the gas. These barriers are identified in the chapter on the U.S. landfill gas industry.

Global Landfill Methane Emissions

Previous estimates for landfill CH_4 are believed to overstate the emissions primarily due to limitations in available data for waste quantities being landfilled and the use of optimistic assumptions regarding anaerobic decomposition within a landfill. Using data from sites that are collecting and controlling the gas resulting from landfilled waste, the EPA's Air and Energy Engineering Research Laboratory (AEERL) has developed a methodology for estimating global landfill CH_4 emissions (Peer et al., 1992). The country-specific estimates using this methodology are presented in Table 1. The estimate indicates that 22 to 46 Tg/yr of CH_4 (with a midpoint of 34 Tg/yr of CH_4) is resulting from landfilled waste. The information used to develop these estimates is also identified in Table 1. The contribution of these emissions based on geographical region is presented in Figure 4.

The methodology and the assumptions used to develop these estimates are being documented in an EPA report to be published later this year. Earlier reports and papers describing this research are available (Thorneloe, 1992b, Peer et al., 1993, Peer et al., 1992, Campbell et al., 1991). Future revisions of these estimates will be based on the comments received on the initial

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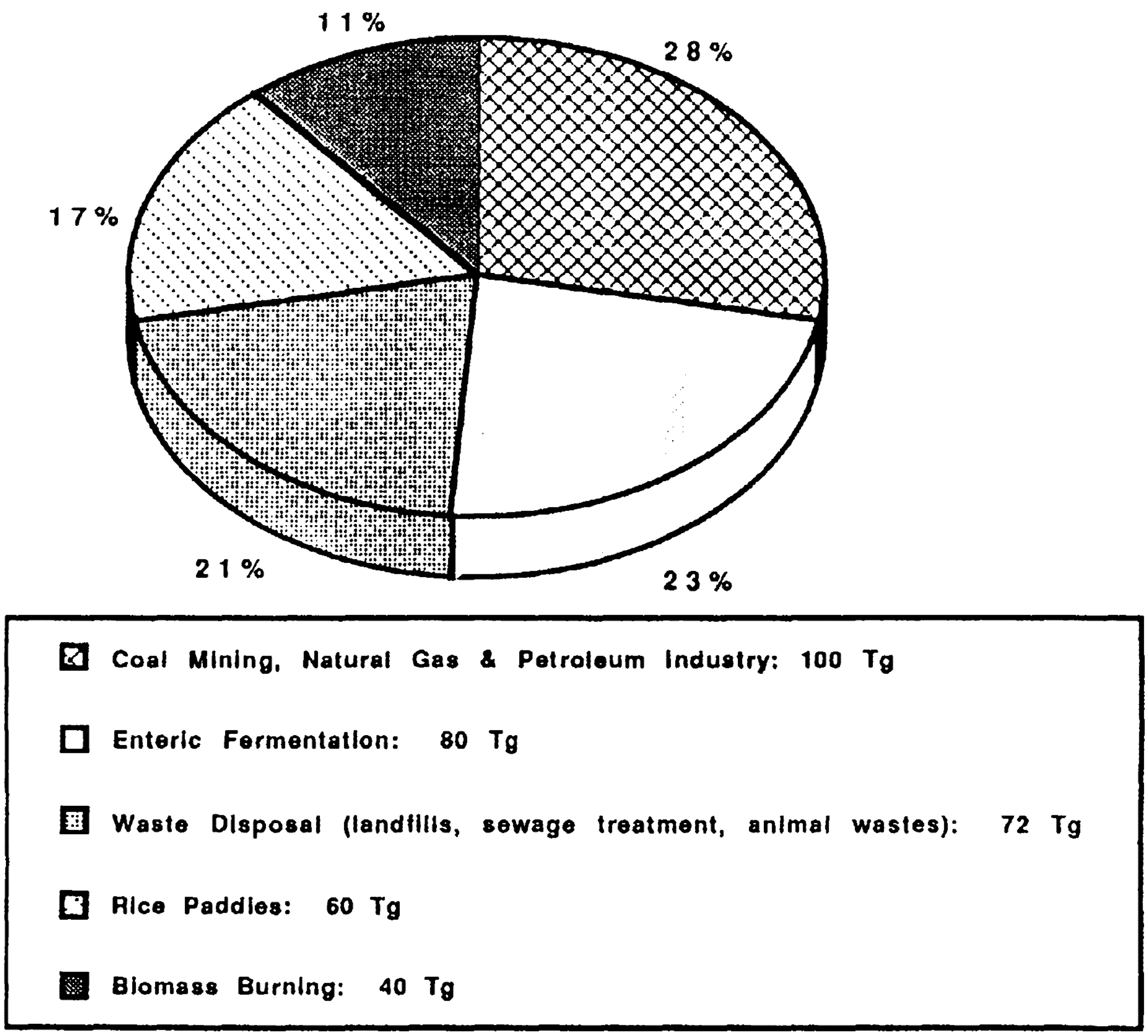
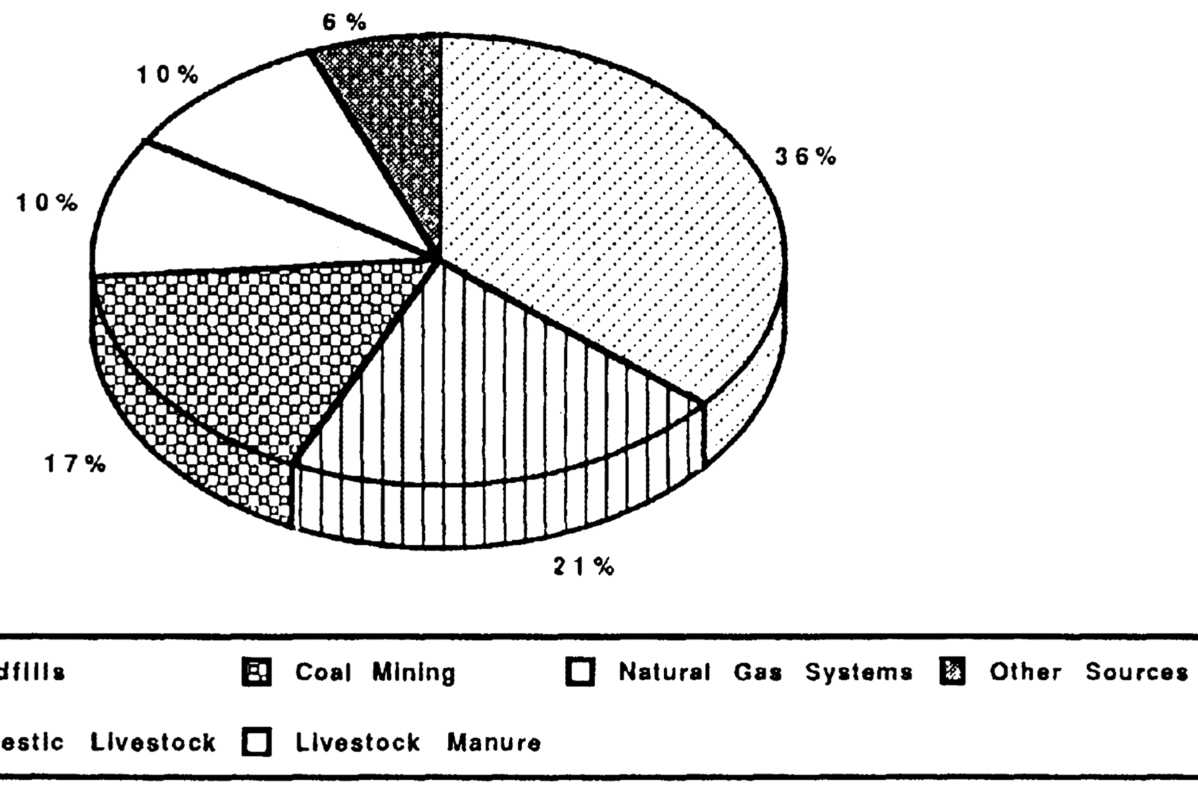
[1]Methane is reported with a GWP of 11 over a 100 year time frame and with indirect effects that could be comparable in magnitude to its direct effect (IPCC, 1992). The GWP reflects the effect that releasing 1 kg of CH_4 would have over a specified time horizon, relative to releasing 1 kg of CO_2.

Figure 2. Contribution of Major Methane Sources to Global Anthropogenic Emissions[1,2]



[1]Estimates are from IPCC, 1992 except for waste disposal estimates from Thorneloe et al., 1993.
[2]Total global anthropogenic emissions are ~350 Tg/yr.

Figure 3. Contribution of Major CH_4 Sources to Total U.S. Anthropogenic Emissions[1]



[1]U.S. EPA, 1993.

TABLE 1. COUNTRY-SPECIFIC METHANE EMISSION ESTIMATES FROM LANDFILLS AND OPEN DUMPS [1]

Country	Waste Generated (Tg/yr)	EPA/AEERL's Regression Model		
		Lower Bound (Tg/yr)	Midpoint (Tg/yr)	Upper Bound (Tg/yr)
Africa				
Congo	0.24	0.00	0.01	0.01
Egypt	6.99	0.08	0.13	0.17
Gambia	0.08	0.00	0.00	0.00
Ghana	2.35	0.03	0.05	0.06
Kenya	2.28	0.04	0.06	0.08
Liberia	0.32	0.01	0.01	0.01
Morocco	3.12	0.05	0.08	0.11
Nigeria	10.61	0.18	0.28	0.38
South Africa	11.17	0.11	0.18	0.24
Sudan	2.79	0.03	0.05	0.07
Tanzania	2.29	0.03	0.04	0.06
Uganda	1.47	0.02	0.03	0.04
Zimbabwe	1.90	0.02	0.03	0.04
Other Africa	31.46	0.48	0.75	1.02
TOTAL - AFRICA	78	1.1	1.7	2.3
Asia				
Bangladesh	7.99	0.08	0.13	0.17
China	134.50	0.64	0.99	1.35
India	66.79	0.74	1.15	1.56
Iran	10.76	0.16	0.25	0.34
Iraq	4.21	0.06	0.10	0.13
Israel	1.20	0.01	0.02	0.03
Japan	41.00	0.24	0.38	0.51
Kuwait	0.59	0.01	0.01	0.02
Malaysia	2.01	0.03	0.05	0.07
Mongolia	0.18	0.00	0.00	0.01
Myanmar	3.11	0.03	0.05	0.07
North Korea	3.74	0.06	0.09	0.12
Pakistan	10.34	0.11	0.17	0.22
Philippines	7.90	0.08	0.13	0.17
Saudia Arabia	3.54	0.05	0.08	0.11
South Korea	28.11	0.04	0.07	0.09
Sri Lanka	2.39	0.02	0.04	0.05
Thailand	7.04	0.09	0.15	0.20
Turkey	9.58	0.18	0.28	0.38
United Arab Emirates	0.41	0.01	0.01	0.01
Vietnam	6.29	0.09	0.14	0.20
Other Asia	34.00	0.60	0.94	1.29
TOTAL - ASIA	390	3.3	5.2	7.1

(Continued)

TABLE 1. COUNTRY-SPECIFIC METHANE EMISSION ESTIMATES FROM LANDFILLS AND OPEN DUMPS (Continued)

Country	Waste Generated (Tg/yr)	EPA/AEERL's Regression Model		
		Lower Bound (Tg/yr)	Midpoint (Tg/yr)	Upper Bound (Tg/yr)
Europe				
Albania	0.37	0.01	0.01	0.02
Austria	2.60	0.05	0.08	0.11
Belgium	3.10	0.04	0.06	0.08
Bulgaria	2.20	0.02	0.03	0.04
Czechoslovakia	2.83	0.05	0.09	0.12
Denmark	2.35	0.02	0.03	0.04
Finland	2.50	0.09	0.13	0.18
France	34.00	0.41	0.64	0.87
Germany	33.94	0.48	0.75	1.02
Greece	1.78	0.05	0.08	0.10
Hungary	3.20	0.06	0.09	0.12
Ireland	1.10	0.03	0.05	0.06
Italy	17.30	0.34	0.53	0.72
Netherlands	8.50	0.12	0.19	0.26
Norway	2.00	0.03	0.05	0.06
Poland	7.90	0.11	0.17	0.23
Romania	4.50	0.04	0.06	0.08
Spain	11.00	0.22	0.35	0.48
Sweden	2.30	0.03	0.04	0.05
Switzerland /Liechtenstein	5.80	0.03	0.05	0.07
United Kingdom	32.00	0.75	1.18	1.60
U.S.S.R. (former)	40.84	0.83	1.29	1.76
Yugoslavia	3.26	0.06	0.10	0.13
Other Europe	3.20	0.06	0.10	0.13
TOTAL - EUROPE	230	3.9	6.2	8.3
North and South America				
Canada	21.00	0.57	0.89	1.21
United States of America	281.20	10.90	17.00	23.10
Argentina	5.67	0.10	0.15	0.20
Brazil	31.00	0.66	1.03	1.40
Colombia	6.80	0.15	0.24	0.33
Venezuela	5.23	0.08	0.12	0.17
Other N. & S. America	38.35	0.53	0.83	1.13
TOTAL - N. & S. AMERICA	390	13	20	28
Australia & Oceania				
Australia	11.00	0.23	0.37	0.50
New Zealand	2.10	0.05	0.08	0.11
Other Oceania	0.54	0.01	0.01	0.02
TOTAL - OCEANIA	14	0.3	0.5	0.6
TOTAL GLOBAL	1102	22	34	46

[1] For references used in developing estimates, see Table 2.

NOTE: Decimals in country-specific estimates do not indicate precision. Estimates are considered precise to within 2 significant figures. Totals may not equal sum of individual numbers due to rounding.

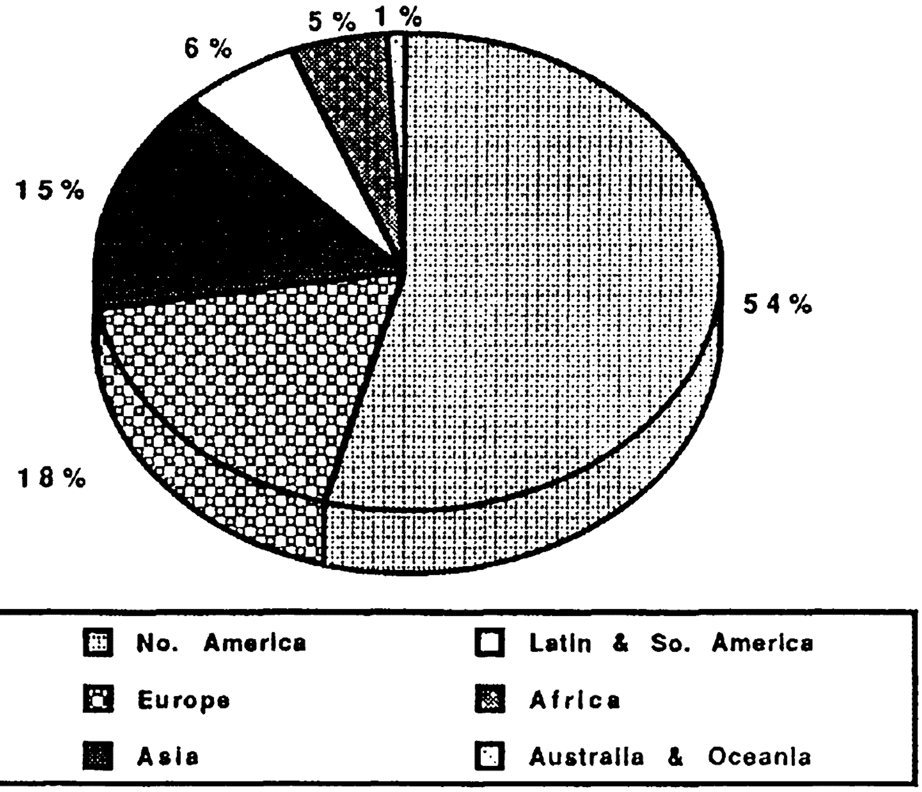
TABLE 2. REFERENCES USED IN DEVELOPING ESTIMATES OF TABLE 1

Geographic Region	References*
Africa	1-15
Asia and the Middle East	16-29
Europe	30-45
North America	46-48
Oceania	49-50
South and Central America	51-56

*Reference Key

1. Bartone, 1990b.
2. El-Halwagi et al., 1988.
3. El-Halwagi et al., 1986.
4. Kaltwasser, 1986.
5. United Nations Development Programme (UNDP) et al., 1987.
6. Holmes, 1984.
7. Monney, 1986.
8. Cointreau, 1984.
9. Cointreau, 1987.
10. The World Bank, 1985.
11. Mwiraria et al., 1991.
12. United Republic of Tanzania, 1989.
13. Verrier, 1990.
14. World Resources Institute, 1990.
15. Rettenberger and Weiner, 1986.
16. Bhide and Sundaresan, 1990.
17. Bhide et al., 1990.
18. United Nations, 1989.
19. Maniatis et al., 1987.
20. Lohani and Thanh, 1980.
21. Ahmed, 1986.
22. Pairoj-Boriboon, 1986.
23. Gadi, 1986.
24. Mei-Chan, 1986.
25. Kaldjian, 1990.
26. Diaz and Goulueke, 1987.
27. Cossu, 1990a.
28. Hayakawa, 1990.
29. Swartz, 1989.
30. World Resources Institute, 1990.
31. Carra and Cossu, 1990.
32. Ettala, 1990.
33. Stegmann, 1990.
34. Ernst, 1990.
35. Cossu and Urbini, 1990.
36. Beker, 1990.
37. Gandolla, 1990.
38. Cossu, 1990b.
39. Swartz, 1989.
40. Richards, 1989.
41. Kaldjian, 1990.
42. Scheepera, 1990.
43. Bartone and Haley, 1990.
44. Bartone, 1990a,b,c,d.
45. Bingemer and Crutzen, 1987.
46. U.S. EPA, 1988.
47. Kaldjian, 1990.
48. El Rayes and Edwards, 1991.
49. Bateman, 1988.
50. Richards, 1989.
51. Kessler, 1990.
52. Kaldjian, 1990.
53. World Resources Institute, 1990.
54. Diaz and Golueke, 1987.
55. Bartone et al., 1991.
56. Yepes and Campbell, 1990.

Figure 4. Contribution of Landfill CH_4 to Global Landfill CH_4 Emissions (Tg/yr)1



[1]Estimates for this figure are from Table 1 using the midpoint.

estimates and additional data and information being collected. For example, the estimates in Table 1 do not adjust for the type of waste being landfilled. Ongoing research by EPA will result in gas potential data that will provide factors for adjusting for the types of waste being landfilled (Barlaz, 1991). This is considered important because there are definite differences in geographical regions as to the types of waste being landfilled.

There are changes occurring in waste management practices worldwide. For example, industrialized countries are adopting recycling programs to help extend the life of landfills, particularly where landfilling space is at a premium. This results in less paper, food, and yard waste being landfilled. The effect of this on future landfill emissions is presently unknown. Developing countries are adapting "sanitary" landfills, resulting in increased CH_4 emissions. Other factors important to the accurate characterization of landfill CH_4 are being investigated, such as the inhibition of leachate on CH_4 generation trends in worldwide waste management practices, changing composition of waste in landfills, and implementation of regulations requiring control of landfill air emissions. These ongoing efforts will help to provide data and other information that will be used to reduce the uncertainties associated with estimating global landfill CH_4.

EPA's Research Program on Waste Methane Utilization

Currently there are 114 landfill-gas-to-energy projects in the U.S. and about 200 worldwide (Thorneloe, 1992a). Technology transfer/technical assistance programs have been initiated by EPA's AEERL to help encourage the utilization of waste CH_4 and to help implement the soon-to-be-promulgated Clean Air Act regulations for MSW landfills. For example, AEERL is working with a consortium of local government representatives to explore the application of EPA research on CH_4/energy recovery from MSW landfills. AEERL also serves on the International Energy Agency (IEA) Expert Working Group on Landfill Gas and the Steering Committee for the Solid Waste Association of North America (SWANA) and participates in the International Solid Waste Association. In collaboration with SWANA, the IEA, and the United Kingdom's Energy Technology Support Unit, the EPA is developing a database of landfill-gas-to-energy projects. An EPA report, along with computer software, is scheduled to be published in April 1994, which will provide an up-to-date list and information for landfill-gas-to-energy projects in North America (Thorneloe, 1992b). AEERL is also responsible for demonstrating innovative approaches to control waste CH_4 such as the application of fuel cell technology to also recover energy from landfill gas (Sandelli, 1992).

To help promote and encourage landfill gas (LFG) utilization, case studies of six different sites were conducted. The final report (Augenstein and Pacey, 1992) contains detailed information on the six LFG-to-energy projects. In addition, the report provides information on 42 other LFG-to-energy projects including four projects in the United Kingdom. This report is regarded as an "enabling" tool that provides up-to-date information on the different options for LFG utilization for landfill owners and operators. It also provides information on the economics, and technical and non-technical issues regarding LFG utilization.

A follow-up technology transfer project is focusing on the technical issues associated with gas cleanup and energy equipment modifications for LFG application. The different philosophies of the major U.S. developers and operators are provided, along with information on European projects. The EPA report for this project is expected to be published in the spring of 1994. This technology transfer project is intended to help ensure that future utilization projects are designed and operated using the most up-to-date knowledge and information on gas cleanup and energy equipment modifications.

There are emerging technologies for waste CH_4 utilization. Fuel cells are considered an ideal solution for LFG utilization, particularly where there is concern for emissions of nitrogen oxides and carbon monoxide. The EPA/AEERL initiated a project in 1991 to demonstrate the use of fuel cells to recover energy from LFG at a site in California. The advantages with the use of fuel cells include higher energy efficiency, availability to smaller as well as larger landfills, minimal by-product emissions, minimal labor and maintenance, and minimal noise impact (i.e., because there are no moving parts). The type of fuel cell being demonstrated for LFG application is the commercially available 200 kW_e phosphoric acid fuel cell power plant. A 1-year full-scale demonstration is scheduled for completion in 1994 (Sandelli, 1992).

The major technical issue associated with the application of fuel cells to LFG is finding a gas cleanup system that effectively and economically cleans the gas to the fuel cell's stringent requirements. Landfill gas composition can be quite variable as to the type of constituents and concentration. Chloride and sulfur compounds are quite common. "Slugs" of condensate have also been known to cause havoc at gas turbine and internal combustion engine projects (Augenstein and Pacey, 1992). If this project is successful, it will provide a more environmentally attractive option for waste CH_4 utilization that is also more energy efficient.

Other emerging technologies for LFG include the production of liquid diesel fuel such as the process in Pueblo, Colorado, that began operation last year. A second site in the U.S. has been proposed to produce vehicular fuel from LFG. The South Coast Air Quality Management District has awarded a contract to demonstrate a process for producing methanol from LFG. The site selected for this demonstration is the BKK landfill, where there was co-disposal of hazardous and municipal waste. This demonstration which is scheduled to begin in 1994, is to be conducted for 1 year.

The EPA is developing a report on innovative technologies for waste CH_4 utilization. This report is expected to be published in 1994. Opportunities for future demonstrations of innovative technologies are being considered. Efforts are also ongoing to identify the existing technical and nontechnical barriers that affect waste CH_4 utilization.

SUMMARY

Landfill CH_4 is a major source of CH_4 particularly in the U.S. where emissions contribute about 50 percent (i.e., ~15 Tg) of the estimate of total global landfill CH_4. Because landfill CH_4 is amenable to cost-effective control, clarification of the emission potential and opportunities for control has been given a high priority. The U.S. EPA is issuing final regulations for MSW landfills that are expected to result in a reduction of 7 to 10 Tg/yr of CH_4. Controlling CH_4 from landfills is regarded as a significant step toward reaching the goals established in 1992 at the UNCED. Research being conducted by EPA's AEERL is designed to help with the successful implementation of the regulations affecting U.S. MSW landfills and to help encourage the utilization of landfill CH_4, both nationally and internationally.

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16. ABSTRACT The chapter describes the relative importance of landfills to global warming and identifies the major sources of uncertainty with current emission estimates. It also provides an overview of EPA's research program on global landfill methane, including developing more reliable estimates of global landfill methane emissions, characterizing the current state of technology for controlling and utilizing landfill methane, and demonstrating innovative technologies for mitigating and utilizing landfill methane. Landfills are considered a major source of methane, which is a potent greenhouse gas. Because this source is amenable to cost effective control measures, research designed to reduce the uncertainty associated with methane emissions estimates has been given high priority. The methane can be either flared or utilized for its energy potential. Lanfills contribute an estimated 20-40 Tg/yr of methane.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Methane	Stationary Sources	07C
Earth Fills	Global Climate Change	13C
Estimating	Flaring	14G
Greenhouse Effect		04A
Combustion		21B

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