Annex I
Methodology for Estimating Methane Emissions from Landfills

Landfill methane is produced from a complex process of waste decomposition and subsequent fermentation under anaerobic conditions. The total amount of methane produced in a landfill from a given amount of waste and the rate at which it is produced depends upon the characteristics of the waste, the climate, and operating practices at the landfill. To estimate the amount of methane produced in a landfill in given year the following information is needed: quantity of waste in the landfill, the waste characteristics, the residence time of the waste in the landfill, and landfill management practices.

The amount of methane emitted from a landfill is less than the amount of methane produced in a landfill. If no measures are taken to extract the methane, a portion of the methane will oxidize as it travels through the top layer of the landfill cover. The portion of the methane that oxidizes turns primarily to carbon dioxide (CO_2). If the methane is extracted and combusted (e.g., flared or used for energy), then that portion of the methane produced in the landfill will not be emitted as methane, but again would be converted to CO_2. In general, the CO_2 emitted is of biogenic origin and primarily results from the decomposition—either aerobic or anaerobic—of organic matter such as food or yard wastes.[7]

To take into account the inter-related processes of methane production in the landfill and methane emission, this analysis relied on a simulation of the population of landfills and waste disposal. A starting population of landfills was initialized with characteristics from the latest survey of municipal solid waste (MSW) landfills (EPA 1988). Using actual national waste disposal data, waste was simulated to be placed in these landfills each year from 1990 to 1996. If landfills reach their design capacity, they were simulated to have closed. New landfills were simulated to open only if annual disposal capacity was less than total waste disposal. Of note is that closed landfills continue to produce and emit methane for many years. This analysis tracks these closed landfills throughout the analysis period, and includes their estimated methane production and emissions.

Using this approach, the age of the waste in each landfill was tracked explicitly. This tracking allowed the annual methane production in each landfill to be estimated. Methane produced in industrial landfills was also estimated. It was assumed to be 7 percent of the total methane produced in MSW landfills. Finally, methane recovered and combusted and methane oxidized were subtracted to estimate final methane emissions.

Using this approach, landfill population and waste disposal characteristics were simulated over time explicitly, thereby allowing the time-dependent nature of methane production to be modeled. However, the characteristics used to initialize the landfill population in the model were relatively old and may not represent the current set of operating landfills adequately. There is also uncertainty in the methane production equation developed in EPA (1993), as well as in the estimate of methane oxidation (10 percent).

Step 1: Estimate Municipal Solid Waste in Place Contributing to Methane Emissions

The landfill population model was initialized to define the population of landfills at the beginning of 1990. Waste was simulated to be placed into these landfills for the years 1990 through 1996 using data on the total waste landfilled from Biocycle (1997). The annual acceptance rates of the landfills were used to apportion the total waste by landfill. More waste was preferentially disposed in "Large" landfills (see Table I-3), reflecting the trend toward fewer and more centralized disposal facilities. The model updates the landfill characteristics each year, calculating the total waste in place and the full time profile of waste disposal. This time profile was used to estimate the portion of the waste that contributes to methane emissions. Table I-1 shows the amount of waste landfilled each year and the total estimated waste in place contributing to methane emissions.

[7] Emissions and sinks of biogenic carbon are accounted for under the Land-Use Change and Forestry sector.

Step 2: Estimate Landfill Methane Production

Emissions for each landfill were estimated by applying the emissions model (EPA 1993) to the landfill waste in place contributing to methane production. Total emission were then calculated as the sum of emissions from all landfills.

Step 3: Estimate Industrial Landfill Methane Production

Industrial landfills receive waste from factories, processing plants, and other manufacturing activities. Because there were no data available on methane generation at industrial landfills, the approach used was to assume that industrial methane production equaled about 7 percent of MSW landfill methane production (EPA 1993), as shown below in Table I-2.

Step 4: Estimate Methane Recovery

To estimate landfill gas (LFG) recovered per year, data on current and planned LFG recovery projects in the United States were obtained from Governmental Advisory Associates (GAA 1994). The GAA report, considered to be the most comprehensive source of information on gas recovery in the United States, has estimates for gas recovery in 1990 and 1992. Their data set showed that 1.20 and 1.44 teragrams (Tg) of methane were recovered nationally by municipal solid waste landfills in 1990 and 1992, respectively. In addition, a number of landfills were believed to recover and flare methane without energy recovery and were not included in the GAA database. To account for the amount of methane flared without energy recovery, the estimate of gas recovered was increased by 25 percent (EPA 1993). Therefore, net methane recovery from landfills was assumed to equal 1.50 Tg in 1990, and 1.80 Tg in 1992. The 1990 estimate of methane recovered was used for 1991 and the 1992 estimate was used for the period 1992 to 1996. EPA is currently reviewing more detailed information on LFG recovery projects and expects that the total recovery figure could be significantly higher.

Step 5: Estimate Methane Oxidation

As discussed above, a portion of the methane escaping from a landfill through its cover oxidizes in the top layer of the soil. The amount of oxidation that occurs is uncertain and depends upon the characteristics of the soil and the environment. For purposes of this analysis, it was assumed that 10 percent of the methane produced was oxidized in the soil.

Step 6: Estimate Total Methane Emissions

Total methane emissions were calculated by adding emissions from MSW and industrial waste, and subtracting methane recovered and oxidized, as shown in Table I-2.

Table I-1: Municipal Solid Waste (MSW) Contributing to Methane Emissions (Tg)

Description	1990	1991	1992	1993	1994	1995	1996
Total MSW Generated[a]	264	255	265	278	293	296	297
Percent of MSW Landfilled[a]	71%	76%	72%	71%	67%	63%	62%
Total MSW Landfilled	189	194	190	197	196	187	184
MSW Contributing to Emissions[b]	4,926	5,027	5,162	5,292	5,428	5,559	5,676

[a] Source: Biocycle (1997). The data, originally reported in short tons, are converted to metric tons.
[b] The EPA emissions model (EPA 1993) defines all waste younger than 30 years as contributing to methane emissions.

Table I-2: Methane Emissions from Landfills (Tg)

Activity	1990	1991	1992	1993	1994	1995	1996
MSW Generation	11.6	11.8	12.2	12.5	12.8	13.2	13.5
Large Landfills	4.53	4.62	4.76	4.91	5.11	5.29	5.45
Medium Landfills	5.79	5.91	6.07	6.23	6.36	6.53	6.62
Small Landfills	1.27	1.30	1.33	1.36	1.39	1.41	1.42
Industrial Generation	0.73	0.75	0.77	0.79	0.81	0.83	0.85
Potential Emissions	12.3	12.6	12.9	13.3	13.7	14.1	14.3
Recovery	(1.50)	(1.50)	(1.80)	(1.80)	(1.80)	(1.80)	(1.80)
Oxidation	(1.09)	(1.12)	(1.12)	(1.16)	(1.19)	(1.23)	(1.26)
Net Emissions	**9.82**	**10.0**	**10.1**	**10.4**	**10.8**	**11.1**	**11.4**

Note: Totals may not sum due to independent rounding.

Table I-3: Municipal Solid Waste Landfill Size Definitions (Tg)

Description	Waste in Place
Small Landfills	< 0.4
Medium Landfills	0.4 - 2.0
Large Landfills	> 2.0