User's Manual
Central America Landfill Gas Model

Version 1.0

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DISCLAIMER

This user's guide has been prepared specifically for Central America on behalf of the U.S. EPA's Landfill Methane Outreach Program, U.S. Environmental Protection Agency and U.S. Agency for International Development. The methods contained within are based on engineering judgment and represent the standard of care that would be exercised by a professional experienced in the field of landfill gas projections. The U.S. EPA and SCS Engineers do not guarantee the quantity of available landfill gas, and no other warranty is expressed or implied. No other party is intended as a beneficiary of this work product, its content, or information embedded therein. Third parties use this report at their own risk. The U.S. EPA and SCS Engineers assume no responsibility for the accuracy of information obtained from, compiled, or provided by other parties.

ABSTRACT

This document is a user's guide for a computer model, Version 1.0 of a landfill gas generation model for estimating landfill gas generation and recovery from municipal solid waste landfills in Central America (Central America LFG Model). The model was developed by SCS Engineers under contract to the U.S. EPA’s Landfill Methane Outreach Program (LMOP). The Central America LFG Model can be used to estimate landfill gas generation rates from landfills, and potential landfill gas recovery rates for landfills that have, or plan to have, gas collection and control systems in Central America.

The Central America LFG Model is an Excel® spreadsheet model based on a first order decay equation. The model requires the user to input site-specific data for landfill opening and closing years, refuse disposal rates, average annual precipitation, and collection efficiency. The model provides default values for waste composition and input variables (k and L0) for each country. The default values were developed using data on climate, waste characteristics, and disposal practices in Central America, and the estimated effect of these conditions on the amounts and rates of LFG generation. Actual LFG recovery rates from two landfills in Central America were evaluated, but insufficient data were available for model calibration. A guide to evaluate a site’s collection efficiency, which is used by the model to derive LFG recovery estimates from model projections of LFG generation, is also provided.

The Central America LFG Model was developed with the goal of providing accurate and conservative projections of LFG generation and recovery. Other models evaluated during the model development process included the Mexico LFG Model, Clean Development Mechanism (CDM) Method AM0025 v.3.(March 2006), and the Intergovernmental Panel on Climate Change (IPCC) 2006 Waste Model. The Central America LFG Model incorporates components of each of these models that help it to reflect conditions at disposal sites in Central America. A comparison of model results shows that the Central America Model typically provides estimates of LFG generation that are approximately mid-way between the CDM Method and IPCC Model results.

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GLOSSARY OF TERMS

Term	Definition
Collection Efficiency	The estimated percentage of generated landfill gas which is or can be collected in a gas collection system.
Collection System Coverage	The estimated percentage of a landfill's refuse mass that is potentially within the influence of a gas collection system's extraction wells. Collection system coverage describes the fraction of recoverable gas that can be captured and can reach 100% in a comprehensive collection system (unlike collection efficiency which is always less than 100%).
Design Capacity of the Landfill	The total amount of refuse that can be disposed of in the landfill.
Landfill Gas	Landfill gas is a product of biodegradation of refuse in landfills and consists of primarily methane and carbon dioxide, with trace amounts of non-methane organic compounds and air pollutants.
Methane Generation Rate Constant (k)	k is a model constant that determines the estimated rate of landfill gas generation. The first-order decomposition model assumes that k values before and after peak landfill gas generation are the same. k is a function of moisture content in the landfill refuse, availability of nutrients for methanogens, pH, and temperature. (Units = 1/year)
Potential Methane Generation Capacity (L_0)	L_0 is a model constant that represents the potential capacity of a landfill to generate methane (a primary constituent of landfill gas). L_0 depends on the amount of cellulose in the refuse. (Units = m3/Mg)
Closure Year	The year in which the landfill ceases, or is expected to cease, accepting waste.

1.0: INTRODUCTION

The Central America Landfill Gas Model (Central America LFG Model) provides an automated estimation tool for quantifying landfill gas generation and recovery from municipal solid waste (MSW) landfills in Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. This manual provides an introduction to the model and step-by-step instructions for using the model.

The main purpose of the Central America LFG Model is to provide landfill owners and operators with a tool to use to evaluate the feasibility and potential benefits of collecting and using the generated landfill gas for energy recovery or other uses. To accomplish this purpose, this computer model provides estimates of potential landfill gas recovery rates. This is accomplished using the landfill gas generation rates estimated by the model and estimates of the efficiency of the collection system in capturing generated gas, known as the collection efficiency. The model provides landfill gas recovery estimates by multiplying the landfill gas generation by the estimated recovery efficiency.

Landfill gas is generated by the decomposition of refuse in the landfill, and can be recovered through the operation of gas collection facilities installed at the landfill. The following information is needed to estimate landfill gas generation and recovery from a landfill (see the Glossary of Terms):

- The design capacity of the landfill;
- The amount of refuse in place in the landfill, or the annual refuse acceptance rate for the landfill;
- The methane generation rate (k) constant;
- The potential methane generation capacity (L0);
- The collection efficiency of the gas collection system; and
- The years the landfill has been and will be in operation.

The model employs a first-order exponential decay function that assumes that LFG generation is at its peak following a time lag representing the period prior to methane generation. The model assumes a six month time lag between placement of waste and LFG generation. For each unit of waste, after six months the model assumes that LFG generation decreases exponentially as the organic fraction of waste is consumed.

For sites with known (or estimated) year-to-year solid waste acceptance rates, the model estimates the LFG generation rate in a given year using the following equation, which is used by the U.S. EPA's Landfill Gas Emissions Model (LandGEM) version 3.02 (EPA, 2005).

$$Q_M = \sum_{i=1}^{n} \sum_{j=0.1}^{1} 2\, k\, L_o\, (M_i/10)\, (e^{-kt_{ij}})$$

Where:
Q_M = maximum expected LFG generation flow rate (m^3/yr);
i = 1 year time increment
n = (year of the calculation) – (initial year of waste acceptance)
j = 0.1 year time increment
k = methane generation rate (1/yr);
L_o = potential methane generation capacity (m^3/Mg);
M_i = mass of solid waste disposed in the i^{th} year (Mg);
t_{ij} = age of the j^{th} section of waste mass disposed in the i^{th} year (decimal years).

The above equation is used to estimate LFG generation for a given year from cumulative waste disposed up through that year. Multi-year projections are developed by varying the projection year, and then re-applying the equations. The year of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years).

The Central America LFG Model requires site-specific data for all the information needed to produce generation estimates, except for the k and L_0 values. The model provides default values for k and L_0. The default values are based on climate and waste composition data gathered from representative landfills and cities in Central America. The default k and L_0 values vary depending on country, waste composition, and average annual precipitation, and can be used to produce typical landfill gas generation estimates for landfills located in each of the seven countries in Central America.

EPA recognizes that modeling landfill gas generation and recovery accurately is difficult due to limitations in available information for inputs to the model. However, as new landfills are constructed and operated, and better information is collected, the present modeling approach can be improved. In addition, as more landfills in Central America develop gas collection and control systems, additional data on landfill gas generation and recovery will become available for model calibration and the development of improved model default values.

Questions and comments concerning the landfill gas model should be directed to Victoria Ludwig of EPA's LMOP at (202) 343-9291, or by e-mail at Ludwig.Victoria@epamail.epa.gov.

1.1 Landfill Gas Generation

The Central America LFG Model estimates landfill gas generation resulting from the biodegradation of refuse in landfills. The anaerobic decomposition of refuse in solid waste landfills generates landfill gas. The composition of MSW landfill gas is assumed by the model to be about 50 percent methane (CH4) and 50 percent other gases, including carbon dioxide (CO2) and trace amounts of other compounds.

This computer model uses a first-order decomposition rate equation and estimates volumes of landfill gas generation in cubic meters per hour (m3/hr) and cubic feet per minute (cfm). It also estimates the energy content of generated landfill gas in million British Thermal Units per hour (mmBtu/hr), and the maximum power plant capacity that could be fueled by the collected landfill gas (MW). Total landfill gas generation is estimated by doubling methane generation (the landfill gas is assumed to be half methane and half carbon dioxide). Methane generation is estimated using two parameters: (1) L_0 is the potential methane generation capacity of the refuse, and (2) k is the methane generation rate. Landfill gas generation is assumed to be at its peak upon closure of the landfill or final placement of waste at the site. Although the model allows the user to enter L_0 and k values derived using site-specific data collected at the landfill, it is recommended that the provided default values be used for most modeling applications.1

1.1.1 Methane Generation Rate Constant (k)

The methane generation rate constant, k, determines the rate of generation of methane from refuse in the landfill. The units for k are in year-1, and describes the rate at which refuse placed in a landfill decays and produces biogas. The higher the value of k, the faster total methane generation at a landfill increases (as long as the landfill is still receiving waste) and then declines (after the landfill closes) over time. The value of k is a function of the following factors: (1) refuse moisture content, (2) availability of nutrients for methane-generating bacteria, (3) pH, and (4) temperature.

Different waste types can have significantly different k values as a result of differences in decay rates. Food waste, for example decays faster than paper or wood. The Central America LFG Model assigns two different categories of k values to organic waste materials depending on whether they decay rapidly or slowly. Fast-decay waste materials include food waste and selected garden and park waste ("green waste"). Slow-decay waste materials include all other organic materials, including the remaining portion of garden and park waste, paper, textiles, rubber, leather, and bones. Because individual materials in each category also will differ, the ratio between the fast-decay waste k value and the slow-decay waste k value varies depending on waste composition.

The k values also vary with climate, especially precipitation. Because most of Central America experiences high rainfall, most landfills experience moisture conditions that tend to maximize waste decay rates and k values. The Central America LFG Model assumes no differences in k values for sites experiencing 1,000 mm per year or more precipitation. For the few areas that receive less than 1,000 mm per year precipitation, the model assigns lower k values appropriate for the local climate.

Unless user-specified k values, or user-specified waste composition data, are entered into the Central America LFG Model, default values are used for k. For each of the seven countries

[1] Site-specific L_0 and k values may be developed for landfills with operating gas collection and control systems by calibrating the Central America LFG Model using known landfill gas recovery data.

default k values have been calculated, including a fast-decay k and a slow-decay k. The fast decay k values are the same for all seven countries, and are set at 0.23 per year, the value used by CDM Method AM0025 (UNFCCC, 2006). The slow decay k values vary depending on waste composition. The model also adjusts the k values downward for sites experiencing less than 1,000 mm per year precipitation. Tables 1 through 3 provide the default k values used by the program, depending on the amount of precipitation experienced at the landfill:

TABLE 1: METHANE GENERATION RATE (k)
WET CLIMATE (Rainfall >= 1,000 mm/year)

Country	Fast k (per year)	Slow k (per year)
Belize	0.23	0.033
Costa Rica	0.23	0.028
El Salvador	0.23	0.027
Guatemala	0.23	0.030
Honduras	0.23	0.030
Nicaragua	0.23	0.025
Panama	0.23	0.029

TABLE 2: METHANE GENERATION RATE (k)
MODERATE CLIMATE (Rainfall = 750-999 mm/year)

Country	Fast k (per year)	Slow k (per year)
Belize	0.20	0.029
Costa Rica	0.20	0.024
El Salvador	0.20	0.023
Guatemala	0.20	0.026
Honduras	0.20	0.026
Nicaragua	0.20	0.022
Panama	0.20	0.025

TABLE 3: METHANE GENERATION RATE (k)
DRY CLIMATE (Rainfall = 500-749 mm/year)

Country	Fast k (per year)	Slow k (per year)
Belize	0.18	0.026
Costa Rica	0.18	0.022
El Salvador	0.18	0.021
Guatemala	0.18	0.024
Honduras	0.18	0.023
Nicaragua	0.18	0.020
Panama	0.18	0.022

1.1.2 Potential Methane Generation Capacity (L_0)

Except in dry climates where a lack of moisture limits methane generation, the value for the potential methane generation capacity of refuse (L0) depends almost exclusively on the type of refuse present in the landfill. The higher the cellulose content of the refuse, the higher the value of $L_{0.}$ The units of L_0 are in cubic meters per tonne of refuse, which means that the L0 value describes the total amount of methane gas potentially produced by a tonne of refuse as it decays. The values of theoretical and obtainable L_0 range from 6.2 to 270 m^3/Mg refuse (EPA, 1991). Unless a user-specified L_0 value is entered into the Central America LFG Model, default values are used for L_0. The model uses waste composition data to calculate default L_0 values for each country, including a total waste L_0, a fast decay organic waste L_0, and a slow-decay organic waste L_0. The default L_0 values shown in Table 4 are used by the model for each of the seven countries.

TABLE 4: POTENTIAL METHANE GENERATION CAPACITY (L_0)

Country	Total Waste L0 (m3/Mg)	Fast-decay Waste L0 (m3/Mg)	Slow-decay Waste L0 (m3/Mg)
Belize	78	71	199
Costa Rica	96	70	200
El Salvador	91	68	189
Guatemala	89	71	198
Honduras	70	68	209
Nicaragua	82	72	183
Panama	101	68	207

1.1.2.1 Methane Correction Factor

The Methane Correction Factor (MCF) is a final adjustment to model estimates of LFG generation that accounts for the degree to which wastes will decay anaerobically. The MCF varies depending on waste depth and landfill type, as defined by site management practices. At managed, sanitary landfills, it is assumed that all waste decay will be anaerobic (MCF of 1). At landfills or dumps with conditions less conducive to anaerobic decay, the MCF will be lower to reflect the extent of aerobic conditions at these sites. Table 5 summarizes the recommended MCF adjustments.

TABLE 5: METHANE CORRECTION FACTOR (MCF)

Site Management	Depth <5m	Depth >=5m
Unmanaged Disposal Site	0.4	0.8
Managed Landfill	0.8	1.0
Semi-Aerobic Landfill	0.3	0.5
Unknown	0.4	0.8

Waste depth of at least five meters promotes anaerobic decay; at shallower sites, waste decay may be primarily aerobic. A managed landfill is defined as having controlled placement of waste (waste directed to specific disposal areas, a degree of control of scavenging and fires), and one or more of the following: cover material, mechanical compacting, or leveling of waste (IPCC, 2006). A semi-aerobic landfill has controlled placement of waste and all of the following structures for introducing air into the waste layer: permeable cover material, leachate drainage system, regulating pondage, and gas ventilation system (IPCC, 2006).

1.2 Landfill Gas Recovery

Landfill gas generated in landfills can be captured by gas collection and control systems that typically burn the gas in flares. Alternatively, the collected gas can be used beneficially. Beneficial uses of landfill gas include use as fuel in energy recovery facilities, such as internal combustion engines, gas turbines, microturbines, steam boilers, or other facilities that use the gas for electricity generation.

In addition to the energy benefits from the beneficial use of landfill gas, collection and control of generated landfill gas helps to reduce landfill gas emissions that are harmful to the environment. The U.S. EPA has determined that landfill gas emissions from MSW landfills cause, or contribute significantly to, air pollution that may reasonably be anticipated to endanger public health or welfare. Some are known or suspected carcinogens, or cause other non-cancerous health effects. Public welfare concerns include the odor nuisance from the landfill gas and the potential for methane migration, both on-site and off-site, which may lead to explosions or fires. The methane emitted from landfills is also a concern because it is a greenhouse gas thereby contributing to the challenge of global climate change.

The main purpose of the Central America LFG Model is to provide landfill owners and operators in Central America with a tool to use to evaluate the feasibility and potential benefits of collecting and using the generated landfill gas for energy recovery or other uses. To fulfill this purpose, the model provides estimates of potential landfill gas recovery rates. This is accomplished using the landfill gas generation rates estimated by the model and estimates of the efficiency of the collection system in capturing generated gas, known as the collection efficiency. The model provides landfill gas recovery estimates by multiplying the landfill gas generation by the estimated collection efficiency.

1.3 The Model

The Central America LFG Model can be operated in a Windows 98®, Windows 2000®, Windows XP®, or Vista environment. The program is a Microsoft Excel® spreadsheet, which allows the user considerable control over model calculations and output appearances. Open the model file ("LMOP Central America Model.xls") by choosing "file" "open," and then "open" when the correct file is highlighted. The model has seven worksheets that are accessible by clicking on the tabs at the bottom of the Excel® window screen. The seven worksheets are as follows:

- A model inputs worksheet;
- A waste composition worksheet;
- A model outputs worksheet in a table format;
- A model outputs worksheet in a graph format; and
- Three model calculations worksheets ("amounts," "calcs1," and "calcs2").

When using the model, most of the editing by the user takes place in the model inputs worksheet. Some editing may be required in the outputs worksheet for formatting purposes. Also, selected cells in the waste composition worksheet allow the user to input site-specific waste composition data. The remaining cells in the waste composition worksheet and all calculation worksheets should not be changed and are password-protected to prevent changes.

2.0 ESTIMATING LANDFILL GAS GENERATION AND RECOVERY

2.1 Model Inputs

All model inputs except for site-specific waste composition data are to be entered into the "Inputs" worksheet. Cells with red bold text require user inputs. See Figure 1 for model inputs. Cells highlighted in yellow should not be changed. The following inputs are required to run the model properly and produce acceptable outputs (tables and graphs):

Step 1: Enter the name and location of the landfill (Cell A4). The information entered here will automatically appear in the heading of the output table.

Step 2: Select the name of the country in which the landfill is located (Cell B5). The country selected here will be used by the model to look up waste composition data.

Step 3: Select either a "Yes" to indicate that there is site-specific waste composition data available to use in the model or a "No" for the model to run with the country-specific default waste composition figures (Cell B6). If a "Yes" is entered here, the model will run with waste composition figures entered into the Waste Composition worksheet by the user. Enter site specific waste composition data into Cells B4 through B10 and B14 through B17 of the waste composition worksheet. You will be prompted to enter a password to unlock the cells for editing. Enter "lmop" (all lowercase letters).

Step 4: Enter the year the landfill opened and began receiving waste (Cell B7). This value will feed into the table of numbers below and in the output table.

Step 5: The estimated annual growth in disposal rates (goes into Cell B8 – see Figure 1). The rate entered will feed into the table of numbers below and in the output table.

Step 6: The average annual precipitation in mm per year at the landfill (goes into Cell B9 – see Figure 1). This information can be obtained by looking up precipitation data for the closest city or town at www.worldclimate.com. This value will be used to adjust default values for k if the site experiences less than 1,000 mm per year of precipitation.

Step 7: Enter the average landfill depth in areas filled with waste (Cell B10). This value will be used to calculate the Methane Correction Factor.

Step 8: Enter the number which designates the landfill type, as defined by site design and management practices (Cell B11). Instructions in Cell C11 list the numbers to use for designating site type (see Table 5 and page 1-7 above for details). The information entered here will be used to calculate the Methane Correction Factor.

FIGURE 1. MODEL INPUTS

	A	B	C
1	**LMOP CENTRAL AMERICA BIOGAS MODEL v.1 March 2007**		
2	Developed by SCS Engineers, LMOP contractor		
3	**PROJECTION OF BIOGAS GENERATION AND RECOVERY**		
4	**_______ LANDFILL, _______, El SALVADOR**		
5	**Country:**	**3**	
6	**Site-Specific Waste Composition Data?**	**N**	
7	**Year Opened:**	**1978**	
8	**Estimated Growth in Annual Disposal:**	**2.0%**	
9	**Average annual precipitation:**	**1,200**	mm/yr
10	**Average Landfill Depth:**	**20.0**	m
11	**Site Design and Management Practices:**	**2**	
12	Methane Content of Landfill Biogas Adjusted to:	**50%**	
13	Methane Correction Factor (MCF):	**1.0**	
14	Fast-decay Organic Waste Methane Generation Rate (k):	**0.23**	1/yr
15	Slow-decay Organic Waste Methane Generation Rate (k):	**0.027**	1/yr
16	Potential Methane Generation Capacity (L_0):	**91.0**	m^3/Mg
17	Fast-decay Organic Waste L_0:	**67.6**	m^3/Mg
18	Slow-decay Organic Waste L_0:	**189.0**	m^3/Mg

Step 9: Enter the amount of wastes disposed (in metric tonnes) for each year the site is open (Cells B25 – B125). See Figure 2. The disposal estimates should be based on available records of actual disposal rates and be consistent with site-specific data on amount of waste in place, total site capacity, and projected closure year. If the landfill has a history of significant fires, an estimated amount or percentage of waste combusted should be subtracted from the annual disposal inputs.

- Enter in the annual disposal rates for years with recorded data.
- For years without historical data, adjust the opening year disposal amount until the calculated total tonnes in place matches estimated actual tonnes in place (as of the most recent year with waste in place data). The estimated annual growth rate (user input in Cell B8) is used to fill in disposal figures for years without data.
- The model uses the estimated growth rate to calculate future waste disposal rates unless the user enters values in cells that provide future disposal inputs. Future disposal estimates should be adjusted to be consistent with estimates of remaining site capacity and closure year.
- Enter a "0" into the cell corresponding to the year following site closure. The model accommodates up to 101 years of waste disposal history.

Step 10: Enter the estimated collection efficiency for each year after a gas collection system was/will be installed (Cells D25 – D125). See Figure 2.

- The input sheet currently has 0% collection efficiency for the first 30 years of site operation and 60% for the remaining years.
- Collection system efficiency for years prior to the present should reflect the status of the collection system in prior years.
- Collection system efficiency for future years should reflect the estimated collection system build-out in future years.
- Additional instruction on how to estimate collection efficiency is provided in Subsection 2.1.1.

Step 11: Enter the actual landfill gas recovery rates in cubic meters per hour (for sites with active gas collection systems) into Cells E25 – E125 (see Figure 2). This should be the average annual total landfill gas flow at the flare station and/or energy recovery plant (NOT the sum of flows at individual wells). Adjust all flow rates to 50% methane equivalent by multiplying the measured flow by the measured methane content of the landfill gas and then dividing the result by 50%. The numbers placed in these cells will be displayed in the graph output sheet, so do not input zeros for years with no flow data (leave blank).

Equation for adjusting methane content to 50%:

$$\text{Measured Flow Rate} \times \frac{\text{Measured methane \%}}{\text{50 \% methane}} = \text{Flow rate at 50\% methane}$$

FIGURE 2. MODEL INPUTS (Continued)

23	A	B	C	D	E
24	**Year**	**Metric Tonnes Disposed**	**Cumulative Metric Tonnes**	**Collection System Efficiency**	**Actual Recovery (m3/hr)**
25	1978	**175,000**	175,000	**0%**	
26	1979	**179,000**	354,000	**0%**	
27	1980	**183,000**	537,000	**0%**	
28	1981	**187,000**	724,000	**0%**	
29	1982	**191,000**	915,000	**0%**	
30	1983	**195,000**	1,110,000	**0%**	
31	1984	**199,000**	1,309,000	**0%**	
32	1985	**203,000**	1,512,000	**0%**	
33	1986	**207,000**	1,719,000	**0%**	
34	1987	**211,000**	1,930,000	**0%**	
35	1988	**215,000**	2,145,000	**0%**	
36	1989	**219,000**	2,364,000	**0%**	
37	1990	**223,000**	2,587,000	**0%**	
38	1991	**227,000**	2,814,000	**0%**	
39	1992	**232,000**	3,046,000	**0%**	
40	1993	**237,000**	3,283,000	**0%**	
41	1994	**242,000**	3,525,000	**0%**	
42	1995	**247,000**	3,772,000	**0%**	
43	1996	**252,000**	4,024,000	**0%**	
44	1997	**257,000**	4,281,000	**0%**	
45	1998	**262,000**	4,543,000	**0%**	
46	1999	**267,000**	4,810,000	**0%**	
47	2000	**272,000**	5,082,000	**0%**	
48	2001	**277,000**	5,359,000	**0%**	
49	2002	**283,000**	5,642,000	**0%**	
50	2003	**289,000**	5,931,000	**0%**	
51	2004	**295,000**	6,226,000	**0%**	
52	2005	**301,000**	6,527,000	**0%**	
53	2006	**307,000**	6,834,000	**0%**	
54	2007	**313,000**	7,147,000	**0%**	
55	2008	**0**	7,147,000	**60%**	**2,500**
56	2009	**0**	7,147,000	**60%**	
57	2010	**0**	7,147,000	**60%**	
58	2011	**0**	7,147,000	**60%**	
59	2012	**0**	7,147,000	**60%**	
60	2013	**0**	7,147,000	**60%**	
61	2014	**0**	7,147,000	**60%**	
62	2015	**0**	7,147,000	**60%**	
63	2016	**0**	7,147,000	**60%**	
64	2017	**0**	7,147,000	**60%**	
65	2018	**0**	7,147,000	**60%**	
66	2019	**0**	7,147,000	**60%**	
67	2020	**0**	7,147,000	**60%**	

2.1.1 Estimating Collection Efficiency

Collection efficiency is a measure of the ability of the gas collection system to capture generated landfill gas. It is a percentage value that is applied to the landfill gas generation projection produced by the model to estimate the amount of landfill gas that is or can be captured for flaring or beneficial use. Although rates of landfill gas capture can be measured, rates of generation in a landfill cannot be measured (hence the need for a model to estimate generation); therefore there is considerable uncertainty regarding actual collection efficiencies achieved at landfills.

In response to the uncertainty regarding collection efficiencies, the U.S. EPA (EPA, 1998) has published what it believes are reasonable collection efficiencies for landfills in the U.S. that meet U.S. design standards and have “comprehensive” gas collection systems. According to the EPA, collection efficiencies at such landfills typically range from 60% to 85%, with an average of 75%. A comprehensive landfill gas collection system is defined as a system of vertical wells and/or horizontal collectors providing 100 percent collection system coverage of all areas with waste within one year after the waste is deposited. Most landfills, particularly those that are still receiving wastes, will have less than 100 percent collection system coverage, and will require a “coverage factor” adjustment to the estimated collection efficiency. Sites with security issues or large numbers of uncontrolled waste pickers will not be able to install equipment in unsecured areas and cannot achieve comprehensive collection system coverage.

Table 6, “Landfill Collection Efficiency,” shows an example of how to estimate the collection efficiency using the landfill characteristics listed and deducting percentages for landfills without these characteristics. For example, if a landfill has all the characteristics listed in Table 6, then the estimated efficiency is 85% times the coverage factor.

TABLE 6: LANDFILL COLLECTION EFFICIENCY

Item No.	Landfill Characteristics	Collection Efficiency Discount	
		Site meets some criteria	Site meets none of the criteria
1	Managed placement of waste, waste compaction, and grading	8%	15%
2	Waste depths at least 8 m, preferably > 15m	5%	10%
3	Soil cover applied over newly deposited refuse at least weekly, preferably on a daily basis. Closed sites should have a final soil cover installed within a few years of closure.	5%	10%
4	A composite bottom liner consisting of synthetic (plastic) layer over 2 feet (0.6 meter) of clay or similar material.	2%	5%
5	A comprehensive landfill gas collection system with vertical wells and/or horizontal collectors providing 100% collection system coverage of all areas with waste within one year after the waste is deposited.	% of filled area without wells	
6	A gas collection system which is operating effectively so that all wells are fully functioning (i.e., relatively free of liquids and drawing landfill gas under vacuum).	% wells not fully functioning or filled with leachate	

Note that the recommended method for estimating collection efficiency assumes that some portion (at least 15%) of generated landfill gas will escape collection, no matter how well designed the landfill or how comprehensive the gas collection system is. The following steps are recommended to adjust the efficiency below 85%:

- To evaluate collection efficiency, start at 85%, and then apply a discount to the extent the site does not meet the criteria of landfill characteristics, as described in Table 6 and below.
- We suggest up to a 15% discount for not meeting item number 1, up to a 10% discount each for not meeting items 2 and 3, and up to a 5% discount for not meeting item number 4 (i.e., a 40% discount to collection efficiency if the landfill does not, even in part, meet any of the first four criteria).
- To account for item number 5, the resulting discounted estimate should then be multiplied by the existing or forecasted collection system coverage of the refuse mass (see glossary for a definition of collection system coverage). Tips to consider when evaluating collection system coverage are provided below.
- The final discount to collection efficiency (item 6 above) involves an evaluation of collection system operations to determine the percentage of operational wells. This evaluation should consider the effect of high leachate levels on limiting LFG

extraction. The determination of whether or not a well is operational should be based on available wellfield monitoring data, including wellhead pressure (all wells should be under vacuum), well methane content, and well oxygen contents (low methane percentages under 40% and high oxygen percentages over 5% indicate that air instead of landfill gas is being drawn into the well). After accounting for the importance of the non-functioning wells (see below), multiply the percentage of operational wells by the value calculated in the above steps to develop a collection efficiency estimate.

- The importance of a non-functioning well should be taken into account when estimating the percentage of non-functioning wells. For example, a site with a non-functioning well in the vicinity of other wells that are functional should cause less of a collection efficiency discount than a site with a non-functioning well that is the only well in the area available to draw landfill gas from a significant portion of the site.

Evaluation of collection system coverage requires a fair degree of familiarity with the system design. Well spacing and depth are important factors. The following describes the various scenarios to consider:

- Deeper wells can draw landfill gas from a larger volume of refuse than shallow wells because greater vacuum can be applied to the wells without drawing in air from the surface.
- Landfills with deep wells (greater than about 20 meters) can effectively collect landfill gas from all areas of the site with vertical well densities as low as two wells or less per hectare.
- Landfills with shallower wells will require greater well densities, perhaps more than 2 wells per hectare, to achieve the same coverage.
- Although landfills with a dense network of wells will collect more total gas than landfills with more widely spaced wells, landfills with a small number of well-spaced wells typically collect more gas per well (due to their ability to influence a larger volume of refuse per well) than wells at landfills with a dense network of wells.

2.2 Model Outputs - Table

Model results are displayed in a table located in the “Outputs-Table” worksheet that is ready for printing with minimal editing (see Figure 3 for a sample table layout). The title of the table has been set by user inputs in the Inputs worksheet. The table provides the following information which was either copied from the Inputs worksheet or calculated by the model:

- Projection years starting with the landfill opening year and ending in a year of the user’s choosing.
- Annual disposal rates.
- Cumulative amount of waste in place for each projection year.

- Landfill gas generation rates for each projection year in cubic meters per hour, cubic feet per minute, and million British Thermal Units (mmBtu) per hour.
- Collection system efficiency for each projection year.
- Landfill gas recovery rates for each projection year in cubic meters per hour, cubic feet per minute, and mmBtus per hour.
- The maximum power plant capacity that could be supported by this flow in MW.
- The estimated baseline landfill gas recovery rate in cubic meters per hour.
- The estimated methane emission reductions in tonnes CH_4/year and in tonnes CO_2e/year
- The methane content assumed for the model projection (50% in most cases).
- The k values used for the model run.
- The L_0 values used for the model run.

The table is set up to display up to 100 years of landfill gas generation and recovery estimates. As provided, the table shows 53 years of information. The last 47 years are in hidden rows. The user will likely want to change the number of years of information displayed, depending on how old the site is and how many years into the future the user wants to display information. Typically, projections up to the year 2030 are adequate for most uses of the model. To hide additional rows, highlight cells in the rows to be hidden and select "Format" "Row" "Hide". To unhide rows, highlight cells in rows above and below rows to be displayed, and select "Format" "Row" "Unhide".

To print the table, select "File" "Print" "OK". The table should print out correctly formatted.

FIGURE 3. SAMPLE MODEL OUTPUT TABLE

TABLE 1
PROJECTION OF BIOGAS GENERATION AND RECOVERY
________ LANDFILL, ________, El SALVADOR

Year	Disposal Rate	Refuse In-Place	LFG Generation			Collection System Efficiency	Predicted LFG Recovery			Maximum Power Plant Capacity*	Methane Emissions Reduction Estimates**	
	(Mg/yr)	(Mg)	(m^3/hr)	(cfm)	(mmBtu/hr)	(%)	(m^3/hr)	(cfm)	(mmBtu/hr)	(MW)	(tonnes CH_4/yr)	(tonnes CO_2eq/yr)
1978	175,000	175,000	0	0	0.0	0%	0	0	0.0	0.0	0	0
1979	179,000	354,000	380	224	6.8	0%	0	0	0.0	0.0	0	0
1980	183,000	537,000	701	413	12.5	0%	0	0	0.0	0.0	0	0
1981	187,000	724,000	975	574	17.4	0%	0	0	0.0	0.0	0	0
1982	191,000	915,000	1,211	713	21.6	0%	0	0	0.0	0.0	0	0
1983	195,000	1,110,000	1,417	834	25.3	0%	0	0	0.0	0.0	0	0
1984	199,000	1,309,000	1,599	941	28.6	0%	0	0	0.0	0.0	0	0
1985	203,000	1,512,000	1,762	1,037	31.5	0%	0	0	0.0	0.0	0	0
1986	207,000	1,719,000	1,910	1,124	34.1	0%	0	0	0.0	0.0	0	0
1987	211,000	1,930,000	2,046	1,204	36.6	0%	0	0	0.0	0.0	0	0
1988	215,000	2,145,000	2,172	1,279	38.8	0%	0	0	0.0	0.0	0	0
1989	219,000	2,364,000	2,291	1,348	40.9	0%	0	0	0.0	0.0	0	0
1990	223,000	2,587,000	2,404	1,415	43.0	0%	0	0	0.0	0.0	0	0
1991	227,000	2,814,000	2,511	1,478	44.9	0%	0	0	0.0	0.0	0	0
1992	232,000	3,046,000	2,615	1,539	46.7	0%	0	0	0.0	0.0	0	0
1993	237,000	3,283,000	2,718	1,600	48.6	0%	0	0	0.0	0.0	0	0
1994	242,000	3,525,000	2,820	1,660	50.4	0%	0	0	0.0	0.0	0	0
1995	247,000	3,772,000	2,922	1,720	52.2	0%	0	0	0.0	0.0	0	0
1996	252,000	4,024,000	3,023	1,779	54.0	0%	0	0	0.0	0.0	0	0
1997	257,000	4,281,000	3,124	1,839	55.8	0%	0	0	0.0	0.0	0	0
1998	262,000	4,543,000	3,224	1,898	57.6	0%	0	0	0.0	0.0	0	0
1999	267,000	4,810,000	3,325	1,957	59.4	0%	0	0	0.0	0.0	0	0
2000	272,000	5,082,000	3,425	2,016	61.2	0%	0	0	0.0	0.0	0	0
2001	277,000	5,359,000	3,526	2,075	63.0	0%	0	0	0.0	0.0	0	0
2002	283,000	5,642,000	3,626	2,134	64.8	0%	0	0	0.0	0.0	0	0
2003	289,000	5,931,000	3,729	2,195	66.6	0%	0	0	0.0	0.0	0	0
2004	295,000	6,226,000	3,833	2,256	68.5	0%	0	0	0.0	0.0	0	0
2005	301,000	6,527,000	3,939	2,318	70.4	0%	0	0	0.0	0.0	0	0
2006	307,000	6,834,000	4,046	2,382	72.3	0%	0	0	0.0	0.0	0	0
2007	313,000	7,147,000	4,154	2,445	74.2	0%	0	0	0.0	0.0	0	0
2008	0	7,147,000	4,264	2,510	76.2	60%	2,558	1,506	45.7	4.2	8,023	168,478
2009	0	7,147,000	3,680	2,166	65.8	60%	2,208	1,300	39.5	3.7	6,925	145,423
2010	0	7,147,000	3,209	1,889	57.3	60%	1,925	1,133	34.4	3.2	6,038	126,797
2011	0	7,147,000	2,827	1,664	50.5	60%	1,696	998	30.3	2.8	5,319	111,698
2012	0	7,147,000	2,516	1,481	45.0	60%	1,509	888	27.0	2.5	4,734	99,410
2013	0	7,147,000	2,262	1,331	40.4	60%	1,357	799	24.2	2.2	4,255	89,362
2014	0	7,147,000	2,052	1,208	36.7	60%	1,231	725	22.0	2.0	3,862	81,103
2015	0	7,147,000	1,880	1,106	33.6	60%	1,128	664	20.2	1.9	3,537	74,271
2016	0	7,147,000	1,736	1,022	31.0	60%	1,041	613	18.6	1.7	3,266	68,581
2017	0	7,147,000	1,615	950	28.9	60%	969	570	17.3	1.6	3,038	63,806
2018	0	7,147,000	1,512	890	27.0	60%	907	534	16.2	1.5	2,846	59,763
2019	0	7,147,000	1,425	839	25.5	60%	855	503	15.3	1.4	2,681	56,310
2020	0	7,147,000	1,350	794	24.1	60%	810	477	14.5	1.3	2,540	53,331
2021	0	7,147,000	1,284	756	22.9	60%	770	453	13.8	1.3	2,416	50,735
2022	0	7,147,000	1,226	722	21.9	60%	736	433	13.1	1.2	2,307	48,450
2023	0	7,147,000	1,175	691	21.0	60%	705	415	12.6	1.2	2,210	46,417
2024	0	7,147,000	1,128	664	20.2	60%	677	399	12.1	1.1	2,123	44,591
2025	0	7,147,000	1,087	640	19.4	60%	652	384	11.6	1.1	2,045	42,935
2026	0	7,147,000	1,048	617	18.7	60%	629	370	11.2	1.0	1,972	41,419
2027	0	7,147,000	1,013	596	18.1	60%	608	358	10.9	1.0	1,906	40,020
2028	0	7,147,000	980	577	17.5	60%	588	346	10.5	1.0	1,844	38,719
2029	0	7,147,000	949	559	17.0	60%	569	335	10.2	0.9	1,786	37,501
2030	0	7,147,000	920	542	16.4	60%	552	325	9.9	0.9	1,731	36,354

MODEL INPUT PARAMETERS:

Assumed Methane Content of LFG:	50%		
	Fast Decay	Slow Decay	Total Site Lo
Methane Generation Rate Constant (k):	0.230	0.027	
Methane Generation Potential (Lo) (m3/Mg	68	189	91

NOTES:

* Maximum power plant capacity assumes a gross heat rate of 10,800 Btus per kW-hr (hhv).

**Emission reductions do not include electricity generation, assume a January 1, 2008 system start-up date, and are calculated using a methane density (at standard temperature and pressure) of 0.000716 Mg/m^3.

2.3 Model Outputs - Graph

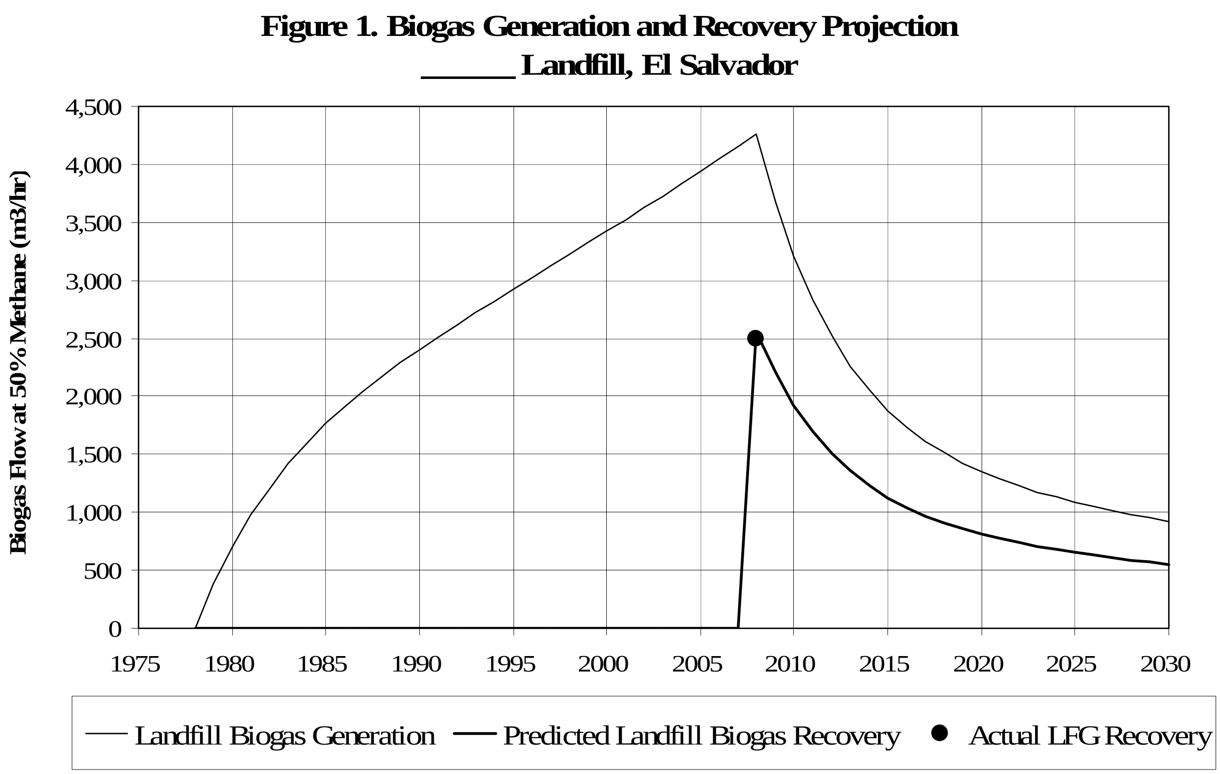
Model results are also displayed in graphical form in the “Outputs-Graph” worksheet (see Figure 4 for a sample graph layout). Data displayed in the graph includes the following:

- Landfill gas generation rates for each projection year in cubic meters per hour
- Landfill gas recovery rates for each projection year in cubic meters per hour.
- Actual (historical) landfill gas recovery rates in cubic meters per hour.

As noted in the instructions listed below the graph, the title of the graph will need to be edited by clicking on the graph title and typing the desired title. The timeline shown in the x-axis will need editing if the user wishes to not have the projection end in 2030. To edit the x-axis for displaying an alternative time period, click on the x-axis and select “Format” “x-axis”. Then select the “Scale” tab and input the desired opening and closing year for the projection. Also, because the graph is linked to the table, it will show data for all projection years shown in the table (given the limits set for the x-axis). It will not show any hidden rows. If the table shows years beyond the range set for the x-axis, the line of the graph will appear to go off of the edge of the graph. To correct this, the user will need to either hide the extra rows or edit the x-axis range to display the additional years.

To print the graph, click anywhere on the graph and select “File” “Print” OK”. If the user does not click on the graph prior to printing, the instructions will also appear in the printout.

FIGURE 4. SAMPLE MODEL OUTPUT GRAPH



3.0 REFERENCES

EPA, 1991. Regulatory Package for New Source Performance Standards and III(d) Guidelines for Municipal Solid Waste Air Emissions. Public Docket No. A-88-09 (proposed May 1991). Research Triangle Park, NC. U.S. Environmental Protection Agency.

EPA, 1998. Compilation of Air Pollutant Emission Factors, AP-42, Volume 1: Stationary Point and Area Sources, 5th ed., Chapter 2.4. Office of Air Quality Planning and Standards. Research Triangle Park, NC. U.S. Environmental Protection Agency.

EPA, 2005. Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide. EPA-600/R-05/047 (May 2005), Research Triangle Park, NC. U.S. Environmental Protection Agency.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change (IPCC), Volume 5 (Waste), Chapter 3 (Solid Waste Disposal), Table 3.1.

UNFCCC, 2006. Revision to the approved baseline methodology AM0025,"Avoided from organic waste through alternative waste treatment processes." United Nations Framework Convention on Climate Change (UNFCCC), 03 March 2006.