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User's Manual
Mexico Landfill Gas Model

Version 2.0

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DISCLAIMER

This user's guide has been prepared specifically for Mexico on behalf of the Landfill Methane Outreach Program, U.S. Environmental Protection Agency, as part of the Methane to Markets program activities in Mexico. 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 guide 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, Mexico Landfill Gas Model Version 2.0 (Model), for estimating landfill gas (LFG) generation and recovery from municipal solid waste landfills in Mexico. The Model was developed by SCS Engineers under contract to the U.S. EPA's Landfill Methane Outreach Program (LMOP). The 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 Mexico.

The Model is an Excel® spreadsheet model that calculates LFG generation by applying a first order decay equation. The model requires the user to input site-specific data for landfill opening and closing years, refuse disposal rates, landfill location, and to answer several questions regarding the past and current physical conditions of the landfill. The model provides default values for waste composition and input variables (k and L_0) for each state and estimates the collection efficiency based on the answers provided. The default values were developed using data on climate, waste characteristics, and disposal practices in Mexico, and the estimated effect of these conditions on the amounts and rates of LFG generation. Actual LFG recovery rates from four landfills in Mexico were evaluated to help guide the selection of model k and L_0 values.

The 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 Version 1.0 and the Intergovernmental Panel on Climate Change (IPCC) 2006 Waste Model (IPCC Model). The Model incorporated waste composition data used to develop the Mexico LFG Model Version 1.0 and expanded the data to include information from additional cities and landfills throughout Mexico. The Model also incorporated the structure of the IPCC Model with revised input assumptions to make it better reflect local climate and conditions at disposal sites in Mexico.

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GLOSSARY OF TERMS

Actual Landfill Gas (LFG) Recovery (m^3/hr at 50% CH_4) - Annual average LFG recovery recorded at the blower/flare station in cubic meters per hour normalized at 50% methane. For instructions on how to normalize to 50% see Section 2.2 of the manual.

Baseline Landfill Gas (LFG) Recovery (m^3/hr at 50% CH_4) - This term is applicable for projects looking to pursue carbon credits and is defined as the amount of LFG recovery that was occurring prior to the start up of the LFG project and would continue to occur (as required by applicable regulations or common practices). For a precise definition of baseline recovery and emissions for Clean Development Mechanism (CDM) projects, please refer to the "Glossary of CDM Terms" available on the UNFCCC website at: http://cdm.unfccc.int/Reference/Guidclarif/glos_CDM_v04.pdf

Closure Year - The year in which the landfill ceases, or is expected to cease, accepting waste.

Collection System Efficiency - The estimated percentage of generated landfill gas which is or can be collected in a gas collection system. Collection efficiency is a function of both collection system coverage and the efficiency of collection system operations.

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.

Design Capacity of the Landfill - The total amount of refuse that can be disposed of in the landfill, calculated in terms of volume (m^3) or mass (Mg).

Garden Waste – The fraction of the total waste stream that contains plants trimmings from homes or city parks (also known as green waste).

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.

Landfill Gas (LFG) Generation - Total amount of LFG produced by the decomposition of the organic waste present at a landfill.

Landfill Gas (LFG) Recovery - The fraction of the LFG generation that is or can be captured by a landfill gas collection and control system. Modeled LFG recovery is calculated by multiplying the LFG generation rate by the collection system efficiency.

Managed Landfill - 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.

Methane Correction Factor (MCF).- Adjustment to model estimates of LFG generation that accounts for the degree to which waste decays anaerobically (See section 1.2.2.1 for more details).

Methane Generation Rate Constant (k).- Model constant that determines the estimated rate at which waste decays and generates LFG. The k value is related to the half-life of waste ($t_{1/2}$) according to the formula: $t_{1/2} = \frac{\ln(2)}{k}$. The k is a function of the moisture content in the landfill refuse, availability of nutrients for methanogens, pH, and temperature. (Units = 1/year).

Potential Methane Generation Capacity (L_o).- Model constant that represents the maximum amount of methane (a primary constituent of LFG) which can be generated from a fixed amount of waste, given an infinite period of time for it to decompose. L_o depends on the amount of cellulose in the refuse. (Units = m^3/Mg).

Semi-Aerobic Landfill - 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, and gas ventilation system.

Unmanaged Waste Disposal Site – An unmanaged waste disposal site is a dump site that does not meet the definition of a managed waste disposal site.

Waste Disposal Estimates (Metric Tonnes or Mg).- Annual total waste disposal tonnages recorded at the scale-house or estimated using other methods.

1.0 INTRODUCTION

Landfill gas (LFG) is generated by the decomposition of refuse in a landfill under anaerobic conditions, and can be recovered through the operation of gas collection and control systems that typically burns the gas in flares. Alternatively, the collected gas can be used beneficially. Beneficial uses of LFG 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 or heat generation.

In addition to the energy benefits from the beneficial use of LFG, collection and control of generated LFG helps to reduce LFG emissions that are harmful to the environment. The U.S. EPA has determined that LFG emissions from municipal solid waste (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 LFG 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 Mexico LFG Model (Model) is to provide landfill owners and operators in Mexico with a tool to use to evaluate the feasibility and potential benefits of collecting and using the generated LFG for energy recovery or other uses. To fulfill this purpose, the Model uses Excel® spreadsheet software to calculate LFG generation by applying a first order decay equation. The Model provides LFG recovery estimates by multiplying the calculated amount of LFG generation by estimates of the efficiency of the collection system in capturing generated gas, which is known as the collection efficiency.

The Model uses the following information to estimate LFG generation and recovery from a landfill (see the Glossary of Terms):

- The amounts of waste disposed at the landfill annually.
- The opening and closing years of landfill operation.
- The methane generation rate (k) constant.
- The potential methane generation capacity (L_0).
- The methane correction factor (MCF).
- The fire adjustment factor (F).

- The collection efficiency of the gas collection system.

The model estimates the LFG generation rate in a given year using the following first-order exponential equation which was modified from the U.S. EPA's Landfill Gas Emissions Model (LandGEM) version 3.02 (EPA, 2005).

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left[\frac{M_i}{10}\right] (e^{-kt_{ij}}) \text{ (MCF) (F)}$$

Where:

Q_{LFG} = 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 M_i disposed in the i^{th} year (decimal years)
MCF = methane correction factor
F = fire adjustment factor.

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 equation. Total LFG generation is equal to two times the calculated methane generation.[1] The exponential decay function 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. 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 Model estimates of LFG generation and recovery in cubic meters per hour (m^3/hr) and cubic feet per minute (cfm). It also estimates the energy content of generated and recovered LFG in million British Thermal Units per hour (mmBtu/hr), the system collection efficiency, the maximum power plant capacity that could be fueled by the collected LFG (MW), and the emission reductions in tonnes of CO_2 equivalent (CERs) achieved by the collection and combustion of the LFG.

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[1] The composition of landfill gas is assumed by the Model to consist of 50 percent methane (CH_4) and 50 percent other gases, including carbon dioxide (CO_2) and trace amounts of other compounds.

The Model can either calculate annual waste disposal rates and collection efficiency automatically using the information provided by the user in the "Inputs" worksheet, or the user can manually input annual waste disposal rates and collection efficiency estimates in the "Disposal & LFG Recovery" worksheet. The model automatically assigns values for k and L_0 based on climate and waste composition data. The k values vary depending on climate and waste group. The L_0 values vary depending on waste group. Climate is categorized into one of five climate regions within Mexico based on average annual precipitation and temperature (see Figure 1). Each state is assigned to a climate region. Waste categories are assigned to one of five groups, including four organic waste groups based on waste decay rates, and one inorganic waste group. If site-specific waste composition data are available, the user can enter the waste composition data in the "Waste Composition" worksheet. Otherwise, the model will assign the default waste composition percentages for the selected state, which are based on waste composition data gathered from the state or from other states within the same climate region.

Figure 1. Mexico Climate Regions

The annual waste disposal rates, k and L_0 values, methane correction and fire adjustment factors, and collection efficiency estimates are used to produce LFG generation and recovery estimates for landfills located in each state in Mexico. Model results are displayed in the “Output-Table” and “Output-Graph” worksheets.

EPA recognizes that modeling LFG 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 Mexico develop gas collection and control systems, additional data on LFG generation and recovery will become available for model calibration and the development of improved model default values.

Questions and comments concerning the LFG model should be directed to Victoria Ludwig of EPA's LMOP at Ludwig.Victoria@epamail.epa.gov.

2.0 MODEL DESCRIPTION

2.1 Background on the Old (Version 1.0) Mexico LFG Model

The first version of the Mexico Landfill Gas Model (v. 1.0), which was presented in December 2003, was developed by SCS Engineers for the SEDESOL, IIE and CONAE under a contract with LMOP and USAID. This model applied single k and L_0 values to the LandGEM equation which were assigned based on average annual precipitation at the landfill location. The k values were estimated based on models prepared for two landfills in Mexico and general observations at U.S. landfills regarding the variation in k with precipitation. The L_0 values were assigned based on the average composition of wastes in Mexico, derived from data from 31 cities.

In 2008, LMOP contracted with SCS Engineers to develop an updated and improved version of the Mexico LFG Model. Some of the shortcomings of the original model which were targeted for revision included the following:

- The model assumed an average waste composition for all of Mexico and did not account for region or state-specific variations, or allow for the user to input site-specific waste composition values if available. Variations in waste composition can have a large impact on LFG generation. For example, Mexico City has a significantly lower organic content in the waste stream.
- The application of a single k value in the LandGEM equation assumes a single decay rate for all wastes in a landfill and does not account for variations in the average decay rates over time. This becomes a significant source of error when a large percentage of wastes consists of food and other rapidly decaying materials. In Mexico and other developing countries with a large food waste component, single k models tend to over-estimate LFG generation in wet climates after the landfill closes and under-estimate LFG generation in dry climates while the landfill is still receiving wastes.
- The default k values were based on a limited amount of data from only two landfills (Simeprodeso Landfill in Monterrey was the only site with complete flow data).
- The model used an outdated version of the LandGEM equation.
- The model did not include estimates of certified emission reductions (CERs).
- The model required the user to input detailed waste disposal rates and to evaluate collection efficiency.

2.2 Mexico LFG Model Version 2.0

The Mexico LFG Model Version 2.0 (March 2009) provides an automated estimation tool for quantifying LFG generation and recovery from MSW landfills in all states of Mexico. The Model applies separate equations to calculate LFG generation from each of the following four organic waste[2] categories that are grouped according to waste decay rates:

1. Very fast decaying waste – food waste, other organics, 20% of diapers.
2. Medium fast decaying waste – garden waste (green waste), toilet paper.
3. Medium slow decaying waste – paper and cardboard, textiles.
4. Slowly decaying waste – wood, rubber, leather, bones, straw.

Total LFG generation for all wastes is calculated as the sum of the amounts of LFG generated by each of the four organic waste categories. Each of the four organic waste groups are assigned different k and L_0 pairs that are used to calculate LFG generation. The Model's calculations of LFG generation also include an adjustment to account for aerobic waste decay known as the methane correction factor (MCF), and an adjustment to account for the extent to which the site has been impacted by fires. LFG recovery is estimated by the Model by multiplying projected LFG generation by the estimated collection efficiency. Each of these variables – k, L_0, MCF, fire impact adjustments, and collection efficiency – are discussed in detail below.

2.2.1 Model k Values

The methane generation rate constant, k, determines the rate of generation of methane from refuse in the landfill. The units for k are in $year^{-1}$. The k value describes the rate at which refuse placed in a landfill decays and produces methane, and is related to the half-life of waste according to the equation: half-life = ln(2)/k. 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. Moisture conditions inside a landfill typically are not well known and are estimated based on average annual precipitation. Availability of nutrients is a function of waste amounts and waste composition. The pH inside a landfill is generally unknown and is not evaluated in the model. Temperature in a landfill is relatively constant due to the heat generated by anaerobic bacteria and tends to be independent of outside temperature except in shallow landfills in very cold climates. Therefore the Model estimates k values based on waste type and climate.

The four waste categories listed above have been assigned different k values to reflect differences in waste decay rates. The k values assigned to each of the four waste groups also vary based on the average annual precipitation in the climate region where the landfill is located. Each state is assigned to one of the 5 climate regions shown in Figure 1 based on average annual precipitation.[3] The k values that the Model uses for each waste category and region are shown in Table 1.

Table 1: Methane Generation Rate (k) Values by Waste Category and Region

Waste Category	Region 1	Region 2	Region 3	Region 4	Region 5
	Southeast	West	Central / Interior*	Northeast	Northeast & Interior North
1	0.300	0.220	0.160	0.150	0.100
2	0.130	0.100	0.075	0.070	0.050
3	0.050	0.040	0.032	0.030	0.020
4	0.025	0.020	0.016	0.015	0.010

*Includes Federal District

2.2.2 Waste Composition and Potential Methane Generation Capacity (L_0)

The value for the potential methane generation capacity of refuse (L_0) describes the total amount of methane gas potentially produced by a tonne of refuse as it decays, and depends almost exclusively on the composition of wastes in the landfill. A higher cellulose content in refuse results in a higher value of L_0. The units of L_0 are in cubic meters per tonne of refuse (m^3/Mg). The values of theoretical and obtainable L_0 range from 6.2 to 270 m^3/Mg refuse (EPA, 1991).

The L_0 values used in the Model are derived from waste composition data from 40 cities (including 3 landfills in Mexico City) that represent 18 states and the Federal District. Average waste composition was calculated for each state and each region using population

[2] Inorganic waste does not generate LFG and is excluded from the model calculations.
[3] A state's average annual precipitation was estimated using data from www.worldclimate.com, www.weatherbase.com, or www.worldweather.org from the state's largest cities. State's averages were calculated from the data using population as a weighting factor.

to weight the contribution of each data set to the average. States that had no waste composition data available were assigned the regional average waste composition. Default waste composition values for each state are used by the Model unless the user indicates that they have site-specific waste composition data in the "Inputs" worksheet and enters the data in the "Waste Composition" worksheet.

The model uses the state default or site-specific waste composition data to calculate L_0 values for each of the four waste categories. The L_0 values which are used by the Model are shown in Table 2. The L_0 values for each waste group are assumed to remain constant across all climates, except for Category 2, which will have some variation with climate due to differences in the types of vegetation included in the green waste.

Table 2: Potential Methane Generation Capacity (L_0) Values

Waste Category	Region 1	Region 2	Region 3	Region 4	Region 5
	Southeast	West	Central / Interior*	Northeast	Northeast & Interior North
1	69	69	69	69	69
2	115	126	138	138	149
3	214	214	214	214	214
4	202	202	202	202	202

*Includes Federal District

2.2.3 Methane Correction Factor

The Methane Correction Factor (MCF) is an adjustment to model estimates of LFG generation that accounts for the degree to which wastes decay aerobically. The MCF varies depending on waste depth and landfill type, as defined by site management practices. At managed, sanitary landfills, all waste decay is assumed to 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 3 summarizes the MCF adjustments applied by the model based on information on waste depths and site management practices that are provided by the user in response to Questions #11 and #12 in the "Inputs" worksheet.

Table 3: 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	0.4	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, and gas ventilation system (IPCC, 2006).

2.2.4 Adjustments for Fire Impacts

Landfill fires consume waste as a fuel and leave behind ash that does not produce LFG. LFG generation can be significantly impacted at landfills that have had a history of fires. Model users are asked if the site has been impacted by fires in Question 13a in the "Inputs" worksheet. If the answer is yes, the user is asked to answer questions on the percent of landfill area impacted by fires and the severity of fire impacts. The Model discounts LFG generation by the percent of landfill area impacted multiplied by an adjustment for severity of impacts (1/3 for low impacts, 2/3 for medium impacts, and 1 for severe impacts).

2.2.5 Estimating Collection Efficiency and LFG Recovery

Collection efficiency is a measure of the ability of the gas collection system to capture generated LFG. It is a function of both system design (how much of the landfill does the system collect from?) and system operations and maintenance (is the system operated efficiently and well-maintained?). Collection efficiency is a percentage value that is applied to the LFG generation projection produced by the model to estimate the amount of LFG that is or can be recovered for flaring or beneficial use. Although rates of LFG recovery can be measured, rates of generation in a landfill cannot be measured (hence the need for a model to estimate generation); therefore considerable uncertainty exists regarding actual collection efficiencies achieved at landfills.

In response to the uncertainty regarding collection efficiencies, the U.S. EPA (EPA, 1998) published what it believed 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%. More recently, a report by the Intergovernmental Panel on Climate Change (IPCC, 2006) stated that ">90% recovery can be achieved at cells with final cover and an efficient gas extraction system." While modern sanitary landfills in Mexico can achieve maximum collection efficiencies of greater than 90% under the best conditions, unmanaged disposal sites may never exceed 50% collection efficiency even with a comprehensive system.

The Model calculates collection efficiency automatically based on user responses to a series of questions in the "Inputs" worksheet. The calculation method that the model uses is described below in Subsection 2.2.5.1. Alternatively, the user can override the Model's calculations and manually input estimated collection efficiencies. We recommend that the user keep the automatic collection efficiency calculations intact unless the site already has a gas collection system in place and flow data is available. The process for manually adjusting collection efficiency so that the LFG recovery rates projected by the Model match actual recovery are described in Subsection 2.2.5.2.

2.2.5.1 Model Calculation of Collection Efficiency

The Model automatically calculates collection efficiency based on the following factors:

- Collection system coverage – collection efficiency is directly related to the extent of wellfield coverage of the refuse mass.
- Waste depth – shallow landfills require shallow wells which are less efficient because they are more prone to air infiltration.
- Cover type and extent – collection efficiencies will be highest at landfills with a low permeable soil cover over all areas with waste, which limits the release of LFG into the atmosphere, air infiltration into the gas system, and rainfall infiltration into the waste.
- Landfill liner – landfills with clay or synthetic liners will have lower rates of LFG migration into surrounding soils, resulting in higher collection efficiencies.

- Waste compaction – uncompacted waste will have higher air infiltration and lower gas quality, and thus lower collection efficiency.
- Size of the active disposal (“tipping”) area – unmanaged disposal sites with large tipping areas will tend to have lower collection efficiencies than managed sites where disposal is directed to specific tipping areas.
- Leachate management – high leachate levels can dramatically limit collection efficiencies, particularly at landfills with high rainfall, poor drainage, and limited soil cover.

Each of these factors are discussed below. While answering the questions in the Inputs worksheet which are described below, the model user should understand that conditions which affect collection efficiency can change over time as landfill conditions change. For example, the landfill depth or the estimated percentages of area with each cover type (final, intermediate, and daily) often will change over time. We recommend that the model user’s answers to the questions reflect current conditions if a gas collection system is already installed. If no system is installed, the model user should try to estimate the future conditions that will occur in the year that the system will begin operation. The calculated collection efficiency will then reflect conditions in the current year or the first year of system operation. Adjustments to later years’ collection efficiency estimates can be guided by actual recovery data using a process that is described in Subsection 2.2.5.2.

Collection System Coverage

Collection system coverage describes the percentage of the waste that is within the influence of the existing or planned extraction wells. It accounts for system design and the efficiency of wellfield operations. Most landfills, particularly those that are still receiving wastes, will have considerably less than 100 percent collection system coverage. Sites with security issues or large numbers of uncontrolled waste pickers will not be able to install equipment in unsecured areas and cannot achieve good collection system coverage.

The Model user is requested to estimate current or future collection system coverage in Question #15 of the “Inputs” worksheet, which asks for “Percent of waste area with wells.” Estimates of collection system coverage at landfills with systems already in operation should include discounts for non-functioning wells. The importance of a non-functioning well should be taken into account when estimating the discount for 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 LFG 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 LFG 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 LFG 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.

Waste Depth

Deeper waste depths allow deeper wells to be installed. As noted in the above discussion of collection system coverage, deeper wells can operate more effectively than shallow wells because a greater vacuum can be applied to the wells. Wells installed in shallow waste less than about 10m will tend to have greater air infiltration. Model users are requested to input average landfill depth in Question #11 in the “Inputs” worksheet. The Model assumes a 5% discount to estimated collection efficiency for every 1m of waste depth less than 10m.

Cover Type and Extent

The type and extent of landfill cover can have a significant influence on achievable collection efficiency. Unmanaged disposal sites with little or no soil cover will have high rates of LFG emissions into the atmosphere and air infiltration into the collection system, resulting in lower rates of LFG capture. Areas without a soil cover also will have high rates of rainfall infiltration, causing leachate levels to build up and cause the gas collection system to be blocked with liquids. Installation of a soil cover will decrease LFG emissions and lower air and rainfall infiltration. These effects will depend on cover permeability, cover thickness, and the percentage of landfill area with cover. Typically, a final cover will have the greatest thickness and lowest permeability and will be the most effective in terms of increasing collection efficiency. Most landfills will have at least an intermediate soil cover installed over areas that have not been used for disposal for an extended period; intermediate soils provide a moderate level of control over air infiltration, LFG emissions, and rainfall infiltration. Daily soil cover typically is a shallower layer of soil that is installed at the end of the day in active disposal areas and provides a more permeable barrier to air and water than final or intermediate cover soils.

Model users are asked to estimate the percentage of landfill area with each soil cover type in Questions #16, 17, and 18 in the "Inputs" worksheet. The Model automatically calculates the percentage of landfill area with no soil cover as the remaining area. The Model calculates a weighted average collection efficiency adjustment to account for the percentages of each soil cover type by assigning 90% collection efficiency to the percentage of landfill area with final cover, 80% collection efficiency to the percentage of landfill area with intermediate cover, 75% collection efficiency to the percentage of landfill area with daily soil cover, and 50% collection efficiency to the percentage of landfill area with no soil cover.

Landfill Liner

Clay or synthetic bottom liners act as a low-permeability barrier which is effective at limiting off-site LFG migration into surrounding soils, particularly when there is an active LFG collection system operating. Model users are asked to estimate the percentage of landfill area with a clay or synthetic bottom liner in Question #20 in the "Inputs" worksheet. The Model calculates a discount to collection efficiency equal to 5% times the percent area without a clay or synthetic liner.

Waste Compaction

Waste compaction helps promote anaerobic waste decay and tends to improve collection efficiency by limiting air infiltration and improving gas quality. Model users are asked if waste compaction occurs on a regular basis in Question #21 of the "Inputs" worksheet. Collection efficiency is discounted by 3% if regular waste compaction does not occur.

Focused Tipping Area

Landfills where waste delivery trucks are directed to unload wastes in a specific area will provide better management of disposed wastes, including more efficient compaction, more frequent and extensive soil covering of exposed wastes, and higher waste depths, all of which contribute to higher collection efficiencies. Model users are asked if waste is delivered to a focused tipping area in Question #22 of the "Inputs" worksheet. Collection efficiency is discounted by 5% if waste is not delivered to a focused tipping area.

Leachate

Leachate almost always limits effective collection system operations at landfills in developing countries due to the high waste moisture content and the lack of proper drainage. Areas with heavy rainfall are especially susceptible to leachate buildup in the landfill. High leachate levels in a landfill can dramatically limit collection efficiency by blocking well perforations and preventing wells from applying vacuum to draw in LFG from the surrounding waste mass. Unless the climate is extremely dry or the landfill has been designed to provide good management of liquids through proper surface drainage and cost effective systems for collection and treatment of leachate, the landfill often will show signs of the accumulation of liquids through surface seeps or ponding. This evidence of high leachate levels in the landfill may be temporary features that appear only after rainstorms, suggesting that leachate problems may be less severe, or they may persist for longer periods, suggesting that high leachate levels are an ongoing problem.

The impacts of leachate on collection efficiency are evaluated by the Model based on evidence of leachate at the landfill surface, whether the evidence appears only after rainstorms, and climate. Model users are asked if the landfill experiences leachate surface seeps or surface ponding in Question 23a of the "Inputs" worksheet. If the answer is yes, the Model user is asked in Question 23b if this occurs only after rainstorms. If evidence of leachate accumulation appears only after rainstorms, the Model applies a 2% to 15% discount to collection efficiency depending on climate (rainy climates receive a higher discount). If the evidence of leachate accumulation persists between rainstorms, the Model applies a 10% to 40% discount to collection efficiency, depending on climate.

Model Estimate of Collection Efficiency

The Model calculates collection efficiency as the product of all the factors listed above. If the collection efficiency factor involves a discount, a value of one minus the discount is used in the calculation. Each step in the collection efficiency calculation and the resulting collection efficiency estimate are shown in Cells J15 through J22 of the “Disposal & LFG Recovery” worksheet. The calculated collection efficiency value also is displayed in Column D of the “Disposal & LFG Recovery” worksheet for each year starting with the year of initial collection system start up indicated by the Model user in response to Question #14 in the “Inputs” worksheet.

2.2.5.2 Adjustments to Collection Efficiency

Accurate estimates of collection efficiency can be difficult to achieve, given all of the influencing factors described above. The accuracy of the estimate tends to be higher when collection efficiency is high and lower when collection efficiency is low. This is because determining that collection system design and operations are being optimized is easier than estimating how much discount should be applied to the collection efficiency estimate when multiple factors create sub-optimal conditions for LFG extraction. The Model is intended to be used by non-professionals who are not trained in methods for evaluating collection efficiency. For this reason, we recommend that the Model’s calculations of collection efficiency be left intact for most applications. The one exception is for modeling sites with active LFG collection systems installed and actual flow data available for comparison to the Model’s recovery estimates.

If the flow data includes both LFG flows and the methane content of the LFG, and includes an extended period of system operation (enough to represent average recovery for a year), we recommend adjusting the collection efficiency estimates. Actual LFG recovery data should be adjusted to 50% methane equivalent (by calculating methane flows and multiplying by 2) and then averaged on an annual basis. The resulting estimate of actual LFG recovery should be entered into the appropriate row in Column E of the “Disposal & LFG Recovery” worksheet. Collection efficiency estimates in Column D of the “Disposal & LFG Recovery” worksheet can then be adjusted so that the Model’s projected LFG recovery rate shown in Column F closely matches the actual LFG recovery rate.

3.0 MODEL INSTRUCTIONS

The LFG Model is a Microsoft Excel® spreadsheet operated in a Windows XP® or Vista environment. Open the Model file ("Mexico LFG Model v.2.xls") by choosing "file" "open," and then "open" when the correct file is highlighted. The Model has five worksheets that are accessible by clicking on the tabs at the bottom of the Excel® window screen. The five worksheets are as follows:

1. **Inputs**. This worksheet will ask the user a series of 24 questions. Depending on the answers of these questions the Model will select the appropriate default values for k, L_0, MCF, fire adjustment factor, and collection efficiency. The Model also will develop annual disposal rate estimates.
2. **Disposal & LFG Recovery**. This worksheet will provide the user the opportunity to enter annual disposal rates, actual LFG recovery rates, and baseline LFG recovery, if available. If actual LFG recovery data are available, the user also can make adjustments to the Model's automated estimates of collection efficiency so that projected recovery matches actual recovery.
3. **Waste Composition**. This worksheet will provide the user the opportunity to enter site-specific waste characterization data if available.
4. **Output-Table**. This worksheet will provide the results of the model in a tabular form.
5. **Output-Graph**. This worksheet will provide the results of the model in a graphic form.

All worksheets have been divided in the following two sections:

- **Input Section**: This section has a blue background and is the location where questions need to be answered or information must be provided. Cells with text in white provide instructions or calculations and cannot be edited. Cells with text in yellow require user inputs or edits. In some instances dropdown menus are provided to limit user inputs to "Yes" or "No" answers or to a specific list of possible inputs (e.g. state names).
- **Instruction Section**: This section has a light blue background and provides specific instructions on how to answer questions or input information.

3.1 Inputs Worksheet

The "Inputs" worksheet has 27 rows of text which require user inputs in Column C for 24 items. All 24 questions or phrases that have yellow text in Column C need to be responded to with site-specific information (items 4, 19, and 24 are calculated automatically and do not require user inputs). Some questions will have drop-down menus in their answer cell to guide the user and limit the range of answers. A drop-down menu will appear when the user selects cells with drop-down menus; the user should select a response from the list of items in the drop-down menu. Figure 2 below shows the layout of the Inputs Section showing all questions and user inputs.

Instructions on each item in the Inputs Section are provided on the corresponding row in the Instruction Section. Figure 3 shows the layout of the Instruction Section.

3.2 Disposal & LFG Recovery Worksheet

The "Disposal & LFG Recovery" worksheet (Figure 4) does not require user inputs but provides the user the ability to change automatically calculated annual estimates for waste disposal and collection system efficiency, and assumed values for actual LFG recovery and baseline LFG recovery (0 m^3/hr). Each of these inputs are described below.

3.2.1 Waste Disposal Estimates

The user is encouraged to input annual disposal estimates in Column B for years that data are available. Enter the waste disposal estimates in metric tonnes (Mg) for each year with disposal data; leave the calculated disposal estimates for years without disposal data, including future years. The disposal estimates should be based on available records of actual disposal rates and be consistent with site-specific data on amounts of waste in place, total site capacity, and projected closure year. Disposal estimates should exclude soil and other waste items that are not accounted for in the waste composition data (see "Waste Composition" worksheet).

Mexico Landfill Gas Model v.2

Release Date: March 2009

Methane to Markets Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY INPUT WORKSHEET			
1	Landfill name:	Simeprodeso Landfill	
2	City:	Monterrey	
3	State:	Nuevo Leon	
4	Region:	Northeast	4
5	Site-specific waste composition data?	Yes	
6	Year opened:	1978	
7	Annual disposal in 2008 or most recent year:	200,000	Mg
8	Year of disposal estimate:	2006	
9	Projected or actual closure year:	2007	
10	Estimated growth in annual disposal:	2.0%	
11	Average landfill depth:	20	m
12	Site design and management practices:	2	
13a	Has site been impacted by fires?	Yes	
13b	If 13a answer is Yes, indicate % of landfill area impacted:	30%	
13c	If 13a answer is Yes, indicate the severity of fire impacts:	1	
14	Year of initial collection system start up:	2009	
15	Percent of waste area with wells:	90%	
16	Percent of waste area with final cover:	0%	
17	Percent of waste area with intermediate cover:	0%	
18	Percent of waste area with daily cover:	100%	
19	Percent of waste area with no soil cover:	0%	
20	Percent of waste area with clay or synthetic liner:	100%	
21	Is waste compacted on a regular basis?	Yes	
22	Is waste delivered to a focused tipping area?	Yes	
23a	Does the landfill experience leachate surface seeps or surface ponding?	Yes	
23b	If 23a answer is yes, does this occur only after rainstorms?	No	
24	Collection efficiency estimate:	57%	

Figure 2. Inputs Section, Inputs Worksheet

INSTRUCTIONS:

Edit all items with yellow lettering following the instructions next to each item. Items with white lettering cannot be changed. Instructions below describe input requirements.

1. Enter landfill name. This will feed into the Output Table.

2. Enter city where the landfill is located. This will feed into the Output Table.

3. Select state from the dropdown menu. Click on arrow and select state.

4. Software will automatically assign the region based on the state location and climate.

5. Select No if there is no data, Yes if there is data. If Yes, input site specific data in Waste Composition worksheet.

6. Enter year landfill began receiving waste.

7. Enter disposal in 2008 or most recent year of disposal before site closure. If multiple years of disposal data are available, enter annual tonnes disposed for each year with data in Disposal & LFG Recovery worksheet.

8. Enter most recent year of disposal reflecting tonnes listed above.

9. Enter actual or projected year landfill stops receiving waste.

10. Enter estimated porcentage annual growth in disposal

11. Enter average waste depth in meters.

12. Select value from dropdown menu: 1=Unmanaged disposal site; 2=Engineered/sanitary landfill; 3=Semi-aerobic landfill; 4=Unknown. See Users Manual for definitions of each category.

13a. Select Yes or No from dropdown menu. If unknown, select No.

13b. If 13a answer is yes (impacted by fires) estimate % area impacted.

13c. If 13a answer is yes, estimate severity of impacts (1=low impacts; 2=medium impacts; 3=severe impacts)

14. If no system is installed, give projected year of system installation

15. Enter a value up to 100% for current or future wellfield coverage of waste footprint (active disposal sites will be < 100%)

16. Enter a value up to 100% for % of waste area with final cover

17. Enter a value up to 100% for % of waste area with intermediate cover but no final cover

18. Enter a value up to 100% for % of waste area with daily cover only

19. Value automatically calculated as the remaining area

20. Enter a value up to 100% for % of waste area with clay or synthetic liner

21. Select Yes or No from dropdown menu.

22. Select Yes or No from dropdown menu.

23a. Select Yes or No from dropdown menu.

23b. If 23a answer is yes, indicate if seeps or ponding occur only immediately following rainstorms.

24. This value is calculated based on the inputs above.

Figure 3. Instructions Section, Inputs Worksheet

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Release Date: March 2009

Methane to Markets Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

DISPOSAL AND LFG RECOVERY WORKSHEET

Year	Waste Disposal Estimates (Metric Tonnes)	Cumulative Metric Tonnes	Collection System Efficiency	Actual LFG Recovery (m3/hr at 50% CH4)	Projected LFG Recovery (m3/hr at 50% CH4)	Baseline LFG Recovery (m3/hr at 50% CH4)
1978	114,900	114,900	0%		0	0
1979	117,200	232,100	0%		0	0
1980	119,500	351,600	0%		0	0
1981	121,900	473,500	0%		0	0
1982	124,300	597,800	0%		0	0
1983	126,800	724,600	0%		0	0
1984	129,300	853,900	0%		0	0
1985	131,900	985,800	0%		0	0
1986	134,500	1,120,300	0%		0	0
1987	137,200	1,257,500	0%		0	0
1988	139,900	1,397,400	0%		0	0
1989	142,700	1,540,100	0%		0	0
1990	145,600	1,685,700	0%		0	0
1991	148,500	1,834,200	0%		0	0
1992	151,500	1,985,700	0%		0	0
1993	154,500	2,140,200	0%		0	0
1994	157,600	2,297,800	0%		0	0
1995	160,800	2,458,600	0%		0	0
1996	164,000	2,622,600	0%		0	0
1997	167,300	2,789,900	0%		0	0
1998	170,600	2,960,500	0%		0	0
1999	174,000	3,134,500	0%		0	0
2000	177,500	3,312,000	0%		0	0
2001	181,100	3,493,100	0%		0	0
2002	184,700	3,677,800	0%		0	0
2003	188,400	3,866,200	0%		0	0
2004	192,200	4,058,400	0%		0	0
2005	196,000	4,254,400	0%		0	0
2006	200,000	4,454,400	0%		0	0
2007	204,000	4,658,400	0%		0	0
2008	0	4,658,400	0%		0	0
2009	0	4,658,400	57%		1,147	0
2010	0	4,658,400	57%		1,078	0
2011	0	4,658,400	57%		1,015	0
2012	0	4,658,400	57%		958	0

Figure 4. Inputs Section, Disposal & LFG Recovery Worksheet

3.2.2 Actual LFG Recovery

If available, actual LFG recovery data from operating LFG collection systems should be converted to m^3/hr, adjusted to 50% methane equivalent, and averaged using the following process:

- Multiply each measured value for the LFG flow rate by the methane percentage at the time of the measured flow to calculate methane flow.
- Convert units to m^3/hr if necessary.
- Calculate the average methane flow rate using all data for the calendar year.
- Convert to LFG flow at 50% methane equivalent by multiplying by 2.

The calculated average LFG recovery rate should be the average annual total LFG flow at the flare station and/or energy recovery plant (NOT the sum of flows at individual wells). Enter the actual annual average LFG recovery rates in cubic meters per hour in Column E in the row corresponding to the year represented in the flow data. If methane percentage data are not available, the flow data are not valid and should not be entered. 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).

3.2.3 Collection Efficiency

As described in Section 2.2.5.2, adjustments to the automatically calculated collection efficiency estimates are not recommended unless actual LFG recovery data are available. The Model user can make adjustments to collection system efficiency values in Column D for each year with valid flow data. The effects of the collection efficiency adjustments on projected LFG recovery will be immediately visible in Column F (projected LFG recovery values cannot be adjusted). Continue adjusting collection efficiency for each year with flow data until projected recovery closely matches actual recovery shown in Column E. The user also may want to adjust collection efficiency estimates for future years to match the most recent year with data.

3.2.4 Baseline LFG Recovery

Baseline LFG recovery estimates are subtracted from projected LFG recovery to estimate certified emission reductions (CERs) achieved by the LFG project. The default value for baseline LFG recovery is zero for all years, which will be appropriate for most landfills in Mexico that were not required to collect and flare LFG under any existing regulation.

Baseline LFG recovery can be adjusted in Column G. Consult the most recent CDM methodologies for estimating baseline LFG recovery.

The Instructions Section (Figure 5) provides instructions on adjusting values for waste disposal, collection efficiency, actual LFG recovery, and baseline LFG recovery. The automatic calculation of default values for collection efficiency based on user inputs also is shown.

INSTRUCTIONS:

Waste Disposal Estimates: Input annual waste disposal rates in Column B below only for years with available disposal data. Inputs will override calculations based on estimates provided by user in "Inputs" worksheet.

Collection System Efficiency: Collection system effciency is calculated based on user inputs. To override automatic calculations enter values by year in Column D below.

Actual LFG Recovery: If a collection system is installed, input into Column E below the average annual biogas flows at 50% methane. DO NOT PUT IN ZEROS.

Baseline LFG Recovery: Enter into Column F below the baseline LFG flows at 50% methane. See UNFCCC CDM website for baseline methodologies.

	Collection Efficiency Calculation	
Account for waste depth:	**100%**	Progressive discount if <10 m deep (5% for each meter < 10m)
Account for wellfield coverage of waste area:	**90%**	Coverage factor adjustment
Account for soil cover type and extent:	**68%**	Final cover = 90%; intermediate cover = 80%; daily cover = 75%; no cover = 50%
Account for liner type and extent:	**68%**	Discount is 5% x % area without liner
Account for waste compaction:	**68%**	Discount is 3% if no compaction
Account for focused tip area:	**68%**	Discount is 5% if no focused tip area
Account for leachate	**57%**	Discount is up to 25% depending on climate and frequency of leachate ponding/runoff
CALCULATED COLLECTION EFFICIENCY:	**57%**	

Figure 5. Instructions Section, Disposal & LFG Recovery Worksheet

3.3 Waste Composition

Waste composition is used by the Model to automatically calculate L_0 values and the percentage of waste assigned to each of the four waste groups described in Section 2.2. Default waste composition values for each state are shown in the Waste Composition worksheet. The state default values are used by the Model to calculate L_0 unless the user selects "Yes" in response to Question #5 in the "Inputs" worksheet, "Site-specific waste composition data?", in which case, site specific waste composition data are used. The user should enter the site-specific waste composition data in Column B of the "Waste Composition" worksheet (see Figure 6). Be sure that the percentages add up to 100%.

INSTRUCTIONS: If site specific waste composition data are available, "Yes" should be entered into Cell B10 of the Inputs worksheet and the percentages of indicated waste categories disposed (wet weight basis) should be entered into Cells B7 through B20 below.

Methane to Markets

Mexico Landfill Gas Model v.2

Release Date: March 2009

Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

SITE-SPECIFIC AND DEFAULT WASTE COMPOSITION TABLE FOR MODEL INPUTS

Waste Category	Enter Site Specific Data	Nuevo Leon	USA	Aguascalientes	Baja California North	Baja California South
Food Waste	21.3%	38.5%	13.4%	45.1%	35.8%	30.7%
Paper and Cardboard	19.3%	11.7%	23.8%	16.5%	13.1%	16.3%
Garden Waste (Green Waste)	8.3%	4.2%	4.8%	11.3%	15.5%	9.9%
Wood Waste	0.5%	2.2%	10.1%	0.3%	0.5%	1.1%
Rubber, Leather, Bones, Straw	0.7%	2.2%	2.8%	0.7%	0.7%	1.2%
Textiles	10.5%	6.4%	4.4%	0.8%	4.1%	5.4%
Toilet Paper	0.0%	3.5%				
Other Organics	0.0%	0.0%	0.9%	0.0%	1.6%	1.9%
Diapers (assume 20% organics / 80% inorganics)	4.9%	0.0%		2.8%	11.9%	6.4%
Metals	2.8%	31.2%	6.3%	2.2%	3.2%	
Construction and Demolition Waste	1.5%	0.0%	12.8%	0.1%	0.0%	
Glass and Ceramics	3.0%	0.0%	5.4%	4.6%	3.5%	26.9%
Plastics	20.8%	0.0%	12.7%	13.1%	7.5%	
Other Inorganic Waste (bulky items)	6.4%	0.0%	2.7%	2.5%	2.7%	
Percent very fast decay organic waste (1)	22.3%	38.5%	14.3%	45.7%	39.7%	34.0%
Percent medium-fast decay organic waste (2)	8.3%	7.7%	4.8%	11.3%	15.5%	9.9%
Percent medium-slow decay organic waste (3)	29.7%	18.1%	28.2%	17.3%	17.2%	21.7%
Percent slow decay organic waste (4)	1.2%	4.4%	12.9%	1.0%	1.2%	2.2%
Total Organic Waste	61.5%	68.8%	60.2%	75.3%	73.5%	67.9%
Total Inorganic Waste	38.5%	31.2%	39.8%	24.7%	26.5%	32.1%
Average very fast decay organic waste moisture (1)	70%	70%	70%	70%	70%	70%
verage medium fast decay organic waste moisture (2)	40%	40%	45%	40%	35%	35%
erage medium-slow decay organic waste moisture (3)	7%	7%	7%	7%	7%	7%
Average slow decay organic waste moisture (4)	12%	12%	16%	12%	12%	12%
U.S. Waste % dry organics			44%			
Calculated Fast-decay Organic Waste Lo	69	69		69	69	69
Calculated medium fast decay Organic Waste Lo	138	138		138	149	149
Calculated medium slow decay Organic Waste Lo	214	214		214	214	214
Calculated Slow decay Organic Waste Lo	202	202		202	202	202

Figure 7. Portion of the Waste Composition Worksheet

3.4 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 8 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 "Disposal & LFG Recovery" worksheet or calculated by the model:

- Years starting with the landfill opening year and ending in a year the user selects.
- Annual disposal rates in Mg per year.
- Refuse in place in Mg.
- LFG generation for each projection year in m^3/hr, cfm, and mmBtu/hr.
- Collection system efficiency estimates for each projection year.
- LFG recovery rates for each projection year in m^3/hr, cfm, and mmBtus/hr.
- Maximum power plant capacity that could be supported by this flow in MW.

INSTRUCTIONS: Table title is linked to Inputs sheet. Column titles cannot be changed. Contents of print table cannot be changed (except for power plant capacity) and are derived/calculated based on user inputs. Print table format will need adjustment. User will need to adjust page breaks and unhide or hide the rows at bottom of table as needed.

Methane to Markets

Mexico Landfill Gas Model v.2

Release Date: March 2009

Developed by SCS Engineers for the U.S. EPA Landfill Methane Outreach Program

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY
Mexico Landfill
Guadalajara, Jalisco

Year	Disposal (Mg/yr)	Refuse In-Place (Mg)	LFG Generation			Collection System Efficiency (%)	Predicted LFG Recovery			Maximum Power Plant Capacity* (MW)	Baseline LFG Flow (m3/hr)	Methane Emissions Reduction Estimates**	
			(m^3/hr)	(cfm)	(mmBtu/hr)		(m^3/hr)	(cfm)	(mmBtu/hr)			(tonnes CH_4/yr)	(tonnes CO_2eq/yr)
1978	114,900	114,900	0	0	0.0	0%	0	0	0.0	0.0	0	0	0
1979	117,200	232,100	147	86	2.6	0%	0	0	0.0	0.0	0	0	0
1980	119,500	351,600	279	164	5.0	0%	0	0	0.0	0.0	0	0	0
1981	121,900	473,500	399	235	7.1	0%	0	0	0.0	0.0	0	0	0
1982	124,300	597,800	510	300	9.1	0%	0	0	0.0	0.0	0	0	0
1983	126,800	724,600	613	361	10.9	0%	0	0	0.0	0.0	0	0	0
1984	129,300	853,900	709	417	12.7	0%	0	0	0.0	0.0	0	0	0
1985	131,900	985,800	799	470	14.3	0%	0	0	0.0	0.0	0	0	0
1986	134,500	1,120,300	885	521	15.8	0%	0	0	0.0	0.0	0	0	0
1987	137,200	1,257,500	967	569	17.3	0%	0	0	0.0	0.0	0	0	0
1988	139,900	1,397,400	1,046	615	18.7	0%	0	0	0.0	0.0	0	0	0
1989	142,700	1,540,100	1,122	660	20.0	0%	0	0	0.0	0.0	0	0	0
1990	145,600	1,685,700	1,195	704	21.4	0%	0	0	0.0	0.0	0	0	0
1991	148,500	1,834,200	1,267	746	22.6	0%	0	0	0.0	0.0	0	0	0
1992	151,500	1,985,700	1,338	787	23.9	0%	0	0	0.0	0.0	0	0	0
1993	154,500	2,140,200	1,407	828	25.1	0%	0	0	0.0	0.0	0	0	0
1994	157,600	2,297,800	1,475	868	26.4	0%	0	0	0.0	0.0	0	0	0
1995	160,800	2,458,600	1,542	908	27.6	0%	0	0	0.0	0.0	0	0	0
1996	164,000	2,622,600	1,609	947	28.8	0%	0	0	0.0	0.0	0	0	0
1997	167,300	2,789,900	1,675	986	29.9	0%	0	0	0.0	0.0	0	0	0
1998	170,600	2,960,500	1,741	1,025	31.1	0%	0	0	0.0	0.0	0	0	0
1999	174,000	3,134,500	1,806	1,063	32.3	0%	0	0	0.0	0.0	0	0	0
2000	177,500	3,312,000	1,872	1,102	33.4	0%	0	0	0.0	0.0	0	0	0
2001	181,100	3,493,100	1,937	1,140	34.6	0%	0	0	0.0	0.0	0	0	0
2002	184,700	3,677,800	2,002	1,178	35.8	0%	0	0	0.0	0.0	0	0	0
2003	188,400	3,866,200	2,067	1,217	36.9	0%	0	0	0.0	0.0	0	0	0
2004	192,200	4,058,400	2,133	1,255	38.1	0%	0	0	0.0	0.0	0	0	0
2005	196,000	4,254,400	2,198	1,294	39.3	0%	0	0	0.0	0.0	0	0	0
2006	200,000	4,454,400	2,264	1,333	40.5	0%	0	0	0.0	0.0	0	0	0
2007	204,000	4,658,400	2,331	1,372	41.6	0%	0	0	0.0	0.0	0	0	0
2008	0	4,658,400	2,398	1,411	42.8	0%	0	0	0.0	0.0	0	0	0
2009	0	4,658,400	2,199	1,294	39.3	54%	1,188	699	21.2	2.0	0	3,724	78,214
2010	0	4,658,400	2,028	1,193	36.2	54%	1,095	644	19.6	1.8	0	3,434	72,105
2011	0	4,658,400	1,878	1,105	33.6	54%	1,014	597	18.1	1.7	0	3,180	66,777
2012	0	4,658,400	1,746	1,028	31.2	54%	943	555	16.8	1.6	0	2,957	62,098
2013	0	4,658,400	1,630	959	29.1	54%	880	518	15.7	1.5	0	2,760	57,962
2014	0	4,658,400	1,526	898	27.3	54%	824	485	14.7	1.4	0	2,585	54,281
2015	0	4,658,400	1,434	844	25.6	54%	774	456	13.8	1.3	0	2,428	50,984
2016	0	4,658,400	1,350	795	24.1	54%	729	429	13.0	1.2	0	2,286	48,013
2017	0	4,658,400	1,274	750	22.8	54%	688	405	12.3	1.1	0	2,158	45,319
2018	0	4,658,400	1,205	709	21.5	54%	651	383	11.6	1.1	0	2,041	42,863
2019	0	4,658,400	1,142	672	20.4	54%	617	363	11.0	1.0	0	1,934	40,613
2020	0	4,658,400	1,084	638	19.4	54%	585	344	10.5	1.0	0	1,835	38,541
2021	0	4,658,400	1,030	606	18.4	54%	556	327	9.9	0.9	0	1,744	36,625
2022	0	4,658,400	980	577	17.5	54%	529	311	9.5	0.9	0	1,659	34,847
2023	0	4,658,400	933	549	16.7	54%	504	297	9.0	0.8	0	1,580	33,190
2024	0	4,658,400	890	524	15.9	54%	480	283	8.6	0.8	0	1,507	31,641
2025	0	4,658,400	849	500	15.2	54%	458	270	8.2	0.8	0	1,438	30,190
2026	0	4,658,400	811	477	14.5	54%	438	258	7.8	0.7	0	1,373	28,826
2027	0	4,658,400	774	456	13.8	54%	418	246	7.5	0.7	0	1,312	27,542
2028	0	4,658,400	740	436	13.2	54%	400	235	7.1	0.7	0	1,254	26,330
2029	0	4,658,400	708	417	12.7	54%	382	225	6.8	0.6	0	1,199	25,184
2030	0	4,658,400	678	399	12.1	54%	366	215	6.5	0.6	0	1,148	24,098
2031	0	4,658,400	649	382	11.6	54%	350	206	6.3	0.6	0	1,099	23,069
2032	0	4,658,400	621	366	11.1	54%	335	197	6.0	0.6	0	1,052	22,092
2033	0	4,658,400	595	350	10.6	54%	321	189	5.7	0.5	0	1,008	21,164
2034	0	4,658,400	570	336	10.2	54%	308	181	5.5	0.5	0	966	20,280
2035	0	4,658,400	547	322	9.8	54%	295	174	5.3	0.5	0	926	19,439

MODEL INPUT PARAMETERS
Assumed Methane Content of LFG: 50%
Methane Correction Factor (MCF): 1.0

Waste Category:	Fast Decay	Moderately Fast Decay	Moderately Slow Decay	Slow Decay
CH4 Generation Rate Constant (k):	0.220	0.100	0.040	0.020
CH4 Generation Potential (Lo) (m3/Mg)	62	114	192	182

NOTES
* Maximum power plant capacity assumes a gross heat rate of 10,800 Btus per kW-hr (hhv).
**Emission reductions do not account for electricity generation or project emissions and are calculated using a methane density (at standard temperature and pressure) of 0.0007168 Mg/m3.

Figure 7. Sample Model Output Table

- Baseline LFG flow in m^3/hr.
- Methane emission reduction estimates in tonnes CH_4/year and in tonnes CO_2e/year (CERs).
- The methane content assumed for the model projection (50%).
- 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 LFG 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.

3.5 Model Outputs - Graph

Model results are also displayed in graphical form in the “Outputs-Graph” worksheet (see Figure 8 for a sample graph layout). Data displayed in the graph includes the following:

- LFG generation rates for each projection year in m^3/hr.
- LFG recovery rates for each projection year in m^3/hr.
- Actual (historical) LFG recovery rates in m^3/hr.

The graph title says “Landfill Gas Generation and Recovery Projection” and shows the landfill name and state. The user can make edits 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 or to change the start year. 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.

INSTRUCTIONS:
Graph needs x-axis scale formatting to start and end in the year of choice. Lines will fall short of end date if rows in output table are hidden. Hide rows in output table for years beyond desired end date, or unhide rows to prevent this. Actual landfill gas recovery data should be entered in the Disposal & LFG Recovery worksheet if there is data. If not, delete from legend by clicking on the legend, then clicking on "Actual Landfill Gas Recovery", then pressing the delete key.

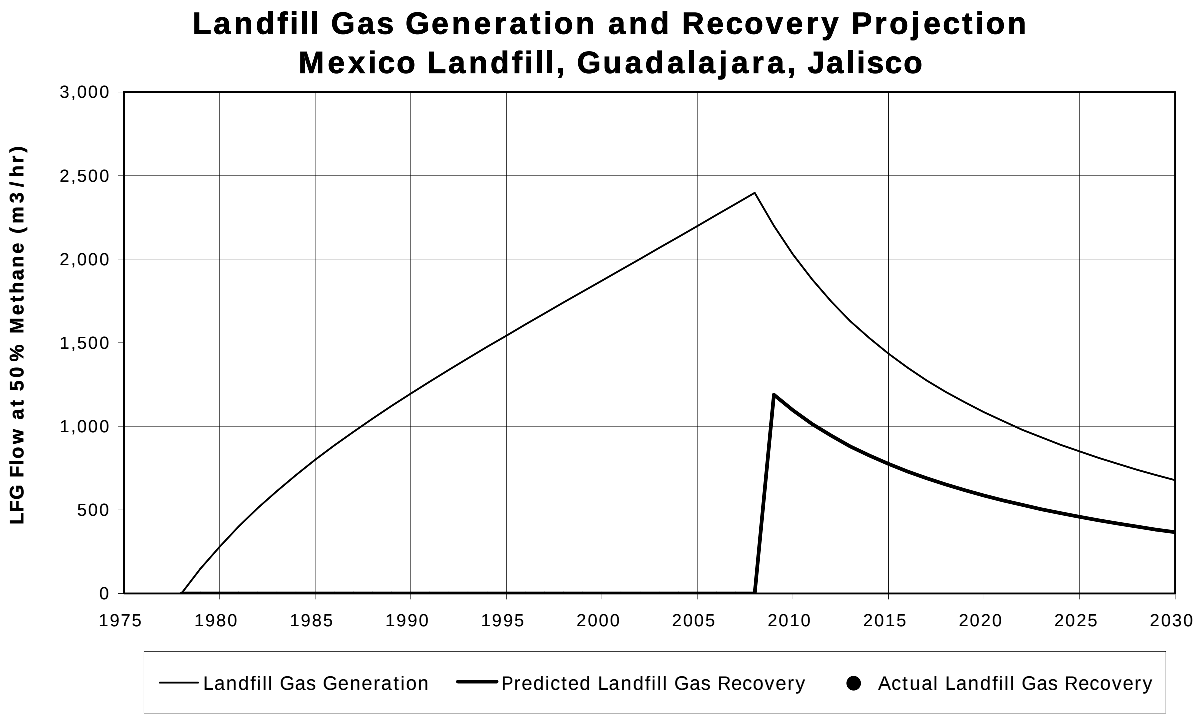

Figure 8. Sample Model Output Graph

4.0 REFERENCES

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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.