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User's Manual Colombia Landfill Gas Model

Version 1.0

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DISCLAIMER

This user's guide has been prepared specifically for Colombia on behalf of the Landfill Methane Outreach Program, U.S. Environmental Protection Agency, as part of the Methane to Markets program activities in Colombia. 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, the Colombia Landfill Gas Model Version 1.0 (Model), for estimating landfill gas (LFG) generation and recovery from municipal solid waste landfills in Colombia. 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 Colombia.

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, and 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 of the 33 departments in Colombia. The default values were developed using data on climate, waste characteristics, and disposal practices in Colombia, and the estimated effect of these conditions on the amounts and rates of LFG generation. Actual LFG recovery rates from two landfills in Colombia were evaluated to help guide the selection of model k and L_0 values.

Model users can either rely on waste composition and disposal rates automatically calculated by the Model or input site-specific values. The Model applies the disposal data along with the default k and L_0 values for the selected department to estimate average LFG generation rates for each projection year. The Model also applies the user's answers to questions about site conditions to develop estimates of collection efficiency for each year the LFG collection system is expected to operate. LFG recovery in each year is projected by multiplying LFG generation by the collection efficiency.

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 2.0 and the Intergovernmental Panel on Climate Change (IPCC) 2006 Waste Model (IPCC Model). The Model incorporated the structure of the Mexico LFG Model and IPCC Model, with revised input assumptions to reflect local climate and conditions at disposal sites in Colombia.

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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_0).- 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_0 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 may include upgrading to pipeline quality methane gas (if there is sufficient quantity and quality to support gas processing costs), or more often using it as fuel in energy recovery facilities, including internal combustion engines, gas turbines, microturbines, steam boilers, or other types of facilities that can use LFG 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 Colombia LFG Model (Model) is to provide landfill owners and operators in Colombia 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).

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

Where:

- Q_{LFG} = maximum expected LFG generation flow rate (m³/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 (m³/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 LFG generation and recovery in cubic meters per hour (m³/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

¹ The composition of landfill gas is assumed by the Model to consist of 50 percent methane (CH₄) and 50 percent other gases, including carbon dioxide (CO₂) and trace amounts of other compounds.

(MW), and the emission reductions in tonnes of CO₂ equivalent (CERs) achieved by the collection and combustion of the LFG.

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 L₀ based on climate and waste composition data. The k values vary depending on climate and waste group. The L₀ values vary depending on waste group. Climate is assigned by the Model based on geographical region or is selected by the Model user.

Colombia is divided into five geographical regions (see Figure 1) based on topography and climate. Each geographical region includes several departments, some of which may occur in (straddle) more than one geographical region. Although Regions 1, 4, and 5 (Amazonica, Orinoquia, and Pacifica) have very wet climates in almost all locations, Regions 2 (Andia) and 3 (Caribe) experience climates that can range from dry to very wet. For Region 2 or 3 locations, Model users are required to select the average annual precipitation at the site from a list of five precipitation ranges found within Colombia. The Model makes corrections to the selected climate if it does not exist in the area where the landfill is located.

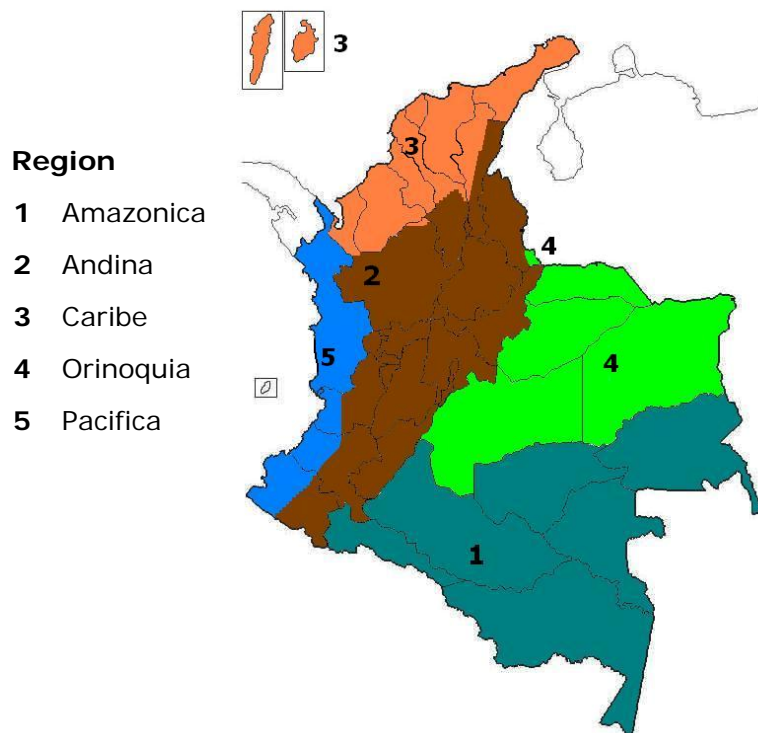


Figure 1. Colombia's Geographical Regions

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 department, which are based on waste composition data gathered from the department or from other nearby departments with data.

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 department in Colombia. 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 Colombia 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 Colombia LFG Model Version 1.0

The Colombia LFG Model Version 1.0 provides an automated estimation tool for quantifying LFG generation and recovery from MSW landfills in all departments of Colombia. The Model applies separate equations to calculate LFG generation from each of the following four organic waste² 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 is 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.

2.1.1 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: $\text{half-life} = \ln(2)/k$. 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 according to average annual precipitation, which is used to characterize moisture conditions in the landfill. The model user is asked to select one of the following 5 climate categories based on the average annual precipitation at the closest weather station with historical data:

- Dry (<500 mm/yr precipitation).
- Moderately dry (500-999 mm/yr precipitation).
- Moderately wet (1,000-1,499 mm/yr precipitation).
- Wet (1,500-1,999 mm/yr precipitation).
- Very wet (>2,000 mm/yr precipitation).

The climate categories for the largest cities in Colombia are as follows:

- Bogota – moderately dry.
- Medellin – wet.
- Cali – moderately wet.
- Barranquilla – moderately dry.
- Cartagena – moderately dry to moderately wet.

The Model will automatically select k values based on the climate. The k values that the Model uses for each waste and climate category are shown in Table 1.

² Inorganic waste does not generate LFG and is excluded from the model calculations.

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

Waste Category	Climate 1	Climate 2	Climate 3	Climate 4	Climate 5
	Very Wet	Wet	Moderately Wet	Moderately Dry	Dry
1	0.400	0.340	0.260	0.180	0.100
2	0.170	0.150	0.120	0.090	0.050
3	0.070	0.060	0.048	0.036	0.020
4	0.035	0.030	0.024	0.018	0.010

2.1.2 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 57 cities that represent 21 departments. Average waste composition was calculated for each department using population to weight the contribution of each data set to the average. Departments that had no waste composition data available were assigned the average waste composition of nearby departments. Default waste composition values for each department 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 department 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 calculated according to the IPCC methodology, which assigns default values for degradable organic carbon (DOC) for each waste material type, along with a default value of 0.5 for the fraction of DOC which is dissimilated (DOC_F) and the methane content of LFG (F), to calculate L_0 according to the following formula: $L_0 = DOC \times DOC_F \times F \times 16/12 \times 0.0007168$.³ The resulting L_0 values by material type are shown in Table 2. The L_0 values for each of the four waste categories used in by the Model vary slightly by department

³ Formula for L_0 includes conversion factors of 16/12 (ratio of methane and carbon molecular weights) and 0.0007168 Mg/m^3 (density of methane at standard conditions).

based on the different mix of material types included in each waste category. The L_0 values for Category 2 will have some additional 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 by Waste Type

Food Waste	Garden Waste	Paper	Wood and Straw	Textiles & Disposable Diapers
70 m ³ /Mg	93 - 134 m ³ /Mg	186 m ³ /Mg	200 m ³ /Mg	112 m ³ /Mg

2.1.3 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 #17 and #18 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 (none of which are known to exist in Colombia) 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).

2.1.4 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 19a 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).

2.1.5 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 Colombia 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 2.1.5.1. 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 2.1.5.2.

2.1.5.1 Model Calculation of Collection Efficiency

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

- Site management practices – properly managed landfills will have characteristics (cover soils, waste compaction and leveling, control of waste placement, control of scavenging, control of fires, leachate management systems) which allow for achievement of higher collection efficiencies than unmanaged dump sites.
- 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 is 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 2.1.5.2.

Site Management Practices

As discussed above, unmanaged dump sites have characteristics which prevent the achievement of collection efficiencies that can be reached at modern sanitary landfills. User inputs in response to questions regarding several of these specific characteristics will trigger collection efficiency discounts in the Model that are described below. An additional discount of 15% is applied for unmanaged sites to account for other characteristics not specifically addressed as well as the combined effect of dump site characteristics on collection efficiency. For example, a dump site that never applied a daily or intermediate cover but which receives a final cover after closure will not be able to achieve the same collection efficiency as a sanitary landfill that consistently applied soil cover as part of its disposal operations as well as a final cover after site closure.

The Model user is requested to indicate site management practices in Question #18 of the "Inputs" worksheet. The different categories of site management practices are described above in Section 2.1.3.

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 extent to which the installed wells are actively drawing LFG from deposited waste. Most landfills, particularly those that are still receiving wastes or which have substantial areas with steep slopes that prevent well installation, 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 #21 of the "Inputs" worksheet, which asks for "Percent of waste area to be covered with wells." Estimates of collection system coverage at landfills without systems already in operation should try to account for conditions anticipated for the date that system start-up will occur, including the percentage of areas available for installing extraction 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 #17 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 #22, 23, and 24 in the "Inputs" worksheet. Estimates of percentage of each cover type at landfills without collection systems already in operation should try to project the distribution of cover types anticipated for the date that system start-up will occur. 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 #26 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 #27 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 #28 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 29a of the "Inputs" worksheet. If the answer is yes, the Model user is asked in Question 29b 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 (wetter climates receive a higher discount). If the evidence of leachate accumulation persists between rainstorms, the Model applies a 5% to 30% 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 J14 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 #20 in the "Inputs" worksheet.

2.1.5.2 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 (“Colombia LFG Model v.1.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 30 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. department names).
- **Instruction Section:** This section has a light blue background and provides specific instructions on how to answer questions or input information. The instruction section also includes (in red) messages to the model user regarding input error or corrections to the user’s selection of local climate.

3.1 Inputs Worksheet

The “Inputs” worksheet has 33 rows of text which require user inputs in Column C for 30 items. All 30 questions or phrases that have yellow text in Column C need to be responded to with site-specific information (items 25 and 30 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. Mistakes by the user in making selections may result in error messages in the Inputs worksheet. For example, the selection of a geographical region (item 4) that is in a different location than the selected department will produce an error message, and the model will not function. Also, if the model user selects a climate (Item 5) that is not found in the department where the landfill is located, an error message will appear in the Inputs worksheet and the model will automatically select an appropriate climate for that department. 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 ($0 \text{ m}^3/\text{hr}$). Each of these inputs is 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).

PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY INPUTS WORKSHEET		
1	Landfill name:	Antanas Landfill
2	City:	Pasto
3	Department:	Nariño
4	Select one of 5 geographic regions in Colombia	Andina Get Map
5	Select one of 5 climate zones based on average annual rainfall:	Moderately Wet (1000-1499 mm/yr)
6	Site specific waste composition data?	No
7	Year opened:	2001
8	Annual disposal for latest year with data in tonnes per year (Mg/yr)	80,000 Mg
9	Year of disposal estimate:	2009
10	Is there site data available on estimated waste in place (volume or mass)? If NO, then skip to #15	Yes
11	Is there historical waste tonnage data to estimate Mg in place?	No
12	Waste in place estimate for end of year listed in #9 (most recent data):	800,000 m3
13	Estimated in place waste density in Mg per m ³ (typical range: 0.5-1.0):	0.80 Mg/m ³
14	If waste in place estimate is in volume (m3), convert to Mg:	640,000 Mg
15	Projected or actual closure year:	2018
16	Estimated growth in annual disposal:	1.0%
17	Average landfill depth:	20 m
18	Site design and management practices (historical average conditions):	2
19a	Has site been impacted by fires?	No
19b	If 13a answer is Yes, indicate % of landfill area impacted:	0%
19c	If 13a answer is Yes, indicate the severity of fire impacts:	1
20	Year of initial collection system start up.	2009
21	Percent of waste area with to be covered with wells:	85%
22	Percent of waste area with final cover:	0%
23	Percent of waste area with intermediate cover:	50%
24	Percent of waste area with daily cover:	50%
25	Percent of waste area with no cover:	0%
26	Percent of waste area with clay or synthetic liner:	100%
27	Is waste compacted on a regular basis?	Yes
28	Is waste delivered to a focused tipping area?	Yes
29a	Does the landfill experience leachate surface seeps or surface ponding?	No
29b	If 23a answer is yes, does this occur only after rainstorms?	Yes
30	Collection efficiency estimate:	66%

Figure 2. Inputs Section, Inputs Worksheet



INSTRUCTIONS:

Edit all items with yellow lettering. Follow instructions left of each item and below. 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 department from the dropdown menu. Click on arrow and select department.
4. Select one of 5 geographical regions in Colombia (see map). Selected region must include at least a portion of selected department for the model to function.
5. Select climate zone based on average annual rainfall. If selected climate is not found in department, model will select appropriate climate. Model selection is shown at left.
6. Select **No** if there is no data, **Yes** if there is data. If **Yes**, input site specific data in Waste Composition worksheet.
7. Enter year landfill began receiving waste.
8. Enter disposal in 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.
9. Enter most recent year of disposal reflecting tonnes listed above.
10. Indicate whether data is available on in-place waste volume or mass. If "No" then tonnage estimates will be based on a Mg/yr disposal rate (#8) and estimated annual growth.
11. Indicate whether data is available on metric tonnes of waste in place. Select "No" if only volume data are available. If annual disposal data are available, enter figures for each year with data in Disposal & LFG Recovery worksheet.
12. Enter estimated amount of waste in place. Estimate should reflect the most recent end-of-year value available. Units of measure for mass (Mg) or volume (m³) will be automatically selected based on answer to #11.
13. Enter estimated in-place density. Expected values are 0.5 to 1.0 Mg/m³ for MSW landfills.
14. This value is calculated automatically (no user inputs)
15. Enter actual or projected year landfill stops receiving waste.
16. Enter estimated percentage annual growth in disposal.
17. Enter average current waste depth in meters for areas with wells or targeted for well installation.
18. Select value from dropdown menu: 1=Unmanaged disposal site; 2=Engineered/sanitary landfill; 3=Unknown. See Users Manual for definitions of each category.
- 19a. Select Yes or No from dropdown menu. If unknown, select No.
- 19b. If 19a answer is yes (impacted by fires) estimate % area impacted.
- 19c. If 19a answer is yes, estimate severity of impacts (1=low impacts; 2=medium impacts; 3=severe impacts)
20. If no system is installed, give projected year of system start-up, and complete questions 17-22 based on anticipated conditions as of start-up date.
21. Enter a value up to 100% for current or future wellfield coverage of waste footprint (active disposal sites will be < 100%)
22. Enter a value up to 100% for % of waste area with final cover
23. Enter a value up to 100% for % of waste area with intermediate cover but no final cover
24. Enter a value up to 100% for % of waste area with daily cover only
25. Value automatically calculated as the remaining area
26. Enter a value up to 100% for % of waste area with clay or synthetic liner
27. Select Yes or No from dropdown menu.
28. Select Yes or No from dropdown menu.
- 29a. Select Yes or No from dropdown menu.
- 29b. If 29a answer is yes, indicate if seeps or ponding occur only immediately following rainstorms.
30. This value is calculated based on the inputs above.

Figure 3. Instructions Section, Inputs Worksheet



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)
2001	68,000	68,000	0%		0	0
2002	68,680	136,680	0%		0	0
2003	69,370	206,050	0%		0	0
2004	70,060	276,110	0%		0	0
2005	70,760	346,870	0%		0	0
2006	71,470	418,340	0%		0	0
2007	72,180	490,520	0%		0	0
2008	72,900	563,420	0%		0	0
2009	80,000	643,420	66%		461	0
2010	80,800	724,220	66%		496	0
2011	81,610	805,830	66%		525	0
2012	82,430	888,260	66%		552	0
2013	83,250	971,510	66%		575	0
2014	84,080	1,055,590	66%		596	0
2015	84,920	1,140,510	66%		615	0
2016	85,770	1,226,280	66%		632	0
2017	86,630	1,312,910	66%		649	0
2018	87,500	1,400,410	66%		664	0
2019	0	1,400,410	66%		679	0
2020	0	1,400,410	66%		557	0
2021	0	1,400,410	66%		461	0
2022	0	1,400,410	66%		385	0
2023	0	1,400,410	66%		325	0
2024	0	1,400,410	66%		277	0
2025	0	1,400,410	66%		238	0
2026	0	1,400,410	66%		207	0
2027	0	1,400,410	66%		181	0
2028	0	1,400,410	66%		160	0
2029	0	1,400,410	66%		143	0
2030	0	1,400,410	66%		129	0
2031	0	1,400,410	66%		117	0
2032	0	1,400,410	66%		107	0
2033	0	1,400,410	66%		98	0
2034	0	1,400,410	66%		90	0
2035	0	1,400,410	66%		84	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 m³/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 m³/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 2.1.5.2, 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 Colombia 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 efficiency 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 G the baseline LFG flows at 50% methane. See UNFCCC CDM website for baseline methodologies.

	Collection Efficiency Calculation	
Account for site management practices:	100%	Discount is 15% if site is or was not operated as a managed landfill
Account for waste depth:	100%	Progressive discount if <10 m deep (5% for each meter < 10m)
Account for wellfield coverage of waste area:	85%	Coverage factor adjustment
Account for cover type and extent:	66%	Final cover = 90%; intermediate cover = 80%; daily cover = 75%; no cover = 50%
Account for liner type and extent:	66%	Discount is 5% x % area without liner
Account for waste compaction:	66%	Discount is 3% if no compaction
Account for focused tip area:	66%	Discount is 5% if no focused tip area
Account for leachate	66%	Discount is up to 30% depending on climate and frequency of leachate ponding/runoff
CALCULATED COLLECTION EFFICIENCY:	66%	

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 2.1. Default waste composition values for each department are shown in the Waste Composition worksheet. The department default values are used by the Model to calculate L_0 unless the user selects "Yes" in response to Question #6 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%.

SITE-SPECIFIC AND DEFAULT WASTE COMPOSITION TABLE FOR MODEL INPUTS					
Waste Category	Enter Site Specific Data	Nariño	Amazonas	Antioquia	Arauca
Food Waste	58.8%	58.8%	69.8%	52.4%	52.0%
Paper and Cardboard	7.4%	7.4%	3.6%	8.6%	7.2%
Garden Waste (Green Waste)	6.4%	6.4%	7.8%	6.2%	5.5%
Wood Waste	0.7%	0.7%	0.6%	3.2%	1.4%
Rubber, Leather, Bones, Straw	1.0%	1.0%	1.1%	0.2%	1.2%
Textiles	3.8%	3.8%	1.7%	2.6%	2.5%
Toilet Paper	0.0%	0.0%	0.0%	0.0%	2.5%
Other Organics	0.0%	0.0%	0.0%	0.5%	3.0%
Diapers (assume 20% organics / 80% inorganics)	3.6%	3.6%	0.0%	0.0%	3.5%
Metals	0.0%	0.0%	1.5%	1.3%	1.0%
Construction and Demolition Waste	18.2%	18.2%	0.0%	0.0%	3.0%
Glass and Ceramics	0.0%	0.0%	3.3%	3.1%	2.0%
Plastics	0.0%	0.0%	10.4%	14.8%	10.4%
Other Inorganic Waste	0.0%	0.0%	0.4%	7.1%	5.0%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Percent very fast decay organic waste (1)	59.5%	59.5%	69.8%	52.9%	55.7%
Percent medium-fast decay organic waste (2)	6.4%	6.4%	7.8%	6.2%	7.9%
Percent medium slow decay organic waste (3)	11.3%	11.3%	5.3%	11.2%	9.7%
Percent slow decay organic waste (4)	1.7%	1.7%	1.6%	3.4%	2.6%
Total Organic Waste	78.9%	78.9%	84.5%	73.7%	75.9%
Total Inorganic Waste	21.1%	21.1%	15.5%	26.3%	24.1%
Calculated Fast-decay Organic Waste Lo	70	70	70	69	68
Calculated medium fast decay Organic Waste Lo	103	103	93	103	99
Calculated medium slow decay Organic Waste Lo	161	161	161	169	167
Calculated Slow-decay Organic Waste Lo	200	200	200	200	200

Figure 6. 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 7 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 m³/hr, cfm, and mmBtu/hr.
- Collection system efficiency estimates for each projection year.
- LFG recovery rates for each projection year in m³/hr, cfm, and mmBtus/hr.
- Maximum power plant capacity that could be supported by this flow in MW.



PROJECTION OF LANDFILL GAS GENERATION AND RECOVERY													
Antanas Landfill													
Pasto, Nariño, Colombia													
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 ₂ eq/yr)
2001	68,000	68,000	0	0	0.0	0%	0	0	0.0	0.0	0	0	0
2002	68,680	136,680	158	93	2.8	0%	0	0	0.0	0.0	0	0	0
2003	69,370	206,050	286	168	5.1	0%	0	0	0.0	0.0	0	0	0
2004	70,060	276,110	390	229	7.0	0%	0	0	0.0	0.0	0	0	0
2005	70,760	346,870	475	279	8.5	0%	0	0	0.0	0.0	0	0	0
2006	71,470	418,340	545	321	9.7	0%	0	0	0.0	0.0	0	0	0
2007	72,180	490,520	604	356	10.8	0%	0	0	0.0	0.0	0	0	0
2008	72,900	563,420	655	385	11.7	0%	0	0	0.0	0.0	0	0	0
2009	80,000	643,420	698	411	12.5	66%	461	271	8.2	0.8	0	1,445	30,345
2010	80,800	724,220	751	442	13.4	66%	496	292	8.9	0.8	0	1,554	32,633
2011	81,610	805,830	796	469	14.2	66%	525	309	9.4	0.9	0	1,648	34,607
2012	82,430	888,260	836	492	14.9	66%	552	325	9.9	0.9	0	1,730	36,334
2013	83,250	971,510	871	513	15.6	66%	575	338	10.3	1.0	0	1,803	37,866
2014	84,080	1,055,590	903	531	16.1	66%	596	351	10.6	1.0	0	1,869	39,243
2015	84,920	1,140,510	932	548	16.6	66%	615	362	11.0	1.0	0	1,928	40,496
2016	85,770	1,226,280	958	564	17.1	66%	632	372	11.3	1.0	0	1,983	41,651
2017	86,630	1,312,910	983	579	17.6	66%	649	382	11.6	1.1	0	2,035	42,728
2018	87,500	1,400,410	1,006	592	18.0	66%	664	391	11.9	1.1	0	2,083	43,741
2019	0	1,400,410	1,028	605	18.4	66%	679	400	12.1	1.1	0	2,129	44,703
2020	0	1,400,410	844	497	15.1	66%	557	328	10.0	0.9	0	1,747	36,682
2021	0	1,400,410	698	411	12.5	66%	461	271	8.2	0.8	0	1,446	30,361
2022	0	1,400,410	583	343	10.4	66%	385	227	6.9	0.6	0	1,208	25,360
2023	0	1,400,410	492	290	8.8	66%	325	191	5.8	0.5	0	1,018	21,387
2024	0	1,400,410	419	247	7.5	66%	277	163	4.9	0.5	0	867	18,215
2025	0	1,400,410	360	212	6.4	66%	238	140	4.3	0.4	0	746	15,669
2026	0	1,400,410	313	184	5.6	66%	207	122	3.7	0.3	0	648	13,612
2027	0	1,400,410	275	162	4.9	66%	181	107	3.2	0.3	0	569	11,939
2028	0	1,400,410	243	143	4.3	66%	160	94	2.9	0.3	0	503	10,567
2029	0	1,400,410	217	128	3.9	66%	143	84	2.6	0.2	0	449	9,435
2030	0	1,400,410	195	115	3.5	66%	129	76	2.3	0.2	0	404	8,491
2031	0	1,400,410	177	104	3.2	66%	117	69	2.1	0.2	0	367	7,697
2032	0	1,400,410	162	95	2.9	66%	107	63	1.9	0.2	0	334	7,024
2033	0	1,400,410	148	87	2.7	66%	98	58	1.7	0.2	0	307	6,447
2034	0	1,400,410	137	81	2.4	66%	90	53	1.6	0.1	0	283	5,948
2035	0	1,400,410	127	75	2.3	66%	84	49	1.5	0.1	0	263	5,513

MODEL INPUT PARAMETERS

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

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.

Waste Category:	Fast Decay	Moderately Fast Decay	Moderately Slow Decay	Slow Decay
CH4 Generation Rate Constant (k):	0.260	0.120	0.050	0.025
CH4 Generation Potential (Lo) (m3/Mg)	70	103	161	200

Figure 7. Sample Model Output Table

- Baseline LFG flow in m³/hr.
- Methane emission reduction estimates in tonnes CH₄/year and in tonnes CO₂e/year (CERs).
- The methane content assumed for the model projection (50%).
- The k values used for the model run.
- The L₀ 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 40 years of information. The last 60 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 2035 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 m³/hr.
- LFG recovery rates for each projection year in m³/hr.
- Actual (historical) LFG recovery rates in m³/hr.

The graph title says "Landfill Gas Generation and Recovery Projection" and shows the landfill name, city, and department. 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.

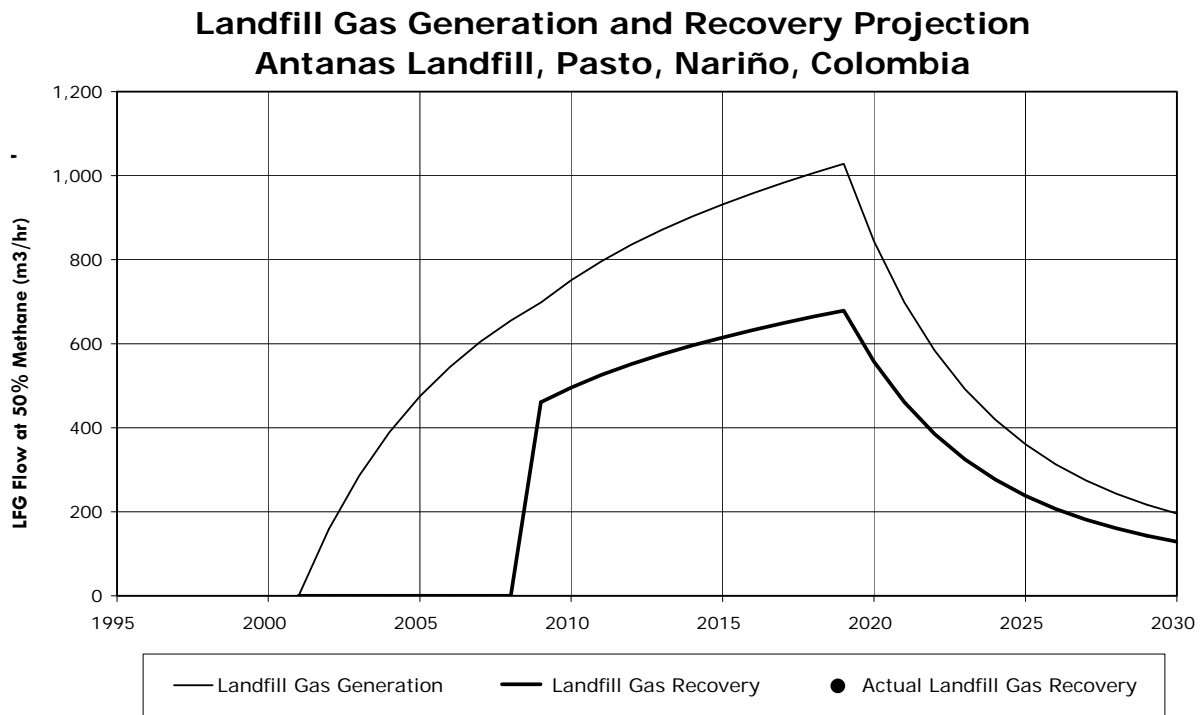


Figure 8. Sample Model Output Graph

4.0 REFERENCES

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