DEVELOPMENT OF A BIOGAS MODEL FOR CENTRAL AMERICA

Landfill Methane Outreach Program (LMOP)
U.S. Environmental Protection Agency

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Alex Stege
SCS Engineers, LMOP Contractor

Presentation Summary

- Model overview and introduction to biogas generation and recovery
- Published biogas generation models (USEPA LandGEM; LMOP Mexico; CDM AM0025v.3.; IPCC Model)
- Development of the Central America Biogas Model
- Estimating system collection efficiency to project biogas recovery

Central America Model Overview

- **Uses First Order Decay (FOD) method**
- **Estimates biogas generation and recovery**
  - Model estimates are based on waste disposal rates and waste composition (has default waste composition %s for each country)
  - Landfill characteristics and climate also affect biogas generation and recovery
- **Users can also adjust with landfill-specific data, if available**

Modeling Methane Generation

- **Methane (CH_4) Generated = CH_4 Emitted + CH_4 Recovered + CH_4 Oxidized + Δ Landfill CH_4 Storage**
  - Methane generation in a landfill is unknown (not measurable)
  - A biogas model provides estimates needed for project planning
  - Methane emissions can be reduced to a small % of generation at sites with comprehensive collection systems
  - Measurements of methane recovery typically provide the only known term in the generation equation

Projecting Recovery for LFG Projects

- **Measured landfill methane recovery at sites with active collection systems**
  - Theoretically can be used to estimate current generation, calibrate biogas model, or test model accuracy
  - Requires evaluating the site's collection efficiency (% methane generated that is recovered)
  - Estimates of collection efficiency and methane generation will be approximate, especially with partial systems
- **Projections of landfill methane recovery at sites without collection systems installed (forecasts)**
  - Requires applying assumed collection efficiency % to modeled generation estimates
  - Error from collection efficiency assumption can be > model error projecting generation

Landfills With Biogas Collection Systems

- **2 landfills with active collection systems and electricity-generation projects under development:**
  - Rio Azul Landfill – San Jose, Costa Rica
  - Nejapa Landfill – San Salvador, El Salvador
- **2 landfills have been evaluated for possible project development:**
  - El Trebol Landfill – Guatemala City, Guatemala
  - Cerro Patacon – Panama City, Panama

Flow Data for Model Calibration?

- **Biogas recovery data available from Rio Azul (Costa Rica) and Nejapa (El Salvador)**
  - Data for 2004 provided by Rio Azul; monitoring data for Nejapa (6/06 – 1/07) now available on UNFCCC website
  - Rio Azul provided site maps and wellfield monitoring data for estimating collection efficiency
- **Use data to calibrate model?**
  - Low recovery rates at both sites reflect low collection efficiencies
  - Low collection efficiencies are difficult to accurately estimate, which prevents model calibration with flow data
- **Lack of adequate data for model calibration**
  - Need to rely on waste composition data and landfill characteristics to develop model – theoretical basis
  - Biogas recovery data may be used to test model or estimate collection efficiency

First-Order Decay Equation

- $$Q_{CH_4} = \sum_{i=1}^{n} k\, L_0\, M_i\, e^{-kt_i}$$
  - Q_{CH_4} = methane generation
  - M_i = annual waste disposal in year i (tonnes)
  - k = methane generation (decay) rate constant (1/year)
    - Function of organic waste type and site conditions (moisture, temperature, pH)
  - L_0 = potential methane generation capacity (m^3/tonne)
    - Function of % organic waste (dry weight)
    - Site conditions (lack of moisture) can affect L_0
  - t = time elapsed (years)

U.S. EPA's LandGEM

- **U.S. EPA's LandGEM**
  - Latest version (2005) uses 0.1 year increments in calculation
  - L_0 value
    - EPA Inventory default L_0 = 100 m^3/Mg = Good value for typical U.S. landfills
  - k value
    - EPA Inventory default k values: dry sites=0.02; wet sites=0.04 (~17 year half-life)
    - One average k for all wastes = single-phase FOD model

Mexico Biogas Model

- **Developed by LMOP and released at workshop in Monterrey Mexico in Dec. 2003**
- **Single-phase FOD model with modifications to account for waste composition and climate in Mexico**
  - Default L_0 = 84 m^3/tonne based on comparison of U.S. to Mexico waste composition – % of dry organic material
    - Mexico L_0 lower than U.S. due to higher % of water weight included in disposal estimates
  - Default k values range from 0.04 to 0.08, depending on precipitation
    - Mexico k values higher than U.S. due to higher % of food waste, which decays faster

Limitations of Mexico Biogas Model

- **Problems with single-phase model**
  - Single phase model was developed with data from U.S. landfills; Mexico Model had good data from Monterey only
  - Accounting for waste composition – effects of high food waste %
    - Food waste will decay most rapidly
    - Over time, % food waste declines, leaving slowly-decaying organics
    - Need “multi-phase” model (>1 k) to account for variation in average waste decay rates over time
- **Accounting for climate**
  - Central American countries have much wetter climate than much of Mexico

CDM Method AM0025

- **CDM Method AM0025: Avoided Emissions from Organic Waste through Alternative Waste Treatment Processes** – conservative estimates
  - Combines several variables to estimate m^3 methane generated per tonne of waste (L_0 equivalent) by waste type:
    - Degradable organic carbon (DOC)
    - Fraction of DOC dissimilated (DOC_f)
    - Methane correction factor (MCF)
  - Multi-phase FOD model – uses 2 organic waste k values:
    - Food waste = 0.231/year (3 year half-life)
    - Other organic waste (garden waste, paper, textiles, wood, straw, etc.) = 0.023/year (30 year half-life)

CDM Method AM0025 k Values

- **CDM Method k values:**
  - No variation with climate
    - Food waste k value (0.231) appears appropriate for wet climate of Central America
    - Other organics k (0.023) appears to be low for some materials
  - 2-k model groups all non-food organics into one category – 10 times slower decay than food
    - Problem: Decay rates for garden waste >> paper >> leather
    - Impact of assigning one k value to group depends on mix of different waste types

IPCC Waste Model

- **Intergovernmental Panel on Climate Change (IPCC) Model (2006)**
  - Designed to estimate methane emissions from countries/regions, but can be adjusted for landfills
- **Has default model L_0 and k values based on waste composition and climate**
  - L_0: Uses same L_0 equivalent calculation as CDM method
    - Values estimated based on laboratory studies, landfill research, and expert judgment
  - k: Assigns different k values for 4 waste categories x 4 climate zones
    - (1) Food waste and sewage sludge; (2) garden/park waste; (3) paper and textiles; (4) wood and straw
    - Temperate wet and dry; tropical wet and dry

IPCC Model k Values

- **4 k values for 4 waste categories helps account for varying waste composition**
  - Does model precision and waste composition data quality justify using 4 k values?
- **4 climate categories: Tropical Wet and Dry, Temperate Wet and Dry**
  - Tropical = Annual average temperature >20^{o}C
    - Only higher elevation areas would be temperate (few landfills)
  - Wet = Average annual precipitation >1000 mm
    - Most areas in Central America would be the wet climate zone
    - A few locations in Honduras (Tegucigalpa=918 mm), Guatemala, and Nicaragua would be in dry climate zone with much lower k values
- **k values higher than CDM Method (e.g., Tropical wet food waste k = 0.4 = 1.7 year half-life)**

Central America Model

- **Goals:**
  - To provide an accurate and easy-to-use biogas model
  - To provide realistic and conservative projections of biogas recovery
  - To account for climate, waste characteristics, and site conditions in Central American countries
  - To provide a useful screening tool for preliminary evaluations of project potential at landfills in Central America

Central America Model
k Values

- **Central America climate and waste characteristics maximize decay rates (k)**
  - What is maximum k (for food wastes)?
- **To be conservative, use modified version of CDM Method AM0025 (2 k):**
  - Fast decay organics (food waste) k value: Fixed at 0.23
  - Slow-decay organics k value: Varies between 0.025 and 0.033 depending on the mix of organic materials
    - Calculated using waste composition and fixed ratios of fast to slow decay k values
    - Garden waste split into fast and slow categories using waste composition data
  - Lower k values for areas with less than 1000 mm/year rainfall

Comparison of Model k Values

Type of Waste		IPCC - Tropical		CDM Method	Central America Model(1)
		Dry	Wet		
Slowly degrading waste	Paper/textile waste	0.045	0.07	0.023	0.025 - 0.033(2)
	Wood/ straw/ rubber waste	0.025	0.035		
Moderately degrading waste	Garden and park waste	0.065	0.17		(3)
Rapidly degrading waste	Food waste/ sewage sludge	0.085	0.40	0.231	0.23
	Ratio: Fast to slow (paper) k	1.9	5.7	10	7.0 - 9.2(2)

Notes on Central America k Values:

(1) k values for wet sites (>1000 mm/year precipitation) shown

(2) Slow-decay organic waste k varies depending on % waste mix

(3) Garden waste is divided into fast-decay and slow-decay organic wastes

Central America Model L_0 Values

- **Development of model L_0 values:**
  - Use Mexico Model method with some modifications
    - Based on ratio of organics dry weight % (Central America country vs. Mexico)
    - Separate L_0 values for fast and slow decay organic waste
    - Includes Methane Correction Factor to account for aerobic decay at dump sites, shallow landfills

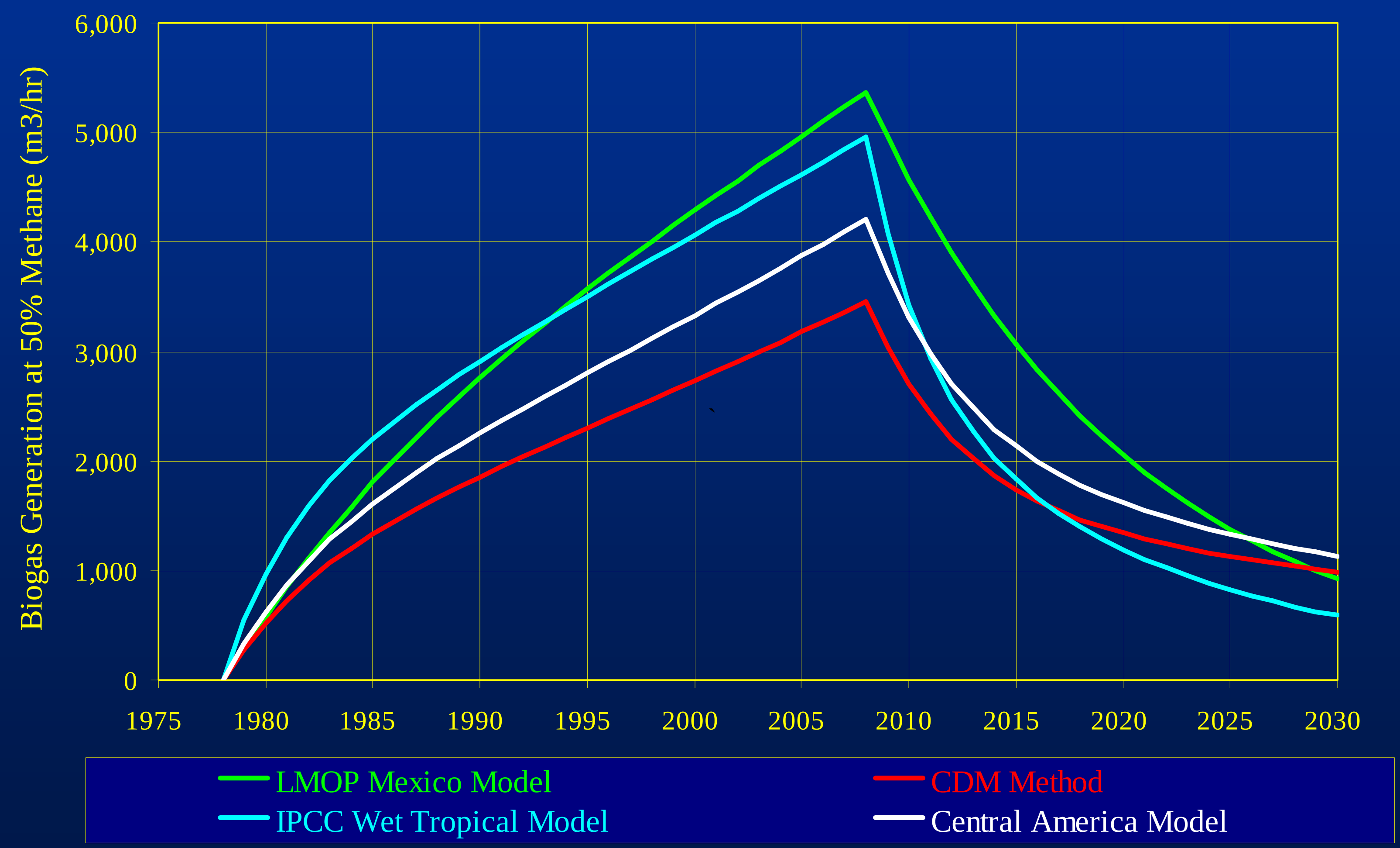
Methane Correction Factor (MCF)

- **Adjustment to model L_0:**

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

*Based on IPPC, 2006. Table 3.1, SWDS Classification and Methane Correction Factor (MCF), with modifications.

Comparison of Model Results



Collection Efficiency

- **A measure of the ability of the gas collection system to capture generated biogas**
- **Independent estimate of collection efficiency required to estimate biogas recovery from modeled generation**
  - Generation x Collection Efficiency % = Recovery
  - Collection efficiency is a function of system efficiency and % system coverage
  - US EPA estimates that the maximum collection efficiency achievable at a landfill with a comprehensive gas system is 60 – 85%
  - Dump sites: maximum collection efficiency only ~30-60%, even with remediation

Estimating Collection Efficiency

- **Assume = 85% x coverage factor (% of waste volume [area] covered with wells), with discounts to the extent that the following conditions are not met:**
  - Some degree of managed placement of waste and waste compaction and grading
  - Waste depths of at least 10 m, preferably >20 m
  - Daily or at least weekly soil cover placed on deposited refuse
  - Final cover placed in areas that have stopped receiving waste
  - Composite bottom liner consisting of plastic layer over 2 feet (0.6 meter) of clay or similar material
  - Leachate levels maintained near bottom of landfill

Estimating Collection System Coverage

- **Coverage factor = % of waste volume (area) covered with functioning extraction wells**
  - For sites with collection systems installed:
    - Use site drawing showing wellfield to estimate % of waste volume with wells
    - Discount wells not contributing methane based on wellfield monitoring data and leachate levels
    - Consider realistic schedule for expanding wellfield when estimating future coverage
  - For sites prior to installing collection systems:
    - Consider realistic schedule for installing wellfield
    - Easier to install and maintain wells in areas closed and with final cover

Summary

- **A FOD biogas generation model was developed by LMOP for all 7 countries in Central America**
  - Model reflects data on climate, waste composition, and site characteristics obtained from the 7 countries
  - Inadequate data exists for empirical model calibration; Central America model developed from prior models based on theoretical considerations
- **Model provides estimates which are mid-range between CDM Method (low) and IPCC Model for tropical wet climates (high)**
- **Methods for estimating collection efficiency and biogas recovery were introduced**

Questions?