Landfill Gas Quality and Quantity
Significance of Landfill Gas

- Potential energy recovery of methane
- Methane is a potent greenhouse gas
- Explosive danger
- Health hazards associated with trace gases
- Odor nuisance
Legislative Issues

- Public Utility Regulatory Policy Act (PURPA-1978) governs the sale of electric power generated by LFG-to-energy plants (and other renewable energy sources).
- Federal tax credits and state regulations which provide financial assistance and incentives to recover and reuse LFG.
- PURPA only calls for renewable energy if it is cost competitive with conventional polluting resources.
- Many of the benefits of renewables are not included in the price, such as clean air.
RCRA Subtitle D

- RCRA, Subtitle D and Chapter 17-701, FAC, with respect to LFG monitoring, control, and recovery for reuse
- Concentration of methane cannot exceed 25% of the lower explosive limit in on-site structures
NSPS and Emission Guidelines

- Promulgated under the Clean Air Act
- New and existing landfills
- Capacities equal to or greater than 2.75 million tons
- Regulates methane, carbon dioxide and NMOCs
- Require
  - Well designed/operated collection system
  - Control device capable of reducing NMOCs by 98%
NESHAP Rules

- National Emission Standards for Hazardous Air Pollutants: Municipal Solid Waste Landfills
- Additional requirements for landfills constructed since Nov. 2000
- Additional controls for HAPs identified in the CAA
AP-42 Emission Factors (EF)

- An EF is related to the quantity of pollutants emitted from a unit source.
- Important for developing control strategies, applicability of permitting programs, evaluating effects of sources and mitigation.
- When site specific data are not available, EFs are used to estimate area-wide emissions:
  - For a specific facility
  - Relative to ambient air quality.
EFs for LFG

- EFs provided for controlled and non-controlled and secondary emissions from landfills
- EFs developed for NOx, CO, PM, SO\(_2\), NMOCs, HAPs, others (HCl, H\(_2\)S, CH\(_4\))
Methanogenesis Reactions

\[ \text{CH}_3\text{COO}^- + \text{H}_2\text{O} \rightarrow \text{CH}_4 + \text{HCO}_3^- \]
acetate + water \rightarrow methane + bicarbonate

\[ 4\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]
hydrogen + carbon \rightarrow methane + water dioxide
Favorable Conditions for Methanogenesis

- Sufficient moisture content
- Sufficient nutrients
- Absence of oxygen and toxics
- Relatively neutral pH, 6.7 - 7.2
- Alkalinity greater than 2000 mg/l as calcium carbonate
- Volatile Acids less than 3000 mg/L as Acetic Acid
- Internal temperature between 86°F and 131°F
Properties of Methane

- Molecular Formula: CH$_4$
- Heating value: 2350 J g$^{-1}$
- Solubility in water: 17 mg/L
- Ratio of O$_2$:CH$_4$ req. for combustion: 2
Gas Composition - Major Gases

- Methane (45 - 60 % by volume)
- Carbon Dioxide (40 - 60 % by volume)
- Nitrogen (2 - 5 % by volume)
- Oxygen (0.1 - 1.0 % by volume)
- Ammonia (0.1 - 1.0 % by volume)
- Hydrogen (0 - 0.2% by volume)
Gas Composition - Trace Gases (less than 0.6 % by volume)

- Odor causing compounds
- Aromatic hydrocarbons
- Chlorinated solvents
- Aliphatic hydrocarbons
- Alcohols
- Polyaromatic hydrocarbons
Estimating Gas Quantities

- Gas Yield
- Duration of Gas Production
- Shape of Batch Production Curve
- Lag Time Estimate
Gas Yields

3 - 90 L/kg dry
Stoichiometric Estimate of Gas Potential

\[
CH_a O_b N_c + \frac{1}{4} (4 - a - 2b + 3c)H_2O \rightarrow \\
\frac{1}{8} (4 - a + 2b + 3c)CO_2 + \frac{1}{8} (4 + a - 2b - 3c)CH_4 + cNH_3
\]
Problems with Stoichiometric Estimates

- Some fractions are not biodegradable (lignin, plastics)
- Moisture limitations
- Toxins
- Some fractions are not accessible (plastic bags)
### Biochemical Methane Potential

<table>
<thead>
<tr>
<th>Sample</th>
<th>Methane Yield, $m^3$/kg VS</th>
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<tbody>
<tr>
<td>Mixed MSW</td>
<td>0.186 - 0.222</td>
</tr>
<tr>
<td>Mixed Yard Waste</td>
<td>0.143</td>
</tr>
<tr>
<td>Office Paper</td>
<td>0.369</td>
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<tr>
<td>Newsprint</td>
<td>0.084</td>
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<td>Magazine</td>
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<tr>
<td>Food Board</td>
<td>0.343</td>
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<tr>
<td>Milk Carton</td>
<td>0.318</td>
</tr>
<tr>
<td>Wax Paper</td>
<td>0.341</td>
</tr>
</tbody>
</table>

*From Owens, J.M. and D.P. Chynoweth*
Duration of Gas Production

- Waste composition (degradability)
- Moisture conditions
- For first order kinetic models, controlled by first order reaction rate constant \((k)\)
a) CONSTANT RATE MODEL

b) SHELDON-ARLETA MODEL

(c) SCHOLL CANYON MODEL
(No lag assumed)

d) EMCON MGM (Simplified)
Estimates of Gas Production Rates

- Rapid degradation conditions: 3 to 7 years (4 to 10 L/kg/yr)
- Moderate degradation conditions: 10 to 20 years (1.5 to 3 L/kg/yr)
- Slow degradation conditions: 20 to 40 years (0.7 to 1.5 L/kg/yr)
New Source Performance Standards

- Applies to MSW landfills only
- Landfill maximum design capacity > 100,000 metric tons
- NMOC emission rate > 150 metric tons/yr
NSPS 3 tier Calculation

- Tier 1 - use default values and determine whether NMOC > 150 tons/yr, if yes ---> Tier 2
- Tier 2 - Determine NMOC conc., redetermine whether NMOC > 150 tons/yr, if yes ---> Tier 3
- Tier 3 - Determine LFG generation rate, using site specific data, determine whether NMOC > 150 tons/yr, if yes, install controls
Landfill Gas Emission Models

- Palos Verdes Kinetic Model
- Sheldon Arleta Kinetic Model
- Scholl Canyon Model
- Landfill Odor Characterization Model
- Methane Generation Model (EMCON)
- LFGGEN (UCF)
- LANDGEM (EPA)
EPA’s Landfill Gas Emissions Model

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Purpose of Model and Software

- To provide “easy” approach to estimating landfill gas emissions (e.g., carbon dioxide, methane, VOC, hazardous air pollutants) using type of data available at municipal solid waste landfills

- Defaults are provided unless site-specific data are available
  - Emissions are projected over time using first-order decomposition equation
EPA LandGEM

- LandGEM is available (http://www.epa.gov/ttn/catc/).
  - Windows 95-based software
  - Read.me file
  - User’s Manual

- Questions/comments on software - instructions in read.me file on where to send
Equation and Inputs

First Order Decomposition Rate Equation -

- Design Capacity of Landfill
- Amount of Refuse in place in landfill or the annual refuse acceptance rate for the landfill
- Methane generation rate ($k$)
- Potential methane generation capacity ($L_0$)
- Concentration of total nonmethane organic compounds (NMOC) and speciated NMOC found in landfill gas
- Years the landfill has been in operation
- Whether the landfill has been used for disposal of hazardous waste
$Q_T = \sum_{i=1}^{n} 2kL_o M_i e^{-kt_i}$

Where:

- $Q_T$ = total gas emission rate from a landfill, mass/time
- $k$ = landfill gas emission constant, time$^{-1}$
- $L_o$ = methane generation potential, volume/mass of waste
- $t_i$ = age of the $i^{th}$ section of waste, time
- $M_i$ = mass of wet waste, placed at time $i$
- $n$ = total time periods of waste placement
EPA Emission Rate Model - Cont’d

CAA Default Values:
\[ k = 0.05 \text{ yr}^{-1} \]
\[ L_o = 170 \text{ m}^3/\text{Mg} \]

AP 42 Default Values:
\[ k = 0.0 \text{ yr}^{-1} \]
\[ L_o = 140 \text{ m}^3/\text{Mg} \]
Gas Enhancement Techniques

- Moisture Content
- Shredding
- Leachate Recycle
- Inoculum Addition
- Buffer
- Nutrient Addition
- Temperature
Field Measurements - Gas Composition

- Surface Sweep
- Passive sampling
- Vent sampling
Field Measurements - Emission Rates

- Area of Influence
- Flux Chamber/Tube
- Gas meter
Estimating Landfill Gas Production Rates - Gas Generation

- **Minimum:** \( \text{Tons in place} \times 0.25 = \text{ft}^3/\text{d} \)
- **Average:** \( \text{Tons in place} \times 0.5 = \text{ft}^3/\text{d} \)
- **Maximum:** \( \text{Tons in place} \times 1.0 = \text{ft}^3/\text{d} \)

\[ \text{Tons in place} = \text{Average Depth X Acres} \times 1000 \]

(Assumes 1200 lb/yd\(^3\))
Estimating Landfill Gas Production Rates - Collection

No Cap:

- Minimum: \( LFG \times 0.25 \)
- Average: \( LFG \times 0.50 \)
- Maximum: \( LFG \times 0.75 \)

Cap:

- \( LFG \times (0.8 - 0.9) \)
Economic Issues

- Gas quantity/quality
- Site age and projected gas production life
- Availability of an end user for LFG or energy
Economic Issues – Cont’d

- Economics of utilization
  - administrative costs/project development
  - capital costs
  - operating and maintenance costs
  - royalty payments to landfill owner ...
  - federal tax credits (Section 29 of Internal Revenue Code)
  - revenue from energy sales
Beneficial Reuse Applications

- Flares
- Boilers
- Microturbines
- Vehicular Fuel
- Synthetic Fuels
- Electric Power Generation
- Pipeline Quality Natural Gas
Gas Cleanup

- Particulate removal
- Condensate removal
- Trace compound removal
- Upgrading to natural gas quality
Gas Cleanup
Gas Cleanup
Electric Power Generation

Advantages:

- Large market of stable, continuous demand
- Easy access to wide energy distribution network
- Low pollutant emissions
- Practical for a large range of landfill sizes
- Wide variety of viable technologies
Electric Power Generation

Disadvantages:

- Air pollution emissions may restrict LFG utilization
- Relatively high capital, operating and maintenance costs
Generator
Power Generation - Microturbines

- Advantages
  - Low gas flow
  - Lower temperature
  - Lower emissions of pollutants
  - Flexible

- Disadvantages
  - Low flow range
  - New technology
Microturbines
Medium BTU Use -
Boilers, Dryers, Space Heating

- Disadvantages:
  - Requires stable, continuous, end user demand
  - May be uneconomical to pipe LFG long distances (typically > 2 miles)
Medium BTU Use - Boilers, Dryers, Space Heating

Advantages:

- Low capital, O & M costs
- Low system equipment and design requirements
- Higher LFG extraction rates possible
- Lower NOx emissions than conventional fuels
Landfill Gas-Fed Boiler
Pipeline Quality Natural Gas

Advantages

- Large market of stable, continuous, long-term demand
- Easy access to wide energy distribution network
- Low pollutant emissions
- By-product CO2 has market value
Pipeline Quality Natural Gas

Disadvantages:

- Strict limits on oxygen and nitrogen restrict LFG extraction
- High parasitic energy requirements
- High capital and operating costs
- Uneconomical for smaller landfills
- Low current and forecast energy prices hinder feasibility
Pipeline
Vehicular Fuel

Advantages:

- Potential large market of stable, continuous, long-term demand
- Low pollutant emissions
- Simplified modular processing system design
- Low area requirements
- By-product CO2 has market value
Vehicular Fuel

Disadvantages:

- Strict limits on oxygen and nitrogen restrict LFG extraction
- High parasitic energy requirements
- High capital and operating costs
- Major engine modifications required
- Limited distribution network
- Uneconomical for small landfills
Vehicular Fuel
Synthetic Fuels and Chemicals

Advantages:

- Large and varied markets for fuels and chemicals
- Low pollutant emissions in processing
- Simplified modular processing system design
- By-product CO2 has market value
Synthetic Fuels and Chemicals

Disadvantages:

- Strict limits on oxygen and nitrogen restrict LFG extraction
- High parasitic energy requirements
- High capital and operating costs
- Uneconomical for smaller landfills
Steps for Gas Collection
System Design

- Calculate annual gas production (peak)
  - LandGEM (use realistic $k$, $L_0$ values, for example $k = 0.1 \text{ yr}^{-1}$ for 20 yrs)

- Pick type of system (passive, active, vertical, horizontal, combination)

- Layout wells
  - 30-40 scfm/well
  - 100-300 ft spacing
Steps for Gas Collection
System Design - Cont’d

- Size blowers (calculate pressure drop)
- Calculate condensate
- Prepare gas monitoring plan
- NSPS calculations using default values