Estimating Global Methane Emissions from Landfills

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Topics to be Covered

- Background on methane emissions from landfills and dump sites
- IPCC methods for calculating global methane emissions from landfills
- Use of a modified IPCC method (Bogner and Matthews, 2003) to estimate global landfill methane emissions through 1996
- Extrapolate results to estimate global methane emissions through 2006
Landfills and Landfill Biogas

- Landfill biogas is approximately 50-60% methane and 40-50% CO₂
- Methane is 21 more times more potent GHG than CO₂
- Biomass derived CO₂ from landfills is not “counted” as contributing to global warming by UNFCCC
Waste Decay and Methane Generation in Landfills

- Engineered and Sanitary Landfills
  - Soil cover and waste compaction - anaerobic conditions quickly established
  - Long, stable period of production of methane and CO$_2$

- Dump Sites
  - Limited/no soil cover or waste compaction – aerobic conditions persist
  - Long period (perhaps years) before waste burial creates anaerobic conditions and significant methane is generated
Dump Sites – Environmental Issues

- Aerobic conditions predominate and lead to:
  - High landfill temperatures and landfill fires
  - High carboxylic acid concentrations (BOD) in leachate
  - Poor drainage leads to leachate runoff into surface and groundwater
Methane Emissions: Developed Countries

- Methane emissions decreasing due to:
  - Waste generation is stabilizing
  - Limits to landfill space; future limits to organics disposal
  - Increases in recycling and composting
  - Increases in methane recovery from landfills
Methane Emissions: Developing Countries

- Methane emissions increasing due to:
  - Increases in population and urbanization
  - Increases in waste generation
  - Conversion from dump sites to landfills – a plus for environment but causes increased methane generation
  - Passive venting of landfill biogas is a common practice
  - Insignificant methane recovery due to limited knowledge and funding
Methane Emissions from Landfills - Overview

- Range of estimates of global landfill methane emissions: 9 – 70 Tg/year
- Methane mass balance:
  - $\text{CH}_4$ Production = $\text{CH}_4$ Emitted + $\text{CH}_4$ Oxidized + $\text{CH}_4$ Recovered + Lateral $\text{CH}_4$ Migration + $\Delta\text{CH}_4$ Storage
Methodologies for Estimating Global Methane Emissions

- Limited field data on measured methane emissions – empirical models for methane recovery only

- Annual methane emissions from each country are estimated based on waste disposal data
  - IPCC methodology (“Tier 1” method)
  - First-order decay models (“Tier 2” method)
IPCC Method (Tier 1)

CH₄ emitted (Tg/yr) = \{[(MSW_t)(MSW_f)(MC_f) (DOC)(DOC_f)(F)(16/12)] - R\}(1 – OX),

Where:
• MSWₜ = Municipal solid waste generated
• MSWᵥ = Fraction of generated MSW disposed in landfills
• MCᵥ = Fraction of landfilled MSW which decomposes anaerobically (“correction factor”)
• DOC = Fraction of biodegradable organic carbon in landfilled MSW
• DOCᵥ = Fraction of DOC “dissimilated” (converted to CH₄ and CO₂ in landfill biogas)
• F = Fraction of CH₄ in landfill biogas
• R = Amount of recovered CH₄
• OX = Fraction of CH₄ oxidized in cover soils
Advantages of IPCC Method

- Minimizes data requirements
  - Annual waste generation can be derived from waste generation per capita estimates (where data are lacking)
  - IPCC guidance and default values for terms in equation
Disadvantages of IPCC Method

- Estimates based on current year’s disposal
  - Do not account for methane from prior years’ waste
  - Do not account for waste decay rates (wide range depending on types of waste, moisture content)

- Reliance on per capita waste generation estimates for developing countries
  - Per capita estimates derived from limited (urbanized) areas with waste collection data
  - Does not account for effect of affluence on waste disposal rates
1\textsuperscript{st} Order Decay Method (Tier 2) – e.g. LandGEM

\[ Q_M = \sum_{i=1}^{n} 2k Lo M_i (e^{-kt_i}) \]

\( Q_M = \) landfill biogas generation rate (m\(^3/\)yr);
\( \sum_{i=1}^{n} = \) sum from opening year (i=1) through year of projection (n);
\( k = \) methane decay rate constant (1/yr);
\( Lo = \) ultimate methane generation potential (m\(^3/\)Mg);
\( M_i = \) mass of solid waste disposed in the \( i \)\textsuperscript{th} year (Mg);
\( t_i = \) age of the waste disposed in the \( i \)\textsuperscript{th} year (years).

Note: Equation for calculation in 1 year increments shown; latest version (LandGEM v. 3.02) uses 0.1 year increments.
More on 1st Order Decay Method

- Also approved by IPCC
- Estimates landfill methane generation x 2
- Need to apply estimates of % recovery and oxidation (e.g., IPCC values)
- Commonly used in developing countries for individual landfills
  - Required for regulatory compliance – conservative estimates of landfill biogas emissions
  - Useful for evaluating methane recovery project requirements
Advantages of 1<sup>st</sup> Order Decay Method

- Accounts for methane generation from historic waste disposal
- Accounts for waste composition and moisture effects on waste decay rates
- Site-specific landfill biogas recovery models have been validated with flow data
Disadvantages of 1st Order Decay Method

Problems: historical waste disposal estimates

- Greater data requirements magnify problem of scarce, poor quality data
- Uncertainty assigning single set of model parameters for entire country
- Decay rates vary significantly with climate and waste composition differences
- Inexperienced modelers rely on USEPA regulatory default values
  - Results in high estimates for developed countries
  - Inappropriate for developing countries
Summary of Methodologies

- 1st Order decay (Tier 2) method most accurate but not practical yet
- IPCC Tier 1 method more practical for global estimates, but accuracy can be improved
- Alternative: Tier 1 IPCC method modified per Bogner and Mathews, 2003*

Proposed Revisions to IPCC Methodology

- Use per capita annual energy consumption as a surrogate for per capita waste generation
  - Relationship of energy consumption to waste generation found through linear regression
  - Accounts for effects of both population and affluence on waste generation

- Use total population for developed countries; urban population for developing countries (where rural waste typically is not landfilled)

- Use revised estimates of degradable organic carbon dissimilated ($\text{DOC}_r$), methane recovery, and oxidation
Basis for Revised Value for $\text{DOC}_f$

- Degradable Organic Carbon Dissimilated ($\text{DOC}_f$) – Use 0.5 instead of 0.77
  - 0.77 from original IPCC method based on optimized low solids anaerobic digestion is too high for non-optimized high solids waste in landfills
  - 0.5 recommended by IEA/OECD/IPCC expert group meeting, Argonne National Laboratory, 1996
  - Laboratory studies indicate $\text{DOC}_f$ of 0.25-0.5 for optimized landfills; lower for non-optimized
Basis for Revised Values for Methane Recovery (R)

- R: Use updated methane recovery values extrapolated from database of commercial projects (beneficial use)
  - Approximately 50-100% underestimate for many countries because flared methane excluded
Basis for Revised Values for Methane Oxidation (OX)

- OX: Use 0.1 for methane oxidation
  - Based on field study in New Hampshire, USA
  - Field studies found OX values ranged from 0 to >100%
    - OX maximized at sites with engineered gas recovery systems and thick, compost-amended soil covers
Compost Biocovers

- Simple to construct, local equipment and materials
- Significant use of low-grade (or better) compost products derived from waste sources
- Methane emissions reduced vs. traditional methods
- Use of cover soils is reduced
- Trial demonstrations already in-place in USA and Europe
Cross-section of Biocover

- Mound to drain
- Nested probes, gas collection from various depths
- Yard waste compost
- Varies 36”-60”
- 12” (Typ.)
- Existing soil cover (thickness varies)
- 6” existing soil cap (leave in place)
- Municipal solid waste
- 2”-4” river gravel, wood chips, tire chips or glass cullet

Biological permeable cover
Cross section
## Results: Global Landfill Methane Emissions Estimates (Tg/year)

<table>
<thead>
<tr>
<th>Year</th>
<th>1986</th>
<th>1996</th>
<th>Projected 2006</th>
<th>2006 Projection Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Emissions</td>
<td>18.0</td>
<td>20.7</td>
<td>21.3</td>
<td>17 Tg net emissions and 20% recovery</td>
</tr>
<tr>
<td>Percent Recovery</td>
<td>2.4%</td>
<td>18.2%</td>
<td>20%</td>
<td>Assumes 10% increase from 1996</td>
</tr>
<tr>
<td>Global Recovery</td>
<td>0.4</td>
<td>3.8</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Net Emissions</td>
<td>17.6</td>
<td>16.9</td>
<td>17.0</td>
<td>USEPA* 1995-2005 est. increase = 0.6%</td>
</tr>
</tbody>
</table>

Conclusions

- Total global landfill methane emissions in 2006 = ~16.9 Tg = 355 million tonnes CO$_2$e
- Accuracy of estimates limited by lack of data, particularly in developing countries
- Large increases in emissions from developing countries could cause sharp increase in future global emissions
- Methane recovery and oxidation estimates are conservative – large potential for emissions reductions at landfills with methane recovery and good soil covers