Regional Prediction of LFGTE Potential: Florida Case-Study

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Project Objectives

- Predict Florida LFG and LFGTE production potential
- Improve the viability of LFGTE projects through case study analysis
Waste Generated GHGs

- LFG is generated from the anaerobic decomposition of MSW, consisting of:
  - $\text{CH}_4$, 50-60% 
  - $\text{CO}_2$, 40-50% 
  - Other trace gases, <1%

- Methane believed to be of higher importance, due to:
  - Landfill $\text{CO}_2$ emissions are biogenic 
  - $\text{CH}_4$ has a GWP of 21 greater than $\text{CO}_2$
US CH$_4$ Emission Sources

- Enteric Fermentation
- Landfills
- Natural Gas Systems
- Coal Mining
- Manure Management
- Petroleum Systems
- Wastewater Treatment
- Forest Land Remaining Forest Land
- Rice Cultivation
- Stationary Combustion
- Abandoned Underground Coal Mines
- Mobile Combustion
- Composting
- Field Burning of Agricultural Residues
- Petrochemical Production
- Iron and Steel Production & Metallurgical Coke Production
- Ferroalloy Production
- Silicon Carbide Production and Consumption
- Incineration of Waste

CH$_4$ as a Portion of all Emissions: 8.2%

LFGTE Projects

- LFG has an energy value of 18-22 MJ/m³, due to methane content

- Across the United States, as of July 2010:
  - 518 operational LFGTE projects, 1615 MW electricity production and 3000 Mm³ direct thermal use annually
  - 520 other potential landfills, 1200 MW electricity production potential annually

- As of January 2010, 33 states had established RPSs, almost all considering LFGTE as a renewable energy resource
Florida MSW & LFGTE

- About 60% of Florida MSW, over 16 million tonnes, was landfilled in 2007
- Most of the 64 active landfills collect LFG, but only 16 landfills operate or support a LFGTE facility, with annual design capacity of:
  - 61 MW of electricity production, and
  - 39 Mm³ to direct thermal use
LFG Collection Modeling

- First-order model (modified LandGEM)

\[ Q_c = \sum_{i=1}^{n} \sum_{j=0.1}^{1} \eta_{iz} \alpha k \left( \frac{M_i}{10} \right) L_{0i} e^{-kt_{zj}} \]

where:
- \( Q_c \) = Annual collected LFG flow rate, m\(^3\)yr\(^{-1}\)
- \( k \) = Methane generation rate constant, yr\(^{-1}\)
- \( M_i \) = Disposed waste tonnage in year \( i \), Mg
- \( L_{0i} \) = Methane generation potential of \( M_i \), m\(^3\) CH\(_4\).Mg\(^{-1}\) waste (wet basis)
- \( t_{zj} \) = Age of \( j^{th} \) section of waste \( M_i \) in year \( z \), yr
- \( \alpha \) = Inverse ratio of methane content
- \( z \) = Time period of LFG generation from \( M_i \), yr
- \( \eta_{iz} \) = Collection efficiency in year \( z \) from \( M_i \), fraction
## Case-Study Landfills

<table>
<thead>
<tr>
<th>Landfill</th>
<th>Waste Type</th>
<th>Year Opened</th>
<th>Year Closed</th>
<th>Operational Practice</th>
<th>LFG Collection System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill 1</td>
<td>MSW</td>
<td>1985</td>
<td>Open</td>
<td>Traditional</td>
<td>Active; Vertical wells + Horizontal trenches</td>
</tr>
<tr>
<td>Landfill 2</td>
<td>MSW</td>
<td>1978</td>
<td>Open</td>
<td>Traditional</td>
<td>Active; Vertical wells</td>
</tr>
<tr>
<td>Landfill 3</td>
<td>MSW</td>
<td>1972</td>
<td>1999</td>
<td>Traditional, Wet-cell</td>
<td>Active; Vertical wells</td>
</tr>
<tr>
<td>Landfill 4</td>
<td>MSW + C&amp;D</td>
<td>1977</td>
<td>Open</td>
<td>Traditional</td>
<td>Active; Vertical wells + Horizontal trenches</td>
</tr>
<tr>
<td>Landfill 5</td>
<td>MSW</td>
<td>1986</td>
<td>Open</td>
<td>Traditional, Bioreactor</td>
<td>Active; Vertical wells</td>
</tr>
</tbody>
</table>
Uncertainty

- Oracle Crystal Ball was used to study the uncertainty in the first order model, based on uncertainties in $L_0$ and $k$
  - Crystal Ball uses Monte-Carlo simulation method to calculate range of variations and probabilities
Florida LFG & LFGTE Potential

- Base-case assumptions:
  - LFG Generation:
    i. Study period: 1991-2035 (1991 start year of FDEP data)
    ii. $k_{\text{bulk}} = 0.08 \text{ yr}^{-1}$ for traditional landfilling operation
    iii. $L_0$ from 2007 disposed waste composition data for each County
    iv. $M$ from 1991-2007 data; extrapolated to future based on population growth
    v. Methane content on average 50% over the study period
    vi. LFG generation model uncertainty applied
Fast vs. Moderate LFG Generation Rate

- Food waste decompose much faster than other MSW components
- LFG collection modeling based on:

\[
Q_{c_{total}} = Q_{c_{food\_waste}} + Q_{c_{other\_waste}}
\]

- \(k_{food\_waste} = 0.26\ \text{yr}^{-1}\)
- \(k_{other\_waste} = 0.06\ \text{yr}^{-1}\)
Florida LFG & LFGTE Potential

- Base-case assumptions:
  - LFG collection:
    i. Start gas collection after five years
    ii. Average LFG collection efficiency at 0.75 from 2010 to 2035
  - LFGTE production:
    i. All Florida landfills operate a LFGTE facility
    ii. Utilization ratio ($\varphi_1$) of 0.90
    iii. Electrical efficiency ($\varphi_2$) of 0.35 (typical for IC engines)
    iv. Energy content ($\varepsilon$) of 5.2 kWh/m$^3$ LFG (~18,000 Btu/m$^3$ CH$_4$)

$$E_g = \varepsilon \times \varphi_1 \times \varphi_2 \times Q_c$$
Current vs. Future Potential

Model Uncertainty (max)

Model Uncertainty (min)

Current LFG flow to energy production

Year

Annual LFG Collection (Billion m³/yr)

Annual LFGET Production (Billion kWh/yr)
LFGTE vs. Counties

![Bar chart showing the fraction of cumulative energy production against the number of counties.

The chart displays bars for different numbers of counties ranging from 1 to 67. The y-axis represents the fraction of cumulative energy production, while the x-axis represents the number of counties.

- For 1 county, the fraction is around 0.15.
- As the number of counties increases, the fraction also increases, reaching approximately 1.0 for 67 counties.

This suggests a positive correlation between the number of counties and the fraction of cumulative energy production.]
Operation Strategies

- With application of horizontal trenches/blankets, LFG collection and LFGTE production can be started much earlier in the lifetime.

- Bioreactor operation (adding liquid to optimize moisture content) can enhance LFG generation, thus increase energy production over a fixed timeframe.
## Sensitivity Analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$k_1$, $k_2$</th>
<th>LFG collection start year</th>
<th>LFG collection efficiency</th>
<th>Utilization ratio</th>
<th>Electrical efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1. Base case</td>
<td>0.26, 0.06</td>
<td>6</td>
<td>0.75</td>
<td>0.90</td>
<td>0.35</td>
</tr>
<tr>
<td>Scenario 2. Early gas collection</td>
<td>0.26, 0.06</td>
<td>3</td>
<td>0.75</td>
<td>0.90</td>
<td>0.35</td>
</tr>
<tr>
<td>Scenario 3. Bioreactor operation</td>
<td>0.48, 0.11</td>
<td>3</td>
<td>0.90</td>
<td>0.90</td>
<td>0.35</td>
</tr>
<tr>
<td>Scenario 4. Improved utilization ratio and electrical efficiency</td>
<td>0.26, 0.06</td>
<td>6</td>
<td>0.75</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Scenario 5. Optimized energy production</td>
<td>0.48, 0.11</td>
<td>3</td>
<td>0.90</td>
<td>1.00</td>
<td>0.50</td>
</tr>
</tbody>
</table>
## Sensitivity Analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cumulative LFG collection, Billion m³ (uncertainty range)</th>
<th>Cumulative LFGTE production, Billion kWh (uncertainty range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1. Base case</td>
<td>19 (9-29)</td>
<td>32 (14-48)</td>
</tr>
<tr>
<td>Scenario 2. Early gas collection</td>
<td>25 (13-37)</td>
<td>42 (22-61)</td>
</tr>
<tr>
<td>Scenario 3. Bioreactor operation</td>
<td>34 (20-47)</td>
<td>56 (34-78)</td>
</tr>
<tr>
<td>Scenario 4. Improved utilization ratio and electrical efficiency</td>
<td>19 (9-29)</td>
<td>35 (16-54)</td>
</tr>
<tr>
<td>Scenario 5. Optimized energy production</td>
<td>34 (20-47)</td>
<td>89 (53-123)</td>
</tr>
</tbody>
</table>
Results

- Presently about 50% of Florida LFGTE potential is being produced
- Florida LFGTE production can be four times greater than current production level, in 2035
- Statewide LFGTE power density (base-case) was estimated as 5.3 W/m$^2$ in 2010, increasing to 13.6 W/m$^2$ in 2035 (annual average of 9.5 W/m$^2$)
Power Density

- Thermal power plants
- Coal fields
- Central solar towers
- Geothermal
- Tidal
- Hydro
- Photovoltaics
- Flat plate collectors
- Phytomass
- Wind
- Ocean heat
- Hydro

Power Density

Results (Continued)

- Early LFG collection can increase LFGTE production by 32%
- Operating all landfills as bioreactor landfills can increase LFGTE production by 80%
- Optimizing LFG collection and LFGTE production can increase energy production by a factor of 2.8
Conclusions

- Florida landfills operators can prevent over 290 MT eCO$_2$ fugitive GHG emissions in the next 25 years
- About 90 billion kWh of electricity can be generated from Florida LFGTE projects by 2035, equivalent to:
  - removing some 90 million vehicles from Florida highways, or
  - eliminating the need for about one billion barrels of oil, from offshore drilling or importing from foreign countries
Acknowledgements

- The Environmental Research & Education Foundation (EREF)
- The Hinkley Center for Solid & Hazardous Waste Management (HCSHWM)
- The case-study landfill officials
Questions?