Sustainable Landfills Using Bioreactors

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Sustainable solid waste management involves socially-acceptable solutions that minimize environmental impacts and cost.
Objectives of a Sustainable Landfill

- Landfill emissions must be controlled to ensure minimal environmental impacts.
- The residues left in landfills should not pose unacceptable risk to the environment and the need for post-closure care should not be passed to the next generation.
What is a Bioreactor Landfill?

- A landfill operated to rapidly degrade biodegradable organic waste
- Increased stabilization rates because of liquids and air addition
How Are Bioreactor Landfills Unique?

- Leachate or other liquids are injected into a bioreactor landfill with the objective of accelerating waste stabilization.
- Different from landfills that recirculate leachate for liquid management.
How Are Bioreactor Landfills Sustainable?

- Waste decomposition is accelerated mainly because of:
  - Improved moisture content and distribution
  - Improved nutrient distribution
  - Improved microorganisms distribution

- As a result:
  - Leachate quality improves
  - Gas generation rates increase
  - Residue solid waste stability improves
Evidence of Bioreactor Sustainability

- Leachate quality changes
- Settlement
- Temperature Increase
- Direct evidence of enhanced degradation
- Increased gas production
Leachate Quality

Chemical Oxygen Demand (mg/L)

Year


Close
Test Cells – Yolo County

Ramin Yazdani, Yolo County
Settlement and Moisture Addition

![Graph showing the relationship between moisture added and settlement. The x-axis represents moisture added in gallons, ranging from 0 to 400,000, and the y-axis represents settlement in feet, ranging from 3.00 to 9.00. The data points are scattered, but a trend line indicates a positive correlation.]

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Effect of Recirculation on Temperature

Days: 0 200 400 600 800 1000 1200 1400

Temperature (°C): 20 30 40 50 60

Recirculation Initiated
For Monitoring Well MC7

R = 15 ft
Y = 30 ft
G = 50 ft
Waste Degradation – Impact of MC

Excavated - Fall 1998
Test Cell #1  Test Cell #2

Chicken Leg  Chicken Leg
Excavated Waste Methane Yield Data
(Alachua County, Florida)

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Landfill Gas Emissions
Landfill Gas Emissions

- Landfill gases are rich in Methane – \( \text{CH}_4 \)
- This is an environmental problem.
- Methane is significantly more effective a greenhouse gas than \( \text{CO}_2 \).
- Methane from landfills is now captured and then burned into \( \text{CO}_2 \) before release, according to EPA regulations.
# Wet Cell Model Parameters Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>( k ) (yrs(^{-1}))</th>
<th>( L_o ) (m(^3)/Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single Placement Sites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brogborough Wet</td>
<td>0.39</td>
<td>73</td>
</tr>
<tr>
<td>Yolo Full-scale NE</td>
<td>0.20</td>
<td>83</td>
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<tr>
<td>Yolo Pilot Wet</td>
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<tr>
<td><strong>Multiple Placement Sites</strong></td>
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<td></td>
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<tr>
<td>SSWMC</td>
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<tr>
<td>Landfill A</td>
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</tr>
<tr>
<td>CSWMC</td>
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<td>87</td>
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<tr>
<td><strong>Mixed-effects Model</strong></td>
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<tr>
<td>Mean</td>
<td>0.28</td>
<td>76</td>
</tr>
<tr>
<td>Upper 95%</td>
<td>0.28</td>
<td>96</td>
</tr>
<tr>
<td>Lower 95%</td>
<td>0.28</td>
<td>54</td>
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</tbody>
</table>
Selected Single Points

![Graph showing selected single points with Weighted Age (yrs) on the x-axis and Specific Methane Flow Rate (m³/Mg-yr) on the y-axis. Various locations are represented by different markers and colors. Each location is listed below the graph: Wijster BR, Netherlands, Sorab Test Cells, Middle Peninsula, VA, Alachua Co, FL, Crow Wing, MN, and Salem Co., NJ. The graph includes a best fit curve connecting the points.](image)
Study Recommendations

- $k = 0.3 \text{ year}^{-1}$
- Lo of 100 m$^3$/Mg
Wet Cell Gas Generation

LFG Flow Rate (m³/Yr)

Year

$k = 0.5$

$k = 0.2$

$k = 0.04$
Landfill Carbon Balance

- Carbon Inputs:
  - Degradable/Nondegradable
- Carbon Storage:
  - Lignin, biomass, undecomposed cellulose and hemicellulose, etc.
- Leachate Collection
- CH₄ Recovery
- CH₄, CO₂, VOCs
Landfill Impacts on GHG

- Fugitive methane emissions
- Avoided utility emissions from energy recovery
- Carbon sequestration
- Emissions related to transportation of waste to landfills
Greenhouse Gases

- Globally, landfills are the third-largest anthropogenic source of methane emissions,
- U.S. landfills are the largest anthropogenic source, accounting for 26% of total US methane emissions for a CO$_2$ equivalent of 140.9 Tg in 2004
Mitigation of Fugitive Emissions

- Recovery and flaring or energy production
- Aeration
- Oxidation
Net GHG Emissions from Landfilling

- Landfill without LFG Recovery
- Landfills with LFG Recovery and Flaring
- Landfills with LFG Recovery and Electric Generation
US LFGE Projects

- 400 operating 40 states
- Equivalent to powering 725,000 homes and heating 1.2 million homes
- Generate 9 billion kW hrs of electricity
- Methane emissions reductions of 16.7 million tonnes carbon equivalent
US LFG Environmental Benefits and Energy Savings

Equivalent to:

- Planting 19,000,000 acres of forest,
- Preventing the use of 150,000,000 barrels of oil
- Removing the CO2 emissions equivalent to 14,000,000 cars, or
- Offsetting the use of 325,000 railcars of coal.
Impact of Cover on Gas Collection

![Graph showing impact of cover on gas collection](image)

- Gas Collection Initiated
- Fugitive Gas Emissions

<table>
<thead>
<tr>
<th>Year</th>
<th>Methane Flow Rate (m^3/yr)</th>
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<tbody>
<tr>
<td>1994</td>
<td>4.0e+6</td>
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<tr>
<td>1996</td>
<td>6.0e+6</td>
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<tr>
<td>1998</td>
<td>8.0e+6</td>
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<tr>
<td>2000</td>
<td>1.0e+7</td>
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<tr>
<td>2002</td>
<td>1.2e+7</td>
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<tr>
<td>2004</td>
<td>1.4e+7</td>
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</table>
Collection Efficiencies
LFG Collection From Operating Landfills

Leachate Collection System ~ LFG Collector Network
Impact of Delayed Gas Collection

Cumulative CH₄, m³/Mg

Time, years

Bioreactor Landfill

Dry Landfill

Gas Collection Started
Aerobic Landfills

Source: www.wastemanagement.com
Impact of Initial Aeration

Cumulative CH4, m3/Mg

Time, years

No Aeration

Gas Collection Started

Aeration
CH₄ + 2O₂ → CO₂ + 2H₂O
$\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$

$5\text{H}_2\text{S} + 8\text{NO}_3^- \rightarrow 4\text{N}_2 + 5\text{SO}_4^{2-} + 4\text{H}_2\text{O} + 2\text{H}^+$
Carbon Sequestration in Landfills

- Much of the disposed wood and paper products remain in the landfill for very long periods of time
- Landfills mitigate carbon buildup in the atmosphere through carbon sequestration, offsetting methane emissions
- Landfilled paper, yard trimmings, and food wastes accounted for 1 percent of the total US carbon sequestration in 2004
Carbon Sequestration in US Landfills

![Graph showing the increase in Tg Carbon from 1900 to 2050. The graph shows a steady increase with a sharp rise around 2000.]
Carbon Storage in Landfills

![Graph showing carbon storage in different types of waste.](image-url)
Bioreactor Landfilling Impact on Carbon Sequestration

- Perhaps none
- Bioreactor landfill studies will improve our understanding of waste degradation under optimum environmental conditions
The End of Post-closure Care

- Regulatory-stipulated 30 years is arbitrary
- No clearly defined process on how to exit post-closure care period
Bioreactor Landfilling Impact on Post-Closure

- Reduce length of post closure period
- Reduce costs associated with post closure
- Provide more data to make risk-based decision regarding ending Post-closure
- Provide means to address recalcitrant organics and nitrogen??
Leachate Ammonia

* Taken from Ehrig 1989
Why Remove Ammonia?

- Potential nitrogen loss
- Toxicity
- Oxygen demand
- Impact on post-closure
In Situ Nitrification/Denitrification

- Ammonia readily and rapidly disappears at all oxygen levels and can occur at temperatures as high as 45°C.
Field-Scale Implementation Plan

Nitrogen Removal Zone

Landfill

No Air Addition – Anoxic Region for Denitrification

Leachate Injection

Nitrification Region

Air Injection
Organic Waste Degradation

- MSW
- Organic Fraction
- Non-Biodegradable
- Biodegradable
- Insoluble
- Soluble
Why Treat Recalcitrant Organics?

- Potential carbon loss
- Adverse health and environmental effects
- Source of methane
- Potential metal transport
The Pump and Treat Aerobic Flushing Bioreactor Landfill

- Destruction of recalcitrant organics and nitrogen
- Complete stabilization of solid waste cells
- Reduction of landfill aftercare
Beyond the Bioreactor Landfill

The Pump and Treat Aerobic Flushing Bioreactor Landfill

Complete Stabilization of Solid Waste Cells
Bioreactor Landfill Economics
Conclusions

- Landfilling of waste is inevitable, modern landfill practices can promote safe land disposal.
- Organic fractions of waste entering the landfill are converted to methane and carbon dioxide which can be captured.
- Methane can be beneficially used.
- Carbon dioxide can be sequestered cryogenically or sold for commercial use.
- Recalcitrant carbon can be stored in the landfill, all resulting in greenhouse gas emission offsets.
Landfill Gas: Possible Uses

- No more flaring
- Direct Use
  - Fischer-Tropsch Conversion and Storage
  - Liquid Fuel
- Aviation/Rocket Engines
- Auto Engines
- Distributed Generation of Power
- Micro-turbine, generators
- Solid Oxide Fuel Cell
- Hydrogen