Economic Analysis of Bioreactor Landfills

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Objectives:

- Evaluate the economic feasibility of aerobic and anaerobic bioreactor landfills, comparing their costs to conventional landfills
Presentation Overview

- Bioreactor cost elements
- Economic analysis approach
- Assumptions
- Results
Prior to investing in bioreactor landfills, landfill owners must be convinced that short-term expenses are balanced by economic benefits, including reduced long-term environmental risks, which are difficult to financially quantify at present.
Economics in Technical Literature

- Chong et al (2005) found semi-aerobic landfills to be a viable method in developing countries compared to conventional landfills.
- Karnich and Parry (1997) found flushing bioreactors cost more than conventional landfills, but were not financially prohibitive.
- Hater et al (2001) compared eight different scenarios of retrofit, hybrid, facultative, and conventional landfills - over the long term bioreactor life would permit longer use of existing landfills.
- Yolo County Public Works Department (2000) bioreactor landfill financially favorable when compared to a conventional landfill.
Factors Included in the Analysis

- **Costs**
  - Cell Construction
  - O&M (leachate treatment, gas collection, monitoring)
  - Cell Closure
  - Gas Collection and Use
  - Post Closure Care
Factors Included in the Analysis

- Bioreactor Benefits:
  - Airspace recovery
  - Reduction of leachate volume and treatment requirements
  - Gas recover and use. Tax credits were not included
  - Reduction of post-closure care period
  - Environmental and Long-term liability (no $)
Factors Included in the Analysis

- Bioreactor Additional costs (compared to conventional landfills):
  - Liquid injection
  - Gas recovery equipment
  - Electricity
  - Monitoring equipment
  - Leachate Seeps
  - Aerobic bioreactor only - air injection system (piping and blowers) and electricity
Assumptions

- Cell is filled over 5 yrs, during which all construction costs are incurred
- The retrofit bioreactor is operated for 10 years after closure, as-built for 5 years before and 5 years after closure.
- The monetary gain from airspace recovery is a function of the mass of additional waste that can be placed and a tipping fee.
- 70% of the settlement is assumed to be recoverable.
- Cost savings due to the deferment of another cell construction is taken into account in the as-built landfill.
- The gas collection/extraction system is constructed after aeration is discontinued.
Assumptions – Cont’d

- 13-ha single cell was used
- While the cell is being filled, the gas capture efficiency is low and gas is collected and used only in the as-built.
- Leachate treatment occurs only for leachate that is not being recirculated.
- Evaporation of leachate occurs as a result of aeration.
- Cell closure occurs during year 6.
- Costs are determined for two PCC periods for bioreactors. One occurs during the bioreactor operation period and one afterwards.
- For the as-built bioreactor, all monitoring equipment is purchased over a 5-year period, for the retro-fit the equipment is purchased in year 6.
Construction costs are similar in traditional landfills and retrofit bioreactor landfills. These costs include:

- Initial Work (survey and clearing of site)
- Bottom Liner System
- Leachate Collection System
- Support Facilities
- Gas Flare
- Top Cover
- Engineering Costs
Construction Cost

- In as-built bioreactor landfills, add:
  - Leachate injection system
  - In retrofit bioreactor landfills, this cost is added to closure costs

- Major differences are in timing of expenditures
# Operation and Maintenance Costs

<table>
<thead>
<tr>
<th>Type of Cost</th>
<th>Traditional Landfill</th>
<th>Anaerobic Bioreactor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>As-Built</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retrofit</td>
</tr>
<tr>
<td>Leachate injection</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Leachate out breaks</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Maintenance of bioreactor operations</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Operation of traditional landfill</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Additional staff to operate as a bioreactor</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Additional environmental sampling</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Additional engineering services</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
</table>
Leachate Treatment Costs

- Leachate treatment costs - $US0.03 – $US0.12/L
- Leachate recirculated is not included
- Costs are based on leachate volumes:
  - Avg. = 7500 L/day-ha
- % of Leachate produced that is recirculated:
  - Aerobic operation = 65% (base case)
  - Anaerobic operation = 75% (base case)
- When adding air, the leachate evaporation factor = 50% of leachate produced
Monitoring Costs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Logging</td>
<td>Station to connect all MTG sensors/thermocouples</td>
</tr>
<tr>
<td>Station</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Thermocouples</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>MTG Sensors</td>
</tr>
<tr>
<td>Settlement</td>
<td>GPS Unit + training</td>
</tr>
</tbody>
</table>
## Closure Costs

<table>
<thead>
<tr>
<th>Type of Cost</th>
<th>Traditional Landfill</th>
<th>Anaerobic Bioreactor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>As-Built</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retrofit</td>
</tr>
<tr>
<td>Traditional landfill closure</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Gas collection system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Leachate recirculation system</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

### COSTS: Construction | O&M | Leachate Treatment | Monitoring | Closure | Post Closure Care
Cost items are similar in all cases and include maintenance of:

- Security and fencing
- Final cap and cover
- Wells/Probes
- Environmental monitoring
- Gas collection
- Leachate management

Bioreactor operation
Airspace Benefits

Ramin Yazdani, Yolo County
Air Space Recovery Benefits

- Settlement Rates (reduction in elevation is converted to reduction in volume)
- Re-utilization factors 0.7 was used
- Resulting volume reused at a tipping fee of $44 per Tonne
Air Space Recovery Benefits

**As-Built**

- Utilization as Cell is Filled: 20%
- No Cover Replaced

**Retrofit**

- Utilization After Cell is Filled: 20%
- Cover on Top of Cell Replaced

**BENEFITS:**

- Air Space Recovery
- Gas Recovery/Use
- PCC
Gas Recovery Costs/Benefits

- EPA emission rate model was used to predict gas volume
- An internal combustion engine system is used to generate electricity
- Gas collection during filling only for as-built
- Gas capture improves significantly after closure

**BENEFITS:**

<table>
<thead>
<tr>
<th>Air Space Recovery</th>
<th>Gas Recovery/Use</th>
<th>PCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>BENEFITS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFG Flow Rate (m³/Yr)</td>
<td>Year</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

For $k = 0.5$, $k = 0.2$, and $k = 0.04$.

Graph showing LFG Flow Rate (m³/Yr) vs. Year.
### Gas Recovery Costs/Benefits

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Traditional Landfill</th>
<th>Anaerobic Bioreactor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>During Filling</td>
<td>After Filling</td>
</tr>
<tr>
<td>LandGEM first-order rate (yr⁻¹)</td>
<td>0.04 0.04</td>
<td>0.30 0.30</td>
</tr>
<tr>
<td>Gas capture (%)</td>
<td>0 90</td>
<td>50 90</td>
</tr>
</tbody>
</table>

**BENEFITS:**

- Air Space Recovery
- Gas Recovery/Use
- PCC
Post Closure Care

- If biological stability is achieved,
  - Time of PCC may be reduced
  - PCC requirements may be reduced
Results
### Total Present Worth Cost Comparison – with Gas Recovery

<table>
<thead>
<tr>
<th>Type</th>
<th>Settlement (%)</th>
<th>Gas recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>During filling</td>
<td>After filling</td>
</tr>
<tr>
<td>Traditional</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Retrofit bioreactor (anaerobic)</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>As-built bioreactor (anaerobic)</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>

*Air space recovery is assumed to be utilized at the end of the retrofit bioreactor life and as it occurs in the as-built bioreactor.*
Total Present Worth Cost Comparison – with no Gas Recovery

- Traditional Retrofit (anaerobic)
- As-Built (anaerobic)
Itemized Cost Analysis – Base Case

- Includes leachate recirculating system
- Bioreactor yrs 1-15
- Bioreactor yrs 6-15
- 30-yr post-closure period

% of Total PW Costs

- Traditional
- Retrofit
- As-Built

- Construction
- Air Space
- O&M
- Leachate Treatment
- Gas Recovery
- Closure
- Post-Closure
- Monitoring
Impact of Leachate Treatment Cost on PW

Fraction of Traditional PW

Leachate Cost, $/gal

- Anaerobic Retrofit
- 1-Yr Aerobic Retrofit
- 3-Yr Aerobic Retrofit
- 5-Yr Aerobic Retrofit
- As-Built
- 1-Yr Aerobic As-Built
- 3-Yr Aerobic As-Built
- 5-Yr Aerobic As-Built
Impact of PCC Duration on Cost
Comparison of Bioreactor to Traditional as a Function of Total Settlement
Benefits of Increased Settlement

- Completely Aerobic
- Anarobic Retrofit
- 1 yr Aerobic Retrofit
- 3 yr Aerobic Retrofit
- 5 yr Aerobic Retrofit
- Anarobic Asbuilt
- 1 yr Aerobic Asbuilt
- 3 yr Aerobic Asbuilt
- 5 yr Aerobic Asbuilt

Monetary Benefit Associated with Air-Space Recover ($10^9)

% Settlement

- Traditional Landfill (no monetary benefit)
Impact of Gas Selling Price
Impact of Aeration time on PW Cost

Fraction of Traditional PW Cost

Aeration Time

Retrofit
As-Built

90 days 1 yr 2yr 3 yr 4 yr 5 yr
Impact of Aeration Time on Gas Recovery Benefits

**Graph:**
- **Y-axis:** Present Worth Cost of Gas recovery and Use ($10^6)
- **X-axis:** Aeration Time (year)

**Legend:**
- **Retrofit**
- **As-Built**

**Lines:***
- **Blue line:** Retrofit
- **Pink dashed line:** As-Built

**Points:**
- **Blue diamond:** Gain More Revenue from Gas Recovery and Use than Traditional Landfill
- **Pink square:** Gas Recovery and Use Not Advantageous

**Notes:**
- Gain More Revenue from Gas Recovery and Use than Traditional Landfill
- Gas Recovery and Use Not Advantageous
Conclusions

- Without advantages associated with reduced PCC, retrofit bioreactor and traditional landfill PW costs are extremely close.
- As-built bioreactor landfills have lower costs than traditional and retrofit bioreactor landfills, mainly because of air space recovery and leachate treatment.
- Increased O&M costs appeared to offset advantages associated with leachate treatment and air space recovery in a retrofit bioreactor.
- Cost savings associated with environmental impact reduction and long term liability reduction have not been estimated.
Conclusions – Cont’d

- Impact of settlement is important. More research is needed to evaluate settlement achievable and recoverable.
- Utilization time of recovered air space is important. If utilized at the end of a bioreactor it is not nearly as profitable as if utilized as it is occurring.
- Cost of aerobic landfills is greater than anaerobic when gas recovery and use is possible. The difference reduces when no gas recovery is planned or where leachate treatment costs are high.
- Gas use can reduce the total cost of anaerobic landfills but if it is combined with aeration, gas use can increase the total cost.
- Inefficient gas collection during active phase reduces the benefit of enhanced gas production.
These conclusions are based on assumptions made for this analysis and may change where cost input data are significantly different.
Acknowledgements

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Questions?