Sustainable Biochar-amended Soil Cover Systems for Landfill Gas Mitigation

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Sustainable Engineering Research Laboratory (SERL)
Geotechnical and Geoenvironmental Engineering Laboratory (GAGEL)

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Environmental Remediation of Soils, Sediments, Groundwater and Stormwater
- In-situ remediation technologies
- Mixed and emerging contaminants
- Heterogeneous and low permeability subsurface environments
- New development or optimization of technologies:
  - Electrokinetic/electrochemical remediation
  - Air sparging/bio-sparging
  - Chemical oxidation
  - Chemical reduction by nanoparticles
  - Bioremediation/phytoremediation
  - Stabilization
  - Active and passive containment
  - Integrated technologies
- Green, sustainable and resilient remediation

Life Cycle Assessment and Sustainable Engineering
- LCA, SLCA, Rating systems
- Sustainable civil engineering materials
  - Scrap tires versus sand as drainage material in landfill covers and liners
  - Biochar versus compost as landfill cover material
- Sustainable civil infrastructure
  - Foundations (e.g., piles versus caissons)
  - Earth-retaining systems (e.g., Reinforced cantilever retaining wall versus mechanically stabilized wall)
  - Ground improvement (e.g., lime treatment versus organic amendment)
- Sustainable waste management
  - Landfilling versus incineration
- Sustainable environmental remediation
  - Quantitative assessment of sustainability metrics
  - Social sustainability evaluation matrix (SSEM)

Waste Management and Treatment/Landfill Engineering
- Beneficial use of waste and recycled materials
- Anaerobic digestion/composting
- Mechanical stability and chemical containment of landfills (coupled processes/modeling)
- Sustainable landfill liner and cover systems
- Biocovers
- Bioreactor landfills

Geotechnical Engineering
- Site investigations
- Structural foundations
- Earth-retaining structures
- Dams and levees
- Ground improvement techniques
- Geomechanics
- Geotechnical earthquake engineering

http://geotech.lab.uic.edu
**Methane Emission Problem**

**Landfills: 18%- 3rd largest source of CH₄ emissions in the US**

**Hazards of CH₄:**
- Explosive hazard
- Greenhouse gas
- Asphyxiant

**Controls on CH₄ emission**
- Soil Cover: Thickness/Presence
- Oxidation by methane oxidizing bacteria
- LFG recovery

*Not Adequate to control CH₄???

**Microbial Methane Oxidation**
\[ CH₄ + 2O₂ \rightarrow CO₂ + 2H₂O + \text{heat} \]

**‘Fugitive emissions’**

**Landfill gas recovery**
**Biocovers**

- Add organic-rich amendment (e.g., compost) to soil to promote nutrient and water retention and increase porosity.

- Enhances growth/activity of methane-oxidizing bacteria and methane oxidation within the cover.

- Biocovers, biowindow & biofilter designs.

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**Microbial Methane Oxidation**

\[ CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{heat} \]

*Source:* Scheutz et al. (2011)
Current Biocover Technologies

• Biocovers investigated in prior studies have used a variety of organic materials:

<table>
<thead>
<tr>
<th>Material</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>Peat Moss</td>
</tr>
<tr>
<td>Sewage Sludge</td>
<td>Yard waste</td>
</tr>
<tr>
<td>Mulch</td>
<td>Corn Stover</td>
</tr>
<tr>
<td>Activated Carbon</td>
<td>Wheat straw</td>
</tr>
<tr>
<td>Wood/bark chips</td>
<td>Earthworm cast</td>
</tr>
</tbody>
</table>

**Need a superior material to sustain CH$_4$ oxidation for longer periods**

• Oxidation efficiencies limited by several factors:

- Material degradation and subsequent pore clogging
  - Formation of exo-polysaccharides (EPS) that reduces gas transport and cover aeration
- CH$_4$ generation (rather than oxidation) in ‘immature’ or water-logged compost
- Inhibition of methanotrophic activity due to NH$_4^+$ or competition with heterotrophic bacteria
Use of Biochar as Amendment

**What is biochar?**
Solid product of biomass pyrolysis or gasification in anoxic or low-O₂ environments

- Agricultural waste (straw, corn husks)
- Wastewood
- Any organic waste

**Biomass** → **Pyrolysis or Gasification Reactor** → **Waste Heat Recovery** → **Biochar** → **Syn-gas & Syn-fuel**

**How can it promote methane oxidation?**

- High internal porosity and surface area
- Can be furnished with nutrients to support microbial activity
- More stable source of organic carbon
- Related studies indicate biochar can adsorb CH₄ to its surface
- High water-holding capacity
Batch Experiments

Column Experiments

Significant amount of CH₄ oxidation observed for biochar amended landfill cover soil; Only one biochar type was investigated
Comprehensive Research Goals

1. Assess the impacts of biochar-amendments to landfill cover soil on microbial methane oxidation rates.

2. Identify dominant factors affecting methanotrophic growth and activity in biochar-amended soil covers over long timescales to obtain field-relevant laboratory data.

3. Assess performance of biochar-based covers under field conditions.

4. Develop design guidelines for the construction of biochar-based landfill covers for methane mitigation.

CMMI#1200799  Sustainable Biocover System for Methane Oxidation in Landfills (PI: K. Reddy)
Biochars Tested

- BS
- CE-WP1
- Ash retained
- CK
- CE-WP2
- Ash Removed
- AW
- CE-AWP
- Aged for >2 years
- GAC
Biochar Selection

• CE-WP biochars selected for use based on:

  ➢ High fixed C content (35%) and surface porosity (41.4%)

  ➢ Low PAH and trace metal contents

  ➢ Low dust generation (pelleted)

  ➢ High CH$_4$ adsorption capacity

CE-WP Biochar (ash removed) – derived from pinewood, produced via gasification at ~ 520°C
### Column Testing

<table>
<thead>
<tr>
<th>Soil Control</th>
<th>2% biochar-soil layer, 20-40 cm bgs</th>
<th>10% biochar-soil layer, 20-40 cm bgs</th>
<th>10% biochar-amended soil</th>
</tr>
</thead>
</table>

[Image of the experiment setup with labeled columns for different biochar treatments.]
### Outlet CH₄ Fluxes Over Time

<table>
<thead>
<tr>
<th>Test Stage</th>
<th>Duration (days)</th>
<th>Inlet Gas</th>
<th>Inlet Q (ml/min)</th>
<th>CH₄ Influx (g CH₄ m⁻² d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Pre-incubation</td>
<td>50</td>
<td>1% CH₄, 99% N₂</td>
<td>2.5</td>
<td>0.95</td>
</tr>
<tr>
<td>II Acclimation Stage 1</td>
<td>30</td>
<td>60% CH₄, 40% CO₂</td>
<td>1.8</td>
<td>66.8</td>
</tr>
<tr>
<td>III Acclimation Stage 2</td>
<td>43</td>
<td></td>
<td>9.2</td>
<td>195.3</td>
</tr>
<tr>
<td>IV Moderate Flux, Steady-State</td>
<td>30</td>
<td></td>
<td>7.2</td>
<td>152.1</td>
</tr>
<tr>
<td>V High Flux, Steady State</td>
<td>112</td>
<td></td>
<td>8.8</td>
<td>185.2</td>
</tr>
<tr>
<td>VI Diffusion-dominant steady state</td>
<td>145</td>
<td></td>
<td>4.7</td>
<td>101.9</td>
</tr>
<tr>
<td>VII ‘After-care’ (50% CH₄)</td>
<td>68</td>
<td>50% CH₄, 50% CO₂</td>
<td>4.8</td>
<td>86.8</td>
</tr>
</tbody>
</table>

### Graphical Representation

- **Axis:** Avg. Daily CH₄ Outflux (g m⁻² d⁻¹)
- **Labels:** Soil Control, 2% BC, 20-40 cm, 10% BC, 20-40 cm, 10% BC, 0-60 cm
### Batch Tests: Maximum and Overall Average Oxidation Rates

<table>
<thead>
<tr>
<th>Material</th>
<th>Column</th>
<th>Depth at Max (cm)</th>
<th>MC at Max Rate (% wet wt.)</th>
<th>%WHC (wet wt.)</th>
<th>Max. Ox. Rate (µg/day/g-soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>C1</td>
<td>30</td>
<td>8.4</td>
<td>48.0</td>
<td>179.6</td>
</tr>
<tr>
<td>2%BC/98% Soil</td>
<td>C2</td>
<td>30</td>
<td>8.1</td>
<td>44.8</td>
<td>221.9</td>
</tr>
<tr>
<td>10%BC/90% Soil</td>
<td>C4</td>
<td>30</td>
<td>10.2</td>
<td>52.3</td>
<td>270.2</td>
</tr>
</tbody>
</table>

- Across all depths/trials, 10% biochar-amended column (C4) had higher CH₄ oxidation rates.
- Lowest rates observed in soil control.
- Highest oxidation rates observed at moisture contents of ~50% WHC.
### Microbial Community Characterization

- Relatively low abundance of methylotrophic & methanotrophic bacteria in columns

- Possible that low abundance is due to low activity & biomass following exhumation
Field Testing

| P1/P5       | Soil control |
| P2/P6       | 2% biochar-amended soil at 6-12” depth |
| P3/P7       | Thin (1”) biochar layer at 6” depth |
| P4/P8       | 10% biochar-amended soil at 6-12” depth |
Test Pad Installation

Scraping off ~1 ft of existing cover

Excavation to ~4-5 ft

Backfill ~1 ft cover soil onto re-graded waste
Test Pad Installation

Re-grade existing int. cover manually

~1" thin biochar layer at 6" depth

~1ft gravel for GDL
Test Pad Installation

Soil sampling of bulk cover materials

Compaction
Overall highest CH$_4$ emissions observed at P7, which was located furthest away from the nearest gas extraction well (~70.5 ft)
CH$_4$ Oxidation Rates in Batch Assays

- Highest oxidation rates observed in soil control
- High rates also observed in P5, P6, P7 and P8
- Strong positive correlation between oxidation rate and avg. CH$_4$ concentration at 90 cm depth ($R^2 = 0.986$)
Type I and Type II MOB in Field Samples

- Predominance of Type I MOB over Type II
  - Major Type I genera: *Methylomonas, Crenothrix*
  - Major Type II genera: *Methylosinus*
Environmental Sustainability

Life Cycle Assessment (LCA) using SimaPro Tool
Eco-Indicator 99(E) V2.08 method
Overall Conclusions

- Feedstock and production conditions can significantly impact key physical and chemical properties of biochar. More stable carbon ensures durability.

- Biochar amendment increases: (a) organic content, (b) water-holding capacity, (c) void ratio, and (d) permeability, that favor conditions suitable for increased methanotrophs and methane oxidization.

- Significant variability in the abundance and activity of methane-oxidizing bacteria in the cover soils
  - Dominant methanotrophs in field include Type I methanotrophic taxa related to *Methylomonas, Crenothrix*.

- Exposure conditions and incubation time impact the development of methane-oxidizing bacterial communities.

- Biochar-amended soil covers are *bioengineered* to be effective and durable. *Sustainable???*
Publications

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Several published papers on this topic can be found on this website.