Closure of landfills with geosynthetics – solutions for challenging boundary conditions

C. Niehues
BBG Bauberatung Geokunststoffe GmbH & Co. KG, Espelkamp, Germany
Content

• Introduction: A society without landfills?
  – Aspects from Germany

• Contribution of geosynthetics in landfill engineering

• Quality aspects

• Examples for landfill engineering with geosynthetics
  – Design
  – Application

• Summary
Introduction: A society without landfills? – Aspects from Germany

Generated waste – Federal Republic of Germany

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Mass [Mio. t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>406.7</td>
</tr>
<tr>
<td>2001</td>
<td>395.2</td>
</tr>
<tr>
<td>2002</td>
<td>381.3</td>
</tr>
<tr>
<td>2003</td>
<td>366.4</td>
</tr>
<tr>
<td>2004</td>
<td>339.4</td>
</tr>
<tr>
<td>2005</td>
<td>331.9 (340.9)</td>
</tr>
<tr>
<td>2006</td>
<td>372.9</td>
</tr>
<tr>
<td>2007</td>
<td>386.9 (351.1)</td>
</tr>
<tr>
<td>2008</td>
<td>382.8 (344.6)</td>
</tr>
<tr>
<td>2009</td>
<td>359.4 (322.3)</td>
</tr>
<tr>
<td>2010</td>
<td>373.9 (332.7)</td>
</tr>
<tr>
<td>2011</td>
<td>386.7 (342.8)</td>
</tr>
<tr>
<td>2012</td>
<td>380.6 (333.6)</td>
</tr>
</tbody>
</table>

Source: German Federal Environmental Agency

- Residues from waste treatment plants
- Excavation-/ demolition waste
- Non-hazardous industrial waste
- Mining residues
- Municipal waste

© 2014 BBG GmbH & Co. KG  C. Niehues · Closure of landfills with geosynthetics – solutions for challenging boundary conditions
Introduction: A society without landfills? – Aspects from Germany

Recovery of materials – Federal Republic of Germany

<table>
<thead>
<tr>
<th>Year</th>
<th>Excavation-/ demolition waste</th>
<th>Municipal waste</th>
<th>Non-hazardous industrial waste</th>
<th>Hazardous waste</th>
<th>Recovered material, total percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>66.5</td>
<td></td>
<td></td>
<td></td>
<td>66.5</td>
</tr>
<tr>
<td>2001</td>
<td>66.3</td>
<td></td>
<td></td>
<td></td>
<td>66.3</td>
</tr>
<tr>
<td>2002</td>
<td>66.1</td>
<td></td>
<td></td>
<td></td>
<td>66.1</td>
</tr>
<tr>
<td>2003</td>
<td>66.0</td>
<td></td>
<td></td>
<td></td>
<td>66.0</td>
</tr>
<tr>
<td>2004</td>
<td>65.0</td>
<td></td>
<td></td>
<td></td>
<td>65.0</td>
</tr>
<tr>
<td>2005</td>
<td>66.0</td>
<td></td>
<td></td>
<td></td>
<td>66.0</td>
</tr>
<tr>
<td>2006</td>
<td>74.0</td>
<td></td>
<td></td>
<td></td>
<td>74.0</td>
</tr>
<tr>
<td>2007</td>
<td>74.0</td>
<td></td>
<td></td>
<td></td>
<td>74.0</td>
</tr>
<tr>
<td>2008</td>
<td>75.0</td>
<td></td>
<td></td>
<td></td>
<td>75.0</td>
</tr>
<tr>
<td>2009</td>
<td>79.0</td>
<td></td>
<td></td>
<td></td>
<td>79.0</td>
</tr>
<tr>
<td>2010</td>
<td>76.9</td>
<td></td>
<td></td>
<td></td>
<td>76.9</td>
</tr>
<tr>
<td>2011</td>
<td>77.6</td>
<td></td>
<td></td>
<td></td>
<td>77.6</td>
</tr>
<tr>
<td>2012</td>
<td>78.9</td>
<td></td>
<td></td>
<td></td>
<td>78.9</td>
</tr>
</tbody>
</table>

Source: German Federal Environmental Agency
Introduction: A society without landfills? – Aspects from Germany

Waste disposal – Federal Republic of Germany

Source: German Federal Environmental Agency
## Landfill Capacity issue – Federal Republic of Germany

<table>
<thead>
<tr>
<th>Landfill Class</th>
<th>Total Number</th>
<th>Annual deposit [Mio. t/a]</th>
<th>Capacity remaining [Mio. m³]</th>
<th>Remaining term [a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK I (slightly contaminated soil / demolition waste)</td>
<td>158</td>
<td>12.7</td>
<td>188</td>
<td>24</td>
</tr>
<tr>
<td>MINUS: Open-cut mining dumps / ash-dumps</td>
<td>-4</td>
<td>-5.0</td>
<td>-132</td>
<td>11 (!)</td>
</tr>
</tbody>
</table>

### Statistic numbers on total landfill volume and capacity reserves for Germany

*Dr.-Ing. Karl Biedermann (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)*
Introduction: A society without landfills? – Aspects from Germany

ANALOGY: Circulatory systems – Human body and resources management

No landfills – no extraction of pollutants from material cycle!

Landfills are inevitable to prevent accumulation of harmful substances within the material cycle.

Analogism of circulatory systems – human body and resources management, created by Dr.-Ing. Heinz-Ulrich Bertram (Ministry of Environment, Energy and Sustainability of Lower Saxony)
Contribution of geosynthetics in landfill engineering

Geosynthetics contribution to Landfill engineering – central aspects
Geosynthetics increase landfill volume

→ Landfill volume increases by 0.8 m³ (per m² of surface sealing system)
Geosynthetics allow installation for challenging boundary conditions

Installation of compacted clay liner and mineral drainage layer on this slope merely impossible.

Geosynthetic solution:
- Geosynthetic clay liner (GCL)
- Geomembrane
- Geosynthetic drainage mat
- Geogrid

✓ Easy to install
✓ Less transportation
✓ Ecologically efficient
✓ Economically efficient
Geosynthetics allow installation for challenging boundary conditions

- Steep inclinations of slopes - 1(H):1,4(V) (ca. 35,0°)
- Long slopes (ca. 33,0 m)
- Long plateau area (L ≥ 20,0 m)

Contribution of geosynthetics in landfill engineering

Berechnungsquerschnitt Deponie Furth im Wald
Sustainability: Geosynthetics reduce **total energy consumption**

*Table 1: Comparison of energy consumption per square meter between GCLs/geosynthetic drainage systems and compacted clay liner/gravel collection system using the Hillern landfill as an example (values are in kWh)*

<table>
<thead>
<tr>
<th></th>
<th>GCL</th>
<th>Drainage membrane</th>
<th>Compacted Clay Liner</th>
<th>Gravel Collection system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>3.40E-03</td>
<td>-</td>
<td>0.68</td>
<td>2.60</td>
</tr>
<tr>
<td>Transport</td>
<td>4.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feedstock</td>
<td>6.47</td>
<td>15.53</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.95</td>
<td>1.96</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transportation</td>
<td>0.47</td>
<td>0.51</td>
<td>23.83</td>
<td>14.30</td>
</tr>
<tr>
<td>Installation</td>
<td>0.89</td>
<td>0.63</td>
<td>6.19</td>
<td>5.69</td>
</tr>
<tr>
<td>Total</td>
<td>13.03</td>
<td>18.63</td>
<td>30.70</td>
<td>22.59</td>
</tr>
<tr>
<td><strong>Total for landfill (A=32,853 m²)</strong></td>
<td><strong>428,065</strong></td>
<td><strong>612,073</strong></td>
<td><strong>1,008,598</strong></td>
<td><strong>742,149</strong></td>
</tr>
</tbody>
</table>
Quality aspects

Geosynthetic quality

• For landfill engineering, the quality aspect is of central interest to ensure sufficient functionality in the long-term

• Reputable manufacturers of geosynthetics provide continuous quality surveillance over the whole production chain from feedstock to finished product

• Independent institutes carry out external quality surveillance on manufactured products

• Product installation is supervised by third-party inspection on site
BAM – Federal Institute for Materials Research and Testing

• higher federal authority under supervision of the Federal Ministry of Economics and Technology

• head office located in Berlin

• key note: “safety in technology and chemistry”

• for all geosynthetics used on German landfill sites, a BAM approval is mandatory
Approval procedure for geosynthetics in German landfills

Crucial aspect: Long-term behavior for lifetime > 100 years

1. Manufacturer
   - Application for approval

2. Approving Authority
   - Certification Guidelines for each product group
     - Test certificates

3. Advisory committee
   - Federal representatives
     - Institutes
     - Consultants Supervisors
     - Manufacturers

4. Approval
   - For application on landfill sites

5. Dep V
   - German Landfill Ordinance

Quality aspects

Crucial aspect:
Long-term behavior for lifetime > 100 years

Application Standards

Certification Guidelines for each product group

Application for approval

Test certificates

Approval

For application on landfill sites

Dep V

German Landfill Ordinance

© 2014 BBG GmbH & Co. KG

C. Niehues · Closure of landfills with geosynthetics – solutions for challenging boundary conditions
Example: Certification guideline for geogrids

Refers to geogrids used for cap sealing and retaining constructions

Emphasizes the complex behaviour of geogrids in interaction with soil

Differs geogrids by the load transfer mechanisms within the anchorage area:

• Load transfer due to surface friction between geogrid and soil (friction geogrids)
• Load transfer due to surface friction between geogrid and soil and passive earth pressure of soils against the transversal elements of the geogrid (earth pressure geogrids) – demands for high stiffness of the product

Steep slopes

Standard inclination up to 1:3
common systems
usually without geogrid reinforcement

Interim inclination 1:3 ... 1:2,5
special systems, most commonly geogrids
restrictions in earth works
partially cable-guided

Steep areas 1:2,5 ... 1:1,4
geogrids
long arm excavator
cable-guided operation of
earth moving machinery
Calculation example: Slope gradient and landfill capacity

\[ V_{1:3} = 30,0 \text{ m} \times 10,0 \text{ m} \times 0,50 = 150 \text{ m}^3 / \text{ m} \]

\[ V_{1:2} = 20,0 \text{ m} \times 10,0 \text{ m} \times 0,50 + 10,0 \text{ m} \times 10,0 \text{ m} = 200 \text{ m}^3 / \text{ m} \]

\[ \Delta V = V_{1:3} - V_{1:2} = 50 \text{ m}^3 / \text{ m} \]
Examples for landfill engineering with geosynthetics

Landfill Duisburg-Sudamin (monitoring load introduction with strain gauges since 2008)
Examples for landfill engineering with geosynthetics

Slag heap „Zellerfelder Valley“ (monitoring load distribution in anchorage area with strain gauges)
Examples for landfill engineering with geosynthetics

- Rekultivierungs­boden
- Geogitter
- Dränagematte
- Sand
- Bentonitmatte
- Pochsand
Examples for landfill engineering with geosynthetics

Slag heap „Zellerfelder Valley“ (monitoring load distribution in anchorage area with strain gauges)
Examples for landfill engineering with geosynthetics

Comparing boundary conditions

<table>
<thead>
<tr>
<th>Landfill Duisburg-Sudamin</th>
<th>Slag Heap Zellerfelder Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:2 ($\beta = 26,6^\circ$)</td>
<td>1:2 ($\beta = 26,6^\circ$)</td>
</tr>
<tr>
<td>25,6°</td>
<td>24,7°</td>
</tr>
<tr>
<td>23,64 kN/m</td>
<td>33,5 kN/m</td>
</tr>
<tr>
<td>237,68 kN/m</td>
<td>188,2 kN/m</td>
</tr>
</tbody>
</table>

- Minimum contact friction angle $\delta_k$
- Characteristic tensile load on geogrid $T_k$
- Characteristic pull-out resistance of anchor trench $R_k$
Covered berms for intermediate geogrid anchorage on long slopes

Examples for landfill engineering with geosynthetics

Covered berms for intermediate geogrid anchorage on long slopes
Anchor trench in berm: Landfill Kapiteltal
Examples for landfill engineering with geosynthetics

Landfill Berg

- Steep cap sealing system, inclination → 1(V):2(H)
- Sealing System:
  - Double-layered GCL (needlepunched, $m_A \geq 6000 \text{ g/m}^2$)
  - Structured HD-PE geomembrane
  - Geosynthetic drainage element
  - Geogrid reinforcement
  - 1.5 m recultivation soil
Landfill Berg: Geogrid panel layout plan

Green areas: Longitudinal tensile strength of geogrid 400 kN/m
Red areas: Longitudinal tensile strength of geogrid 200 kN/m
Violet: Anchor trenches on flanks
Examples for landfill engineering with geosynthetics

Anchor trench in a landfill flank

Examples for landfill engineering with geosynthetics
Anchor trench in a landfill flank
Construction of anchor trench in a landfill flank

Successive construction phases for anchor trench in a landfill flank:
• Installation of first geogrid layer
• Installation of interlocking layer
• Installation of second geogrid layer
• Filling the anchor trench
Examples for landfill engineering with geosynthetics

**Landfill Hannover-Lahe**

- Old landfill body, operational phase: 1937-1980
- Landfill-class „DK II“ – municipal waste
- Inclination 1(V):2.8(H) after profiling works
- Geometrical constraint situation at the north slope
Examples for landfill engineering with geosynthetics

Landfill Hannover-Lahe

Regular slope gradient: 1(V):2.8(H)

Boundary of landfill site
Examples for landfill engineering with geosynthetics

Landfill Hannover-Lahe: Mechanically stabilized earth
Examples for landfill engineering with geosynthetics

Landfill Hannover-Lahe
Geosynthetic in landfill applications

- Landfills are an essential part of the public infrastructure

- Within the resource cycles, there must be a pollutant sink to extract environmentally harmful substances

- Geosynthetics ensure that waste is safely encapsulated and prevents emissions from waste bodies

- Furthermore, geosynthetics help to ensure stability issues of landfill bodies or recultivation layers (reinforcement, drainage, filtration) even under challenging boundary conditions