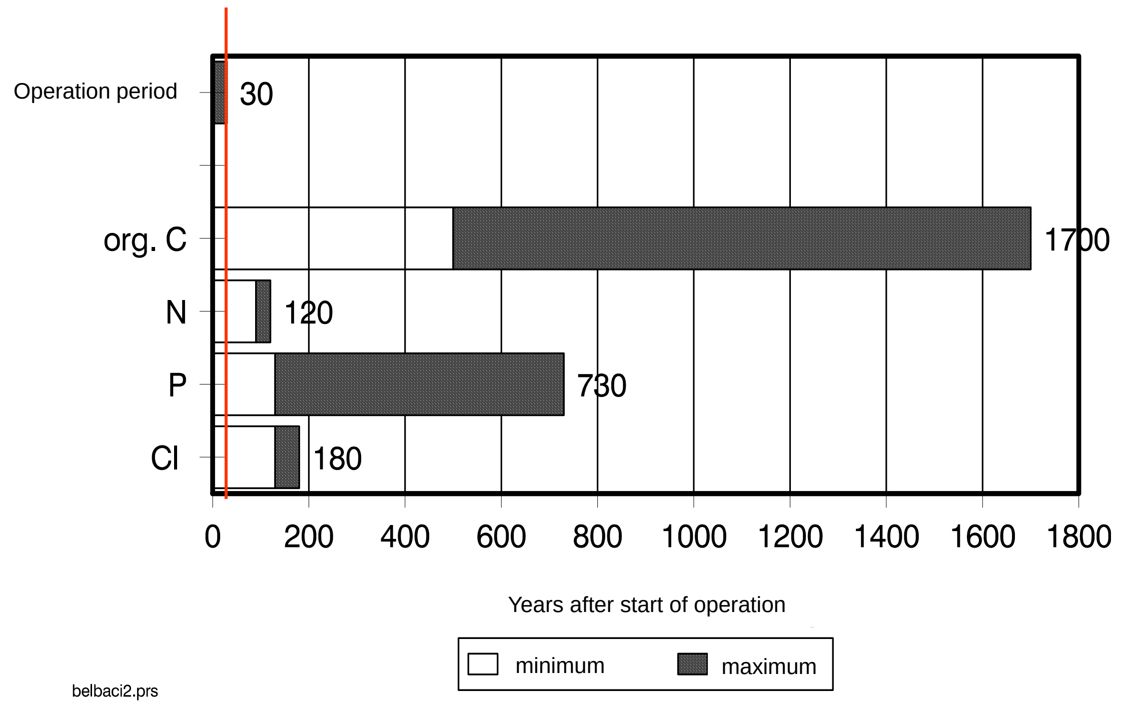
Class on Solid Waste Management

10. Waste Depositing I
    Waste Depositing II

Definitions – Ecological Conseuqneces of the Depositing of Raw Waste

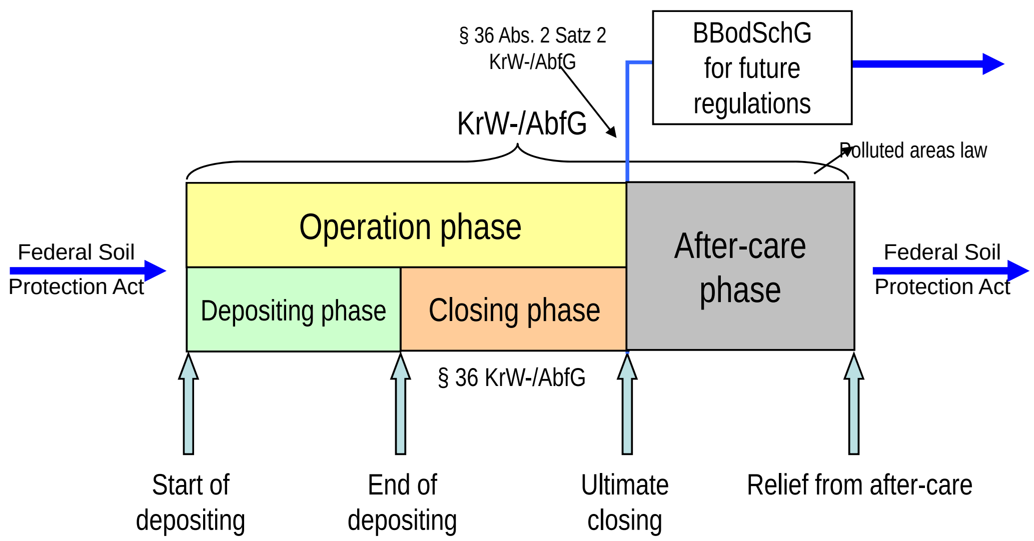
- **Depositing** = no time limit
  (intermediate) storage = time limit
- Consequences of the depositing of raw waste:
  - **Leaching** through rainfall→ leachate → groundwater pollution if the dumping ground bottom is permeable, or – if the bottom is leak-proof – accumulation of leachate + treatment efforts
  - **chemical reactions + bio-chemical conversions**; decomposition in aerobic boundary areas; ageing in the aerobic landfill interior;
  - emergence of **landfill gas** + odour emissions;
  - **noise emissions** (delivery trucks; possibly waste comminution; installation devices);
  - **dust emissions** (delivery trucks; possibly waste comminution), drift-off (particularly plastic foils));
  - infestation with birds and vermin (cause: food supply)
    → hygienic hazards

After-Care Period – Ultimate Disposal Quality in Centuries Source: Belevi / Baccini, 1989



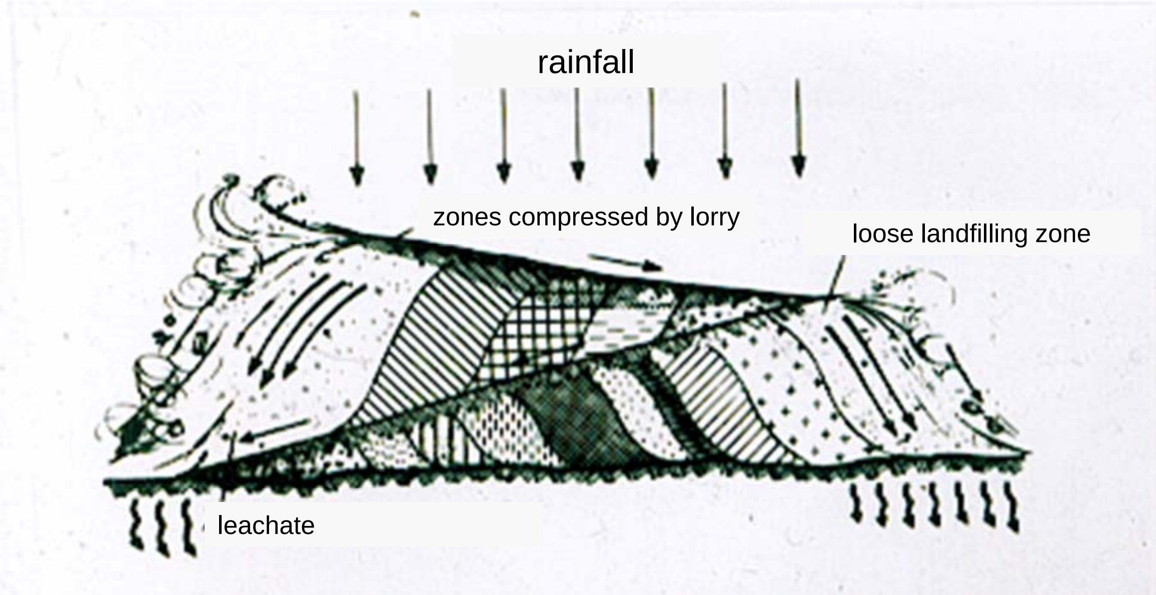
belbaci2.prs

Relation of Waste Law (Landfill Directive) to Soil Protection Law



- §3 Section 1, No. 2 BBodSchG (Federal Soil Protection Act) states that the BBodSchG is applied for regulations of the KrW-/AbfG (Recycling Waste Management Law) on the licensing and operation of waste depositing plants and on the closing of landfills as fas as these directives do not regulate effects on soils.

Loose Landfilling

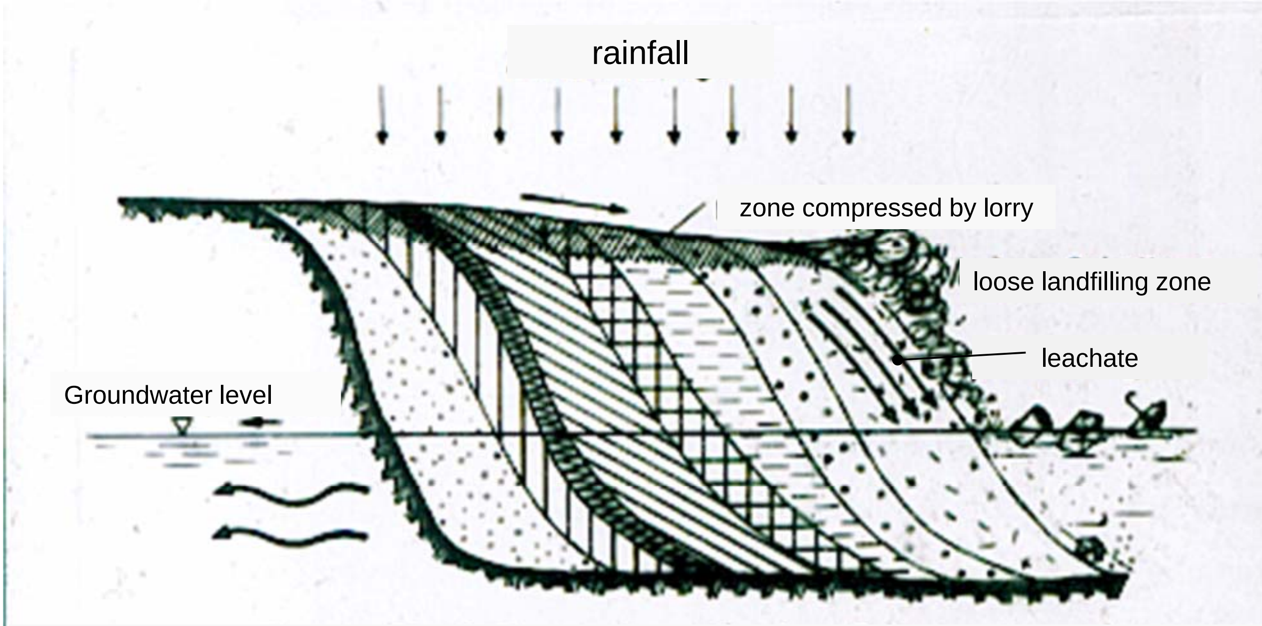


Without closing layer, drainage into the groundwater,

-> impact on the environment and the water supply

Dump site in Thuringia 1991

„Waste Swimming Pool“



Uncontrolled landfilling of pits and holes

Dump site in water body 1971 East Frisia

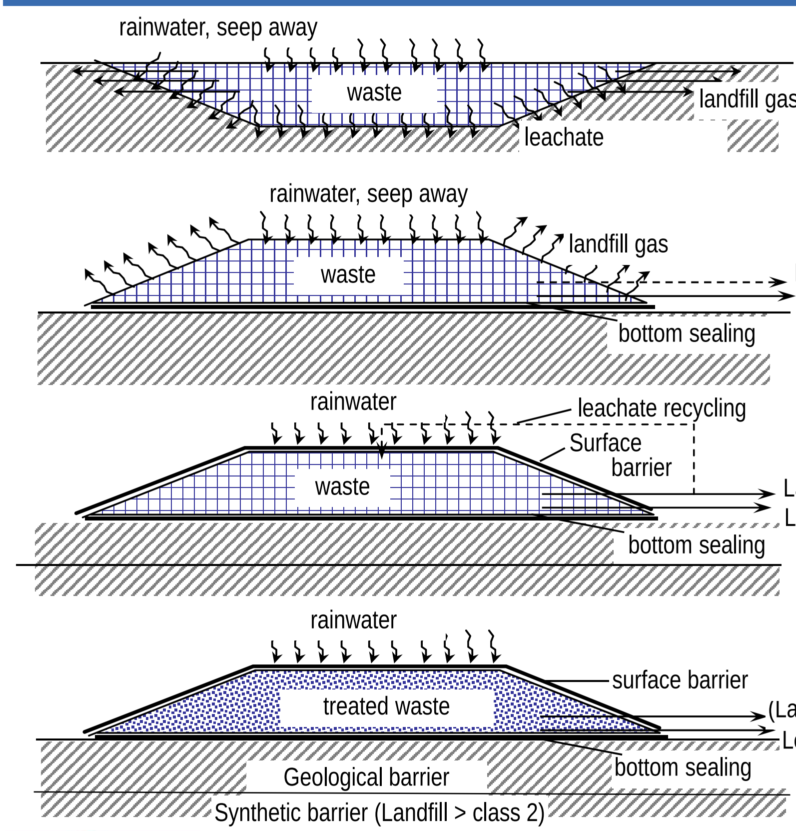
Unseparated MSW after 10 years in a landfill

Newspapers after 10 Years in a Landfill

Strategies to Reduce or Prevent Landfill Emissions

- Purposeful inciting and temporal concentration of the reactions
  - **"Reactor Landfill ":** fixing of the water contents; leachate circulation
  - Elution **= "flushing bed reactor"**
  - **Aerobisation**
- Artificial barriers and architectural solutions
  - the enclosing of landfills is efficient only for a limited time, but necessary „forever" if organic and elutable waste would be preserved in the landfill in a „dry rigour".
- Compacting of elutable waste
- Waste barrier: only low-reactive or elutable waste → preliminary treatment

Development of the Landfilling Concepts in Germany



till 1970:	predominantly open and uncontrolled disposal; often in holes or valleys
from 1970:	bottom sealing; observation of leachate and gas emissions; start of landfill leachate treatment
from 1975:	Developement of landfill degasing
from 1980:	surface barriers; disposal in stockpiles; „landfill reactor" trials; minimization of gas and leachate emission
from ca. 1990/1993	ban of the disposal of untreated waste – Incineration with slag recycling – Mechanical+ Biological Treatment and Incineration of high caloric value
from 06/2005:	realization of the EU standard of treatment and only disposal of harmless remains

Definition according to §2 AbfAblV - Waste Depositing Ordinance

- Landfill
  Waste depositing plant for the dumping of waste on the earth' s surface (aboveground dumping site
- Landfill section
  Separately operated part of a landfill. Landfill sections are allowed to overlap only at acclivities
- Old Landfill
  a. landfill under construction or in operation, or landfill section under construction or in operation, the construction and operation of which had been permitted as of 01.06.1993, or which were permissible according to § 35 of the Recycling Waste Management Law, and
  b. landfills for the licensing of which the project approval procedure had been opened and made public as of 1. 6.1993.

Definition according to §2 AbfAblV - Waste Depositing Ordinance

- **Landfill Category I:**
  Landfill for waste which contains very low organic ratios and for which leaching trials have shown only very low releases of pollutants.

- **Landfill Category II:**
  Landfill for waste, <u>including waste from mechanical-biological treatment</u>, which contains a higher organic ratio than that which is permitted to be deposited on landfills of Category I and which in leaching trials release higher amounts of pollutants than that of Category I. Thus, for Category II the requirements on the landfill location and the landfill sealing are higher.

Definition according to §2 DepV - Landfill Ordinance

- **Landfill of Category 0 (Landfill Category 0, LC 0):**

  Aboveground landfills for waste which complies with the allocation values of Landfill Category 0 according to Appendix 3 (inert waste)

- **Landfill of Category I (Landfill Category I, LC I):**
  Aboveground landfill according to § 2 No. 8 of the Waste Depositing Ordinance
- **Landfill of Category II (Landfill Category II, LC II):**
  Aboveground landfill according to § 2 No. 9 of the Waste Depositing Ordinance.

Definition according to §2 DepV - Landfill Ordinance

- **Landfill of Category III (Landfill Category III, LC III):**
  Aboveground landfill for waste which has a higher ratio of pollutants than that which may be deposited on a landfill of Category II and which in the leaching trials showed a higher pollutant release than that of LC II. Thus, the requirements on the landfill construction and operation are higher than in LC II.
- **Landfill of Category IV (Landfill Category, LC IV):**
  Underground landfill in which the waste is deposited completely enclosed in rock, either
  a.) in a mine with independent depositing areas which is constructed or planned separately from the mineral recovery areas, or
  b.) in a cavern.

Multi-Barrier Concept

- According to Landfill Directive (DepV2009)
  - Qualification of location, underground, environmental conditions,
  - Multi barrier system
  - Safety assessment
- 5 Barriers
  - geological barrier
  - **waste barrier** (type, preliminary treatment, control; observation of allocation values)
  - artificial barrier (top, lateral, and bottom sealing)
  - disposal (leachate and gas)
  - operation (installation technology) and after-care

(TASi 1993, Waste Depositing Ordinance 2001 and Landfill Ordinance 2002 are replaced by Landfill Directive 2009, DepV 2009) - after 1.6.2005 only waste which observes the limit values is allowed to be deposited

Directive 1999/31/EU of the Council from April 26, 1999, on waste dumping ground (Landfill Directive), contains similar targets with considerably lesser requirements

Decision 2003/33/EU Determination of criteria and methods for the acceptance of waste on landfills according to § 16 Appendix II 1999/31/EU effective as of 16.07.2004

Diagram of the options provided in the Landfill Directive for the depositing of waste

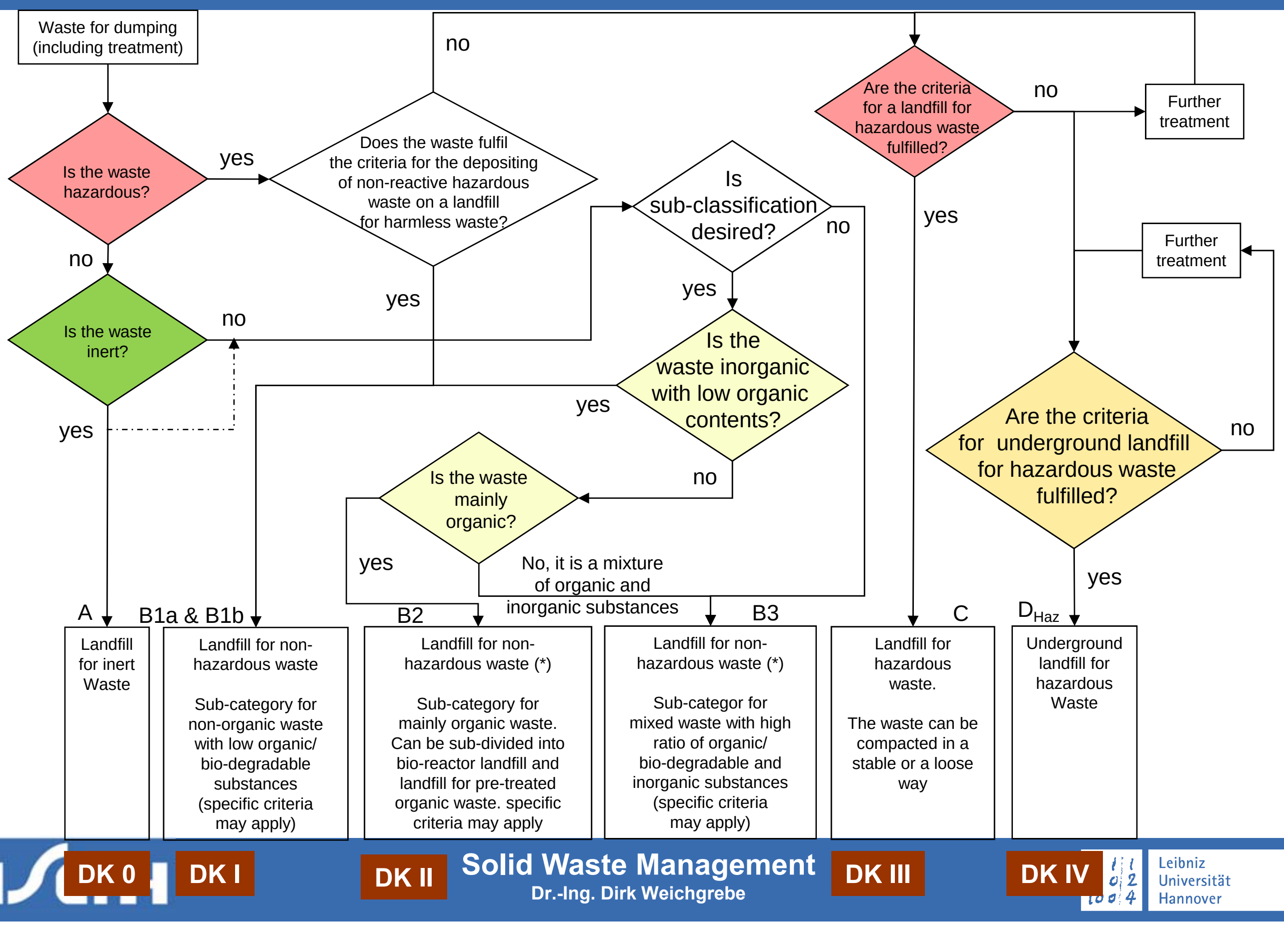


Table 1 from Appendix B of Decision 2003/33/EU Determination of criterai and methods for the accpetance of waste at landfills

Survey of the Landfill Categories and Examples of Sub-Categories

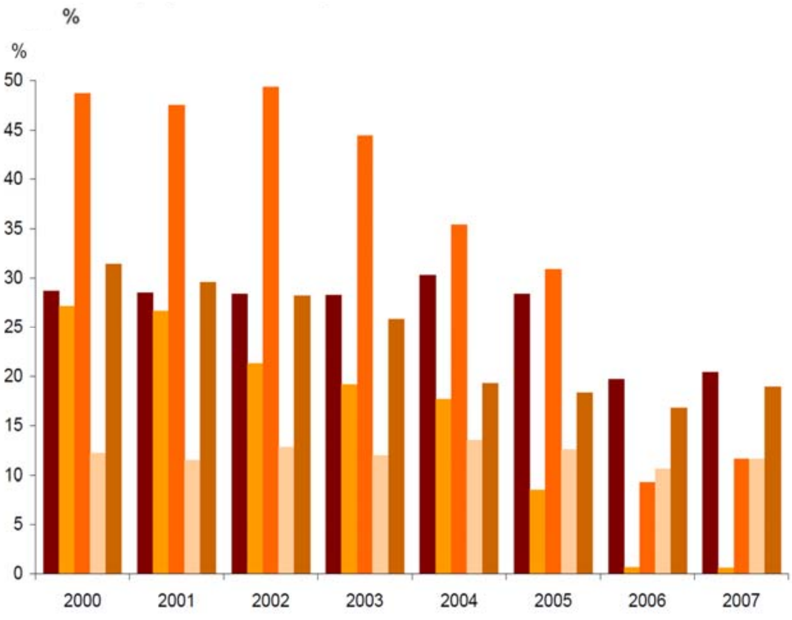
Landfill Category	Main sub-categories (underground landfill, mono landfills and landfills for compacted, monolithic (*) waste which is acceptable for all landfill categories)	ID	Acceptance criteria
Inert waste landfill **DK 0**	Landfill which accepts inert waste	A	Criteria for the leaching behaviour and for the contents of organic components have been determined on an EU level (Section 2.1). Criteria for the inorganic ratios can be determined on the member state level.
Landfill for non-hazardous waste **DK I**	Landfill for inorganic, non-hazardous waste with low organic/bio-degradable contents, with the waste not fulfilling the criteria laid down in Section 2.2.2 for that inorganic non-hazardous waste which can be deposited together with stable non-reactive waste	B1a	Criteria for the leaching behaviour and criteria for the entire contents have not been determined on an EU level yet
DK II	Landfill for inorganic, non-hazardous waste with low organic, bio-degradable contents	B1b	Criteria for the leaching behaviour and for the entire carbon contents (TOC) and other properties have been determined on an EU level; they apply for the grainy, non-hazardous waste and for the stable, non-reactive hazardous waste (Section 2.2). For the latter, the member states have to determine additional stability criteria. Criteria for monolithic waste must be agreed upon on the member state level.
	Landfill for organic, non-hazardous waste	B2	Criteria for the leaching behaviour and criteria for the entire contents have not been determined on an EU level yet.
	Landfill for mixed non-haz. waste with high ratio of both organic/bio degradable & inorganic substances	B3	Criteria for the leaching behaviour and criteria for the entire contents have not been determined on an EU level yet.
Landfill for hazardous waste **DK III**	Surface landfill for hazardous waste	C	Criteria for the leaching behaviour of granulated waste and criteria for the entire contents of some parts are determined on an EU level. Criteria for monolithic waste must be agreed upon on the member state level. More criteria for the content of haz. waste can be determined on the member state level.
DK IV	Underground landfill	D_{HAZ}	Particular requirements on EU level are listed in Appendix A.

(*) Sub-categories for monolithic waste are only relevant for B1, C and D, possibly also for A

Public Plants for Municipal Waste Disposal

Year	Plants for the disposal of municipal waste								Reloading stations and collection points for commercials waste		
		Landfills			Thermal treatment		Composting (MBT)				
	Total number	Total Number/(MSW)		Weight ratio % MSW	Number	Weight ratio % MSW	Number	Weight ratio%	together	Reloading stations	Collection points for CW
1975	4616	4526		83,1	47	13,5	21	1,1			
1977	2865	2756	(1355)	80,3	43	17,7	17	1,7	82	76	6
1980	3033	2918	(530)	79,1	44	19,2	16	1,4	110	106	4
1982	3176	3060	(439)	75,8	44	21,4	15	1,6	122	118	4
1984	3211	3118	(385)	73,3	46	24,3	Composting only for utilisation		136	127	9
1987	3220	3082	(332)	69,3	47	25,4			157	152	5
1990	3231	2874	(290)	69,8	50	22,8	MBT prior to depositing		172	147	25
1990*	7692	7314*	(2622)	82,2	52	15,0			172	150	28
1993*	3586	2948	(550)	69,6	56	21,3	10		243	161	82
1998		2341	(350)	62	60	33,7	25	3		Sorting plants	Demolition WEE
2000		2228	(358)		64	38,2					
2005		1948	(162)		72 (155)	41,2	1682+ (47)	(5,9)		897	313
2006		1740			(153+595)		1742+ (45)			905	312
2007		1706			(157+589)		1793+(50)			958	301
2008		1645			(158+632)		2041+(51)			995	307
2009		1553			(160+633)		2047+(55)			996	304
2010		1165	(94)	21	(163+644)	(≈ 25)	1993+(54)	7,8+(2,5)		1011	301

Depositing Rates



- Waste total (incl. salvage material from mining)
- Municipal waste
- Waste from production and commerce
- Building and demolition waste [1)]
- Hazardous waste

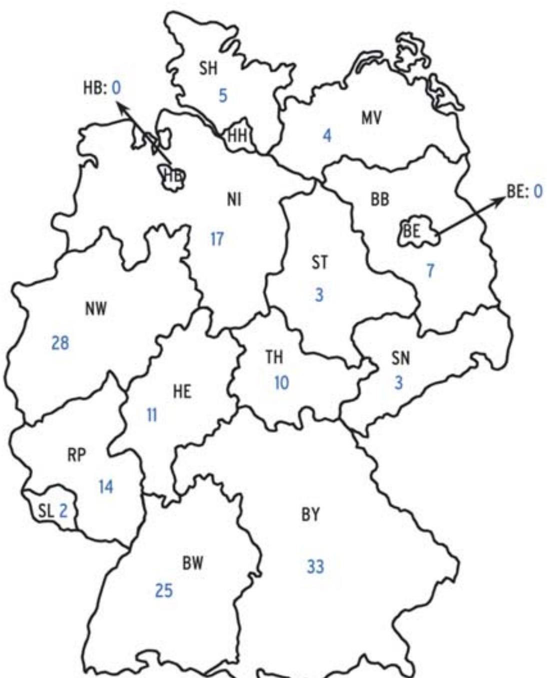
1998: Hamburg with data from 1997
since 1999: change to the European Waste Catalogue (EWC) with shifts in certain sub-division (municipal waste, waste from production and commerce, building and demolition waste
2000: Hamburg with data from 1999
2002: Introduction of the European Waste Register with shifts between non-hazardous and hazardous waste and within municipal waste.
Hazardous waste:
since 2002, the waste which needs particular supervision is contained in the main streams.
1)Since 2004 without used amounts of excavation, building rubble and roadway rubble in public building and recultivation projects.

Salvage material from mining is deposited at a 100%

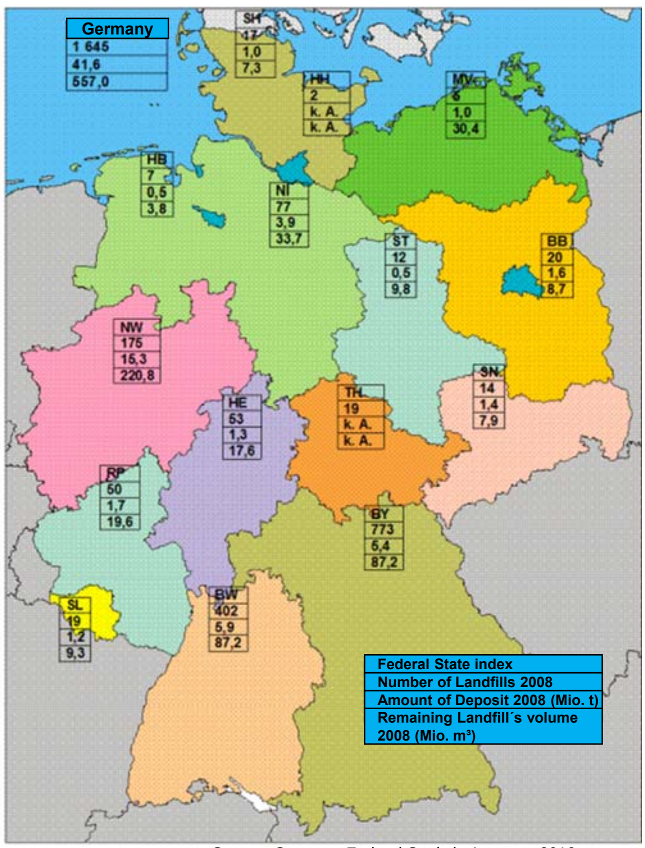
Source: Federal Statistical Office, http://www.destatis.de, (State: August 2007); Federal Environment Agency, our own calculations

Distribution of Category II landfills (formerly: predominantl domestic waste landfills) among the federal lands

Total number: 162 Landfills of Category II (State: 6/2005)

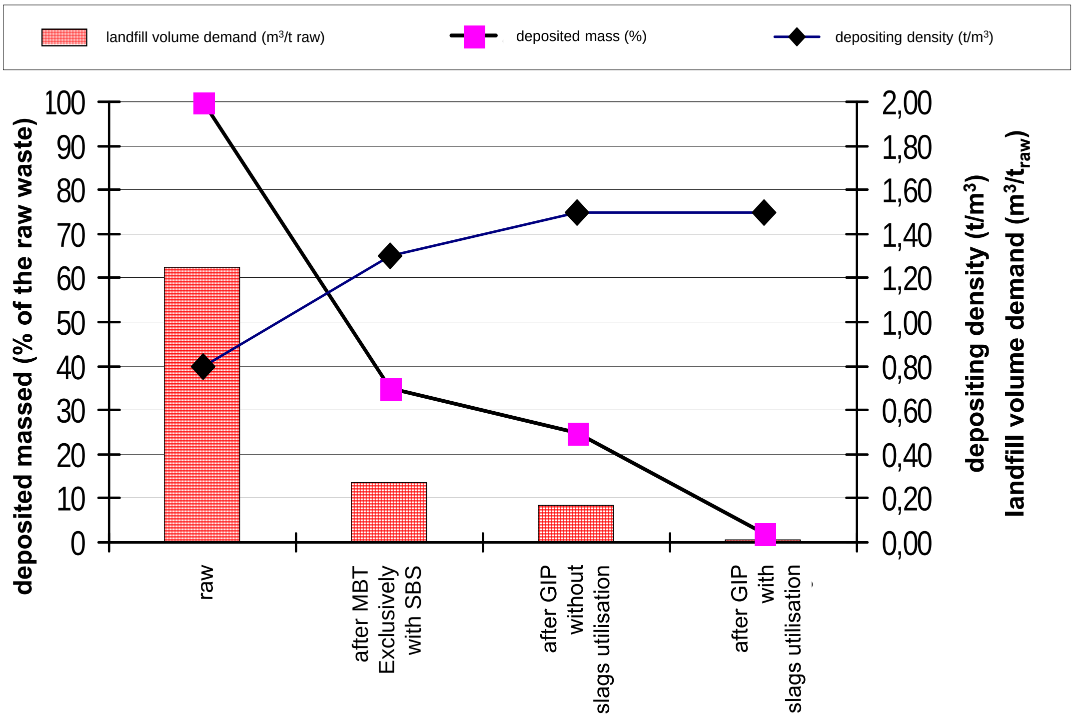


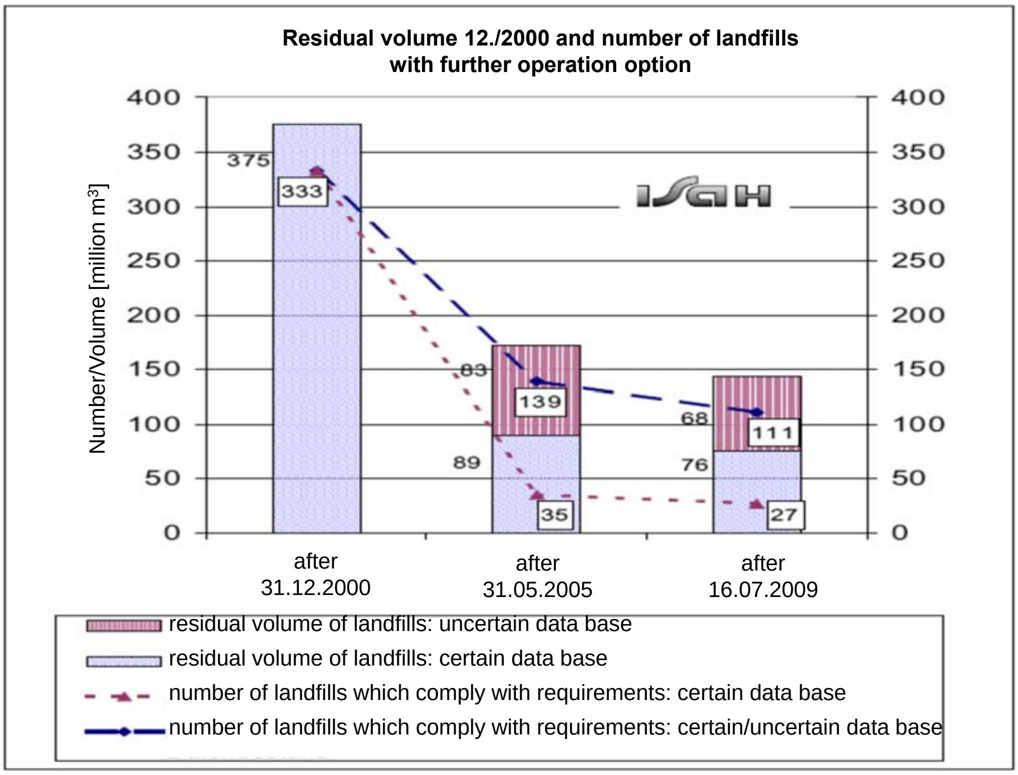
Source: Federal Environment Agency – FEA; survey in the federal states, Jun 2005



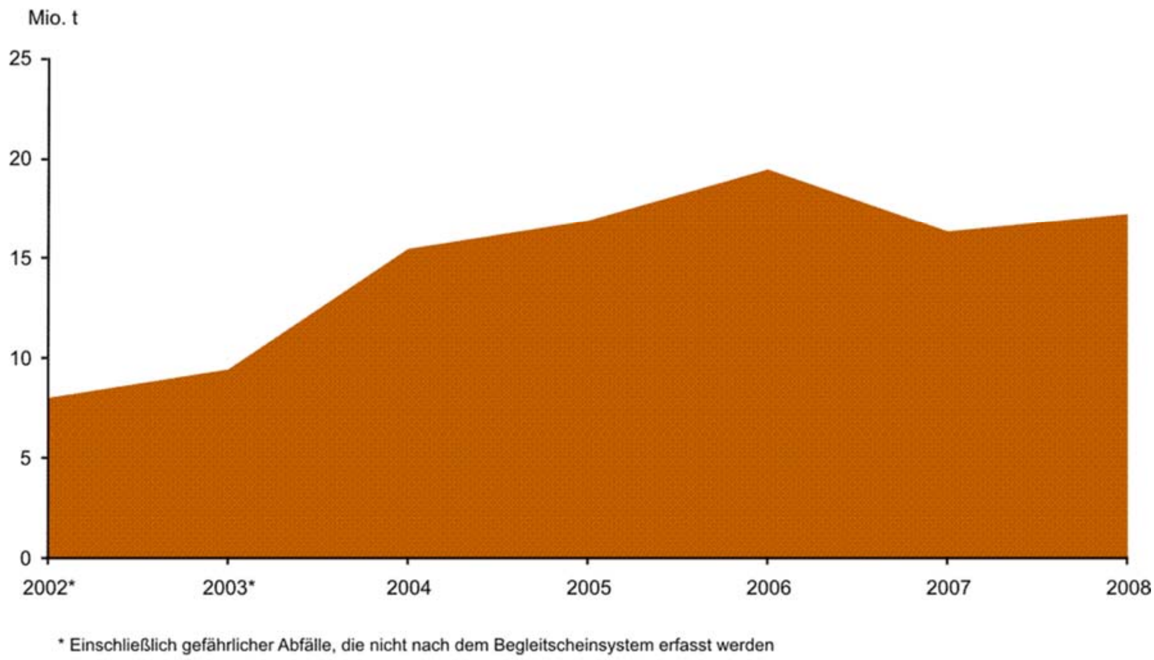
Source: Germany Federal Statistic Agency - 2010

Landfill Volume Demand with Different Kinds of Preliminar Treatment





Reuse of Waste on Landfills 2002 - 2008



*Incl. hazardous waste, which is not recorded with dispatch note

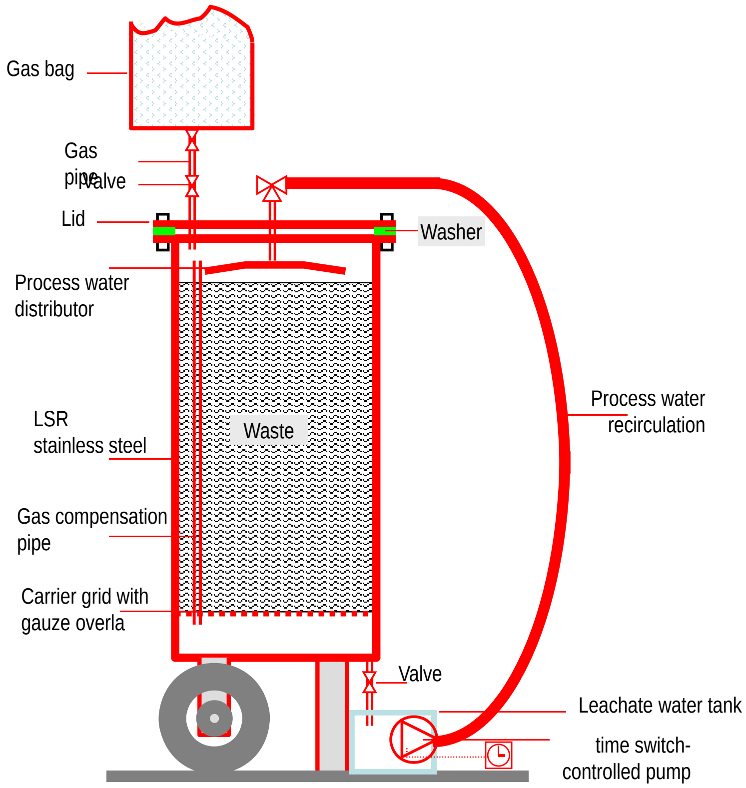
Source: Germany Federal Statistic Agency - 2010

Tests for the Leaching Behaviour

Type of the tests	Waste sample weight kg	Water/ Solids -	Elution -	Waste at rest	 moved	Leaching rate m/a	Test period d or a	Tempe- rature °C
DEV-Elution DIN 38014 S4; shaking test	ca. 0,1	10	once		X	-	24 h	20
pH-Stat-Elution	ca. 0,1 - 0,2	10	once		X	-	24 /48 h	20
Cascade elution test	ca. 0,1 - 0,2	5-30	multiple		X	-		20
DSR; percolation column	50-100	10-50 /a	multiple with ...bei SiW-recirculation	X		10-50	ca. 100 - 1000 d	35
Lysimeter		1-2	multiple with ...bei SiW-recirculation	X		1-5	ca- 1 - 5 a	20-35
Open landfill trial field		ca. 0,015 per a	once	X		natural 0,1-0,5	ca- 1 - 20 a	natural

ISAH
Solid Waste Management
Dr.-Ing. Dirk Weichgrebe
Leibniz Universität Hannover

Landfill Simulation Reactor (LSR)



Limit Values acc. to AbfAblV, DepV and VersatzV

No.	Parameter		LC 0	LC I	LCII Municipal waste App. 1	App. 2	LC III hazardous waste	LC IV except Evaporate
1	Tensile Stength[1]							
1.01	Lateral shearing strength	kN/m^2	≥ 25	≥ 25	≥ 25		≥ 25	
1.02	Axial deformation	%	≤ 20	≤ 20	≤ 20		≤ 20	
1.03	Mono-axial pressure resistance	kN/m^2	≥ 50	≥ 50	≥ 50		≥ 50	
2	Organic ratio of the dry residues of the original substance (OS)							
2.01	determined as ignition loss	Mass %	≤ 3 [2)3)4)]	≤ 3 [2)3)4)]	≤ 5 [2)3)4)]	-	≤ 10 [2) 3)]	≤ 12
2.02	determined as TOC	Mass %	≤ 1 [2)3)]	≤ 1 [2)3)]	≤ 3 [2)3)]	≤ 18 [6)]	≤ 6 [2)]	≤ 6
3	Extractable lipophile substances of the OS	Mass %	≤ 0,1	≤ 0,4	≤ 0,8		≤ 4 [7)]	
4	Eluate criteria							
4.01	pH-value		5,5 - 13	5,5 - 13,0	5,5 - 13,0		4-13	5,5 - 13
4.02	Conductivity	µS/cm	≤ 1.000 [8)]	≤ 10.000	≤ 50.000		≤ 100.000	≤ 500
4.03	TOC	mg/l	≤ 5	≤ 20 [5)]	≤ 100	≤ 250	≤ 200	≤ 5
4.04	Total phenol	mg/l	≤ 0,05	≤ 0,2	≤ 50		≤ 100	
4.05	Arsenic[9)]	mg/l	≤ 0,04	≤ 0,2	≤ 0,5		≤ 1	≤ 0,010
4.06	Lead[9)]	mg/l	≤ 0,05	≤ 0,2	≤ 1		≤ 2	≤ 0,025
4.07	Cadmium[9)]	mg/l	≤ 0,004	≤ 0,05	≤ 0,1		≤ 0,5	≤ 0,005
4.08	Chromium-VI[9)]	mg/l	≤ 0,03	≤ 0,05	≤ 0,1		≤ 0,5 [10)]	≤ 0,008
4.09	Copper[9)]	mg/l	≤ 0,15	≤ 1	≤ 5		≤ 10	≤ 0,05
4.10	Nickel[9)]	mg/l	≤ 0,04	≤ 0,2	≤ 1		≤ 2	≤ 0,05
4.11	Mercur[9)]	mg/l	≤ 0,001	≤ 0,005	≤ 0,02		≤ 0,1	≤ 0,001
4.12	Zinc[9)]	mg/l	≤ 0,3	≤ 2	≤ 5		≤ 10	≤ 0,5
4.13	Fluoride	mg/l	≤ 0,5	≤ 5	≤ 25		≤ 50	
4.14	Ammonium-N	mg/l	≤ 1	≤ 4	≤ 200		≤ 1.000	
4.15	Cyanide, easily purgeable	mg/l	≤ 0,01	≤ 0,1	≤ 0,5		≤ 1	≤ 0,01
4.16	AOX	mg/l	≤ 0,05	≤ 0,3	≤ 1,5		≤ 3	
4.17	Water-soluble ratio (evaporation residue)	Masse-%	≤ 1	≤ 3	≤ 6		≤10	≤ 3
5	Biological degradability of the dry residue of the original substance							
	Respiration activity (AT_4)	mg O_2/g DM				≤ 5		
	or gas production rate in the digestate (GB_{21})	Nl/kg DM				≤ 20		
6	Upper caloric value (H_o)	kJ/kg				≤ 6000 [6)]		

- LC 0
  aboveground landfill for lowest-elutable waste
- LC I
  mostly unpolluted waste
- LC II,
  low-polluted, non-hazardous waste
- LC III
  for hazardous waste
- LC IV
  underground landfill (ULF)

Requirements on Landfill Sites according to DepV Appendix 1 (former TASI 10.3, AbfAblV)

- Comprehensible selection out of all possible landfill sites of a disposal area (negative and positive mapping, site evaluation)
- Safety Distance to residential areas (TASi: 300 m)
- No sites in karst areas, subsidence areas caused by mining, flood plains, certain water protection areas
- Sites in pits only if leachate can be discharged outside by free gradient;
  → stockpile landfills;
  → no shafts in landfill
- For LCs II + III: Underground as geological barrier slightly permeable loose or solid rock with high pollutant retention potential ; for details, see picture. Alternatively, also architectural measures with a corresponding bottom layer.
- Surface of the landfill plain with compacting degree complying with Table 4 of the Prescriptions and Directives for Excavation Work in Road Construction (ZTVE). Distance of the landfill plain after settling:
  1,00 m over the highest groundwater level.

Technical Barriers / Pollutant Transport

- Technical barriers as emission brakes
- For mineral sealing layers according to Holzlöhner et al.,1994

$$\frac{\partial(\Theta \bullet R \bullet c)}{\partial t} = \frac{\partial}{\partial x}\left[\underbrace{(\Theta \bullet d_0 \bullet \gamma}_{\text{Diffusion}} + \underbrace{\alpha \bullet v)\frac{\partial c}{\partial x}}_{\text{Dispersion}} \underbrace{- v \bullet c}_{\text{Advection}}\right] \underbrace{- \mu \bullet \Theta \bullet c}_{\text{Degradation}}$$

Diffusion Dispersion Advection Degradation

R	= 1 + (ρ_d*k_d)/ Θ as retardation coefficient, which after the + sign considers the sorption
c	Concentration of the water-soluble substance (kg/m³)
d_0	Diffusion coefficient of the water-soluble substance in the free water (m²/s)
k_d	Coefficient of thet linear equilibrium isotherm (distribution coefficient) (kg/m³)
t	Time (s)
x	Longitudinal ordinate (m)
v	Filter velocity in x-direction (m/s)
α	Dispersion length (m)
Υ	Impedance factor (-)
Θ	Water contents (m³/m³)
μ	Degradation coefficient
ρ_d	Dry density of the depositing material (kg/m³)

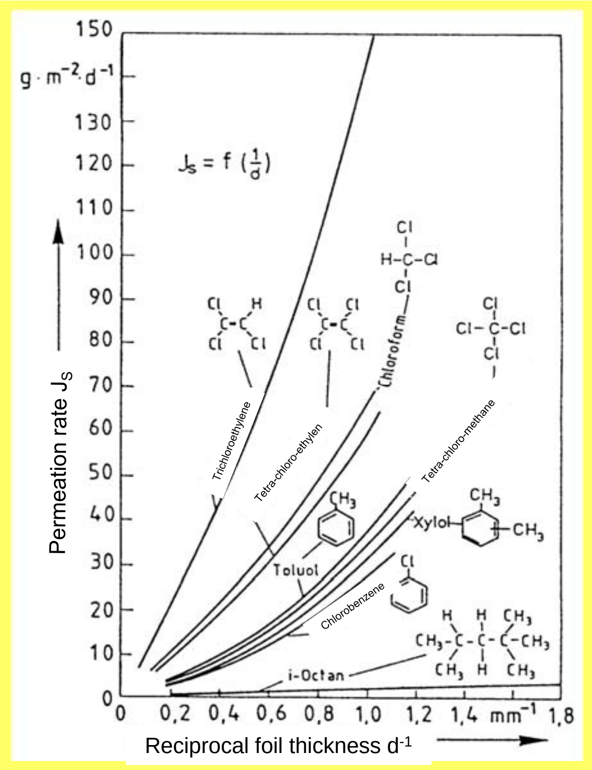
- For plastic liners, diffusion according to Fick´s 1st Law

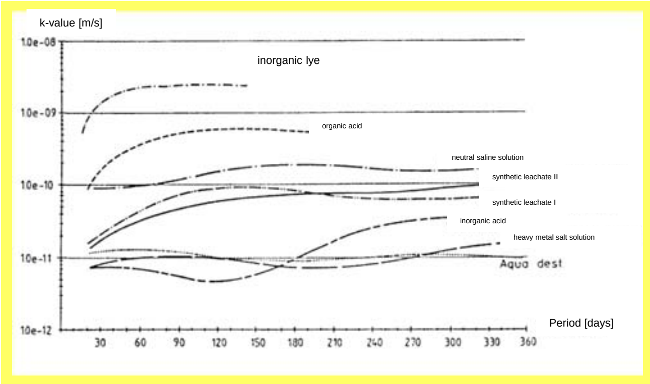
$$J_S\ (kg / m^2 \bullet s) = \frac{d_0}{x} \bullet c$$

d_0 = Diffusion coefficient;
c = Concentration
x = Diffusions path; material thickness

- Plastic liners for salts and heavy metals are almost ideally leak-proof; for other components mineral sealings → Combination sealing for bottom and slopes

Permeation through Plastic Liners and Mineral Sealings





Standard Assembly of the Geological Barrier and the Bottom Sealing System

according to DepV

The permanent protection of soil and groundwater is to be achieved through the geological barrier according to No. 1.2 and a basis sealing system according to 1 Nos. 2-4 of Table 1. If two sealing components are necessary, the convection barrier (synthetic liner (geo-membrane) or asphalt liner) has to be set above the mineral component.
The mineral components has to be multi-layered.
All sealing components should be protected against load-caused damages.

Nr.	System Components	LC 0	LC I	LC II	LC III
1	Geological barrier 1) 2)	$k \le 1*10^{-7}$ m/s $d \ge 1{,}0$ m	$k \le 1*10^{-9}$ m/s $d \ge 1{,}0$ m	$k \le 1*10^{-9}$ m/s $d \ge 1{,}0$ m	$k \le 1*10^{-9}$ m/s $d \ge 5{,}0$ m
2	First sealing component 2)	Not necessary	necessary	necessary	necessary
3	Second sealing component 2)	Not necessary	Not necessary	necessary	Necessary
4	Mineral dewatering layer 3), granularity according DIN 19667	$d \ge 0{,}3$ m	$d \ge 0{,}5$ m	$d \ge 0{,}5$ m	$d \ge 0{,}5$ m

1) The permeability k must be kept at a pressure gradient of i = 30 (lab value).
2) If sealing components are made from mineral substances, a thickness of $d \ge 0{,}5$ m and a permeability of $k \le 1*10^{-9}$ m/s with pressure gradient of i = 30 should guaranteed. If plastic liner is used (HDP), the thickness should be $d \ge 2{,}5$ mm.
3) The responsible authority may on application of the landfill owner permit deviations in the layer thickness and granularity of the dewatering layers if it is proven that the hydraulic capacity will in the long term be sufficient to prevent any damming of water within the landfill body for LCs I, II and III.

Standard Assembly of the Surface Sealing System according tot DepV

In the closedown stage of the landfill or the landfill section, a surface sealing system must be constructed according to Table 2 or with equivalent system components or a combination of equivalent system components.

Nr.	System Components	LC 0	LC I	LC II	LC III
1	Equalisation layer[1)]	not necessary	If so[7] necessary	If so[7] necessary	If so[7] necessary
2	Gas filter layer[1)]	not necessary	not necessary	If so[8] necessary	If so[8] necessary
3	First sealing component	not necessary	necessary[2]	necessary[2]	necessary[3]
4	Second sealing component	not necessary	not necessary	necessary[2]	necessary[3]
5	Leak control system	not necessary	not necessary	not necessary	necessary
6	Dewatering layer[4)] $d \geq 0{,}3$ m ;$k \geq 1*10^{-3}$ m/s, incline > 5 %	not necessary	necessary	necessary	necessary
7	Recultivation layer/ functional layer	necessary	necessary	necessary	necessary

1) The equalisation layer can be used as gas filter layer too, if is fulfilled the function regarding gas permeability and thickness .
2) If mineral substances are used for the sealing component, the calculational permeability should be less than of mineral layer of d = 50 cm with $k \geq 1*10^{-9}$ m/s with pressure gradient of i = 30 and permanent water afflux of 30 cm. Deviant of clause 1 mineral sealing components can be used, which show a flux less than 20 mm/year as average over five years.
3) If mineral substances are used for the sealing component, the calculational permeability should be less than of a mineral layer of d = 50 cm with $k \geq 1*10^{-10}$ m/s with pressure gradient of i = 30 and permanent water afflux of 30 cm. Deviant of clause 1 mineral sealing components can be used, which show a flux less than 10 mm/year as average over five years. If plastic liner is used (i.e. HDP), the thickness should be $d \geq 2{,}5$ mm.
4) The responsible authority may permit deviations of the minimum thickness, permeability and inclination of the dewatering layer, if the hydraulic capability of the dewatering layer as well as the stability of the recultivation layer is ensured permanent.
5) Instead sealing component, dewatering layer and recultivation layer a recultivation layer designed as water balancing layer can be applied; if deviant to the requirements regarding number 2.3.1.1 cipher 3 the flux of the water balancing layer is no more than 20 mm/year.
6) Instead the second sealing component and the recultivation layer a recultivation layer designed as water balancing layer regarding number 2.3.1.1 can be applied. If the first seal component is carried out as a convection barrier, also a control system can be incorporated instead of the second seal component for the convection barrier. In this case has to be installed a second seal component or an equivalent systems direct under the convection barrier in the area from places at which the drainage water is collected and carried off. The clauses 1 to 3 are valid within the case of dumps or dump sections on which household waste, household waste similar trade waste, sewage sludge and other waste with high organic quantity were deposited, with the possible specification, that the dump operator carries or has carried out measures successfully according to §25 paragraph 4 to the acceleration of biological degradation processes and for the improvement of the long-time behaviour.
7) Requirement depend on number 2.3 clause 2.
8) Requirement depend on Appendix 5 number 7.

Recultivation layer

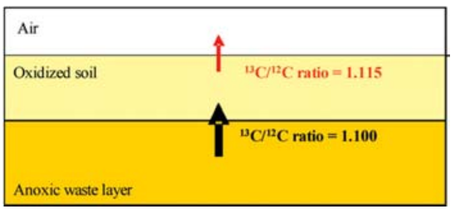
- **Thickness, material selection and vegetation being calculated according to the protection requirements of the system components beneath**
- **Least thickness 1 m**
- **usable field capacity≥ 140 mm (related to the total thickness)**
- **suitable vegetation**
  - **Protection of the surface from wind and water erosion**
  - **evapotranspiration as high as possible**
- **Material according to appendix 3 Nr. 2 (Allocation criteria)**
- **Drainage of grabbed water from the dewatering layer according to the water-legal rules**

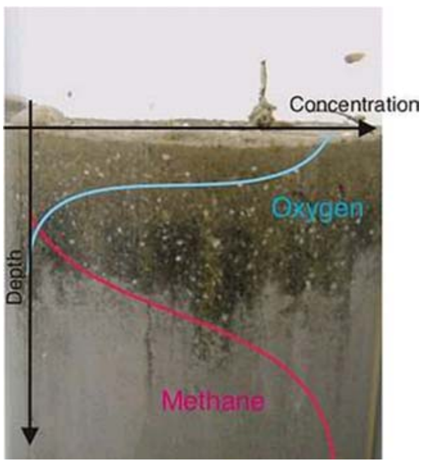
Water balancing layer

- least thickness 1,50 m
- usable field capacity of at least 220 mm (related to the total thickness)
- Percolation
  - at most 10 percent of the long-standing average of the fallout (generally 30 years),
  - at most 60 mm per annum, at the latest five years after construction
- Exception possibility of the usable field capacity near fallout-poor locations (less than 600 mm per annum), if it is proved by rise of the thickness that an equivalent sealing and protection effect is achieved.

Methane oxidation layer

"If the recultivation layer should take over tasks of a methane oxidation of residual gases at the same time, additional requests on the layer construction are to be agreed with the responsible authority. Interactions of the methane oxidation and the water balance of the recultivation layer are to be evaluated."





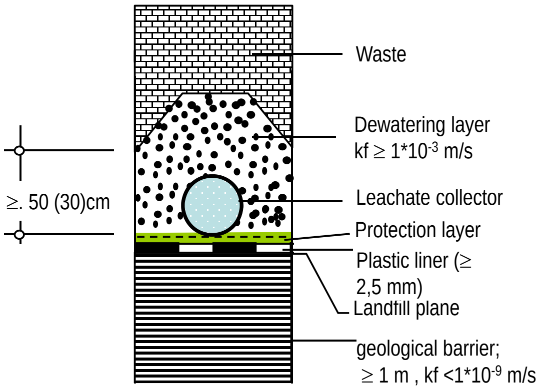
Technical functional layer

- **Material with regard to pollutant content and leachability as at use outside of the landfill under comparable limiting conditions**
- **Thickness being calculated according to the protection requirements of the system components beneath**
- **Drainage of grabbed water from the dewatering layer according to the water-legal rules.**
- **Construction of the layer according the tasks of the technical functionality**
  - **to fulfill the natural function of the location and**
  - **to preserve the protection requirements of the system components beneath**

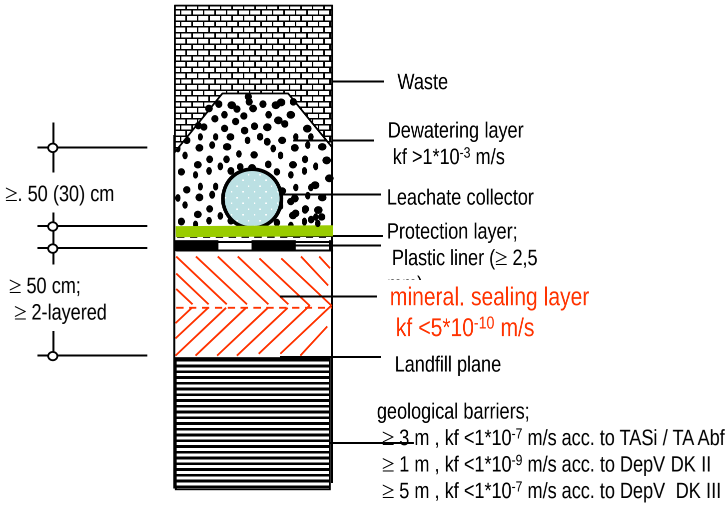
Dewatering layer

- **Deviations allowed for**
  - **Least thickness, Permeability and Inclination**
- **Proofs**
  - **hydraulic efficiency of the drainage layer and**
  - **durable stability of recultivation layer**

Landfill Bottom Sealing according to DepV (and TASi)

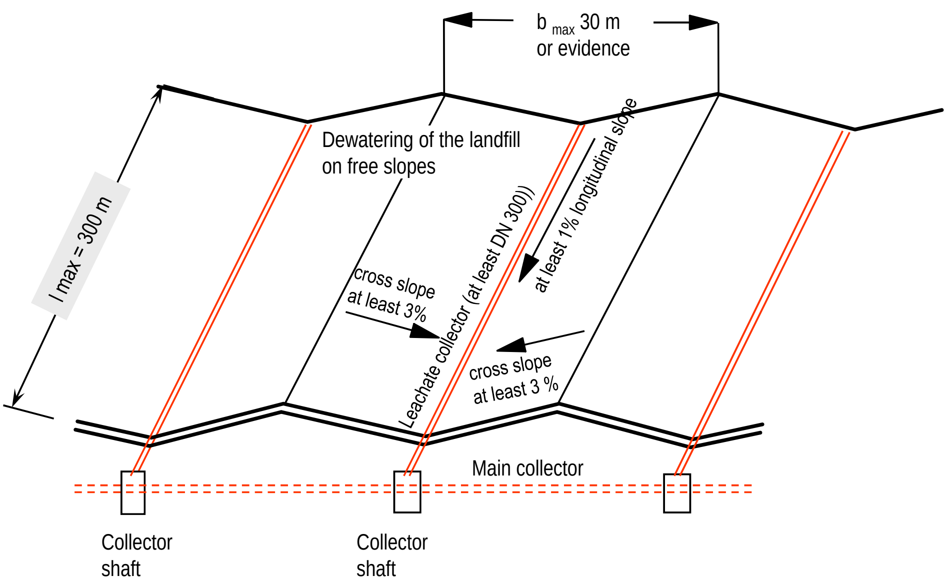


Bottom sealing
Landfill Category I



Bottom sealing
Landfill Categories II and III

Landfill Bottom and Dewatering according to TASi / DepV



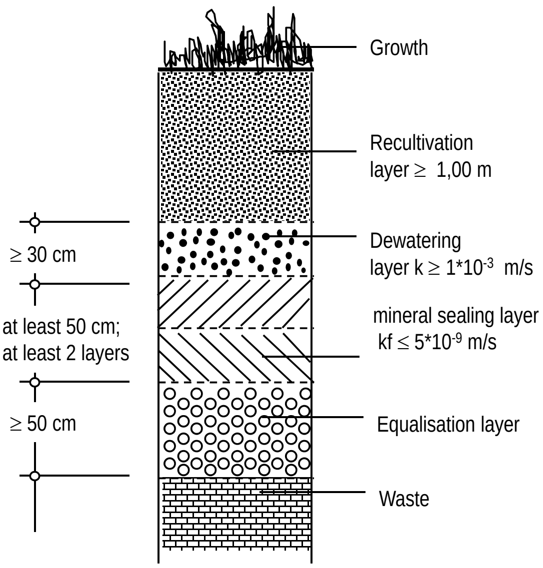
Central Landfill Pohlsche Heide:

Plastic liner Carbofol® 2,5 mm thick and admitted by the authority was layed over the mineral sealing.

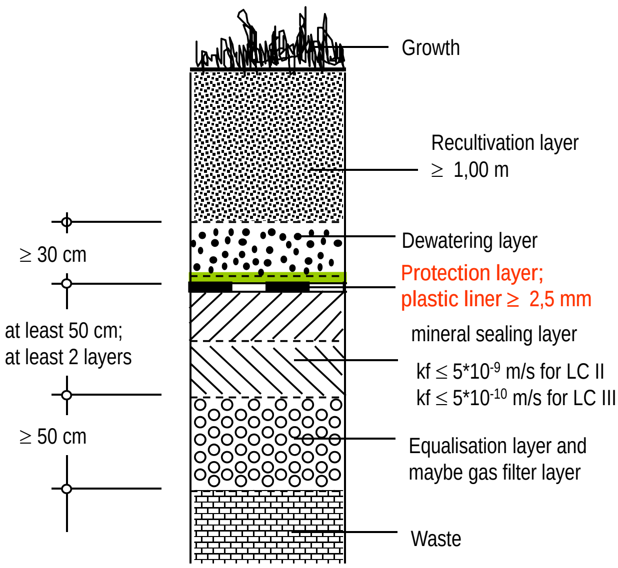
Secutex® protection fleece as protection against the 16/32 mm mineral layer.

Regional landfill Lachengraben:
- asphalt bottom sealing 15.000 m²
- mineral sealing 20.000 m²
- landfill leachate tubes 1.100 m
- plastic liner 2.500 m²

Landfill Surface Sealing according to DepV



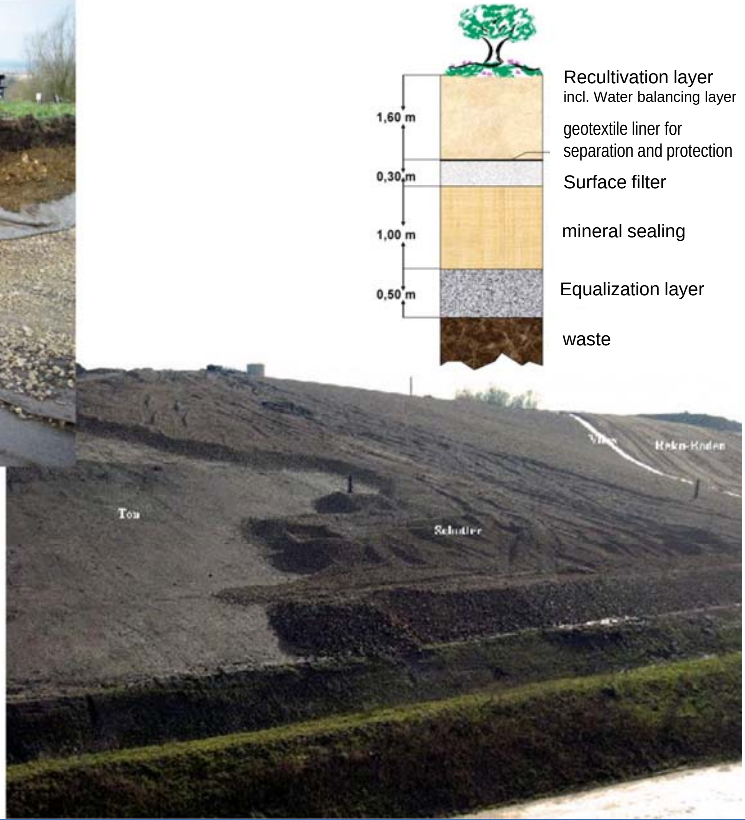
Surface sealing
LC I



Surface sealing
LCs II and III

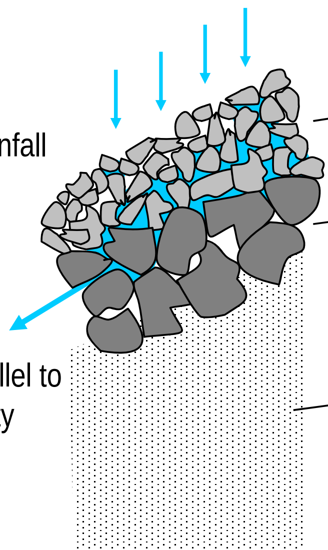
Solid Waste Management
Dr.-Ing. Dirk Weichgrebe
Leibniz Universität Hannover

Construction of the surface sealing of landfill Ibbenbüren

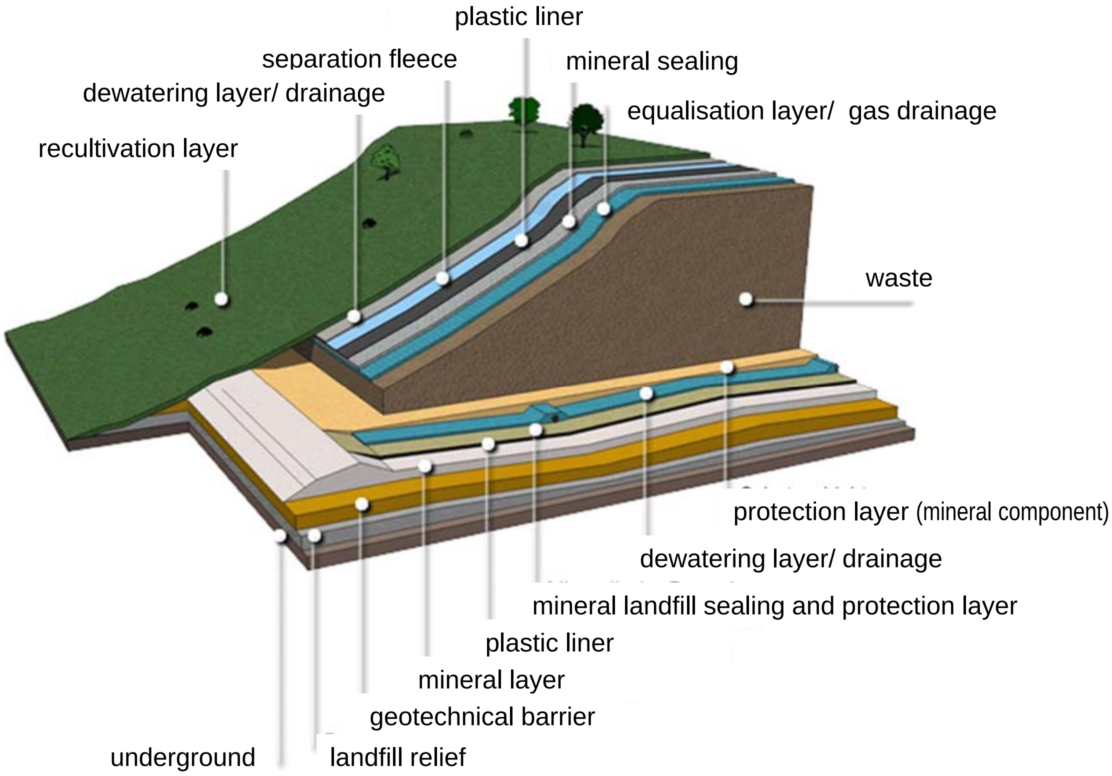


http://www.egst.de/index.php

Dewatering Layer + Equalisation Layer



sectional drawing of a landfill



Elements of Surface Sealing

A: 0,06 m Landfill asphalt concrete sealing layer (DAD)
B: 0,06 m Landfill asphalt concrete sealing layer (DAD)
C: 0,08 m Landfill asphalt concrete base layer (DAT)

A: Hollow chamber contents < 3 volume %
Mineral material mixture with graining 0 – 11 mm
Filler < 0,09 mm between 12 and 16 weight %
Split > 2,00 mm between 40 and 55 weight %

B: Hollow chamber contents < 3 volume %
Mineral material mixture with graining 0 – 11 mm
Filler < 0,09 mm between 12 and 16 weight %
Split > 2,00 mm between 40 and 55 weight %

C: Hollow chamber contents < 5 volume %
Mineral material mixture with graining 0 – 16 mm
Filler < 0,09 mm between 9 and 4 weight %
Split > 2,00 mm between 50 and 65 weight %

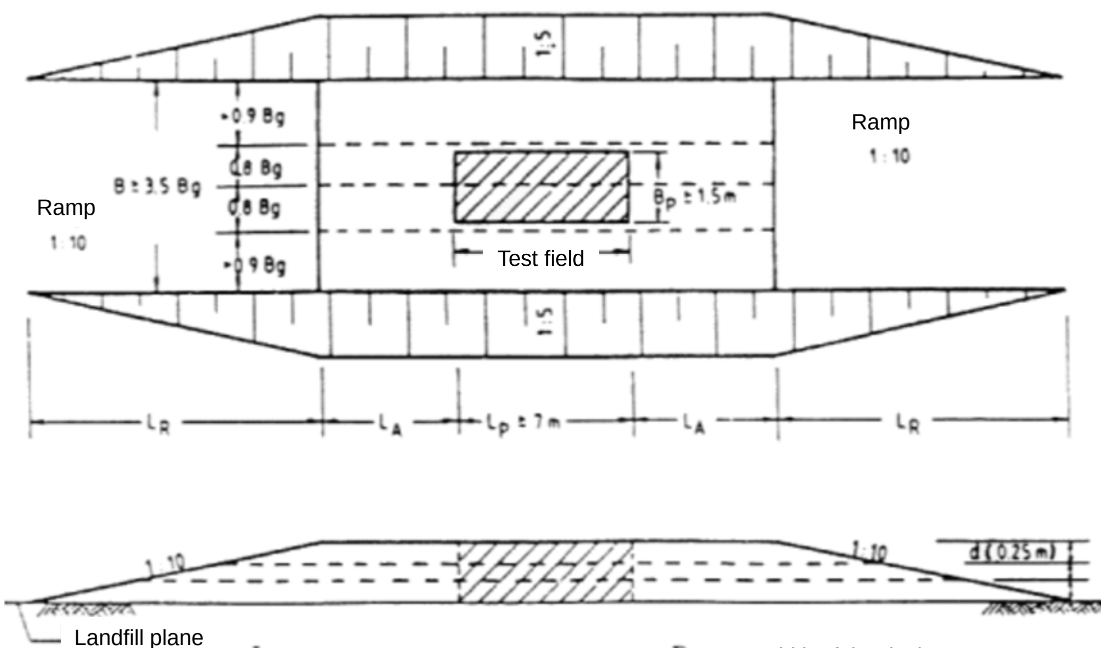
20 mm Drainage mats(dewatering)
15 mm Bentonite mat
20 mm Drainage mats (degassing)

Trisoplast®
(89,1 % sand
10,7 % Bentonite
0,2 % Polymer)

Additional Requirements on Landfill Sealings

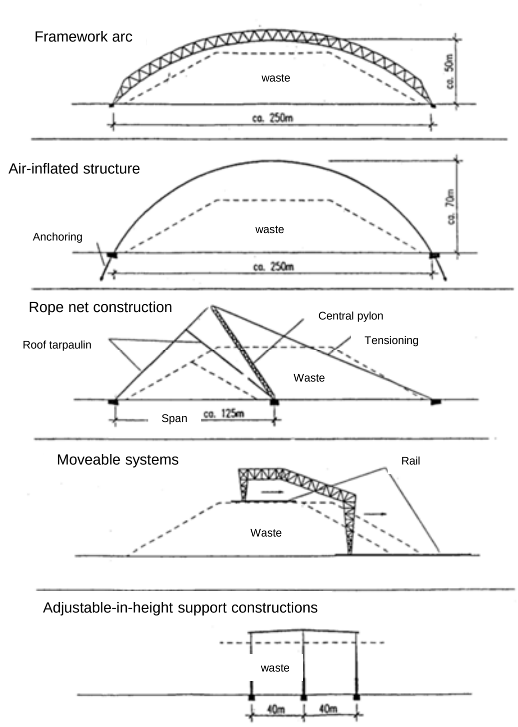
Bottom sealing (TASI 10.4.1.3)	• Quality management plant according to DIN 55350; vertical permeation of the sealing not permissible • for mineral sealing: clay ratio10 weight %; organic substance ≤ 5 weight %; carbonate contents ≤ 15 weight %; built-in water contents above the Proctor water contents and Dpr ≥95%; evidence of the suitability through lab-tests and on an industrial scale through implementation of a trial field (cf. Foil). During execution: attention to the extensive prescriptions on quality management and approval.
Dewatering	• After the subsiding of the settling, bottom with roof-shaped profile with cross slope ≥ 3%, longitudinal slope≥ 1% ; Trickling pipes according to DIN 19967, rinseable and controllable; perforated or slit on 2/3 of the circumference; reach length max. 300 m; hydraulic evidence on 6 l/s*ha; dewatering via a free gradient; shafts outside the landfill area or walk-in tunnels; pipe statics according to ATV Leaflet M127
Dewatering layer	• Preferably made of washed (round) grain and preferably within the particle size distribution curve range 16/32 mm
Surface sealing (TASI 10.4.1.4; TI Waste)	• Cushion = equalisation layer d ≥ 0,50 m of cohesion-less material; • Maybe additional d ≥ 0,3 m gas filter layer with $CaCO_3$ contents ≤ 10 weight % • Roof-shaped; after subsiding of the settling cross slope ≥3% and longitudinal slope ≥1% • Recultivation layer d ≥ 1,00 m with arable soil; growth to minimise the infiltration of rainfall

Test Field for minimum Sealing according to TI Waste, Part 1, Appendix E

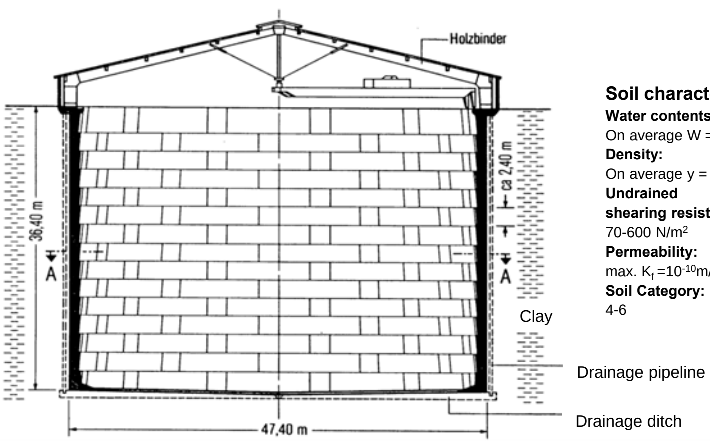


L_p = Lenght of the test field
L_R = Lenght of the ramp
d = Thickness of a compacted lyer
B_g = Width of the device
L_A = Acceleration and Delay stretch
B_p = Width of the test field

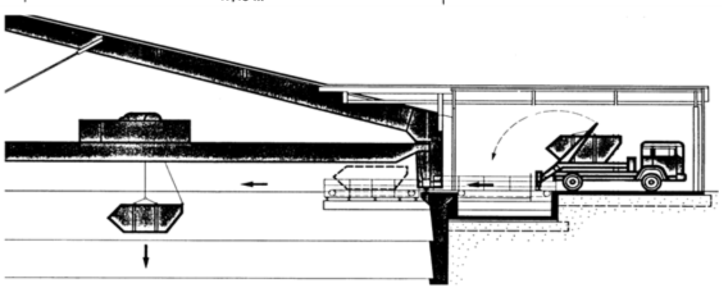
High Security Landfills – Indoor Depositing



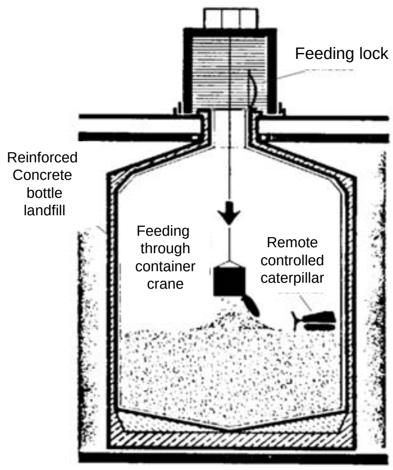
High Security Landfills – Architectural Solutions



Soil characteristics:
Water contents:
On average W = 0.15 to 0.17
Density:
On average y = 21.4 KN/m³
Undrained shearing resistance:
70-600 N/m²
Permeability:
max. $K_f = 10^{-10}$ m/sec
Soil Category:
4-6

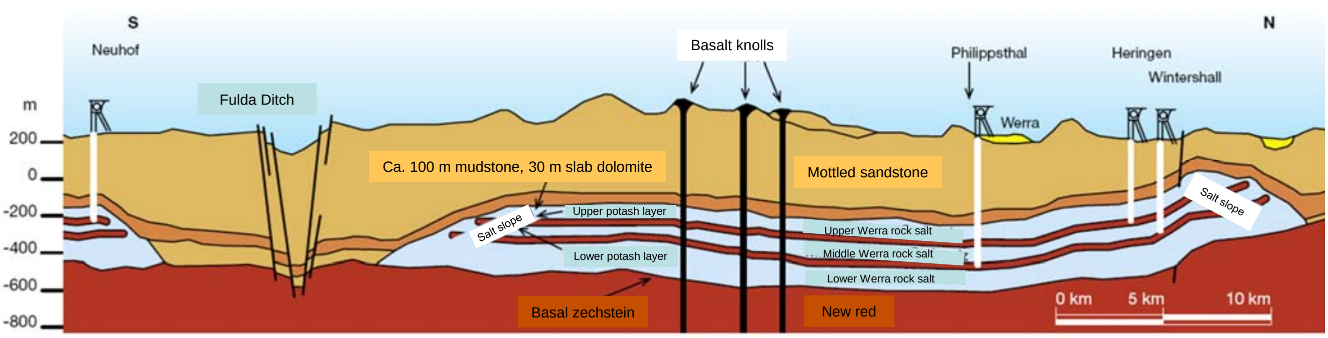


Terra Rotonde



Bottle Landfill

UTD (Underground Landfill) in Herfa Neurode



Geological cross-section through the repository of the River Werra

Depositing Conditions for an UTD

Under depositing conditions, the waste must not be
- explosive
- self-igniting
- automatically combustible

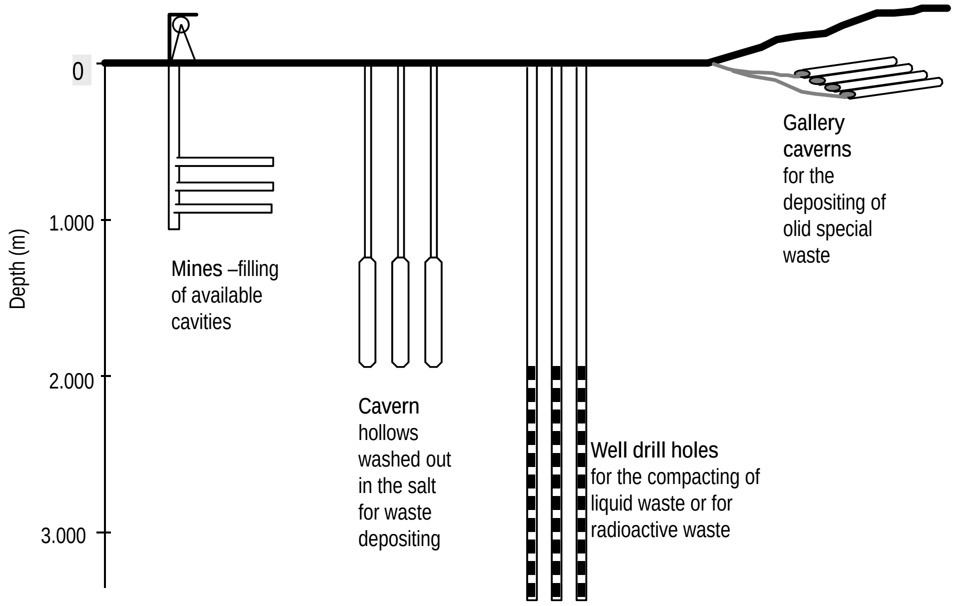
If deposited, the waste must not
- Be prone to reactions which will entail autonomous degassing or gas production in the vessel

Waste must not
- have a pungent stench
- Be liquid, but have at least a semisolid consistency
- React in any hazardous way with the salt rock strata
- Grow in volume
- Be radioactive
- Contain or be able to bring forth pathogens of transmissible diseases
- Waste must be packaged in tightly sealed containers (barrels, containers or protective containers or Big Bags in a design which is harmless in regard to mining hygiene, dust-proof and flame-retardant).

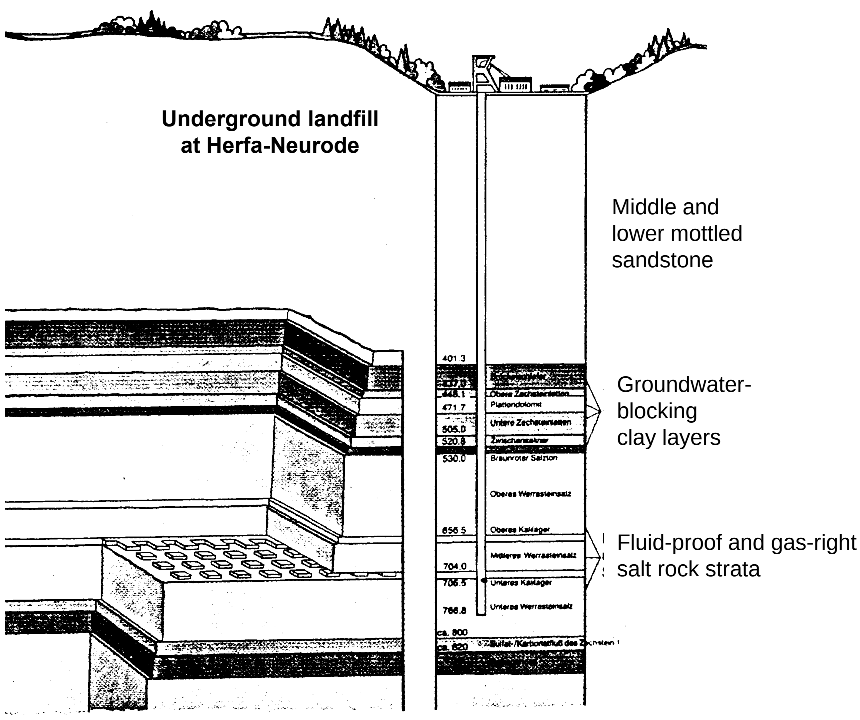
  PCB-contaminated transformators may be deposited without further packaging if the directives for hazardous goods have been observed.

Cavities for Underground Landfills

- Depending on the waste quality: hydrogeologically safe depositing
  - Salt mines (sasfe underground landfill also for dangerous waste)
  - coal mines (mining salvage material for utilisation)



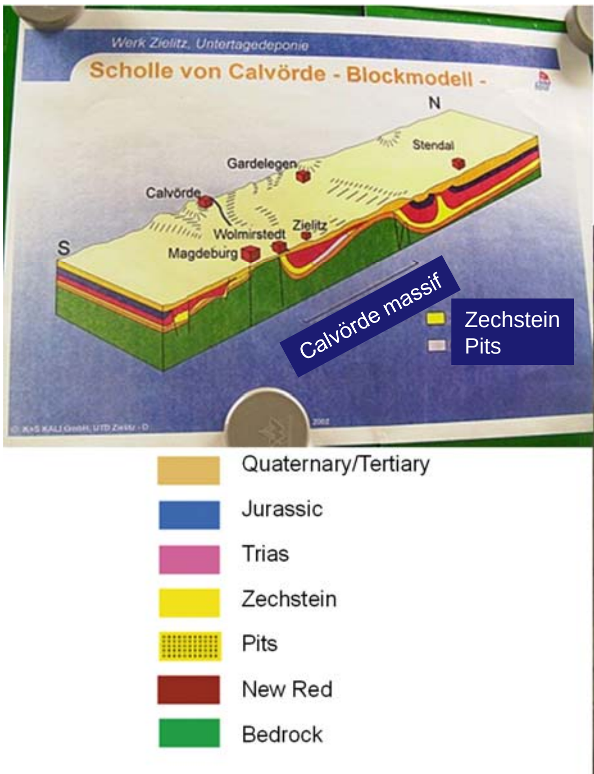
Underground Landfill at Herfa-Neurode near Kassel



Underground Landfill at Herfa-Neurode near Kassel

Filling at the Underground Landfill Herfa

Underground Landfill in the Potash Works in Zielitz near Magdeburg



Examples of Waste Types

- Residues from incineration plants for special waste and domestic waste
- Galvanisation residue
- Hardening salt residues
- Arsenical waste
- Chemical distillation residues
- Mercurial waste
- PCB-containing condensators/ transformators
- Fluorescent lamp cullet
- Filtration and filter bed residues
- Contaminated soils and building rubble
- Evaporation residues from landfill leachate

Examples of Sectors:

- Combustion plants
- Metallurgical plants
- Metal processing industry
- Chemical industry
- Pharmaceutical industry
- Electrical industry
- Glass industry
- Lands and Municipalities
- Sanitation of abandoned polluted areas
- Waste Management Industry

Safety and Depositing Conditions

Ordinance on the underground depositing of waste, Stowing Ordinance as of 24. Jul 2002

- not explosive (under stowing conditions)
- not self-igniting (under stowing conditions)
- not automatically combustible (under stowing conditions)
- the waste must after depositing not incline to any reactions which would cause the autonomous degassing or gas production in the vessel
- the waste must not exude a pungent stench
- the waste must not be liquid and must at least have a semisolid texture
- the waste must not react with the rock salt strata in any hazardous way
- the waste must not grow in volume
- the waste must not be radioactive
- the waste must not contain or be able to generate pathogens or transmittable diseases
- the waste must be packed into tightly sealed repositories (dust-proof barrels, containers, or Big Bags with a low inflammability which comply with the requirements of mining hygiene). PCB-contaminated transformators can be deposited without further packaging if they comply with the requirements for hazardous goods.

Waste which does not fulfil these requirement must not be deposited.

In individual cases, one has to examine if the waste fulfils the conditions for the depositing on underground landfills (possibly after preliminary treatment).

The packaging must comply with the requirements for underground landfill depositing and the ADR/RID regulations. All repositories must be stored on palettes.

Underground Landfill Zielitz & Herfa Neurode






Water Balance of Landfills

- Water = negative as source of emissions;
  positive as accelerator of the stabilisation
- Minimum water contents for degradation:

  <u>for aerobic processes:</u>

suppressed from	ca. <15 % water contents
inhibited from	ca. <30 % water contents and ca. >60 % water contents
optimal	ca. 40 - 60 % water contents

  <u>for anaerobic processes:</u>

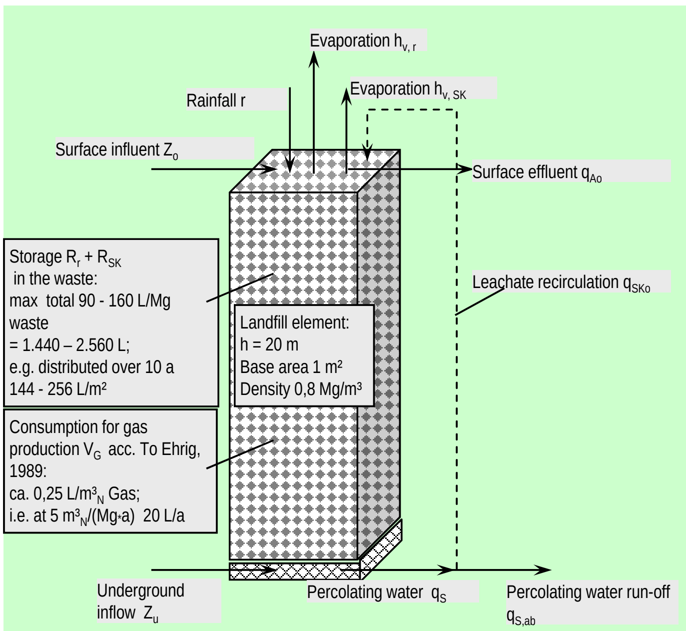
suppressed from	ca. <15 % water contents
inhibited from	ca. <30 % water contents
optimal	ca. >40 % water contents

- As little leachate as possible,
  but as much water as necessary for the residual stabilisation
- Water/solids ratio as measure for the stabilisation of a landfill

Specific leachate amounts (m^3/ha*d)	sealed areas (combined sealing)		covered areas (sparse vegetation)		Open operation areas with leachate recirculation		Open operation areas without leachate recirculation		New open landfill sections without charging	
	average	maximal	average	maximal	average	maximal	average	maximal	average	maximal
SUGGESTION	1,5	3,5	7,5	20	7,5	15	10	40	20	>50

Water Balance of a Landfill Element for Raw Municipal Waste

$$q_{S,ab}\ [m^3/(ha \cdot a)] = r - h_{V,r} - h_{V,Sk} - \frac{M}{\rho_M \cdot A} \cdot (R_r + R_{Sk}) - V_G + Z_o - q_{Ao} + Z_u$$



$q_{S,ab}$	leachate contribution to be discharged in m³/(ha·a)
r	rainfall contribution in m³/(ha·a)
$h_{V,r}$	evaporation of the rainfall in m³/(ha·a)
$h_{V,Sk}$	evaporation from leachate recirculation in m³/(ha·a)
M	deposited waste amount in t/a
ρ_M	depositing thickness in t/m³
A	depositing area in ha

Influences on Leachate Amounts

- Storage potential of raw MSW is usable only once:
  → low initial leachate amounts
- On unsealed landfill areas, evaporation can considerably reduce the leachate amounts (according to, MHB 4623):

Soil surface, Vegetation layer	TOTAL EVAPORATION (L/m²)	TOTAL EVAPORATION % of N	EFFLUENT (L/m²)	EFFLUENT % of N
Naked soil	265	40	398	60
Sparse vegetation	345	52	318	48
Field	431	65	232	35
Grass	497	75	166	25
Forest	597	90	66	11

- Leachate recirculation on landfills with bio-degradable waste if
  - the leachate is low-odour
  - leachate storage capacity is available
  - the rainfall amount is low ≤ 5 mm/d
- Upper sealing/covering; if need be, secondary moistening for water consumption during degradation and moisture extracted with the landfill gas (ca. 35 l / Mg moist matter)

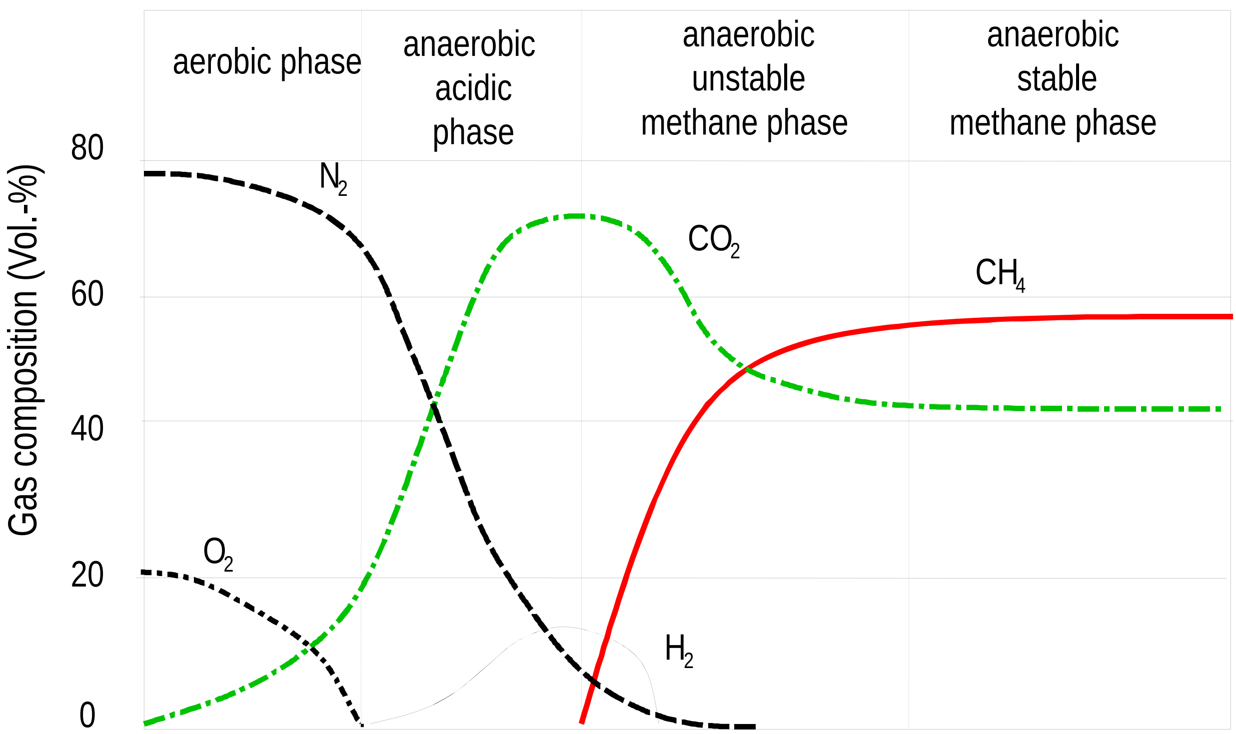
Leachate Quality

		Raw leachate concentrations from landfills for						Discharge limit values
		Raw municipal waste (EHRIG, 1986 and ATV, 1988)				MBT-Output appendix 2 AbfAblV DK II	waste acc. app 1 AbfAblV DK II	Appendix 51 Direct discharge
		acidic phase		methane phase				
		range	average	range	average			
pH		4,5 - 7,5	6,1	7,5 - 9	8			
COD	mg O_2/l	6.000-60.000	22.000	500-4.500	3.000	1.500	< 1.000	≤200 at ≤ 4.000 raw or >95% at ≥ 4.000
BOD_5	mg O_2/l	4.000-40.000	13.000	20-550	180	< 150	< 100	
SO_4	mg/l	70-1.750	500	10-420	80			
Zn	mg/l	0,1-120	5	0,03-45	0,6			≤2,0
Fe	mg/l	20-2100	780	3-280	15			
Parameter without significant changes (acidic/methane)								
		range		average				
NH_4-N	mg/l	30-3.000		1.500		0-250	≤150	
∑N	mg/l			1.500				≤ 70
Waste steam residue	mg/l	10.000		10.000		10.000	500 – 30.000	
Pb	mg/l	0,008-1		0,09				≤0,5
Cd	mg/l	0,0005-0,140		0,006				≤0,1
Cu	mg/l	0,0044-1,4		0,08				≤0,5
Ni	mg/l	0,02-2		0,2				≤1,0
Hg	mg/l							≤0,05
Cr	mg/l	0,030-1,6		0,3				≤0,5 (CrVI ≤0,1)
AOX	mg/l	0,3-3,3		2		0,1 – 1,5		≤0,5
GF	-							≤2

Leachate Treatment

- Both for the indirect discharge into the public sewage system and for the direct discharge into bodies of water, the leachate must be treated on the landfill location.
- Limit values according Appendix 51 of the Wastewater Ordinance, particularly
  - (non-biodegradable) COD
  - N
  - AOX
  - (heavy metals)
- Lecture Prof. Rosenwinkel

Landfill Gas Composition according to Rovers, 1977 (Original Micrografx Picture) Micrograf.bild



Landfill Gas Production from Organic Waste

- *Bio-gas production according to BOYLE*
  $C_aH_bO_cN_dS_e$ + (a - b/4 - c/2 - 3d/4 - e/2) * H_2O <==> (a/2 + b/8 - c/4 -3d/8 -e/4) * CH_4 + (a/2 - b/8 + c/4 + 3d/8 + e/4) * CO_2 + d * NH_3 + e * H_2S
- From the contents of, for instance, 200 kg C/t of moist waste, 200 * 22,4/12 = 200 * 1,868 = 373 m^3 gas /t waste would develop in case of complete C degradation, as CO_2 and CH_4. The theoretical gas potential is practically never achieved and not completely collectable, either. The actually collectible landfill gas volume is:
- **$G_{collectible}$ (m^3/t) = 1,868 * TOC * f_{oa} * f_a * f_o * f_s**
  - with **1,868** = m^3_n gas per kg TOC (m^3/kg) = 22,4 (L/Mol)/ 12 (atomic weight C)
  - TOC = organic carbon contents kg/t of untreated moist waste, for instance

Domestic waste	ca. 180	Bulky waste	ca. 255
Commercial waste	ca. 270	Industrial waste	ca. 195
Mixed construction waste	ca. 75	Digested sludge	ca. 300

  - **f_{oa}** = Initial time factor for the consideration of the gas production or conversion before depositing (e.g. also during preliminary treatment)
  - **f_a** = Degradation factor as ratio of TOC gasifiable under optimal test conditions to total TOC (f_a 0,5 -0,9)

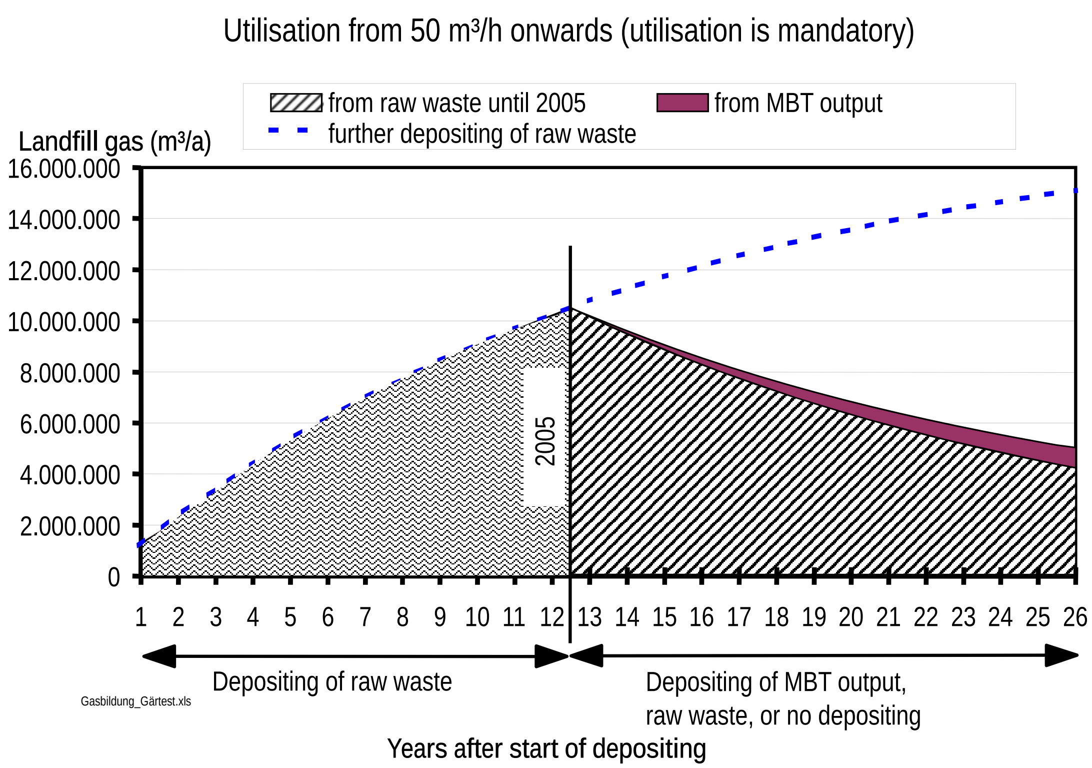
Gas Production (2)

  - **f_o** = Optimisation factor as ratio of TOC gasified under practical landfill conditions to TOC gasified under optimal degradation test conditions (f_o = 0,5 -0,9; typically f_a*f_o = 0,5 in humid climate)
  - **f_s** = system-inherent capacity as ratio of the gas amount collected under landfill conditions with current degassing to the actually produced gas amount (fs = 0 -1,00; high values with fast degassing start and upper combination sealing), also for losses at the beginning of a collection and after the end of a purposeful collection.
- Gas production – gas collection = gas loss
- With open or only covered landfills, a maximum of 50% of the produced gas amount will be collected also with suction operation (active degassing); the rest is emitted into the air.
- Gas production is time-dependent according to degradation kinetics, e. g. monomolecular reaction:
  $dc/dt = k * c$, or $c_t = c_o * e^{-k*t}$
  c_t Mass or concentration of degradable substances at point of time t;
  c_o Mass or concentration of degradable substances at oint of time t = 0;
  k Velocity coefficient
- Half-time **c_o / c_t = 2**
  → **t_H = ln 2 / k = 0,693/ k or**
  → **k = ln 2 / t_H = 0,693/ t_H**

Gas Production (3)

- Raw municipal waste with components with different degradation speeds, for instance
  - easily degradable (e.g. food leftovers, leaves, cut grass): half-life values 0,5 to 2 a
  - medium-heavily degradable (e.g. paper): half-life values 5 to 10 a
  - hardly degradable (e.g. books, cardboards, leather, wood, rags): half-life values 10 to 100 a
- Either for total waste 1 average k value, for instance
  for landfills with raw municipal waste k = 0,05-0,15;
  for digested sludge landfills k = 0,01-0,03,
  or for singel types of waste differentiated values for f_a , TOC and k
- Collectible gas amount of a waste amount M (t) within t years after depositing:
  $G_{collectible}$ (m^3) = 1,868 * M * TOC * f_{ao} * f_a * f_o * f_s * ($1-e^{-k*t}$)
- or in year t after depositing
  $G_{t,collectible}$ (m^3/a) = 1,868 * M * TOC * f_{ao} * f_a * f_o * f_s * k * e^{-k*t}
- Through MBT, about 40-60% of the oDM are degraded: thus – because not the entire oDM is degradable – gas production in the ensuing MBT landfill reduced by ca. 70-90% (f_{ao} =1- (0,7 to 0,9) = 0,3 to 0,1) compared to the raw waste landfill.
- Slags of thermal treatment after sufficient ageing without significant gas production

Gas Production over Time – Example for the Depositing of 100.000 Mg/a



ISAH
Solid Waste Management
Dr.-Ing. Dirk Weichgrebe
Leibniz Universität Hannover

Landfill Gas Components

COMPONENT		CONCENTRATION RANGE	
Methane	CH_4	0- 70	Vol.-%
Carbon dioxide	CO_2	0- 50	Vol.-%
Hydrogen	H_2	0- 3	Vol.-%
Oxygen	O_2	0- 21	Vol.-%
Nitrogen	N_2	0- 78	Vol.-%
Carbon monoxide	CO	0- 3	Vol.-%
Ammoniac	NH_3	0-100	Vol.-ppm
Ethene	C_2H_4	0- 65	Vol.-ppm
Ethane	C_2H_6	0- 30	Vol.-ppm
Acetaldehyde	CH_3CHO	0-150	Vol.-ppm
Acetone	C_2H_6CO	0-100	Vol-ppm
other HCs, without aromatics	C_2-C_{11}	each 0- 50	Vol-ppm
Hydrosulphide	H_2S	0-100	Vol-ppm
Ethyl mercaptan	C_2H_5SH	0-120	Vol-ppm
Benzol, Toluol, Xylol	C_nH_m	0- 15	Vol-ppm
HFC	$C_wH_xCl_yF_z$	0-600	mg/m³

Properties of Landfill Gas Components

* from trace substances
1) at 0°C, 1013 mbar (according to KUCHLING, Taschenbuch der Physik, 1979)
2) related to air = 1; composition of the air: 21% O_2; 78% N_2; 0,03% CO_2
3) at 0°C, 1013 mbar, lower or upper explosion threshold
4) dependent on the air dilution factor
5) at 40% CO_2 ratio in the landfill gas

Properties		LANDFILL GAS COMPONENTS						
		Methane CH_4	Carbon dioxide CO_2	Hydrogen H_2	Hydro-sulphide. H_2S	Carbon monoxide CO	Nitrogen N_2	Landfill gas with 60%CH_4 and 40 % CO_2
Standard density 1)	kg/Nm³	0,717	1,917	0,090	1,52	1,25	1,251	1,20 5)
relative density 2)	-	0,555	1,520	0,069	1,190	0,967	0,967	0,962
Combustibility	-	yes	no	yes	yes	yes	no	yes
Explosiveness in air 3)	Vol.-%	5-15	no	4-75,6	4,3-45,5	12,5-74	no	yes 4)
Ignition temperature	°C	≈ 650	-	560	270	605	-	≈ 650
Smell		no	no	no	yes	low	no	yes*
Toxicity		no	yes	no	yes	yes	no	yes*
MAC value	Vol.-ppm	-	5.000	-	10	50	-	(12.500) 5)
Caloric value H_u	kJ/Nm³	35.790	0					21.582

Environment Pollution and Hazards Through Landfill Gas

	Source	Emission path	Impact location	Effect	Measures
1	Original landfill gas	Landfill, soil, leak-ages	Shafts, cellars	Suffocation	Optimised gas collection; ventila-tion; compartment air measuring
2	Air-diluted landfill gas	like 1.	Shafts, cellars, closed rooms + vicinity	Danger of explo-sion	Ventilation; com-partment air control
		-	Interior of the de-gassing imple-ments	Danger of explo-sion	active and passive explosion protec-tion
3	Gas migration	Soil	Covering soil, am-bient soil	Plant damages (displacement of air oxygen)	active degassing, maybe combined with (upper) seal-ing
4a	Trace gases H_2S, CO, CFC	like 1. + 5	like 1.-3.	Toxicity generally superposed by 1.	like 1.-3.
4b	Carbon dioxide	like 1. + 5	like 1.-3.	Toxicity, MAC 5‰	like 1.-3.
5	Smell of the gas	Spreading in the air	Landfill vicinity	Annoyance through odours	active degassing, upper sealing

Collection of Landfill Gas (1)

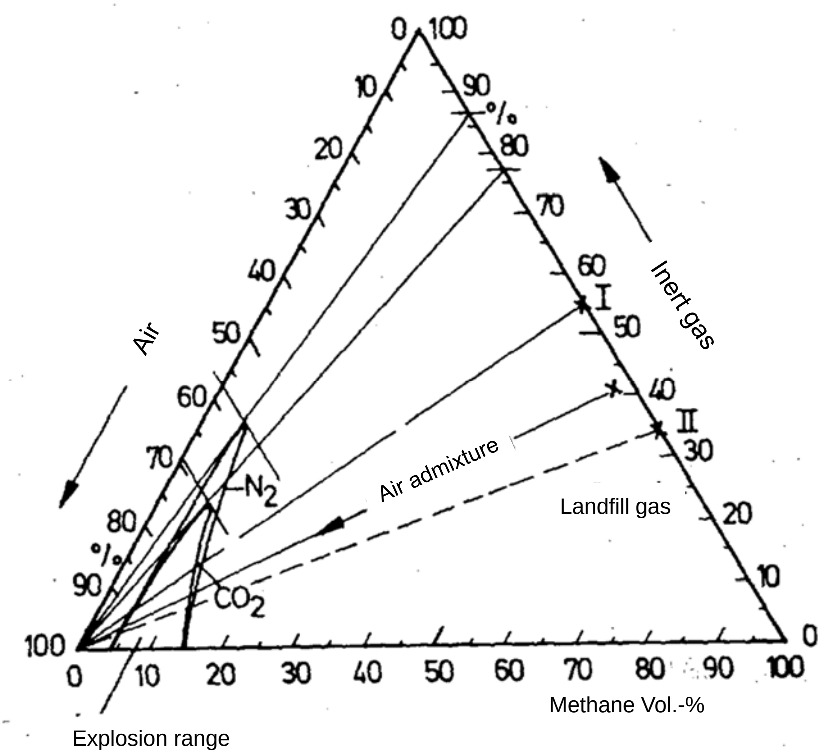
- Gas collection and utilisation are a necessary part of each landfill for raw municipal waste (otherwise emission problems, explosion risks; cf. Appendix C of TASi).
  Greenhouse gas potential of methane is ca. 25 times higher than that of CO_2 $\rightarrow$ purposeful oxidation
  Degassing actively (with low pressure), only on old landfills passively (through auto-overpressure)
  Degassing of a charging field at the latest 6 months after the start of the depositing, to keep initial losses and emissions low (odour, greenhouse gas potential)
- Bottom leachate drain and leachate shafts must not be used for active degassing!
- Vertical gravel or rubble columns to be topped on the „waste cushion“ (10%-15% of the final column height, or 2,00 m) draining of the column; drainage pipe DN 200
- Drilled gas wells (on waste cushion); drainage pipe DN 200;
  Telescope lengths for settling of 10%-20% of the entire waste depositing height

Collection of Landfill Gas (2)

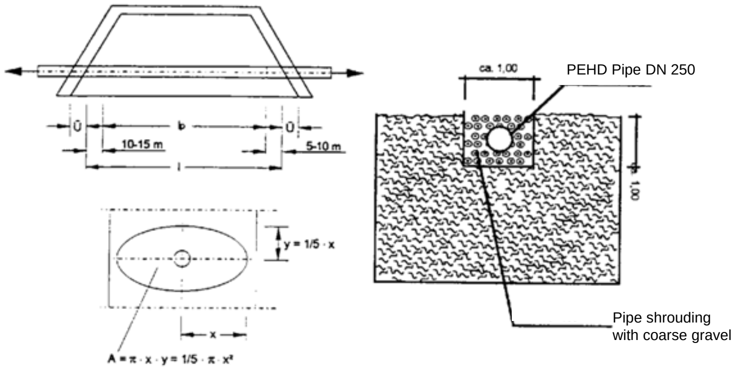
- Horizontal gas drainage layers (e.g. under surface sealing) 5% inclination
- Horizontal gas drainage ditches and pipelines
  - Initial inclination 7%; vertical drainage; pipes DN 250;
  - if exclusively horizontally: horizontal distance 30 m, vertical distance 5-10 m
- Gas pipelines
  - DN $\geq$ 100; v $\leq$ 10 m/s;
    inclination underground $\geq$ 5%, aboveground $\geq$ 2,5% (condensate production, prevention of „water bags")
  - flexible pipeline connections (due to the settling of the landfill)
- Condensate from cooling of the water-saturated gas from, for instance, 40°C to 10°C should be separated, discharged, and treated like leachate

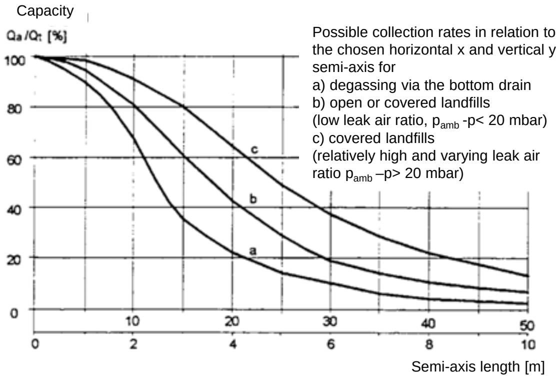
Explosion Triangle for Landfill Gas

according to MÜLLER / RETTENBERGER (1986) "Gasabsauge- und Gasverwertungsanlagen an Mülldeponien“ MFT/UBA, 183 S.

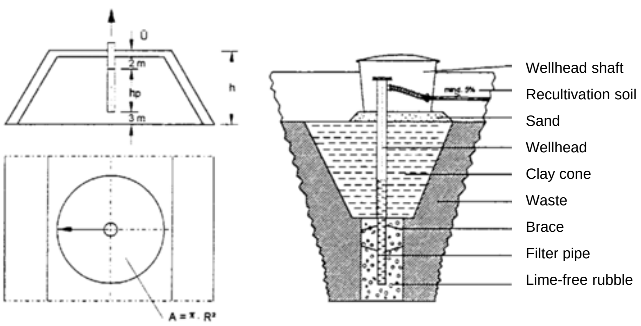


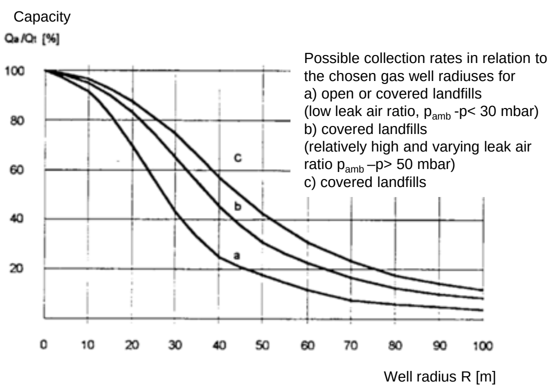
Horizontal Gas Collectors



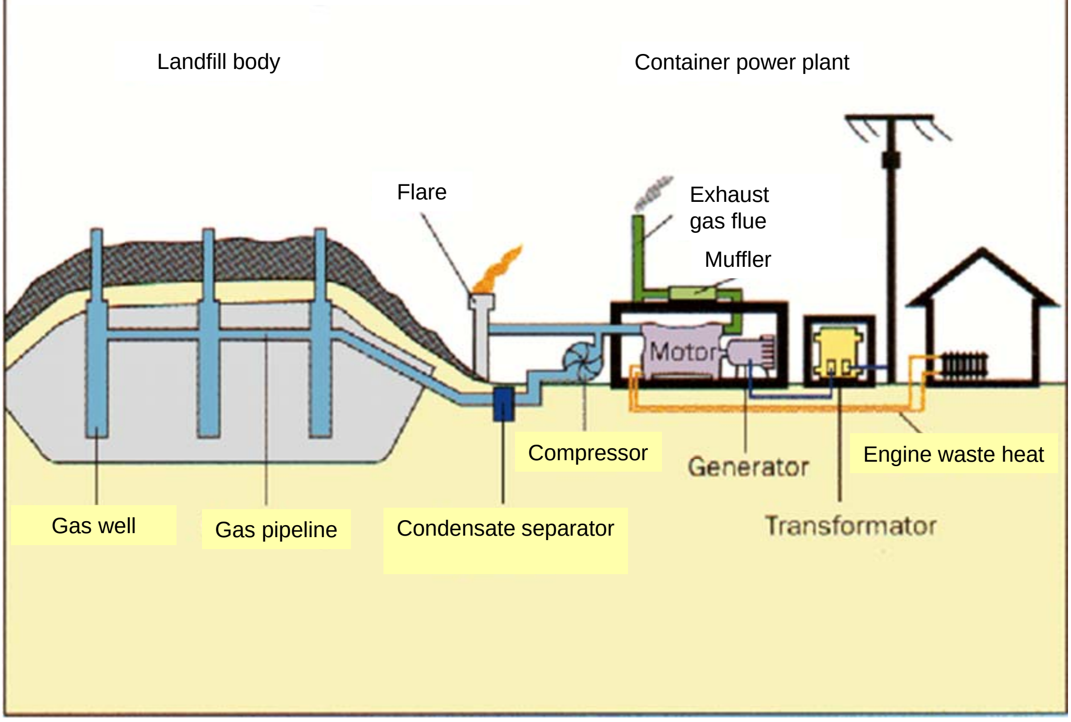


Vertical Gas Collectors

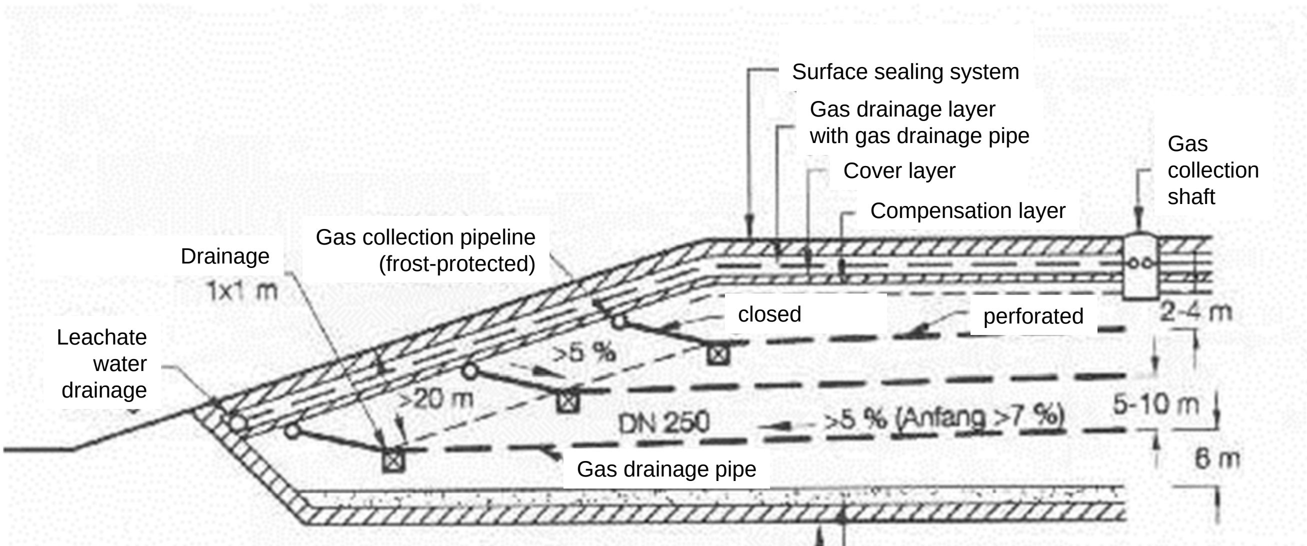




Electric Energy from Landfill Gas

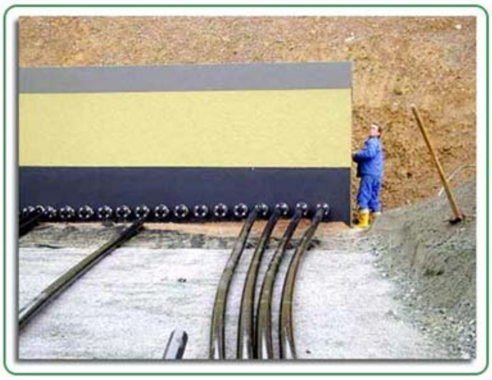


Landfill Structure



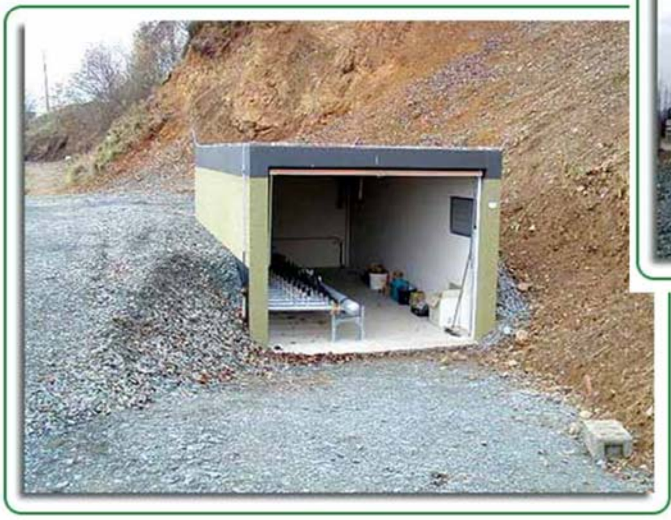
Distance of the horizontal gas drainage pipes from each other ca. 30 m; in the single layers, they should be staggered

Drilling of a Gas Well

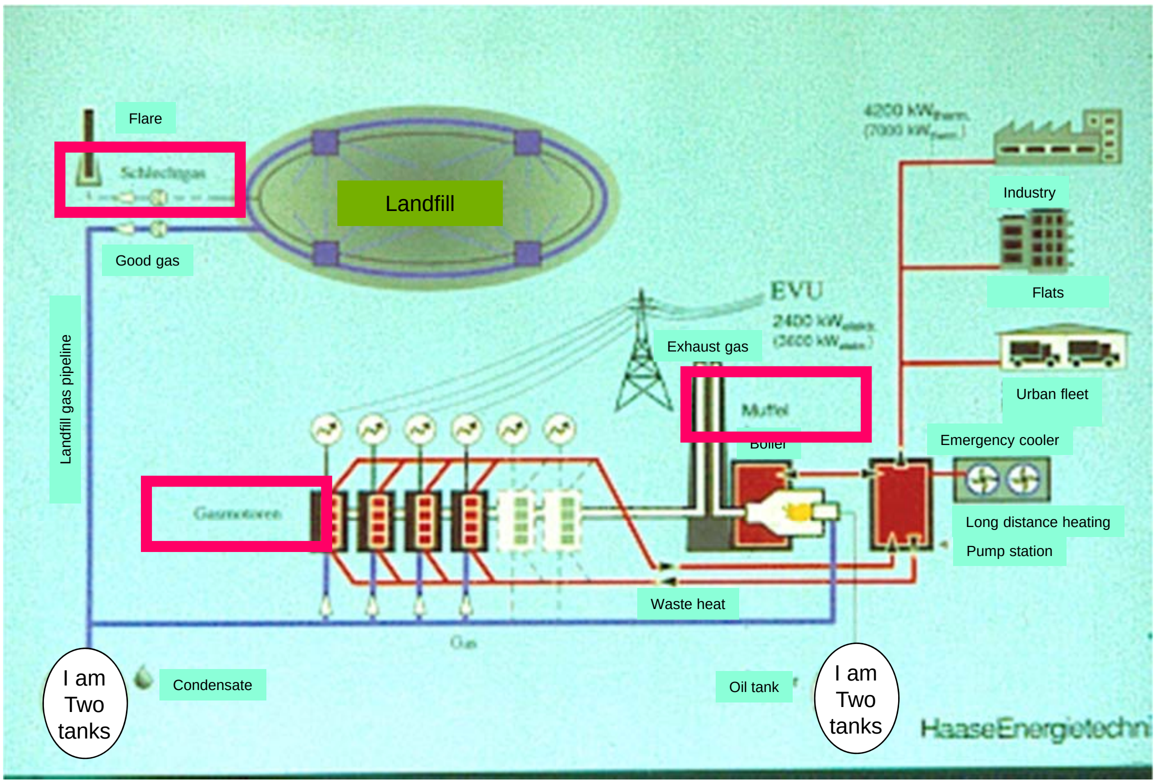


Flexible Gas Well Connections

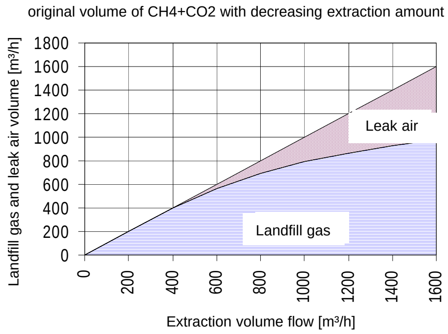
Landfill Gas Collection Station

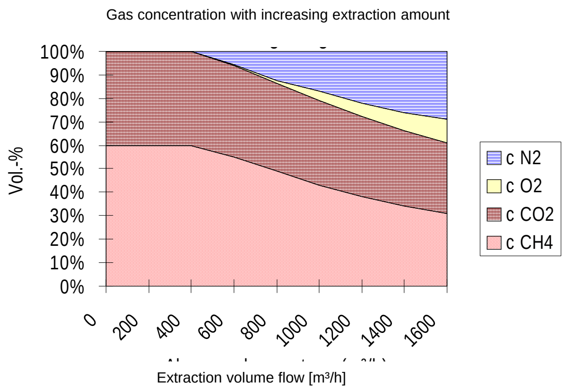


Landfill Gas Utilisatoin in Lübeck



Gas Concentration in Relation to the Extraction Volume Flow





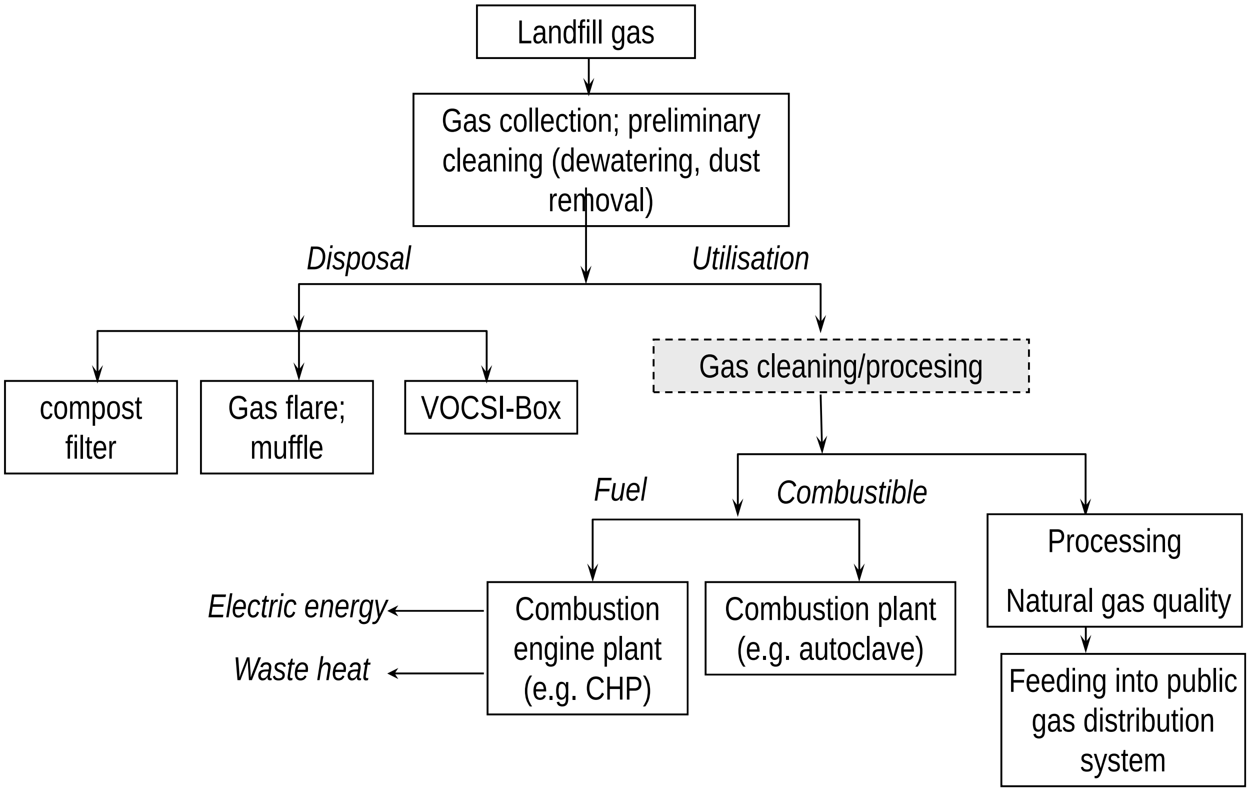
- Collection rate f_s often only up to 50 vol.-% of the produced landfill gas
- In case of excessive extraction:
  → Leak air
  → O_2 partly consumed for oxidation
  → O_2/N_2 ratio shifted from 0,26 (air)

Crucial Components of a Degassing Station

- pressure surge protected gas conveyance aggregate
- continuous (safety) analysis (CH_4, CO_2, O_2)
- Measuring technology (temperature, pressure)
- Aeration and ventilation
- safety fittings (valves, rapid action valves, deflagration implements, etc.)
- connecting pipeline
- electric technology including switching station
- building/containers with compartment air control

ISAH
Solid Waste Management
Dr.-Ing. Dirk Weichgrebe
Leibniz Universität Hannover

Disposal of Landfill Gas



Emission Limit Values for Landfill-Gas Driven Combustion Plants according to 1st BImSchV / TI Air

1) related to dry exhaust gas in the standard state at 5 Vol.-% O_2
2) related to dry exhaust gas in the standard state at 3 Vol.-% O_2
3) related to dry exhaust gas in the standard state at 15 Vol.-% O_2

	Gas-Otto-Engine1) (mg/m³)	Combustion2) (mg/m³)	Gas turbine3) (mg/m³)
Dust	5	5	Smoke number <4
Carbon monoxide	650	100	100
Nitrogen oxides ($NO + NO_2$) meaured as NO_2	500	200	350
Sulphurous oxides ($SO_2 + SO_3$) measured as SO_2	500	500	500
Inorganic chlorine compounds as gas of steam, measured as HCl	30	30	30
Inorganic fluoride compounds as steam or gas, measured as HF	5	5	5
Organic substances according to classi-fication	20-150	20-150	20-150

Landfill Gas Flare and CHPs

Flare in Lübeck

Container-CHP in Borken

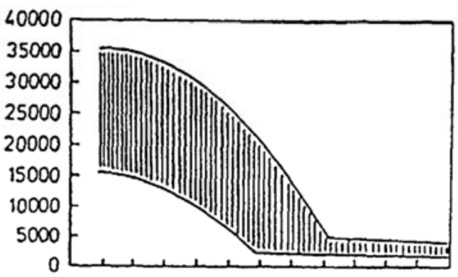
stationary CHPs in Mechernich 6x600 kW_{el}

6,5 MW CHP in Seoul/South Korea

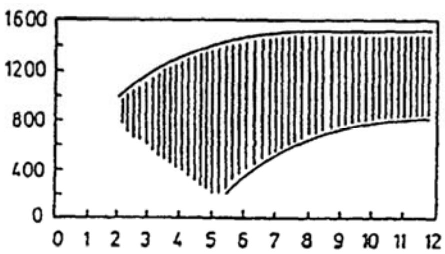
General Development of the COD, BOD_5 and NH_4-N Concentrations

in Relation to the Landfill Age and the Landfill Operation

COD [mg/L]

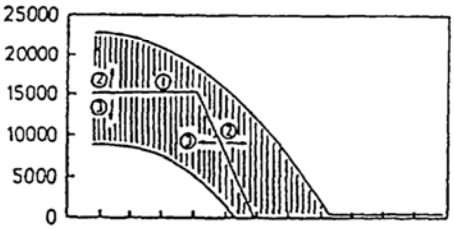


NH_4-N [mg/L]



Landfill age [a]

BOD_5 [mg/L]



General development of the COD, BOD_5 and NH_4-N concentrations in relation to the landfill age

1 = average development with 2 m layers and 2-4 m build-up per year

2 = tendency with faster build-up

3 = tendency with slower build-up or recirculation

Requirements on the Effluent Quality

1. Minimum requirements according to the 51st Appendix of the Wastewater Ordinance (valid version of 1999) for direct and indirect dischargers as well as 23rd Appendix of the Waste Depositing Ordinance (2001), updated on 15.10.2002

2. additional requirements according to municipal sewage statutes for indirect discharge, which are often geared to the ATV Leaflet M 115,

3. more extensive requirements based on the situation of local receiving waters for direct discharge.

Requirements on Wastewater for the Discharge Point

(Appendix 51 of the Wastewater Ordinance, 15.10.02)

		Qualified random sample or 2-hour mixed sample	Common concentration in the raw leachate
Chemical oxygen demand (COD) [1]	mg/L	200	1.000 – 60.000
Bio-chemical oxygen demand in 5 days (BOD_5)	mg/L	20	50 – 40.000
Nitrogen, total, as sum of ammonium, nitrite, and nitrate nitrogen[2]	mg/L	70	400 – 4.000
Phosphorous, total	mg/L	3	0,01 – 1,0
Hydrocarbons, total	mg/L	10	200 – 30.000 (TOC)
Nitrogen from nitrite (NO_2-N)	mg/L	2	< 1
Fish toxicity	mg/L	2	8 - > 64

[1] If it can be assumed that the contents of chemical oxygen demand (CDO) of a given wastewater amounts to more than 4,000 mg/l prior to treatment, there applies for the COD an effluent value of the qualified random sample or the 2-hour mixed sample which is equivalent to a reduction of the COD b at least 95%. The reduction refers to the ratio of the pollutant load in the influent of the wastewater treatment plant to that in the effluent of the WTP within 24 hours.

[2] The requirements on Nitrogen total applies for a wastewater temperature of 12°C or more in the effluent of the biological reactor of the wastewater treatment plant.

Requirements on the Wastewater before Admixing

(Appendix 51 of the Wastewater Ordinance, 1999)

		Qualified random sample or 2-hour mixed sample	Common concentration in the raw leachate
Adsorbable organically bound halogenes (AOX)	µg/L	500	500 – 5.000
Mercury	µg/L	50	< 1 – 50
Cadmium	µg/L	100	0,5 - 140
Chromium	µg/L	500	30 – 1.600
Chromium VI	µg/L	100	k. A.
Nickel	µg/L	1.000	20 – 2.000
Lead	µg/L	500	10 – 1.000
Copper	µg/L	500	4 – 1.400
Zinc	µg/L	2.000	500 – 3.000
Arsenic	µg/L	100	< 0,1 – 1.000
Cyanide, easily releasable	µg/L	200	k. A.
Sulphide	µg/L	1.000	k. A.

Factors Influencing the Leachate Treatment Plants

The crucial parameters for the planning and realisation of leachate treatment plants are the **leachate amount** and the **leachate composition**.
Both dimensioning parameters are influenced by the following factors:

1. **Waste composition**:
   - influenced by separate resource collection, pre-sorting, preliminary treatment and residual waste treatment

2. **Landfill operation**:
   - Filling of the waste (thin layer filling or fast build-up of single landfill sections;
   - intermediate covers)
   - integration of an "aerobic" bottom layer of pre-rotted domestic waste in order to reduce the concentration peaks of organic components (see also WEBER, 1990)
   - management of the closed areas and operation surfaces

3. **Leachate management**:
   - storage to compensate amounts and concentrations,
   - leachate recirculation(optimal water contents)
   - strict separation of unpolluted surface water and leachate

4. **Meteorological conditions**:
   - rainfall volumes, rainfall distribution, general weather data

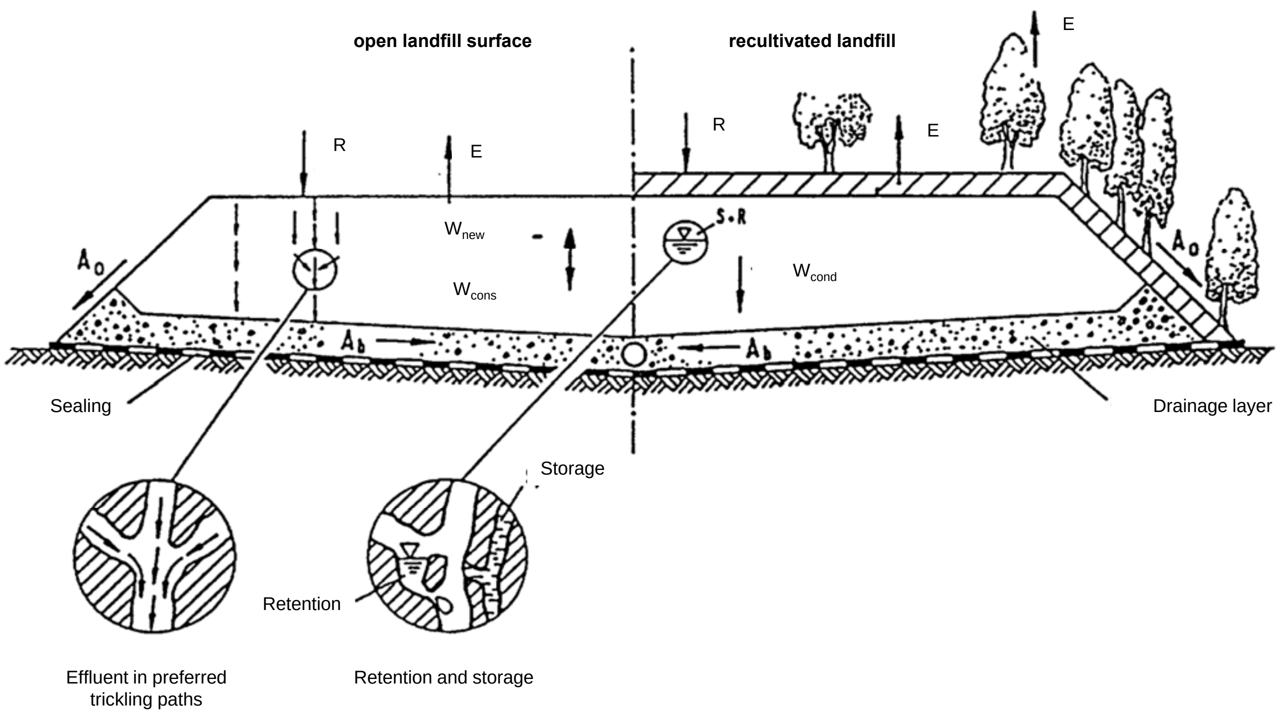
Leachate Production

$$Q_{leach} = R - E - Es - R - S + W_{new\cdot} - W_{cons\cdot} + W_{cond\cdot}$$

with

Q_{leach} Leachate production
R Rainfall
E Evaporation and Transpiration
Es Surface effluent (unpolluted) without mixing with the leachate
R Retention
S Storage
$W_{new\cdot}$ Water production due to microbial processes
W_{cons} Water consumption due to microbial processes
W_{cons} Water discharge due to consolidation processes (e.g. with sewage sludge)

Schematic Presentation of the Water Management of a Landfill (RAMKE, 1993)



Data from Reference Literature on Specific Leachate Amounts (THEILEN,1995)

	Sealed surfaces Combined sealing		Covered surfaces Thin Vegetation		Operation surfaces with Leachate recirculation		Operation surfaces without Leachate recirculation		New landfill sections without pouring	
	average	max.	average	max.	average	max.	average	max.	average	max.
EHRIG, 1980	nda	nda	nda	nda	nda	nda	4	20	nda	nda
LAGA, 1984	nda	nda	nda	nda	nda	nda	4,8	> 48	nda	nda
EHRIG, 1989	nda	nda	nda	nda	nda	nda	5	20	nda	nda
DOEDENS / THEILEN, 1990	1	2,5	nda	nda	3 (irrigation)	8	5	20	nda	nda
THEILEN, 1992	2	3,5	nda	nda	6 (trickling)	9	7,5	> 20	nda	nda
RAMKE, 1993	3,4 (from sewage sludge consolidation)	6,6	7,6 (withouth sewage sldge consolidation)	nda	nda	nda	10,8	100	nda	nda
CAPTAIN / RIEGLER,1994	1,2	nda	nda	nda	nda	nda	12,8	nda	19	nda
Dimensioning suggestion [m³/(ha*d)]	**1,5**	**3,5**	**7,5**	**20**	**7,5**	**15**	**10**	**40**	**20**	**> 50**

TASI had forbidden it, the Landfill Ordinance of 2002 permits it again, with the pertaining controls (bottom sealing necessary)

Leachate concentrations of conventional Municipal Waste Landfills

(without waste management measures)

		Acidic Phase		Methanogenic Phase	
		Range	Average	Range	Average
pH-value	---	4,5 –7,5	6,1	7,5-9	8
COD	mg O_2/L	6.000-60.000	22.000	500-4500	3.000
BOD_5	mg O_2/L	4.000-40.000	13.000	20-550	180
Ca	mg/L	10-2.500	1.200	20-600	60
SO_4	mg/L	70-1.750	500	10-420	80
Zn	mg/L	0,1-120	5	0,03-45	0,6
Fe	mg/L	20-2.100	780	3-280	15

		Parameter without significant changes	
		Range	Average
TKN	mg/L	50-5.000	1.350
NH_4-N	mg/L	30-3.000	(750)
Cl	mg/L	100-5.000	2.100
Pb	µg/L	8-1.020	90
Cd	µg/L	0,5-140	6
Cu	µg/L	4-1.400	80
Ni	µg/L	20-2.050	200
Hg	µg/L		
Cr	µg/L	30-1.600	300
AOX	µg/L	320-3.350	2.000

[EHRIG, 1980]

Comparison of various Method Combinations

	SS	BOD_5	COD	Total N_{min}	NH_4-N/ NH_3-N	Heavy metal	AOX	Salt	Fish toxicity
Biological treatment		+	+2)	+	+	-	-	-	7)
Adsorption	-		+3)	-	-		+	-	7)
Sedimentation/ Flotation 8)		-	-	-	-	-	-	-	7)
Flocculation/ Precipitation	-		+3)	-	-	+5)	+	-	7)
Filtration	+	-	-	-	-	-	-	-	7)
Reverse osmosis	+	+1)	+1)	+	+	+	+1)	+	7)
Nano-filtration	+	+	+	-	-	9)	+	9)	7)
Stripping	-	-	-	+	+	-	-6)	-	7)
Chemical oxidation	-		+	-	-	-	+	-	7)
Evaporation	+		+4)	+	-	+	+4)	+	7)
Incineration	+	+	+	+	+	+	+	+	

\+ generally suitable
1) less suitable for small molecule sizes
3) less suitable for bio-degradable substances
5) only with special heavy metal precipitation
7) reaching of a limit value cannot be evaluated safely
9) separation done for bivalent or superior ions

\- generally unsuitable
2) only suitable for degradable organic substances
4) less suitable for substances which are volatile under the process conditions
6) not suitable for hardly volatilisable substances
8) separation of solids in combination with other methods

Effluent Values and Discharged Loads of the Various Method Combinations for Direct Discharge

Effluent concentrations (C_e) and effluent loads (B_a) of various combinations										
Q_d= 150 m³/d		Raw	Combination I		Combination II		Combination III		Combination IV	
Parameter	Unit	leachate	UO/ED/TR/NA		BIO/UO/ED/TR		BIO/CHO/BIO		BIO/AC	
		(influent)	C_e	B_a (t/a)	C_e	B_a (t/a)	C_e	B_a (t/a)	C_e	B_a (t/a)
COD	mg/L	2500	15	0,821	25	1,369	150	8,213	150	8,213
BOD_5	mg/L	250	5	0,274	10	0,548	5	0,274	5	0,274
TKN	mg/L	1300	10	0,548	30	1,643	70	3,833	100	5,475
NH_4-N	mg/L	1100	7	0,383	0,5	0,027	1	0,055	1	0,055
NO_3-N	mg/L	<10	0,1	0,005	60	3,285	60	3,285	60	3,285
inorg. N	mg/L	1110	7	0,383	62	3,395	62	3,395	62	3,395
AOX	µg/L	2500	50	2,738	100	5,475	300	16,425	300	16,425
LF	mS/cm	15	0,40		0,30		12,50	0,684	12,50	0,684
Cl^-	mg/L	2000	50	2,738	150	8,213	2000	109,500	2000	109,500
TR	%	1,00	0,01	5,475	0,09	49,275	0,9	492,750	0,9	492,750

Further Emissions; Vermin

- Pertaining to noise and dust: Federal Emission Control Act, TI Noise and TI Air
- Pertaining to odours: Odour Emission Protection Directive (GIRL)
- Vermin:
  - Insects
  - Rats
  - Birds (seagulls, crows, but also protected species, like the red kite)
  - generally no or very small problems with treated waste

Landfill Operation / Operating Plan

- Landfill sections,
  - maybe separation into types of waste which react differently
- Grids for landfill land register
  - ≤ 1.000 m^2 (for dangerous waste; for mono-landfill also larger) or ≤ 2.500 m^2 (for harmless waste (TASi N0. 10.6.1)) and ≤ 2m height
- Documentation; annual topographic survey of the landfill and explanations on the landfill behaviour
- Filling in a stable way without many hollows
  - Compactors
- Intermediate covers for single landfill layers with bottom often required abroad ???
- Dust, noise, wind drifts

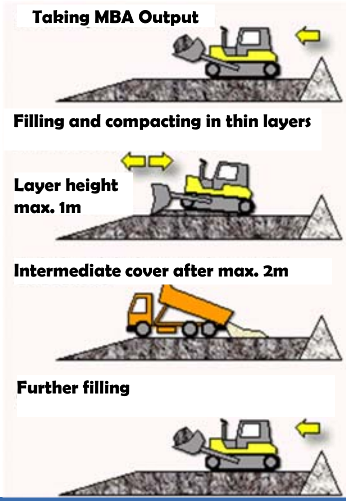
Working Face and Thin Layer Operation

Tipping edge operation

—Unloading———Comminution through overrunning———Tipping edge———

Thin Layer Operation

—Unloading———Comminution through overrunning——— Filling layer———



Compressed Filling with Compactors

Waste compactor

BC 1172 RB

The new dimension of waste compacting

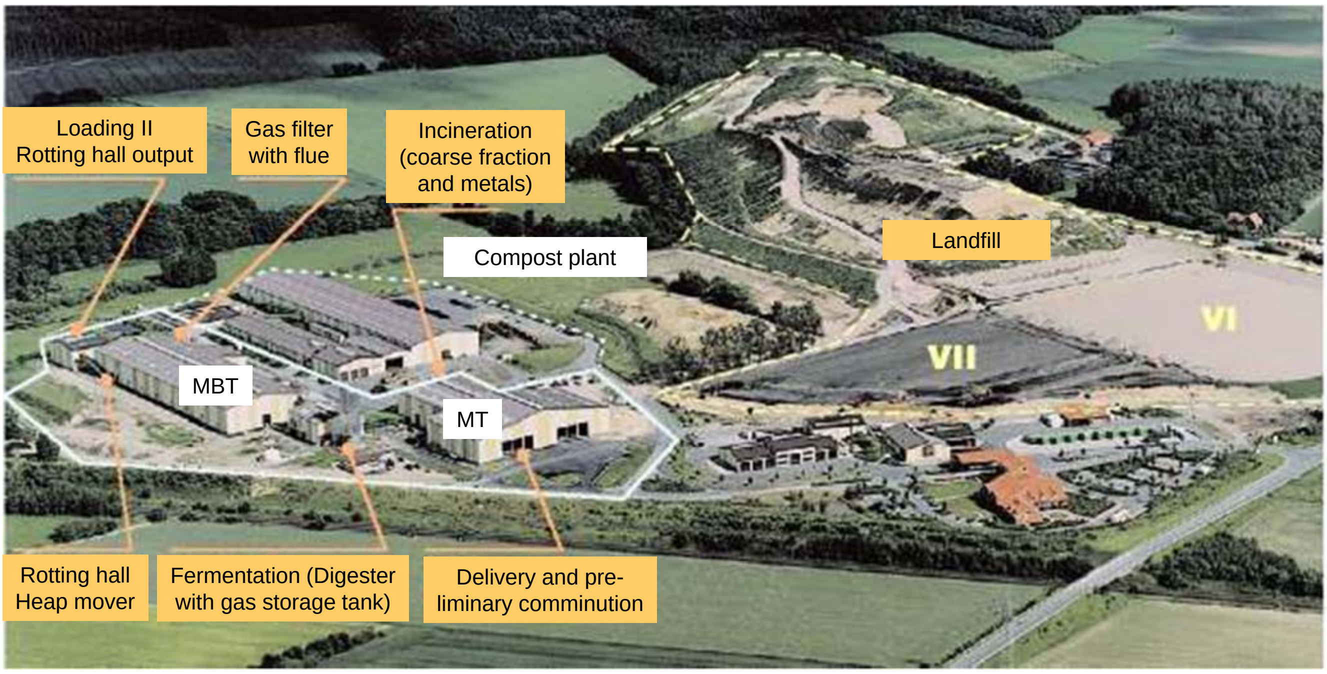
The BC 1172 is the heaviest completely hydrostatically waste compactor. It is particularly suitable for the use on landfills with waste amounts of up to 1500 Mg per day. Excellent efficiency degrees, high performance reserves and superior agility make for the best economic efficiency at highest compacting degrees.

Type	Weight [kg]	Push blade/hovel width [mm]	Power [kW]
BC 572 RB	25.900 to 26.700	3.800	214 (Deutz)
BC 672 RB	32.100 to 32.700	3.800	314 (Deutz)
BC 772 RB	36.500 to 37.100	3.800	330 (Deutz)
BC 772 RS	36.500 to 37.100	3.800	330 (Deutz)
BC 972 RB	45.100 to 46.700	5.200	381 (Deutz)
BC 1172 RB	54.500 to 55.100	5.200	400 (Deutz)

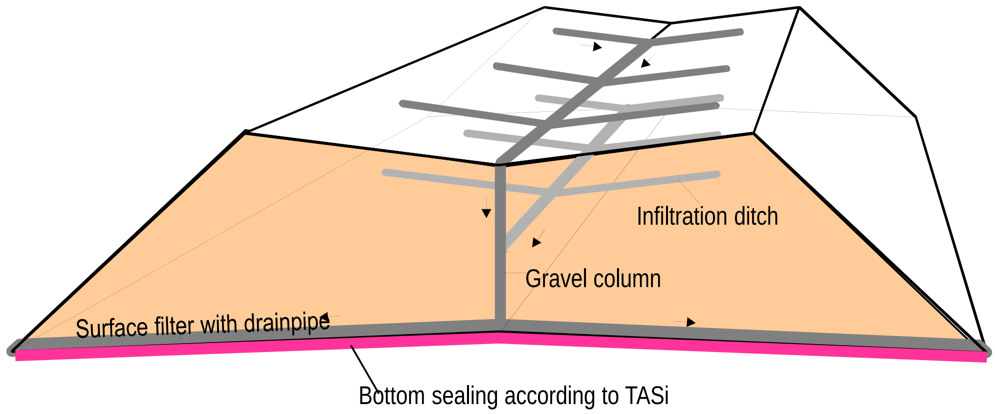
Landfill Operation 2

- Intermediate covers with bottom often required abroad???
- Dust, noise, wind drifts

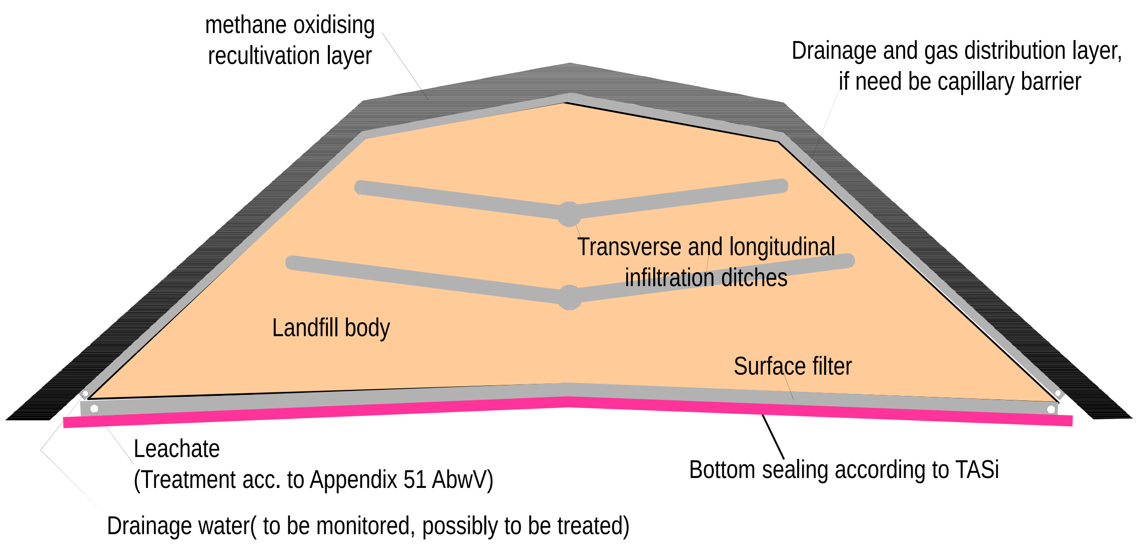
Waste Management Centre at State 2001



MBT Landfill – Internal Drainage



MBT Landfill Structure

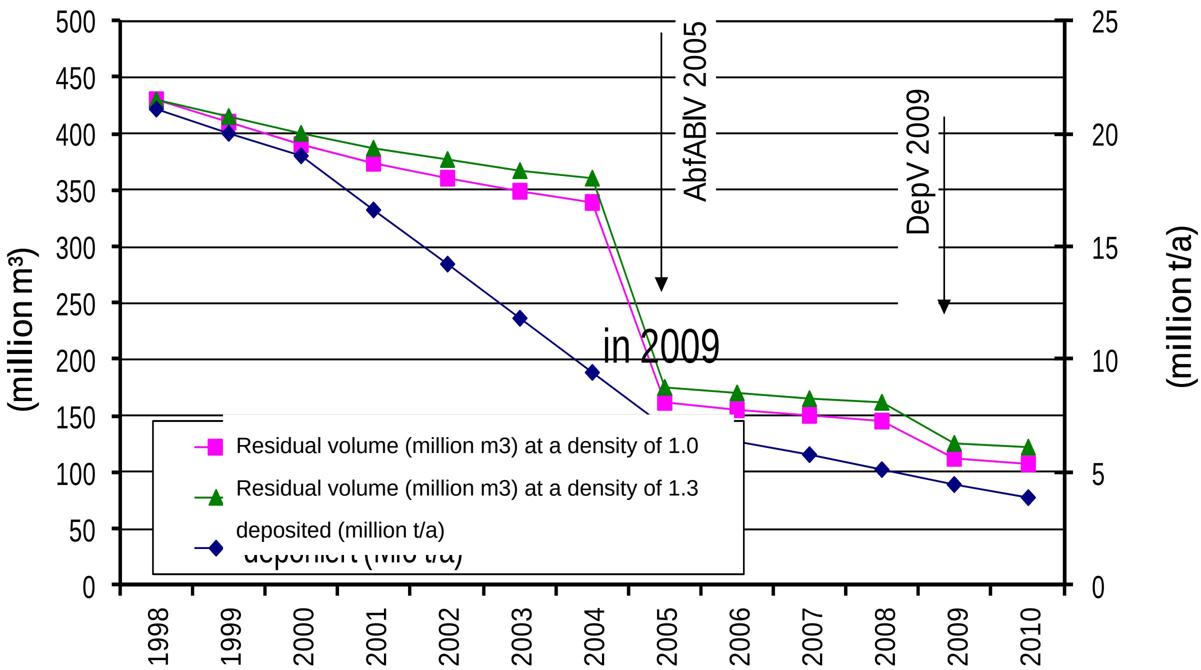


Milestones for the future depositing of municipal waste

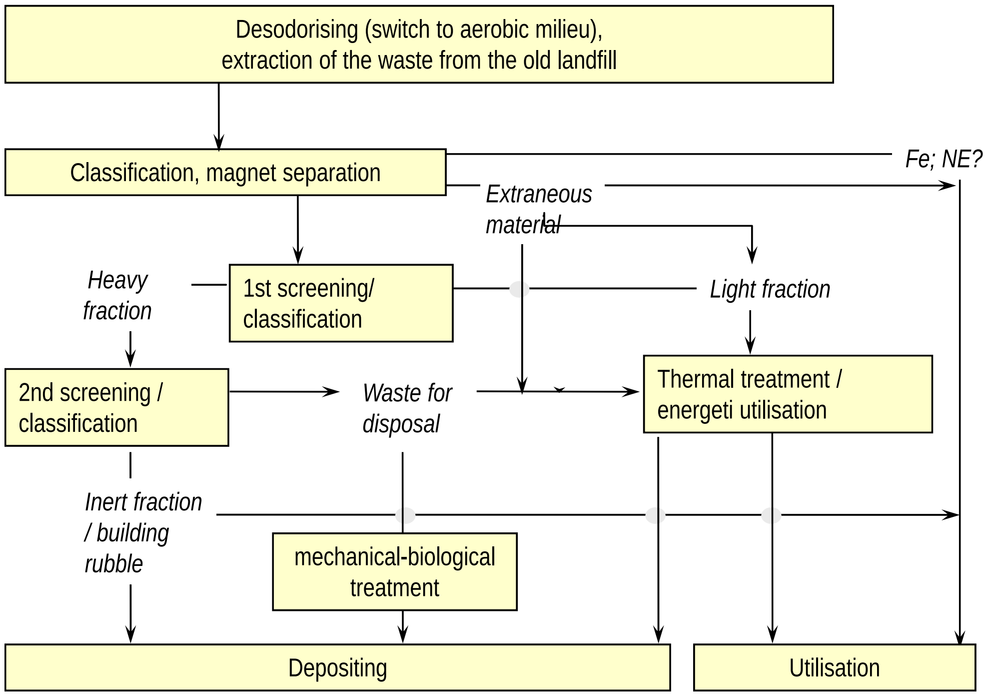
Date	Basis	Consequences
31.05.2005	Waste Depositing Ordinance →TASi	• Closing of landfills which do not comply with No. 10 TASi (without 10.3.1 and .2); • Terminating the depositing of waste which does not comply with Appendices 1 and 2 of the Waste Depositing Ordinance
17.07.2009	Waste Depositing Ordinance / EU Landfill Directive	Closing of all landfills which do not comply with the requirements of the Waste Depositing Ordinance (also location + geology)
2020	Political target of the FEA	No waste for disposal → End of any depositing

Future LC II Depositing Demand and Residual Capacities Source 1998/99: UBA, 2001

Assumptions for closedowns: 50% in 2005, and 20% of the number of the previous year in 2009



Renaturisation of Old Landfills for Raw Municipal Waste



Doedens/ Deponie.ppt