

DISCUSSION OF CRITERIA FOR THE COMPLETION OF LANDFILL AFTERCARE

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SUMMARY: The question when a landfill can be released from aftercare is essential. The question is what kind of criteria should be used. Therefore it is discussed what kind of basic target values may be developed. In addition some proposals are made for leachate and gas emissions. In order to reduce the aftercare period the biological degradation as well as elution processes should be enhanced. This could be achieved by means of in situ aeration and controlled water infiltration.

1. INTRODUCTION

Landfill emissions as leachate and landfill gas (LFG) have to be controlled and treated until their amount and quality has reached a level that is environmentally acceptable. There is a great discussion in Germany when and how this will be the case. This question somehow has to be answered since the landfill owner/operator has to set aside the sufficient funds to be able to cover the whole landfill aftercare. Costs include maintenance of the landfill liner system, leachate treatment, LFG-control and treatment as well as further management and monitoring activities. For many old closed landfills no money is available, since at that time no funds have been established. The main question is, when i.e. under which conditions the aftercare phase of a landfill ends.

Extensive investigations resulted in the conclusion that in order to reach discharge target values for leachate it has to be treated for decades and probably more than 100 years, (Heyer, 2003). Also LFG control may be necessary for several decades after landfill closure, where relatively small amounts of LFG have to be controlled for a long time also in order to protect the atmosphere.

The securing of closed landfills can be achieved – and this is the policy reflected by German legislation – by installing a composite liner (mineral liner plus 2.5mm HDPE membrane on top, on which more than 1 meter of suitable soil has to be placed (Anonymous, 1993)). As a result leachate production will be significantly reduced or stopped and the residual LFG has to be collected and treated. This strategy results in a conservation of the landfilled waste and as a consequence the emission potential remains high. This means once the liner may collapse the emissions from the landfill will occur at this latter time.

The authors favour the strategy to reduce the emission potential of a landfill significantly before the landfill cover is put in place. At that point a liner system constructed of natural materials should be installed where soils with a high water storage potential should be used (f.e. capillary barrier and recultivation layer with > 1.5 m of silty sand on top and controlled revegetation) (Hupe et. al, 2001). A low emission potential of the landfill is also a prerequisite for the end of the aftercare phase.

In order to reduce the emission potential of existing landfills two main activities can be thought of:

- controlled water infiltration f.e. by using treated leachate
- in-situ aeration

For existing and new landfills, mechanical biological pre-treatment is the adequate measure to achieve this goal. Cossu (2001) proposes the PAF-Model representing a semiaerobic/aerobic landfill with enhanced water infiltration.

Figure 1. shows the concept of landfill aftercare as well as municipal solid waste (MSW) pre-treatment as a prerequisite measure in order to operate a sustainable landfill and to reduce the aftercare phase of a landfill significantly.

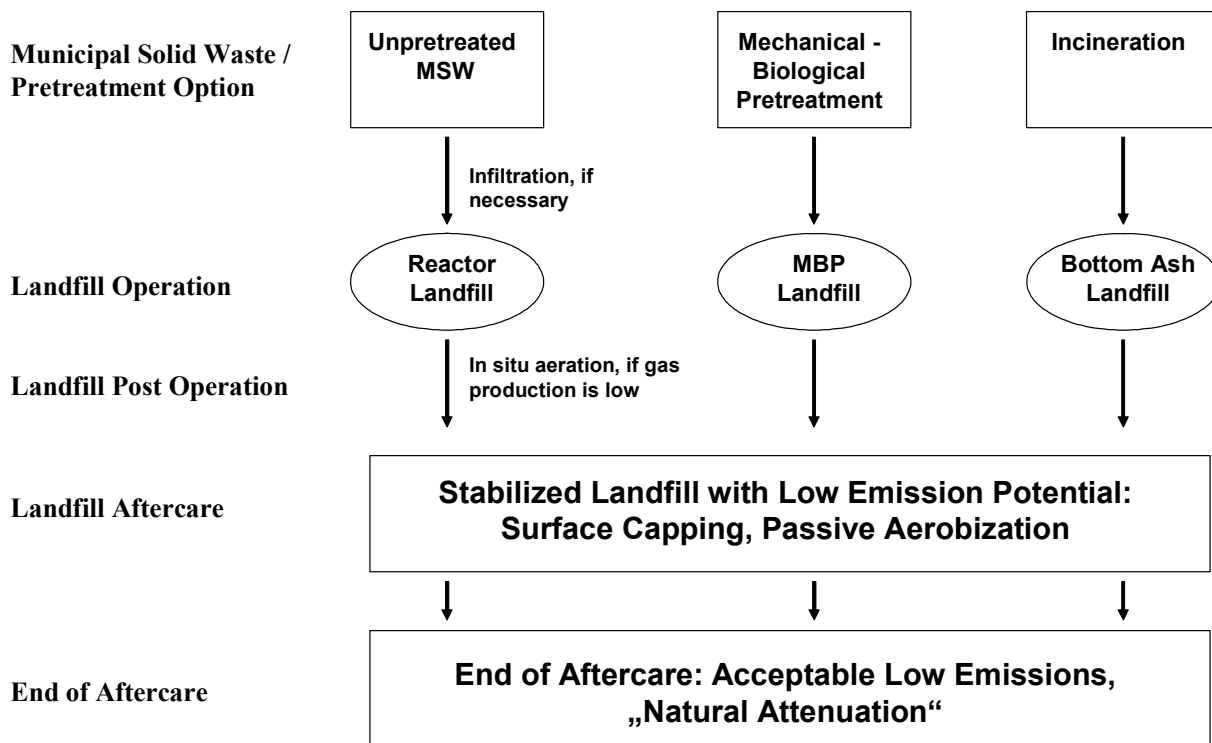


Figure 1. Pretreatment and operation measures for a sustainable landfill

2. MEASURES FOR THE ENHANCED REDUCTION OF THE EMISSIONS OF LANDFILLS

2.1 Water Infiltration

Experience have shown that once landfills have been covered with low permeable soil or liners, gas production may decrease significantly. Also landfills under low rainfall conditions may have a lack of moisture and/or moisture movement. If there is still sufficient biodegradable waste in

the landfill and if in addition the landfill has a bottom liner with a leachate collection system, then artificial water addition (f.e. by means of recirculation of treated leachate) into the landfill body may be beneficial for the enhancement of the biological processes.

Research on long-term stabilization of landfills resulted in the conclusion that the solid liquid ratio i.e. the amount of water that has migrated through the total waste mass of a landfill has a significant influence on the emission potential of landfills. (A solid-liquid ratio of 1 means that the same amount of water has migrated through the same amount of deposited waste). This concept is the base for the so called “flushing bioreactor” where as much water should pass through the waste as technically possible. Research on the emission potential of relatively small closed landfills showed that the solid-liquid ratio of the landfill is an indicator of the existing emission potential (Allgaier and Stegmann, 2002).

The amount of water that can migrate through a landfill is restricted by the permeability of the deposited waste which decreases from the top of the bottom. This effect has to be respected in order to avoid leachate ponding and/or uncontrolled leachate migration out of the slopes of landfills constructed as a mound (Beaven et al., 1997).

As a conclusion leachate infiltration has two effects:

- enhancement of biological processes due to an increase in water content and water flux
- enhanced elution of substances out of the landfill body

Dependent upon the amount of water that is infiltrated the enhanced elution becomes more or less significant.

2.2 In situ Aeration

The aerobic in-situ stabilization accelerates biological degradation processes in the landfill body so that after a treatment time of approx. 2-4 years the emissions are - compared to anaerobic conditions – significantly reduced. This is due to the reduction of organic components that are easier degradable under aerobic than anaerobic conditions. This is also relevant for many hazardous waste components which enter the landfill with the MSW and/or commercial waste (Ritzkowski et. al., 2001).

The basic principle of aeration and waste gas collection is shown in Fig. 2. Ambient air is pressed under low positive pressure into the landfill body via aeration wells by means of a blower. Air resp. atmospheric oxygen is distributed by convection and diffusion processes in the landfill body. Depending on the rate and the duration of aeration, an aerobisation of the almost entire landfill body and an accelerated degradation of the organic waste components is achieved. The equivalence of the infiltrated air is extracted as waste gas out of the landfill via gas wells and treated thermally or biologically and/or physically before it is released into the environment (Heyer et. al., 2001).

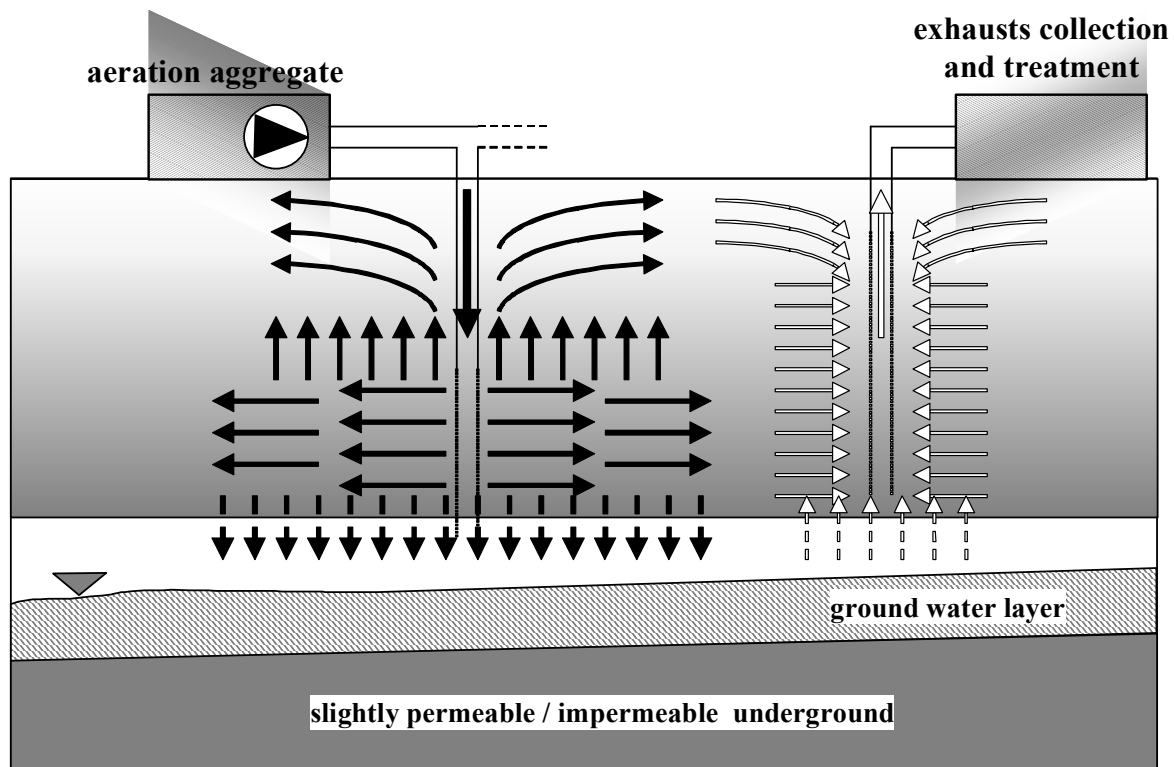


Figure 2. Principle of the in situ aeration of a landfill

3. LEGAL ASPECTS FOR LANDFILL CLOSURE AND AFTERCARE IN GERMANY

The EU-Landfill Directive has been transformed into German Legislation in the Landfill Directive (Deponieverordnung, DepV, 2002). In this directive existing German regulations have been included.

The different landfill phases can be described as follows:

- Operation phase and closure where the landfill closure is part of the operation phase. Beyond others the construction of a top cover liner is the main task in this phase. Since this liner should be installed when the main biological degradation process have come to an end, the closure phase may last over a period of several years.
- The aftercare phase starts when the authorities have formally agreed on the end of the landfill closure resp. operation phase. During the aftercare phase it has to be assured by the former landfill owner/operator that there will be no adverse effects on the environment resulting from the closed landfill.
- The end of the aftercare phase means that almost no activities are required and that there will be no necessity for future remediation.

Regarding the emission behaviour resp. the emission potential of the landfill body at the end of the aftercare phase no detailed information are given by the authorities. In § 13, Abs. 5 of the German Landfill Directive (DepV, 2002) criteria are presented that are the basis for the release out of the aftercare period:

1. Biological degradation processes as well as additional conversion and reaction processes in the landfill body are insignificant.
2. Gas production has decreased to an extent, that no-active gas extraction is necessary and adverse effects due to gas migration into the vicinity can be excluded.

3. Settling of the landfill body has decreased to an extent, that settling related damages of the surface lining systems can be excluded.
4. The surface lining system and the recultivation layer are functional and in a stable condition so that present and future landfill utilisation is not influenced. It has to be ascertained that this is also true when the kind of landfill utilisation changes.
5. Surface water from precipitation is transported via the surface in a controlled way.
6. The landfill is sustainable mechanical stable.
7. The maintenance of constructive and technical installation is no more necessary, a landfill mining has eventually been realised.
8. Any eventually produced leachate is in correspondence with the water regulation for the discharge in natural waters.
9. No groundwater pollution is affected by the landfill which would make an observation or remediation necessary.

Respecting the proportionate principle a landfill should be released from aftercare, when the results from control and supervision measures indicate that no adverse effects can be expected for the benefit of mankind, i.e. that the landfill shows no adverse environmental effect (Steiner, 2002).

The question what kind of general and site specific criteria determine the exact time when a landfill can be released from aftercare is not answered. In the German Technical Regulations Municipal Solid Waste (TASi, 1993) it is only described in a general way: “The control and action measures described in No. 10.6.6. as well as appendix G of the TASI have to be practiced as long as the responsible administration releases the landfill out of the aftercare”.

4. DISCUSSION OF POSSIBLE CRITERIA AND TARGET VALUES FOR THE COMPLETION OF THE AFTERCARE PHASE OF A LANDFILL

In this context the difference between a landfill build as a mound or in a pit becomes relevant. One of the main reasons for operating landfills as a mound is that the leachate can migrate on the basis out of the landfill by gravity while leachate from a landfill pit has to be pumped (unless there is no leachate). The question is whether drain systems have to be observed and cleaned also when the aftercare phase has ended.

4.1 General Approach

The main questions regarding the release of landfills out of the aftercare phase are:

- By means of which criteria resp. parameters the environmental acceptable emissions resp. emission potential may be described?
- In how far is it possible to deduct from those parameters general applicable and /or site specific target values?

For the development of criteria the following “systems” for analysis resp. test methods are available:

- Landfill body:
 - Monitoring of the water budget including leachate production and quality
 - Monitoring of the landfill gas (LFG) production and quality
 - Monitoring of the development of the settling, temperature regime, etc.
- Waste Samples from the investigated landfill
 - Landfill inventory and solid waste sample quality as there are f.e.: water content., carbon- and nitrogen content, volatile solids

- Elution test analysing the eluate for pH, conductivity, nitrogen parameters, COD, TOC, BOD, heavy metal toxicity, SO₄, Cl, buffer capacity etc.
- Biotests for the determination of the biological activity resp. its potential using respiration tests (AT₄) and gas production potential (GB₂₁) (AbfAbIV, 2001)
- Some of these samples can be further investigated in landfill lysimeter tests
- Landfill simulation reactor (LSR) (Ehrig et al., 1997)
 - Monitoring of the water budget including leachate concentration
 - Monitoring of gasproduction and –quality
 - Monitoring waste samples from the investigated landfill before and after the test
 - Operating the LSR with significant higher water application in order to gain long term development results in a short time (enhancement factor ~100)

The investigation of some or all of the above described media will produce results that describe the status of the landfill in a sufficient resp. comprehensive way. The question is how the results should be evaluated and validated in regard to future emissions and this acceptability for a specific landfill situation. In this context the question has to be answered, what kind and amount of environmental loading by means of leachate and gas emissions are acceptable in a specific environment without causing any adverse effects.

This discussion can be made on the basis of different philosophies:

- The emissions should meet set target values independent upon the specific situation (f.e. discharge values for treated sewage, air emission standards)
- The acceptable emissions are dependent upon the specific situation respecting beyond others the geological, hydrogeological soil and surface water situation. In this context also the kind of future utilisation of the landfill may be respected.
- A combination of both models where minimum set target values have to be met and in addition there is a further precision of the site specific target values respecting the specific landfill and its environment as well as the kind of future utilisation.

The authors so far favour the last approach where an acceptable emission behaviour of each landfill is guaranteed by the minimum standards and their adaptation to the specific landfill and its environmental is respected.

4.2 Potential requirements for the landfill gas production resp. emissions

As already stated LFG is produced – although at a low amount - also decades after closure of the landfill. This means that also LFG is a long term problem. Potential effects of LFG-emissions are known as there are global warming, explosions, displacement of air, oxygen reduction in the recultivation layer due to CH₄-oxidation and/or air displacement, controlled migration into adjacent soils etc. The question is how much gas production resp. emission is acceptable. One approach may be to use the CH₄ oxidation potential of the top cover as a measure for maximum gas production in the landfill. Different investigations show that methane oxidation rates dependent on soil quality, temperature, moisture content etc. are in the range of 0,34 – 5,6 CH₄/m²h (Figueroa, 1998).

If f.e. a gas production in the landfill is equivalent to a surface load of 1 lCH₄/m²h, methane oxidation in the surface cap should be in most times of the year possible. Using this value would mean that landfills with a larger surface to the atmosphere (as mounds) may absolutely produce more LFG than landfills in pits. Since the emission of 1 lCH₄/m²h amounts to 20 m³LFG/ha*h, a high landfill may produce per m³ of waste volume less LFG than a shallow one.

On the other hand large landfills may produce absolutely more gas than small ones (f.e. 1 ha landfill produces 20m³LFG/h compared to a 10 ha landfill with 200m³/h). The latter production is at a level when LFG utilisation is still valid.

The actual gas production/extraction rates may either be determined by means of extraction tests (if a LFG extraction system exists) or by using a standardised LFG prediction model. Of course regarding these reflections it should be kept in mind that the LFG production and LFG extraction rates do not correspond.

Based on this discussion the authors propose that the size of the landfill has to be respected as well. As a consequence two target values have to be respected as there are absolute gas production of the landfill and the maximum target values for the specific gas migration through the top cover (in lCH_4/m^2h).

Which values should be chosen? In order to start the discussion the following proposal is made:

Total LFG-production resp. extraction rate

- The total amount of LFG that is extracted from the landfill independent of its size should not exceed 50-70 m^3/h . This amount is the minimum volume that can be treated in a high quality standard flare.
- The LFG surface emission should not exceed 0,5 – 1,0 $l CH_4/m^2h$.

These values would mean that up to a landfill size of around 1 – 2 ha surface area the target value 0,5 – 1,0 $l CH_4/m^2h$. is valid. At larger landfills the LFG emissions could be limited due the production resp. extraction rate which should not exceed around 50 – 70 m^3/h . All these reflections are based on a LFG composition of 50% CH_4 and 50% CO_2 , that means nearly undiluted LFG.

4.3 Potential requirements for leachate emissions

The landfill can only be released from aftercare when either the collected leachate at lined landfills as well as the leachate from unlined landfills that migrate through the unsaturated soil into the groundwater meet the target values of a lined landfill. This refers to the leachate concentrations and the loads resp. quantity. In addition the kind of the bottom liner system installed as well as its functionality has to be respected. It can be expected that those systems may only be effective over a certain period of time.

For the collected leachate that migrates (or is pumped) into the surface waster the discharge values of the German 51th Appendix have to be respected (see table 1). It should be discussed whether a natural treatment/polishing of the leachate also after the aftercare period may be allowed (f.e. constructed wetland, lagoons, sandfilter) in order to reduce the aftercare period. Otherwise this period may exceed 100 years until the leachate meets the above mentioned target values.

The leachate that migrates into the ground water should not cause a significant change of the groundwater quality. It could be discussed whether a large groundwater volume may accept higher leachate loading rates than smaller ones. In addition it can be discussed whether the improvement of the leachate quality in the unsaturated zone by means of sorption as well as biological degradation and chemical oxidation/reduction processes should be respected. These possible processes are summarized under the term “natural attention”. The results from investigations on natural attenuation should be evaluated and may be a basis for the detailed determination of target values.

Ehrig et al. 2002 propose for the leachate quality, leaving the unlined landfill at the bottom COD and anorganic N max. concentrations of ≤ 100 mg COD/l respectively 50 mg anorganic N/l. The loading rates are proposed not to exceed 100 kg COD/ha*a and 50 kg anorganic N/ha*a which results in average concentrations (based on a climatic leachate production of 250 mm/a) of 40 mg COD/l respectively 20 mg anorganic N/l. Another prerequisite is a distance between the landfill bottom and the upper ground water level of ≥ 3 m.

Table 1. Limiting concentrations for the discharge of treated leachate according to German standards (51. Anhang AbwasserV, 1996)

| Parameter | Limiting concentration [mg/l] |
|---|-------------------------------|
| COD | 200 |
| BOD ₅ | 20 |
| Nitrogen (NH ₄ + NO ₂ + NO ₃) | 70 |
| Phosphorus, total | 3 |
| Hydrocarbons | 10 |
| Nitrite-Nitrogen | 2 |
| AOX | 0.5 |
| Hg | 0.05 |
| Cd | 0.1 |
| Cr VI | 0.1 |
| Ni | 1 |
| Pb | 0.5 |
| Cu | 0.5 |
| Zn | 2 |
| Cyanide, easy liberatable | 0.2 |
| Sulfide | 1 |

For these or other potential target values the authors propose to calculate the leachate volumes that enter the subsoil of the landfill by means of a standardised water budget model (f.e. HELP model, Schroeder, 1994) where beyond others the annual precipitation rate as well as the kind of top cover/liner system is respected. The expected leachate concentrations have to be estimated on the basis of standardised analysis of the waste samples taken from the landfill body.

4.4 Utilisation of analytical results from landfill samples for the determination of the landfill emission potential

In order to receive a clear picture of the emission potential of a landfill samples from the landfill body should be taken and analysed. This is necessary since also an old landfill that has been closed before many years or even decades, the emission potential may be still very high. This may be a result of an immediate lining of parts or the entire landfill surface after the landfill operation had come to an end. In this case a high emission potential can be expected. If the landfill had been completely open for decades, the amount of precipitation that has entered the landfill is resulting in a high reduction of the emission potential by means of elution and optimized biological degradation. In addition measures as controlled water infiltration and/or in-situ aeration may have been practiced resulting also in a high reduction of the emission potential.

In order to describe the emission potential of a landfill and to estimate roughly gas production rates and leachate concentrations, the following investigations may be target oriented:

- Taking f.e. mixed waste samples over the entire landfill (f.e. grit of 50 – 100 m f.e.1-4 samples/ha) from 2-3 different depth (the amount of samples taken has somehow to be related to the landfill size) sampling may be practiced due to standard operation procedures (Ehrig et al., 1997). Although representative sampling of waste in a landfill is due to the heterogeneity not possible, experiences show that using the above described procedure meaningful results are gained (Heyer et al, 1997). These samples may f.e. be analysed by using the following procedures:
- Elution tests should be run, where a standardised test (f.e. DEV S4) is used and where - as a general guide – values prescribed in the AbfAbIV (2001) for mechanically biologically pretreated MSW may be used.

- The amount of biologically degradable substances can be indirectly measured by means of a respiration test. Respiration values similar to those in the natural soils may be a guide for setting a target value for the release from aftercare which are in the range of 2-4 mg O₂/gTS*96h.
- Landfill lysimeters are an additional test system by which the actual and future emissions resp. the emission potential of landfill samples can be described. These tests are somewhat time consuming and costly but they deliver very relevant practice oriented values that are a sound basis for a decision regarding the release from aftercare.

5. CONCLUSIONS

The release of landfills from aftercare is a very relevant subject for all landfill owners resp. operators. The aftercare phase may end, when the emission potential is that low, that the actual emissions do not harm the environment. This means, that leachate treatment should not be practiced anymore and that the landfill gas is naturally oxidised in the top cover of the landfill. The emission potential of landfills can be described by means of waste samples taken from the specific landfill areas which may be analysed regarding their biological activity (respiration test), elution potential (elution test) as well as their actual and future landfilling behaviour (landfill lysimeter test). The scale of target values for the different tests as well as emissions is discussed in this paper. In addition a potential procedure for the enhancement of the biological stabilisation and physical elution of waste components is presented as there are in-situ aeration as well as enhanced water infiltration f.e. by using leachate, where the leachate is treated prior to infiltration. Also the role of a landfill cap resp. liner system is discussed.

Release of a landfill out of the aftercare period should mean that the landfill can be left without any operation and/or supervision due to an environmental acceptable emission potential and actual emissions. In this context it should be discussed if this is realistic, since there may be some minor activities also after the aftercare phase as there are f.e. leachate pumping from pit landfills, cleaning of drainage pipes, care of the vegetation, natural post treatment of leachate on the landfill site, control of sewage pipes, manholes as well as groundwater monitoring.

It is time that an intensive discussion starts on this subject where the scientific community and the decision makers work closely together.

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