Mission report

TAIEX Assistance Iceland concerning the implementation of the EU Landfill Directive and landfill gas control

Project:	TAIEX reference 45985
Subject:	Expert mission on assessment of landfill gas
Counterpart:	Samband íslenskra sveitarfélaga
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Executive summary

After the implementation of the EU Landfill Directive (LFD) into Icelandic legislation with Act 55/2003 and regulation 738/2003 the work on conditioning plans for existing sites began in the Environment Agency of Iceland. Unfortunately this work was not followed up. Municipalities were left without guidance. In 2008 it was realised that quite a number of existing landfills would not be able to comply with the technical requirements in the LFD by 16 July, 2009. This included landfill gas control. The Icelandic Minister for the Environment granted in 2009 a derogation of two years for landfill gas control. The derogation time was used for qualitative landfill gas evaluation. This evaluation was meant to be the base for further decisions. With no real experts for landfill gas available in Iceland it was necessary to call upon the TAIEX programme in order to get assistance from experts within the EU to help Iceland with this problem. Iceland has three main focuses for the TAIEX assistance project:

1) Technical possibilities to capture landfill gas in small landfills outside the capital area.
2) Possibilities within the landfill directive to continue landfill operation where landfill gas control is not possible or too costly.
3) Reduction of methane emission and the examination of potential cover layers for methane emission reduction.

With the help of the TAIEX office a team of two experts was formed. Information was exchanged between late October and November 2011 in order to prepare for site visits and a workshop. Site visits, workshop and meetings with landfill operators, the Icelandic Ministry for the Environment, the Environment Agency of Iceland and the Icelandic Association of Local Authorities took place from 29 November to 2 December 2011.

Both representatives from the Icelandic municipalities and the Icelandic Ministry for the Environment acknowledge that reduction of biodegradable waste disposed at landfills is an important option to reduce landfill methane emission from new landfills (or landfill cells). Since political initiatives and economic instruments are not yet fully developed it is recommended to develop them further, in order to reduce future methane emissions from all Icelandic landfills.

Examples of criteria that are most often used to specify the end of active gas control are available from guidance in various EU member states. It is recommended that the Ministry for the Environment or the Environment Agency as the competent authority provides a guidance document on landfill methane emission reduction for Icelandic landfill operators.

At EU-level the TAC (Technical Adaptation Committee) has set down a working group in order to prepare a European guidance document on landfill methane emission reduction. This guidance document is expected to be adopted before summer 2012 and it might be helpful to Iceland. In an Icelandic guidance document it is recommended to consider technical limitations pertaining the size of landfills, the amount of waste input and the amount of gas generated.

Methane oxidising covers might provide a feasible alternative for methane emission reduction on small Icelandic landfills compared to utilization or flaring of the collected landfill gas. The feasibility will depend on targets that need to be specified for oxidation efficiency on a national level. Since there is limited information on microbial methane oxidation in a boreal climate, a demonstration project is recommended. Another potential alternative that could deserve further investigation is aerobic operation of landfills. This method can be applied at a much smaller scale than conventional gas control.

Contents

1. Introduction

After the implementation of the EU Landfill Directive (LFD) into Icelandic legislation with Act 55/2003 and regulation 738/2003 the work on conditioning plans for existing sites began in the Environment Agency of Iceland. Unfortunately this work was not followed up. Municipalities were left without guidance. In 2008 it was realised that quite a number of existing landfills would not be able to comply with the technical requirements of the LFD by 16 July 2009. This included landfill gas control. The Icelandic Minister for the Environment granted in 2009 a derogation of two years for landfill gas control. The derogation time was used for qualitative landfill gas evaluation. This evaluation was meant to be the base for further decisions. With no real experts for landfill gas available in Iceland it was necessary to call upon the TAIEX programme in order to get assistance from experts within the EU to help Iceland with this problem. Iceland has three main focuses for the TAIEX assistance project:

1) Technical possibilities to capture landfill gas in small landfills outside the capital area.
2) Possibilities within the landfill directive to continue landfill operation where landfill gas control is not possible or too costly.
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2. Current landfill situation in Iceland

Iceland has approximately 320.000 inhabitants (2011) and has only two administrative levels, the state and local authorities. In Iceland there are today 76 municipalities, ranging from around 50 inhabitants in the smallest ones to the capital Reykjavik with 117.000 inhabitants,. The geographical areas Höfuðborgarsvæðið ("Capital area") and Suðurnes in the southwest are home to 2/3 of the population on less than 2% of the total land surface. The population density in the municipalities varies between 0.2 and 2100 inhabitants per km^2. The geographical areas Austurland, Norðurland eystra, Norðurland vestra, Suðurland, Vestfirðir and Vesturland are home to 1/3 of the population on 98% of the land surface. The average population density is just above 3 inhabitants per km^2. These are very different conditions that require different approaches.

At present 21 MSW landfills have operation permits, however not all of them are in operation. Álfsnes landfill is the only landfill in the country that has gas recovery (since 1997) and services in 2011 the areas Höfuðborgarsvæðið and Suðurland. The other areas are serviced by the remainder of 20 landfills without gas recovery.

From 2001 to 2006 between 100.000 and 130.000 tonnes were landfilled at Álfsnes landfill, which has been by far the largest Icelandic the landfill, at first serving eight municipalities of the capital area with approximately 200.000 inhabitants but now accepting waste from approximately 220.000 inhabitants.

Other landfills in Iceland are much smaller, the largest ones being Kirkjuferjuhjáleiga in South Iceland, Fíflholt in Western Iceland and Glerárdalur near Akureyri in Northern Iceland. In 2009 the amount of waste landfilled at Kirkjuferjuhjáleiga landfill had declined to 21.500 tonnes per year from a maximum of 34.000 tons in 2000. This landfill was actually closed in 2009, most of the waste once delivered there is now being landfilled in Álfsnes. In 2010 the amount of waste landfilled at Fiflholt landfill had declined to 8.300 tonnes per year from a maximum of about 13.000 tons in 2006. The landfill at Glerárdalur was closed in 2010. The waste of most of the northern part of Iceland is now landfilled at the newly opened (January 2011) landfill at Stekkjarvík. The total amount of MSW landfilled in Iceland in the year 2009 was 190.000 tonnes, of which the landfills mentioned above accepted approximately 170,000 tonnes MSW.

3. Requirements in the EU Landfill Directive

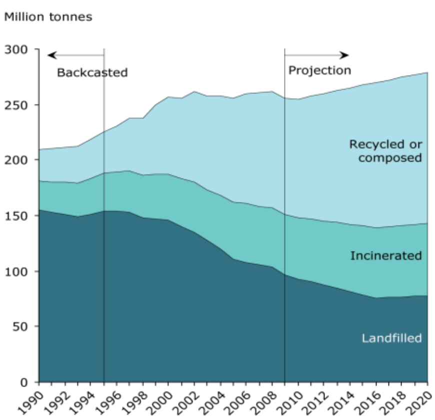
Two aspects can result in an important reduction of landfill gas emission:
a) Reduction of biodegradable organic waste accepted on landfills and;
b) Implementation of technical measures to control the emission of landfill gas.

3.1 Reduction of biodegradable organic waste on landfills

The EU Landfill Directive (LFD) or more precisely the 'Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste' specifies diversion targets for biodegradable municipal waste in Article 5. With 1995 as reference (100% by weight), biodegradable municipal waste disposed at landfills must be reduced to:

- 75% in 2006 (2010);
- 50% in 2009 (2013);
- 35% in 2016 (2020).

Countries that disposed more than 80% of their waste on landfills in 1995 may have max 4 years extension, cf. the years in "brackets". This extension is applied to the following EU Member States: BG, CZ, EST, LV, LT, PL, RO, SK, GR, IR and UK. The targets are to be re-examined by 2014. A projection for MSW generation in the EU-27 is presented in Figure 1. Iceland has adopted the targets from the EU-LFD with regulation 737/2003 and the dates of 2009, 2013 and 2020 are applied.



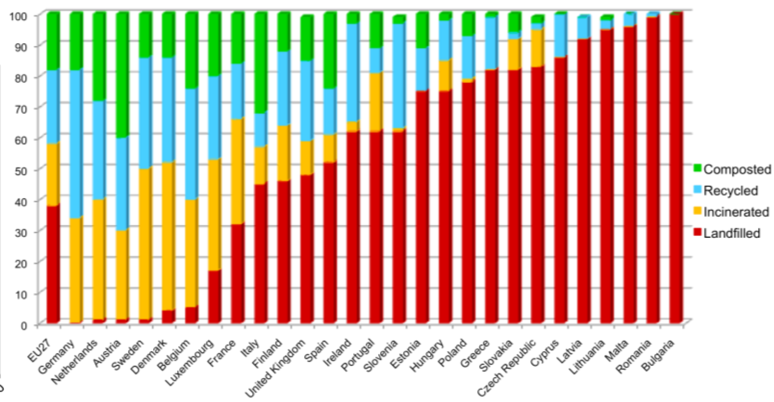


Figure 1. MSW in the EU-27 (EEA, 2010)

Figure 2. Biodegradable MSW treatment in 2009 (Eurostat, 2011)

Article 6 of the LFD states that only waste that has been subject to treatment can be landfilled. This article has caused a lot of problems in the EU Member States. Article 2

(h) defines "treatment" as “the physical, thermal, chemical or biological processes, including sorting, that change the characteristics of the waste in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery”. This is a wide definition that is interpreted differently by different member states. Some member states (e.g. SE, DK, DE, NL, AT, ..) have addressed this by implementing national bans on landfilling of biodegradable waste. Other member states have put the emphasis on Article 5 and continue to landfill untreated biodegradable municipal waste. As Figure 2 indicates many EU member states are struggling to meet the biodegradable waste reduction targets set out in the LFD. A more fundamental problem is that a treatment produces a material with changed characteristics. This means it is a new waste that has to be classified with a new EWC (European Waste Catalogue) code. According to Article 6 in the LFD this new waste cannot be landfilled without treatment. So strictly speaking this could be explained as ‘treatment of treatment residues never stops and landfill should be zero’. This is just one example that shows that the LFD contains principles that require further elaboration in national regulations and guidelines for regulators to include principles in permits in a way that operators can take concrete actions and measures. Because of financial limitations and since for some wastes (e.g. asbestos, inorganic sludges, …) landfill is the best option, this cannot be the intention. Moreover the Waste Framework Directive offers the opportunity to deviate from the waste hierarchy if by means of life cycle assessment it can be shown that landfill in a specific situation is the better waste management option. Many EU member states are failing to fully and correctly implement the requirements of the EU-LFD. An inquiry prompted the European Commission in March 2011 to conclude that there are at least 619 illegal landfills in the 27 member states of the European Union (Figure 3). 15 member states reported to have no illegal landfills. 10 member states reported between 2 and 157 illegal landfills. Two member states did not respond to the inquiry. The number of illegal landfills is therefore likely to be much higher than 619.

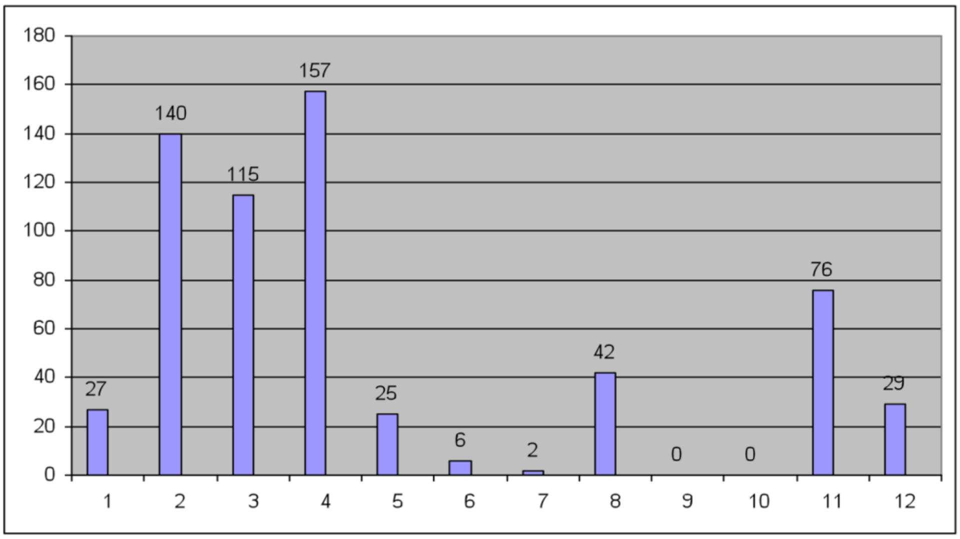


Figure 3. Illegal landfills in the EU-27 (DG Environment, Waste Unit, 2011)

3.2 *Articles in the EU-LFD to control the emission of landfill gas*

The articles in the LFD on gas control are limited and vague. Annex I of the LFD contains three sentences on gas control.

4.1 Appropriate measures shall be taken in order to control the accumulation and migration of landfill gas (Reference to Annex III of the LFD).

4.2 Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas collected cannot be used to produce energy, it must be flared.

4.3 The collection, treatment and use of landfill gas under paragraph 4.2 shall be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.

Position 4.1 refers to Annex III. Annex III exclusively deals with monitoring. Therefore the word 'control' in Position 4.1 should be explained as 'monitor' and cannot refer to concrete reduction measures. Position 4.3 essentially requires, what ever you do, you need to do it in a sound way. Position 4.2 requires gas control only on landfills receiving biodegradable waste. But it does not specify how you should collect landfill gas. Strictly speaking it is possible to comply with Position 4.2 by installing 1 gas well on 100 ha landfill. A best available technique reference document (BREF) on landfill does not exist. Despite requests a BREF Landfill has never been made. The European Commission considered the LFD to be the BREF and for that reason a more detailed guideline would not be necessary. Some EU member states interpret the IPPC (Integrated Pollution Prevention and Control) guideline (Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control (Codified version)) stricter than others. Consequently several member states have very detailed guidelines on landfill gas control, where other member states have no guidelines on landfill gas control. A strict explanation of position 4.2 would require gas collection on every landfill that has accepted a limited amount of biodegradable waste irrespective of the size of the landfill and the amount of biodegradable carbon. Also a strict interpretation of position 4.2 does not consider that the gas generation will decline after many years. At some point it is more or less technically impossible to continue active gas control at some time in the future and due to this fact it should be replaced by passive gas control. However passive gas control is not considered in position 4.2. After many years a situation may be reached that gas generation is at a similar level as natural analogies. Position 4.2 does not give any guidance when it is acceptable to stop active gas control. It is clear that both the competent authorities as well as the landfill operators need more guidance on which measures should be considered in which situation and when it is acceptable to end active gas control.

3.3 *Some examples of guidance on small landfills and ending gas control*

Austria:

Methane oxidising covers can be applied if the amount of methane entering the cover soil is less than 3 kg methane per m^2 and year. During operation of the landfill the average methane emission may not exceed 5 kg methane per m^2 and year, and the emission from hot-spots may not exceed 10 kg methane per m^2 and year.
Source: Huber-Humer, M., (2008) Technischer Leitfaden: Methanoxidationsschichten, ÖVA, Wien, Austria. These values are included in the Austrian landfill legislation.

Denmark:
According to the Danish Statutory Order on landfilling (no. 719 of 24. June 2011) landfill gas has to be monitored at landfills for non-hazardous mixed waste and for landfills for hazardous waste receiving biodegradable waste. The landfill gas from those sites shall be collected and either utilized or flared. But if the amount of landfill gas is low (e.g. from a small landfill), the competent authority can decide that the landfill gas can be treated e.g. in a compost filter or by use of a "bio-cover".

Germany:
Passive gas recovery and treatment is acceptable when:
- Methane generation of the entire landfill <25 m^3/h.
- Methane load to cover <5 $m^3/ha.h$ (<8.6 $g/m^2.d$).
- Surface concentration <25 ppm carbohydrates (method: FID survey).

A landfill can be discharged from aftercare if the amount of methane entering the cover soil is demonstrated to be less than 5 m^3 methane per hectare and hour for several years. In this situation methane oxidation (in the top cover on the landfill) will provide sufficient gas control.
Source: Stegmann, R., K-.U. Heyer, K. Hupe, A. Willand (2006) Deponienachsorge – Handlungsoptionen, Dauer, Kosten und quantitative Kriterien für die Entlassung aus der Nachsorge, UFOPLAN-Nr. 203 34 327, IFAS, Hamburg, Germany. This is a document that was commissioned by the German EPA. The document is mentioned in the German legislation and can therefore not be ignored by the competent authorities and the landfill operators. The document is also referred to in Bräcker, W. (2010): Deponieentgasung bei rückläufigen Deponiegasmengen, Abfallwirtschaftsfakten 19, Staatliches Gewerbeaufsichtsamt Hildesheim und Landesamt Niedersachsen für Bergbau, Energie und Geologie, Hildesheim.

Finland:
The need for remediation is small and biological treatment of the methane gas is sufficient if landfill gas production amounts to less than 10 m^3 landfill gas per hectare and hour (or <5 m^3 methane per hectare and hour) and methane concentration at the landfill surface is less than 100 ppm.
Biological treatment or flaring and preventing gas migration into structures (like houses etc.) is required if the landfill gas production is between 10-50 m^3 landfill gas per hectare and hour (5-25 m^3 methane per hectare and hour) and the methane concentration at the landfill surface is higher than 100 ppm and the energy produced from the extracted gas would be less than 0.5 MW or damage in the vegetation can be noticed.
Gas utilization or flaring and preventing gas migration into structures like houses etc. is required if the landfill gas production is higher than 50 m^3 landfill gas per hectare and hour (>25 m^3 methane per hectare and hour) or the energy production from the extracted gas would be higher than 0.5 MW.
Source: Finnish Environment Institute (2001) Environment Guide 89: Guide for closing landfills (in Finnish), ISSN 1238-8602, ISBN 952-11-1021-X and 952-11-1022-8 (PDF), Helsinki, Finland. This is part of the current Finnish landfill legislation.

France:
A soil cover on former landfills is acceptable if the amount of methane entering the cover is less than 10 m^3 methane per hectare and hour.

Source : Bour. O., C. Couturier, S. Berger, L. Riquier (2005) Evaluation des risques liés aux émissions gazeuses des décharges : propositions de seuils de captages, INERIS-DRC-05-46533/DESP-R01, France. The proposals of this document have been included in French legislation concerning former landfills.

Netherlands:
The 'Decree of 20 January 1993, concerning rules with respect to landfill of wastes' contains an article 6a.1 that requires that from the moment of construction of the landfill measures shall be taken and applied to collect and treat gas. It does however also contain an article 6a.4. This article states that article 6a.1 is not applicable when the permit holder based on the composition of the waste mass can demonstrate that the measures mentioned in Art. 6a.1 have a limited environmental benefit. When the permit holder quantifies gas generation and demonstrates to the competent authority that it is low, the competent authority based on this article can change the permit and allow to not install gas recovery in case of inorganic waste or changing active gas recovery to passive gas recovery and methane oxidation in biofilters.

Sweden:
According to §§ 41 & 42 in "Naturvärdsverkets föreskrifter" regarding landfilling of waste (NFS 2004:10) landfill gas has to be collected and utilized. In case it is not possible to utilize the landfill gas it has to be flared or treated in an environmentally safe way. The Swedish landfill guidance (2004:2) "Deponering af avfall" takes the situation on small landfills into consideration. The requirements for collection of landfill gas for existing landfills receiving biodegradable waste are as follows:

	1,000 tonnes/year	3,000 tonnes/year	5,000 tonnes/year	10,000 tonnes/year
5 years of landfilling	No gas collection	No gas collection	No gas collection	Assessment needed
10 years of landfilling	No gas collection	No gas collection	Assessment needed	Gas collection required
20 years of landfilling	No gas collection	Assessment needed	Assessment needed	Gas collection required
40 years of landfilling	No gas collection	Gas collection required	Gas collection required	Gas collection required

United Kingdom:
The key principles of landfill gas guidance in England and Wales are:
- Mandatory gas collection unless proven not necessary;
- Commence extraction as soon as possible;
- Minimise the active area;
- Cap as soon as possible;
- Minimise emissions from waste flanks;
- Monitor and remediate all infrastructure;
- Optimise collection rates and apply flexible treatment methods over the life of the landfill.

A landfill permit can be surrendered and consequently active gas control can be ended.

The landfill operator needs to demonstrate (by means of monitoring data) that landfill gas is no longer generated at an unacceptable rate. Among these monitoring data gas concentrations in the waste throughout the entire waste body should be <1.5% CH_4 and <5% CO_2 for at least 2 years. Alternatively it can be demonstrated that gas concentrations are similar to background concentrations. That is either due to natural sources in the surrounding environment or as a result of non-landfill activities in the surrounding environment. If the above limits are not met, it has to be demonstrated that gas flow rates in boreholes <0.015 m^3CH_4/h and <0.022 m^3CO_2/h for at least 2 years (based on regular representative monitoring). Moreover no visual evidence of vegetation damage, or alternatively provide soil gas concentration data.
Source: The surrender of permits for the permanent deposit of waste (Environment Agency for England and Wales, 2010). This is part of the landfill guidance in England and Wales.

3.4. European guidance document on gas control

In December 2009 the European Commission - through The Technical Adaptation Committee (TAC) – sat down a "Working Group 1" on landfill gas emission reduction. The task of WG1 was to propose amendment of the gas control articles in Annex I in order to promote further reduction of landfill gas emission. After careful consideration WG1 proposed measures to cap cells for biodegradable waste within 2 years after start of disposal and start high efficiency gas collection within two months after capping. The TAC rejected the proposal in December 2010. The main argument shared by a large number of member states was that the LFD should only contain objectives and principles and that therefore amendment of the LFD was not necessary. These member states considered a non-committal European gas control guidance document helpful. Some member states put forward that improving gas control distracts from the main goal, i.e. to stop landfill of biodegradable waste. In response to the TAC the Commission abandoned the idea of changing Annex I and in March 2011 announced that it will aim at introducing a complete landfill ban for all biodegradable waste in 2014/2015 with the intention to fully comply with that landfill ban between 2020 and 2025. The task of WG1 has been limited to propose a non-committal European gas control guidance document. The qualification non-committal implies that the Commission will not be able to enforce specific measures and that member states consequently have a lot of leeway to implement specific national gas control measures. Assuming that current Icelandic landfill legislation is similar to the LFD, Iceland still has a lot of liberty to determine its own gas control guidance. From a technical perspective the type of waste landfilled, the size of the landfill and the height of the waste body determines the feasibility of gas control measures.

3.5. Conditioning plans and exceptions for technical requirements

In addition to aspects a) and b), mentioned at the beginning of chapter 3, continuation of landfills to a very large extent depends on the implementation of Article 14 on existing landfill sites. Before 16 July 2002 Member States had to assess conditioning plans for existing sites. Sites can only continue operation if the level of environmental protection can be brought in compliance with the minimum standards described in the LFD. Submission of a conditioning plan requires an amount of information including risk assessments that is almost identical to a new permit application. In many cases the absence of a bottom liner and/or geological barrier poses problems to continue operation of existing landfills. Landfills that cannot comply with that level of environmental protection had to be closed before 16 July 2009.

As described below there are two exceptions (Article 4) for implementation of the requirements. The first exception is for landfill sites for non-hazardous or inert wastes with a total capacity not exceeding 15,000 tonnes or with an annual intake not exceeding 1,000 tonnes serving islands, where this is the only landfill on the island and where this is exclusively destined for the disposal of waste generated on that island. Once the total capacity of that landfill has been used, any new landfill site established on the island shall comply with the requirements of the LFD. Landfills on Iceland are unlikely to qualify for this exception. The second exception is for landfill sites for non-hazardous or inert waste in isolated settlements if the landfill site is destined for the disposal of waste generated only by that isolated settlement. An isolated settlement has no more than 500 inhabitants per municipality or settlement and no more than five inhabitants per square kilometre. Moreover the distance to the nearest urban agglomeration with at least 250 inhabitants per square kilometre is not less than 50 km, or with difficult access by road to those nearest agglomerations, due to harsh meteorological conditions during a significant part of the year. Less then 10 of the 76 Icelandic municipalities have more than 250 inhabitants per square kilometre. Some 9 Icelandic landfills (out of a total of 21 landfills) receiving biodegradable waste can qualify for this exception.

The exceptions concern Articles:

- 6(d) use inert waste landfill only for inert waste;
- 7(i) financial security included in the permit;
- 8(a)(iv) financial security;
- 10 cost of landfill accounted in the gate fee;
- 11(1)(a) waste acceptance;
- 11(1)(b) reception procedures;
- 11(1)(c) acknowledgement of reception;
- 12(a) control and monitoring programme;
- 12(c) analysis by competent laboratories;
- Annex I point 3: protection of soil and water (geological barrier, bottom liner, surface sealing);
- Annex I point 4: gas control
- Annex II (except point 3, level 3, and point 4): acceptance criteria;
- Annex III, points 3 to 5: monitoring of water, leachate, gas, groundwater and the waste body.

It is important to note that leachate collection and treatment is not exempted.

4. Methane generation on Icelandic landfills

It can be expected (more detailed analysis is required) that apart from the Álfsnes, Stekkjarvík and Fiflholt landfills none of the other landfills will landfill more than 5,000 tonnes MSW per year. As will be explained in Chapter 5 gas recovery from a technical perspective is difficult on these landfills.

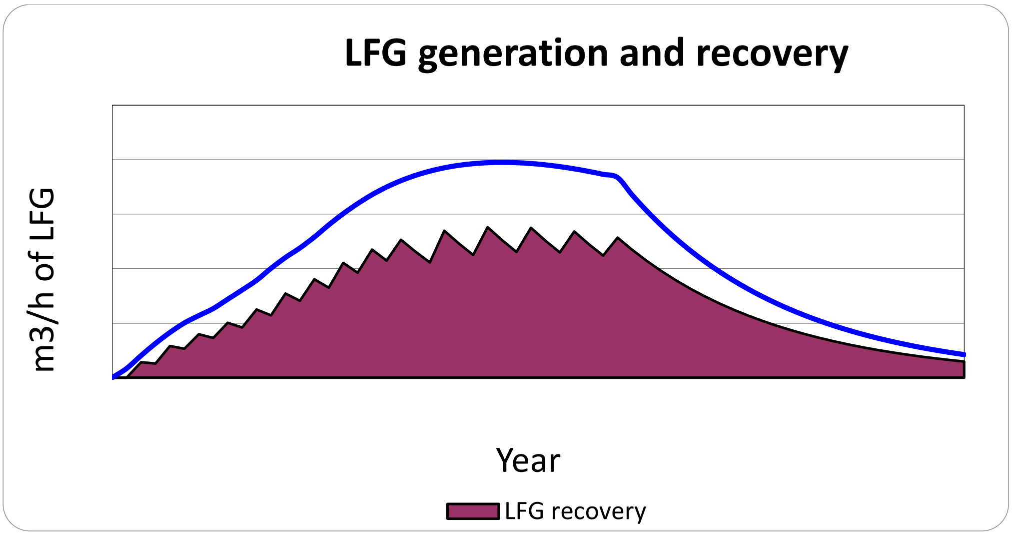


Figure 4. LFG generation and potential recovery on Álfsnes landfill.

For the Álfsnes landfill 70% recovery efficiency was assumed in the generation and recovery prognosis (Figure 4). The results are in line with the data mentioned in the 2007 report Methane recovery from Álfsnes landfill. It should however be emphasised that both the 2007 report and this calculation are a prognosis based on assumptions with uncertainties. The Álfsnes landfill is a 'bale fill'. There is very little documented experience with gas recovery on 'bale fills'.

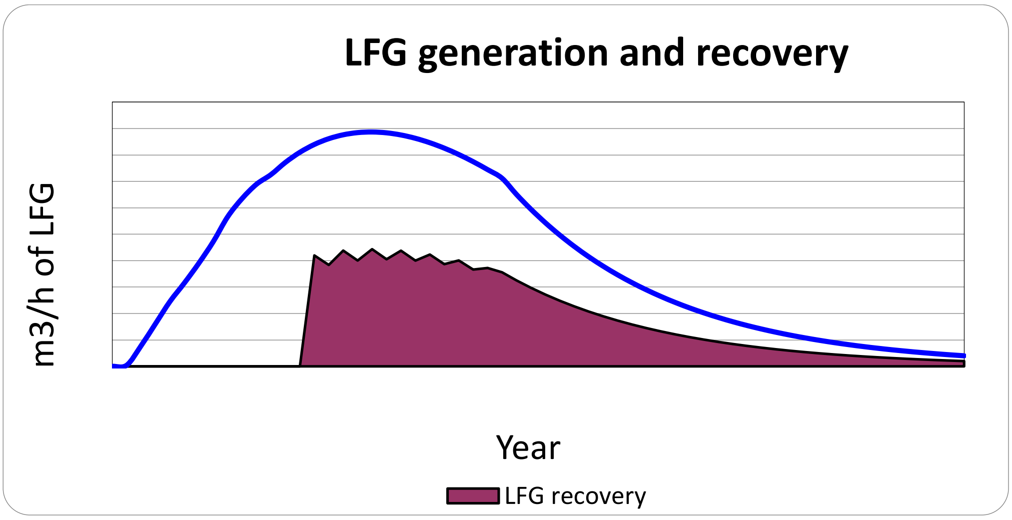


Figure 5. LFG generation and potential recovery on Fiflholt landfill.

Due to its limited height for the Fiflholt landfill 50% recovery efficiency was assumed in the generation and recovery prognosis (Figure 5). With the help of a simple FOD model and IPCC recommended default values for modelling parameters it can be calculated that a shallow Icelandic landfill (~5m height) without impermeable surface sealing receiving maximum 5,000 tonnes MSW/year for 35 years will never exceed 50 m^3LFG/h gas recovery (Figure 6). It requires disposal of more than 5,000 tonnes MSW annually in landfills with a height of more than 5 m (preferably more than 8 m) in order to reach good technical feasibility for gas extraction.

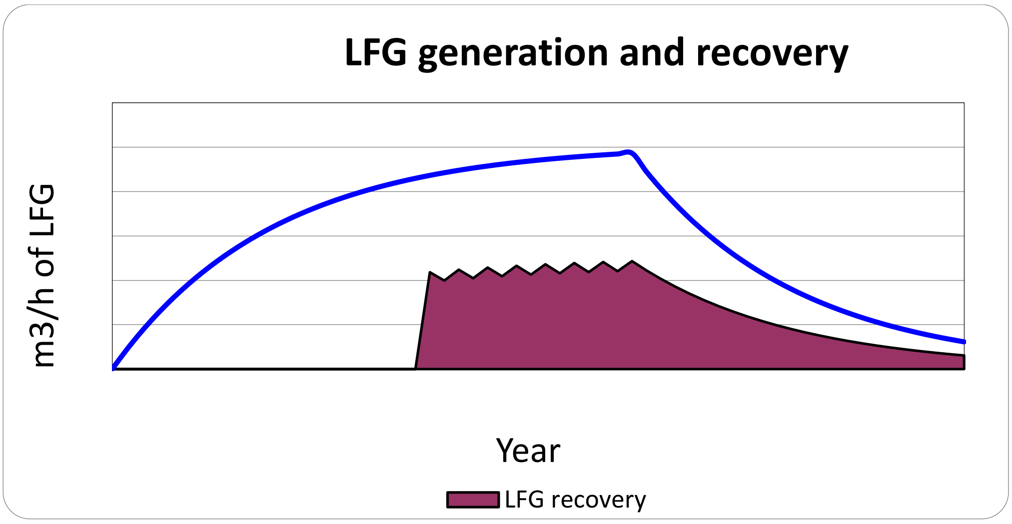


Figure 6. LFG generation and potential recovery on a 5,000 tonnes MSW/year landfill – receiving waste during 35 years (1990-2025)

5. Technical limitations and gas control options for small landfills

Conventional gas recovery entails construction of vertical gas wells (Figure 7) after reaching final height of the landfill cell.

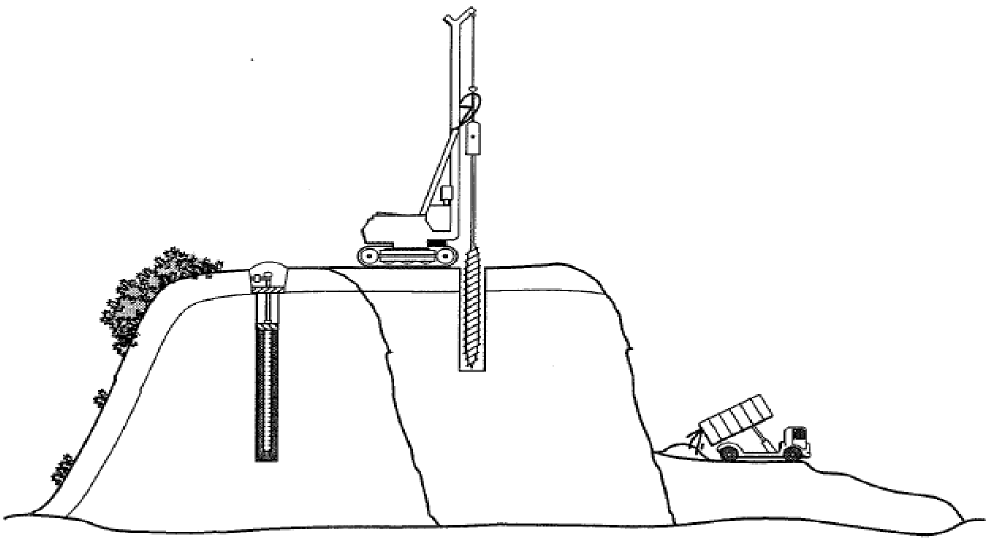


Figure 7. Drilled vertical gas wells

In shallow Icelandic landfills vertical gas wells are not appropriate. The filter section (slotted pipe surrounded by gravel) of a vertical gas well in general is some 2-3 m below the surface. If it is closer to surface a large risk of extracting atmospheric air through the extraction system occurs. The filter section will also not go down all the way. The bottom liner might be damaged during construction. This risk of course does not exist when the gas wells are built up during waste disposal. But close to the bottom liner leachate levels may hamper entry of gas into the gas well. If on a landfill the filter section can only be 1-2 m long either a limited amount of gas can be extracted or a huge number of gas wells per ha needs to be installed. In shallow landfills horizontal gas wells (built during disposal) (Figure 8) are the more appropriate solution. Even when gas extraction occurs with horizontal instead of vertical gas wells there is a risk of taking in atmospheric air through the extraction system. In order to reduce that risk negative pressure on the gas well has to be limited and the horizontal gas wells should be spaced at 20-25 m intervals rather than at 40-50 m intervals. Recovery efficiencies higher than 50% are unlikely on shallow landfills without surface sealing.

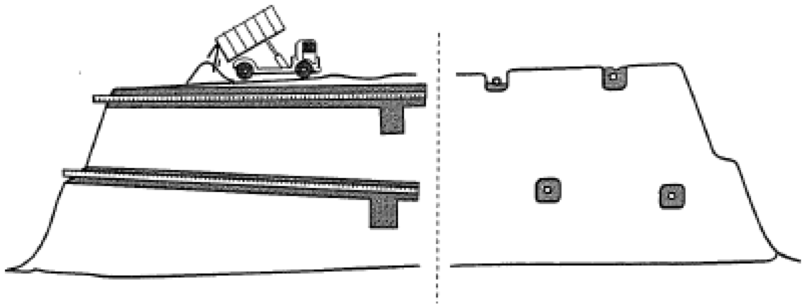


Figure 8. Horizontal gas wells

Technical limitations include the amount of landfill gas that can reasonably, practically and cost-effectively be extracted and flared. In general passive recovery and treatment (oxidation in biocovers, -windows, or –filters) is considered appropriate when methane generation is less than 25 m^3CH_4/h (or less than 50 m^3LFG/h). This is proposed in countries that require a surface sealing where close to 100% gas recovery is assumed. It is technically possible to construct smaller compressors and flares. Manufacturers of extraction systems and flares do however not offer systems smaller than 50 m^3LFG/h. LFG contains traces of chlorinated and fluorinated compounds. In order to prevent formation of dioxins optimal combustion conditions need to be guaranteed. Different national guidelines therefore require enclosed flares with combustion temperatures of 900-1,000°C and a retention time of the flue gas in the enclosed flare of 0.3-1.0 seconds.

6. Microbial methane oxidation as alternative gas control

Microbial methane oxidation (Figure 9) is considered to be no problem when the load to cover is less than 5 $m^3CH_4/ha.h$ (<8.6 $gCH_4/m^2.d$). This value was selected because literature research indicated that most covers under most conditions could oxidise more than 10 $m^3CH_4/ha.h$ (>17.2 $gCH_4/m^2.d$). An Austrian guidance document suggests that well designed methane oxidising covers can oxidise fluxes up to 40 $m^3CH_4/ha.h$ (70 $gCH_4/m^2.d$).

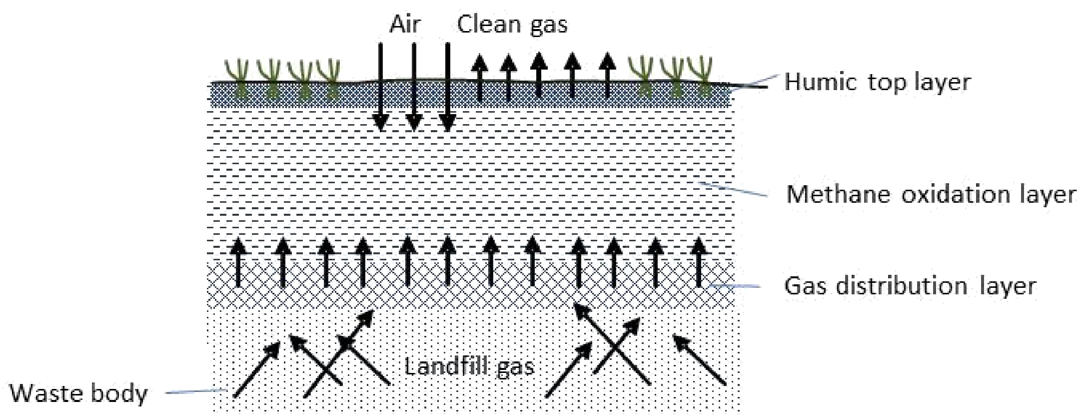


Figure 9. Schematic of a methane oxidising landfill cover

With the help of the abovementioned FOD model it can be calculated for landfills with a height of approximately 5m of MSW (disposed in a particular cell or trench within one year) that the methane generation (= load to cover):

- one year after disposal is 45 m^3CH_4/ha.h;
- four years after disposal is 30 m^3CH_4/ha.h;
- nine years after disposal is 20 m^3CH_4/ha.h;
- fifteen years after disposal is 10 m^3CH_4/ha.h.

A hypothetical landfill that has accepted 5,000 tonnesMSW/year since 1990 from 2010 onwards has a surface load of approximately 20 m^3CH_4/ha.h from 2010 onwards. In these situations methane oxidising covers are a technically feasible alternative offering similar reduction efficiency as conventional gas recovery.

In scientific literature oxidation efficiencies of higher than 90% are reported for methane loading rates up to 170 gCH_4/m^2.d (~100 m^3CH_4/ha.h). Most of these data however are from controlled laboratory studies under close to optimal conditions. In full-scale experiments monitoring methods have been used that have their limitations. The most important drawback has been that in full-scale tests it has been difficult or impossible to precisely determine the methane loading rate. The full-scale results that have been reported do however have an important indicative value.

Methane loading rates up to 170 gCH_4/m^2.d may occur when methane generated in a landfill is piped to a methane oxidising biofliter with a surface much smaller than the landfill itself. In biocovers with larger surface methane loading rates will usually be much smaller than 170 gCH_4/m^2.d. The value of 8.6 gCH_4/m^2.d can be considered very conservative. Most soils in a moderate climate will be able to achieve a high oxidation efficiency with that loading rate.

The most important limiting factor for methane oxidation is availability of oxygen in the methane oxidation layer. Oxygen diffusion into a soil is optimal when the soil has sufficient air-filled porosity. This strongly depends on the material that is available. High contents of clay and peat are not conducive to oxygen diffusion into the biocover. In reality soil is applied with dumpers and bulldozers. Especially the tires of dumpers but also the tracks of bulldozers have a compacting effect during construction of the soil cover. Moisture during construction can further deteriorate the porosity and pore connectivity of the biocover. It is recommended to design the gas distribution layer with In reality with some care and consideration it is feasible to construct high efficiency methane oxidising covers for loading rates up to 70 gCH_4/m^2.d (~40 m^3CH_4/ha.h) for an average annual soil temperature of 10°C.

Methane oxidation rates increase with increasing temperature. The highest methane oxidation rates can be found at soil temperatures around 30°C. In general it is desirable to have the methane oxidation horizon at a depth of 40-60 cm. Closer to the surface the temperature changes are larger and there is a larger occurrence of 0°C. In microbiology there is a rule of thumb that activity doubles with an increase in temperature of 10°C. Most literature data are reported for a soil temperature of 20°C. The average annual air temperature in Iceland is 3 to 4°C. The average annual soil temperature will be slightly higher. If however also in the Icelandic winter season a significant oxidation efficiency is desired, a loading rate should be selected that is 2-3 times lower than in a moderate (NW European) climate.

7. Aerobic landfill as alternative gas control

In-situ aeration of landfills has successfully been applied for remediation of gas migration problems on existing landfills. Injection of oxygen creates conditions under which anaerobic decomposition of organic matter to methane does not occur. In Japan and the USA aerobic landfills have been operated with the aim of rapid stabilisation and volume reduction. The experience shows that it is technically possible to operate aerobic landfills. Gas control on landfills with a height of approximately 5m could alternatively also be realised by means of aerobic processes. This could possibly be achieved in a similar way as windrow composting. Either the waste is composted in windrows and then landfilled as low-tech alternative to mechanical biological treatment (MBT). Or the waste can be aerated in situ in the form of an aerobic landfill (Figure 10). In both cases air is extracted through the waste and treated in a biofilter to remove odour and some methane. There will not be a lot of methane in the exhaust gas. Methane production is stopped due to aerobic conditions in the waste. These processes are preferably tried out full-scale for effectiveness in Icelandic conditions.

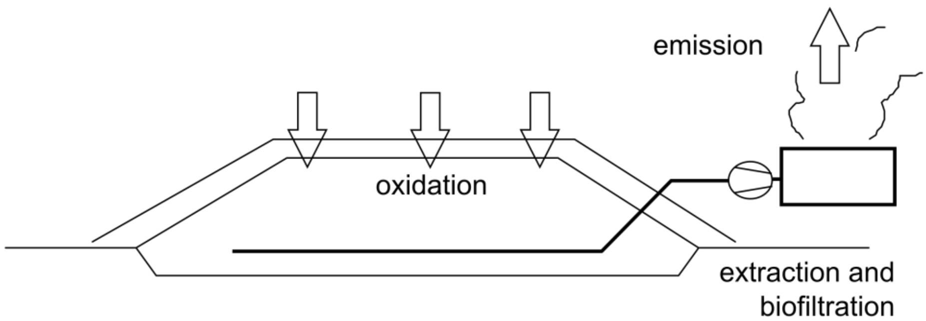


Figure 10. Schematic of landfill aeration

8. Cost-effectiveness

A first indicator of cost-effectiveness is the net present value of gas recovery over the operational and post-operational (aftercare) lifetime of the landfill. For larger landfills this is often between € 0.70 and € 1.50 per tonne of MSW. On larger landfills these costs can often be completely compensated from energy sales when the recovered gas is utilised. A net profit is not uncommon. On smaller landfills the net present value of gas recovery can increase to between € 4 and € 6 per tonne of MSW. On smaller landfills or landfills with small amounts of biodegradable waste utilisation of LFG for energy production is often not financially attractive.

In climate policy cost-effectiveness is used as a criterion to assess whether a measure can be implemented at acceptable cost. In general it is difficult to specify what is acceptable and what is not for specific green house gas emission reduction measures. This is nevertheless an important exercise. A society can only spend its money on a green house gas reduction measure once. Society can therefore benefit from spending that money on the most cost-effective reduction measures. On landfills the most important green house gas is methane. Cost-effectiveness of methane emission reduction measures is to a very large extent dependent on the specific situation of the landfill. This makes it even more difficult to give general cost-effectiveness information on landfill gas control.

There are however some indicators for the range of what can be considered acceptable. In CDM and JI projects carbon credits are traded for € 6 to € 12 per ton CO_2 equivalent. Carbon stock exchange markets have been going up and down a bit. Lately the prices have fluctuated between € 10 and € 12 per ton CO_2 equivalent. Some of the voluntary markets (Canada, USA) have come to a standstill. In 2007, with Kyoto II coming up, sales prices briefly went up to € 20 per ton CO_2 equivalent.

In 2007 the Dutch environment ministry updated the gas control guidance document. It was investigated whether new approaches (e.g. temporary gas wells, methane oxidising covers, aerobic landfills, ..) could constitute cost-effective additional green house reduction measures. In the discussion with stakeholders the market volatility was raised. The ministry therefore did not incorporate any absolute price ranges into the guidance document. At the time there seemed to be a general agreement that whenever a project could be carried out for less than € 5 per ton CO_2 equivalent, it would be considered cost-effective and should be realised. Whenever a project could only be carried out for more than € 15 per ton CO_2 equivalent, it would be considered not cost-effective and should not be realised. Between € 5 and € 15 per ton CO_2 equivalent was considered a 'grey zone', requiring constructive dialogue between landfill operator and competent authority. In light of the latest developments the € 15 per ton CO_2 equivalent as upper level of the 'grey zone' could be considered rather high.

A cost calculation is always highly dependent on assumptions and should therefore be considered with care. For a landfill of 26 ha with a maximum height of 20 m receiving 200,000 tonnes of MSW per year for 20 years followed by an aftercare period of 30 years where gas control is carried out with vertical gas wells, it can be calculated that the total gas recovery costs are approximately € 5.8 million (net present value approximately € 2.9 million, or € 0.75 per tonne of waste). The net present value of electricity sales could be approximately € 8.8 million. A net present value of € 5.9 million is available for investment (and profit) in landfill gas utilisation. If heat could also be sold the project would become more attractive. It could be considered that in this case a profit can be made from green house gas reduction. In the hypothetical case that the gas would be recovered and flared the cost are approximately € 2 per ton CO_2 equivalent. Since gas control is mandatory in the EU the socalled additionality criterion does not apply and the carbon credits cannot be sold.

For a landfill of 4.6 ha with a maximum height of 5 m receiving 10,000 tonnes of MSW per year for 20 years followed by an aftercare period of 30 years where gas control is carried out with horizontal gas wells, it can be calculated that the total gas recovery costs are approximately € 1.7 million (net present value approximately € 825,000, or € 4.10 per tonne of waste). Energy production is not financially feasible. In case the gas would be recovered and flared the cost are approximately € 13 per ton CO_2 equivalent.

For a landfill of 2.5 ha with a maximum height of 5 m receiving 5,000 tonnes of MSW per year for 20 years followed by an aftercare period of 30 years where gas control is carried out with horizontal gas wells, it can be calculated that the total gas recovery costs are approximately € 1.2 million (net present value approximately € 578,000, or € 5.80 per tonne of waste). Energy production is not financially feasible. In case the gas would be recovered and flared the cost are approximately € 19 per ton CO_2 equivalent.

9. Site visits

On 29 and 30 November 2011 site visits were undertaken to Fiflholt and Kirkjuferjuhjáleiga landfills. Fiflholt landfill is in operation, but was closed for the day on account of the wind. It was clearly visible that biodegradable municipal waste is the most important type of waste disposed. It was a cold day, with a temperature of -8°C. On a landfill with active and significant gas production under these conditions and especially in the sections that have not yet been covered, plumes of gas are visible due to condensation of moisture in the LFG. There were no signs of any condensate plumes. The Kirkjuferjuhjáleiga landfill has been closed in December 2009. Also on this site there were no signs of any condensate plumes. Moreover the operator of landfill showed measurements that indicated that settlement over a 1 year period has been between 0 and 1 cm. Data have been published in a recent waste management handbook (eds. Prof. Thomas Christensen, DTU, Denmark) indicating that in the years after closure on a Dutch MSW landfill settlement was 15-20 cm per year. The Kirkjuferjuhjáleiga operator moreover showed leachate concentration measurements indicating significantly lower concentrations than found in MSW landfills in Europe. Similarly low concentrations have however been reported for MSW landfills in northern Norway. All these data and observations indicate that the degradation rates are lower than in a moderate European climate. This consequently means that methane generation also has to be smaller than in a moderate European climate. The methane generation prognoses for Icelandic landfills in Chapter 4 should be considered as a worst-case estimation.

10. Workshop

On 1 December 2011 a workshop was organised. Approximately 20 persons from municipalities, the Ministry for the Environment and the Environment Agency participated in the workshop. The following topics were addressed.

- Current landfill situation in Iceland (Lúðvík Gústafsson)
- Current landfill situation in Europe (Jørgen Hansen)
- Estimation of landfill gas generation (Heijo Scharff)
- Gas generation calculation examples (Heijo Scharff)
- Technical limitations and gas control options for small landfills (Heijo Scharff)
- Potential of methane oxidising cover systems (Heijo Scharff)
- Cost-effectiveness of gas control: example calculations (Heijo Scharff)
- Possibilities within the landfill directive to continue landfill where landfill gas control is not possible or too costly (Jørgen Hansen)
- Options to reduce landfill methane emission (Jørgen Hansen and Heijo Scharff)

During the presentations the participants frequently interrupted to clarify issues pertaining the Icelandic situation or to ask for further details about issues presented. At the end of the presentations the international experts proposed recommendations based on their expertise and impression of the Icelandic situation. The recommendations are summarised in the next paragraph. The workshop was ended with a general discussion.

Representatives from municipalities emphasised they are not against gas control. But they want to do it in the most effective way. Also, they are glad to have received confirmation that there are other possibilities to gas control than gas collection from all landfills (irrespective of the size) receiving biodegradable waste (irrespective of the amount) and produce energy or flare the collected gas. The local authorities are happy to learn that various European member states have made interpretations and found solutions addressing technical limitations, allowing an end of gas control or not implementing gas control.

The Ministry for the Environment and the Environment Agency acknowledged having received valuable information. The information will be considered and the Environment Ministry will propose solutions for the problem. The Environment Agency mentioned that landfill is lowest in the waste management hierarchy. More should be done to recycle waste. The local authorities acknowledge that this is the way for the future. They are developing plans to promote recycling and to realise facilities for recycling waste.

11. Recommendations

Both representatives from the Association of Local Authorities and the Ministry for the Environment acknowledge that reduction of biodegradable waste disposed at landfills is an important option to reduce landfill methane emission from new Icelandic landfills (or landfill cells). The political initiatives and economic instruments to stimulate that development are not fully in place. It is recommended to further develop policy and economic instruments.

Iceland has the authority to determine its own gas control guidance. Within this guidance Iceland (like other EU member states) can specify when active gas control is no longer or not required. Examples of criteria that are most often used to specify end of active gas control are available from guidance in various EU member states. It is recommended that the Ministry for the Environment provides such a guidance document. TAC working group 1 on landfill methane emission reduction is preparing a guidance document. This document might be helpful to Iceland. Given the specific climatic conditions and the specific landfill situation, Iceland might however find that certain parts of the EU guidance will not be beneficial for Iceland. Due to this fact parts of the Icelandic guidance will necessarily has to be “tailor-made” to Icelandic conditions.

Conventional landfill gas recovery does not seem feasible on Icelandic landfills receiving less than 5,000 tonnes MSW per year. Cost-effectiveness of landfill gas recovery seems unfavourable on Icelandic landfills receiving less than 10,000 tonnes MSW per year. It is recommended to consider these limitations in the guidance document.

Methane oxidising covers might provide a feasible alternative for methane emission reduction on small Icelandic landfills. The feasibility will depend on targets that need to be specified for oxidation efficiency. Since there is limited information on microbial methane oxidation in a boreal climate, a demonstration project is recommended.

Another potential alternative that could deserve further investigation is aerobic operation of landfills. This can be applied at a (cost related) much smaller scale than conventional gas control.

Annex I: Waste disposal facilities in Iceland 2011

Black triangles are landfills for municipal waste. Landfills with a blue underline can be classified as landfills for isolated settlements
Green triangles are landfills for inert waste
Red triangles are incinerators, all with energy recovery